DESIGN DATA SHEET
DEPARTMENT OF THE NAVY

NAVAL SHIP ENGINEERING CENTER

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DDS 185-1

# DESIGN OF FOUNDATIONS FOR ARRESTING GEAR SHEAVES

## CONTENTS

Paragraph — Page

185-1-a References 3

185-1-b Introduction 3

185-1-c DESIGN CRITERIA 6
185-1-c(1) Design Requirements 6
185-1-c(2) Design Limits 6

185-1-d Design Methods 11
185-1-d(1) Theory and Rationale 11
185-1-d(2) Arresting Gear Sheave Foundation Design Procedure 16

185-1-e Material Requirements 20
185-1-e(1) Welding 20
185-1-e(2) Mechanical Fasteners 20
185-1-e(3) Materials 20
185-1-e(4) Painting and Preservation 21

185-1-f Quality Assurance 21
185-1-f(5) Testing 21
185-1-f(6) Inspections 21

185-1-g Sample Calculation No. 1 21

Step 1: Arrangement 21
Step 2: Combined Foundation Design 21
Step 3: Foundation Layout
Step 4: Operational Loading 22
Step 5: Structure Model 29
Step 6: Preliminary Scantling 29
Step 7: Shock Loads 32
Step 8: Computerized Analysis 33
Step 9: Hand Calculation 37
Step 10: Foundation Deflection Estimate 49

185-1-h Sample Calculation No. 2
Problem 55
Assumptions 55
Load Acting on the Foundation 55
Sheave Foundation 60
Ring Plate 63
Ship Structure Supporting Sheave Foundation 64
Deflection Calculations (Under Test Load) 69
Deflection Estimate 70

## 185-1-a References

(a) Flight Deck Arresting Gear and Barricade Configuration Criteria for Mark 7 Mod 3 Arresting Engine. NAEC-EBG–7593

(b) CVAN 71 Concept Formulation Deck Pendant and Arresting Gear Configuration, (Mark 14 Arresting Gear Configuration). NAEC-ENG-7682

(c) Fabrication, Welding, and Inspection of Ship Hulls. NAVSHIPS 0900-000-1000

(d) Military Specification - Inspection System Requirements. MIL-I-45208A

(e) Design Data Sheet DDS 072-1(C) Shock Design of Shipboard Equipment Interim Design Inputs for Submarine and Surface Ship Equipment.

(f) Design Data Sheet DDS 100-1. Reinforcement of Openings in Structure of Surface Ships, other than in Protective Plating.

(g) Design Data Sheet DDS 100-3. Structural Design of Flat Plating and Stiffeners subject to Water Pressure.

(h) Design Data Sheet DDS 100-4. Strength of Structural Members.

(i) Design Data Sheet DDS 150-1. Design of Foundations and Other Structures to resist Shock Loading

(j) NAVAL SHIPS MANUAL, CHAPTER 9920. Welding and Allied Process

(k) NAVSHIPS 250-423-30. Shock Design of Shipboard Equipment.

(l) NAEC Drawing No. 618915 "Drive System Arresting Gear Typical Installation - 1 7/16" dia. cable 18" P.D. sheaves".

(m) NAEC Drawing No. 616764 "Drive System - Arresting Gear Typical Installation - 1 1/2" dia. cable, 30" P.D. sheaves".

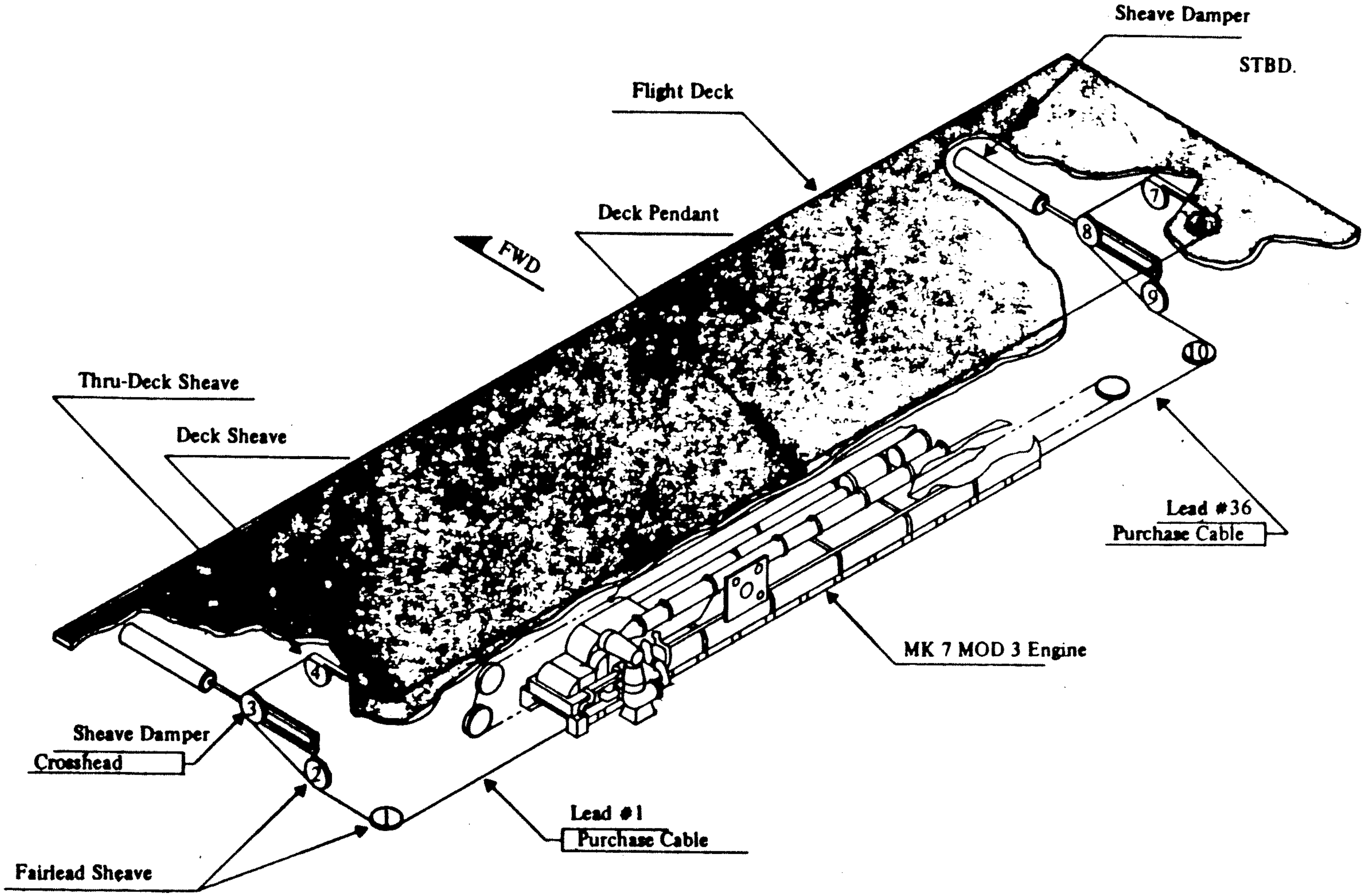
(n) NAEC Drawing No. 612792 Rev D "Typical Installation 1 3/8" dia. cable 28 P.D. sheaves".

## 185-1-b Introduction

The aircraft arresting gear system is a vital characteristic feature of aircraft carriers and is essential to the ship's mission. The currently operational Mark 7 Mod 3 (see figure 1) arresting gear system is described in Reference (b). Each system must arrest all aircraft within dynamic limits of the aircraft and within the geometric limits of the runway. Because of its impact on ship's mission, the system and all its related supporting facilities must have the highest degree of reliability and availability.

Since the system and its supporting structure are exposed to high loads, special consideration must be given to the proper design, fabrication, and installation of all components and supporting structure. This Design Data Sheet (DDS) provides guidance for the design of arresting gear sheave foundations for these systems and also provides related guidance on fabrication, installation, alignment, and testing.

All calculations used in this document are for example only and do not necessarily represent true cable breaking strengths. However, the calculation methods are valid.



Schematic Diagram – MK 7 MOD 3 Arresting Gear Drive System

Fig. 1

## 185-1-c Design Criteria

### 185-1-c (1) Design Requirements

The configuration of arresting gear sheave foundations in the arresting gear drive system shall contain a minimum of five sheaves on each side of the arresting gear engine (figure 1). The sheaves are designated as follows:

1. Below deck fairlead sheave
2. Bottom stationary fairlead sheave of the sheave damper assembly.
3. Crosshead sheave of the sheave damper assembly
4. Thru-deck sheave
5. Flight deck sheave which may be stationary or retractable (to provide a clear deck for aircraft handling operations)

Because of variations in ship structure and cable loading at each sheave location, all sheave foundations must be individually designed. The design of each foundation shall be based on the maximum breaking strength of the largest/strongest arresting gear purchase cable to be used in the system. For systems requiring 1-7/16 inch or 1-1/2 inch diameter cables this data can be obtained from references (n) and (o) respectively. For all other cable sizes the maximum breaking strength of the cable shall be obtained in writing from the Naval Air Systems Command (AIR537).

### 185-1-c (2) Design Limits

Plate Stiffener Combinations - Plate-stiffener combinations when subjected to the above loads shall be designed to meet the criteria as described below.

#### Loading on Short Edges of Plates

Instability of Columns and Stiffeners - The adequacy of column and stiffener scantlings to prevent failure due to local instability shall be checked in accordance with Section 4g of Reference (h), using Figure 8 of that reference as a guide.

Tensile and Bending Stresses - Where there is no danger of failure from instability, allowable limits for the algebraic sums of axial and bending stresses in kips per square inch shall be obtained from the ship's specifications.

Shear Stresses - Where there is no danger of failure from instability, allowable limits for shear stresses are 60% of the allowable tensile stresses.

Column Stresses - Allowable axial stresses on structural members other than plate panels are as follows:

Allowable axial stresses on stanchions and pure compression members shall be 60% of the column strength. Allowable axial stresses on plate-stiffener combinations shall be 67% of the column strength for members with a slenderness ratio greater than 60, and 80% of the column strength for members with a slenderness ratio equal to or less than 60.

Allowable column strength shall be taken from Figure 1 of Reference (h).

Combined Bending and Column Stresses - The sum of the ratios of calculated stress to allowable stress shall not exceed unity, as shown in Stress Calculations, paragraph 185-1d-(2).

Plating Panels Under Edge Loadings - Compressive stresses shall not exceed 80 percent of the ultimate buckling strength of the plating given by Figure 10 of Reference (h) This assumes that the edge support is capable of sustaining yield strength. Where this does not occur, the stresses given by Figure 10 of Reference (h) shall be reduced by the ratio of the column strength to the yield strength, and the combined compressive stresses shall not exceed the plate buckling stresses given in Figures 11 through 21 of Reference (h).

### Loading on Long Edges of Plates

The bending stress in the plate panels resulting from local loads plus the stress from any axial loads shall not exceed the yield strength of the material.

The calculated compressive stress in a plate panel resulting from axial loads shall not exceed 80 percent of the critical buckling stress.

Sheave Alignment. –The sheaves must be aligned with each other so that the interconnecting cable will make a fleet angle with each sheave of not more than 1-1/2 degrees with respect to the flat part of the sheave.

Sheave Foundation and Liner Surfaces. – Liners installed for alignment of sheave assemblies must not be less than 1/8 inch or more than 3/4 inch thick.

Foundation surface and liner surfaces for installation of sheave assembly must be flat within 0.005 inch total. Seventy-five percent of the outer and inner peripheries of the sheave assembly and liner must be in contact with the foundation, with a maximum space gap of 0.010 inch permitted on the remaining 25 percent of the periphery.

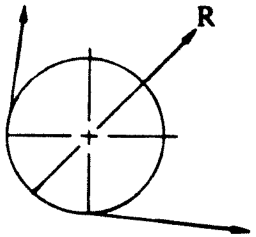
Design for Deflections. – Design for deflection should be calculated for all deck and bulkhead mounted sheaves. Excluded are the retractable sheaves, the thru-deck sheaves, and the movable sheaves of the dampers.

The maximum deflection shall be 0.062 inch in any direction in the horizontal plane and in the vertical direction under the test cable tension resulting from the loads specified below.

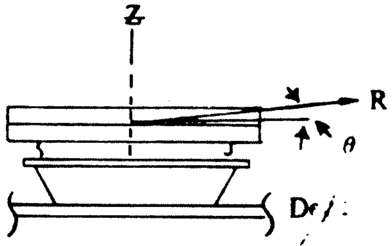
The measurement shall be taken at the sheave foundation base and the top of the sheave cover (see Reference (l), (m), and (n) for indicator test diagrams). No permanent set shall be permitted. These criteria are:

| Arresting Gear Engine | Test Pressure in Arresting Gear Engine | Equivalent Wheel Load |
|---|---|---|
| MK 7 Mod 1 & Mod 3 | 12,500 psi | 110,000 lb |
| MK 7 Mod 2 | 12,500 psi | 95,000 lb |
| MK 14 | | 115,000 lb |

The first step is to determine the resultant of all sheave loads in the horizontal and vertical planes.

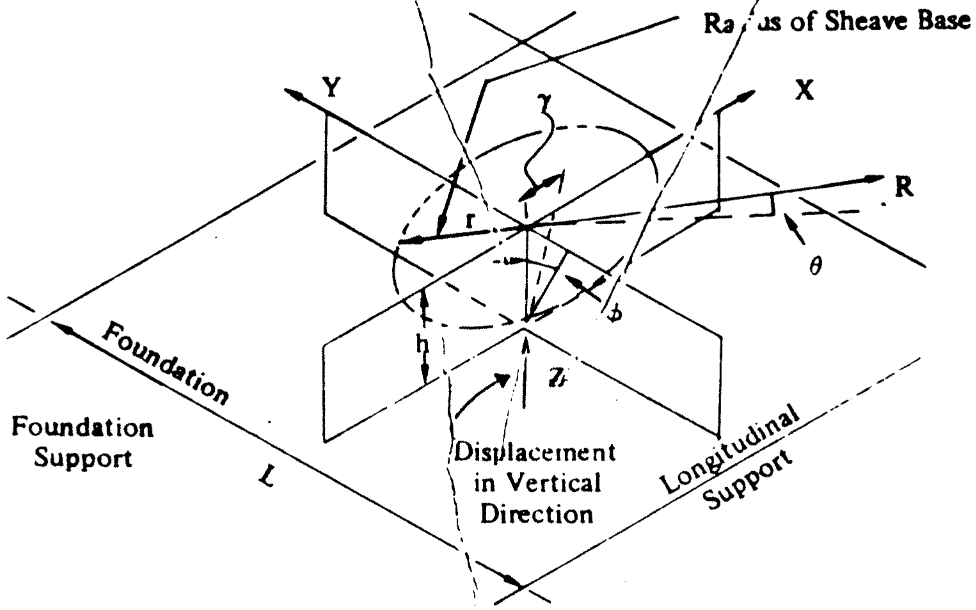


Horizontal Plane



Vertical Plane

The effect caused by the resultant will be rotation about an axis or axes and displacement in the vertical direction. The sketch below illustrates a typical sheave, and points out the individual displacement effects which must be considered.



X,Y,Z define the coordinate system
h = height at junction of sheave base with the pedestal foundation above the deck
$\phi$ = rotation about the X axis
$\gamma$ = rotation about the Y axis
$\theta$ = angle between line of action of resultant and horizontal plane
r = radius of sheave base

Define the X,Y,Z coordinate system in the most convenient orientation, in this case along the axes of the base foundation. The resultant will cause rotations about the X and Y axes. The resultant will also cause a displacement in the positive Z direction. Knowing the rotations and vertical deflection, the final check can be made by the following calculations:

Sheave Axis

Horizontal Displacement

$$\Delta HA = \sqrt{(h \sin 0)^2 + (h \sin \quad)^2}$$

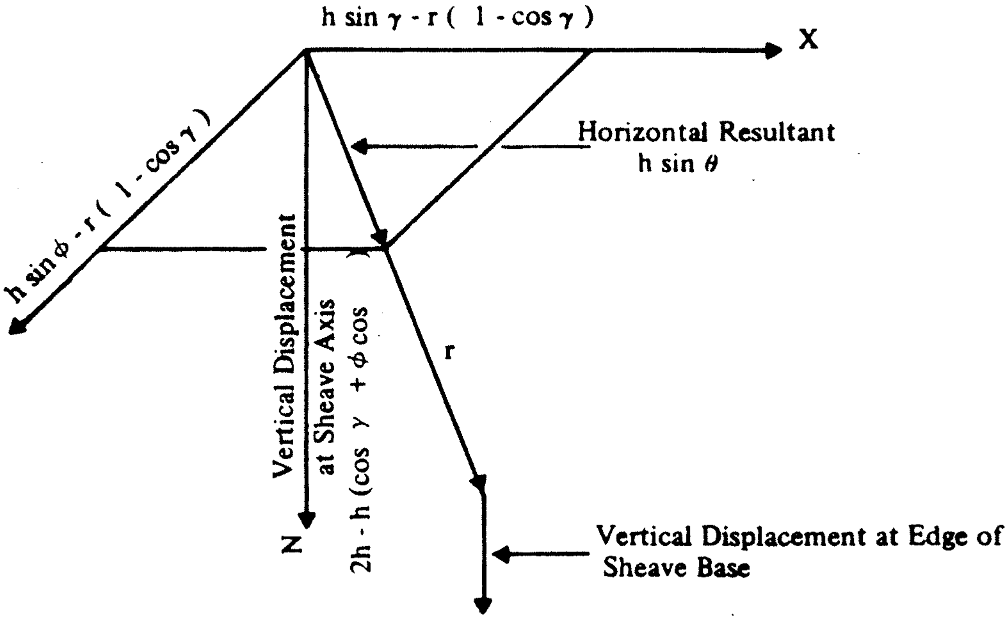
$$\theta = \arcsin\left(\frac{\Delta HA}{h}\right)$$

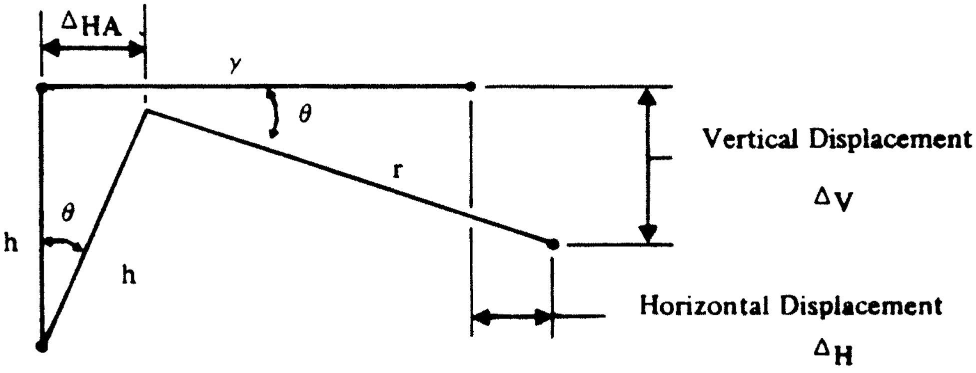
Horizontal Displacement at edge of sheave base

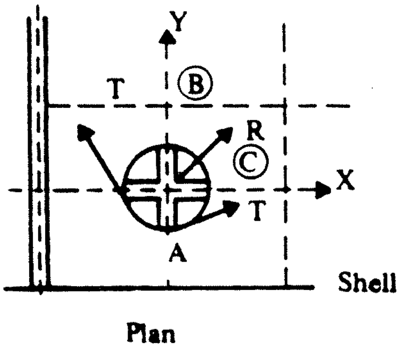
$$\Delta H = h \sin \theta + r\,(1-\cos \theta)$$

Vertical Displacement at edge of sheave base

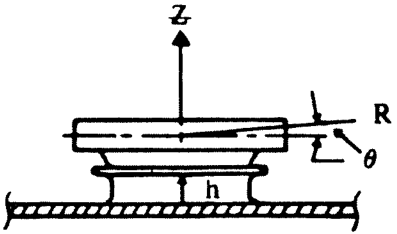
$$\Delta V = h\,(1-\cos \theta) + r \sin \theta + \text{Displacement of sheave in vertical direction}$$







Plan



Elevation

## 185-1-d Design Methods

This paragraph of the DDS describes procedures for designing foundations for the arresting gear sheaves. In addition, the theory and rationale supporting the procedure is presented, and some typical design examples are given. Both manual and computer calculation methods are given so that design activities with the latter capability can make use of structural analysis computer programs for more accurate results.

### 185-1-d (1) Theory and Rationale

The arresting gear sheave foundation design procedure as described in paragraph 185-1-e (2) has certain assumptions associated with it. The design procedure, rationale, and theories involved in each step are given as follows:

Location of Sheave Foundation

Ship Structure in Way of Sheave Foundation

Sheave Foundation Layout

Loadings nad Deflections

Structural Model of Foundation

Stress Calculations

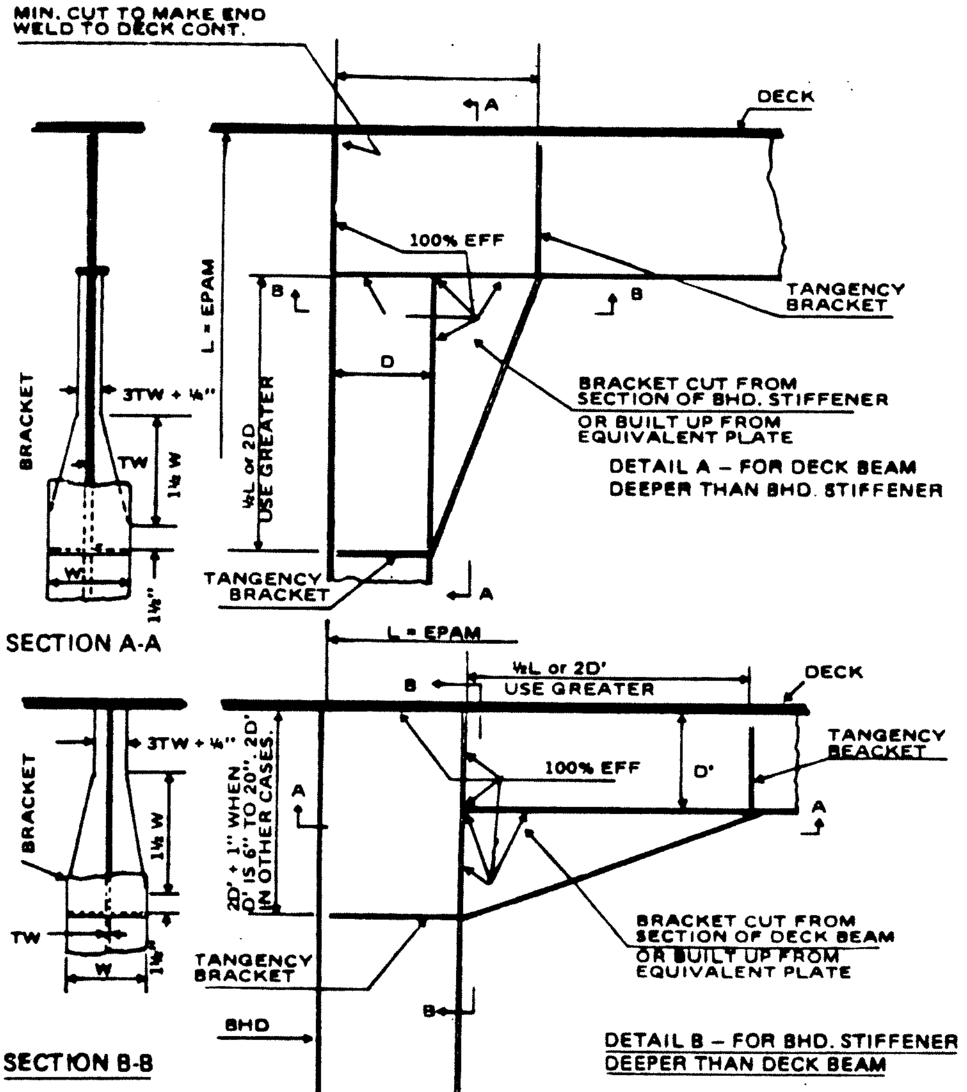
Sheave Foundation Detail Drawings

Location of Sheave Foundation – The required configuration and location of the arresting gear system precludes any significant rearranging, therefore, the foundations for the sheaves shall be located as shown on the arresting gear arrangement drawings.

Ship Structure in Way of Sheave Foundations – The foundations for the arresting gear system shall be arranged so that they take the greatest advantage of the strength available in the adjacent ship structure. The hull structure in the area designated for the sheave foundations usually consists of deck and sideshell plating, deck and sideshell longitudinals, deep transverse bents and their stiffeners, and hanger side bulkheads and their stiffeners.

In addition to considering the general strength of hull structure, the manner in which loading will be applied and distributed shall also be considered. Loading should be distributed into the main hull structure as directly as possible since this will help preclude any local failures. Since the main hull structure members in the sheave foundation area are not best suited for such loading, foundation hull attachments shall be such that no significant torsional loadings result.

Shreave Foundation Layout. – Once the local hull structure has been reviewed and the foundation location resolved, the foundation members can be designed. Drawings or sketches shall be made to show the structural parts of the foundation, and the location and method of attachment to the main hull structure. Some general considerations concerning



BEAM AND STIFFENER BRACKETS

Fig. 2

the foundation are:

Beam End Fixity – Paragraph below titled "Design Assumptions for Beam End Fixity of Stiffeners" gives the beam end fixity assumptions that must be made in developing the structural model of the foundation.

For the same loading, a beam with fixed ends will have a smaller maximum bending moment than one with simply supported ends (maximum moment is at a different location in each case). Therefore, in general, if a high moment loading is anticipated, adequate bracketing shall be provided to insure beam end fixity. See Figure 2 herein for examples of beam and stiffener brackets, and Figures 6 and 7 of Reference (g) for details of brackets and welding procedures.

Penetrations -- Every opening in a stressed area of a structural member causes stress concentrations. If an opening is large in proportion to the width of a member, or too near an edge, the effects of stress concentration on the behavior of the member is increased. If size or location of the opening is such as to impair the strength of an important member, measures should be taken to reduce the stress in way of it. This may be done in the following ways:

a. Changing the location of the opening, e.g., in a beam, locate the hole near the neutral axis

b. Changing the shape to a long shallow opening

c. Fitting a reinforcing ring around the opening

d. Fitting an insert plate around the opening

### Loadings and Deflections

#### Loadings

The sheave foundation shall be capable of transmitting loadings from the sheave to the main hull structure without failing itself or causing failure in the main hull structure. The sheave foundation and associated main hull structure shall withstand applied loads discussed herein. In general, distributed loads acting over a short distance can be approximated by concentrated loads acting at the center of the distributed load length. Loadings to be considered are as follows:

Gravity and Dynamic Inertia Forces With the Ship in a Seaway. Because the weight of the sheave and foundation is small compared to the operating loads, gravity and dynamic ship inertia forces in a seaway need not be included. In addition, ship motions are not significant during landing of aircraft.

Inertia Forces Resulting From Vibratory Motion of the Hull Structure. These will obviously be much less than those due to shock and operational loads, and will not be considered in the procedure.

Weather Effects such as Ice, Snow and Wind. These are small compared to the shock and operational loads, and will not be considered.

Landing Wheel Loads of Airplances. Because of the distance between the aircraft landing wheel touchdown area and the arresting gear sheave foundations, these loads will not be considered.

Primary Longitudinal Hull Stresses. Aircraft landings normally will not take place in severe storm conditions, therefore the hull primary stress soluld not be significant. For this reason it need not be combined with the sheave loading.

Shock Loads. Sheave foundation shall be designated grade A for shock and shall be designed according to the dynamic shock analysis design procedure described in Reference (k) and in accordance with Reference (i). The procedure in Reference (k) for the design of single mass systems based on load and energy criteria is directly applicable. The mass is assumed to include the entire weight of the sheave and one-half of the sheave foundation weight. The spring is assumed to represent the foundation stiffness. The shock inputs shall be obtained from Reference (e) and will depend upon the type of ship, weight of equipment, location within the ship, the service required, and the direction of loading. It shall be assumed that the shock design value will always be acceleration-limited (this precludes the calculation of the stiffness of the foundation, since the natural frequency of vibration is not needed). Operational loads shall not be combined with shock loads.

Operational Loads. The maximum working load anticipated for the cable is 121,000 pounds (considered to be the operational load). However, as the maximum designed breaking strength of the fictitious cable used in these sample calculations is 175,000 pounds, supporting structure is based on 175,000 pounds breaking strength.

The sheave shall be assumed to rotate on a frictionless axle, implying that only loads normal to the sheave perimeter and acting through the center of the sheave will be experienced, so that no torques can be developed around the sheave axle.

## Deflections

The maximum permissible deflection imposes additional restrictions on the sheave supporting structure. Each portion of the support structure must be examined, and the horizontal, vertical, and rotational deflections caused by the test loads must be calculated. The deflections of connected support members must be combined to give the total deflection of the sheave pedestal foundation. The calculated maximum horizontal or vertical displacement, to be measured at the sheave foundation base and top of sheave cover, must not exceed the permissible deflection of 0.062 inch. Deflection criteria is illustrated in 185-1-c(2), Design for Deflections.

Structure Model of Foundation. - The analysis of the arresting gear sheave foundation and associated main hull structure can be accomplished by considering all involved structural members as plate-stiffener combinations, and evaluating the stresses of the resulting frame. Local panel buckling must then also be checked. This analysis is less rigorous than considering a plate and beam finite element representation. In addition, the plate and beam finite element approach requires considerably more time. The structural models, whether computer or manual, should include all pertinent structure and loadings. If more than one foundation is secured to the same section of hull structure, then the model should include all the foundation, however, if two foundations are attached to the same hull structure, and the loadings on each foundation are in different directions, the two should be analyzed together.

### Plate-Stiffener Combination in Bending

The section modulus of a plate-stiffener combination may be calculated by using a maximum stiffener spacing of $2t \quad e/F_y$ where:

$E$ = Modulus of elasticity

$F_y$ = Tensile yield strength of material

$t$ = Thickness of plating or structural element

Stiffener spacing, less than this value, should be used where adjacent similarly loaded stiffeners justify uniform closer spacing. Where beams are of varying cross section, the minimum scantlings should be used. If this results in overstress, then a more detailed analysis should be performed and the beam appropriately changed to correct the calculated stress.

### Plate-Stiffener Combination in Torsion

Open sections (i.e., I, T, L beams) have little torsional rigidity so that this may be assumed negligible with little loss in accuracy.

### Shear Area of Beams

As a simplifying assumption, the shear area in a particular direction may be assumed to be equal to that of deep sections in that direction only.

### Design Assumptions for Beam End Fixity of Stiffeners

1. In theory, a stiffener end is fixed only if there is no rotation of the tangent to the elastic curve, comparing the unloaded and the loaded conditions. In practice, complete fixity may be assumed when:

    a. The stiffener end is adequately bracketed (see Figure 2) and is welded to stiff structure whose moment-of-inertiato-length ratio (I/L) is relatively large with respect to that of the stiffener under design. The bracket provides a rigid joint so that the stiffener end and the supporting structure rotate the same amount when under load.

    b. The stiffener under design is continuous over a support and there is symmetrical loading on each side of the support.

2. When these conditions for complete fixity are not met, the stiffener end is generally to be designed as simply supported.

3. In special cases, as the specific situation warrants, partial fixity may be considered by standard structural analysis.

### Computer Analysis Model

The intent here is to outline a procedure that can be used to analyze the arresting gear sheave foundations by use of a structural analysis computer program. This procedure is preferred over the manual method in that a more rigorous structural analysis can be accomplished. Computer programs acceptable for use in these structural analyses are:

| | |
|---|---|
| STRUDL | (MIT) |
| STRESS | (MIT) |
| NASTRAN | (NASA) |

Use of any computer program other than these must require prior approval from NAVSEC.

Since indeterminate structures are allowed in this analysis method, a more detailed study is possible. Arresting gear sheave foundations should be modeled completely. All main hull structure to which the foundations are attached should be included in the model. The model should extend to a point where it is obvious that inclusion of further structure will result in little stress and deflection changes.

Assumptions of the end fixity of members should be made only at the supports of the computer model. All other joints should be left free to move.

The joint connections of the structural members should be such that any rotation of the joint will be transmitted to each member of the joint. Exception to this is when a member has a connection with a small moment of inertia at a joint.

### Manual Analysis Method

If a computer facility or structural program is not available, then the manual method should be used. Generally, the same procedure must be followed as with the computer analysis method, except that the structure can be analyzed by partitioning, using members or groups of members, provided that the interaction of the partitions is taken into account, and that in so doing, conservative assumptions are made.

Stress Calculations. - The calculations by the computer method should be performed by the computer programs as specified above in Computer Analysis Model.

The calculations for the manual method should begin with the foundation member in direct contact with the loading. The end reactions of this member should then be applied to members adjacent to it. This process should continue until all members have stresses and deflections in the allowable range.

### 185-1-d (2) Arresting Gear Sheave Foundation Design Procedure

The design procedure for arresting gear sheave foundations is given in detail below. Rationale for each step can be found in corresponding subsections in Section 185-1-d (1). In addition, the documents which are needed for the design procedure are References (c), and (e)

The design procedure for arresting gear sheave foundations is given in detail below. Rationale for each step can be found in corresponding subsections in Section 185-1-d'(1). In addition, the documents which are needed for the design procedure are References (c), (d), (g), through (n), and the Ship Specifications and drawings for the particular ship under construction.

Location of Sheave Foundation. - The locations of the sheave foundations should be based on the location of the arresting gear systems as shown on the arresting gear general arrangement drawings.

Ship Structure in Way of the Sheave Foundation. - The considerations in choosing the hull structure that will anchor the sheave foundation are given below.

A. Strength - Structural members should have adequate strength for sheave foundation support. Ship and foundation structural members should be approximately the same size.

B. Load Dispersion - Foundation structural members should have short runs when attached to larger ship structure so as to afford quick dissipation of load into the main hull.

C. Proximity - Sheave locations should be as close as possible to the major ship supporting structure in order to minimize the size of the sheave foundation.

D. Loading - Torsional loading of hull members should be avoided if possible.

Sheave Foundation Layout

A. After choosing hull structure, select the best local hull structural members to support the foundation.

B. Selected foundation members shall be checked in the stress analysis and altered as necessary. Loads and deflections covered below and in the following shall be considered:

1. If a high moment is anticipated at the ends of a member, adequate bracketing shall be provided to insure end fixity.
2. Any penetrations that are made in the foundation or supporting members shall be in compliance with Reference (f).
3. All fillet welds can be assumed to be 100 percent effective.

C. Prepare sketches of the foundation, including types of connections to the hull structures.

Loadings and Deflections. - In general, distributed loads acting over a short distance can be assumed to be concentrated loads acting at the center of the distributed load length, since this will be conservative. Point loads and longer distributed loads should be applied as such.

A. Shock Loads

1. Determine weight of sheave and sheave foundation. The sum of the sheave weight and half the foundation weight is the model weight.

2. Using the model weight, calculate the "g" shock value using the acceleration-limited criterion as described in Reference (e).

B. Operational Loads

Use the maximum breaking strength of the 1-3/8" diameter cable (175,000 pounds) as the operating load. The sheaves should be assumed to rotate on a frictionless axle, therefore loads will always be normal to the sheave perimeter and will act through the center of the sheave, so that no torques can be developed.

Structural Model of Foundation. - Consider all involved structure as plate-stiffener combinations. Panel buckling will be considered separately after the frame model has been analyzed. The structure to be considered consists of the sheave foundations and all main hull structure to which the foundations are attached (this should extend to a point where it is obvious that further load dispersion will result in little stress to adjoining structure.) If some main structure member is simultaneously loaded by more than one foundation, the structure model should incorporate all the loads which may act on the member at any one time. If two foundations are attached to the same hull structure, and loadings on each foundation are in different directions, the two should be analyzed together. The following (see rationale under Structure Model of Foundation, paragraph 185-1-a(1)0 is to be used in developing the model:

1. Plate-Stiffener Combinations in Bending

2. Plate-Stiffener Combinations in Torsion

3. Shear Area of Beams

4. Beam End Fixity of Stiffeners

5. Computer Analysis Model

6. Manual Analysis Method

Stress Calculations. - The steps in this part are identical for either the computer method or the manual method.

A. Calculate the stresses and deflections in the plate-stiffener combinations, and calculate plate buckling stresses.

B. Determine if the model meets the stress limitations which follow.

1. Loading on short edges of plates

Let: $f_s$ = Calculated sheraing stress

$f_c$ = Calculated compressive stress on plate-stiffener combination or column

$f_b$ = Calculated compressive bending stress on plate-stiffener combination

$F_y$ = Yield strength of material (from Ship Specifications)

$F_c$ = Column buckling strength of plate-stiffener combination or stanchions (from Figure 1 of Reference (h)

$F_b$ = Allowable stress of plate-stiffener combination (from Ship Specifications)

$F_u$ = Ultimate strength of plating (from Figure 10 or Section 4-h of Reference (h.)

$F_p$ = Plate buckling strength

L = Equivalent free length of beam

R = Radius of gyration of cross-sectional area

**Allowable Shear Stress**

$f_s$ = $< 0.06 \, F_y$ (provided there is no danger of instability). Check for instability using Figure 8 of Reference (h) and Section 3F of Reference (g).

**Allowable Column Stresses**

Stanchions $f_c < 0.60 \, F_c$

Plate-stiffener Combinations:

$f_c < 0.67 F_c$ for $L/R > 60$

$f_c < 0.80 F_c$ for $L/R < 60$

**Combined Bending and Column Stresses**

$$\frac{f_c}{0.67 \, F_c} + \frac{f_b}{F_b} < 1.0 \text{ for } L/R > 60$$

$$\frac{f_c}{0.80 \, F_c} + \frac{f_b}{F_b} < 1.0 \text{ for } L/R < 60$$

**Stress in Plates**

$$f_c + f_b < 0.80 \, \frac{F_u \; F_c}{F_y}$$

where: $F_c$, $f_b$, $F_c$, $F_y$ = same as defined for plate-stiffeners but made appropriate for panels

2. Loading on long edges of plates

Combined bending and axial loads

$f_c + f_b < F_y$

Compressive Stress

$f_c < 0.80\ F_p$

C. Compare calculated deflections with the deflection criteria.

185-1-e Material Requirements

185-1-e (1) Welding

In design of sheave foundations, verification of the weldability of the foundation assembly must be assured by thorough checking of weldment drawings. Some causes of sheave foundation failures in service have been attributed to poor weldment designs having unweldable segments. All welded joints, especially ship installation welds, shall be readily accessible for proper welding and subsequent inspection.

Welding of surface ship structures shall be in accordance with References (c) and (j) which require main foundation welded connection efficiencies to be 100 percent. It is important that all facets of the welding procedure be in accordance with References (c) for new construction and (j) for ship alterations, in order to insure adequate weld and workmanship.

185-1-e (2) Mechanical Fasteners

Mechanical fasteners of structures shall be in accordance with Section 16 of Reference (c). Fastenings for anchorage of sheave assemblies shall be by high tensile steel throughbolts as specified in references (a) and (b).

185-1-e (3) Materials

Materials for sheave foundations in new construction ships shall conform to the Ship Specification. Structural materials for use in repair or alteration of sheave foundations in existing ships shall conform to the requirements of Reference (j).

The steel hull shall be protected against galvanic or electrolytic corrosion caused by materials mounted externally to the ships structure.

Dissimilar metals shall not be used in direct contact with each other. They must be adequately protected against electrolytic corrosion.

### 185-1-e (4) Painting and Preservation

All foundation structures shall be prepared for preservation, and pained in accordance with the instructions provided in Section 631 of the Ship Specifications.

Generally, protective finishes shall be applied to individual parts prior to assembly if assembled by mechanical means, and after assembly if parts are assembled by fusion methods. Materials exposed to sea water shall have a minimum life expectancy of three years. Protective surface treatment of these materials is permitted, but shall not require services to maintain its protective properties at intervals of less than one year.

### 185-1-f (5) Testing

Nondestructive testing of welding and material shall meet the requirements of Sections 7 and 8 of Reference (c).

Under the specified test load, the maximum allowable sheave deflection shall be no greater than 0.062 inch in any direction in the horizontal plane and in the vertical direction. The measurement shall be taken at the sheave foundation base and the top of the sheave cover. (see References (k), (m), and (n) for indicator diagrams.) No permanent set is permitted.

### 185-1-f (6) Inspections

Inspection of welding and material shall be in accordance with Section 6 of Reference (c). Inspections and tests required but not specifically described in References (a) through (c) shall be conducted in accordance with Reference (d).

### 185-1-g Sample Calculation No. 1

PROBLEM

Design the foundations for the retractable sheave and the tru-deck sheave shown in Figure 3 using computer analysis and hand calculations.

STEP 1: ARRANGEMENT

The desired arrangement of the sheave with respect to the major structural ship members is shown in Figure 3.

STEP 2: COMBINED FOUNDATION DESIGN

The proximity of the two sheaves and the fact that any foundation arrangement will load the same ship structural members for loads acting on the two sheaves suggest a combined foundation design.

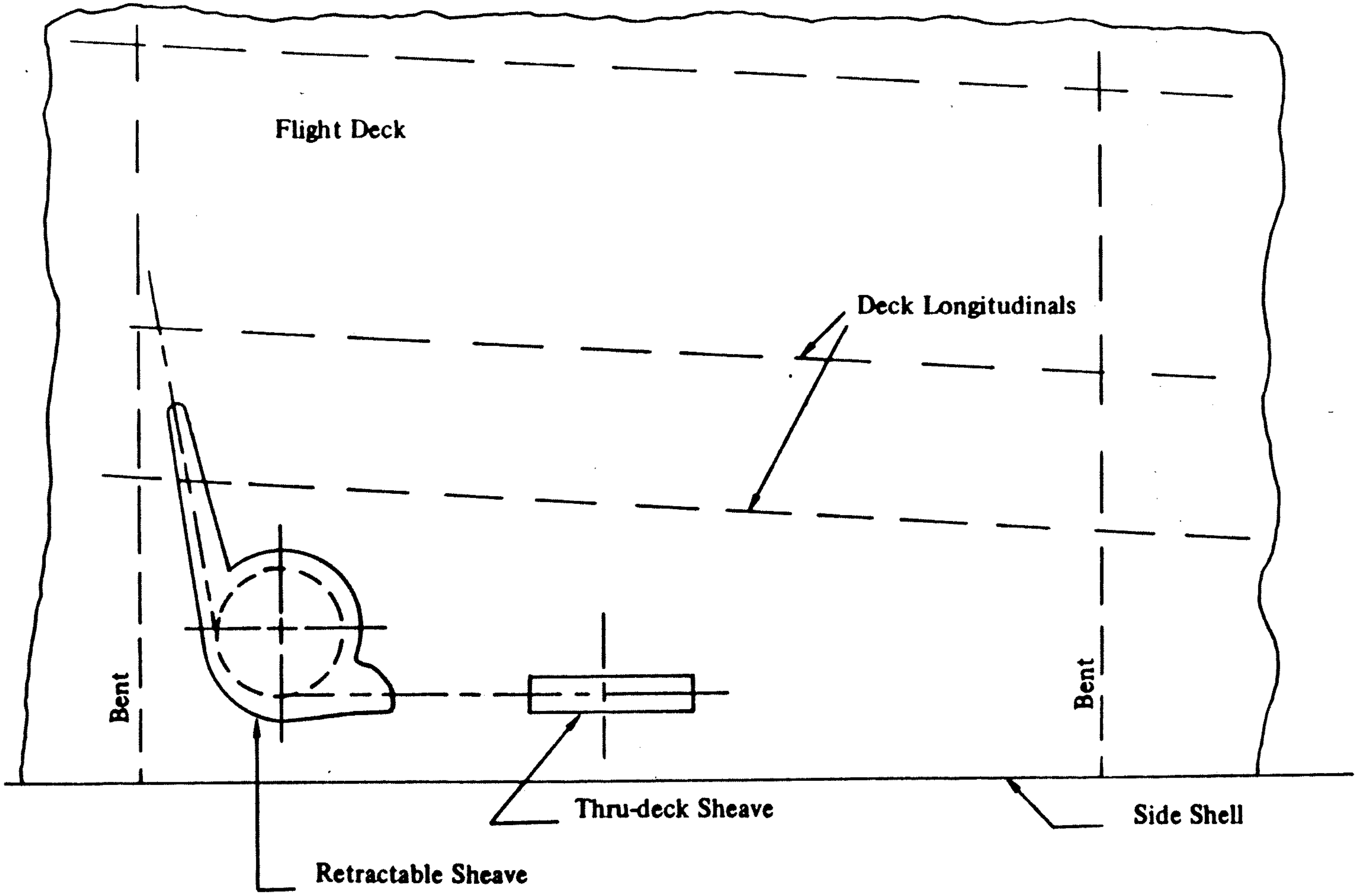
## STEP 3: FOUNDATION LAYOUT

The selected foundation layout is shown in Figure 4. The major ship components included are:

1. Ship side shell
2. Transverse bents 20 feet apart
3. The first deck longitudinal from the shell

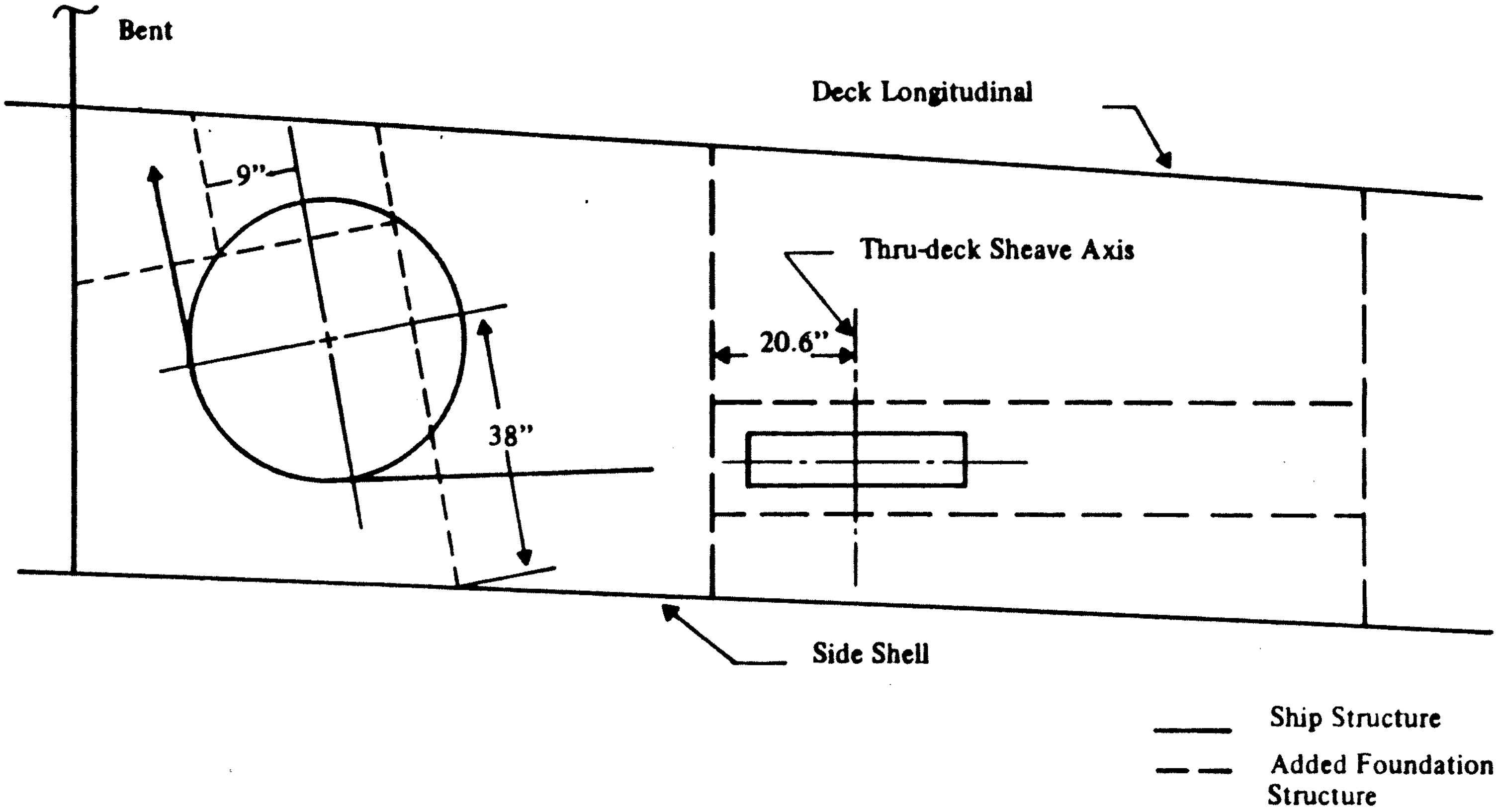
## STEP 4: OPERATIONAL LOADING

The fictitious cable for the arresting gear used in these examples has a maximum breaking strength of 175,000 pounds. (See references (l), (m) and (n) for 1-7/16 inches, 1-1/2 inches and 1-3/8 inches diameter cable criteria). Figure 5 is a structure model of the system which identifies the members and joint numbers. Figure 6 shows the reeving arrangement for the two sheaves under investigation.



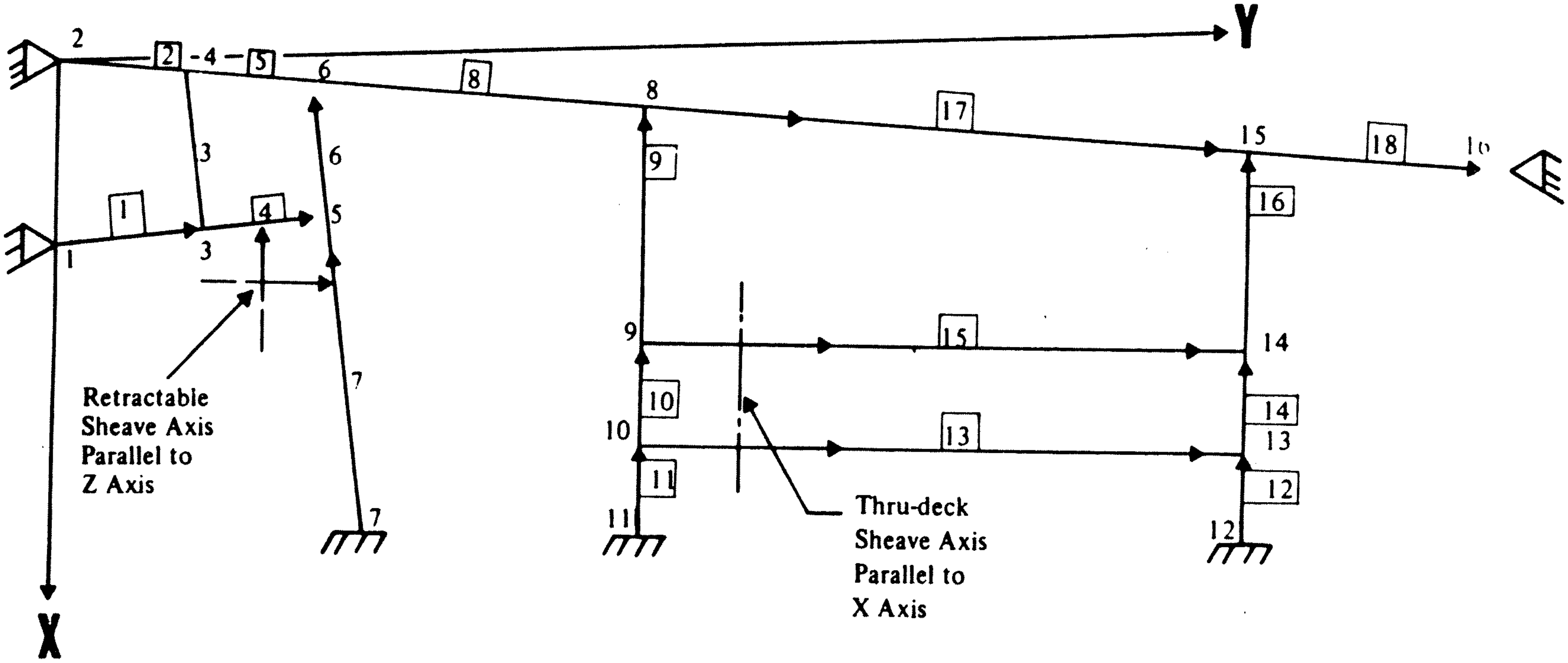
Sheave Locations and Surrounding Ship Structure Geometry

Fig. 3



Foundation Effective Members

Fig. 4

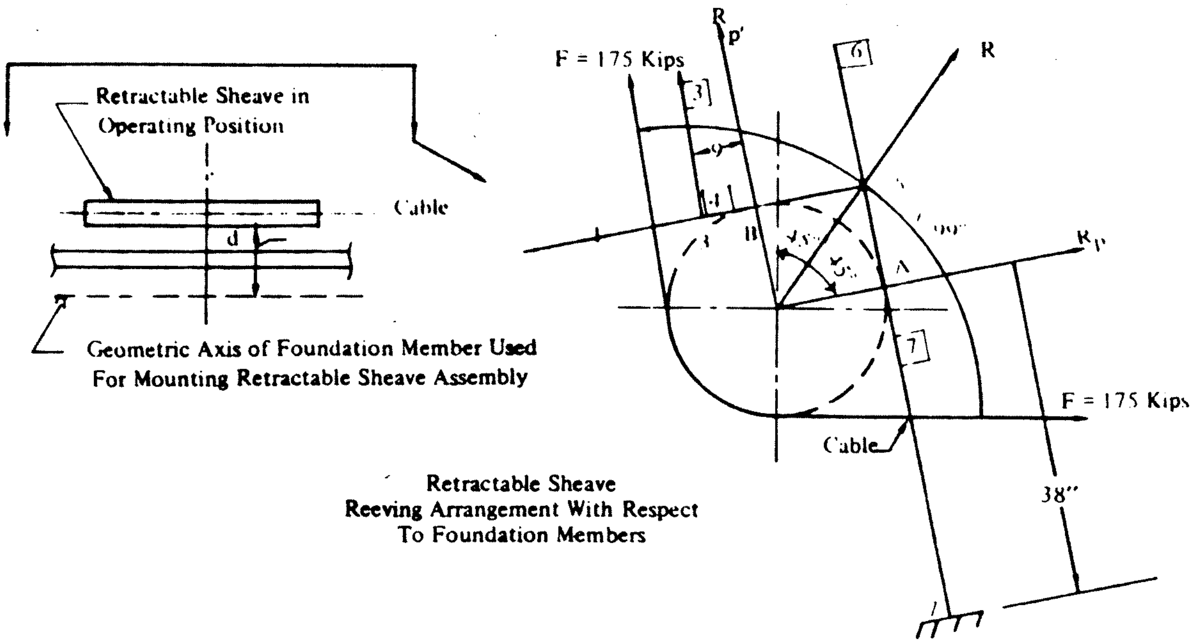


Retractable
Sheave Axis
Parallel to
Z Axis

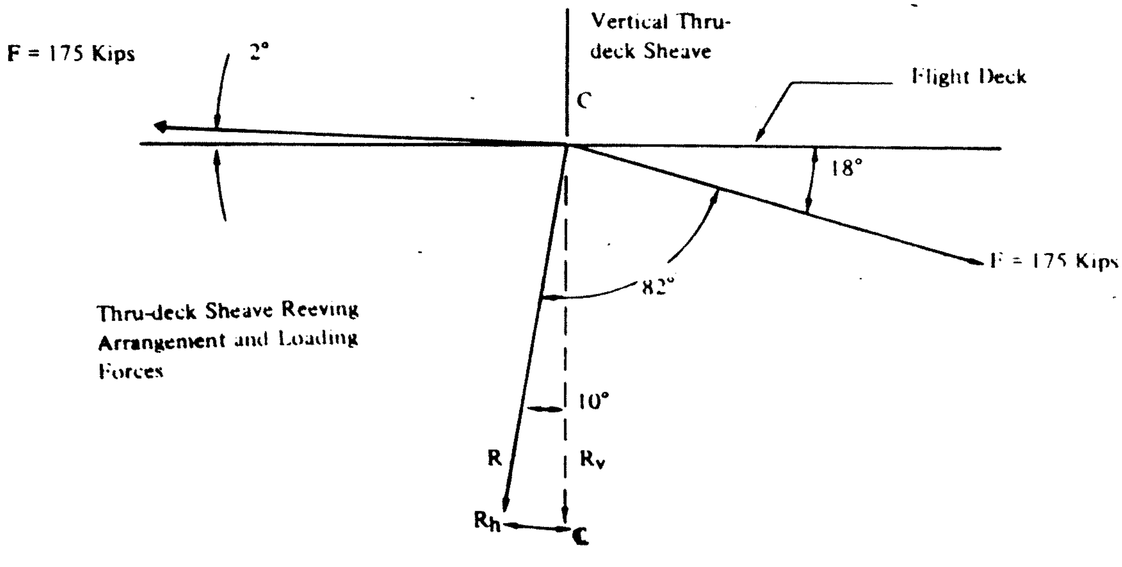
Thru-deck
Sheave Axis
Parallel to
X Axis

Structure Model

Fig. 5



Retractable Sheave
Reeving Arrangement With Respect
To Foundation Members



Thru-deck Sheave Reeving
Arrangement and Loading
Forces

Sheave Reeving Arrangements

Fig. 6

Retractable Sheave (Figure 6)

The resultant force R due to an angle of wrap of 81° is:

$$R = 2F \times \cos\frac{99^\circ}{2} = 2\,(175) \times 0.64945 = 227.3 \text{ kips}$$

The components perpendicular to Members 7 and 4 of the computer model are, respectively:

On Member 7, $R_P = R \cos 45^\circ = 227.3\,(0.707) = 160.73$ kips

On Member 4, $R_P' = R \cos 45^\circ = 227.3\,(0.707) = 160.73$ kips

These forces are transmitted to the foundation member thru the mounting plate of the retractable sheave. It will be assumed that the forces act concentrated at Points A and B (Figure 7).

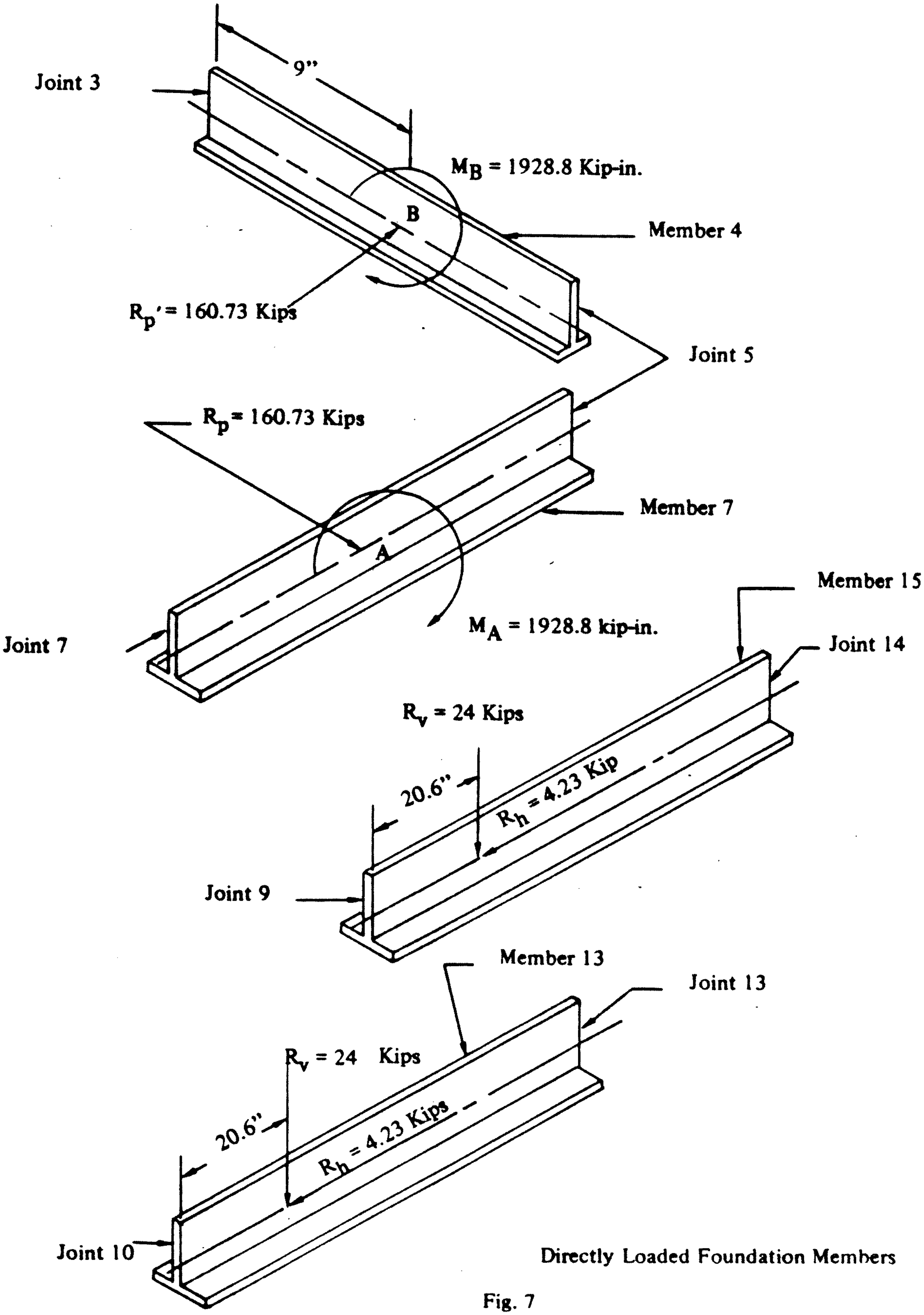
The forces $R_P$ and $R_P'$ are not applied at the geometric axis of Members 7 and 4 but at a distance "d" equal to the distance of the plane of load of the sheave from the geometric axis. Since the foundation member by assumption has negligible torsional resistance, this moment will be resisted by the bending of the members. The assumption here is that the retractable sheave enclosure plates and sheave mountings will transmit the developed load to the adjacent ship structure.

Assuming d = 12 inches (See Figure 6),

The component $R_P$, perpendicular to Member 7 acting on the plane of the sheave, will pass through the axis of the member by introducing a couple that will produce a moment equal to:

$M_B = R_P \times 12 = 160.72 \times 12 = 1928.8$ kip-in

This bending moment $M_B$ will be resisted only by Member 4 and will act at Point B.



Directly Loaded Foundation Members

Fig. 7

Using the same concept, the component $R_p$, perpendicular to Member 4 and acting on the plane of the sheave will pass through the axis of the member by introducing a couple that will produce a moment equal to:

$M_A = R_p, \times 12 = 160.72 \times 12 = 1928.8$ kip-in.

and acting on Member 7 at Point A.

$R_h = 2F \cos 82^\circ \times \sin 10^\circ = 2(175)(0.1391)(0.1736) = 8.46$ kips

$R_v = 2F \cos 82^\circ \times \cos 10^\circ = 2(175)(0.1391)(0.985) = 48.00$ kips

These forces will be assumed to act concentrated on Members 13 and 15 at the sheave axis location (half the force for each member). The loads for the operational condition are shown in Figure 7.

STEP 5: STRUCTURE MODEL

This structure model (Figure 5) indicates a plate-stiffener combination which will be treated as a grillage and be in accordance with plate stiffener combination in Bending, Section 185-1-d (1).

Boundary Conditions

The joint, bent, and model member connections at #1, #2, and #16 will be assumed as simply supported since the stiffeners of the vertical members of the bent are approximately of the same order of magnitude as the members of the structure model to which they are connected.

The shell and model member connection at joints #7, #11 and #12 will be considered fixed. The rationale here is that the rotation of model members would be restrained, due to the greater stiffness of side shell frames in comparison to the model members to which they are connected.

STEP 6: PRELIMINARY SCANTLING

The preliminary scantling of the structure model was derived from experience, taking into account the boundary assumption of Step 5. The members will be comprised of a plate-stiffener combination as described in plate stiffener combination in Bending, Section 185-1-d(1).

From the existing applicable ship structural drawing, the following data was obtained:

Longitudinal: 16 x 8½ x 64# I-T (HTS)

Deck Plating: 66.3# HY-100

Longitudinal Spacing: 36" centers

Distance of the furthest outboard longitudinal to the shell is 60".

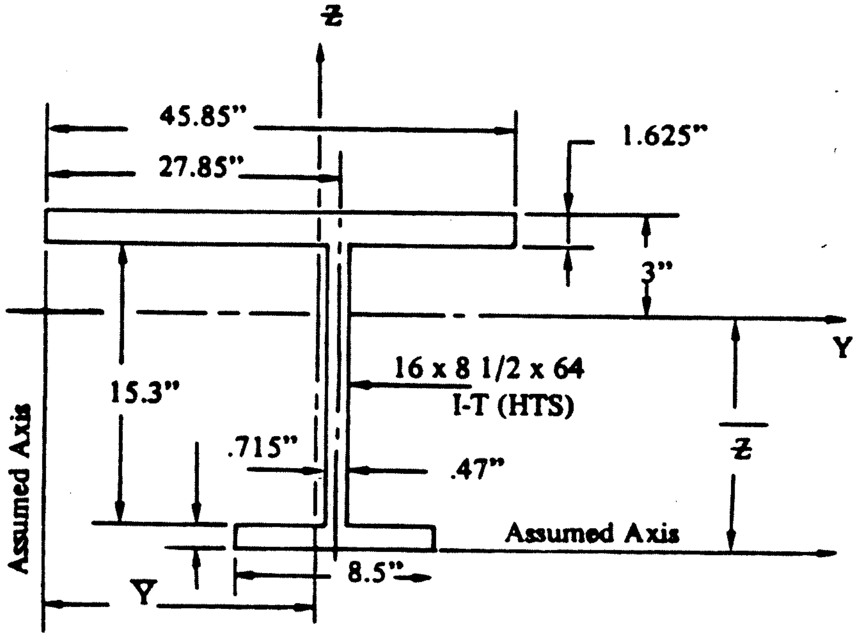
The expression $2t\sqrt{\frac{E}{F_y}}$, gives the maximum effective width of plating, when using the properties of the above scantlings.

$E = 29,600$ KSI

$F_y = 100$ KSI

$t = 1.625$ inches

then $2\,(1.625)\sqrt{\frac{29,600}{100}} = 55.70$ inches. Therefore, the effective plate width associated with the outermost deck longitudinal will be equal to the sum of one-half of the calculated width of 55.7 inches and one-half of the longitudinal spacing of 36 inches which numerically equals $\frac{55.7}{2} + \frac{36}{2} = 45.85$ inches. Elsewhere, the effective width equals the longitudinal spacing, and the properties are as on the following page.



Effective Shear Area $= .47\,(.715 + 15.3 + 1.625) = 8.29$ in.$^2$
(In Y Direction)

Effective Shear Area $= .715\,(8.5) + 45.85\,(1.625) = 80.6$ in.$^2$
(In Z Direction)

IZ = Torsional moment of inertia. Assume $\sim 0.0$ since an open section can withstand little torsion. This assumption will force the bending and shear capabilities of the beam to make up deficiencies.

The following is a summary of the properties of longitudinals:

AX = Normal cross-sectional area = 87.8 in.$^2$

| PART | ABOUT Y AXIS |  |  |  |  | ABOUT Z AXIS |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Area A | d | Ad | $Ad^2$ | io | Area A | d | Ad | $Ad^2$ | io |
| 1. Deck Plate | 74.51 | 16.83 | 1254. | 21105. | 16.4 | 74.51 | 22.93 | 1703.5 | 39176.2 | 13052.4 |
| 2. T-Web | 7.19 | 8.365 | 60.14 | 503.1 | 140.3 | 7.19 | 28.09 | 201.97 | 5675.3 | .132 |
| 3. T-Flange | 6.1 | .358 | 2.18 | .78 | .26 | 6.1 | 28.09 | 171.3 | 4813. | 36.59 |
| TOTALS | 87.8 |  | 1316.4 | 21609.5 | 156.96 | 87.8 |  | 2081.8 | 49663. | 13089. |

$$Z = \frac{\Sigma Ad}{\Sigma A} = \frac{1316.4}{87.8} = 15.0 \text{ in.}$$

$$Y = \frac{2081.8}{87.8} = 23.71 \text{ in.}$$

$$I_Y = 21609.5 + 156.96 - 15.0^2\,(87.8)$$

$$= 2011.5 \text{ in.}^4$$

$$I_Z = 13394. \text{ in.}^4$$

$$S_Z = \frac{13394.}{23.71} = 564.9 \text{ in.}^3$$

$$S_Y = 134.10 = \frac{2011.5 \text{ in.}^3}{15.0}$$

**WHERE**: d = Distance of each part's centroid above assumed axis.

io = Moment of inertia of each part about its own axis (through centroid) parallel to the assumed axis.

AZ = Effective shearing area in the Z direction = 80.6 in.$^2$

AY = Effective shearing area in the Y direction = 8.29 in.$^2$

IX = Torsional moment of inertia = 0

IZ = Moment of inertia about Z axis = 13379. in.$^4$

IY = Moment of inertia about Y axis = 2011.5 in.$^4$

SZ = Section modulus about Z axis = 564.9 in.$^3$

SY = Section modulus about Y axis = 134.1 in.$^3$

The properties of the model members used in this sample calculation, shown in Table 1, are from a previous design where the effective width of plating was considered.

## STEP 7: SHOCK LOADS

The weight of the sheaves and foundation estimate, on the basis of the scantling selection of Step 6, lead to the following data:

Retractable Sheave

| Foundation Member | Area (in.$^2$) | Length (ft) | Weight (lb) |
|---|---|---|---|
| 6-7 | 42.5 | 6.0 | 857 |
| 1-4 | 40.8 | 3.5 | 479 |
| 3 | 12.8 | 2.0 | 86 |
| | | | 1422 |
| | | Assume | 1430 lb |

Assembly of retractable sheave = 2566 lb

Total weight associated with shock for retractable sheave

| | |
|---|---|
| Sheave assembly | 2566 lb |
| ½ foundation weight | 714 lb |
| | 3280 lb |

Thru-Deck Sheave

1) Estimated weight of sheave assembly 1544 lb

2) Foundation weight (in accordance with Table I):

| Foundation Member | Area (in.$^2$) | Length (ft) | Weight (lb) |
|---|---|---|---|
| 9-10-11 | 12.5 | 5.5 | 231.1 |
| 15 | 42.7 | 8.17 | 1173.0 |
| 13 | 20.8 | 8.17 | 571.2 |
| 12-14-16 | 101.5 | 5.5 | 1876.0 |
| Other | | | 1575.0 |
| | | | 5426.3 |
| Due to uncertainty: | | 25% allowance | 1356.6 |
| | | | 6782.9 lb |

Total weight associated with shock for thru-deck sheave:

| | |
|---|---|
| Sheave assembly | 1544 lb |
| ½ foundation weight | 3392 lb |
| | 4936 lb |

Using the shock design values for acceleration-limited shock in accordance with Reference (e), the following was derived:

| Sheave Foundation | Vertical (g) | Athwart (g) | Fore & Aft (g) |
|---|---|---|---|
| Retractable sheave | 72.4 | 29.08 | 29.08 |
| Thru-deck sheave | 60.1 | 24.04 | 24.04 |

The shock loads are therefore:

| Sheave Foundation | Vertical (kips) | Athwart (kips) | Fore & Aft (kips) |
|---|---|---|---|
| Retractable sheave | 186.0 | 74.4 | 74.4 |
| Thru-deck sheave | 92.6 | 37.0 | 37.0 |

## STEP 8: COMPUTERIZED ANALYSIS

The structure model of Figure 5 for a computer analysis was modified as shown in Figure 8. The modification was made to obtain representative points of the sheaves for the

## TABLE I - FOUNDATION MEMBER PROPERTIES

| MEMBER | Cross Section Area (in.$^2$) $A_x$ | Shear Area Vert. (in.$^2$) $A_z$ | Shear Area Horiz. (in.$^2$) $A_y$ | Moment of Inertia About Horiz. Axis (in.$^4$) $I_y$ | Moment of Inertia About Vert. Axis (in.$^4$) $I_z$ | Section Modulus About Horiz. Axis (in.$^3$) $S_y$ | Section Modulus About Vert. Axis (in.$^3$) $S_z$ |
|---|---|---|---|---|---|---|---|
| 1 | 40.8 | 21.0 | 15.0 | 2,753.0 | 245.0 | 207.60 | 38.04 |
| 2 | 87.8 | 8.3 | 80.6 | 2,011.5 | 13,394. | 134.10 | 564.90 |
| 3 | 12.8 | 8.8 | 4.0 | 286.7 | 21.6 | 30.93 | 5.40 |
| 4 | 40.8 | 21.0 | 15.0 | 2,753.0 | 245.0 | 207.60 | 38.40 |
| 5 | 87.8 | 8.3 | 80.6 | 2,011.5 | 13,394. | 134.10 | 564.90 |
| 6 | 42.5 | 21.5 | 13.0 | 3,217.0 | 338.7 | 242.60 | 45.28 |
| 7 | 42.5 | 21.5 | 13.0 | 3,217.0 | 338.7 | 242.60 | 45.28 |
| 8 | 87.8 | 8.3 | 80.6 | 2,011.5 | 13,394. | 134.10 | 564.90 |
| 9 * | 12.5 | 8.0 | 4.5 | 378.2 | 13.7 | 34.23 | 4.56 |
| 10 * | 12.5 | 8.0 | 4.5 | 378.2 | 13.7 | 34.23 | 4.56 |
| 11 * | 12.5 | 8.0 | 4.5 | 378.2 | 13.7 | 34.23 | 4.56 |
| 12 | 101.5 | 8.0 | 93.5 | 1,547.6 | 23,405. | 94.60 | 840.39 |
| 13 | 20.8 | 8.0 | 9.8 | 943.2 | 75.7 | 82.23 | 18.65 |
| 14 | 101.5 | 8.0 | 93.5 | 1,547.6 | 23,405. | 94.60 | 840.39 |
| 15 | 42.7 | 8.0 | 31.7 | 1,302.5 | 1,652. | 89.95 | 134.86 |
| 16 | 101.5 | 8.0 | 93.5 | 1,547.6 | 23,405. | 94.60 | 840.39 |
| 17 | 87.8 | 8.3 | 80.6 | 2,011.5 | 13,394. | 134.10 | 564.90 |
| 18 | 87.8 | 8.3 | 80.6 | 2,011.5 | 13,394. | 134.10 | 564.90 |

*No effective plate associated with beam due to cuts (conservative assumption).

evaluation of deflection and rotation values. The changes are:

- Addition of Joints 17 to 22
- Addition of Members 19 to 26

The properties of the additional members are:

| Member | Same Properties as Member |
|---|---|
| 19 | 4 |
| 20 | 7 |
| 23 | 15 |
| 24 | 13 |

Members 21 and 22 are fictitious and represent the sheave assembly which is assumed very stiff. Members 21 and 22 will couple the deflection and rotations of Joints 17 and 19 so that Joint 18 can be assumed to deflect and rotate as the axis of the retractable sheave.

The sum of $I_Y$ and $I_Z$ of the fictitious stiff Members 21 and 22 is assumed to be 10,000 in.$^4$. Members 25 and 26 model the connection between Joints 20 and 22 made by the thru-deck sheave axis. Their properties will be the properties of that axis. Since no bending can be resisted by the sheave axis, it will be assumed that: Member 26 is pin connected at Joint 22, and Member 25 is pin connected at Joint 20. Since Joint 21 is the center of the sheave axis, it will, by its deflection and rotation, give the data required to estimate the sheave deflections.

Loading Conditions (loads described for the computer model)
(See Figure 8)

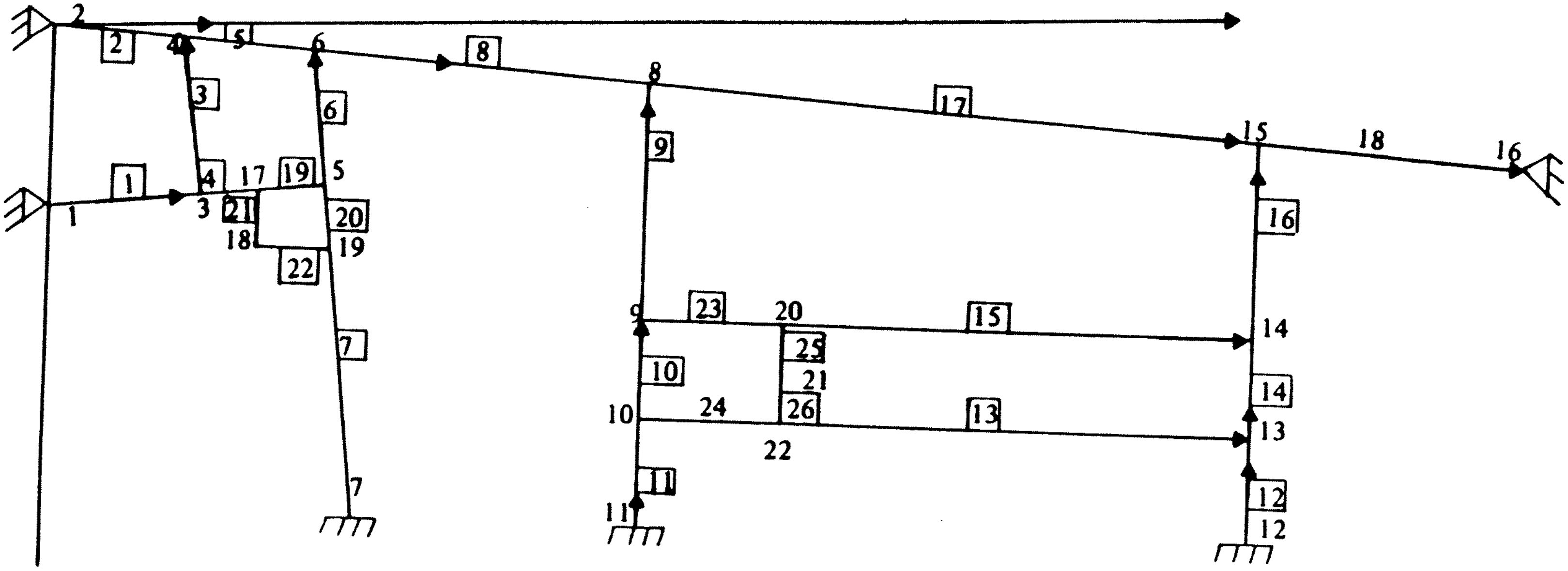
1) Operational Load

Retractable Sheave

| | | |
|---|---|---|
| Joint 17 | Force Y | = -160.7 kips |
| | Moment Y | = 1928 kip-in. |
| Joint 19 | Force Y | = 160.7 kips |
| | Moment Y | = -1928 kip-in. |

Thru-deck Sheave

| | | |
|---|---|---|
| Joints 20 and 22 | Force Z | = -24 kips |
| | Force Y | = -4.2 kips |



Computer Model

Fig. 8

2) Vertical Shock (Downward)

Retractable Sheave

Joints 17 and 19 Force Z = -93 kips

Thru-deck Sheave

Joints 20 and 22 Force Z = -46.3 kips

3) Athwartship Shock (acting in negative X direction)

Assuming that the center of gravity of the sheave assembly is in the same horizontal plane of the geometric axis of the model members, no concentrated moment will act on the Members 1-4, and 6-7.

Retractable Sheave

Joints 17 and 19 Force X = -37.2 kips

Thru-deck Sheave

Joints 20 and 22 Force X = -18.5 kips

4) Fore and Aft Shock (acting in positive Y direction)

Retractable Sheave

Joints 17 and 19 Force Y = 37.2 kips

Thru-deck Sheave

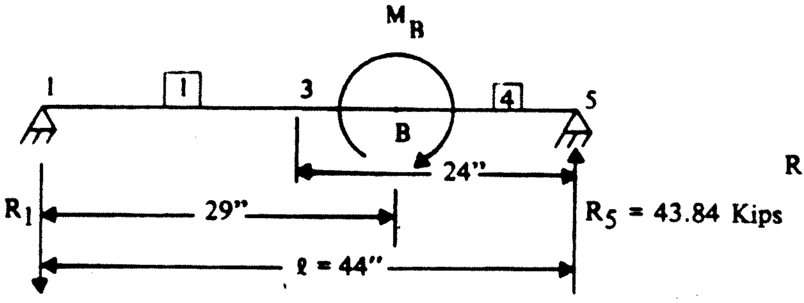
Joints 20 and 22 Force Y = 18.5 kips

## STEP 9: HAND CALCULATION

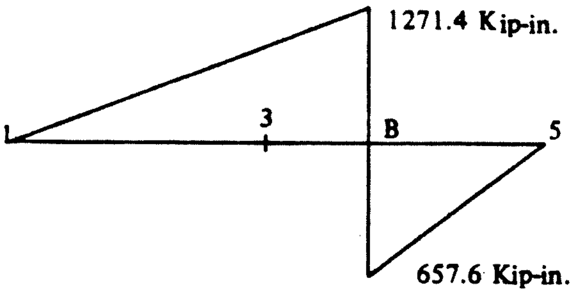
Operating and other conditions will be calculated in a similar manner. Hand calculation will begin with the member directly loaded by the sheaves and carried out to the boundary of the model (Figure 5). Since both foundation members (for thru-deck and retractable sheaves) are independently stressed until the load is transmitted to the flight deck longitudinals (Members 2, 5, 8, 17, and 18), each foundation member can be calculated separately in sequence until reaching the common connecting member.

### Retractable Sheave

Members 1 and 4 (Figures 5, 7, and 9) will be considered as a single member supported at both ends (and at Joint 3 for forces acting in the horizontal plane). The forces acting on the member are:

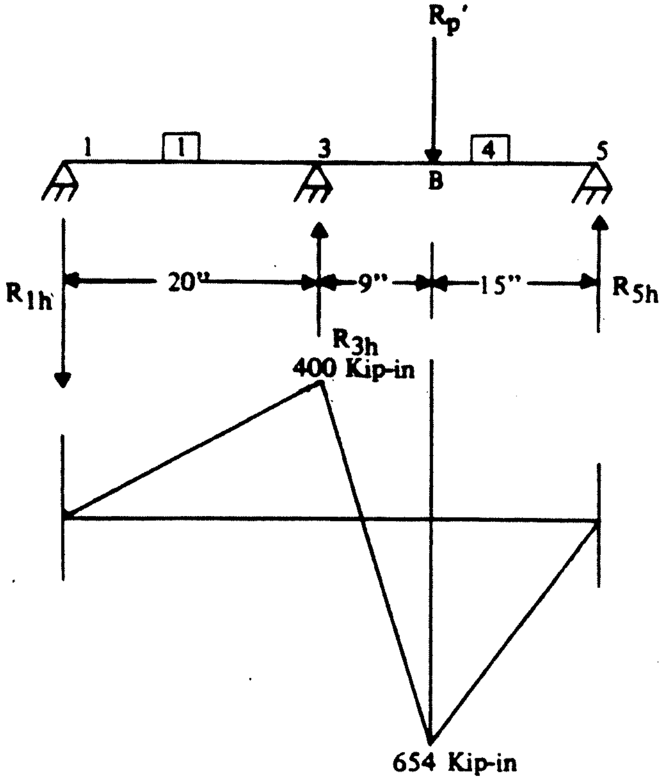


$$R_5 = -R_1 = \frac{M_B}{\ell} \quad \text{(Vertical force)}$$



Bending moment about horizontal Axis- (maximum value $M_B$ at B)

Note: Joint 3 is not restrained against rotation in accordance with Plate Stiffener Combination in Torsion, Section 185-1-e(1).



$$R_{5h} = \frac{BM_3 - R_p' \times 9}{\ell - 20}$$

$$R_{1h} = \frac{BM_3}{20}$$

$$R_{3h} = R_p' - R_{5h} - R_{1h}$$

Bending moment diagram about vertical axis

Fig. 9 Forces on Member 1 and 4

1) Concentrated moment $M_B$ = 1928.8 kip-in. acting 9 inches from Joint 3 (Negative)

2) Concentrated force in the horizontal place = 160.73 kips acting at a section 9 inches from Joint 3.

The moment $M_B$ will induce vertical force $R_5$ on Joint 5 acting downward.

$$R_5 = 43.84 \text{ kips}$$

For the force $R_p'$ = 160.73 kips, Joint 3 is assumed supported by Member 3 (Figure 5) in the horizontal direction. From the data shown in Figure 9 and using moment distribution, we have:

MOMENT DISTRIBUTION CALCULATION

| Member | 1-3 | 3-1 | 3-5 | 5-3 |
|---|---|---|---|---|
| Rotational Stiffness | | 10 | 12 | |
| Distribution Factor | 1 | 0.545 | 0.455 | 1 |
| Carry-Over Factor | 0.5 → | ← 0.5 | 0.5 → | ← 0.5 |
| Fixed-End Moment | | | 565.07 | -339.04 |
| | -153.98 | -307.96 | -257.11 | -128.55 |
| | +153.98 | + 76.99 | +233.79 | +457.59 |
| | - 84.62 | -169.37 | -141.41 | - 70.70 |
| | + 84.62 | + 42.34 | + 35.35 | + 70.70 |
| | | - 42.34 | - 35.35 | |
| Moment (kip-in.) | 0 | -400.34 | +400.22 | 0 |

$BM_3 \cong 400$ kip-in.

The reaction at Joint 1: $R_{1h} = \dfrac{BM_3}{20 \text{ in.}} = \dfrac{400}{20} = -20$ kips

The reaction at Joint 5: $R_{5h} = \dfrac{BM_3 \quad R_p' \text{ x } 9}{24 \text{ in.}} = \dfrac{400 - 160.73 \text{x} 9}{24} = 43.6$ kips

The reaction at Joint 3: $R_{3h} = R_p' + R_{1h} - R_{5h} = 160.73 + 20 - 43.6 = 137.13$ kips

The bending moment at B: $M_{Bh} = R_{5h} \text{ x } 15 = 43.6 \text{ x } 15 = 654$ kip-in.

Summary of Forces:

$BM_y$ = 1271.4 kip-in.

$BM_z$ = 654 kip-in.

Shear (vert) = 43.84 kips

Shear (horiz) = $R_{p'}$ $R_{5h}$ = 160.73 43.6 = 117.13 kips

Axial force = 0

From values in Table I, stress $\sigma$ may be calculated.

$$\sigma = \frac{1271.4}{207.6} + \frac{654}{38.04} = 23.3 \text{ KSI}$$

Members 6 and 7 (Figure 10)

By calculations from data in Figure 10, vertical reactions at Joints 6 and 7 are:

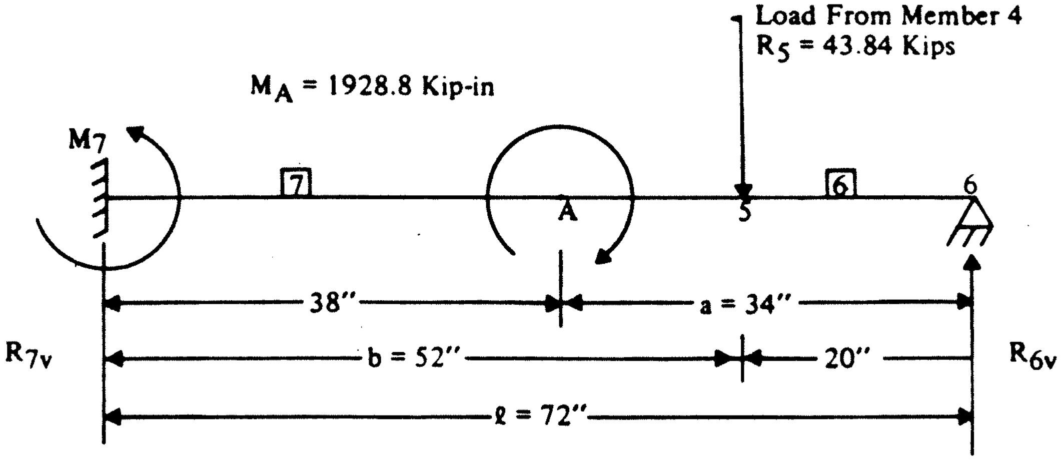
$R_{6v}$ = 57.26 kips

$R_{7v}$ = 13.42 kips

Moment about horizontal axis at the fixed support 7 is:

$M_7$ = 85.5 kip-in.

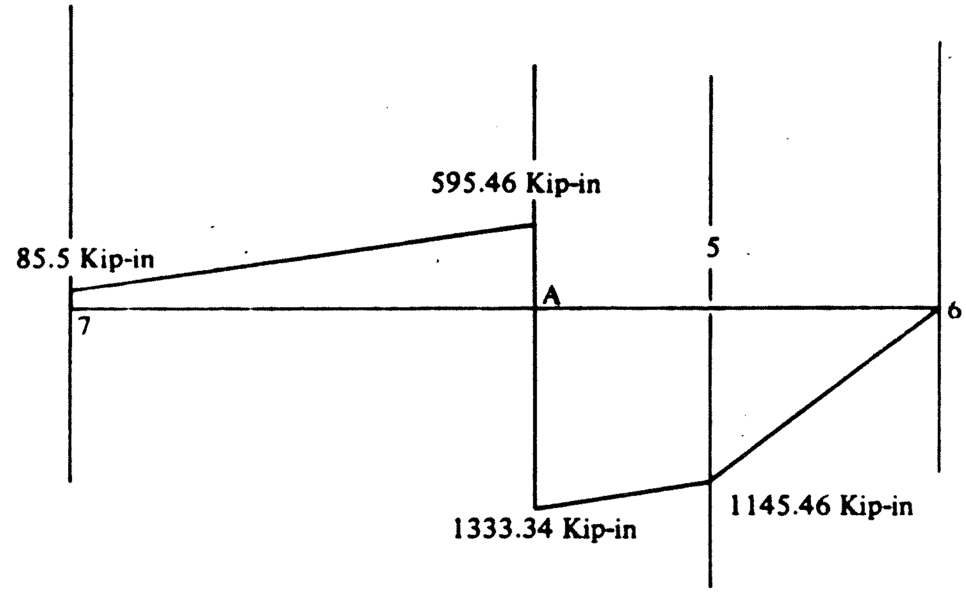
The bending moment is shown in Figure 10.



$$M_7 = \frac{1}{2} M_A \left(1 - 3\frac{a^2}{\ell^2}\right) + \frac{1}{2} R_5 \left(\frac{b^3 + 2b\ell^2 - 3b^2}{2}\right)$$

$$R_{6v} = \frac{3}{2} \frac{M_a}{\ell}\left(\frac{\ell^2 - a^2}{\ell^2}\right) + \frac{1}{2} R_5 \left(\frac{3b^2 - b^3}{\ell^3}\right)$$

$$R_{7v} = -\frac{3}{2} \frac{M_a}{\ell}\left(\frac{\ell^2 - a^2}{\ell^2}\right) + \frac{R_5}{2\ell^3} \left(2\ell^3 - 3b^2\ell + b^3\right)$$



Bending Moment Diagram About Horizontal Axis

Vertical Reactions at Joints 6 and 7

Figure 10

For the force acting in the horizontal direction perpendicular to Member 7 as shown in Figure 11, the bending moment distribution assuming Joint 7 fixed, Joint 5 supported, and Joint 6 supported by Member 5 leads to

## MOMENT DISTRIBUTION CALCULATION

| Member | 7-5 | 5-7 | 5-6 | 6-5 |
|---|---|---|---|---|
| Rotational Stiffness | | 5 | 13 | |
| Distribution Factor | | 0.278 | 0.722 | 1 |
| Carry-Over Factor | | ← 0.5 | 0.5 → | ← 0.5 |
| Fixed-End Moment | +422.72 | -1201.67 | | |
| | +167.03 | +334.07 | +867.6 | +433.8 |
| | | | -216.9 | -433.8 |
| | + 30.15 | + 60.3 | +156.6 | + 78.3 |
| | | | - 39.15 | - 78.3 |
| | + 5.44 | + 10.88 | + 28.26 | + 14.13 |
| | | | - 7.06 | - 14.13 |
| | + 0.98 | + 1.96 | + 5.09 | + 2.54 |
| | | | - 1.27 | - 2.54 |
| | + 0.17 | + 0.35 | + 0.92 | 0 |
| Moment (kip-in.) | +626.67 | -794.10 | +794.10 | 0 |

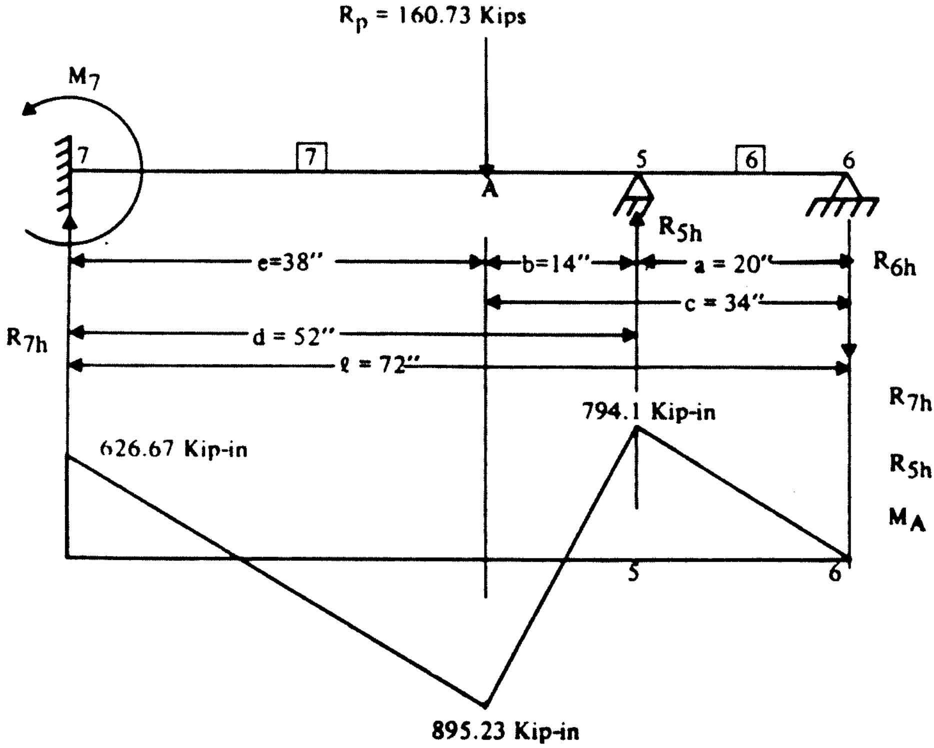
Therefore (Figure 11),

$$R_{6h} = -\frac{M_5}{a} = -\frac{794.10}{20} = -39.7 \text{ kips}$$

$R_{7h}$ = 40.05 kips

$R_{5h}$ = 160.38 kips

$M_A$ = 1690.5 kip-in.



$$R_{6h} = -\frac{M_5}{20}$$

$$R_{7h} = \frac{R_p \times b - R_{6h} \times a + M_7}{d}$$

$$R_{5h} = R_p + R_{6h} \quad R_{7h}$$

$$M_A = R_{7h}\,\ell - M_7$$

Horizontal Reactions at Joints 6 and 7

Fig. 11

Summary of forces (maximum values)

$BM_y$ = 1333.3 kip-in.

$BM_A$ = 895.23 kip-in.

Shear (vert) = 57.20 kips

Shear (horiz) = 120.68 kips

Axial force = 0

From values in Table I,

$A_z = 21.5$ in.$^2$, $A_y = 13.0$ in.$^2$, $S_y = 242.60$ in.$^3$, $S_z = 45.28$ in.$^3$

$$\sigma = \frac{1333.3}{242.60} + \frac{895.23}{45.28} = 25.26 \text{ KSI}$$

$$\text{Shear stress (vert)} = \frac{57.20}{21.5} = 2.66 \text{ KSI}$$

$$\text{Shear stress (horiz)} = \frac{120.68}{13.0} = 9.28 \text{ KSI}$$

Member 3

Compressive load = 97.13 kips

Cross-section area from Table I: $A_x = 12.8$ in.$^2$

$$F_c = \frac{97.13}{12.8} = 7.60 \text{ KSI}$$

Thru-deck Sheave

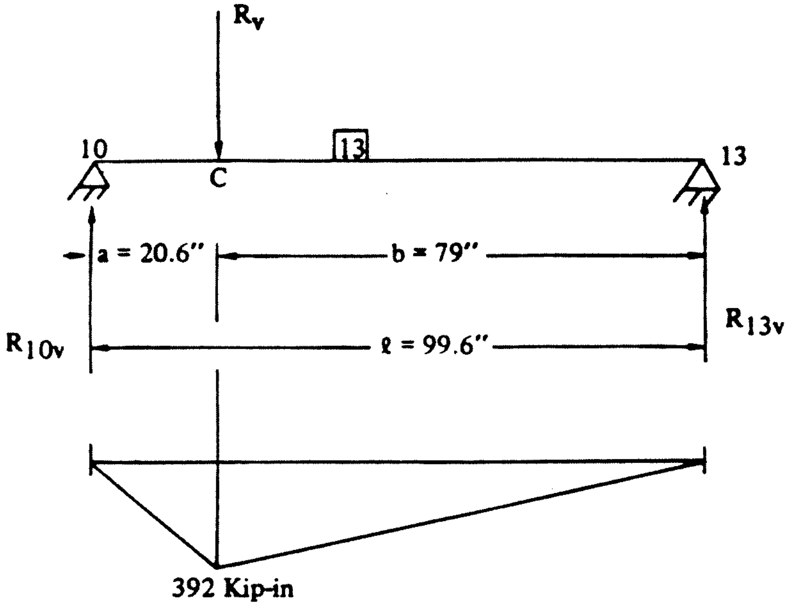
Member 13 (Figure 12)

Vertical Load $R_v$ = 24 kips

$R_{10v}$ = 19.03 kips

$R_{13v}$ = 4.97 kips

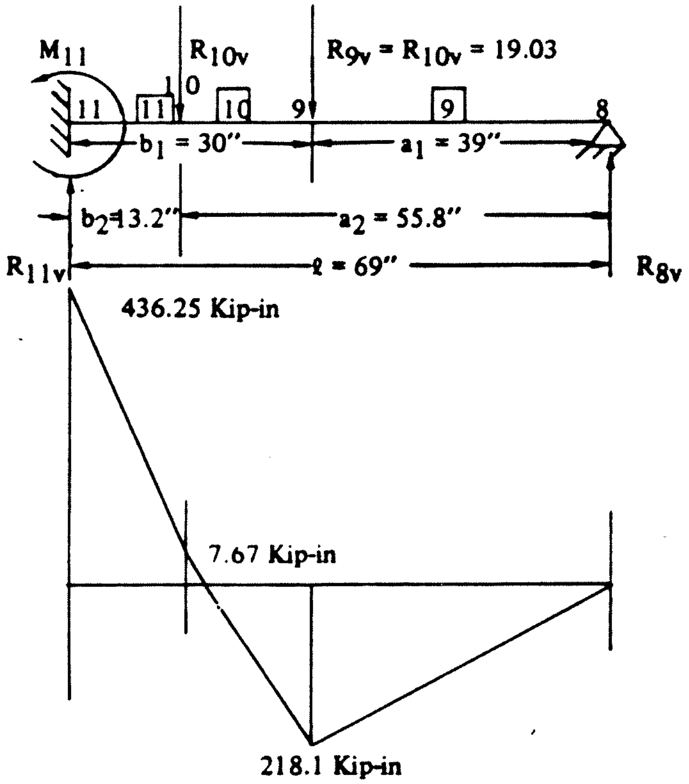
$M_C$ = 392 kip-in.



$$R_{10v} = \frac{R_v b}{\ell}$$

$$R_{13v} = \frac{R_v a}{\ell}$$

$$M_C = \frac{R_v ab}{\ell}$$



$$R_{8v} = \frac{R_{10v}}{2\ell^3} \sum_{i=1}^{2} (a_1 + 2\ell)\, b_1{}^2$$

$$R_{11v} = 2\,R_{10v} - R_{8v}$$

$$M_{11} = R_{8v}\,\ell - R_{10v}\,(b_1 + b_2)$$

Forces On Members 13 and 9-10-11

Fig. 12

Horizontal Load = $R_h = \frac{1}{2}(8.46) = 4.23$ kips

Compressive load between C and 10: $F_{c\text{-}10} = 3.35$ kips

Tensile load between 13 and C: $F_{13\text{-}c} = 0.88$ kips

Shear (vert) = 19.03 kips

From Values in Table I,

$S_y = 82.23$ in.$^3$

$A_x = 20.8$ in.$^2$

$A_z = 8$ in.$^2$

$$\sigma \max = \frac{392}{82.23} + \frac{3.35}{20.8} = 4.92 \text{ KSI}$$

$$\text{Shear stress (max)} = \frac{19.03}{8} = 2.38 \text{ KSI}$$

Member 15 (same force value as 13)

$R_{9v} = 19.03$ kips

$R_{14v} = 4.97$ kips

$M_{max} = 392$ kip-in.

Max compressive force = 3.35 kips

From values in Table I,

$$\sigma \max = \frac{392}{89.95} + \frac{3.35}{42.7} = 4.44 \text{ KSI}$$

$$\text{Shear stress (max)} = \frac{R_{9v}}{A_z} = 2.38 \text{ KSI}$$

Member 9-10-11 (Figure 12)

The forces acting on this overall member are the reactions from Members 13 and 15 with the values of

$R_{10v} = 19.03$ kips

The member reaction and moments are:

$R_{8v}$ = 5.59 kips

$R_{11v}$ = 32.47 kips

$M_{11}$ = −436.25 Kip-in.

$M_9$ = 218.1 kip-in.

$M_{10}$ = −7.67 kip-in.

Force Summary

Axial force = 0

$BM_{max}$ = 436.25 kip-in.

Shear (vert) = 32.47 kips

From values in Table I,

$$\sigma = \frac{436.25}{34.23} = 12.75 \text{ KSI}$$

$$\text{Shear stress} = \frac{32.47}{8} = 4.06 \text{ KSI}$$

Member 12-14-16 (Figure 13)

Using the same formulas as for Member 9-10-11 for $R_{13v}$ = 4.97 kips, we have:

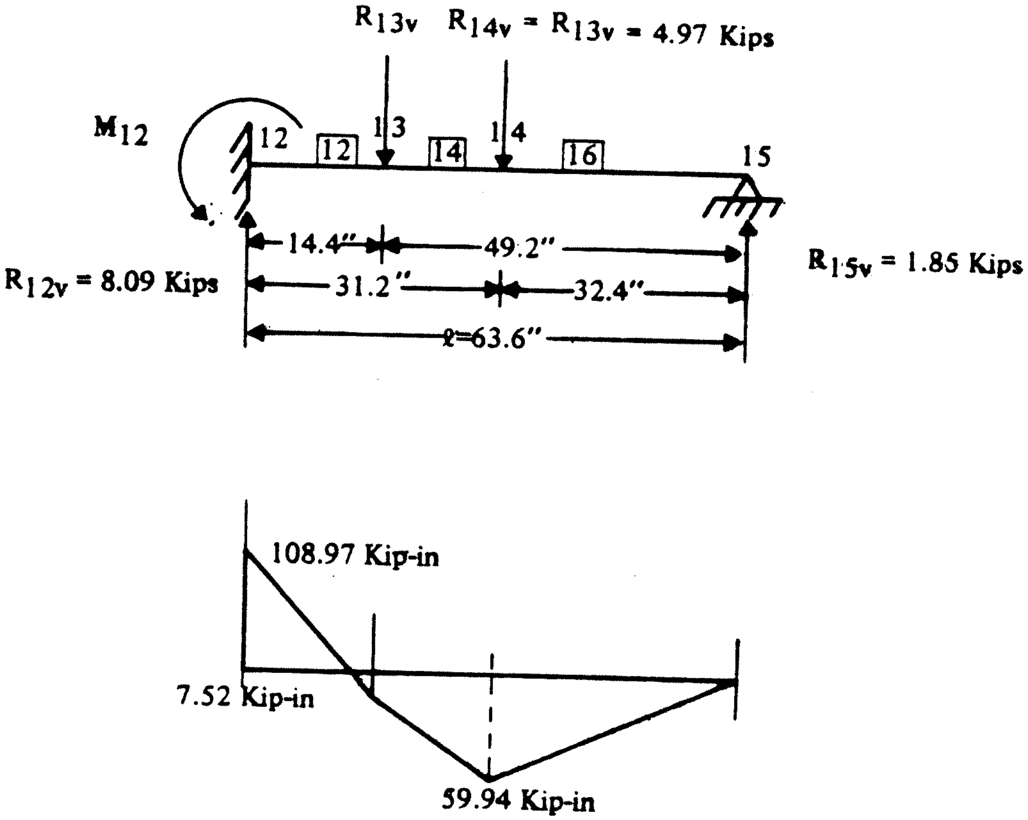
$R_{15v}$ = 1.85 kips

$R_{12v}$ = 8.09 kips

$M_{12}$ = 108.97 kip-in.

$M_{13}$ = 7.52 kip-in.

$M_{14}$ = 59.94 kip-in.



Forces on Member 12-14-16

Figure 13

From values in Table I;

$$\sigma = \frac{108.97}{94.6} = 1.15 \text{ KSI}$$

$$\text{Shear stress} = \frac{8.09}{8} = 1.01 \text{ KSI}$$

Member Common To Both Foundations

Member 2-5-8-17-18 (Figure 14)

The maximum stresses are:

BM (about horizontal axis) = 2144.15 kip-in.

Shear (vert) = 50.93 kips

Axial force (2 to 6) = 32.75 kips

From values in Table I:

$A_x = 87.8$

$S_y = 134.10$

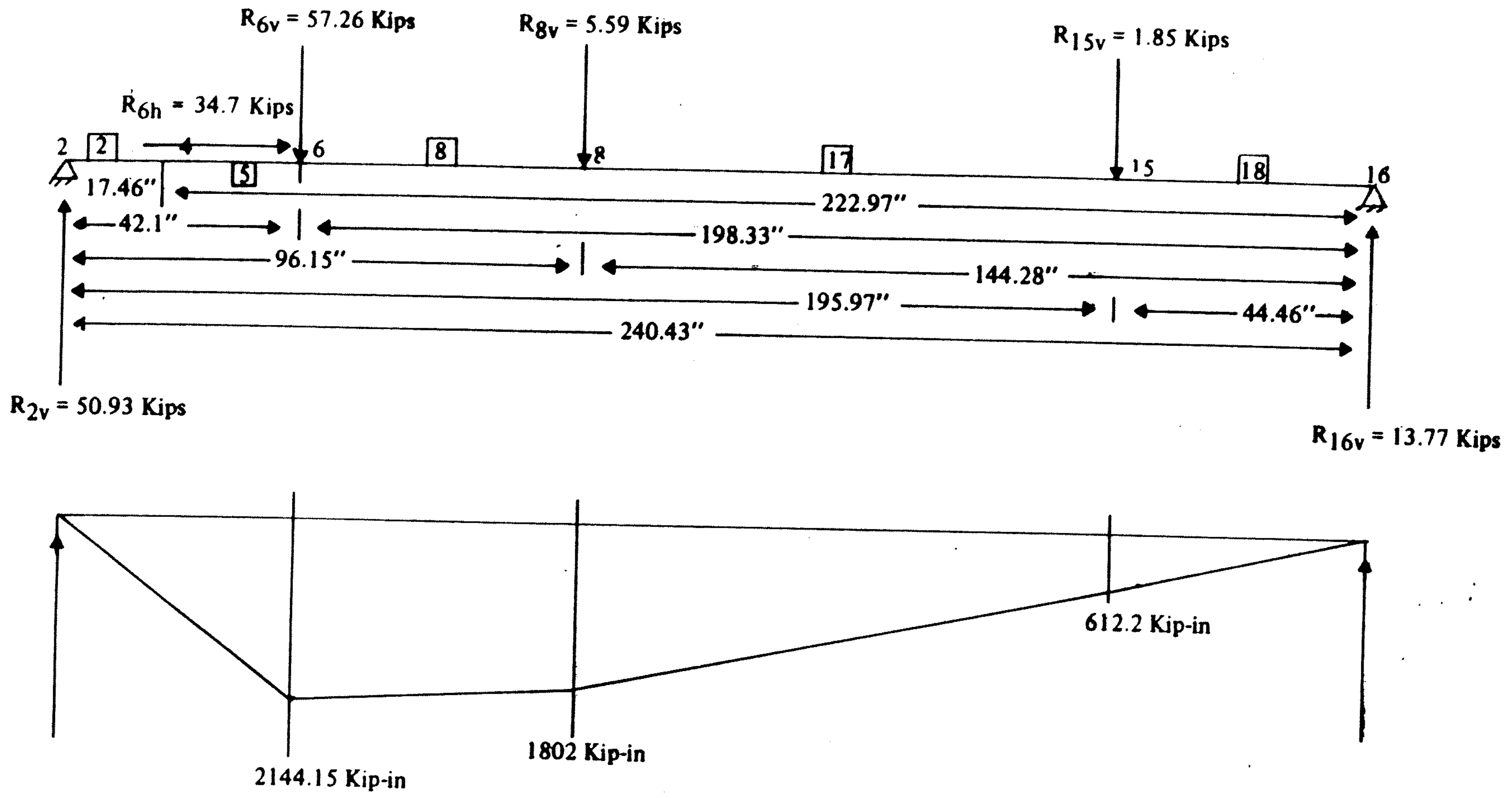
$A_z = 8.3$

$$\sigma = \frac{32.35}{87.8} + \frac{2144.15}{134.10} = 16.36 \text{ KSI}$$

$$\text{Shear stress} = \frac{\text{Shear vert.}}{A_z} = \frac{50.93}{8.3} = 6.14 \text{ KSI}$$

STEP 10: FOUNDATION DEFLECTION ESTIMATE

Foundation deflection estimates are not required for retractable sheaves, thru-deck sheaves, and the movable sheaves on the dampers due to the location of and deck structure for these sheaves.



Vertical Forces and Moments about Horizontal Axis on Member 2-5-8-17-18

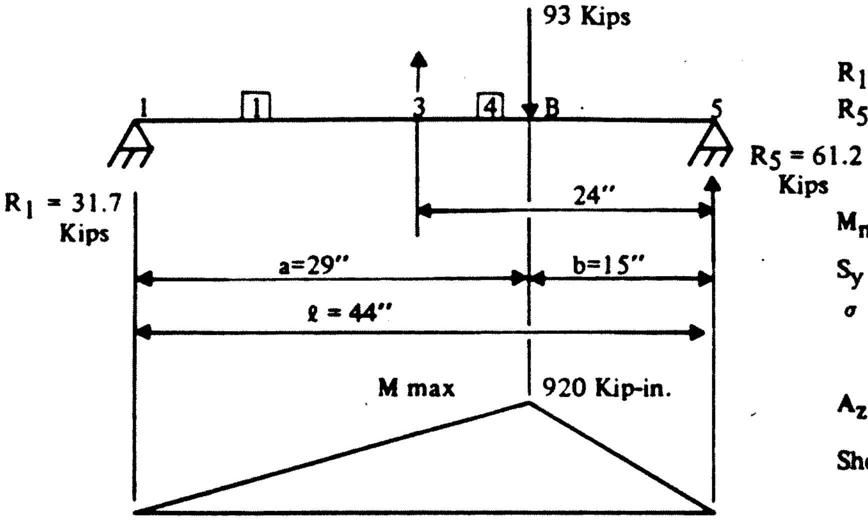
Fig. 14

### Check for Shock Loads

#### 1. Vertical Loads

##### a) Retractable Sheave

Member 1-4



$R_1 = 31.7^k = V_1$

$R_5 = 61.2^k = V_5$

$M_{max} = 920^{k''}$

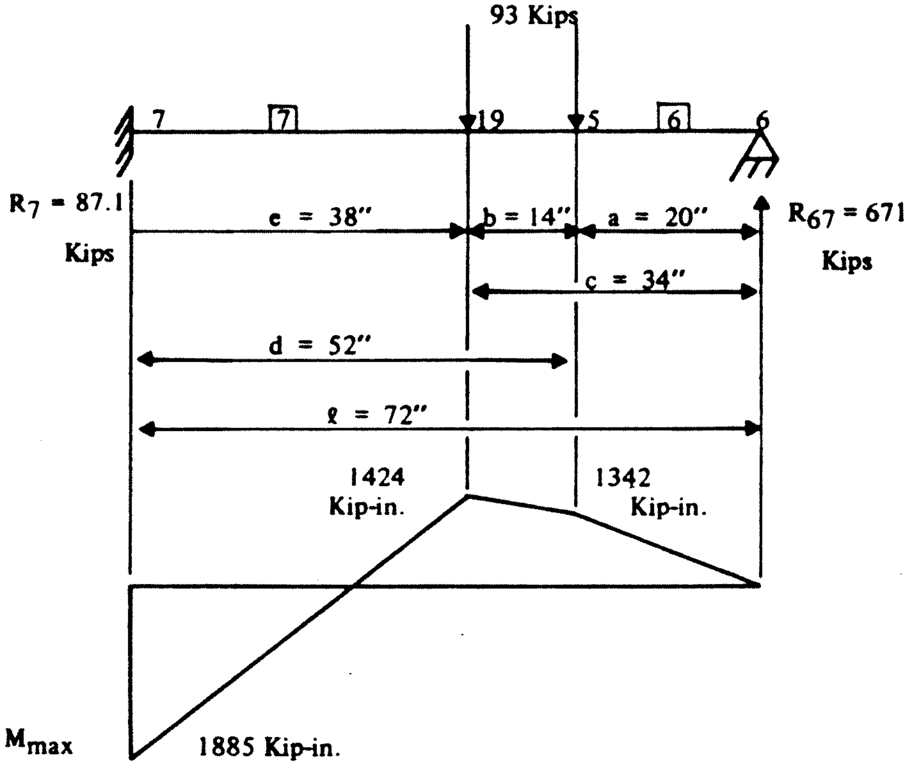
$S_y = 207.60 \text{ in}^3$ from Table I

$\sigma = \frac{M}{S_y} = 4.68$ KSI

$A_z = 21.0 \text{ in}^2$ from Table I

Shear force $= \frac{V_5}{A_z} = 2.9$ KSI

Member 6-7



$R_6 = 67.1^k = V_6$

$R_7 = 87.1^k = V_7$

$M_1 = 1342^{k''}$

$M_2 = 1424^{K''}$

$M_{max} = 1885^{k''}$

$S_y = 242.6 \text{ in}^3$ (Table)

$\sigma = \frac{M}{S_y} = 7.8$ KSI

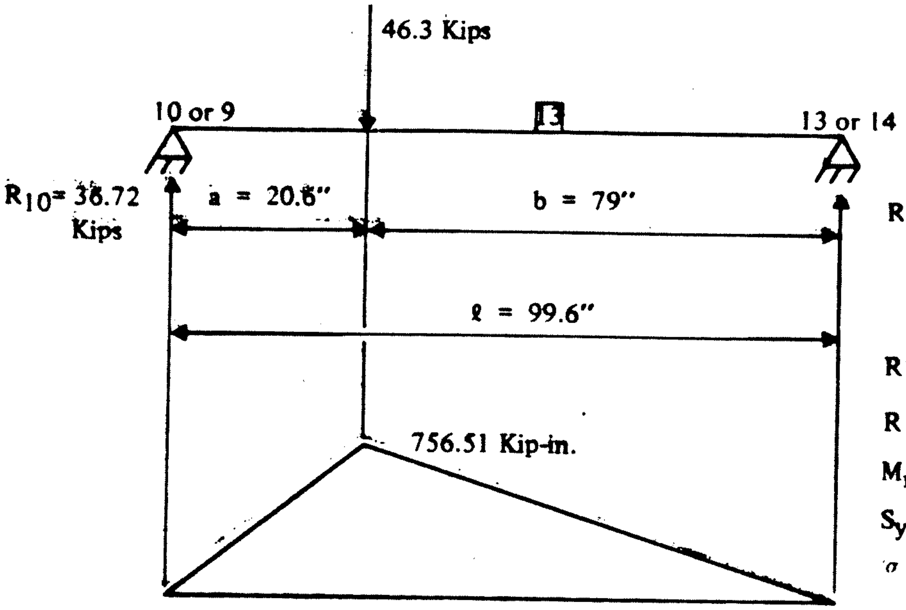
$A_z = 21.5 \text{ in}^2$ (Table I)

Shear force

$\frac{V_7}{A_z} = 4$ KSI

b) Thru-deck Sheave

Member 13



$R_{13} = 9.59$ kips

$R_{10} = 36.72^k = V_{10}$

$R_{13} = 9.59^k = V_{13}$

$M_{max} = 756.51^{k''}$

$S_y = 82.23$ (from Table I)

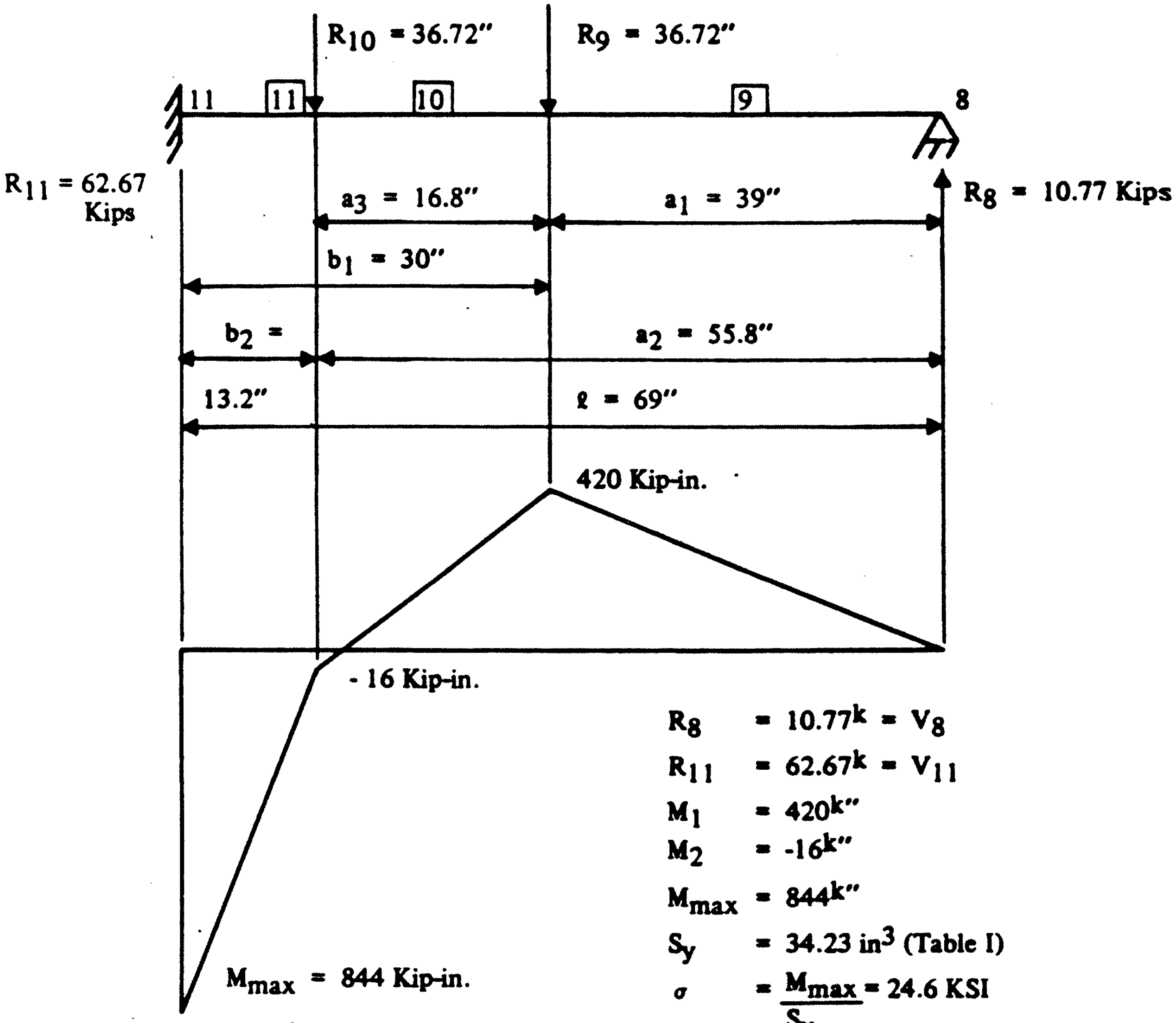
$\sigma = \frac{M}{S_y} = 9.2$ KSI

$A_z = 8.0\ in^2$ (from Table I)

Shear force

$\frac{V_{10}}{A_z} = \frac{36.72}{8} = 4.6$ KSI

Member 9, 10, & 11



$R_8 = 10.77^k = V_8$

$R_{11} = 62.67^k = V_{11}$

$M_1 = 420^{k''}$

$M_2 = -16^{k''}$

$M_{max} = 844^{k''}$

$S_y = 34.23\ in^3$ (Table I)

$\sigma = \frac{M_{max}}{S_y} = 24.6$ KSI

$A_z = 8$ (Table I)

Shear Force

$\frac{V_{11}}{A_z} = 7.8$ KSI

2) Members analyzed above for vertical shock loads specified, indicate stresses below the allowable stresses, and for this reason, members between Joints 2-16 and 12-15 have not been calculated. The athwartship and fwd and aft shock loads also produce stresses that are less than the allowable stresses of the material, and therefore are not analyzed for this sample calculation. However, shock loads are not to be ignored. They should be calculated completely.

## 185-1-h Sample Calculation No. 2

### PROBLEM

Design the foundations for the sheave shown in Figures 15, 16, and 17 mounted on a partial bulkhead extending from the gallery deck to the flight deck.

### ASSUMPTIONS

Figure 18 shows the structure model selected to analyze the transfer of load from the sheave foundation to the main ship structure.

For the boundary conditions, Joints 1 and 6 (Figure 18) will be considered fixed since the bulkhead plating will prevent rotations about the Z axis, and the two deck beams directly under the bulkhead are of greater stiffness on the bulkhead side. Joints 4 and 9 will be assumed fixed for rotation about the Z axis and simply supported for rotation about X axis.

The foundation will be subdivided in two parts for the analysis:

a. Sheave foundation from the bolting plate to the partial bulkhead connection (Figure 16).

b. Ship structure supporting sheave foundation (Figure 18).

### LOAD ACTING ON THE FOUNDATION

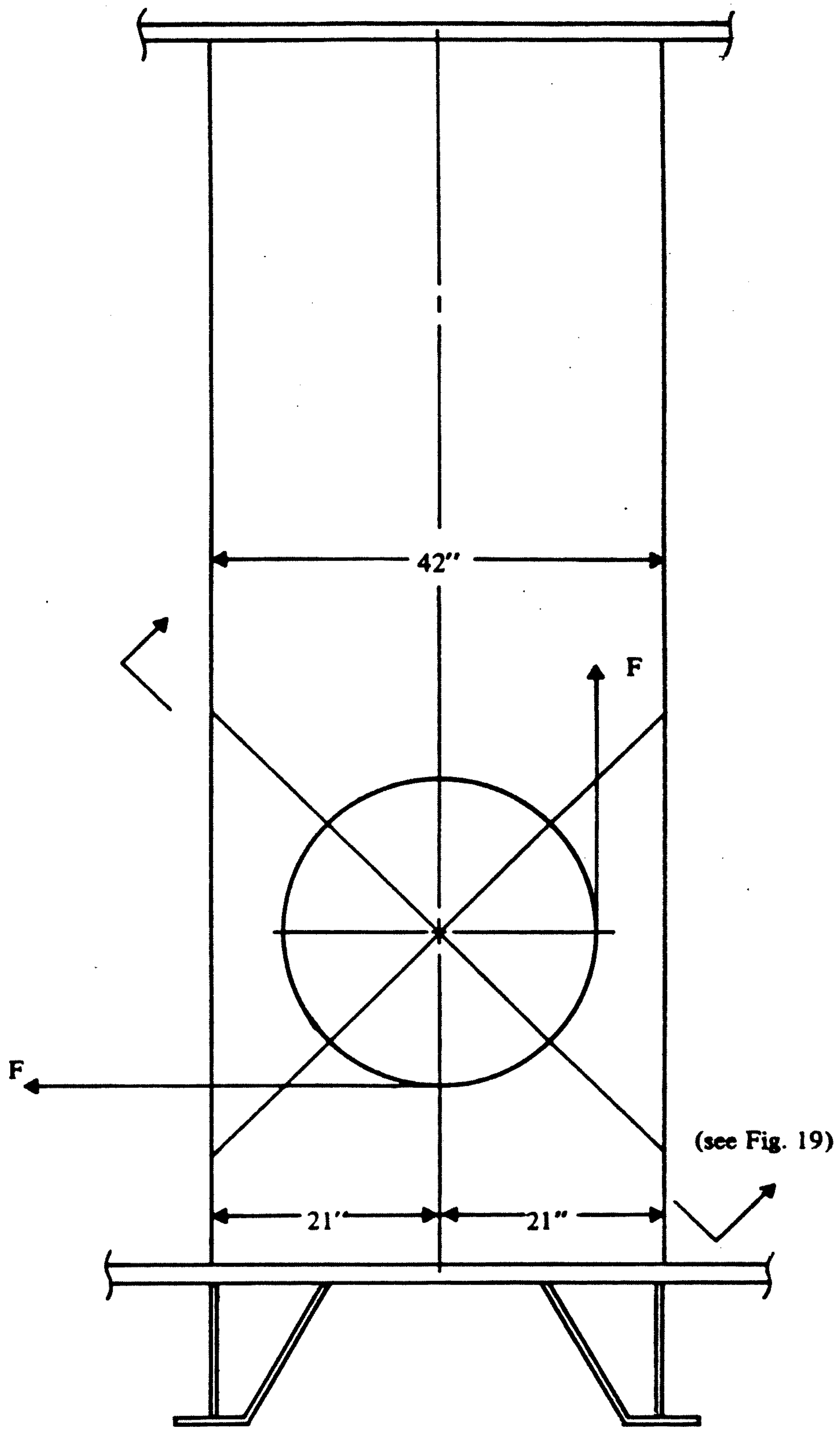
The resultant load acting on the sheave axis for a wrap angle of 92 degrees (Figure 19 is):

[illegible]

$$R = 2F \cos \left( \frac{180^\circ - 92^\circ}{2} \right)$$

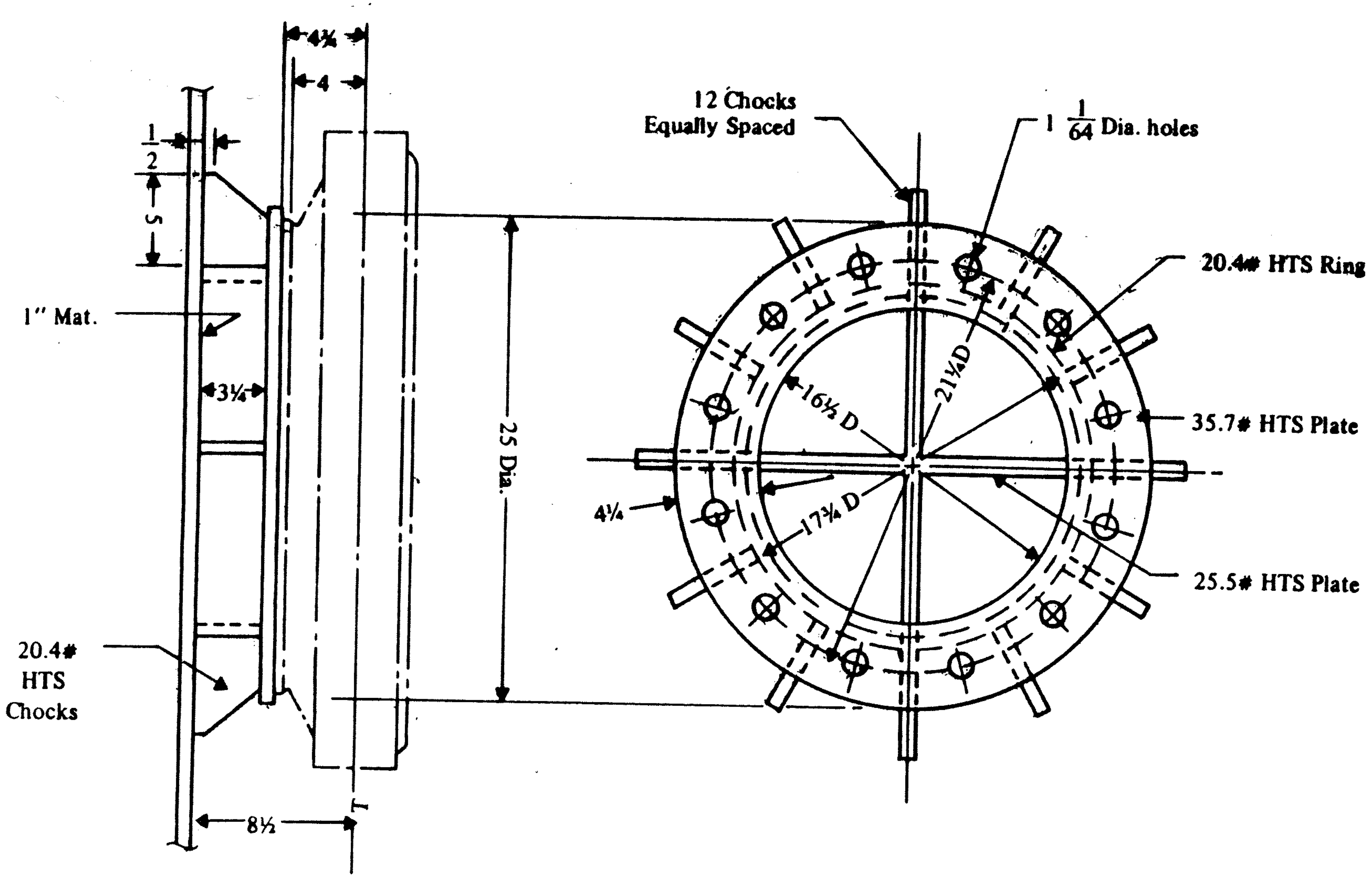
For the maximum fictitious cable tension F of 175,000 pounds,

$$R = 251.7 \text{ kips}$$



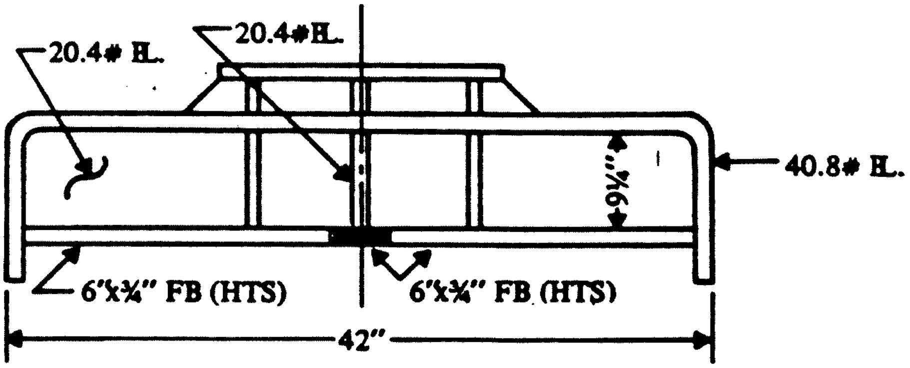
Sheave Mounting Arrangement on Partial Bulkhead

Fig. 15



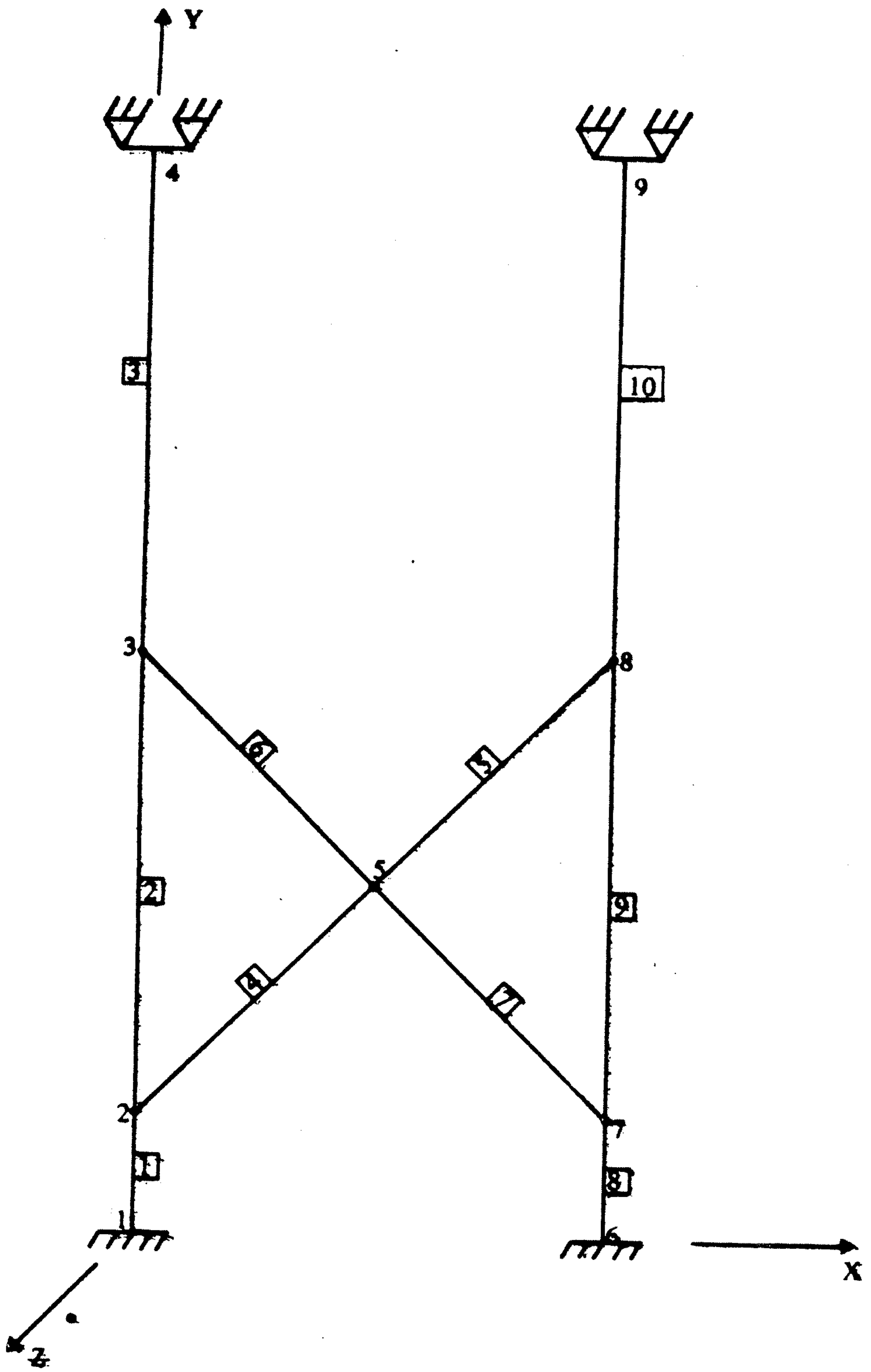
Sheave Foundation

Fig. 16



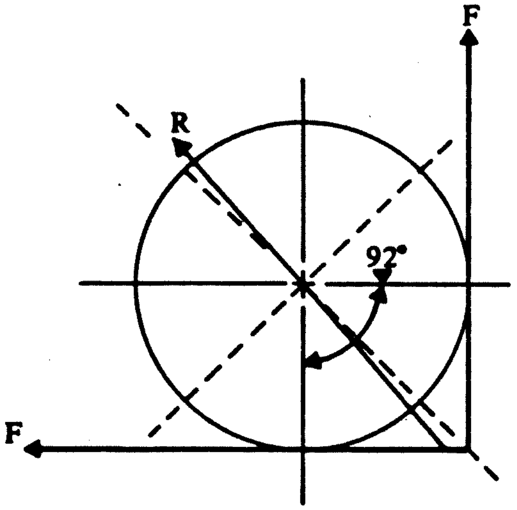
Section Taken From Fig. 15

Fig. 17



Structure Model of Sheave Shown in Figures 15, 16, and 17

Fig. 18



Resultant Load For Wrap Angle of 92°

Fig. 19

## SHEAVE FOUNDATION (Figure 16)

At bolted plate connection, the load-induced moment is:

$M_A$ = 251.7 x 4.75 = 1196 kip-in.

Bolt: Diameter 1 inch, area = o.7854 in.$^2$, number of bolts = 12, total bolt area = 9.425 in.$^2$.

The flange plate is assumed to resist the compression load while the bolts resist tensions. Figure Figure 20 shows the partitioning of the section for this example, and the section modulus calculations give the following values:

Maximum distance of neutral axis from flange foundation = $\sim$ 4 in.

Maximum distance of neutral axis from flange

Maximum distance of neutral axis from bolt = 18.65 in.
Moment of inertia of mixed section = 1348 in.$^4$
Section modulus at bolt center = 72.28 in.$^3$

The distance of the resultant load R from the bolting plate is 4.75 in. (Figure 16). Therefore the bending moment at the bolt connection:

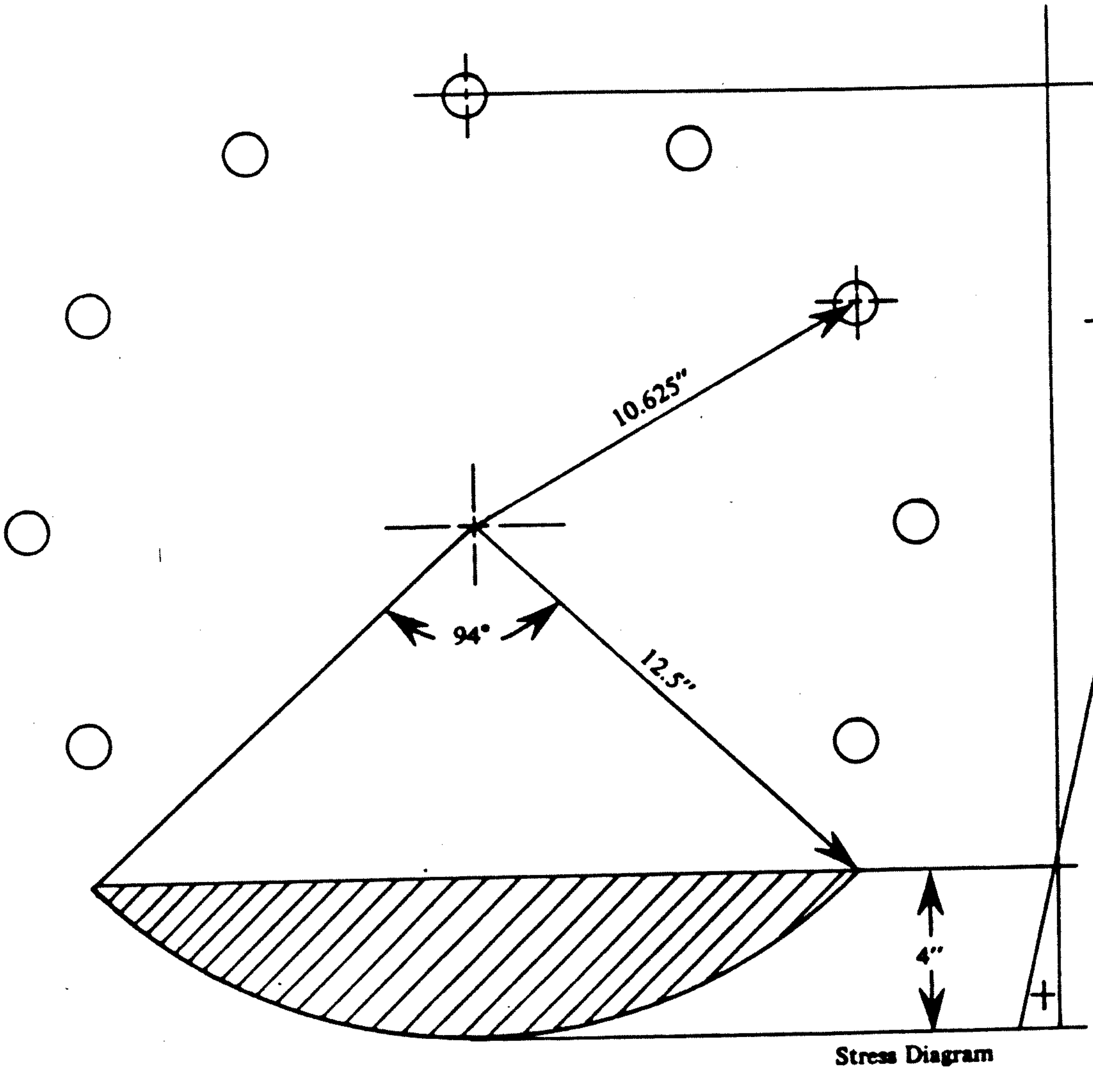
BM = R x 4.75 = 251.7 x 4.75 = 1196 kip-in.

The tensile stress at the center of the farthest bolt from the neutral axis is:

$$\sigma = \frac{1196}{72.28} = 16.55 \text{ KSI}$$

The force applied by the bolt to the flange plate in the upward direction (assume 1-in. bolt) is:

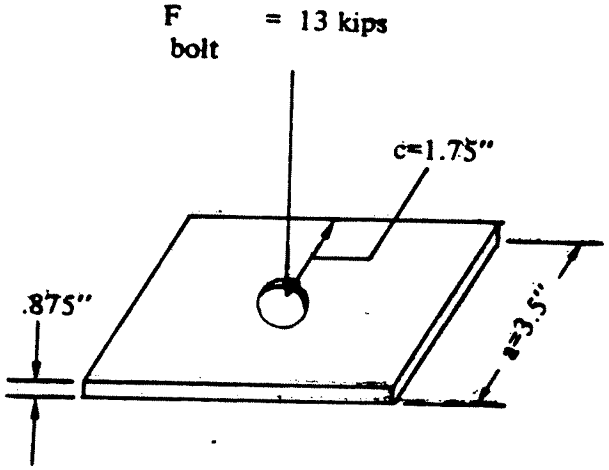
$F_{bolt}$ = Area x $\sigma$ = 0.7854 x 16.55 = 13 kips Considering the portion of the flange supported as in Figure 21, and if the flange is 0.875 inch thick, then (see Figure 21).



Effective Section To Resist
Bending At Flange Connection

Partitioning of Sheave Section

Fig. 20



Flange Support

Fig. 21

$\sigma_{max}$ = 16.55 KSI

$\sigma$ allowable using HTS = 38 KSI

$\sigma_{max} < \sigma_{allowable}$

The force due to the sheave load R is assumed to induce a uniform shear load on the chocks supporting the flange plate and the cylindrical body. The minimum section occurs directly under the flange plate. Shear area and stress may be calculated as follows:

Chocks: $A_c = 8 \times 0.5 \times 3.125 = 12.5 \text{ in.}^2$

Cross beams: $A_{CB} = 2 \times 0.625 \times 27.75'' = 34.4 \text{ in.}^2$

Cylindrical portion: $A_{BC} = 0.5 \times \pi \times 18.25 = 28.7 \text{ in.}^2$

Total shear area $= 75.6 \text{ in.}^2$

$$\text{Shear stress} = \frac{R}{75.6} = \frac{251.7}{75.6} = 3.3 \text{ KSI}$$

For design purposes the bending moment may be assumed to act in the plane normal to the bulkhead containing Members 6 and 7. (For more direct calculations, the components along the two cross beams should be determined and the two cross beams designed for those moment complements).

Assume that only Members 6 and 7 will resist bending since the chocks are welded to flexible foundation plating, and the other cross Members 4 and 5 are not capable, by assumption, of resisting torsion.

RING PLATE

The maximum bolt force applied to the ring plate is 13 kips. Assuming that the plate is a cantilever fixed at the cylindrical portion, which is very conservative, we have (See Figure 21)

$$\sigma \max = K_m\left(\frac{6F_{bolt}}{t^2}\right)$$

for c/a $= 0.5$; $K_m = 0.37$

$$\sigma \max = 0.37\left(\frac{6 \times 13}{0.875^2}\right) = 37.69 \text{ KSI}_{max}$$

Moment arm of R with respect to foundation plate connections = 8.5 in. (Figure 16).

Bending moment at base of sheave foundation = 8.5 x R = 8.5 x 251.7 = 2140 kip-in.

Moment of inertia of the section connecting the sheave mounting to bulkhead plate = 1237 in.$^4$

Section modulus = 86 in.$^3$

$\sigma$ = 24.88 KSI

## SHIP STRUCTURE SUPPORTING SHEAVE FOUNDATION

### Member 6-7

The properties of Member 6-7:

Cross-sectional area = 21.12 in.$^2$

Distance of neutral axis from bulkhead upper face = 3.78 in.

Minimum moment of inertia = 344.5 in.$^4$

Minimum section modulus Z (at end of member) = 47.71 in.$^3$

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{344.5}{21.12}} = 4.04 \text{ in.}$$

The value of the moment due to R is:

BM = 251.7 (8.5 + 3.78) = 3091.7 kip-in.

Assume a triangular distribution of the load. As shown in Figure 22,

$$\text{Moment arm} = \frac{2a}{3} = \frac{2(18.75)}{3} = 12.5 \text{ in.}$$

$$\text{Force value of each triangular load} = \frac{BM}{12.5} = \frac{3091.7}{12.5} = 247.3 \text{ kips}$$

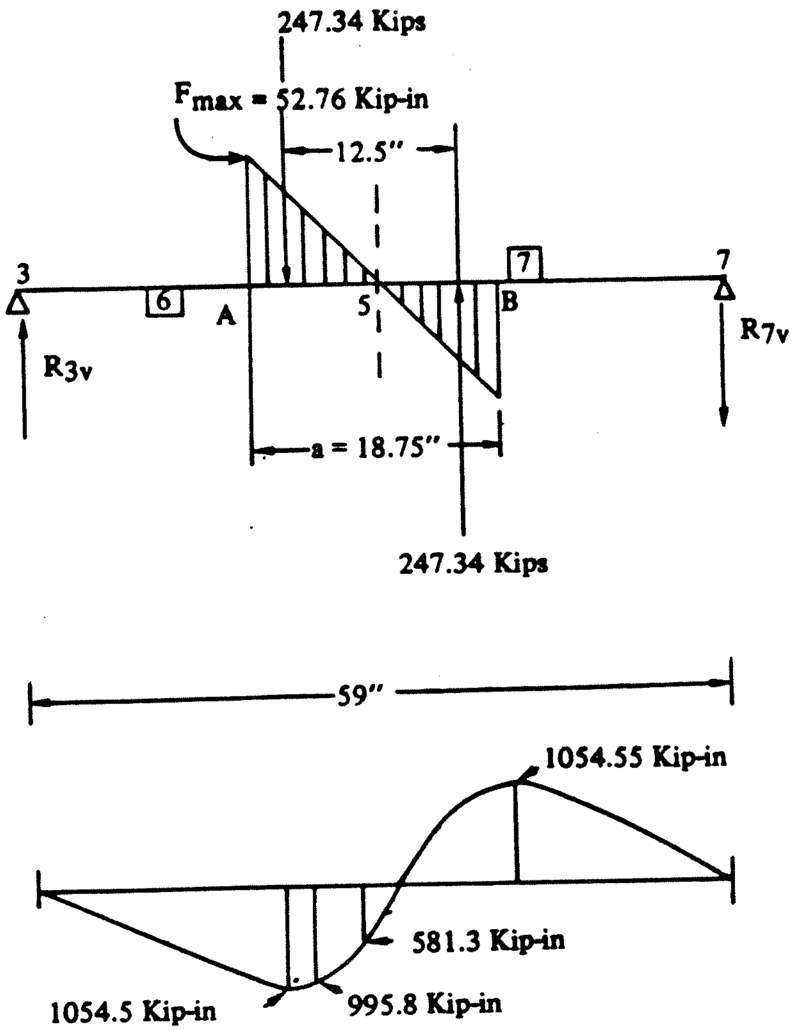
$$\text{Maximum value of distributed load at end of triangular load} = \frac{247.3 \times 4}{18.75}$$

= 52.76 kip-in.

$$R_{3_v} = -R_{7_v} = \frac{3091.7}{59} = 52.4 \text{ kips}$$

The bending moment value at 5 is 0.

The bending moment value at A is 1054.5, or approximately 1060 kip-in.



Bending Moment Diagram

Forces On Member 6-7

Fig. 22

Member 6 and 7 Check for Stress

Assume that half of the axial load acts in compression on Member 6 and half in tension on Member 7.

Allowable stress (HTS): $F_b = 38$ KSI

Member length: $\ell = 59$ in.

$$r = \sim 4$$

$$\frac{\ell}{r} = \sim 15$$

$$F_c = 45 \text{ KSI}$$

$$f_c = \frac{1}{2} \times \frac{251.77}{21.12} = 5.96 \text{ KSI}$$

$$f_b = \frac{1060}{47.71} = 22.21 \text{ KSI}$$

$$\frac{f_c}{0.8\,F_c} + \frac{f_b}{F_b} = \frac{5.96}{0.8 \times 45} + \frac{22.21}{38} = 0.75 = < 1$$

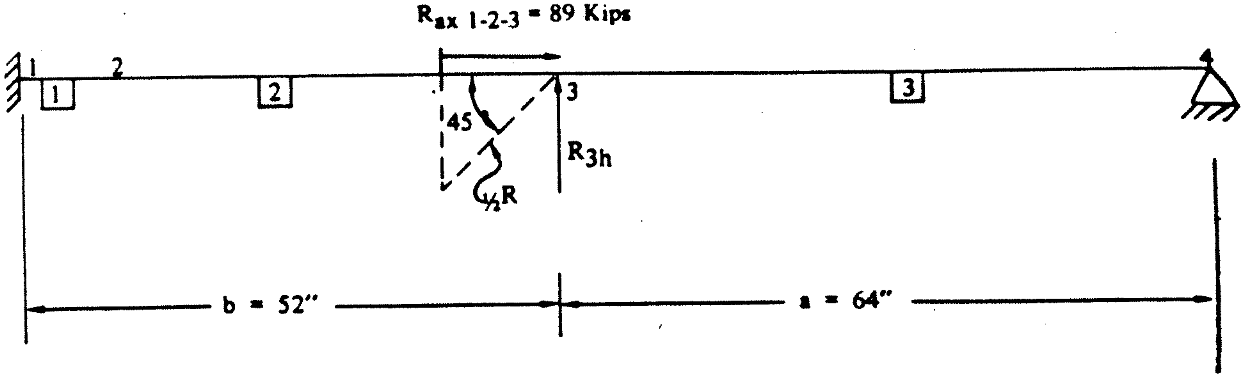
Member 1-2-3

The force applied by Member 6 to Member 1-2-3 may be resolved into three componen (Figures 18 and 23): an axial compressive force $R_{ax}$ 1-2-3 in the direction of the axis of the member, a force $R_{3h}$ acting in the plane of the bulkhead, and a bending force $R_{3v}$ acting in a plane normal to the bulkhead. Force $R_{3h}$ will be neglected since it is acting in the plane of the supporting bulkhead and is assumed to be taken in shear, but the other two resultant forces will be considered.

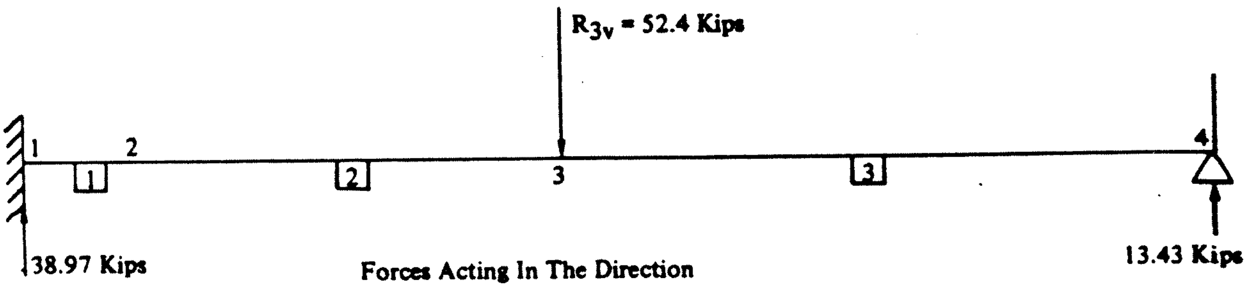
Since Member 6 applies one-half of the resultant R, arising from the sheave shaft, to Member 1-2-3, and R is 251.7 kips,

$$R_{ax\ 1\text{-}2\text{-}3} = \frac{R}{2} \cos 45° = \frac{251.7}{2} = \cos 45° = 89 \text{ kips}$$

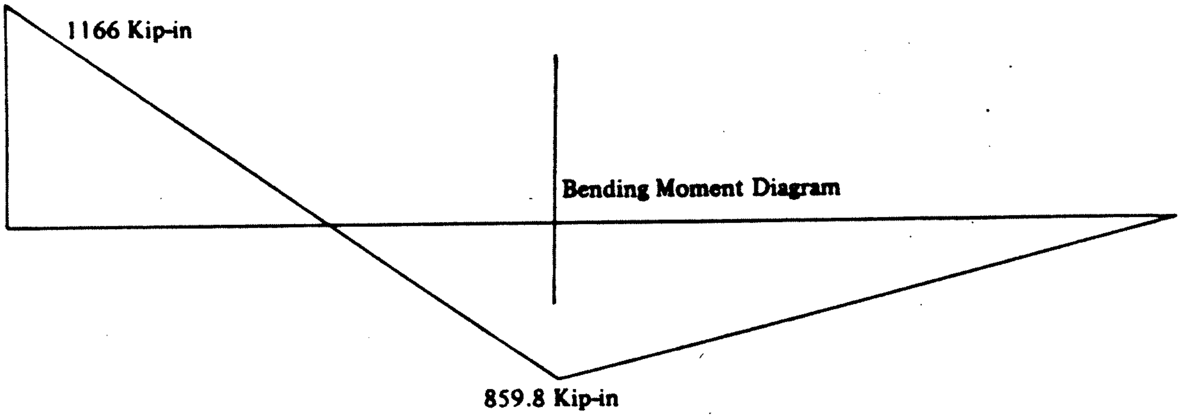
$$R_{3h} = \frac{R}{2} \cos 45° = \frac{251.7}{2} \cos 45° = 89 \text{ kips}$$



Forces Acting In The Bulkhead Plane



Forces Acting In The Direction Perpendicular To The Bulkhead



Bending Moment Diagram

Forces On Member 1-2-3

Fig. 23

The bending moment induced by the component $R_{3v}$ of Member 6 is shown in Figure 23.

The properties of Member 1-2-3 are:

Area = 32 in.$^2$

Shear Area = 12 in.$^2$

$I$ = 371 in.$^4$

$Z$ = 39.8 in.$^3$

$r$ = $\sim$ 3.4 in.

$\ell$ = 116 in.

$$\ell/r = \frac{116}{3.4} = 34$$

$$\text{Compressive force on Member 1-2-3} = \frac{R_{ax}\ 1\text{-}2\text{-}3 \times 52}{116} = \frac{89 \times 52}{116}$$

$$= 40 \text{ kips}$$

$$f_c = \frac{40}{33} = 1.2 \text{ KSI}$$

$$f_b = \frac{1166}{46.24} = 25.2 \text{ KSI}$$

$$\frac{f_c}{0.8F_c} + \frac{f_b}{F_b} = \frac{1.2}{0.8(45)} + \frac{25.5}{38} = 0.70 = < 1$$

Maximum shear force = 38.97 kips

$$f_s = \frac{38.97}{12} = 3.25 \text{ KSI}$$

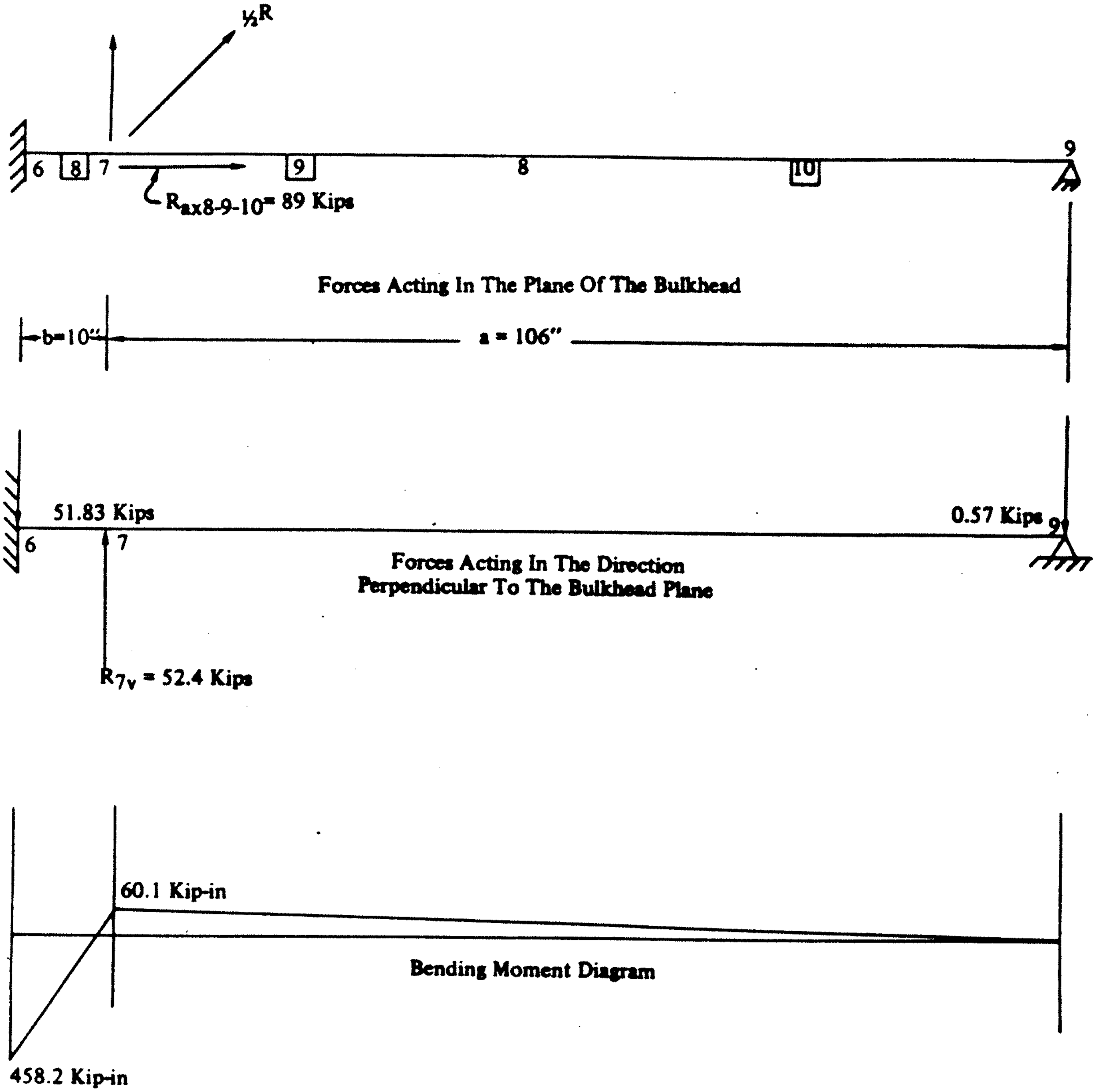
$$F_s = 0.6\, F_b = 0.6 \times 38 = 22.8 \text{ KSI}$$

$$f_s = < F_s$$

## Member 8-9-10

Proceeding in the same manner as for Member 1-2-3 and as shown in Figure 24:

BM = 458.2 kip-in.



Forces Acting In The Plane Of The Bulkhead

Forces Acting In The Direction Perpendicular To The Bulkhead Plane

Bending Moment Diagram

Forces On Member 8-9-10

Fig. 24

Compressive force Member 8 $= \dfrac{89 \times 106}{116} = 81.32$ kips

Shear force - 51.83 kips

$$f_s = \frac{51.83}{12} = 4.3 \text{ KSI}$$

$$f_c = \frac{81.32}{33} = 2.46 \text{ KSI}$$

$$f_b = \frac{458.2}{46.24} = 9.92 \text{ KSI}$$

$$\frac{f_c}{(0.8)F_c} + \frac{f_b}{F_b} = \frac{2.46}{(0.8)\,45} + \frac{9.92}{38} = 0.33 = < 1$$

Similar calculations must be performed to check structure adequacy for the three shock loads (vertical, athwartship, and fore/aft).

## DEFLECTION CALCULATIONS (UNDER TEST LOAD)

The moment area method will be used; the displacements are given by the static moment of the bending moment/EI diagram acting on the simple supported beam about the section under examination. The calculation will be carried out only for the thru-deck sheave. A similar process should be used for the retractable sheave.

Starting from the most remote member supporting the sheave:

1. Deflection of Member 1-2-3

   Ratio of design load/test load: $\dfrac{175{,}000}{110{,}000} = 1.591$

   Load normal to bulkhead at Joint 3: $\dfrac{52.4}{1.591} = 32.94$ kips

   Moment of inertia $= 469$ in.$^4$

   Deflection at point of load (downward) $= \Delta_3$

   From structural design manual,

   $$\Delta_3 = \frac{Pa^2\, b^3}{12\, EI\, \ell^3}(3\ell + a) = 0.029 \text{ in.}$$

   Calculating the shear at Joint 3 of the beam loaded with the bending moment/EI diagram,

   $\theta_3 = -0.016$ degrees

2. Deflection of Member 8-9-10

Load normal to bulkhead: $\frac{52.4}{1.591} = 32.94$ kips

$I = 469$ in.$^4$

$\Delta_7 = -0.0006$ in.

$\theta_7 = -0.005$ deg.

3. Deflection of Member 6-7

Beam properties

Between points A and B (Figure 25):

$A_x = 35.46$ in.$^2$

$I = 473.4$ in.$^4$

Outside A-B Region:

$A_x = 21.12$ in.$^2$

$I = 344.5$ in.$^4$

The deflection of Joint 5 is:

$\Delta_5' = 0.0$ in.

and the rotation is:

$\theta_5 = 9 \times 10^{-6}$ deg.

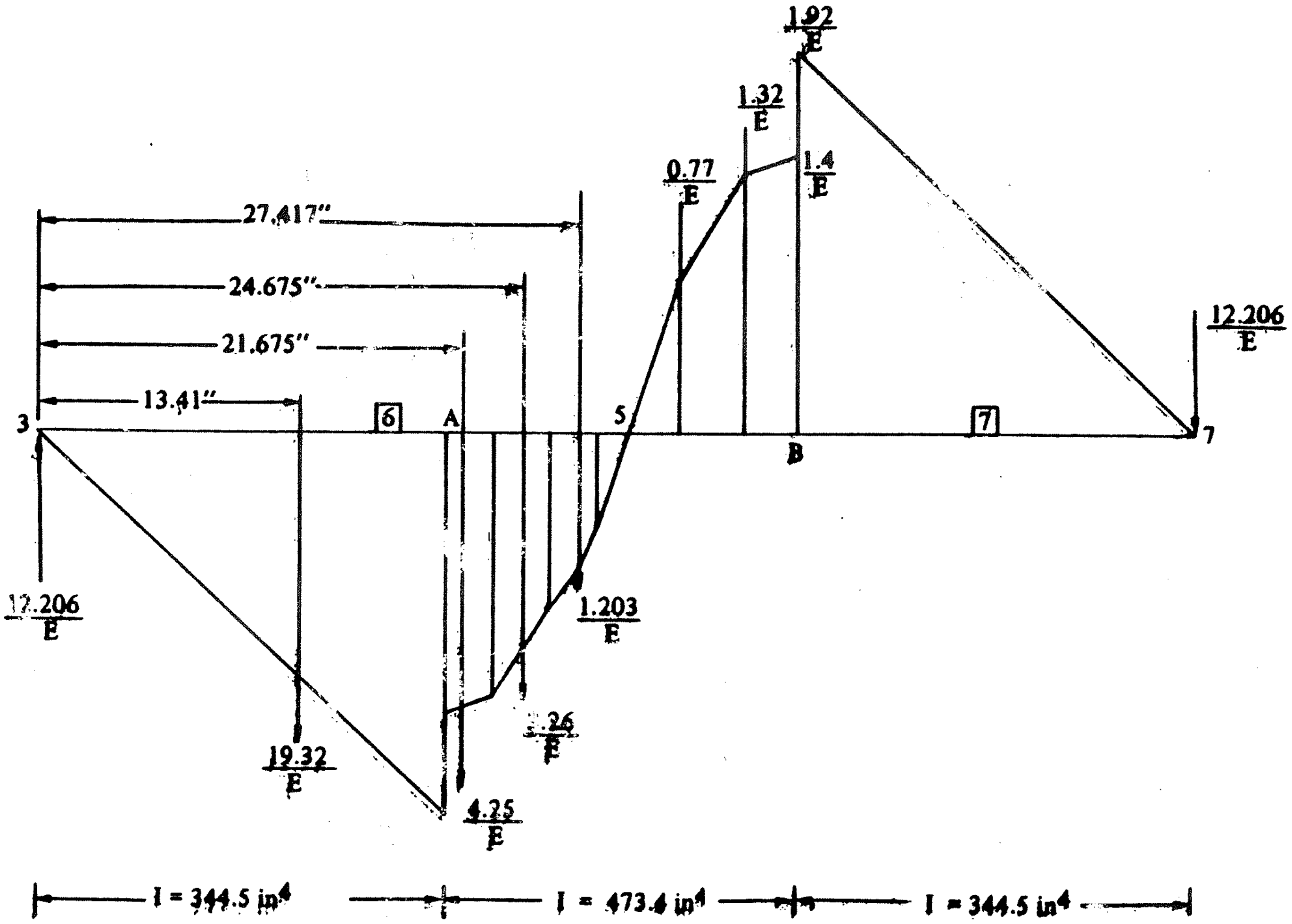
$\simeq 0$ deg.

## DEFLECTION ESTIMATE

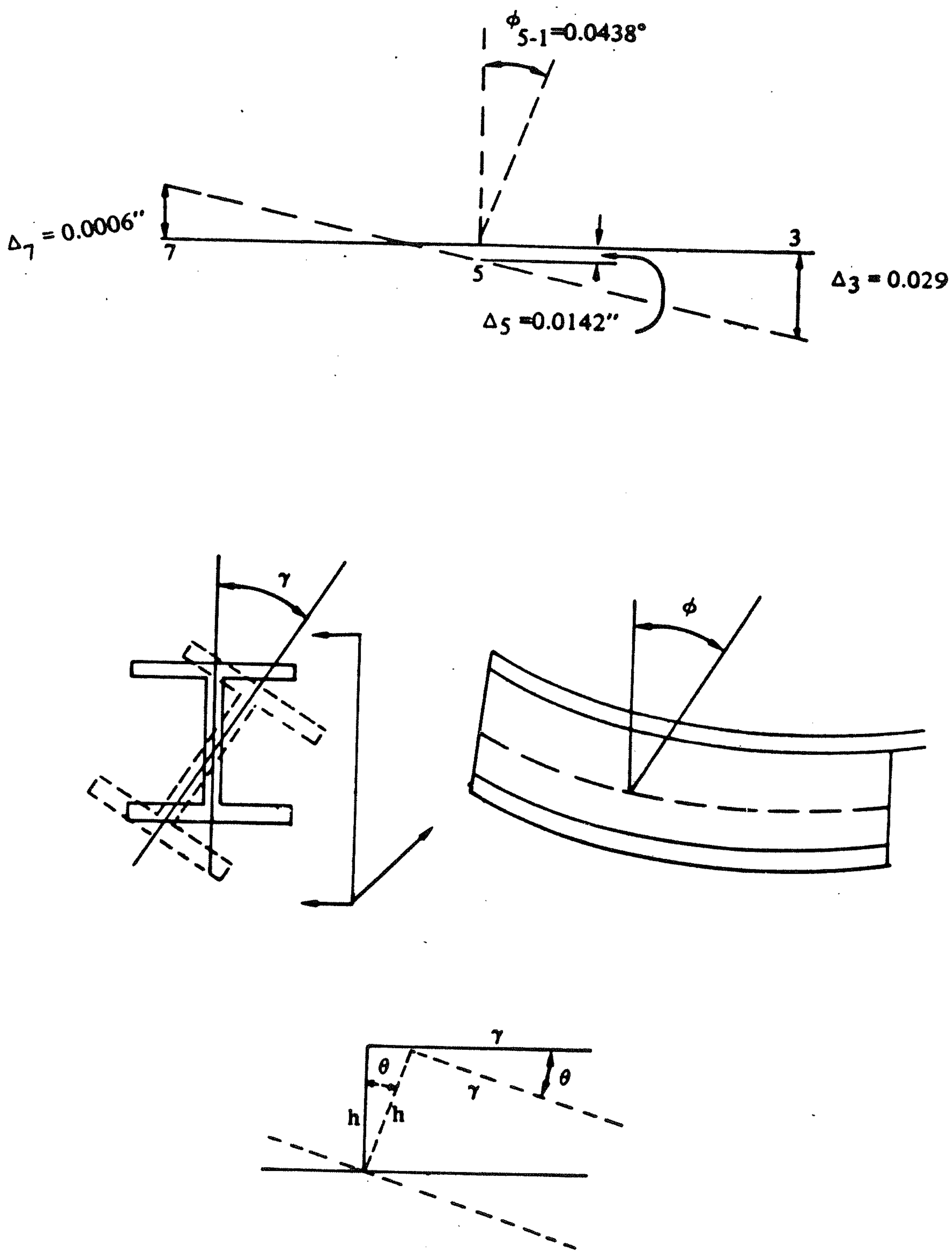
All axial deflections are neglected. The sheave axis passes initially through Joint 5 anc orthogonal to Members 4-5 and 6-7.

a. Due to the deflection of Joints 3 and 7, Joint 5 will deflect (Figure 26).

$$\Delta_5 = \frac{1}{2} \quad (\Delta_3 + \Delta_7) = \frac{1}{2} (0.029 - 0.0006) = 0.0142 \text{ in.}$$



Deflection Data for Member 6-7
Between Points A and B
Fig. 25



Deflection of Joint 5

Fig. 26

Joint 5 will rotate about the axis in the plane of the bulkhead perpendicular to Member 6-7-8

$$\phi_{5\text{-}1} = \arctan \frac{0.045}{59} = 0.0438 \text{ deg.}$$

b. Due to the rotation of Joints 3 and 7, Joint 5 will rotate about an axis which is in the plane of the bulkhead perpendicular to Member 1-2-3 and which passes through Joint 5.

$$\phi_{5A} = \frac{1}{2} \quad (0.016 + 0.005) = 0.0105 \text{ deg.}$$

Rotation $\phi_{5A}$ can be resolved into two components: $\gamma$ about the axis of the beam and $\phi_{5\text{-}1}$ about the axis perpendicular to the beam in the bulkhead plane.

$$\gamma = \phi_{5A} \cos 45^\circ = 0.0075 \text{ deg.}$$

$$\phi_{5\text{-}1'} = \phi_{5A} \sin 45^\circ = 0.0075 \text{ deg.}$$

Since the two rotations $\phi_{5\text{-}1}$ and $\phi_{5\text{-}1'}$ occur about the same axis, they are additive.

$$\phi = \phi_{5\text{-}1} + \phi_{5\text{-}1'} = 0.0438 + 0.0075 = 0.0513 \text{ deg.}$$

with

| | |
|---|---|
| $h = 9$ in. | $\phi = 0.0513^\circ$ |
| $r = 17$ in. | $\gamma = 0.0075^\circ$ |

Sheave axis displacement in horizontal direction,

$$\Delta_{HA} = h \sqrt{\sin^2 \phi + \sin^2 \gamma} = 0.00814 \text{ in.}$$

$$\gamma = \arcsin \frac{0.00814}{9} = 0.0518^\circ$$

Horizontal displacement at edge of sheave base,

$$\Delta_H = 9 \times \sin 0.0518 + 17 (1 - \cos 0.0518)$$

$$= 0.00814 + 0.0000069 = 0.008147 \text{ in.} = < 0.062$$

Vertical displacement at edge of sheave base:

$$\Delta_y = 9 \; (1 - \cos 0.0518) + 17 \sin 0.0518 + 0.0142 = 0.029 = < 0.062$$