A030 854

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Contract Report K-76-1

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER: WES/CR-K-76-1-Vol-1

4. TITLE (and Subtitle): GENERAL PURPOSE COMPUTER-AIDED ANALYSIS AND DESIGN OF TAINTER GATES. VOLUME I. THEORETICAL MANUAL.

5. TYPE OF REPORT & PERIOD COVERED: Final report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): Leroy Z. Emkin

8. CONTRACT OR GRANT NUMBER(s): DACW39-76-M-0869 and DACW39-76-M-2230

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
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10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 167 p.

11. CONTROLLING OFFICE NAME AND ADDRESS:
U. S. Army Engineer Division
Lower Mississippi Valley
P. O. Box 80, Vicksburg, Miss. 39180

12. REPORT DATE: Aug [redacted] 76

13. NUMBER OF PAGES: 166

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
Automatic Data Processing Center
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report):

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

A029 938

18. SUPPLEMENTARY NOTES: Further questions about the program can be directed to:
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Computer applications
Engineer manuals
Gates (Hydraulic structures)
Tainter gates

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

A method is formulated for analyzing and designing tainter gate hydraulic structures by a general purpose, structural analysis and design computer system. This theoretical manual consists of a discussion of tainter gate design criteria, including the effects of the hoisting cables, side seal friction, trunnion pin friction, and sidesway constraint limit, and their application, followed by the development of a procedure for using ICES STRUDL II for

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

409 847

20. ABSTRACT (Continued).

tainter gate analysis and design. The procedure includes a special FORTRAN program to solve for coefficients used to link two STRUDL runs. The ICES STRUDL II computer system is selected for use since it is the only general purpose, structural computer program that has all the necessary characteristics to perform the analysis and design. The STRUDL approach described herein was intended to demonstrate the validity of the procedure. The recommended STRUDL solution procedure for use in the design office environment is presented in the companion report, Contract Report K-76-1, Volume II, "General Purpose Computer-Aided Analysis and Design of Tainter Gates; Procedural Manual."

PREFACE

This report is the result of work performed under Contract No. DACW39-76-M-0869, dated September 3, 1975, and No. DACW39-76-M-2230, dated December 9, 1975, between U. S. Army Engineer Waterways Experiment Station (WES) and the author, Dr. Leroy Z. Emkin, Consulting Engineer, for development of a procedure to use Structural Design Language (STRUDL), a subsystem of the Integrated Civil Engineering System (ICES), for analysis and design of 3-girder tainter gates. The task was directed by the Automatic Data Processing Center (ADPC), Computer Analysis Branch (CAB), WES as part of a project to furnish assistance to the sponsor, the Computer-Aided Structural Design (CASD) Committee of the U. S. Army Engineer Division, Lower Mississippi Valley (LMVD). The report is in two volumes, a theoretical and a procedural manual.

The author would like to thank Dr. N. Radhakrishnan, Special Technical Assistant to the Chief , ADPC, WES, who managed the project, Mr. W. A. Price III, Computer-Aided Structural Design Project Engineer, WES, Mr. D. R. Dressler, Chairman of the CASD Committee and Sponsor Representative, LMVD, and Mr. J. J. Smith, Structural Engineer, U. S. Army Engineer District, St. Louis, Missouri, for their expert advice and technical assistance during this study.

The task was under the general supervision of J. B. Cheek, Chief, CAB, and D. L. Neumann, Chief, ADPC. COL G. H. Hilt, CE, was Director of WES, and F. R. Brown was Technical Director.

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1. INTRODUCTION

A tainter gate is a commonly used hydraulic structure for navigation and flood control projects. Their analysis and design by the Corps of Engineers is largely performed by hand calculations and very special purpose computer programs. Although this has been the accepted procedure in the past, it nevertheless retains several serious deficiencies. Among these are:

1. The hand analysis calculations are highly time consuming, tedious, repetitive, and costly. As such, they tend to restrain new and innovative design concepts due to the high cost of doing something different.

2. These computer programs are highly specialized to analyze a "standard" configuration of tainter gate. They do not permit a great deal of variation from the standard gate and, consequently, also restrain new and innovative design concepts.

3. Both hand and computer analysis procedures are based upon highly approximate simplifications of the tainter gate structure's behavior. For example, several plane frame and localized analyses are performed to determine the force distributions throughout a complex space frame. Although this was an acceptable procedure in the past, especially in view of the lack of alternative procedures, this is no longer the case as will be described in this report.

4. These special purpose computer programs do not now perform design. Instead, design is performed by hand, and for the large number of members

and design loading conditions, hand design becomes highly time consuming and costly.

It is not the intent of this report to suggest that the use of hand calculations and special purpose programs should be abandoned. On the contrary, it is intended to describe and recommend the use of an alternate analysis and design process to more cost-effectively utilize existing procedures, while at the same time permitting greater exercise of engineering judgement, design decisions, and innovation in the tainter gate design process. The ultimate goals, of course, are to increase the reliability and accuracy of the final design, improve gate performance, and minimize both design and constructed cost of gates.

The procedures described in this and a companion report(1)[1] describe a procedure for computer-aided analysis and design of tainter gates using the ICES STRUDL II(7) computer system. This procedure will permit the engineer to utilize his design experience, and to exercise his decision making and innovative abilities in a more cost-effective manner to reach these goals.

This report describes the procedures and mathematical details that were used to develop the recommended procedure. The recommended procedure is described in detail in the companion report(1).

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[1]Numbers in parentheses refer to references in the REFERENCES Section.

2. PROBLEM DEFINITION

2.1 Introduction

A typical tainter gate, as sketched in Fig. 1, is characterized by a skin plate to retain water, and vertical stiffening ribs, horizontal girders, strut arms, and a trunion girder, to support and stabilize the skin plate. In addition, hoisting cables are used to lift the gate on occasion to permit the flow of water. A complete and detailed description of the specific tainter gate considered in this study is shown in Reference (3), U.S. Army Engineer District, St. Louis, Corps of Engineers Drawings for the Clarence Cannon Reservoir Re-Regulation Dam and Spillway Tainter Gate, Drawing Nos. S-CC 45/11, 45/12, 45/13, 45/14, and 45/15, with Code Identification No. DACW 43.

In order to analyze the tainter gate by a general purpose structural analysis computer program, the supporting structure of the gate may be easily modeled as a space frame, while the skin plate may be modeled using a finite element mesh of flat plate bending-and-stretching finite elements. The cable may be modeled as an unknown force, T, at the point of attachment to the skin plate, in addition to the effect of the radial cable pressure, T/R, against the skin plate (Fig. 2).

There are three additional characteristics of the gate structure which require special attention. The first is associated with friction forces (df/ds) caused by the skin plate neoprene side seals, along the skin plate side edges, bearing against the side piers of the hydraulic channel. This effect can be accounted for as an applied load as will

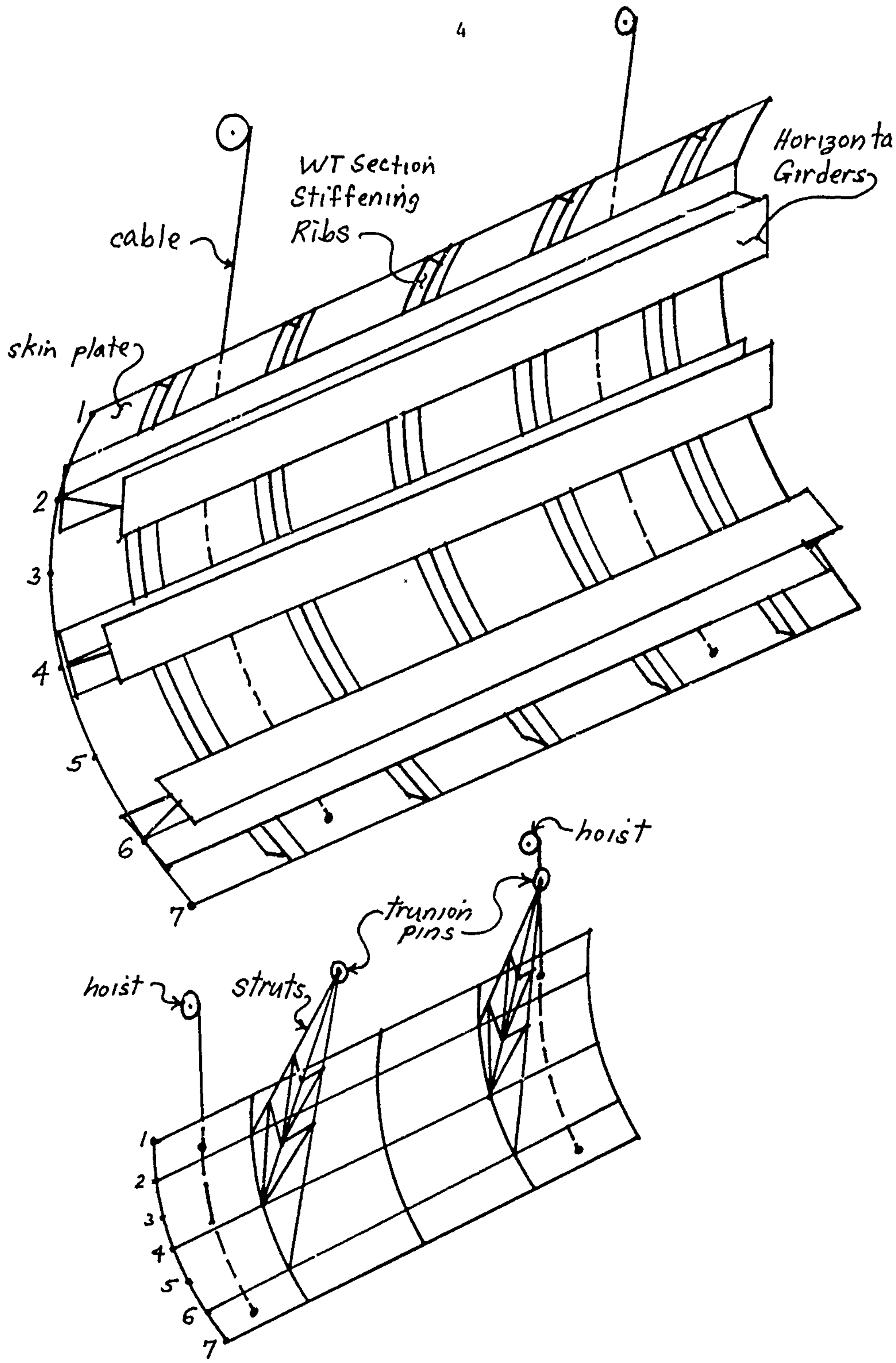

Figure 1. Typical Tainter Gate Configuration

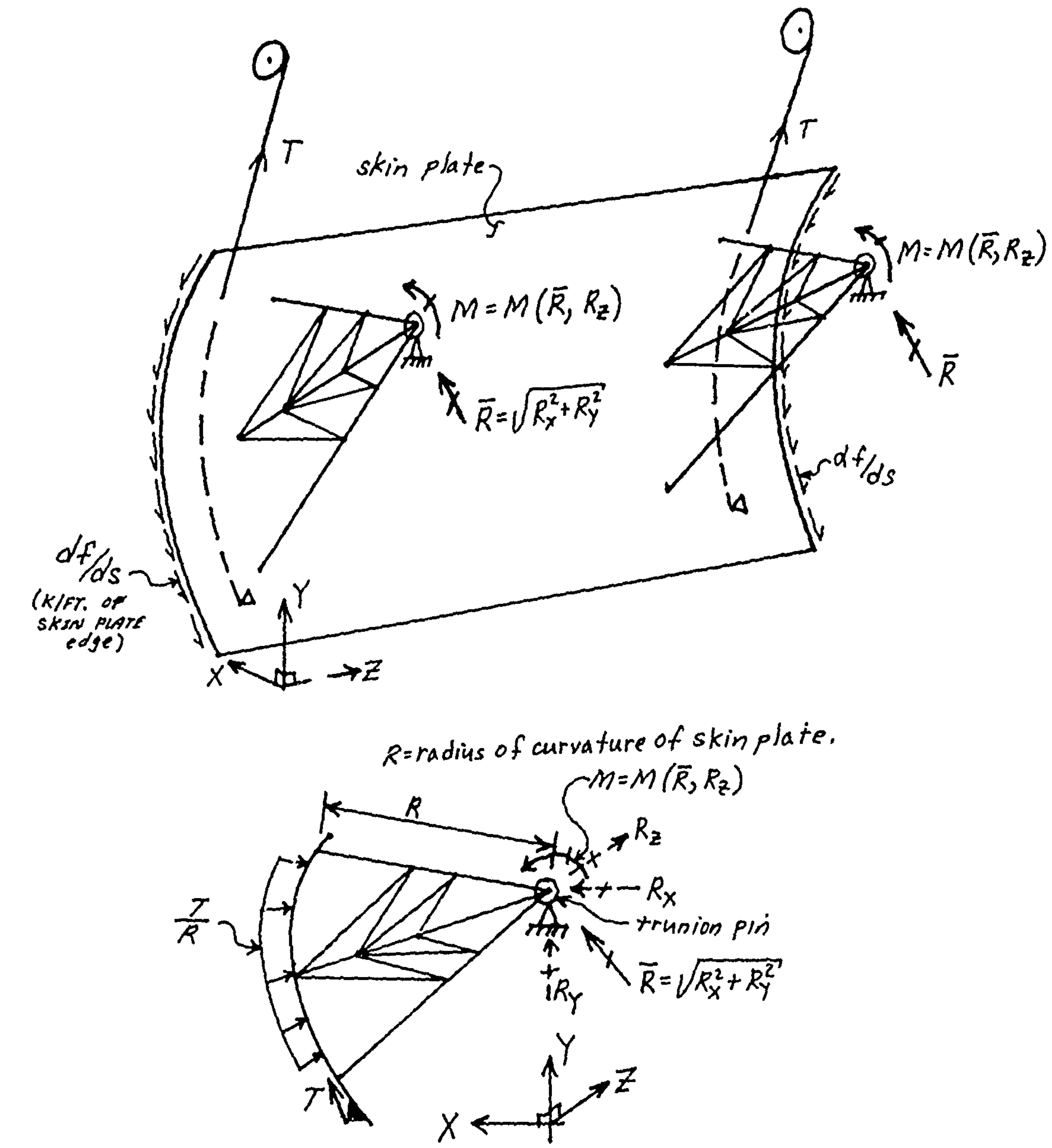

Figure 2. General Tainter Gate Computer Model

be shown in Section 2.2. The second special characteristic is associated with the effect of friction forces at the trunion pin locations providing resisting moments M. This moment M is a function of the unknown resultant R of the global X and Y components of trunion pin reaction as will be shown in Section 2.3. This causes very great difficulty in analysis since, to the author's knowledge, there is no available general purpose computer program for structural analysis that permits the direct modeling of an applied external force, such as M, whose magnitude is a function of another unknown externally applied force, such as R. Consequently, in order to accurately model this effect, a special analysis procedure was developed as described in Sections 2.3 and 3.4. The third special characteristic is associated with a situation when only one cable supports the gate. In this case, the gate experiences lateral deflections which may be large enough so that the gate will touch the side walls of the hydraulic channel. This is of course a non-linear behavior since, if the gate does in fact touch the side walls, the external boundary conditions must be changed to reflect the new side support and the analysis repeated. This procedure is described in Section 4.4.

The balance of Section 2 will discuss the nature of the side seal friction, the trunion pin friction, and the design loading conditions as specified by Corps requirements.

2.2 Side Seal Friction Effect

This discussion of side seal friction is based upon a similar presentation by Dressler (2).

A neoprene "J" seal is placed along the two vertical skin plate side edges (Fig. 3) to provide a watertight seal. The "J" seal friction force per unit length along the skin plate edge (df/ds) is due to the product of the friction factor and normal force exerted on the side wall. The normal force is generated by a preset in the "J" seal and the hydrostatic pressure against the "J" seal.

It is assumed that a 0.25 inch preset induces a normal force k of 0.048 K/ft applied uniformly along the entire length of the skin plate edge. The normal force due to hydrostatic pressure is 0.0624dh, where d is the effective width of the "J" seal (2.25 in. = 0.1875 ft. in our case), and h is taken from the top of the skin plate. Note that taking h from the top of the skin plate is correct when the water level is 530 ft., and slightly conservative when the water level is 528 ft. The friction is equal to the product of the coefficient of side seal friction, μ_s, taken as 0.5 from Corps Manual (11) EM 1110-2-2702, page 18, and the normal force. So, due to both preset and hydrostatic pressure,

$$\frac{df}{ds} = (\mu_s k + 0.0624\mu_s dh) \text{ K/ft} \qquad (1)$$

For the specific tainter gate under consideration, $\mu_s = 0.5$, $k = 0.048$, $d = 0.1875$ ft. So,

$$\frac{df}{ds} = 0.5(0.048) + 0.0624(0.5)(0.1875)h$$

$$= (0.024 + 0.00585h) \text{ K/ft} \qquad (2)$$

Note that df/ds is simply an externally applied force in a direction tangent to the skin plate side edges and opposite to the upward movement of the gate (Figs. 2 and 3).

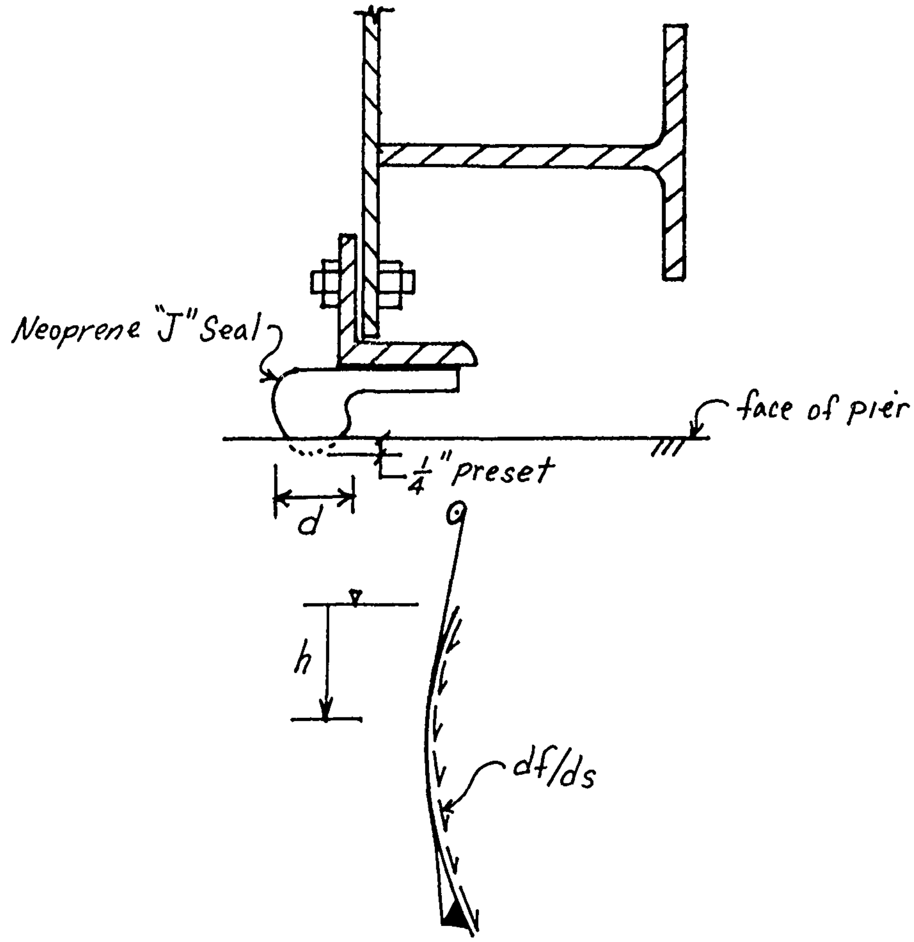

Figure 3. Neoprene Side Seal Friction Effect

2.3 Trunion Pin Friction Effect

This discussion of trunion pin friction is also based upon a similar presentation by Dressler (2), except that several corrections are made to the analysis.

Each trunion pin total reaction is composed of three global components, R_x, R_y, and R_z, which are parallel to the global X, Y, and Z axes as shown in Fig. 2. Components R_x and R_y lead to a resultant force R which exerts pressure directly on the trunion pin as shown in Fig. 4. This pressure leads to a friction force df_t/ds around the trunion pin which is statically equivalent to a resisting moment and a resultant force in the y' direction. Component R_z reacts through a trunion yoke on end bearing plates, exerting pressure which leads to a friction force that is only statically equivalent to a resisting moment. It is the purpose of this Section to evaluate the relationship between the statically equivalent friction forces and the reaction components R_x, R_y, and R_z.

First, consider the effect of R_x and R_y. It is assumed that the resultant of R_x and R_y, $R = \sqrt{R_x^2 + R_y^2}$, is uniformly distributed across the projected area of the trunion pin for a unit width of pin (Fig. 4). The projected area, A, is equal to $2r_p(1)$, where r_p is the trunion pin radius. Therefore, the assumed average trunion stress, σ_p, on the projected area of the trunion pin is,

$$\sigma_p = \frac{R}{A} = \frac{R}{2r_p(1)} \quad \text{(3)}$$

Referring to Fig. 4, if $\overline{R}$ is now defined as the proportion

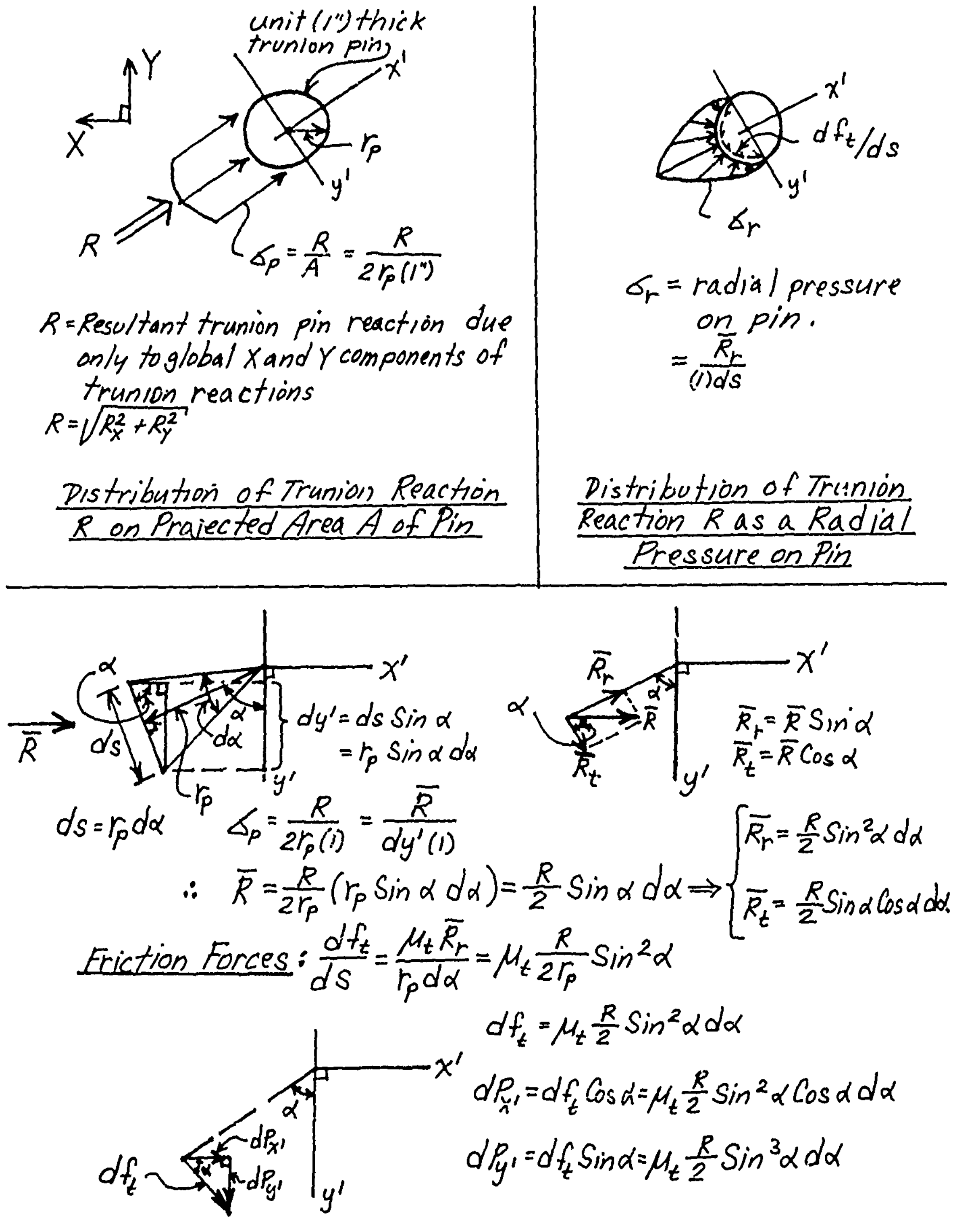

Figure 4. Trunion Pin Friction Effect

of R acting over a differential length of pin circumference, ds, then σ_p can also be expressed as,

$$\sigma_p = \frac{\overline{R}}{(1)dy'} \qquad \text{.......(4)}$$

where dy' is the projection of ds on the y' axis, and,

$$dy' = ds \, \text{Sin}\alpha \qquad \text{.......(5)}$$

Since ds = $r_p d\alpha$, where r_p = trunion pin radius, then,

$$dy' = r_p \, \text{Sin}\alpha(d\alpha) \qquad \text{.......(6)}$$

Substituting Eq. (6) into Eq. (4), and equating the result to Eq. (3) leads to,

$$\overline{R} = \frac{R}{2} \, \text{Sin}\alpha \, d\alpha \qquad \text{.......(7)}$$

Now, the friction force per unit length of pin circumference is directly related to the force component of $\overline{R}$ acting normal to the pin, $\overline{R}_r$. From the geometry of $\overline{R}$ in Fig. 4,

$$\left.\begin{aligned} \overline{R}_r &= \overline{R} \, \text{Sin} \, \alpha \\ \overline{R}_t &= \overline{R} \, \text{Cos} \, \alpha \end{aligned}\right\} \qquad \text{.......(8)}$$

where $\overline{R}_r$ and $\overline{R}_t$ are the normal and tangential components of $\overline{R}$ respectively, and α is the angle from the y' axis to the point on the pin circumference in question. Substituting Eq. (7) into Eq. (8),

$$\overline{R}_r = \frac{R}{2} \, \text{Sin}^2\alpha \, d\alpha \qquad \text{.......(9)}$$

$$\overline{R}_t = \frac{R}{2} \, \text{Sin} \, \alpha \, \text{Cos} \, \alpha \, d\alpha \qquad \text{.......(10)}$$

Since only $\overline{R}_r$ leads to friction force, then,

$$\frac{df_t}{ds} = \mu_t \overline{R}_r \qquad \text{.......(11)}$$

where df_t/ds = friction force per unit length of pin circumference, and μ_t = coefficient of pin friction force (= 0.3 by Corps Manual (11) EM 1110-2-2702). Therefore, from Eqs. (9) and (11),

$$\frac{df_t}{ds} = \mu_t \left(\frac{R}{2r_p}\right) \operatorname{Sin}^2 \alpha \quad \text{.........................} (12)$$

It is now of interest to determine the statical equivalents of df_t/ds. In the y' direction, df_t/ds is statically equivalent to a force $P_{y'}$, where

$$P_{y'} = \int dP_{y'} \quad \text{.................................} (13)$$

and where $dP_{y'}$ = the y' component of df_t or,

$$dP_{y'} = (df_t)\operatorname{Sin} \alpha \quad \text{...........................} (14)$$

Substituting Eq. (12) into Eq. (14) and recalling that $ds = r_p d\alpha$, leads to,

$$dP_{y'} = \mu_t \frac{R}{2} \operatorname{Sin}^3\alpha d\alpha \quad \text{.........................} (15)$$

and then substituting Eq. (15) into Eq. (13) results in,

$$\begin{aligned} P_{y'} &= \int_0^{\pi} \mu_t \frac{R}{2} \operatorname{Sin}^3\alpha \, d\alpha \\ &= \mu_t \frac{R}{2} \int_0^{\pi} \operatorname{Sin}^3\alpha \, d\alpha \\ &= \mu_t \frac{R}{2}((-(\operatorname{Cos} \alpha)/3)(\operatorname{Sin}^2 \alpha + 2))_0^{\pi} \\ &= \mu_t \frac{R}{2}((-1/3)(-1)(2) - (-1/3)(1)(2)) \end{aligned}$$

$$P_{y'} = \frac{2}{3}\mu_t R \quad \text{..................................} (16)$$

For the specific gate under consideration, $\mu_t = 0.3$. So,

$$\begin{aligned} P_{y'} &= 0.20R \\ &= 0.20\sqrt{R_x^{\,2} + R_y^{\,2}} \quad \text{..........................} (17) \end{aligned}$$

In the x' direction, df_t/ds is statically equivalent to a force $P_{x'}$, where,

$$P_{x'} = \int dP_{x'} \quad \text{.................................(18)}$$

and where $dP_{x'}$ = the x' component of df_t. Note that $P_{x'}$ must equal '0' since only R can be the resultant force in the x' direction. So,

$$dP_{x'} = (df_t)\text{Cos}\ \alpha \quad \text{.............................(19)}$$

Substituting Eq.(12) in Eq. (19) and recalling that $ds = r_p d\alpha$ leads to,

$$dP_{x'} = \mu_t \frac{R}{2} \text{Sin}^2\alpha\ \text{Cos}\ \alpha\ d\alpha \quad \text{....................(20)}$$

and then substituting Eq. (20) into Eq. (18) results in,

$$P_{x'} = \int_0^\pi \mu_t \frac{R}{2} \text{Sin}^2\alpha\ \text{Cos}\ \alpha\ d\alpha$$

$$= \mu_t \frac{R}{2}\int_0^\pi \text{Sin}^2\alpha\ \text{Cos}\ \alpha\ d\alpha$$

$$= \mu_t \frac{R}{2}\left(\frac{\text{Sin}^3\alpha}{3}\right)_0^\pi$$

$$P_{x'} = 0.0 \quad \text{...(21)}$$

Finally, and most importantly, df_t/ds is statically equivalent to a moment, M_R, about the global Z axis (perpendicular to X-Y and x'-y'), where,

$$M_R = \int (df_t) r_p \quad \text{.................................(22)}$$

Substituting Eq. (12) into Eq. (22) and recalling that $ds = r_p d\alpha$ leads to,

$$M_R = \int_0^\pi \mu_t \frac{R}{2} r_p \text{Sin}^2\alpha\ d\alpha$$

$$= \frac{\mu_t R r_p}{2}\int_0^\pi \text{Sin}^2\alpha\ d\alpha$$

$$= \frac{\mu_t R r_p}{2}\left(\frac{\alpha}{2} - \frac{\text{Sin}\ 2\alpha}{4}\right)_0^\pi$$

$$= \frac{\mu_t R r_p}{2} \left(\frac{\pi}{2}\right)$$

$$M_R = 0.7854 \mu_t R r_p \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

Next, consider the effect of R_z. This trunion pin reaction component reacts through the trunion yoke on end bearing plates leading to a resultant friction force $\mu_t R_z$ acting around the pin circumference at an approximate radius of r_p. Since the direction of R_z, either plus or minus, leads to the same moment due to R_z, then

$$M_{R_z} = \mu_t |R_z| r_p \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

where $|R_z|$ = absolute value of R_z.

Consequently, the total trunion friction moment, M, due to R_x, R_y, and R_z, is,

$$M = M_R + M_{R_z}$$

or,

$$M = 0.7854 \mu_t R r_p + \mu_t |R_z| r_p \quad \ldots\ldots\ldots\ldots\ldots\ldots (25)$$

where,

$$R = \sqrt{R_x^2 + R_y^2}$$

To summarize, the resultant trunion pin global reaction components, R_x, R_y, and R_z result in friction forces on the pin, $P_{x'}$, $P_{y'}$, and M such that,

$$\left.\begin{aligned} P_{x'} &= 0.0 \\ P_{y'} &= \tfrac{2}{3}\mu_t R = \tfrac{2}{3}\mu_t \sqrt{R_x^2 + R_y^2} \\ M &= 0.7854 \mu_t r_p \sqrt{R_x^2 + R_y^2} + \mu_t |R_z| r_p \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (26)$$

and, for the specific tainter gate under consideration, $\mu_t = 0.3$ and $r_p = 5.0$ in. $= 0.41667$ ft.,

$$\left.\begin{aligned} P_{x'} &= 0.0 \\ P_{y'} &= 0.20\sqrt{R_x^2 + R_y^2} \\ M &= 0.098167\sqrt{R_x^2 + R_y^2} + 0.1250|R_z| \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots (27)$$

Now, $P_{x'}$ is zero and does not effect any final analysis results. $P_{y'}$ is non-zero and must be included in the analysis. However, since it is a concentrated force in a direction perpendicular to R at the trunion pin, it need only be added to the resultant reaction at the pin in a direction perpendicular to R, and only affects the force the trunion girder must resist (see Section 5.2). The moment M, on the other hand, not only is the torsion moment that must be resisted by the trunion girder, but it must also be included in the tainter gate analysis itself. This is where the difficulty occurs, since M is a highly non-linear function of R_x, R_y, and R_z, and also since, to the author's knowledge, there are no available general purpose computer programs for structural analysis that can model such a behavioral relationship. Section 3.4 discusses how this effect is to be accounted for.

2.4 Design Loading Conditions

The specification of design loading conditions must recognize a variety of boundary conditions and geometric states of the gate. One is associated with the gate resting on the sill. Another is associated with both cables lifting the gate, but the gate may be in any position from one in which it is just beginning to open, to one in which it is fully open. Another is associated with only one cable lifting the gate (i.e. one cable has broken), but the gate may again be in any position from just starting to open to fully open. In addition, for the one cable situation, lateral displacements of the gate may be large enough to cause the gate to touch the side pier walls which lead to another boundary condition. This is a non-linear behavior since it must be determined if the gate touches the side piers and if so (or if not), the boundary conditions may need to be changed. Another is associated with either one or two cables lifting the gate with the gate in any position, but in addition, the gate binds at the side seals and the force in the cable(s) increase to the maximum hoisting force that the hoisting motor can exert.

Considering this variety of gate states, it is clear that there are an infinite number of different loading conditions that could be used for design. It is, of course, the responsiblity of the engineer and appropriate design specifications to select a finite number for actual use. For the specific gate used in this study, there were eight design loading conditions specified in the design notes (3) of the Clarence Cannon Re-Regulation Dam Tainter Gate Design. They were as shown in Table 1. It should be noted that the eighth loading, Loading Condition VIII, was not used in this study primarily because it was not considered to be worth the effort to recompute the gate geometry in view of the goal of this report to describe an analysis procedure to handle any gate geometry. Consequently, only Loading Conditions I - VII were considered. However, Loading Condition VIII would make an excellent

TABLE 1

Clarence Cannon Re-Regulation Dam Tainter Gate
Design Loading Conditions

Loading Condition I

a. Dead load of gate
b. Hydrostatic load. Water to top of gate, elevation 530.0 ft.
c. Hoist cables slack, gate resting on sill. All forces reacted by sill and trunions.
d. Normal Group I loading - no overstress permitted.

Loading Condition II

a. Dead load of gate
b. Hydrostatic load. Water to top of gate, elevation 530.0 ft.
c. Gate supported by both hoisting cables. All forces reacted by trunion pins and hoisting cables.
d. Gate strating to open. Friction factor of 0.3 at trunion pins and 0.5 at side seals.
e. Normal Group I loading - no overstress permitted.

Loading Condition III

a. Same as Loading Condition I plus wave loading.
b. Group II Loading - 1/3 overstress permitted.

Loading Condition IV

a. Dead load of gate
b. Hydrostatic load. Water at elevation 528.0 ft.
c. Impact load of 5 K/ft of gate width applied at elevation 528.0 ft.
d. Gate resting on sill. All forces reacted by sill and trunions.
e. Group II loading - 1/3 overstress permitted.

Loading Condition V

a. Dead load of gate
b. Hydrostatic load. Water at elevation 528.0 ft.
c. Impact load of 5 K/ft of gate width applied at elevation 528.0 ft.
d. Gate supported by both hoisting cables. All forces reacted by trunions and hoisting cables.
e. Gate starting to open. Friction factor of 0.3 at trunion pins and 0.5 at side seals.
f. Group II loading - 1/3 overstress permitted.

Loading Condition VI

a. Same as Loading Condition II, except all forces are reacted by trunions and only <u>one</u> hoisting cable.
b. Group III loading - 50% overstress permitted.

TABLE 1 - CONTINUED

Loading Condition VII (See Note 1) a. Same as Loading Condition II, except gate is assumed held down by friction and binding. Hoist cable load becoming 280% of normal cable tension due to development of maximum design torque in hoist. b. Group III loading - 50% overstress permitted.
Loading Condition VIII (See Note 2) a. Dead load of gate b. Gate wide open against stops. Bottom of gate at elevation 535.0 ft. c. Hoisting cable loads equal to 280% of normal maximum cable tension due to development of design torque in hoist. d. Gate supported by both hoisting cables. All forces reacted by trunions and hoisting cables. e. Group III loads - 50% overstress permitted.

Note 1: (a) It is assumed that Loading Condition II forces, including cable force F and trunion moment M, are developed prior to binding.
(b) Binding occurs, after which an additional 1.8F and 0.0M are applied to the bound gate developing additional gate forces which are added to the Loading Condition II gate forces.

Note 2: Loading Condition VIII was not used in this study primarily because it was not considered to be worth the effort to recompute the gate geometry since the goal of this report was to describe an analysis procedure to handle any gate geometry.

case to analyze in order to test one's understanding of many of the concepts presented in this report and the companion report (1).

2.5 Summary

Tainter gates are highly unusual structures requiring special analysis techniques. They are characterized by one or two cables lifting the gate which rotates about a pair of trunion pins. They are subjected to a variety of loading conditions associated with several different boundary condition and geometric states, all of which must be considered in design. Friction effects must be considered for an accurate analysis. Side seal friction is easily accounted for as an applied loading condition. However, trunion pin friction is extremely difficult to model since it is a highly non-linear function of unknown reaction forces at the trunion pin, which in turn are a function of the pin friction effects.

Chapter 3 describes the details of the proposed structural model to analyze these types of tainter gates.

3. GENERAL MODEL FORMULATION

3.1 Introduction

In order to obtain a highly accurate analysis of the type of tainter gates described in Section 2, a special structural model was developed. This model had to reflect four special characteristics which were, (1) all structural boundary condition cases must be easily identified and included in the analysis, (2) all independent loading conditions must be easily identified and subject to analysis, (3) the difficult trunion pin friction effect must be accounted for, and (4) analysis results for each independent loading must be easily combined with other independent loading results to generate the design loading conditions. Sections 3.2, 3.3, 3.4, and 3.5 consider these requirements respectively.

Before proceeding, however, it is helpful at this point to understand how the cable is modeled. Rather than modeling the cable as a separate structural element, only its effect on the skin plate is modeled. At the connection of the cable to the skin plate, the cable is modeled either as a reaction component in the direction of the cable, i.e. in a direction which is tangent to the skin plate surface and in a vertical plane, or as a known applied force (in the case of the gate bound at the side seals). The value of this reaction, or the known applied force, is the cable force. This part of the cable effect is accounted for in the structural boundary condition cases as described in Section 3.2. In addition, the cable exerts a radial pressure on the skin plate over the length of contact between the cable and skin plate, and is equal to the value of the cable force divided by the radius of curvature of the skin plate (since the skin plate has a constant radius of curvature in a vertical plane), in units of force/length. This part of the cable effect is modeled as an applied load as will be shown in Section 3.4.

3.2 Structural Boundary Condition Cases

Referring to the seven design loading conditions used in this study, Loading Conditions I - VII in Table 1, it is clear that there are four distinct structural boundary condition cases. These cases are identified here as Load Groups, where a Load Group is defined as a set of independent loads applied to the structure with a particular set of boundary conditions. The boundary conditions associated with each of the four Load Groups are as follows:

Load Group A: gate resting on sill; translational force reactions in the global Y direction at each contact point with the sill; and translational force reactions in the global X, Y, and Z directions at each trunion pin (Fig. 5a).

Load Group B: gate supported by two hoisting cables, just starting to open; single translational force reaction at both cable support points on skin plate,(to simulate cable effect at point of connection to skin plate), and in a direction which is tangent to skin plate; translational force reactions at each trunion pin in global X, Y, and Z directions (Fig. 5b).

Load Group C: gate supported by only one hoisting cable, just starting to open; translational force reactions at one cable support

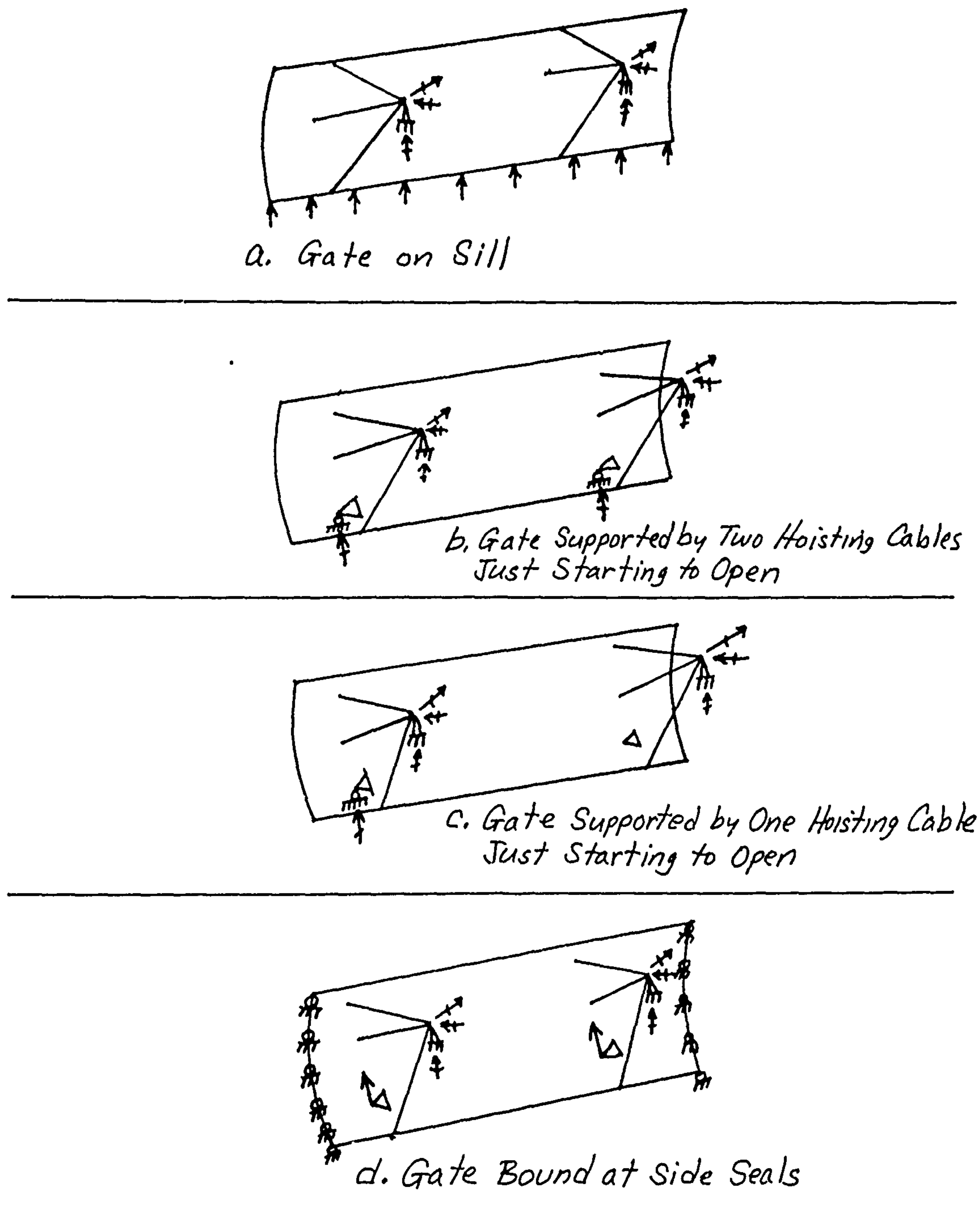

Figure 5. Boundary Condition Cases

point on skin plate (to simulate one cable effect at point of connection to skin plate), and in a direction which is tangent to skin plate; translational force reactions at each trunion pin in global X, Y, and Z directions (Fig. 5c).

Load Group D: gate bound at side seals; effect of two hoisting cables at skin plate connections accounted for by applying known cable forces at both points of connection to skin plate; translational force reactions at each trunion pin in global X, Y, and Z directions; translational force reactions at side seals in directions which are tangent to skin plate edges and in a vertical plane (Fig. 5d).

It should be noted that Load Group C may be divided into two different cases. One is associated with the gate not experiencing sufficient lateral displacements to touch the side piers, and another is associated with the gate experiencing sufficiently large lateral displacements (.25 inches for the specific gate used in this study), so that lateral supports must be added to the Load Group C boundary conditions.

The detailed specification of these boundary condition cases are described in Chapter 4.

3.3 Independent Loading Conditions by Load Group

Upon inspection of the seven design loading conditions considered in this study (see Table 1), it is seen that there are six distinct independent loading conditions which are (1) dead load of gate, (2) hydrostatic load, water at elevation 530.0 ft., (3) hydrostatic load water at elevation 528.0 ft., (4) impact load at elevation 528.0 ft.,

(5) wave load, water at elevation 530.0 ft., and (6) 1.8 x cable force from design Loading Condition II. In addition, as was shown in Section 2.2, the side seal friction effect may be considered as an applied loading condition. So, a seventh independent load is, (7) side seal friction. Also, as will be shown in Section 3.4, the trunion pin friction effect may be accounted for by a superposition technique which requires the application of two more independent loading conditions which are, (8) gate skin plate pressure due to a 1,000 K cable force, and (9) a 1,000 K-ft moment about the global Z axis applied at one or both trunion pins and in a direction which resists the upward movement of the gate. Finally, since Load Group C may be associated with the gate displacing laterally until it touches the side piers, after which it is restrained from further lateral movement at the points of contact, a tenth independent loading condition should be considered which is, (10) a specified lateral joint displacement ($\pm$0.25 inches for the specific gate considered in this study) applied at the joints which may be in contact with the side piers.

Although there are ten independent loading conditions which can be identified, it is not clear that these are the ones which are used in a structural analysis. In particular, there are also four boundary condition (Load Group) cases which were identified in Section 3.2, and most of these independent loading conditions are associated with two or more boundary condition cases. If an independent loading condition is associated with two boundary condition cases, for example, it generates two independent loading conditions for structural analysis purposes since, even though the applied loads are the same, different structural analysis results will be generated for the different boundary conditions. Consequently, it is necessary to identify the independent loading conditions in terms of their corresponding boundary condition cases to properly account for the actual number of independent loads.

For the specific gate under consideration in this study, there are twenty independent loading conditions which must be considered. Tables 2, 3, 4, and 5 summarize them. Details of the loading computations are shown in Appendix D.

Now, before describing how these twenty independent loading conditions are combined to form the seven design loading conditions, it is necessary to show how the trunion pin friction effect is accounted for. This will be described next.

3.4 Special Analysis Procedure to Account for the Trunion Pin Friction Effect

As was shown in Section 2.3, Eq. (26), the trunion pin friction effect leads to three additional reaction components at the trunion pins, $P_{x'}$, $P_{y'}$, and M. This equation is repeated below for reference purposes,

$$\left.\begin{aligned} P_{x'} &= 0.0 \\ P_{y'} &= \frac{2}{3}\,\mu_t\sqrt{R_x^{\,2} + R_y^{\,2}} \\ M &= 0.7854\mu_t r_p\sqrt{R_x^{\,2} + R_y^{\,2}} + \mu_t r_p|R_z| \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots(28)$$

where μ_t is the coefficient of trunion pin friction, r_p = trunion pin

TABLE 2

Independent Loadings - Load Group A
Gate Resting on Sill

Independent Load Number	Independent Load Description
1	Dead load of gate structure
2	Hydrostatic load, water at top of gate, elevation 530.0 ft.
3	Wave load, elevation 530.0 ft.
4	Hydrostatic load, water at elevation 528.0 ft.
5	Impact load of 5 K/ft of gate width applied to gate skin plate at elevation 528.0 ft.

TABLE 3

Independent Loadings - Load Group B
Gate Supported by Two Cables, Just Starting to Open

Independent Load Number	Independent Load Description
6	Dead load of gate structure.
7	Hydrostatic load, water at top of gate, elevation 530.0 ft.
8	Hydrostatic load, water at elevation 528.0 ft.
9	Impact load of 5 K/ft of gate width applied to gate skin plate at elevation 528.0 ft.
10	Side seal friction in a direction resisting gate opening.
11	Skin pressure due to 1,000 K. cable force in both cables
12	1,000 K-ft trunion pin friction moment at both pins and in a direction resisting gate opening.

TABLE 4

Independent Loadings - Load Group C
Gate Supported by One Cable, Just Starting to Open

Independent Load Number	Independent Load Description
13	Dead load of gate structure.
14	Hydrostatic load, water at top of gate, elevation 530.0 ft.
15	Side seal friction in a direction resisting gate opening.
16	Skin pressure due to 1,000 K cable force in one cable.
17	1,000 K-ft trunion pin friction moment at one pin (joint 38 in gate under study) in a direction resisting gate opening.
18	1,000 K-ft trunion pin friction moment at one pin (joint 1038 in gate under study) in a direction resisting gate opening.
20	Joint displacement load, in gate under study, at joint 1001 = +0.25 inches, at joint 7 = -0.25 inches, to simulate part of lateral constraint provided by side pier walls.

TABLE 5

Independent Loadings - Load Group D
Gate Bound at Side Seals, Supported by Two Cables

Independent Load Number	Independent Load Description
19	Skin pressure due to 1,000 K. cable force in both cables, and 1,000 K. force at both points of connection of the cable to the skin plate in an upward direction and tangent to the skin plate.

radius, and R_x, R_y, and R_z = trunion pin reaction components as a function of the externally applied loads and trunion pin friction moment M, but independent of trunion pin friction reactions $P_{x'}$ and $P_{y'}$.

Since $P_{x'}$ equals zero, it has no effect on the analysis. The force $P_{y'}$ is non-zero, but it only adds to the force components that must be resisted by the trunion pins (and in turn the trunion girder), while not affecting any other analysis results. As shown in Section 2.2, $P_{y'}$ is in a direction perpendicular to R, the resultant of global reaction components R_x and R_y at the trunion pins. The trunion pin friction moment M is also non-zero, but it affects both the trunion pin reaction and other gate analysis results. The moment M is equal to the actual moment at the trunion pins, and therefore is the torsion moment that must be resisted by the trunion girder. In addition, the moment M is directly involved in the equilibrium equations for the gate, and this is where the difficulty in analysis lies.

Consider the schematic drawing of the effect of M on the gate in Fig. 6. Since the trunion pin friction is only associated with Load Groups B or C, this schematic is associated with the gate supported by one or two cables and just starting to open. In this Figure, F represents the cable force effect at its point of connection to the skin plate, r is the radius of curvature of the skin plate, F/r is the radial pressure effect of the cable on the skin plate, and W represents the externally applied loads such as dead weight, hydrostatic force, and side seal friction.

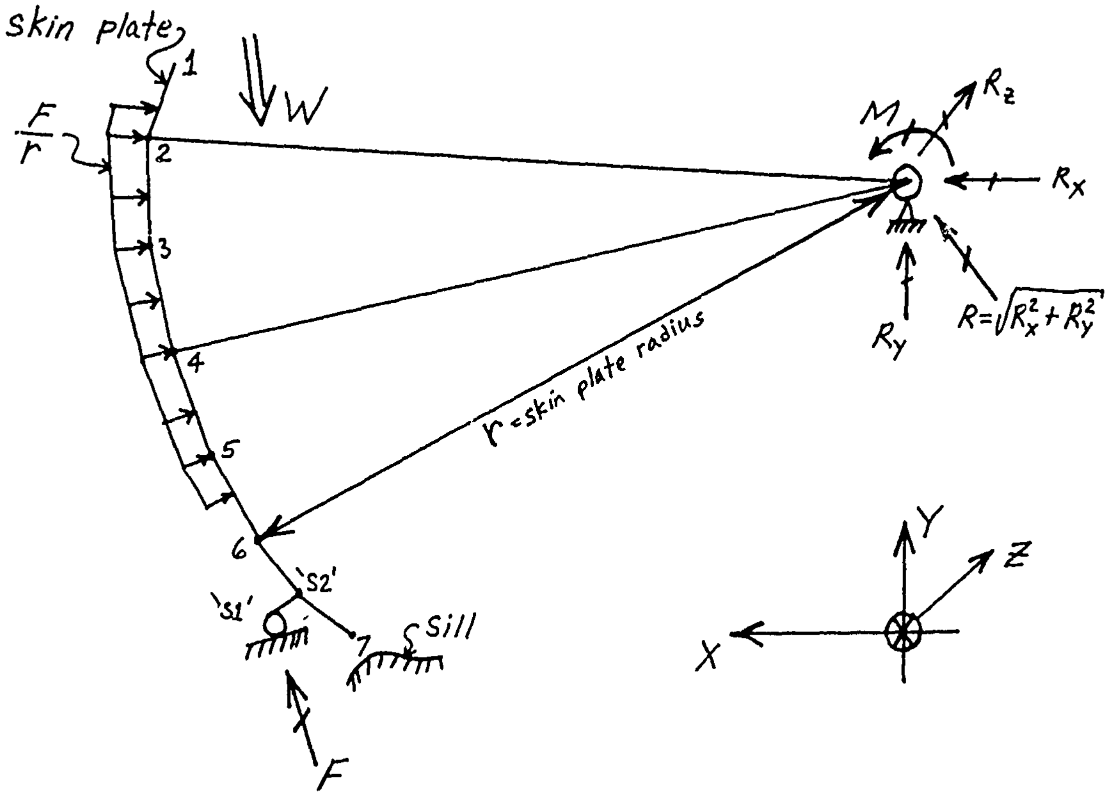

Figure 6. Effe .t of Trunion Pin Friction Moment M

There are five unknown forces, R_x, R_y, R_z, F, and M. In order to solve for these unknowns, five independent equations are needed. Four of them are equilibrium equations; three force equilibrium equations in the X, Y, and Z directions, and one moment equilibrium equation about the Z-axis. The fifth equation is the relation between M and R_x, R_y, and R_z in Eq. (28). These five equations in five unknowns can now be solved. However, there are two distinct problems in the solution. One is that the system of equations is highly non-linear. This cannot be avoided in any case. The second is that the generation of the equilibrium equations is enormously time consuming if performed by hand due to the complexity of the loading conditions and also due to the large number of loading conditions for which a solution is required. Therefore, a hand solution is not cost-effective. Since this study is intended to demonstrate how a general purpose computer program may be used to analyze this structure, it is desirable to have the program do the equilibrium analysis. Unfortunately, to the author's knowledge, there are no available general purpose structural analysis computer programs that can model the effect of an unknown reaction force M as a function of other unknown reaction forces R_x, R_y, and R_z, not to mention the non-linear relationship which also needs to be modeled. Consequently, a special structural analysis model was formulated to minimize hand computations, and maximize the use of the general purpose structural analysis computer program, thereby leading to a highly cost-effective solution process.

The special model that was developed needed to distinguish between a symmetrical gate behavior (for the case where the gate is supported by two cables), and a non-symmetrical gate behavior (for the case where the gate is supported by only one cable). These are described in detail in the following Sections 3.4.1 and 3.4.2.

3.4.1 2-Cable Symmetrical Case

When the gate is supported by two cables (Load Group B boundary conditions and design Loading Conditions II, V, and VII), it experiences completely symmetrical behavior. Consequently, only the symmetrical part of the trunion pin friction moment effect needs to be considered, i.e. only one trunion pin and one cable need be included in the formulation.

Referring to Fig. 7, the technique used is to identify three components of the structure's behavior, and then to superimpose these components in such a way as to result in the actual behavior of the structure. Each of the three components consists of the full structure supported by Load Group B boundary conditions, i.e. supported at the trunion pins and at the points of connection of the cables to the skin plate. In addition, the first component is subjected to some combination of the Load Group B independent loading conditions 6 to 10 as represented by W in Fig. 7. R_{x1}, R_{y1}, and R_{z1} are the global reaction components at a trunion pin, and F_1 is the cable force, all due to W.

The second component is subjected only to the effect of the radial pressure part, S, of a 1,000 K. cable force. R_{x2}, R_{y2}, and R_{z2} are the global reaction components at a trunion pin, and F_2 is the cable force due to the radial pressure effect. It should be noted that F_2 should

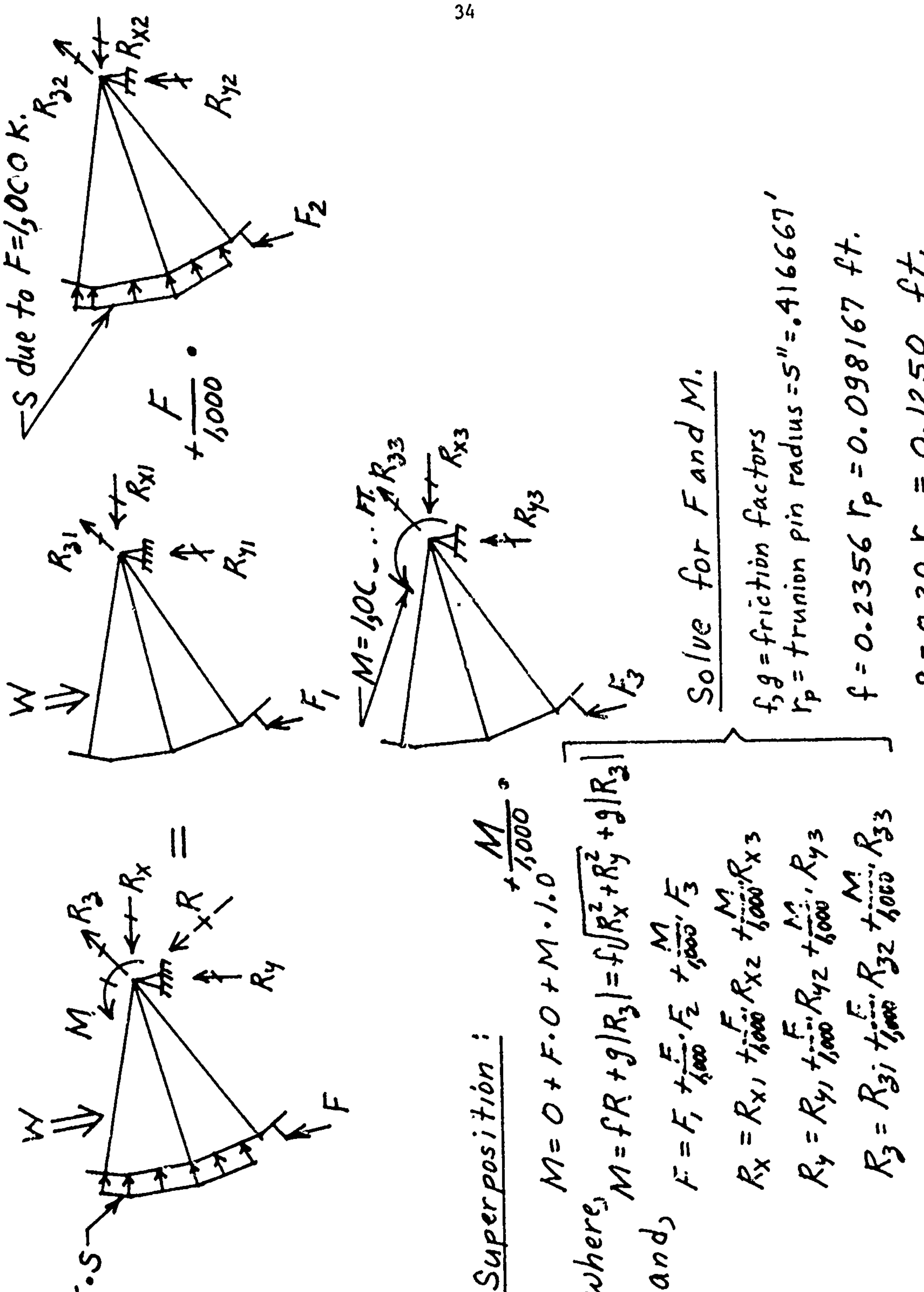

Figure 7. 2-Cable Symmetrical Case

really be identically zero since the only externally applied force in the second component is a radial pressure, the resultant of which passes through the projection of the trunion pin on a plane containing this resultant and F_2. However, in the actual structural model used, as will be described in detail in Chapter 4, the cylindrical skin plate is modeled as a series of flat plate finite elements where the resultant of the applied cable pressure load does not exactly go through the projection of the trunion pin, thereby resulting in a very small value of F_2. This small value is used since it is consistent with the other force results in the analysis of the second component.

The third component is subjected only to the effect of a 1,000 K-ft counter-clockwise moment about the global Z-axis at a trunion pin. R_{x3}, R_{y3}, and R_{z3} are the global reaction components at a trunion pin, and F_3 is the cable force, all due to the 1,000 K-ft moment.

Each of these three components can easily be analyzed by a general purpose structural analysis computer program. However, the behavior of the actual structure must be determined by properly superimposing the results of each component's analysis. In particular, if Q represents the force and displacement results in the actual structure, and q_1, q_2, and q_3 represent the force and displacement results in the first, second, and third components respectively, then the proper superposition is computed as,

$$Q = q_1 + \frac{F}{1000} q_2 + \frac{M}{1000} q_3 \qquad (29)$$

where F is the actual cable force in both cables and M is the actual trunion pin friction moment.

Now, the combination factors F and M must be computed. In order to do this, at least two independent equations involving the two unknowns F and M are required. One of these equations is taken from Eq. (28). However, Eq. (28) introduces three new unknowns, R_x, R_y, and R_z. Consequently, three additional equations, or a total of four more equations, are needed. These may be determined by applying Eq. (29) four times to reflect the respective superposition of F_i, R_{xi}, R_{yi}, and R_{zi}, for i = 1, 2, 3 (the three component cases in Fig. 7), to generate F, R_x, R_y, and R_z. The resulting five equations are,

$$\left.\begin{aligned} M &= f\sqrt{R_x^2 + R_y^2} + g|R_z| \\ F &= F_1 + F\cdot\frac{F_2}{1000} + M\cdot\frac{F_3}{1000} \\ R_x &= R_{x1} + F\cdot\frac{R_{x2}}{1000} + M\cdot\frac{R_{x3}}{1000} \\ R_y &= R_{y1} + F\cdot\frac{R_{y2}}{1000} + M\cdot\frac{R_{y3}}{1000} \\ R_z &= R_{z1} + F\cdot\frac{R_{z2}}{1000} + M\cdot\frac{R_{z3}}{1000} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots(30)$$

where $f = 0.7854\mu_t r_p$, and $g = \mu_t r_p$. For the specific tainter gate considered in this study, where $\mu_t = 0.3$ and $r_p = 0.41667$ ft., the friction factors f and g are: f = 0.098167 and g = 0.1250.

Eq. (30) may be solved for F, M, R_x, R_y, and R_z. Note that μ_t and r_p are specified, and F_i, R_{xi}, R_{yi}, and R_{zi}, i = 1, 2, 3 are computed in the structural analyses of the three component structures described above.

Since Eq. (30) is highly non-linear it was decided to use a Newton-Raphson Iteration procedure to solve. The details of this procedure are fully described in Reference 4, and will only be summarized here. So, to find the value X_k such that a function $h(X_k) = 0$, the following iteration may be performed,

$$X_{k+1} = X_k - \frac{h(X_k)}{h'(X_k)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (31)$$

where $h'(X_k)$ is the derivative of $h(X_k)$ with respect to X_k at the point X_k. The derivative of $h(X_k)$, $h'(X_k)$, was computed numerically by an equally-spaced five-point Lagrangian interpolation formula expanded about the middle, i.e. third, point (see Reference 5) as follows,

$$h'_0 = \frac{1}{12t}(h_{-2} - 8h_{-1} + 8h_{+1} - h_{+2}) \ldots\ldots\ldots\ldots\ldots\ldots (32)$$

where t is the spacing between the five points, h'_0 is the value of the derivative at the middle point, and h_{-2}, h_{-1}, h_{+1}, and h_{+2} are the values of the function h at the two points on either side of the third point. Now, it was decided to let $t = 1.0$ and $h_0 = X_k$. Therefore, the derivative $h'(X_k)$ was computed by,

$$h'(X_k) = \frac{1}{12}[h(X_k - 2.0) - 8h(X_k - 1.0) + 8h(X_k + 1.0) - h(X_k + 2.0)] \quad \ldots\ldots (33)$$

Now, in order to apply this procedure, Eq. (30) must be rewritten in the following form,

$$h(X_k) = X_k - f\sqrt{R_x^2 + R_y^2} - g|R_z| = 0$$

where,

$$M = X_k$$

$$F = \frac{F_1 + X_k F_3}{(1 - F_2)}$$

$$R_x = R_{x1} + \frac{F}{1000} R_{x2} + \frac{X_k}{1000} R_{x3}$$

$$\left.\begin{aligned} R_y &= R_{y1} + \frac{F}{1000} R_{y2} + \frac{X_k}{1000} R_{y3} \\ R_z &= R_{z1} + \frac{F}{1000} R_{z2} + \frac{X_k}{1000} R_{z3} \end{aligned}\right\} \qquad \text{........(34)}$$

Table 6 summarizes the step-by-step procedure to solve Eq. (34). A computer program, XFTWO, was written to execute this procedure. A description and listing of XFTWO is given in Appendix G . It is interesting to note that for the specific tainter gate considered in this study and for an input convergence tolerance of 0.01, XFTWO converged in two cycles.

1. Let $X_1 = X_0$

→ 2. Compute $F = \frac{F_1 + X_1 F_3}{(1 - F_2)}$, eq. ([illegible])

3. Compute R_x, R_y, R_3 by eq. (3.[illegible]).

4. Compute a new value of X by eq. (31):

$$X_2 = X_1 - \frac{h(X_1)}{h'(X_1)}$$, $h(X_1)$ from eq. ([illegible]4), $h'(X_1)$ from eq. ([illegible]3)

5. If $|X_2 - X_1| \le$ tolerance, GO TO 7

   Else, GO TO 6

6. Set $X_1 = X_2$

   GO TO 2

→ 7. $M = X_2$

$$F = \frac{F_1 + X_2 F_3}{(1 - F_2)}$$

TABLE 6

Solution for F and M for the 2-Cable Symmetrical Case by the Newton-Raphson Iteration Procedure

3.4.2 1-Cable Non-Symmetrical Case

When the gate is supported by one cable (Load Group C boundary conditions, and design Loading Condition VI), it experiences non-symmetrical behavior. Consequently, unlike the 2-cable symmetrical case, this 1-cable case requires consideration of the entire structure including the trunion pin friction effect for both trunion pins, in addition to the one cable support.

Referring to Fig. 8, this case required the identification of four components of the structure's behavior which, when properly superimposed, will result in the actual behavior of the structure. Each of the four components consists of the full structure supported by Load Group C boundary conditions, i.e. trunion pins and one cable support. In addition, the first component is subjected to the Load Group C independent boundary conditions 13 to 15 as represented by W in Fig. 8. R_{x1a}, R_{y1a}, R_{z1a}, and R_{x1b}, R_{y1b}, R_{z1b} are the global reaction components at trunion pins 'a' and 'b' (joints 38 and 1038 in the specific tainter gate structural model described in Chapter 4) respectively, and F_1 is the cable force, all due to W.

The second component is subjected only to the effect of the radial pressure part, S, of a 1,000 K. cable force in the one supporting cable. R_{x2a}, R_{y2a}, R_{z2a} and R_{x2b}, R_{y2b}, R_{z2b} are the global reaction components at trunion pins 'a' and 'b' respectively, and F_2 is the cable force due to this radial pressure effect. Note that F_2 is not exactly zero in the actual structural analysis for the same reason as for the 2-cable case.

The third component is subjected only to the effect of a 1,000 K-ft counter-clockwise moment about the global Z-axis at trunion pin 'a' (joint 38) only. R_{x3a}, R_{y3a}, R_{z3a} and R_{x3b}, R_{y3b}, R_{z3b} are the global

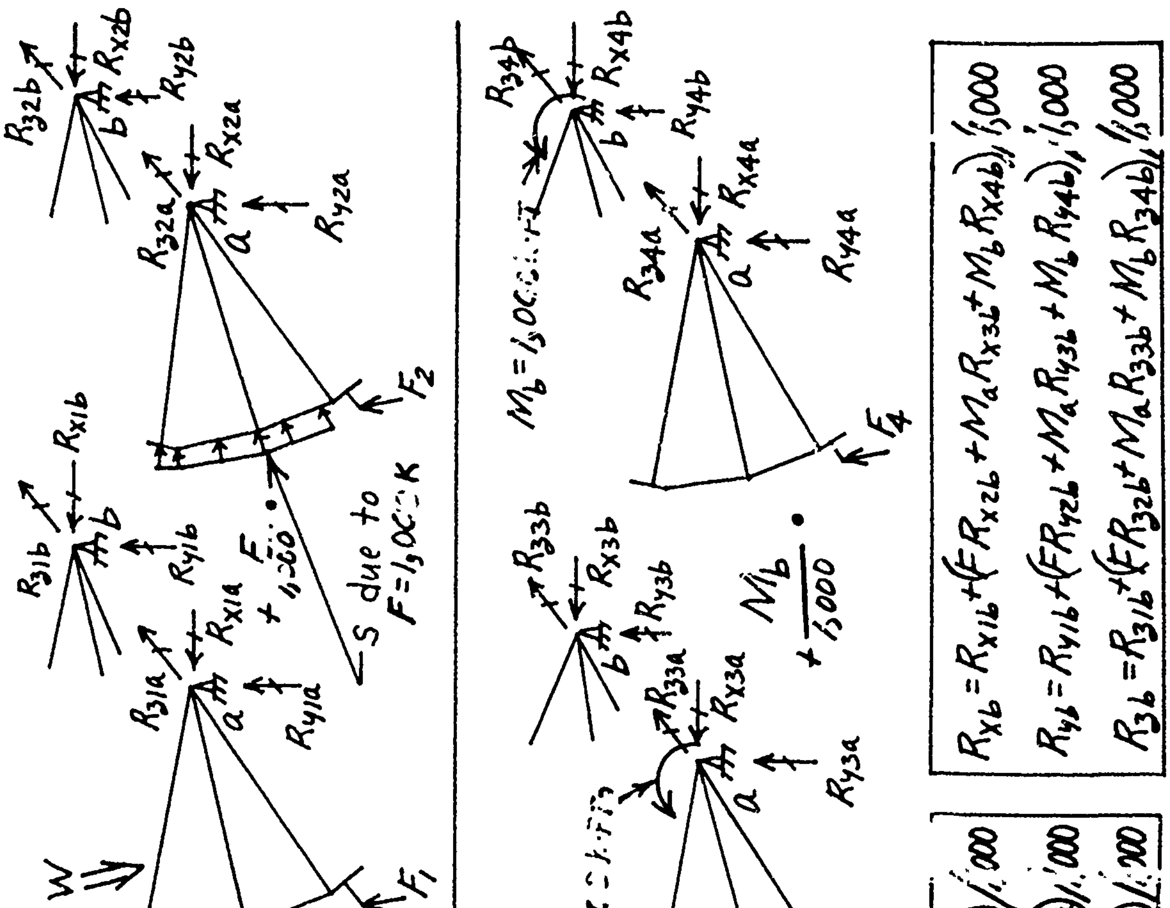

Figure 8. 1-Cable Non-Symmetrical Case

reaction components at trunion pins 'a' and 'b' respectively, and F_3 is the cable force, all due to the 1,000 K-ft moment at 'a'.

The fourth component is subjected only to the effect of a 1,000 K-ft counter-clockwise moment about the global Z-axis at trunion pin 'b' (joint 1038) only. R_{x4a}, R_{y4a}, R_{z4a} and R_{x4b}, R_{y4b}, R_{z4b} are the global reaction components at trunion pins 'a' and 'b' respectively, and F_4 is the cable force, all due to the 1,000 K-ft moment at 'b'.

Each of these four components can easily be analyzed by a general purpose structural analysis computer program, the proper superposition of which leads to the behavior of the actual structure. As in the 2-cable case, the superposition principle can be expressed by an equation similar to Eq. (29) or,

$$Q = q_1 + \frac{F}{1000} q_2 + \frac{M_a}{1000} q_3 + \frac{M_b}{1000} q_4 \quad \ldots\ldots\ldots\ldots\ldots\ldots (35)$$

where Q represents the force and displacement results in the actual structure, q_1, q_2, q_3, and q_4 represent the force and displacement results in each of the four structural components respectively, F is the actual cable force in the one supporting cable, and M_a and M_b are the actual trunion pin friction moments at trunion pins 'a' and 'b' (joints 38 and 1038) respectively.

There are now three combination factors, F, M_a, and M_b, which must be computed, as opposed to two in the 2-cable case. In order to compute them, at least three independent equations involving these factors are required. Two of these equations are taken from Eq. (28) by applying the equation for M at both trunion pins 'a' and 'b' , i.e. M_a and M_b. However, these two equations introduce six new unknowns, R_{xa}, R_{ya}, R_{za}, and R_{xb}, R_{yb}, R_{zb} at trunion pins 'a' and 'b' respectively. Consequently, six additional equations, or a total of seven more equations are needed. These may be determined by applying Eq. (35) seven times to reflect the respective superposition of F_i, R_{xia}, R_{yia}, R_{zia}, R_{xib}, R_{yib}, and R_{zib}, for i = 1, 2, 3, 4 (the four component cases in Fig. 8), to generate F, R_{xa}, R_{ya}, R_{za}, R_{xb}, R_{yb}, and R_{zb}. The resulting equations, which are similar in form to Eq. (30), may be rewritten to conform with a Newton-Raphson Iteration solution as follows,

$$h_a(X_{ka}) = X_{ka} - f\sqrt{R_{xa}^2 + R_{ya}^2} - g|R_{za}| = 0$$

$$h_b(X_{kb}) = X_{kb} - f\sqrt{R_{xb}^2 + R_{yb}^2} - g|R_{zb}| = 0$$

where,

$$M_a = X_{ka}$$

$$M_b = X_{kb}$$

$$F = \frac{F_1 + X_{ka}F_3 + X_{kb}F_4}{(1-F_2)}$$

$$R_{xa} = R_{x1a} + \frac{F}{1000} R_{x2a} + \frac{X_{ka}}{1000} R_{x3a} + \frac{X_{kb}}{1000} R_{x4a}$$

$$R_{ya} = R_{y1a} + \frac{F}{1000} R_{y2a} + \frac{X_{ka}}{1000} R_{y3a} + \frac{X_{kb}}{1000} R_{y4a}$$

$$R_{za} = R_{z1a} + \frac{F}{1000} R_{z2a} + \frac{X_{ka}}{1000} R_{z3a} + \frac{X_{kb}}{1000} R_{z4a}$$

and,

$$R_{xb} = R_{x1b} + \frac{F}{1000} R_{x2b} + \frac{X_{ka}}{1000} R_{x3b} + \frac{X_{kb}}{1000} R_{x4b}$$

$$R_{yb} = R_{y1b} + \frac{F}{1000} R_{y2b} + \frac{X_{ka}}{1000} R_{y3b} + \frac{X_{kb}}{1000} R_{y4b}$$

$$R_{zb} = R_{z1b} + \frac{F}{1000} R_{z2b} + \frac{X_{ka}}{1000} R_{z3b} + \frac{X_{kb}}{1000} R_{z4b}$$

...(36)

Table 7 summarizes the step-by-step procedure to solve Eq. (36). A computer program, XFONE, was written to execute this procedure. A description and listing of XFONE is given in Appendix G . It is interesting to note that for the specific tainter gate considered in this study and for an input convergence tolerance of 0.01, XFONE converged in seven cycles.

3.5 <u>Design Loading Combinations</u>

Section 2.4 and Table 1 summarize the seven design loading conditions considered for the specific tainter gate used in this study. In Section 3.2, it was shown that these loading conditions are associated with four distinct boundary condition states, and in Section 3.3 and Tables 2, 3, 4, and 5, it was shown that there are a total of twenty independent loading conditions associated with these four boundary condition states. Also, Section 3.4 demonstrates how the tainter gate final behavior is a superposition of cases involving forces identified in Figs. 7 and 8 as W, radial pressure due to a 1,000 K cable force, and a 1,000 K-ft moment, as well as combination factors F/1000 and M/1000. This Section will describe the formulation for combining the independent loading conditions to form the design loading combinations in such a way as to be consistent with the different boundary condition cases as well as to be consistent with the superposition required in the computation of cable force F and trunion pin friction moment M.

First it should be noted that Corps design specifications, as taken from Reference (3), require that allowable stresses, computed from

1. Let $X_{a1} = X_{ao}$ and $X_{b1} = X_{bo}$
2. $F = \dfrac{F_1 + X_{a1}F_3 + X_{b1}F_4}{(1-F_2)}$, eq. (14)
3. Compute $R_{xa}, R_{ya}, R_{3a}, R_{xb}, R_{yb}, R_{3b}$ by eqs. (15)–(20)
4. $X_{a2} = X_{a1} - \dfrac{h_a(X_{a1})}{h_a'(X_{a1})}$, $h_a(X_{a1})$ from eq. (12), $h_a'(X_{a1})$ from eq. (21)
5. If $|X_{a2} - X_{a1}| \leq$ tolerance (0.01), GO TO 7
   Else, GO TO 6
6. Set $X_{a1} = X_{a2}$
   GO TO 2
7. Set $X_{a1} = X_{a2}$
8. $F = \dfrac{F_1 + X_{a1}F_3 + X_{b1}F_4}{(1-F_2)}$
9. Compute $R_{xa}, R_{ya}, R_{3a}, R_{xb}, R_{yb}, R_{3b}$
10. $X_{b2} = X_{b1} - \dfrac{h_b(X_{b1})}{h_b'(X_{b1})}$, $h_b(X_{b1})$ from eq. (13), $h_b'(X_{b1})$ from eq. (21)
11. If $|X_{b2} - X_{b1}| \leq$ tolerance, GO TO 13
    Else, GO TO 12
12. Set $X_{b1} = X_{b2}$, GO TO 8
13. If $|h_a(X_{a2})| \leq$ tolerance
    and $|h_b(X_{b2})| \leq$ tolerance, GO TO 15
    Else, GO TO 14.
14. Set $X_{b1} = X_{b2}$, GO TO 2
15. $M_a = X_{a2}$, $M_b = X_{b2}$, $F = \dfrac{F_1 + X_{a2}F_3 + X_{b2}F_4}{(1-F_2)}$

TABLE 7: Solution for F, M_a, and M_b for the 1-Cable Non-Symmetric Case by the Newton-Raphson Iteration Procedure

the 1969 American Iron and Steel Institute Specifications (6), are to be reduced by 83-1/3%. This is precisely equivalent to increasing all analysis element force results by the factor 1.0/0.83333 = 1.20. In addition, the Corps specifications permit three cases of stress design. One case permits no overstress. In this case, the combination factor applied to the independent load combinations would be 1.2 x 1.0 = 1.2. The second case permits a 1/3 overstress (i.e. computed stress may exceed allowable by 1/3 x allowable). In this case, the combination factor applied to the independent load combinations would be 1.2 x 1.0/(4/3) = 1.2 x 0.75. The third case permits a 50% overstress. In this case, the combination factor applied to the independent load combinations would be 1.2 x 1.0/(3/2) = 1.2 x 0.6667.

Now, in order to combine the independent loading conditions, it must be recognized that for any one load combination, all the independent loading conditions involved must be associated with the same boundary condition case. That is, for any one loading combination, the independent loads must all be taken from either Table 2 or 3 or 4 or 5, depending on the required boundary conditions. Now, design loading conditions I, III, and IV (See Table 1), are associated with Load Group A, the gate resting on the sill (Table 2), and reacted by sill and trunion pins, and not involving any cable force or trunion pin friction moment. The required combinations are,

$$\left.\begin{aligned} (I) &= 1.2 \times (1 + 2) \\ (III) &= 1.2 \times 0.75 \times (1 + 2 + 3) \\ (IV) &= 1.2 \times 0.75 \times (1 + 4 + 5) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots (37)$$

where the integer numbers are independent load numbers from Table 2.

Note that design loads III and IV permit a 1/3 overstress as described in Table 1.

Design loading conditions II and V are associated with Load Group B, the gate supported by two cables, and the gate just starting to open (Table 3). Since these conditions must include the effects of the cable force F and trunion pin friction moment M, the combination of independent loads must be consistent with the formulation for computing F and M whereby a proper superposition of cases is required as represented by Eq. (29) and repeated here for reference,

$$Q = q_1 + \frac{F}{1000} q_2 + \frac{M}{1000} q_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (38)$$

where Q may be interpreted as the design load combination force results, and therefore where q_1 = forces due to applied loads other than the effects of cable force F (i.e. forces due to W in Fig. 7, and independent loads 6, 7, 8, 9, and 10), q_2 = forces due to the effect of the radial skin pressure equivalent of a 1,000 K. cable force (independent load 11), and q_3 = forces due to the effect of a 1,000 K-ft trunion pin friction moment (independent load 12). The required combinations are,

$$\left.\begin{aligned} (II) &= 1.2 \times (6 + 7 + 10 + \frac{F}{1000} \times 11 + \frac{M}{1000} \times 12 \\ (V) &= 1.2 \times 0.75 \times (6 + 8 + 9 + 10 + \frac{F}{1000} \times 11 + \frac{M}{1000} \times 12) \end{aligned}\right\} \ldots (39)$$

where the integer numbers are independent load numbers from Table 3, and F and M are the cable forces and trunion pin friction moments computed for the 2-cable symmetrical case by the computer program XFTWO (Appendix G) according to Eq. (34) and the procedure summarized in Table 6. Note that a 1/3 overstress is permitted in design load condition V.

Design loading condition VI is associated with Load Group C, the gate supported by only one cable, and the gate just starting to open (Table 4). Since this condition must include the effects of cable force F, and trunion pin friction moments M_a and M_b, the combination of independent loads must be consistent with the formulation for computing F, M_a, and M_b for the 1-cable unsymmetrical case which requires a proper superposition of cases as represented by Eq. (35) and repeated here for reference,

$$Q = q_1 + \frac{F}{1000} q_2 + \frac{M_a}{1000} q_3 + \frac{M_b}{1000} q_4 \quad \text{.....................(40)}$$

where Q may be interpreted as the design load combination force results, and therefore where q_1 = forces due to applied loads other than the effects of cable force F (i.e. forces due to W in Fig. 8, and independent loads 13, 14, 15, and 20), q_2 = forces due to the effect of the radial skin pressure equivalent of a 1,000 K. cable force in one cable (independent load 16), q_3 = forces due to the effect of a 1,000 K-ft trunion pin friction moment M_a in one trunion pin (independent load 17), and q_4 = forces due to the effect of a 1,000 K-ft trunion pin friction moment M_b in the other trunion pin (independent load 18).

Now, since this is the unsymmetrical design loading condition, before the required combination is shown, it must be noted that there are two possible states for this combination. One state is associated with the gate experiencing small enough lateral displacements so that the gate does not touch the side pier walls. This state involves independent loads 13 to 18 analyzed for Load Group C boundary conditions which do not include side wall constraints. The second state is associated with the gate experiencing sufficiently large lateral displacements so that the gate touches the side pier walls.

This state involves independent loads 13 to 18 and 20 analyzed for Load Group C boundary conditions which include the side wall constraints. Each state must, of course, be investigated, and the one which occurs used for design. The second state, i.e. with side wall constraints, occurred for the specific tainter gate considered in this study as described in Section 4. So, the two different possible combinations are,

$$(VI)_{\substack{\text{no side}\\ \text{wall}\\ \text{constraint}}} = 1.2(0.6667)(13 + 14 + 15 + \frac{F}{1000}(16) + \frac{M_a}{1000}(17) + \frac{M_b}{1000}(18)) \quad \ldots.(41)$$

or,

$$(VI)_{\substack{\text{with side}\\ \text{wall}\\ \text{constraint}}} = 1.2(0.6667)(13 + 14 + 15 + 20 + \frac{F}{1000}(16) + \frac{M_a}{1000}(17) + \frac{M_b}{1000}(18)) \quad \ldots.(42)$$

where the integer numbers are independent load numbers from Table 4, and F, M_a, and M_b are the cable force, and trunion pin friction moments computed for the 1-cable unsymmetrical case by the computer program XFONE (Appendix G) according to Eq. (36) and the procedure summarized in Table 7. Note that a 50% overstress is permitted in this design condition.

Finally, design loading condition VII is associated with Load Group D, the gate bound at the side seals, and the gate supported by two cables (Table 5). This design load condition is specified to have the same load combination as design load II, but in addition, the force in the cable increases to a value of 280% of the cable force in design load II. Consequently, this load condition first uses the same results as generated in design load II, and then adds the results of an analysis for an additional 180% of the design load II cable force applied to the gate with the side seals bound (Load Group D boundary conditions).

The required combination is,

$$(VII) = 0.6667 \times (II) + 1.2 \times 0.6667 \times (1.8 \times \frac{F}{1000} \times 19) \quad .....(43)$$

where the integer number is an independent load number from Table 5, the (II) refers to design load combination II (see Eq. (39)), and F = the cable force used in design load combination II. Note that a 50% overstress is permitted in this design load condition.

Table 8 summarizes the required seven design load combinations considered for the specific tainter gate studied in this report.

TABLE 8

Force Design Loading Combination Summary

Design Load Combination	Independent Load Combinations
I	$1.2 \times (1 + 2)$
II	$1.2 \times (6 + 7 + 10 + \frac{F}{1000} \times 11 + \frac{M}{1000} \times 12)$
III	$1.2 \times 0.75 \times (1 + 2 + 3)$
IV	$1.2 \times 0.75 \times (1 + 4 + 5)$
V	$1.2 \times 0.75 \times (6 + 8 + 9 + 10 + \frac{F}{1000} \times 11 + \frac{M}{1000} \times 12)$
VI (no side wall constraint)	$1.2 \times 0.6667 \times (13 + 14 + 15 + \frac{F}{1000} \times 16 + \frac{M_a}{1000} \times 17 + \frac{M_b}{1000} \times 18)$
VI (with side wall constraint)	$1.2 \times 0.6667 \times (13 + 14 + 15 + 20 + \frac{F}{1000} \times 16 + \frac{M_a}{1000} \times 17 + \frac{M_b}{1000} \times 18)$
VII	$0.6667 \times (II) + 1.2 \times 0.6667 \times (1.8 \times \frac{F}{1000} \times 19)$

Final Combination Factors for Initial STRUDL II Runs:

II: F = 17.257 K, M = 58.366 K-ft
V: F = 3.611 K, M = 58.903 K-ft
VI: F = 34.627 K, M_a = 59.927 K-ft, M_b = 56.805 K-ft

4. DETAILS OF INITIAL STRUDL II SOLUTION PROCEDURE

4.1 Introduction

In order to use a general purpose computer program to perform an accurate structural analysis and design of the type of tainter gate under consideration, it must possess certain special and sophisticated capabilities including:

1. the ability to perform multiple analyses in the same computer run,

2. the ability to change the data base between the different analyses so that each analysis may be based on different boundary conditions, and/or loading conditions, etc.,

3. the ability to save on the computer, for any length of time, the status of a problem solution at any point, display results for engineering review, and subsequently continue the problem solution with a modified data base,

4. the ability to combine analysis results for different loading conditions used in the same analysis,

5. the ability to combine analysis results for different loading conditions used in several different analyses involving different boundary conditions,

6. the ability to include in the model description such special conditions as the eccentricity of the end of a member element from the joint center it connects to, the location of the shear center of a member element from its centroid, and others,

7. the ability to perform design of steel member elements according to AISC Specifications (6).

The only commercially available general purpose structural analysis and design computer program that has all of the above, and many more advanced capabilities is the STRUDL II subsystem (7) of the ICES system (8). This program was used through the facilities of the McDonnell Automation Co. (9).

4.2 Overview of the Analysis and Design Approach

The general approach followed to analyze and design the specific tainter gate (the Clarence Cannon Tainter Gate) considered in this report first involved describing the structure's geometry, topology, element properties, material properties, loading conditions, and boundary conditions. Four analyses were performed, each one corresponding to the loading and boundary conditions associated with a particular Load Group (Tables 2, 3, 4, and 5). The analysis for Load Group C did not include Loading 20 since the side wall constraint was not used at first. Each of these analyses was performed in a different computer run. The results of each run were saved on the computer for future use by the STRUDL SAVE command. This process involved the use of extensive data base management facilities, as only contained in the STRUDL II computer system.

Before proceeding, it was necessary to determine if the first analysis for Load Group C was appropriate since it did not include any side wall constraint. First, the cable force F, and trunion pin friction moments M_a and M_b were computed by program XFONE. The the SAVE'ed STRUDL problem was restored with the STRUDL RESTORE command, and the displacements for design load VI were formed and output. It was then noted that the lateral displacements for this unsymmetrical case exceeded the 0.25 inch clearance between the gate and side walls. Consequently, it was necessary to RESTORE the problem, change the boundary conditions for Load Group C to include the side wall lateral constraint, and reanalyze the structure for the Load Group C loading conditions including Loading 20. It was then necessary to compute cable force F and trunion pin friction moment M for design loads II and V using program XFTWO, and cable force F and trunion pin friction moments M_a and M_b for design load VI using program XFONE. Then, form design load combinations I to VII for element forces and reactions using the loading combinations as summarized in Table 8 where the combination factors are,

Design Load II: F = 17.257 K., M = 58.366 K-ft

Design Load V: F = 3.611 K., M = 58.903 K-ft

Design Load VI: F = 34.627 K., M_a = 59.927 K-ft, M_b = 56.803 K-ft

The input to XFTWO and XFONE used to compute these values of cable forces and trunion pin friction moments is shown in Appendix H .

Seven additional combinations were formed, D1 to D7, for displacements corresponding to design loads I to VII. The displacements are formed by dividing the displacements from design loads I to VII by the stress decrease and/or increase factors, since these factors are only applicable to stresses and not displacements. Table 9 summarizes the appropriate combinations.

Finally, STRUDL II was used to perform a design check on the member elements of the existing Clarence Cannon Tainter Gate.

TABLE 9

Displacement Combination Summary

Load Combination	Displacement Combination
D1	(I)/1.2
D2	(II)/1.2
D3	(III)/(1.2 x 0.75)
D4	(IV)/(1.2 x 0.75)
D5	(V)/(1.2 x 0.75)
D6	(VI)/(1.2 x 0.6667)
D7	(VII)/(1.2 x 0.6667)

4.3 Geometry, Topology, and Loading Computations

The structural model of the Clarence Cannon Tainter Gate used in the initial STRUDL II solution is shown in Figs. 9, 10,and 11. All joints, member elements, and triangular finite elements used to model the skin plate, stiffening ribs, and supporting girders are shown in Figs. 9 and 10. The member elements and joints used in the structure which transfers the skin plate forces to the trunion pins is shown in Fig. 11. The skin plate is modeled by a triangular flat plate bending-and-stretching finite element, the PBS2 element, which exhibits excellent bending and stretching behavior, and which is proprietary to the McDonnell Automation Co.'s version of STRUDL II (9).

The geometry of the tainter gate under study is perfectly symmetrical. The calculation of the joint coordinates and other geometric characteristics is shown in Appendix A. The calculation of the coordinates of the points of support of the cable to the skin plate, and the points of tangency of the cable to the skin plate is shown in Appendix B. Member element Beta angle and end eccentricity calculations are shown in Appendix C. The calculation of independent loading conditions is shown in Appendix D.

4.4 Step-by-Step Procedure Used in the Initial STRUDL II Analysis and Design Problem Solution

In order to demonstrate the validity of the analysis procedure, an initial STRUDL II solution was formulated and is described in this Section. Based on this initial solution, a recommended STRUDL II solution, which is more suitable in a design office environment, was

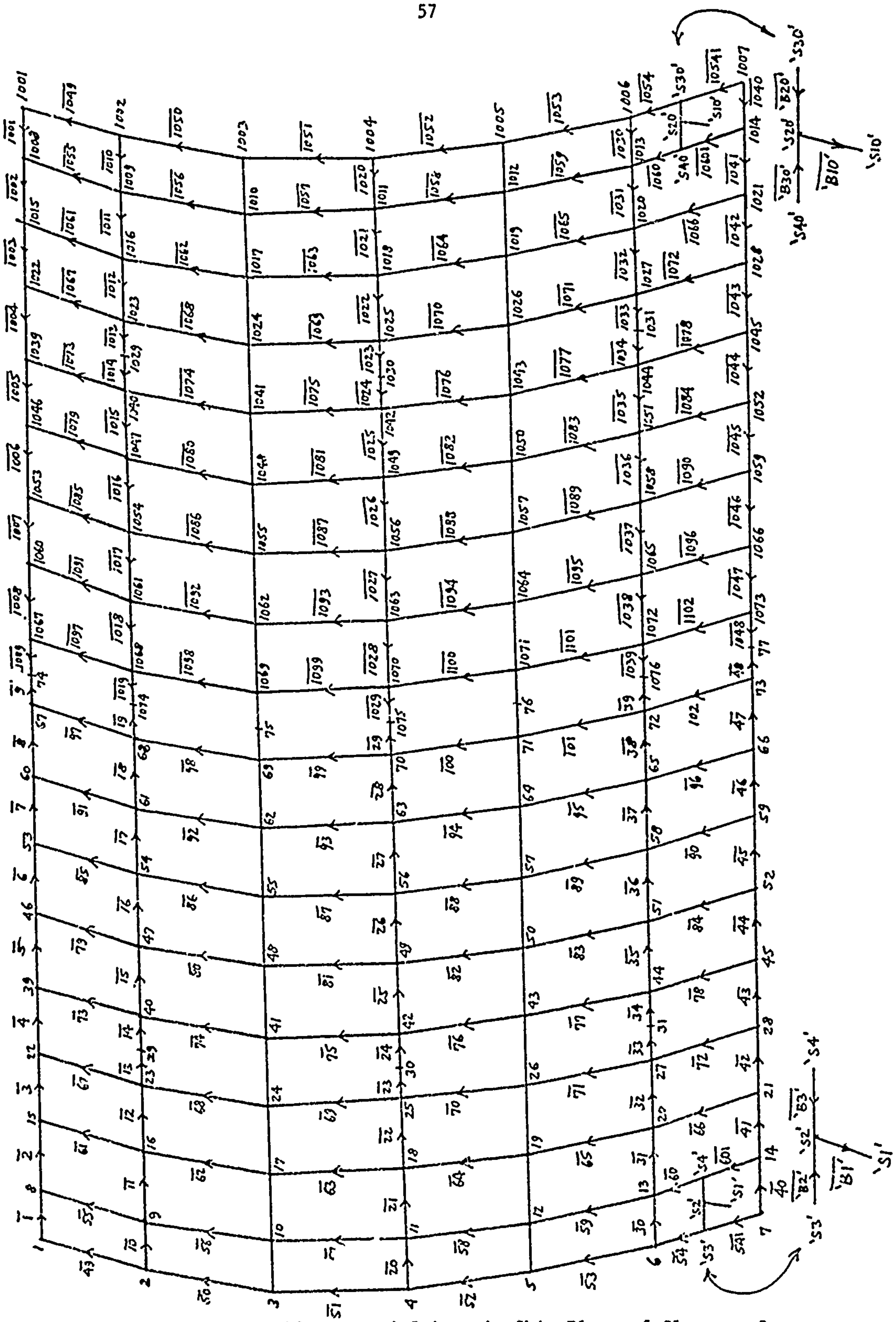

Figure 9. Member Incidences and Joints in Skin Plate of Clarence Cannon Tainter Gate STRUDL II Model

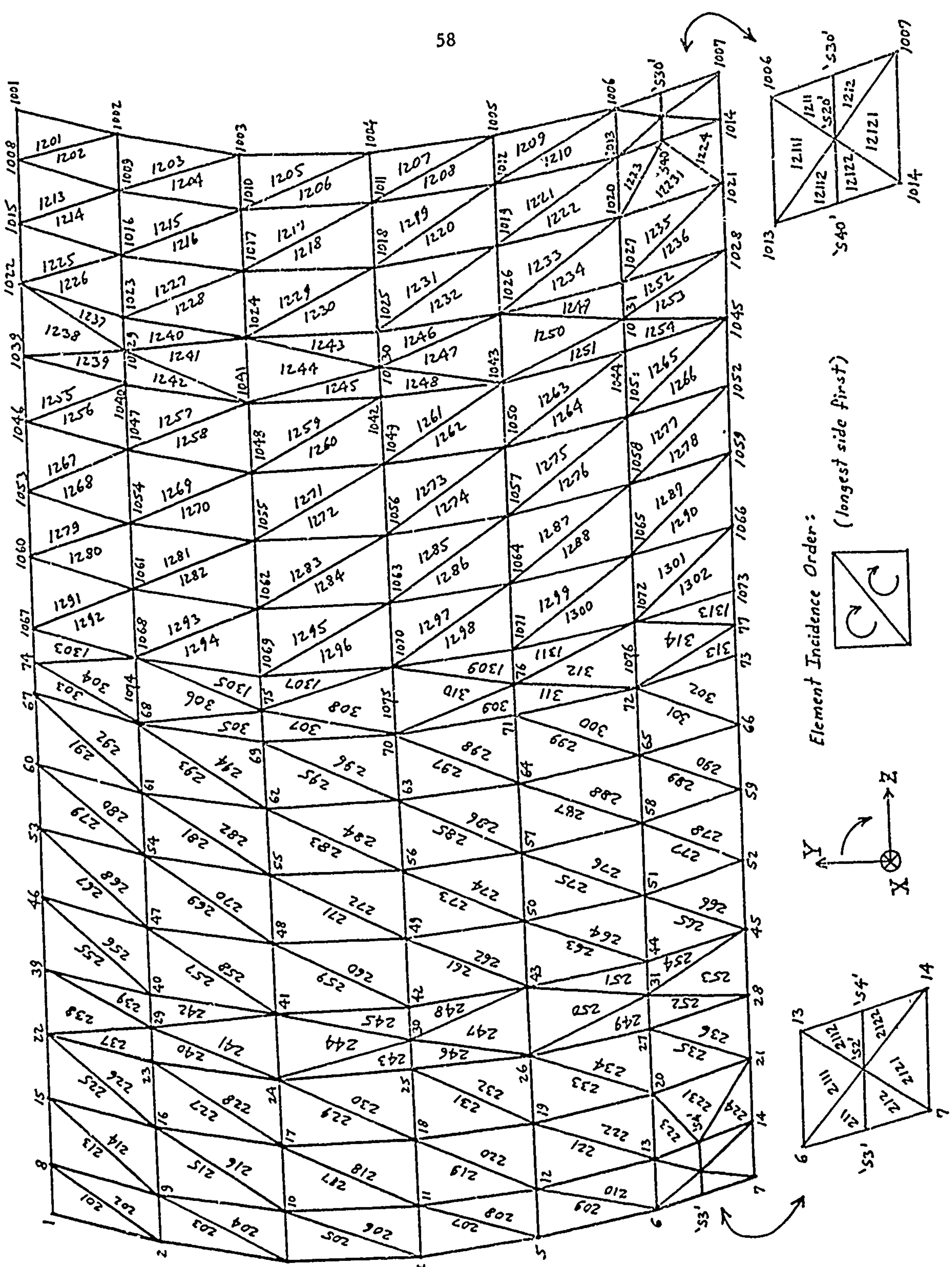

Figure 10. Element Incidences and Joints in Skin Plate of Clarence Cannon Tainter Gate STRUDL II Model

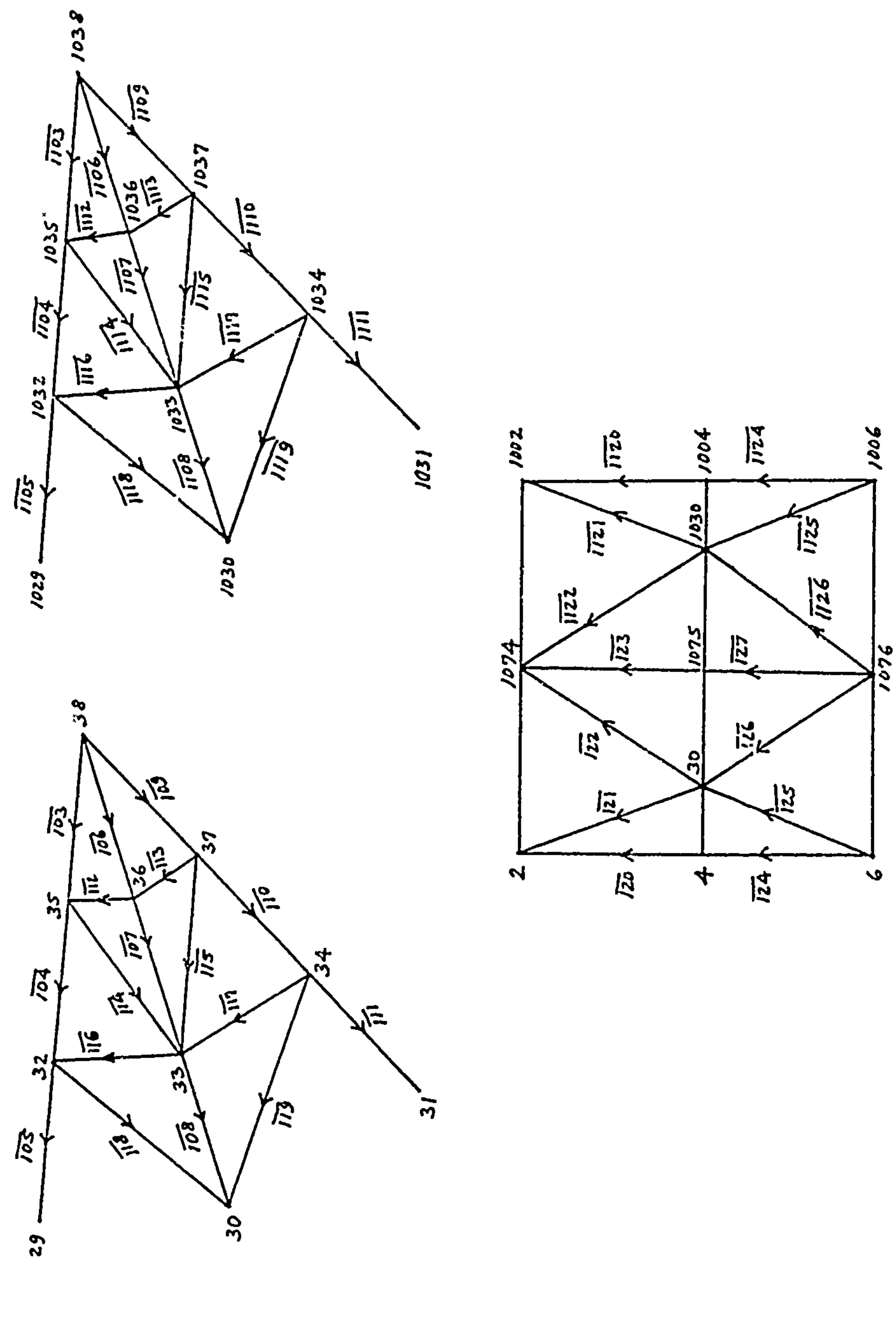

Figure 11. Member Incidences and Joints in Struts and Skin Plate Bracing System for Clarence Cannon Tainter Gate STRUDL II Model

formulated and is presented in Reference (1). The initial procedure follows, while a listing of the actual STRUDL II commands is shown in Appendix E. It is assumed that the reader is familiar with the language conventions and capabilities of STRUDL II (7).

Run 1: First STRUDL II run

(i) The first run defines the complete structural geometry (joint coordinates), topology (member and element incidences), member and structural boundary conditions, material properties, member eccentricities, beta angles, and member and element properties.

(ii) Specify special boundary conditions consistent with Load Group A, the gate resting on the sill.

(iii) Describe Load Group A independent load conditions 1, 2, 3, 4, and 5.

(iv) Request STRUDL PLOT's on the line printer to check the entire geometry and topology of the structure. An alternative checking procedure is to use the McAuto FASTDRAW (10) interactive graphics system. A description of the use of FASTDRAW to display, as well as generate and modify, the geometry and topology of a structure is given in Reference (1).

(v) Issue a CHECK INPUT command which requests STRUDL to perform a data consistency check prior to analysis.

(vi) Issue a SAVE command to save the current status of the problem solution on the computer. This permitted the current state of the problem solution to be reviewed offline before proceeding further.

```
SAVE 'GATE/CK1'
```

Note that the data value 'GATE/CK1' is an arbitrary less-than-or-equal-to eight character file name, of the file which stores the state of the problem at the time the SAVE is given, on the DD1 data set which is a permanent data set defined on a private CORPS 2314 disk pack (see Job Control Language in Appendix F).

Check results of first STRUDL run for input errors before proceeding.

Run 2: Restore the SAVE'd Run 1 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

It should be noted that this RESTORE is non-destructive. This means that if the computer goes down during the run, or if an input error or any other problem causes the problem solution to terminate prematurely, the file associated with 'GATE/CK1' is not detroyed. The problem may then be RESTORE'd again from the same file 'GATE/CK1'.

(i) Perform a STIFFNESS ANALYSIS NJP 4 for the Load Group A case (loads 1, 2, 3, 4, or 5), gate resting on sill. The number of joint partitions (NJP) for analysis was specified as 4. This will increase the efficiency of the equation solution part of the stiffness analysis by partitioning the stiffness equations into 4 joints/partition.

(ii) Output member force, element stress, and reaction results.

(iii) Save the current state of the problem solution.

SAVE 'GATE/CK1'

Review results of Run 2, especially the reactions to verify that all boundary conditions for the gate on sill case are correct.

Run 3: Restore SAVE'd Run 2 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

Load Group A independent loads 1, 2, 3, 4, and 5 and corresponding boundary conditions were described in Run 1 and analyzed in Run 2. This run describes and analyzes the Load Group B case for the gate supported by two cables.

(i) In the STRUDL DELETIONS mode, delete the special boundary conditions associated with Load Group A. This returns released joints on the sill and at the cable support joints to fully fixed SUPPORT joints. Then, in the STRUDL ADDITIONS mode, completely release the joints on the sill to make them free joints, and release the two cable support joints ('S1' and 'S10') in such a way as to retain a single translational restraint in a direction which is tangent to the skin plate (See Appendix B).

(ii) Describe new independent loading conditions 6, 7, 8, 9, 10, 11, and 12.

(iii) Activate loads 6 to 12 using the LOAD LIST command, leaving loads 1 to 5 inactive. This has the effect that for any subsequent analysis, only loads 6 to 12 will be analyzed for the current boundary conditions.

(iv) Perform a STIFFNESS ANALYSIS NJP 4 for the Load Group B case, gate supported by two cables.

(v) Output results.

(vi) Save the current state of the problem solution.

SAVE 'GATE/CK1'

Reveiw results of Run 3 analysis.

Run 4: Restore the SAVE'd Run 3 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

Load Groups A and B have been described and analyzed in Runs 1, 2, and 3. This run describes and analyzes the Load Group C case for the gate supported by one cable.

(i) In the STRUDL DELETIONS mode, delete the special boundary conditions for one cable support joint ('S10') returning the joint to a fully supported joint. Then in the STRUDL ADDITIONS mode, completely release this same joint 'S10' to make it a free joint leaving the structure supported by one cable at joint 'S1'. Note that at this time, the structure is assumed not to displace laterally a sufficient amount to touch the side pier walls. Therefore, no lateral (Z-direction) constraints are specified at this time.

(ii) Describe new independent loading conditions 13, 14, 15, 16, 17, and 18.

(iii) Activate loads 13 to 18 using the LOAD LIST command, leaving loads 1 to 12 inactive for the next analysis.

(iv) Perform a STIFFNESS ANALYSIS NJP 4 for the Load Group C case, gate supported by 1-cable.

(v) Output results.

(vi) Save the current state of the problem solution.

SAVE 'GATE/CK1'

Review results of Run 4 analysis.

Run 5: Restore the SAVE'd Run 4 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

Load Groups A, B, and C have been described and analyzed in Runs 1, 2, 3, and 4. This run will describe and analyze the Load Group D case for the gate bound at the side seals.

(i) In the STRUDL DELETIONS mode, delete the special boundary conditions for the current one cable support joint ('S1') to make it fully supported, and also delete the boundary conditions for the joints along both skin plate vertical side edges (joints 1-7, 'S3', 1001-1007, 'S30') to make them fully supported joints. In the STRUDL ADDITIONS mode, completely release joint 'S1' to make it a free joint. Then, for each joint along the skin plate side edges, release all displacement restraints except for one translational restraint in a direction tangent to the skin plate side edge to simulate the binding of the joint at the side seal.

(ii) Describe a new independent loading condition 19.

(iii) Activate load 19, leaving loads 1-18 inactive for the next analysis.

(iv) Perform a STIFFNESS ANALYSIS NJP 4 for the Load Group D case, gate bound at side seals.

(v) Output results

(vi) Save the current state of the problem solution.

SAVE 'GATE/CK1'

Review results.

Now, investigate the Load Group C case, for 1-cable support, to determine if lateral displacements of the gate are large enough to allow the gate to touch the side pier walls. So, the current Load Group C displacements need to be generated. Combination factors F, M_a, and M_b must first be computed.

Run 6: Restore the SAVE'd Run 5 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

(i) Let load combination 103 be the results of the 1-cable structural analysis due to loads W in Fig. 8. So form load combination 103 by summing the analysis results for independent loads 13, 14, and 15 (103 = 13 + 14 + 15).

(ii) Output reactions at joint 'S1' (cable support joint), and joints 38 and 1038 (trunion pins) for loadings 103, 16, 17, and 18.

(iii) Output reactions at all previously defined support joints for loads 103, 16, 17, and 18.

(iv) Save the current state of the problem solution.

SAVE 'GATE/CK1'

Review results. Verify that non-zero reactions exist only at joints 'S1', 38, and 1038.

Using the reaction values at joints 'S1', 38, and 1038 for loads 103, 16, 17, and 18, compute F, M_a, and M_b for the 1-cable case using FORTRAN program XFONE (Fig. 8, Table 7 and Appendix G). The results were:

$F = 35.21$ K., $M_a = 59.35$ K-ft, $M_b = 57.43$ K-ft

Run 7: Restore the SAVE'd Run 6 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

(i) Form design load combination VI for the case of no side wall constraint (Table 8).

(ii) Form displacement combination D6 (Table 9).

(iii) Output reactions for load combination VI.

(iv) Output displacements along skin plate side edges for displacement combination D6.

(v) Save the current state of the problem solution.

SAVE 'GATE/CK1'

Check results. Verify that the reaction at joint 'S1' and moments at joints 38 and 1038 formed in load combination VI equals F x 1.2 x 0.6667, M_a x 1.2 x 0.6667, and M_b x 1.2 x 0.6667 respectively.

Now, check lateral Z-direction displacements along the skin plate side edges (joints 1 to 7, 'S3', 1001 to 1007, and 'S30'). Several of these exceed the 1/4 inch clearance between the edge of the skin plate and the side pier walls. This indicates that for the 1-cable case, the gate will first hit the side walls at the top on the no-cable side (joint 1001), and at the bottom on the 1-cable side (joint 7).

Consequently, this 1-cable case must be reanalyzed to include the side wall constraint at joints 1001 and 7, for the same loads as before, but also including independent loading 20 (+0.25 inch Z-direction displacement at joint 1001, and -0.25 inch Z-direction displacement at joint 7).

<u>Run 8</u>: Restore the SAVE'd Run 7 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

(i) Change the current boundary condition status of the 1-cable case to include a lateral (Z-direction) support at the top edge of the gate on the no-cable side (joint 1001), and at the bottom edge of the gate on the 1-cable side (joint 7).

(ii) In the DELETIONS mode, delete all results associated with the previous analysis for the 1-cable case (analysis results for loads 13, 14, 15, 16, 17, 18, 103, VI, and D6).

(iii) In the ADDITIONS mode, redefine independent loads 13, 14, 15, 16, 17, and 18.

(iv) Define, for the first time, independent load 20.

(v) Activate loads 13, 14, 15, 16, 17, 18, and 20 using the LOAD LIST command, leaving all other loads inactive.

(vi) Perform a STIFFNESS ANALYSIS NJP 4 for the Load Group C case, gate supported by 1-cable with lateral side support.

(vii) Form load combination 103 again, but this time include load 20 (103 = 13 + 14 + 15 + 20).

(viii) Output reactions at joints 'S1', 38, and 1038 for loads 103, 16, 17, and 18.

(ix) Output reactions for all previously designed SUPPORT joints for loads 103, 16, 17, and 18.

(x) Save the current state of the problem solution.

SAVE 'GATE/CK1'

Check results. Verify that non-zero reactions exist only at joints 7, 1001, 'S1', 38, and 1038.

Using reaction values at joints 'S1', 38, and 1038 for loads 103, 16, 17, and 18, compute F, M_a, and M_b for the 1-cable case using the FORTRAN program XFONE (Fig. 8, Table 7, and Appendix H). The results were:

F = 34.627 K., M_a = 59.927 K-ft, M_b = 56.805 K-ft

Run 9: Restore the SAVE'd Run 8 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

(i) Reform design load combination VI for the case which includes side wall constraints and load 20 (Table 8).

(ii) Reform displacement combination D6 (Table 9).

(iii) Output reactions for load combination VI.

(iv) Output displacements along skin plate side edges for load D6.

(v) Save the current state of the problem solution.

SAVE 'GATE/CK1'

Check results. Verify that the reaction at joint 'S1' and moments at joints 38 and 1038 found in load combination VI equals F x 1.2 x 0.6667, M_a x 1.2 x 0.6667, and M_b x 1.2 x 0.6667 respectively.

Also, verify that the lateral (Z-direction) reactions at joints 7 and 1001 are pushing on gate rather than pulling.

Check that all lateral displacements along skin plate side edges are less than or equal to the 1/4 inch clearance.

All checks were OK.

Now, process results of all remaining unprocessed analysis results (loads 1 to 12, and 19).

<u>Run 10</u>: Restore the SAVE'd Run 9 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

(i) Let load combination 101 be the results of the 2-cable structural analysis due to loads W in Fig. 7, and associated with design load II (Table 8). So, form load combination 101 by summing the analysis results for independent loads 6, 7, and 10 (101 = 6 + 7 + 10).

(ii) Output reactions at joints 'S1' and 'S10' (cable support points) and joints 38 and 1038 (trunion pins), for loadings 101, 11, and 12.

(iii) Output reactions at all previously defined support joints for loads 101, 11, and 12.

(iv) Let load combination 102 be the results of the 2-cable structural analysis due to loads W in Fig. 7, and associated with design load V (Table 8). So, form load combination 102 by summing the analysis results for independent loads 6, 8, 9, and 10 (102 = 6 + 8 + 9 + 10).

(v) Output reactions at joints 'S1', 'S10', 38, and 1038 for loads 102, 11, and 12.

(vi) Output reactions at all previously defined support joints for loads 102, 11, and 12.

(vii) Save the current state of the problem solution.

SAVE 'GATE/CK1'

Review results. Verify that non-zero reactions exist only at joints 'S1', 'S10', 38, and 1038.

Using the reaction values at joints 'S1', 'S10', 38, and 1038 for loads 101, 11 and 12, compute F and M for the 2-cable case (for use in design loads II and VII) using the FORTRAN program XFTWO (Fig. 7, Table 6, and Appendix H). The results for use in forming design loads II and VII were:

F = 17.257 K., M = 58.366 K-ft

Using the reaction values at joints 'S1', 'S10', 38, and 1038 for loads 102, 11, and 12, compute F and M for the 2-cable case (for use in design load V) using the FORTRAN program XFTWO (Fig. 7, Table 6, and Appendix H). The results for use in forming design load V were:

F = 3.611 K., M = 58.903 K-ft

Now, form the remaining design load and displacement combinations (I to V, and VII, and D1 to D5, and D7).

Run 11: Restore the SAVE'd Run 10 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

(i) Form design load combinations II and V (Table 8) using the values of F and M computed following Run 10.

(ii) Form design load combination VII (Table 8) using load II results and F computed following Run 10.

(iii) Form design load combinations I, III, and IV (Table 8).

(iv) Form displacements combinations D1 to D5, and D7 (Table 9).

(v) Output displacements for all joints for loads D1 to D7.

(vi) Output reactions at all support joints for design loads I to VII.

(vii) Output all member end forces for design loads I to VII.

(viii) Output all finite element stresses for loads I to VII. Reference (9) describes how to interpret these results.

(ix) Output all finite element principal stresses for loads I to VII. Note that a special McAuto command was used, since the formal STRUDL command was not available at the time of this writing.

(x) Save current state of problem solution.

SAVE 'GATE/CK1'

Review all results. Check equilibrium, displacements, etc. Verify that trunion pin friction moments in the cable supported cases are properly related to the trunion pin translational reactions R_x, R_y, and R_z by Eq. (27).

Now, STRUDL II was used to perform a 1969 AISC design check on the W-shape member elements of the frame. The recommended procedure described in Reference (1) shows how "angle" and "tee" shape members can be checked in addition to W-shape members.

Run 12: Restore SAVE'd Run 11 file 'GATE/CK1' by,

STRUDL RESTORE 'GATE/CK1'

(i) In order to check members by the 1969 AISC code, certain design information is required, while other design information is optional. This information, referred to as PARAMETERS, is described in References (7) and (9). PARAMETER values specified for this design CHECK were:

(a) 'CODE' 'SP69' ALL, the 1969 AISC code was requested.

(b) 'TBLNAM' 'STEELW' ALL, table of section names taken from the 1969 AISC code to be used to retrieve section properties.

(c) 'FYLD' 50.0 ALL, yield stress for all memebers.

(d) 'KY' 1.2 ALL, and 'KZ' 1.2 ALL, effective length factors for all members about their local z and y principal axes. Note that KY and KZ multiply the length of a member where the eccentricity of a member end from the joint is accounted for in the member's length.

(e) 'LZ' 347.293 103 TO 105, 1103 TO 1105, and 'LZ' 346.942 106 TO 111, 1106 TO 1111, the length of members named to be multiplied by effective length factor KZ to obtain effective length for buckling calculations. This was needed since each group of three members, for example 103 to 105, had no lateral support for buckling about their local z-axis, but each had lateral support at its ends for buckling about its local y-axis. The effective member length used by STRUDL for each member's local y-axis buckling calculation was the product of KY and the distance between the joints the member connected, but modified for any specified member eccentricities.

(ii) The 'TRACE' PARAMETER was specified as 4. This PARAMETER is used to indicate the quantity of output information printed from the CHECK or SELECT commands. The value 4 indicates that summary information for the critical condition be printed for each member CHECK'ed.

(iii) A listing of all current design data was r⁃ uested. This shows all current values of PARAMETERS, CONSTRAINTS, etc. to be used by the CHECK or SELECT commands.

(iv) Print all current member and finite element properties. for reference purposes.

(v) Design or checking code specifications is costly on the computer. It is important to request them to be performed only for those loading conditions which are considered to be the design loading conditions. In this case, only design load combinations I to VII (Tables 1 and 8) need be considered. However, loads I to V and VII lead to perfectly symmetrical structural behavior, while load VI leads to unsymmetrical behavior. Therefore, only a symmetrical set of W-shape members were CHECK'ed for loads I to V and VII, and all W-shape members were checked for load VI. So,

(a) Activate loads I to V and VII by the LOAD LIST command.

(b) Request a code check on the symmetrical set of W-shape members 10 to 39 and 103 to 119.

(c) Activate load VI by the LOAD LIST command.

(d) Request a code check on all W-shape members 10 to 39, 1010 to 1039, 103 to 119, and 1103 to 1119.

(vi) Save current state of problem solution.

SAVE 'GATE/CK1'

Review results.

All members passed the code check except members 103, 1103, 105, 1105, 109, and 1109.

Members 103 and 1103 failed the code check for load V with a design interaccion value of 1.35 for code formula 1.6-1a.

Members 105 and 1105 failed the code check for load IV with a design interaction value of 1.34 for code formula 1.6-1a.

Members 109 and 1109 failed the code check for load II with a design interaction value of 1.01 for code formula 1.6-1a. This 1% overstress, however, is acceptable and these two members could be considered as passing the code check.

It should be noted that the design checks for the struts, members 103 to 111, and 1103 to 1111 are not necessarily valid due to certain conditions which STRUDL cannot account for. Section 5 discusses this problem in more detail.

This ended the initial STRUDL II run which was used to formulate a general purpose computer analysis and design approach to tainter gate design problems. Although design was not explicitly considered in the initial run, it was included in the recommended STRUDL formulation described in the companion document, Reference (1).

5. OBSERVATIONS ON THE INITIAL STRUDL II MODEL AND SOLUTION PROCEDURE

This Section summarizes some observations, oversights, and problems encountered in the initial STRUDL II model.

5.1 Verify Cable Force and Trunion Pin Friction Moment Effect

The reactions for design load combinations II, V, and VI (Table 8) include the cable force and trunion pin friction moments which must be consistent with the special superposition Eqs. (30) and (36). It is of interest to verify that this is in fact true.

5.1.1 F and M Check for 2-Cable Load Combination II

Load Combination II is a symmetrical case, so only the reactions at joints 'S1' and 38 need be checked. At joint 'S1' the reaction components output by STRUDL are,

$$R_{X,S1} = 11.382 \text{ K.}$$

$$R_{Y,S1} = 17.297 \text{ K.}$$

$$R_{Z,S1} = 0.0$$

Since load II has a load factor 1.2 applied to it, the cable force $F_{C,II}$, used to compare to F_{II} computed by program XFTWO for this case, is the resultant of $R_{X,S1}$, $R_{Y,S1}$, and $R_{Z,S1}$ all divided by 1.2. So,

$$F_{C,II} = \sqrt{R^2_{X,S1} + R^2_{Y,S1} + R^2_{Z,S1}}\ /1.2$$

$$= \sqrt{(11.382)^2 + (17.297)^2 + 0^2}\ /1.2$$

$$= 20.706/1.2$$

$$= 17.255 \text{ K.}$$

The cable force computed by XFTWO for Load II, F_{II}, following

STRUDL Run 10 (Section 4.4) was,

$$F_{II} = 17.257 \text{ K.}$$

Since $F_{C,II} = F_{II}$, the result is consistent.

At trunion pin joint 38, the translation reaction components output by STRUDL are,

$$R_{X,38} = 519.684 \text{ K.}$$

$$R_{Y,38} = -252.259 \text{ K.}$$

$$R_{Z,38} = 106.629 \text{ K.}$$

In addition, the moment about the global Z-axis, i.e. the trunion pin friction moment, output is,

$$M_{Z,38} = 70.039 \text{ K-ft, Anti-clockwise}$$

These results must also be divided by the load factor 1.2 before comparing to the trunion pin friction moment M computed by program XFTWO. So,

$$R_{X,II} = R_{X,38}/1.2 = 433.070 \text{ K.}$$

$$R_{Y,II} = R_{Y,38}/1.2 = -210.216 \text{ K.}$$

$$R_{Z,II} = R_{Z,38}/1.2 = 88.858 \text{ K.}$$

$$M_{P,II} = M_{Z,38}/1.2 = 58.366 \text{ K-ft, Anti-clockwise}$$

According to Eq. (30), the trunion pin friction moment, M, must be related to $R_{X,II}$, $R_{Y,II}$, and $R_{Z,II}$ by,

$$M = f\sqrt{R_{X,II}^2 + R_{Y,II}^2} + g|R_{Z,II}|$$

where $f = 0.7854\mu_t r_p$, $g = \mu_t r_p$, $\mu_t = 0.3$, $r_p = 0.41667$ ft.. So,

$$M = 0.098167\sqrt{(433.070)^2 + (-210.216)^2} + 0.1250|88.858|$$

$$= 47.257 + 11.107$$

$$= 58.364 \text{ K-ft, Anti-clockwise}$$

Since $M = M_{P,II} = 58.364$ K-ft, and also since XFTWO computed $M = 58.366$ K-ft following Run 10 (Section 4.4), then the result is consistent.

5.1.2 F and M Check for 2-Cable Load Combination V

Load Combination V is also symmetrical, so only the reactions at joints 'S1' and 38 need be checked where the STRUDL reaction components at joint 'S1' are,

$R_{X,S1} = 1.787$ K.

$R_{Y,S1} = 2.716$ K.

$R_{Z,S1} = 0.0$ K.

The load factor applied to load V which must be divided out for comparison purposes is 1.2 x 0.75. So,

$$F_{C,V} = \sqrt{R^2_{X,S1} + R^2_{Y,S1} + R^2_{Z,S1}}\ /(1.2 \times 0.75)$$

$$= \sqrt{(1.787)^2 + (2.716)^2 + 0^2}\ /(1.2 \times 0.75)$$

$$= 3.251/(1.2 \times 0.75)$$

$$= 3.612 \text{ K.}$$

The cable force computed by XFTWO for load V, F_V, following STRUDL Run 10 was,

$F_V = 3.611$ K.

Since $F_{C,V} = F_V$, the result is consistent.

At trunion pin joint 38, the translation reaction components, and global Z-axis moment (trunion pin friction moment), output by STRUDL were,

$R_{X,38} = 404.743$ K.

$R_{Y,38}$ = -161.973 K.

$R_{Z,38}$ = 81.725 K.

$M_{Z,38}$ = 53.012 K-ft, Anti-clockwise

These results must also be divided by the load factor 1.2 x 0.75. So,

$R_{X,V} = R_{X,38}/(1.2 \times 0.75) =$ 449.714 K.

$R_{Y,V} = R_{Y,38}/(1.2 \times 0.75) =$ -179.970 K.

$R_{Z,V} = R_{Z,38}/(1.2 \times 0.75) =$ 90.806 K.

$M_{P,V} = M_{Z,38}/(1.2 \times 0.75) =$ 58.902 K-ft, Anti-clockwise

But the trunion pin friction moment M must be,

$$M = 0.098167\sqrt{(449.714)^2 + (-179.970)^2} + 0.1250|90.806|$$

$$= 47.551 + 11.351$$

= 58.902 K-ft, Anti-clockwise

Since $M = M_{P,V} = 58.902$, and also since XFTWO computed M = 58.903 K-ft following Run 10, then the result is consistent.

5.1.3 F, M_a, and M_b Check for 1-Cable Load Combination VI

Load Combination VI with side wall constraints (Table 8) is unsymmetrical, so the reactions at joints 'S1', 38, and 1038 need to be checked. At joint 'S1' the reaction components output by STRUDL are,

$R_{X,S1}$ = 15.224 K.

$R_{Y,S1}$ = 23.135 K.

$R_{Z,S1}$ = 0.0 K.

The load factor applied to load VI is 1.2 x 0.6667. So,

$$F_{C,VI} = \sqrt{R^2_{X,S1} + R^2_{Y,S1} + R^2_{Z,S1}}\;/(1.2 \times 0.6667)$$

$$= \sqrt{(15.224)^2 + (23.135)^2 + 0^2}\;/(1.2 \times 0.6667)$$

$$= 27.695/(1.2 \times 0.6667)$$

= 34.617 K.

The cable force computed by XFONE for load VI following Run 10 was,

$F_{VI} = 34.627$ K.

Since $F_{C,VI} = F_{VI}$, the result is consistent.

At trunion pin joints 38 and 1038, the translational reaction components and global Z-axis moment (trunion pin friction moments) output by STRUDL were,

$R_{X,38} = 355.163$ K. $\quad R_{X,1038} = 337.790$ K.

$R_{Y,38} = -171.873$ K. $\quad R_{Y,1038} = -164.483$ K.

$R_{Z,38} = 73.668$ K. $\quad R_{Z,1038} = -68.493$ K.

$M_{Z,38} = 47.942$ K-ft, Anti-clockwise $\quad M_{Z,1038} = 45.444$ K-ft, Anti-clockwise

These results must also be divided by the load factor 1.2 x 0.6667.

So,

$R_{X,VI,38} = R_{X,38}/(1.2 \times 0.6667) = 443.932$ K.

$R_{Y,VI,38} = R_{Y,38}/(1.2 \times 0.6667) = -214.831$ K.

$R_{Z,VI,38} = R_{Z,38}/(1.2 \times 0.6667) = 92.080$ K.

$M_{P,VI,a} = M_{Z,38}/(1.2 \times 0.6667) = 59.925$ K-ft Anti-clockwise

and,

$R_{X,VI,1038} = R_{X,1038}/(1.2 \times 0.6667) = 422.216$ K.

$R_{Y,VI,1038} = R_{Y,1038}/(1.2 \times 0.6667) = -205.593$ K.

$R_{Z,VI,1038} = R_{Z,1038}/(1.2 \times 0.6667) = -85.612$ K.

$M_{P,VI,b} = M_{Z,1038}/(1.2 \times 0.6667) = 56.802$ K-ft, Anti-clockwise

But the trunion pin friction moments M_a and M_b must be,

$$M_a = 0.098167\sqrt{(443.932)^2 + (-214.831)^2} + 0.1250|92.080|$$

$$= 48.414 + 11.510$$

$$= 59.924 \text{ K-ft, Anti-clockwise}$$

$$M_b = 0.098167\sqrt{(422.216)^2 + (-205.593)^2} + 0.1250|-85.612|$$

$$= 46.100 + 10.702$$

$$= 56.802 \text{ K-ft, Anti-clockwise}$$

Since $M_a = M_{P,VI,a} = 59.924$ K-ft, and $M_b = M_{P,VI,b} = 56.802$ K-ft, and also since XFONE computed $M_a = 59.927$ K-ft and $M_b = 56.805$ K-ft following Run 8, then the results are consistent.

5.2 Final Trunion Pin Reactions

As was noted in Eqs. (26) and (27), the trunion pin friction moment is also associated with a resultant force, $P_{y'}$, acting in a direction perpendicular to the resultant of the trunion pin reaction components R_X and R_Y, and is equal to,

$$P_{y'} = \mu_t \frac{2}{3}\sqrt{R_X^2 + R_Y^2}$$

where $\mu_t = 0.3$ for the gate under consideration. So,

$$P_{y'} = 0.2\sqrt{R_X^2 + R_Y^2}$$

Now, using reaction components R_X and R_Y with the load factors divided out, the value of $P_{y'}$ for load cases II, V, and VI are,

$$P_{y',II} = .2\sqrt{(433.070)^2 + (-210.216)^2}$$

$$= 96.279 \text{ K.}$$

$$P_{y',V} = .2\sqrt{(449.714)^2 + (-179.970)^2}$$

$$= 96.878 \text{ K.}$$

$$P_{y',VI,38} = .2\sqrt{(443.932)^2 + (-214.831)^2}$$

$$= 98.636 \text{ K.}$$

$$P_{y',VI,1038} = .2\sqrt{(422.216)^2 + (-205.593)^2}$$

$$= 93.922 \text{ K.}$$

So, the final trunion pin reaction components consist of R_X, R_Y,

R_Z, M, and P_y, acting in a direction perpendicular to the resultant reaction $R = \sqrt{R_X^2 + R_Y^2}$.

5.3 Dead Load Problems

At the conclusion of the initial STRUDL II problem solution, following Run 12, two problems involving dead load were discovered.

The first problem was that the independent load which represented the dead load in each load group, i.e. loads 1, 6, and 13, included the effect of member dead weight applied as uniformly distributed loads to the members, but neglected to include the dead weight of the skin plate. Although this affects the final analysis results, it does not affect the procedural approach which led to the recommended procedure as described in the companion report, Reference (1). The skin plate dead load is included in the description of the recommended procedure in Reference (1).

The second problem is associated with the representation of member dead loads as uniformly distributed loads applied to members. During design or checking by the 1969 AISC specifications, the calculation of the C_m factor in AISC Specification Section 1.6.1 is dependent on whether or not loads are applied to the member between its ends. However, it is not the intent of AISC to include dead weight of members as an applied member load which affects the calculation of C_m. Since STRUDL II cannot distinguish an applied member load as being a dead weight, as opposed to some other kind of load, the computation of C_m for the code checking in Run 12 was affected by the presence of the dead weight applied as a uniform member load. This problem is avoided in

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the recommended procedure in Reference (1) by using the McAuto STRUDL (9) DEAD LOAD command in loads 1, 6, and 13. This command computes the member dead load based on the member's length (including the effect of member eccentricity), area, and weight density given in the CONSTANTS command, and automatically distributes this dead load to the joints at the ends of the member as joint loads. In this way, the C_m factor is computed properly and is not affected by the presence of dead load.

5.4 STRUDL II Design/Check Difficulty

In addition to the code design/check problem associated with dead load application described in Section 5.3 and avoided in the recommended procedure in Reference (1), another difficulty exists which cannot be overcome in certain special situations. Consider the strut members 103 to 111, and 1103 to 1111 in Fig. 11. These members have lateral bracing at their ends for buckling considerations about their local Y-axes (minor axis), but no lateral support, except at the trunion pin ends (joints 38 and 1038 in Fig. 11) of members 103, 106, 109, 1103, 1106, and 1109, and the skin plate ends of members 105, 108, 111, 1105, 1108, and 1111 for buckling considerations about their local Z-axes (major axis). For example, members 103, 105, and 106 must be considered as three separate members when computing their minor axis buckling characteristics, but must be considered as one long member when computing their major axis buckling characteristics. Part of the problem may be accounted for by specifying an unbraced buckling length equal to the three member length (see 'LZ' parameter input in Run 12) for local Z-axis buckling. However, the computation of C_m and C_b

factors depend on the value of member end-moments. For the Z-axis buckling, these moments should be at the ends of the three member length, i.e. at the trunion pin end and skin plate end. However, STRUDL II uses end moments at the real member ends, i.e. at the joints the member connects. Therefore, the C_m and C_b factors are not computed correctly for the strut members. Consequently, for these strut members, STRUDL can only be used to generate a code design or check which is approximate, but which must be verified using a more accurate hand check that accounts for the multi-member length for buckling about the local Z-axis.

Another problem with the struts is that there is a large gussett plate at the trunion pin end of the strut members. Consequently, checking or designing the strut members for moments and shears at the trunion pin end is too conservative. Strut sections should not be checked any closer to the trunion pin than at the edge of the gussett plates. This will be included in the recommended procedure described in Reference (1).

5.5 Member Shapes Checked in Initial STRUDL II Model

In the initial STRUDL II model, only the W-shape members were checked against the 1969 AISC Specifications. It was discovered later that the Tee and Angle shapes could also be checked by McAuto's STRUDL II (9). Consequently, the recommended STRUDL II model presented in Reference (1) includes checking and design for all three shapes (W, Angle, and Tee).

5.6 SAVE/RESTORE Commands

The listing of the initial STRUDL II model commands in Appendix E shows the use of a different SAVE file name for each run (i.e. 'GATE/CK1' to 'GATE/CK9', and 'GATE/CKA' to 'GATE/CKC'). This was done for maximum flexibility during the formulation of tainter gate analysis and design procedures. For example, if it were decided, as occurred several times, to abandon an approach being followed, an alternate approach could be developed and the problem solution RESTORE'd from a previously SAVE'd file where the current state of the problem solution did not reflect any effect of the abandoned approach. This led to a more efficient procedural formulation approach. The step-by-step procedures, described in Section 4.4, only use a simple SAVE file name, 'GATE/CK1', for the convenience of explaining the initial STRUDL II model, and also, since if actually used in the twelve runs described, it would generate results which are identical to the results generated by the commands listed in Appendix F .

The recommended procedure described in Reference (1) uses only two simple SAVE file names, 'GATE/CK1' and 'GATE/CK2'. This requires the least amount of disk storage space. There is no danger of losing this SAVE'd file if a run abnormally terminates during a RESTORE, since the SAVE/ RESTORE process is non-destructive. That is, if a RESTORE abnormally terminates, the job can be rerun to RESTORE the same SAVE'd file as before, since the SAVE'd file is never destroyed during a RESTORE process.

6. CONCLUSIONS AND RECOMMENDATIONS

This report has demonstrated that the analysis and design of a tainter gate may be formulated in such a way that a general purpose computer structural analysis and design program may be used, and include the effect of cable supports, side seal friction, and trunion pin friction moments, provided the program embodies certain special characteristics. These include: (1) the ability to perform multiple analyses in the same computer run; (2) the ability to change the data base between the different analyses so that each analysis may be based on different boundary conditions, and/or loading conditions, etc.; (3) the ability to save on the computer, for any length of time, the status of a problem solution at any point, display results for engineering review, and subsequently continue the problem solution with a modified data base; (4) the ability to combine analysis results for different loading conditions used in the same analysis; (5) the ability to combine analysis results for different loading conditions used in several different analyses involving different boundary conditions; (6) the ability to include in the model description such special conditions as the eccentricity of the end of a member element from the joint center it connects to, the location of the shear center of a member element from its centroid, and others; and (7) the ability to perform design of steel member elements according to AISC Specifications (6).

The only commercially available general purpose structural analysis and design computer program that has all of these, and many more, advanced capabilities is the STRUDL II subsystem (7) of the ICES system (8).

The formulated analysis procedure for the tainter gate involves a superposition of results from a variety of different load cases, and even different boundary conditions. The linear combination factors for the superpositions are computed by solving highly non-linear systems of equations, as programmed in the supplied computer programs XFONE and XFTWO (Appendix G).

The finite element model used for the skin plate is a highly accurate representation of the skin plate stiffness effect on the tainter gate behavior. Although the stresses computed in the coarse mesh finite elements are not sufficiently accurate for design purposes, they are uniformly very low for the skin plate thickness used, and consequently, they justify a conclusion that the existing thickness is adequate from a strength point of view. If a reduction in thickness were desired, a more refined finite element grid size would be required, or the current Corps skin plate design technique could be used. If a more refined finite element analysis were desired, it is only necessary to select the more highly stressed portions of the skin plate based on the coarse grid analysis, break these regions up into finer mesh sizes, and then apply the appropriate external loads to these regions, as well as applying displacement boundary conditions using the displacement values along the region's boundary that were computed in the original coarse mesh analysis.

Although the step-by-step STRUDL II solution procedure described in this report is not entirely suitable in a design office environment, its validity is conclusively demonstrated. A more suitable detailed procedure, which is highly cost-effective and which is the recommended procedure, is described in Reference (1).

It is recommended that the theoretical concepts presented in this report, and the detailed step-by-step STRUDL II solution procedure presented in the companion report, Reference (1), are used to perform an accurate computer analysis and design of the frame portion of the type of tainter gate studied in this report.

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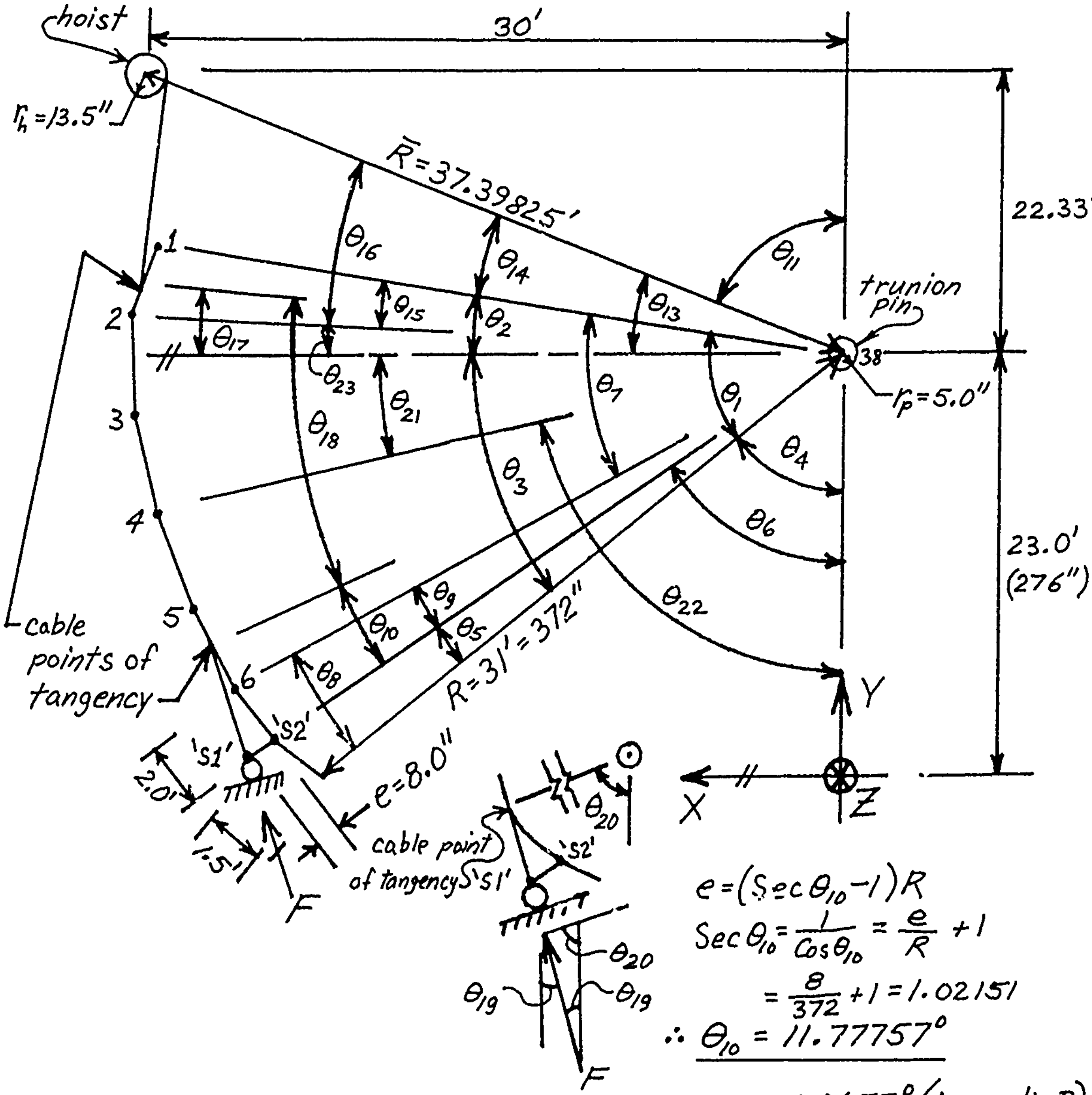
APPENDIX

APPENDIX A

Calculation of Joint Coordinate and Other Characteristic Geometry

This Appendix contains calculations for the relative angular positions of characteristic joints on the STRUDL structural model shown in Fig. 9, and the computations of joint coordinates.



$$e = (\operatorname{Sec}\theta_{10} - 1)R$$

$$\operatorname{Sec}\theta_{10} = \frac{1}{\operatorname{Cos}\theta_{10}} = \frac{e}{R} + 1$$

$$= \frac{8}{372} + 1 = 1.02151$$

$$\therefore \underline{\theta_{10} = 11.77757^\circ}$$

$$\underline{\theta_{17} = 5.8657^\circ \text{ (Appendix B)}}$$

<u>Based on Corps Drawings (3) S-CC, 45/11 - 45/15:</u>

$$\theta_1 = 11.5517 + 23.5764 + 21.2550 + 6.4689$$
$$= 62.8519^\circ$$

$\theta_2 = 14.9553^\circ$	$\theta_5 = \frac{1.5(360^\circ)}{2\pi R} = \frac{1.5(360)}{2\pi(31)} = 2.77238^\circ$
$\theta_3 = \theta_1 - \theta_2 = 47.8966^\circ$	$\theta_6 = \theta_4 + \theta_5 = 44.87578^\circ$
$\theta_4 = 90 - \theta_3 = 42.1034^\circ$	$\theta_7 = 56.3831^\circ$; $\theta_8 = 6.4688^\circ$; $\theta_9 = 3.6964^\circ$

$$\theta_{11} = Tan^{-1}\frac{30}{22.33}$$

$$= 53.33846^\circ$$

$\theta_{13} = 36.66154^\circ$, $\theta_{14} = 21.70624^\circ$, $\theta_{15} = 11.55167^\circ$

$\theta_{16} = \theta_{14} + \theta_{15} = 33.25791^\circ$

$\theta_{18} = 90 - \theta_6 - \theta_{10} + \theta_{17} = 39.21235^\circ$

$\theta_{19} = 90 - \theta_{20} = 33.34665^\circ$

$\theta_{20} = \theta_6 + \theta_{10} = 56.65335^\circ$

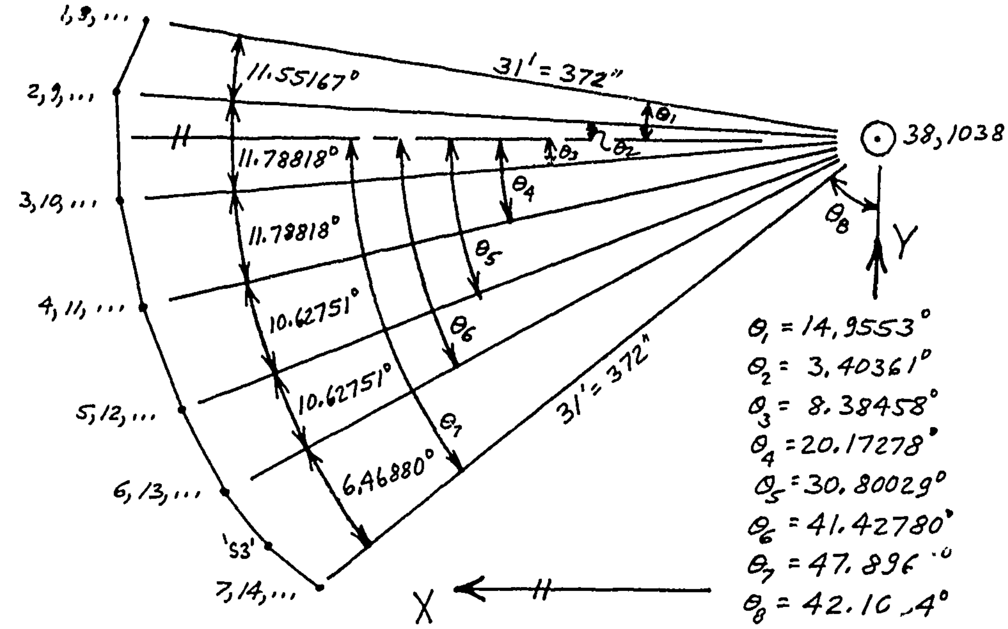
$\theta_{21} = 20.17278^\circ$

$\theta_{22} = 90 - \theta_{21} = 69.82722^\circ$

$\theta_{23} = \theta_2 - \theta_{15} = 3.40363^\circ$

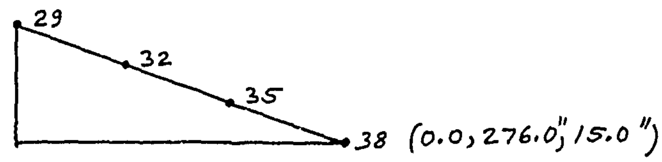
Joints in skin plate: 1, 2, 3, ..., 77, 1001, 1002, 1003, ..., 1076

Angles measured in global X-Y plane:

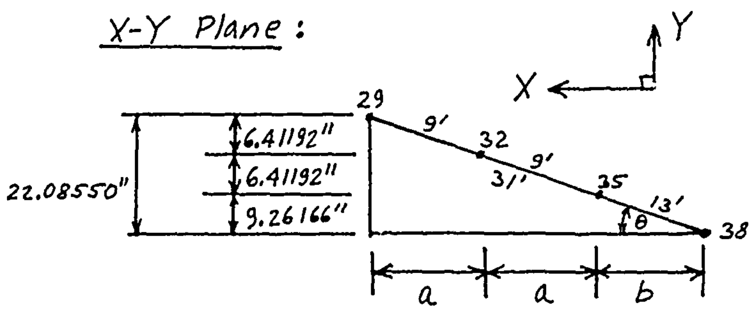


Joint i	X = 372 × Cos θi	Y = 276 ± 372 × Sin θi	Z
1, 8, ...	359.39941"	372.00032"	8.0", ., ., ...
2, 9, ...	371.34382"	298.08550"	8.0", ., ., ...
3, 10, ...	368.02392"	221.75616"	8.0", ., ., ...
4, 11, ...	349.18039"	147.71494"	8.0", ., ., ...
5, 12, ...	319.53212"	85.51844"	8.0", ., ., ...
6, 13, ...	278.92192	29.85662"	8.0", ., ., ...
7, 14, ...	249.41508"	0.0"	8.0", ., ., ...

Joints Along Top Strut Arm



X-Y Plane:



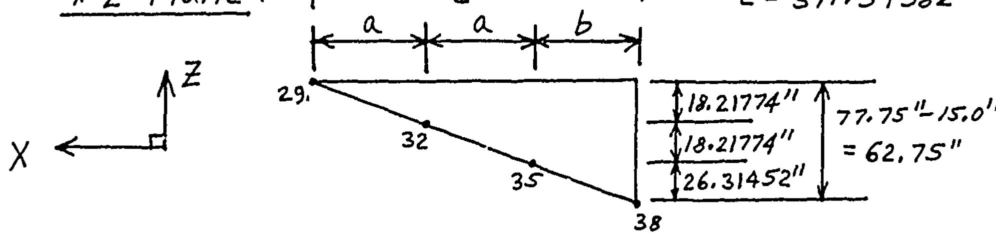
$\theta = 3.40363°$

$a = 107.80950"$

$b = 155.72483"$

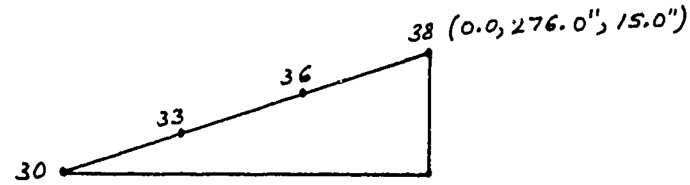
$C = 371.34382"$

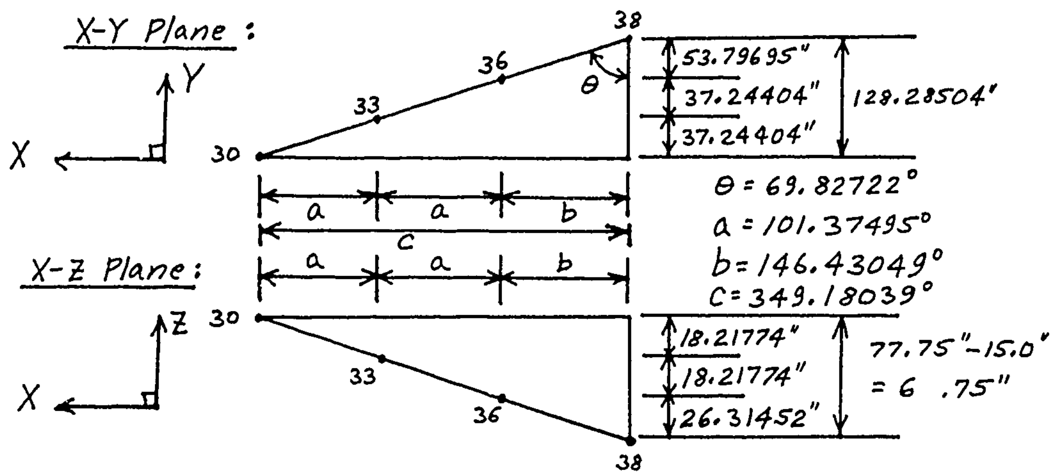
X-Z Plane:



Joint	X	Y	Z
38	0.0	276.0"	15.0"
35	155.72483"	285.26166"	41.31452"
32	263.53433"	291.67358"	59.53226"
29	371.34383"	298.08550	77.75"

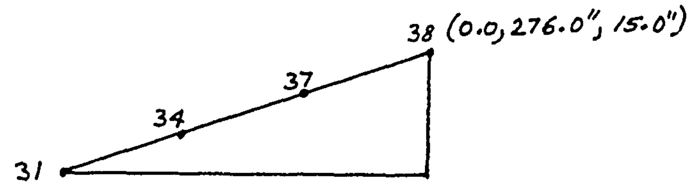
Joints Along Middle Strut Arm:

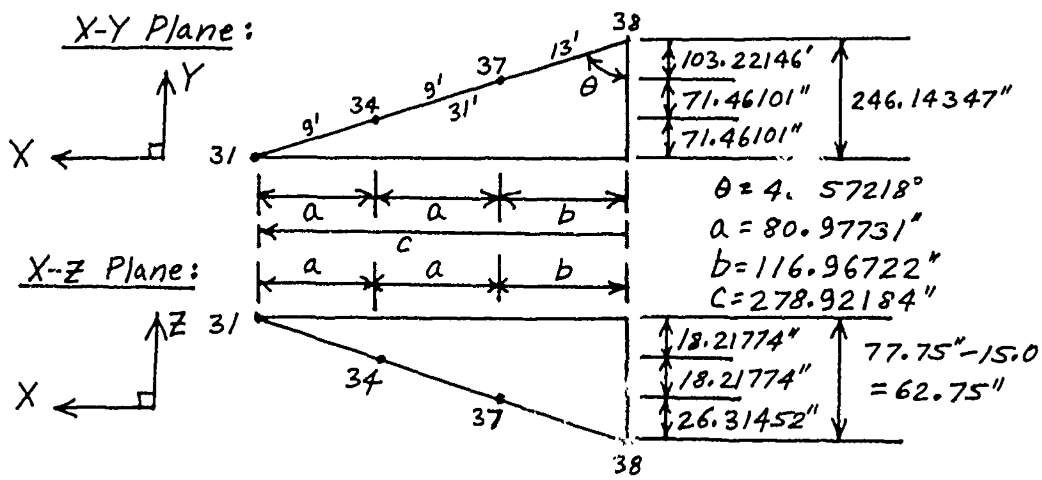




Joint	X	Y	Z
38	0.0	276.0"	15.0"
36	146.43049"	222.20305"	41.31452"
33	247.80544"	184.95901"	59.53226"
30	349.18039"	147.71497"	77.75"

Joints Along Bottom Strut Arm:



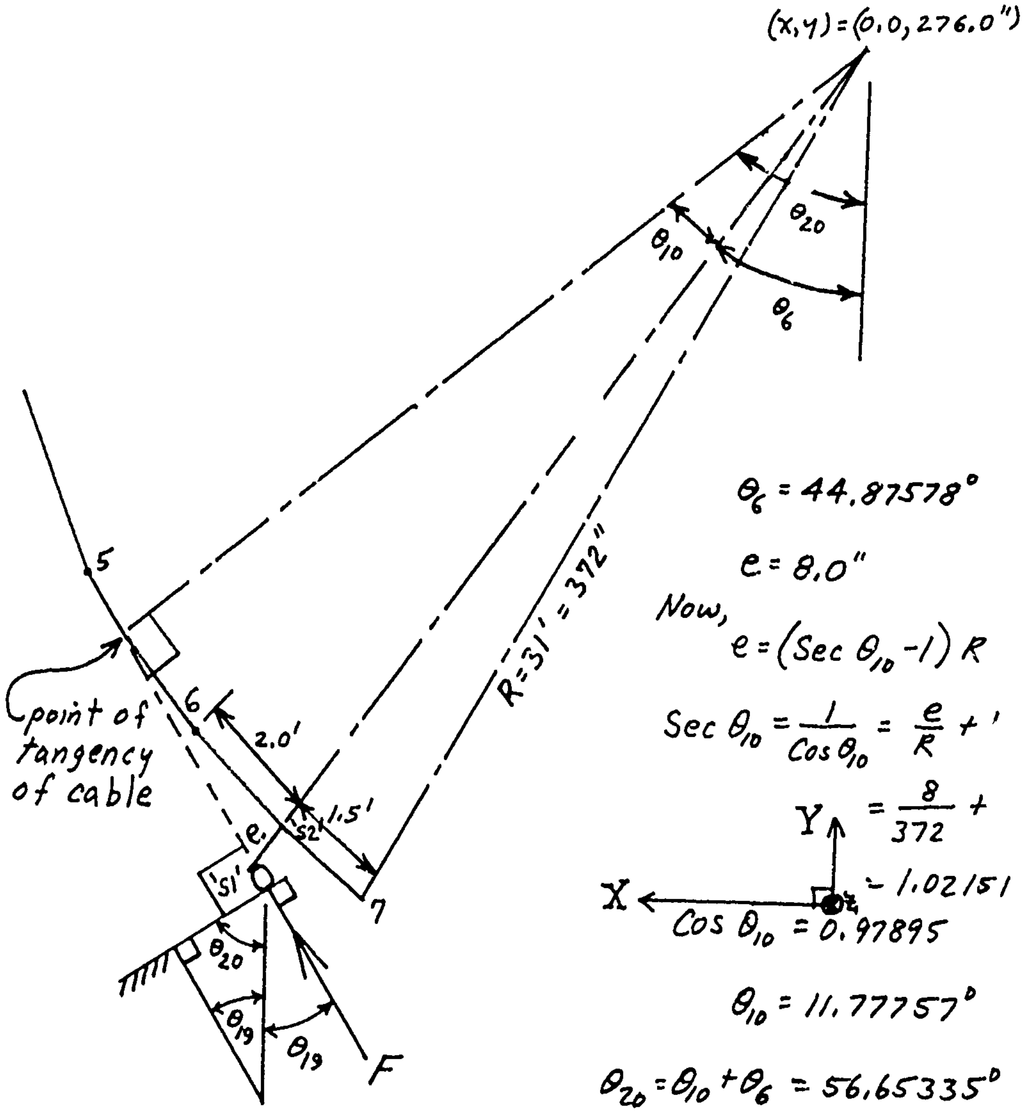


Joint	X	Y	Z
38	0.0	276.0"	15.0"
37	116.96722"	172.77854"	41.31452"
34	197.94453"	101.31753"	59.53226"
31	278.92184"	29.85652"	77.75"

APPENDIX B

Calculation of Cable Reaction Force F Direction and Support Points, and Cable Points of Tangency to the Skin Plate

This Appendix contains the calculations for the direction of the cable reaction force F at joints 'S1' and 'S10' in Fig. 9. This force acts in a direction whose line of action is tangent to the skin plate near the bottom of the skin plate. In addition, the calculation of the location of the points of tangency of the cable to the skin plate at the top and bottom of the skin plate are shown.



$\theta_6 = 44.87578°$

$e = 8.0"$

Now, $e = (\text{Sec}\,\theta_{10} - 1)\,R$

$\text{Sec}\,\theta_{10} = \frac{1}{\text{Cos}\,\theta_{10}} = \frac{e}{R} + 1$

$= \frac{8}{372} + 1$

$\simeq 1.02151$

$\text{Cos}\,\theta_{10} = 0.97895$

$\theta_{10} = 11.77757°$

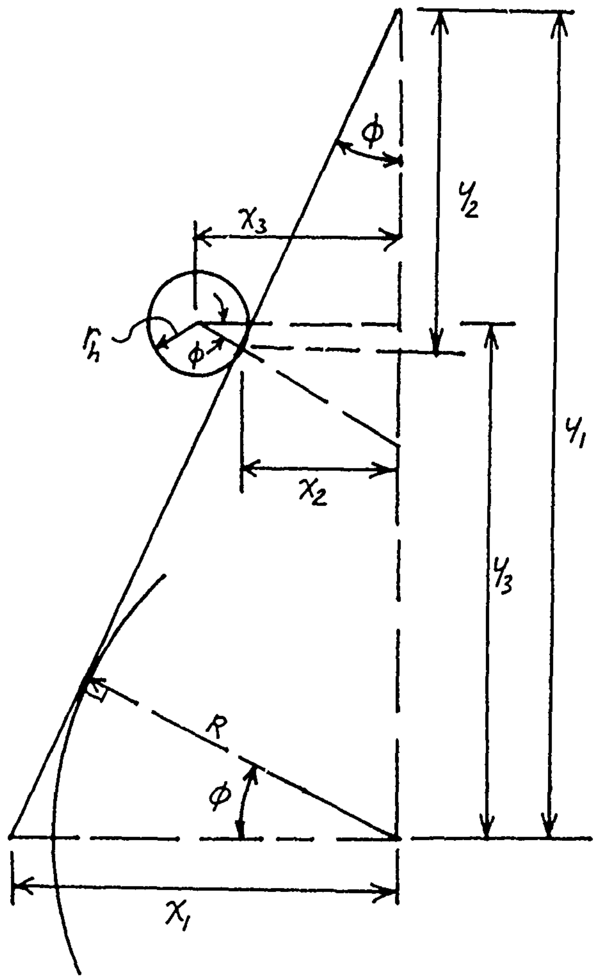
$\theta_{20} = \theta_{10} + \theta_6 = 56.65335°$

$\theta_{19} = 90 - \theta_{20} = 33.34665°$

$X_{S1} = 380\ \text{Sin}\,\theta_6 = 268.1174"$
$Y_{S1} = 276 - 380\,\text{Cos}\,\theta_6 = 6.7175"$
$X_{S2} = 372\ \text{Sin}\,\theta_6 = 262.4728"$
$Y_{S2} = 276 - 372\,\text{Cos}\,\theta_6 = 12.3866"$

$(x, y, z)_{'S1'} = (268.1174, 6.7175, 15.25)$; $(x, y, z)_{'S10'} = (X_{S1}, Y_{S1}, 344.75)$

$(x, y, z)_{'S2'} = (262.4728, 12.3866, 15.25)$; $(x, y, z)_{'S20'} = (X_{S2}, Y_{S2}, 344.75)$



$x_3 = 30' = 360'$

$y_3 = 22.33' = 267.96'$

$r_h = 13.5''$

$R = 31' = 372''$

$$x_2 = x_3 - r_h \cos\phi$$

$$x_1 = \frac{R}{\cos\phi}, \quad y_1 = \frac{R}{\sin\phi}, \quad y_2 = y_1 - y_3 + r_h \sin\phi$$

$$x_2/y_2 = x_1/y_1 \longrightarrow x_2 = x_1 \frac{y_2}{y_1} = \frac{\sin\phi}{\cos\phi}(y_1 - y_3 + r_h \sin\phi)$$

$$x_2 = \tan\phi\,(y_1 - y_3 + r_h \sin\phi) = \tan\phi\left(\frac{R}{\sin\phi} - y_3 + r_h \sin\phi\right)$$

$$\therefore \quad x_3 - r_h \cos\phi = \tan\phi\left(\frac{R}{\sin\phi} - y_3 + r_h \sin\phi\right)$$

$$x_3 + \frac{\sin\phi}{\cos\phi} y_3 = r_h\left(\cos\phi + \frac{\sin^2\phi}{\cos\phi}\right) + \frac{R}{\cos\phi}$$

$$x_3 \cos\phi + y_3 \sin\phi = r_h + R$$

$$y_3\sqrt{1-\cos^2\phi} = (r_h+R) - x_3\cos\phi$$

$$y_3^2(1-\cos^2\phi) = (r_h+R)^2 - 2x_3(r_h+R)\cos\phi + x_3^2\cos^2\phi$$

$$\underbrace{(x_3^2+y_3^2)}_{a}\cos^2\phi \underbrace{-2x_3(r_h+R)}_{b}\cos\phi + \underbrace{[(r_h+R)^2-y_3^2]}_{c} = 0$$

$$a\cos^2\phi + b\cos\phi + c = 0$$

$$a = x_3^2 + y_3^2 = (360^2 + 267.96^2) = 201,402.5616$$

$$b = -2x_3(r_h+R) = -2(360)(13.5+372) = -277,560.0$$

$$c = (r_h+R)^2 - y_3^2 = (13.5+372)^2 - (267.96)^2 = 76,807.6884$$

$$\cos\phi = \frac{-b \pm \sqrt{b^2-4ac}}{2a} = \frac{277,560.0 \pm \sqrt{1.516249282\times10^{10}}}{2(201,402.5616)}$$

$$= \frac{277,560.0 \pm 123,136.0744}{402,805.1232} = \begin{cases} 0.994764 \\ \cancel{0.383371} \end{cases}$$

$$\phi = \begin{cases} 5.8657^\circ \\ \cancel{67.4573^\circ} \end{cases}$$

So,

$$\underline{\underline{\phi = 5.8657^\circ}}$$

APPENDIX C

Calculations for Member Beta Angles, Member Eccentricities, and Member Properties

This Appendix contains the calculations of the STRUDL Beta angles for those members which have non-zero Beta angles. Also, the calculation of the non-zero eccentricities of member ends from joint centers they are incident upon are shown. Finally, member properties are summarized.

After joint coordinates and member incidences are specified, the Beta angles are the final geometric parameters which exactly orient the members in the structure with respect to the global reference frame.

Member eccentricities are required since the ends of many members are attached to joints at points which are not at the center of the specified joint locations.

During the initial STRUDL II run, it was not realized that angle and tee sections could be specified by section name. So, for this initial STRUDL II run, member properties were computed and directly input. However, in the recommended procedure described in Reference (1), the section names were used instead of the individual properties.

BETA Angles and Properties

Members 1 TO 9: L8x4x7/16,

$A = 5.06\ in^2$
$r_y = 0.869\ in$
$I_y = A r_y^2 = (5.06)(.869)$
$= 3.821\ in^4$
$\theta = 15.056°$

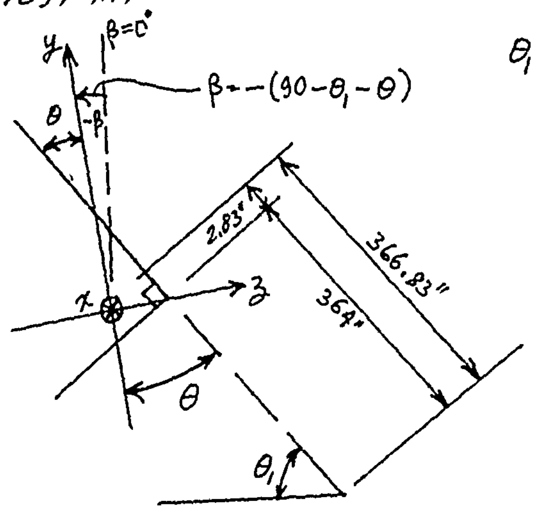
from 1969 AISC, pg. 6-30:

$$I_z = I_{\bar{x}} \cos^2\theta + I_{\bar{y}} \sin^2\theta - K \sin 2\theta$$

$$K = \frac{-abcdt}{4(b+c)} = -\frac{(3.5625)(4)(7.5625)(8)(.4375)}{4(4+7.5625)}$$

$$= -8.15524$$

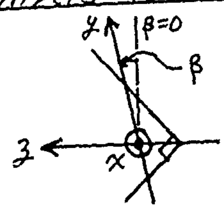
$$I_z = (34.1)(.93252) + 6.02(.06748) - (-8.15524)(.50169)$$
$$= 36.297\ in^4$$



$\theta_1 = 14.9553°$
(Appendix A)

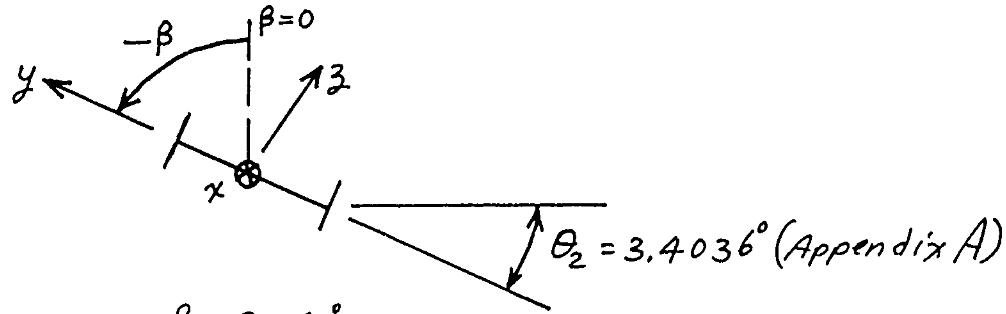
$\beta = -(90 - 14.9553 - 15.056)$
$\beta = -59.989°$

Members 1001 TO 1009: L8x4x7/16



$\beta = +59.989°$

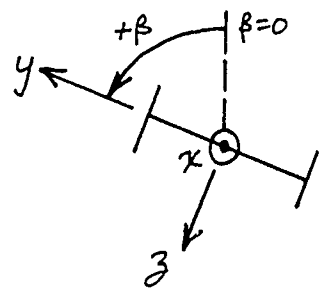
Members 10 TO 19: W24 x 55



$\beta = \theta_2 - 90^\circ$

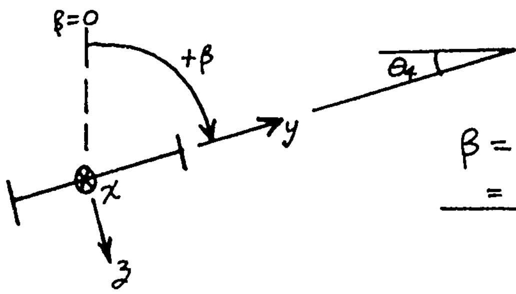
$\beta = -86.5964^\circ$

Members 1010 TO 1019: W24 x 55



$\beta = +86.5964^\circ$

Members 20 TO 29: W24 x 76

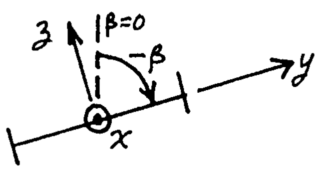


$\theta_4 = 20.17278°$ (Appendix A)

$\beta = 90 - \theta_4$

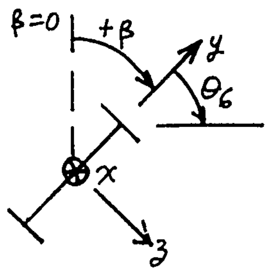
$= 69.82722°$

Members 1020 TO 1029: W24 x 76



$\beta = -69.82722°$

Members 30 TO 39: W24 x 76

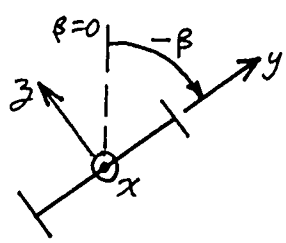


$\theta_6 = 41.42780°$ (Appendix A)

$\beta = 90 - \theta_6$

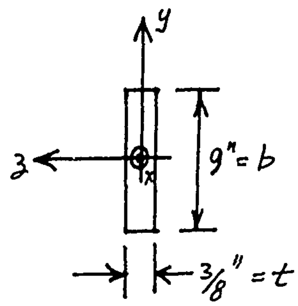
$= 48.5722°$

Members 1030 TO 1039: W24 x 76



$\beta = -48.5722°$

Members 40 TO 48, 1040 TO 1048:



$\beta = 0°$

$I_x = \frac{1}{3} b t^3 = 0.1582 \text{ in}^4$

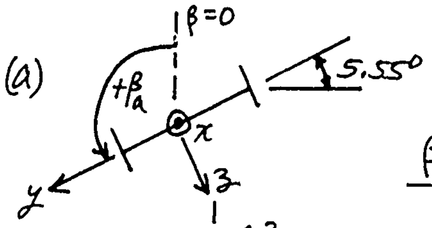
$I_y = \frac{b t^3}{12} = 0.0396 \text{ in}^4$

$I_z = \frac{t b^3}{12} = 22.781 \text{ in}^4$

$A_x = b t = 3.375 \text{ in}^2$

Members: (a) 103 TO 105 } W14×43
(b) 1103 TO 1105

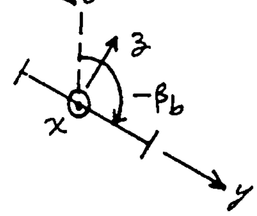
(a)



(Corps Drawings (3))

$\beta_a = 95.55°$

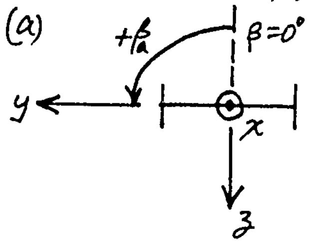
(b)



$\beta_b = -95.55°$

Members: (a) 106 TO 108 } W14×78
(b) 1108 TO 1108

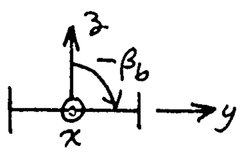
(a)



$\beta_a = 90.0°$

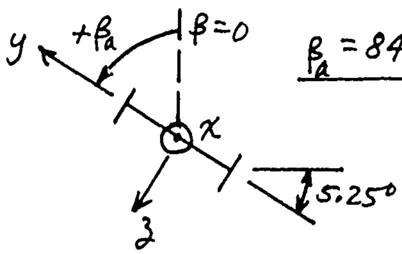
$\beta_b = -90.0°$

(b)



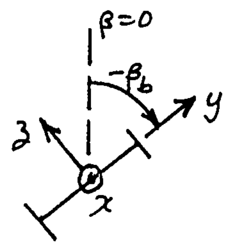
Members: (a) 109 TO 111 } W14×78
(b) 1109 TO 1111

(a)



$\beta_a = 84.75°$

(b)



$\beta_b = -84.75°$

<u>Members</u>: 112 TO 119 } W14x22
1112 TO 1119

From Corps Drawings (3), β appears to be: $\beta = 90.0°$

<u>Members</u> 49 TO 78 } WT7x17, $\beta = 0°$
1049 TO 1078

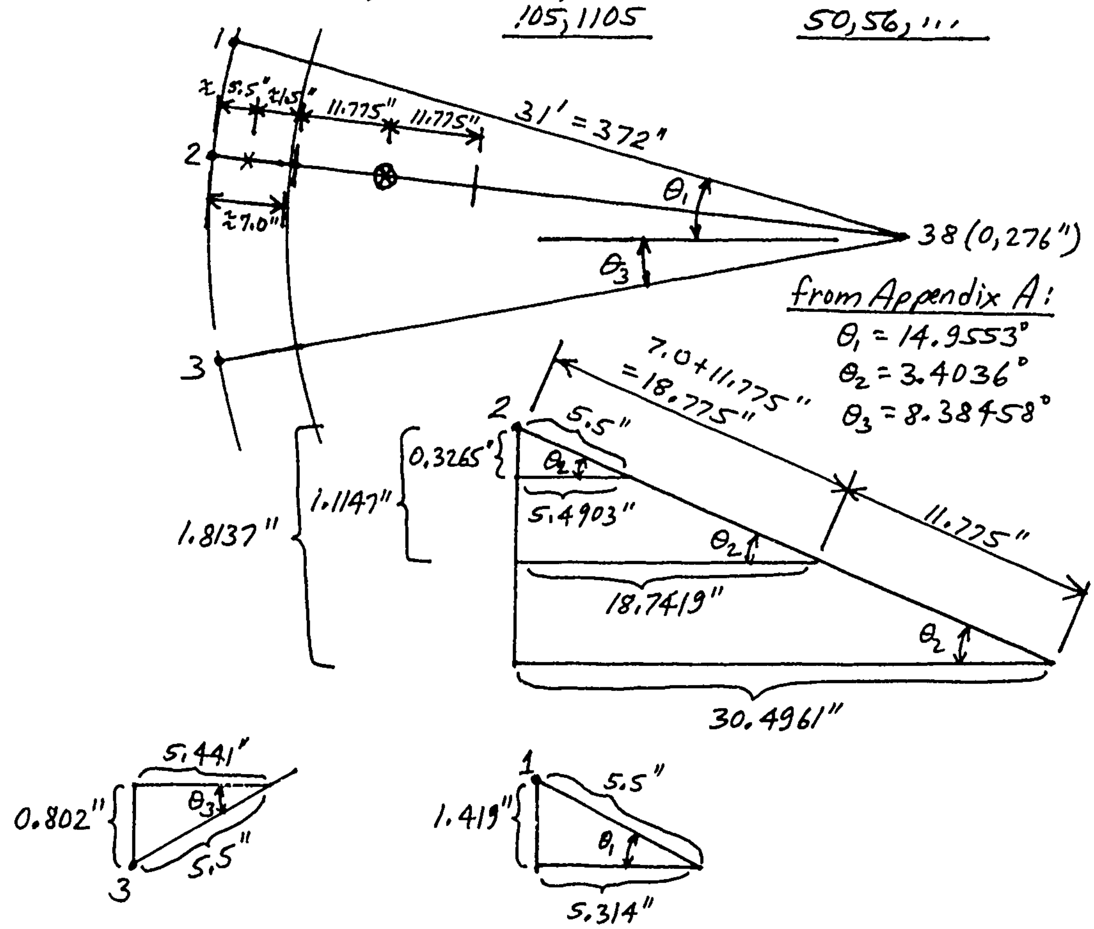
<u>Members</u> 79 TO 102 } WT7x15, $\beta = 0°$
1079 TO 1102

<u>Members</u> 120 TO 127 } WT7x11, $\beta = 0°$
1120 TO 1122
1124 TO 1126

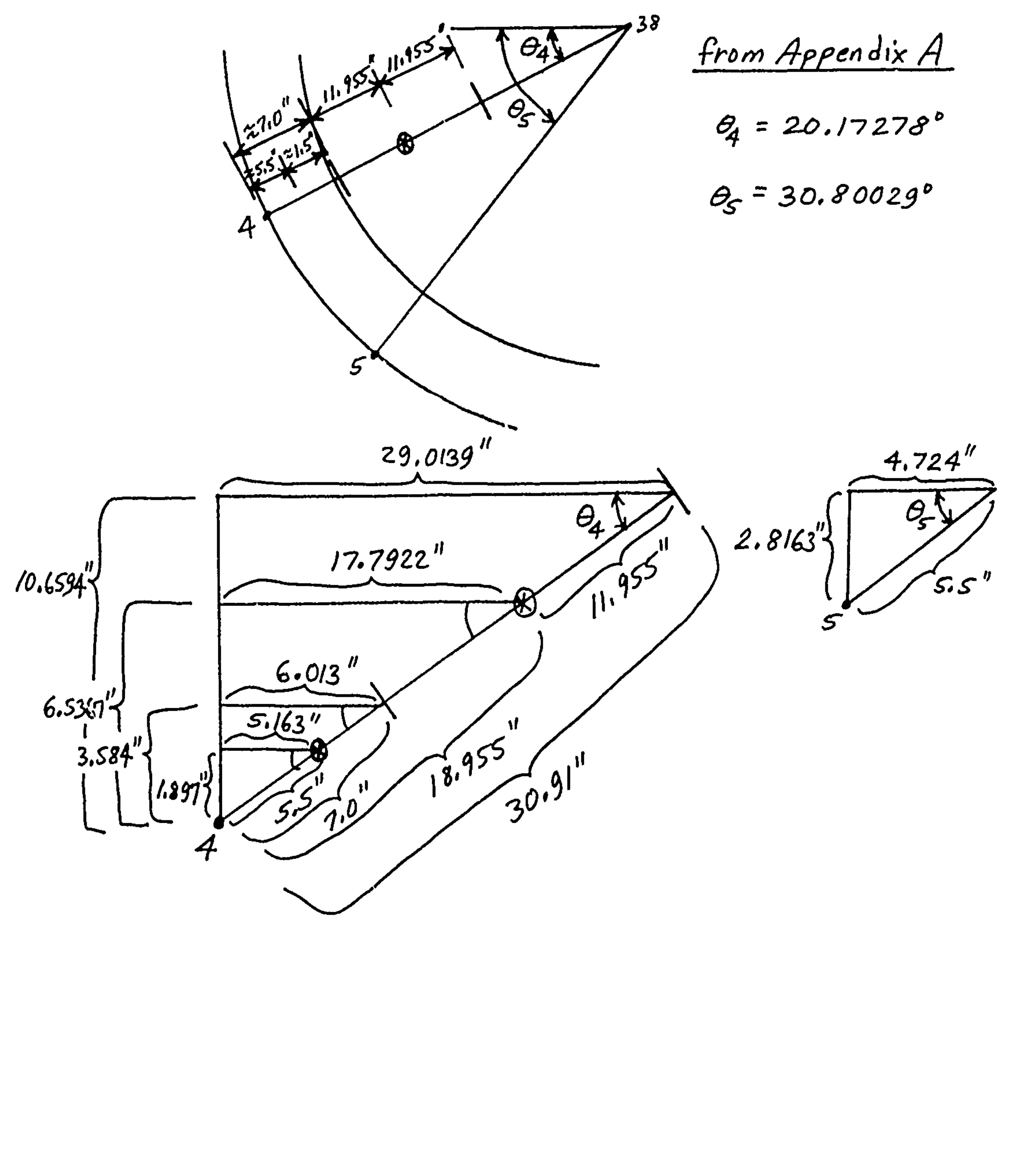
Member Eccentricities

These are the distances from a joint to the end of a member measured parallel to the global X, Y, and Z axes. See listing in Appendix E for the use of the following data:

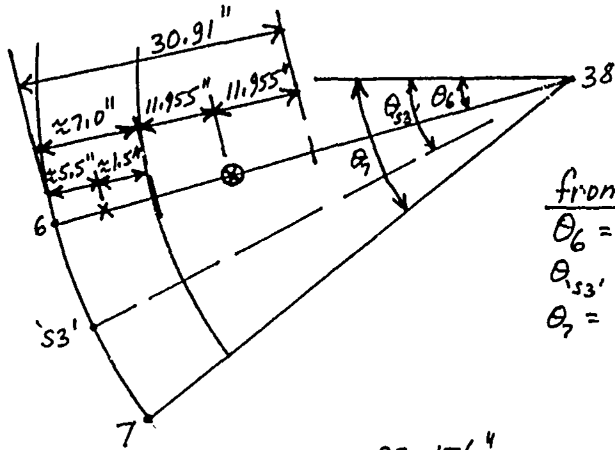
Members 10-19, 1010-1019, 105, 1105, Verticals 49, 55, ... 50, 56, ...



Members 20-29, 1020 TO 1029, Verticals 51, 57, ... / 108, 1108 / 52, 58, ...



Members 30–39, 1030–1039, 111, 1111, Verticals 53, 59, ...
54, 60, ...
541, 601, ...
66, 72, ...

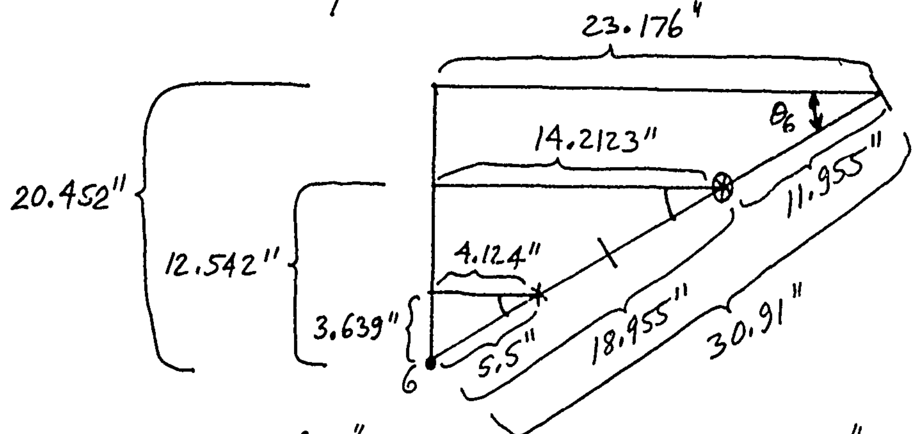


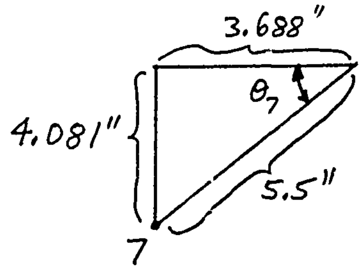
from Appendix A

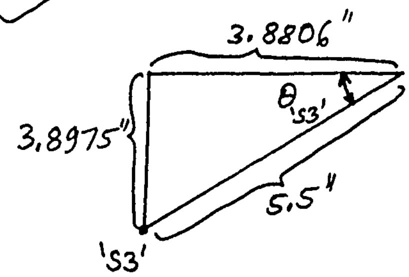
$\theta_6 = 41.42780°$

$\theta_{'S3'} = 45.1242°$

$\theta_7 = 47.8966°$







APPENDIX D

Calculation of Independent Loading Conditions

The calculation of the independent loading conditions, some of which are contained in more than one Load Group, are shown in this Appendix.

LOAD GROUPS

Definition : A load group is a set of loads applied to the structure with a particular set of boundary conditions

Load Group A : Gate resting on sill.

Load Group B : Gate supported by two hoisting cables, just starting to open.

Load Group C : Gate supported by only one hoisting cable, just starting to open.

Load Group D : Gate bound at side seal, supported by two hoisting cables.

LOAD GROUP A

Gate Resting on Sill

Independent Load No.	Load Description
1.	Dead load of gate.
2.	Hydrostatic load, water at top of gate, elevation 530 ft.
3.	Wave load, elevation 530 ft.
4.	Hydrostatic load, water at elevation 528 ft.
5.	Impact load of 5 K/FT. of gate width applied at elevation 528 ft.

Load Group B

Gate Supported by Two Cables

Just Starting to Open

Independent Load No.	Load Description
6.	Dead load of gate.
7.	Hydrostatic load, water at top of gate, elevation 530 ft.
8.	Hydrostatic load, water at elevation 528 ft.
9.	Impact load of 5 K/FT. of gate width applied at elevation 528 ft.
10.	Side seal friction resisting gate opening.
11.	Skin pressure due to 1,000 K. cable force in each cable.
12.	1,000 K-FT trunion friction moment at each pin resisting gate opening.

Load Group C

Gate Supported by One Cable

Just Starting to Open

Independent Load No.	Load Description
13.	Dead load of gate.
14.	Hydrostatic load, water at top of gate, elevation 530 ft.
15.	Side seal friction resisting gate opening.
16.	Skin pressure due to 1,000 K. cable force in one cable.
17.	1,000 K-FT. trunion friction moment at one pin (at joint 38) resisting gate opening.
18.	1,000 K-FT. trunion friction moment at one pin (at joint 1038) resisting gate opening.
20.	Joint displacement load at joint 1001 = +0.25", and at joint 7 = -0.25" to simulate lateral constraint provided by side pier walls.

LOAD GROUP D

Gate Bound at Side Seal

Supported by Two Cables

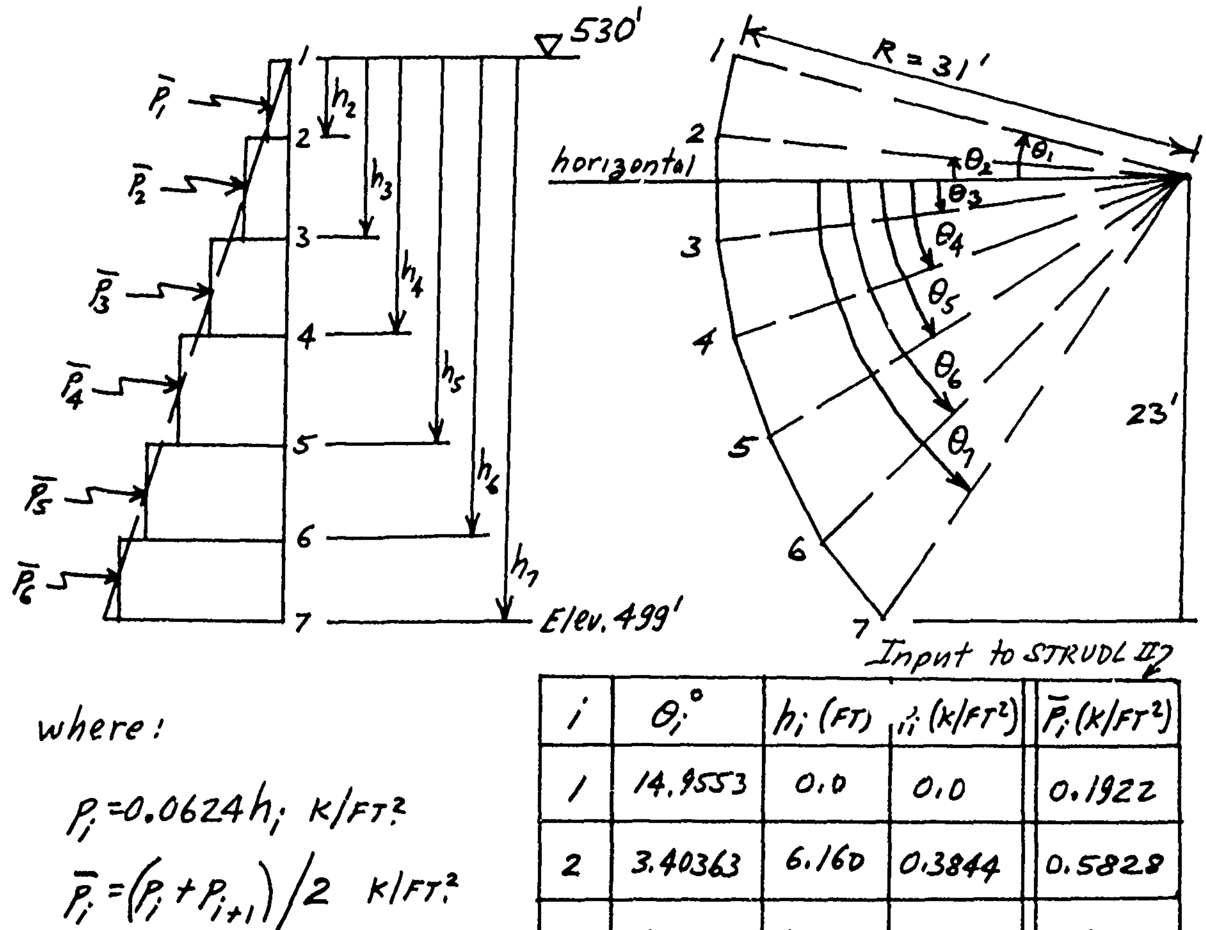
Independent Load No.	Load Description
19.	Skin pressure due to 1,000 k. cable force in each cable.

DEAD LOAD

As was discussed in Section 5.3, only the dead load of the member elements were included in the initial STRUDL II model. They were applied as uniform member loads per unit length of member in the negative Global Y direction (See listing of STRUDL II input in Appendix E).

Hydrostatic Load at Elevation 530 ft.

$\bar{P}_i$: Applied perpendicular to skin plate.



Input to STRUDL II

where:

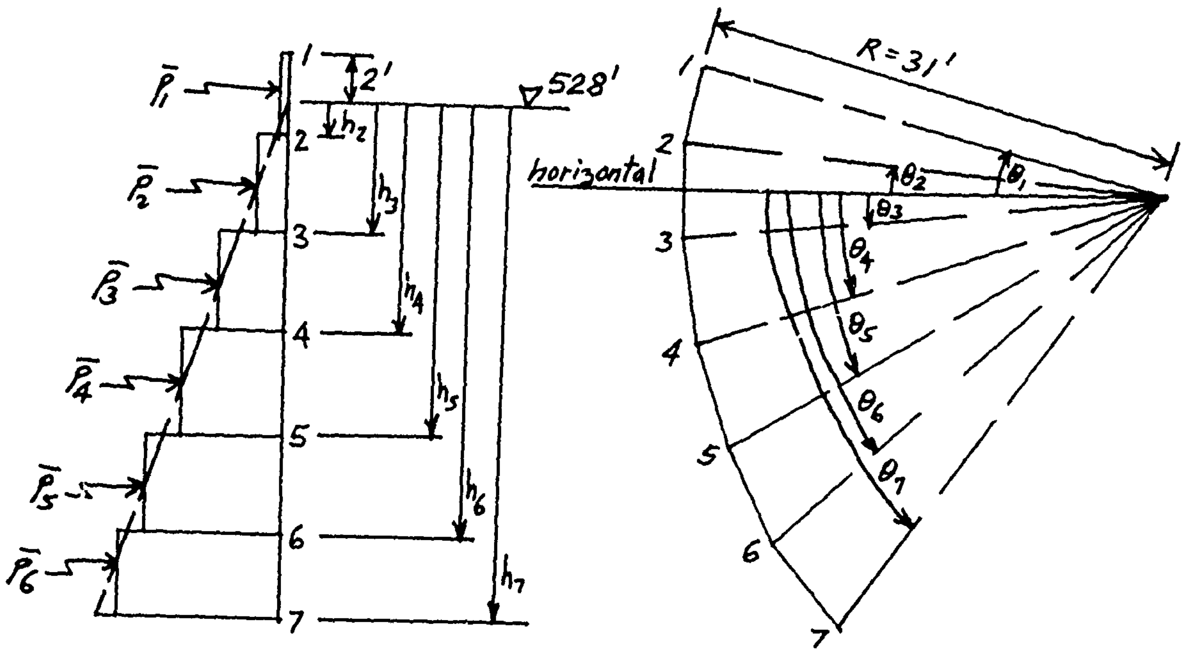
$p_i = 0.0624 h_i$ K/FT²

$\bar{P}_i = (P_i + P_{i+1})/2$ K/FT²

i	θ_i°	h_i (FT)	p_i (K/FT²)	$\bar{P}_i$ (K/FT²)
1	14.9553	0.0	0.0	0.1922
2	3.40363	6.160	0.3844	0.5828
3	8.38458	12.520	0.7812	0.9738
4	20.17278	18.690	1.1663	1.3280
5	30.80029	23.874	1.4897	1.6344
6	41.42780	28.512	1.7791	1.8568
7	47.8966	31.000	1.9344	—

Hydrostatic Load at Elevation 528 ft.

$\bar{P}_i$: Applied perpendicular to skin plate.



where:

$P_i = 0.0624 h_i$ K/FT.²

$\bar{P}_1 = \left(\frac{0+P_2}{2}\right)\left(\frac{h_2}{2+h_2}\right)$ K/FT.²

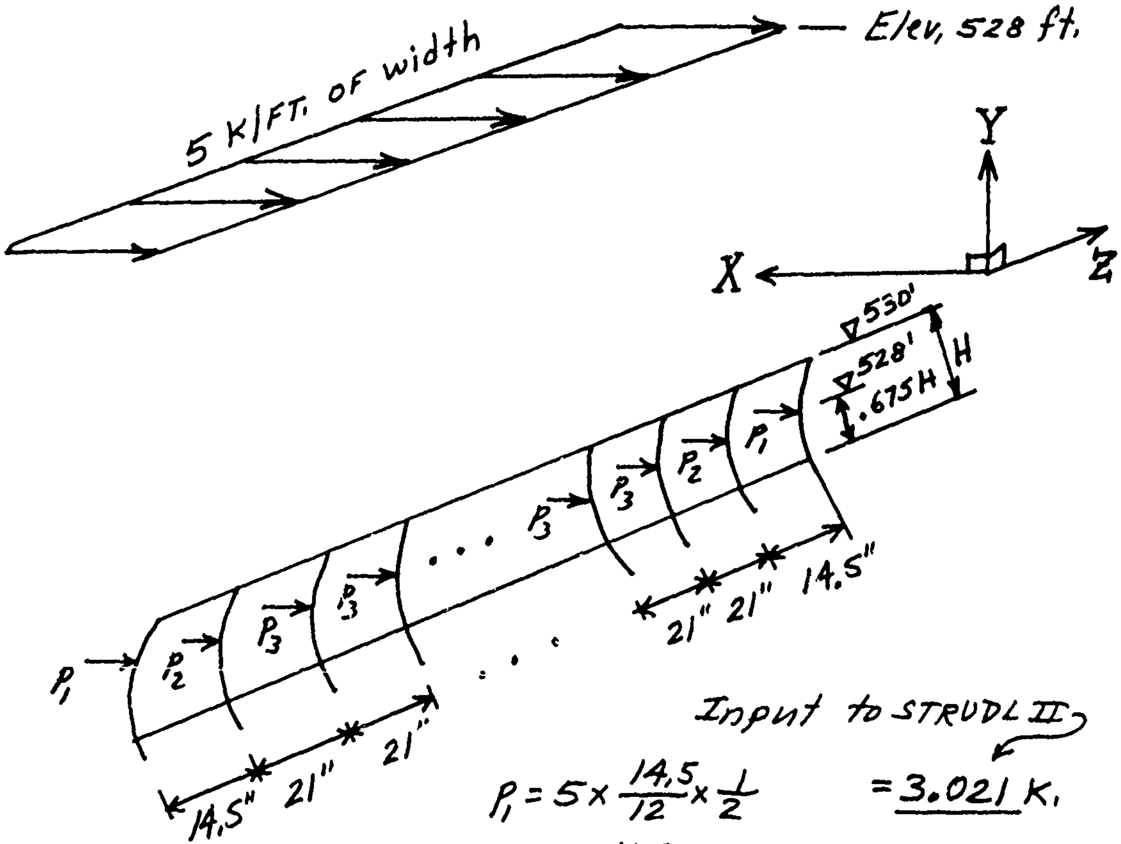
$\bar{P}_i = (P_i + P_{i+1})/2$ K/FT.²

$(i = 2, 3, \cdots, 6)$

i	θ_i°	h_i (FT.)	P_i (K/FT.²)	$\bar{P}_i$ (K/FT.²)
1	14.9553	0.0	0.0	0.0877
2	3.40363	4.160	0.2596	0.4580
3	8.38458	10.520	0.6564	0.8490
4	20.17278	16.690	1.0415	1.2032
5	30.80029	21.874	1.3649	1.5096
6	41.42780	26.512	1.6543	1.7320
7	47.8966	29.0	1.8096	—

Impact Load at Elevation 528 ft.

Assume skin plate is flexible enough so that load is applied directly to vertical ribs as a concentrated load parallel to the global X-axis.



Input to STRUDL II

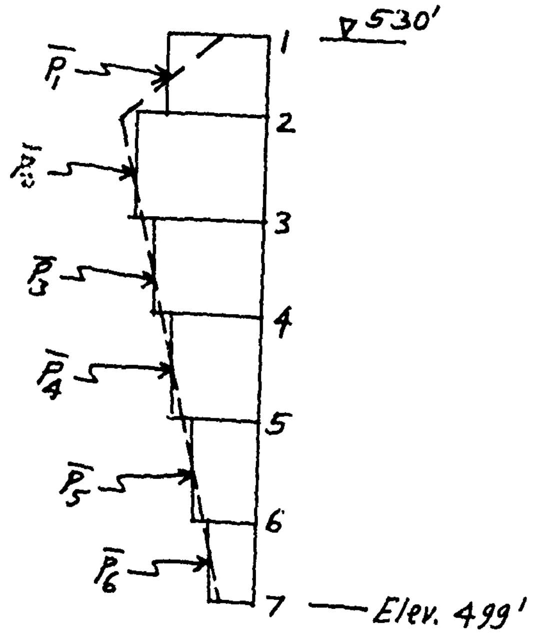
$P_1 = 5 \times \frac{14.5}{12} \times \frac{1}{2}$ = 3.021 K.

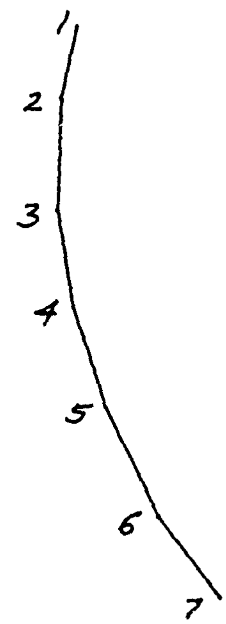
$P_2 = 5 \times \frac{14.5}{12} \times \frac{1}{2} + 5 \times \frac{21}{12} \times \frac{1}{2}$ = 7.396 K.

$P_3 = 5 \times \frac{21}{12}$ = 8.750 K.

Wave Loading at Elevation 530 ft.

$\overline{P}_i$: Applied perpendicular to skin plate.





P_i taken from Re-Regulation Design Notes, Nov. 12, 1970, pg. 10.

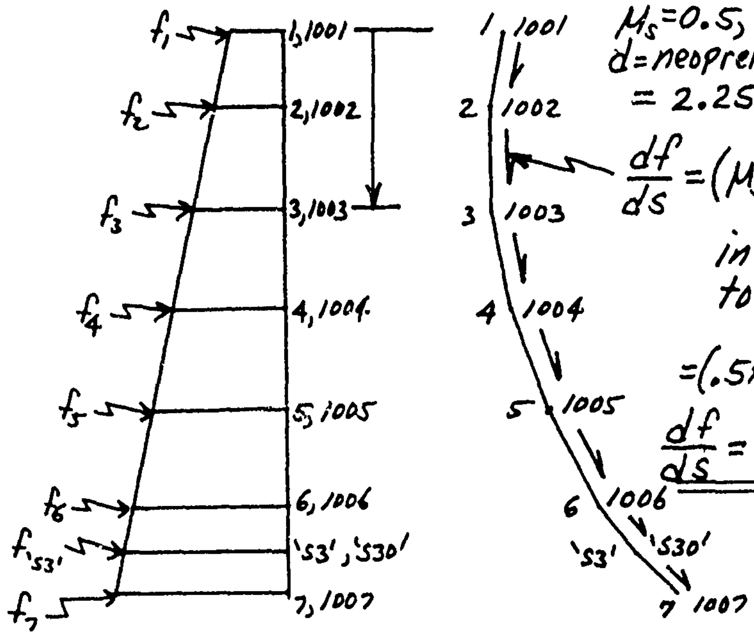
$\overline{P}_i = (P_i + P_{i+1})/2$ K/FT.^{2}

Input to STRUDL II

i	P_i (K/FT.^{2})	$\overline{P}_i$ (K/FT.^{2})
1	0.048	0.094
2	0.140	0.1268
3	0.1136	0.1008
4	0.088	0.0772
5	0.0664	0.0567
6	0.047	0.0420
7	0.037	—

Side Seal Friction Resisting Gate Opening

(from "Hydraulic Structures Research Report" by Don Dressler, January 5, 1970)



$\mu_s = 0.5$, $k = 48$ lb/ft. $= 0.048$ K/FT.

d = neoprene J-seal diameter $= 2.25'' = 0.1875'$

$$\frac{df}{ds} = (\mu_s k + .0624 \mu_s d h) \text{ K/FT.}$$

in a direction parallel to skin plate edge.

$$= (.5 \times .048 + .0624 \times .5 \times .1875 h)$$

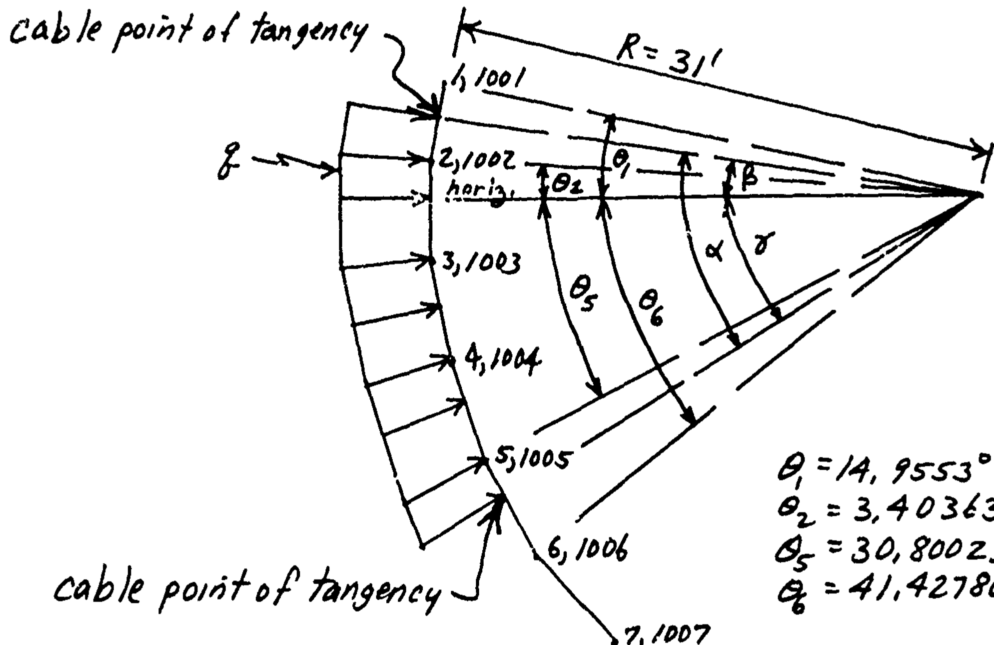
$$\frac{df}{ds} = 0.024 + 0.00585 h \text{ K/FT.}$$

$$f_i = \left(\frac{df}{ds}\right)_i = 0.024 + 0.00585 h_i \text{ K/FT.}$$

f_i applied parallel to edge member local x-axis at both edges of skin plate. ← Input to STRUDL II

i	h_i (FT.)	f_i (K/FT.)
1	0.0	0.024
2	6.160	0.06004
3	12.520	0.09724
4	18.690	0.13334
5	23.874	0.16366
6	28.512	0.19080
'S3'	29.9678	0.1993
7	31.000	0.20535

Skin Pressure Due to 1,000 K. Cable Force



$\theta_1 = 14.9553°$
$\theta_2 = 3.40363°$
$\theta_5 = 30.80029°$
$\theta_6 = 41.42780°$

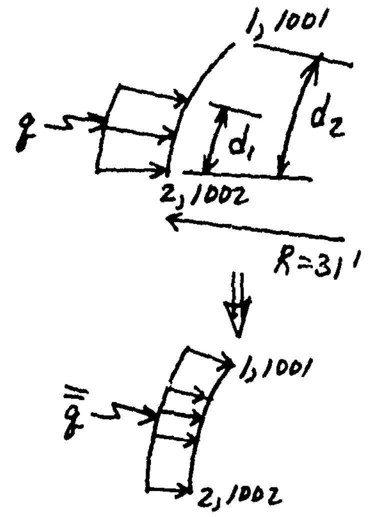
$\alpha = 39.21235°$
$\beta = 5.8657°$
$\gamma = 33.34665°$

$\bar{q}$ = radial force due to a 1,000 K. force in each cable.
$= T/R = \dfrac{1000K}{31\ FT.}$

q = radial pressure on a skin plate width = 14.5" = w
$= \bar{q}/w$
$= \dfrac{1000/(31 \times 12)}{14.5} = 0.18540\ K/in^2$ between joints 2-5, 1002-1005.
$= \underline{26.6976\ K/FT^2}$.

Now, in the region:

Between joints 1-2, and 1001-1002:



$$d_1 = \left(\frac{\beta - \theta_2}{360^\circ}\right)(2\pi R) = 1.33211 \text{ ft.}$$

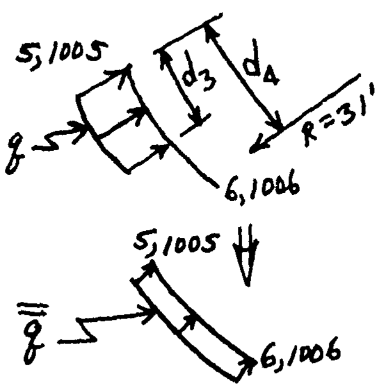
$$d_2 = \left(\frac{\theta_1 - \theta_2}{360}\right)(2\pi R) = 6.25005 \text{ ft.}$$

$$\bar{\bar{q}} = q \times \frac{d_1}{d_2} = .18540\left(\frac{1.33211}{6.25005}\right)$$

$$= .03952 \text{ K/in}^2.$$

$$\bar{\bar{q}} = \underline{5.69088 \text{ K/FT}^2.}$$

Between joints 5-6, and 1005-1006:



$$d_3 = \left(\frac{\gamma - \theta_5}{360}\right)(2\pi R) = 1.37771'$$

$$d_4 = \left(\frac{\theta_6 - \theta_5}{360}\right)(2\pi R) = 5.75004'$$

$$\bar{\bar{q}} = q \times \frac{d_3}{d_4} = .18540\left(\frac{1.37771}{5.75004}\right)$$

$$= .04442 \text{ K/in}^2.$$

$$\bar{\bar{q}} = \underline{6.39648 \text{ K/FT}^2.}$$

Summary:

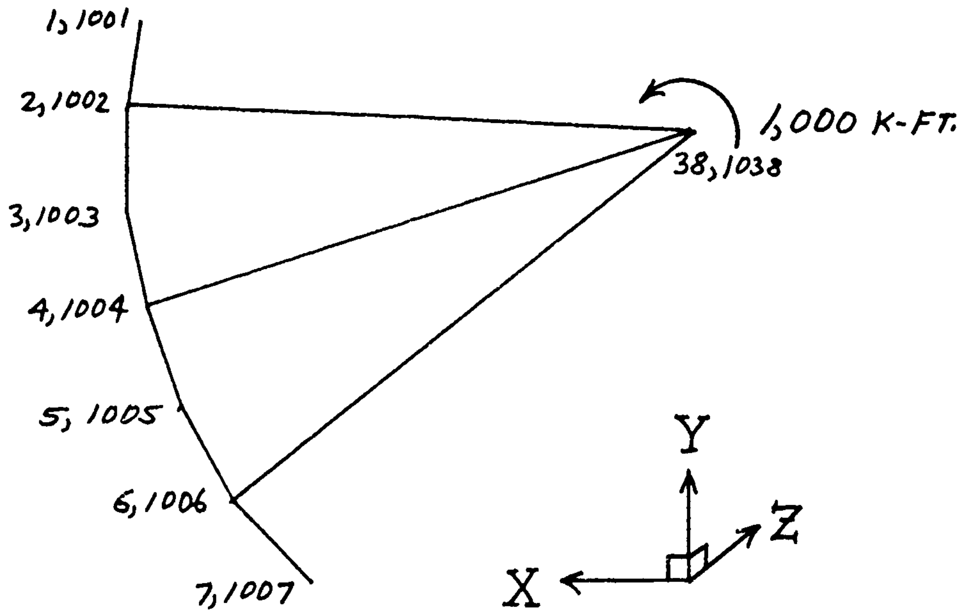
Apply to elements: — Input to STRUDL II

201, 202, 1201, 1202 ⟶ $\bar{\bar{q}} = 5.69088$ K/FT².

203-208, 1203-1208 ⟶ $q = 26.6976$ K/FT².

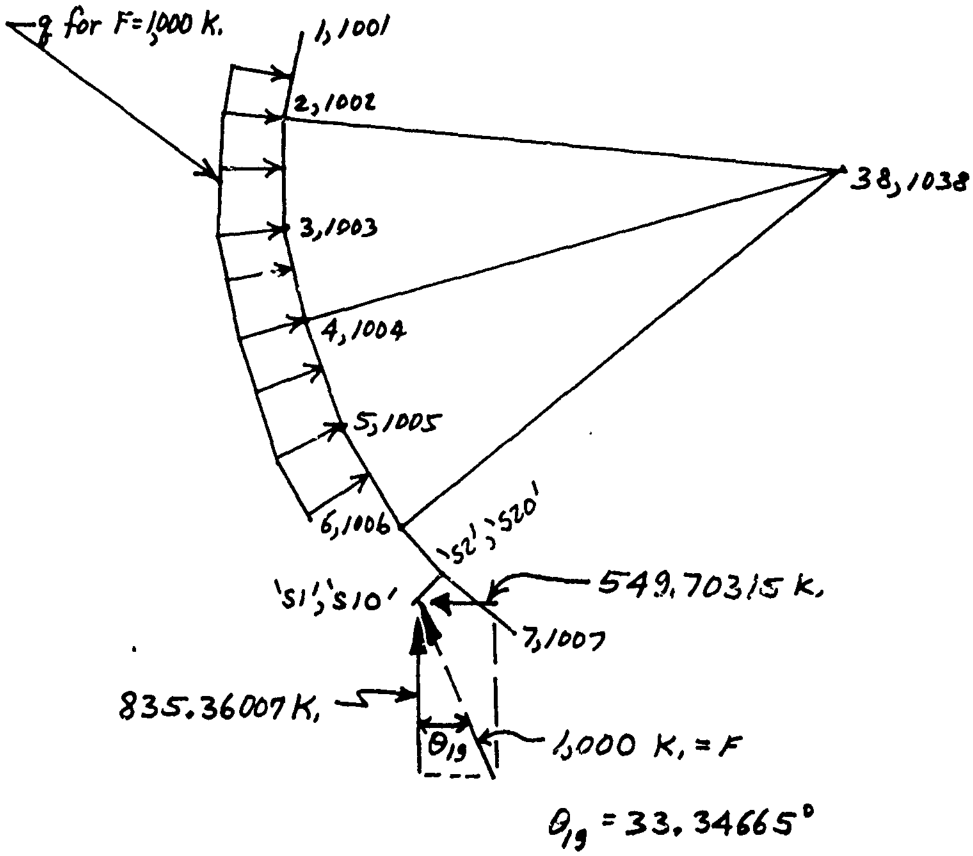
209, 210, 1209, 1210 ⟶ $\bar{\bar{q}} = 6.39648$ K/FT².

1,000 K-FT. Trunion Friction Moment Resisting Gate Opening

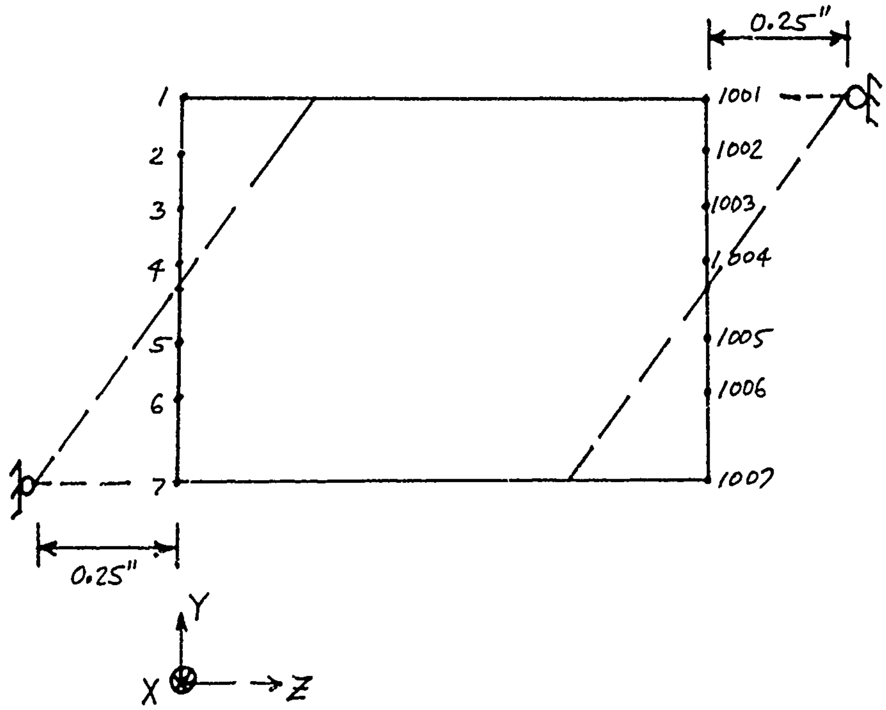


Gate Bound at Side Seal

1,000 K. Force in Each Cable



Lateral Joint Displacements Associated with Side Pier Support Constraint



FINAL DESIGN LOADING COMBINATIONS

(taken from: "Clarence Cannon Re-Regulation Dam Tainter Gate Design Notes")

Notes: In all cases, AISC allowable stresses are to be reduced by 83⅓% or equivalently, increase all applied loads by $1/.833 = 1.20$. So,

a. When no overstress is permitted, load combination factor $= 1.2 \times 1.0 = \underline{1.2}$

b. When 1/3 overstress is permitted, load combination factor $= 1.2 \times \frac{1}{4/3} = \underline{1.2 \times 0.75}$

c. When 50% overstress is permitted, load combination factor $= 1.2 \times \frac{1}{3/2} = \underline{1.2 \times 0.6667}$

Loading Combination No.	Combination
I.	$1.2 \times (1+2)$
II.	$1.2 \times (6+7+10+11 \times .0172565 + 12 \times .0583656)$
III.	$1.2 \times (0.75 \times (1+2+3))$
IV.	$1.2 \times (0.75 \times (1+4+5))$
V.	$1.2 \times (0.75 \times (6+8+9+10+11 \times .0036114 + 12 \times .0589026))$
VI.	$1.2 \times (0.6667 \times (13+14+15+20+16 \times .0346273 + 17 \times .0599272 + 18 \times .0568048))$
VII.	$1.2 \times (0.6667 \times (6+7+10+11 \times .0172565 + 12 \times .0583656 + 19 \times 1.8 \times .0172565))$

APPENDIX E

Listing of Initial STRUDL II Problem Solution Commands

Section 4.4 describes the step-by-step procedures used in the initial STRUDL II analysis and design problem solution. The listing of the input to STRUDL corresponding to this step-by-step procedure consists of twenty-nine pages. Since this input was only applicable during the problem formulation phase as described in this report, and is not considered cost-effective for use in a design office environment, and also since a complete copy of the runs used are available at the Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi, it was not considered necessary to include such a large listing here.

However, a complete listing of the recommended ST‾JDL II commands for the analysis and design procedure which is suitable in a design office environment, and which is directly based upon the problem formulation presented in this report, is contained in the companion report (Reference 1).

APPENDIX F

Job Control Language

The Job Control Language (JCL) used to run the STRUDL runs at McDonnell Automation Co. are shown in this Appendix. It should be noted that the size of the DD1 data set on the private Corps pack VOL=SER=GAITTF must be large enough to store all SAVE'd files. Also, the DD4 data set must be large enough to store the STIFFNESS ANALYSIS generated data, as well as all other input/output cata generated in a problem run. Guidelines for the size of these data sets are given in Reference (9).

1. JCL for Run 1

```
//name JOB (S,accnt,'LZEGATE/WES'),'EMKIN USAE8',MSGLEVEL=(1,1),
//   LIM=(60,300,100),REGION=300K
// EXEC STRUDL,PRI=300
//GO.DD1 DD UNIT=2314,DISP=(NEW,KEEP),DCB=(DSORG=DA,BLKSIZE=7288),
//   VOL=SER=GAITTF,SPACE=(TRK,(800,100)),DSN=SAVE.CLARCANN.WES.LZE1
//GO.FT05F001 DD *
QTITLE DEPTH 60
PAGE LINE 1
STRUDL '---'  '---'
     .
     .
     .
     .
     .
FINISH
/*
```

where,

name = any less-than-or-equal-to eight alphanumeric character string beginning with an alpha character.

accnt= an assigned account number

GAITTF = name of the Corps of Engineers WES 2314 disk pack used for this study.

SAVE.CLARCANN.WES.LZE1 = name of the file on disk pack GAITTF into which STRUDL SAVE files are placed.

Now, it should be noted that the values in the LIM, REGION, PRI, and SPACE parameters depend on the problem being solved and may be highly variable from problem to problem. Care should be taken when selecting these since they will effect the total cost of a computer run. Reference (9) should be consulted for guidelines.

2. <u>JCL for all subsequent Runs following Run 1</u>

Same as above, except change:

REGION=500K

DISP=(OLD,KEEP)

on JCL cards 2 and 4 respectively.

APPENDIX G

Descriptions and Listings of Programs XFTWO and XFONE

This Appendix describes the input requirements for computing F, M, M_a, and M_b by FORTRAN programs XFTWO and XFONE. In addition, listings of the compilations and output of programs XFTWO and XFONE are also included. See Appendix H for the input to these two programs for the initial STRUDL II run considered in this report.

INPUT to FORTRAN Program XFTWO

Program XFTWO is used to compute values of F and M for the 2-cable cases (Load Combinations II and V in the initial STRUDL II run considered in this report). The following assumes the user is familiar with standard FORTRAN FORMAT conventions.

Card 1: READ: MAX,TOL,XSTART

FORMAT(I10,2F10.3)

where,

MAX = maximum number of Newton-Raphson iteration cycles permitted to compute F and M to satisfy tolerance TOL.

TOL = convergence tolerence of Newton-Raphson iteration (see Table 6) for the 2-cable case.

XSTART = starting value of M (or X) in the Newton-Raphson iteration (see Table 6) for the 2-cable case.

Card 2: READ: F,G

FORMAT(2F10.3)

where,

F = friction factor f associated with resultant reaction $R = \sqrt{R_x^2 + R_y^2}$ in Eq. (34) and Fig. 7.

G = friction factor g associated with reaction component R_z in Eq. (34) and Fig. 7.

Card 3: READ: F1X,F1Y,RX1,RY1,RZ1

FORMAT(5F15.3)

where,

F1X,F1Y = average of the global X-direction and Y-direction reaction components respectively at cable support joints 'S1' and 'S10' for load combinations associated with the W forces in Fig. 7 (load 101 or 102 in initial STRUDL run)

RX1,RY1,RZ1 = average of the global X, Y, and Z-direction reaction components respectively, associated with the W load case in Fig. 7, at trunion pin joints 38 and 1038.

Card 4: READ: F2X,F2Y,RX2,RY2,RZ2

FORMAT(5F15.3)

where,

F2X,F2Y = same as F1X,F1Y, except for the load case associated with the application of the 1,000 k. cable force in Fig. 7 (load 11 in initial STRUDL II run) but divided by the factor 1,000.

RX2,RY2,RZ2 = same as RX1,RY1, RZ1, except for the 1,000 K. cable force case in Fig. 7, but also divided by the factor 1,000.

Card 5: READ: F3X,F3Y,RX3,RY3,RZ3

FORMAT(5F15.3)

where,

F3X,F3Y = same as F2X, F2Y, except for the load case associated with the application of the 1,000 K-ft moment at the trunion pins (load 12 in initial STRUDL II run), and also divided by a factor of 1,000.

RX3,RY3,RZ3 = same as RX2, RY2, RZ2, except for the 1,000 K-ft trunion pin moment case in Fig. 7, and also divided by a factor of 1,000.

INPUT to FORTRAN Program XFONE

Program XFONE is used to compute values of F, M_a, and M_b for the 1-cable case (Load Combination VI in the initial STRUDL II run considered in this report). The following assumes the user is familiar with standard FORTRAN FORMAT conventions.

Card 1: READ: MAX,TOL,X10,X20

FORMAT(I10,3F10.3)

where,

MAX = same as for XFTWO, but for F, M_a, and M_b

TOL = same as for XFTWO, but for F, M_a and M_b

X10 = starting value of M_a (or X_a) in the Newton-Raphson iteration (see Table 7) for the 1-cable case.

X20 = starting value of M_b (or X_b) in the Newton-Raphson iteration (see Table 7) for the 1-cable case.

Card 2: READ: F,G

FORMAT(2F10.3)

where,

F = friction factor f associated with resultant reaction $R = \sqrt{R_X^2 + R_Y^2}$ in Eq. (36) and Fig. 8.

G = friction factor g associated with reaction component R_Z in Eq. (36) and Fig. 8.

Card 3: READ: RX1A,RY1A,RZ1A,RX1B,RY1B,RZ1B,F1X,F1Y

FORMAT(8F10.3)

where,

RX1A,RY1A,RZ1A = global X, Y, and Z-direction reaction components at trunion pin joint 38 for load combination associated with W forces in Fig. 8 (load 103 in initial STRUDL II run).

RX1B,RY1B,RZ1B = same as RX1A, RY1A, RZ1A, except at trunion pin joint 1038.

F1X,F1Y = global X and Y-direction reaction components at cable support joint 'S1' for W load case in Fig. 8.

Card 4: READ: RX2A,RY2A,RZ2A,RX2B,RY2B,RZ2B,F2X,F2Y

FORMAT(8F10.3)

where,

RX2A,RY2A,RZ2A = global X, Y, and Z-direction reaction components at trunion pin joint 38 for 1,000 K. cable force load case in Fig. 8 (load 16 in initial STRUDL II run), but divided by a factor of 1,000.

RX2B,RY2B,RZ2B = same as RX2A, RY2A, RZ2A, except at trunion pin joint 1038.

F2X,F2Y = global X and Y-direction reaction components at cable support joint 'S1' for 1,000 K. cable force load case in Fig. 8, but divided by a factor of 1,000.

Card 5: READ: RX3A,RY3A,RZ3A,RX3B,RY3B,RZ3B,F3X,F3Y

FORMAT(8F10.3)

where,

RX3A,RY3A,RZ3A = same as RX2A,RY2A,RZ2A, except for the 1,000 K-ft trunion pin joint 38 moment load case in Fig. 8 (load case 17).

RX3B,RY3B,RZ3B = same as RX3A, RY3A, RZ3A, except at trunion pin joint 1038.

F3X,F3Y = same as F2X,F2Y, except for the 1,000 K-ft moment at joint 38 load case (load case 17).

Card 6: READ: RX4A,RY4A,RZ4A,RX4B,RY4B,RZ4B,F4X,F4Y

FORMAT(8F10.3)

where,

RX4A,RY4A,RZ4A = same as RX3A,RY3A,RZ3A, except for the 1,000 K-ft moment at joint 1038 load case (load case 18 in initial STRUDL II run).

RX4B,RY4B,RZ4B = same as RX4A,RY4A,RZ4A, except reactions are at trunion pin joint 1038.

F4X,F4Y = same as F2X,F2Y, except for the 1,000 K-ft moment at joint 1038 load case (load case 18).

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Program XFTWO source and assembly listings are available separately as provided by Engineer Regulation ER 18-1-6 on request to:

Director
USAE Waterways Experiment Station
ATTN: WESKA
P. O. Box 631
Vicksburg, Mississippi 39180

Results of XFTWO

F and M for use in design load combination II and VII.

```
MAX,TOL,XSTART=      100      .010      1.000


F,G=   .5816700E-01   .1250000E+00

F1X,F1Y,RX1,RY1,RZ1=    .8459312E+01   .1284158E+02   .4229015E+03  -.2059098E+03   .8659901E+02

F2X,F2Y,RX2,RY2,RZ2=   -.3303040E-04  -.5019480E-04   .6496868E+00  -.1586082E+00   .1141507E+00

F3X,F3Y,RX3,RY3,RZ3=    .1773409E-01   .2694972E-01  -.1773335E-01  -.2694676E-01   .5022425E-02

F1,F2,F3=   .1537250E+02   .6008765E-04   .3226120E-01
X,FF,RH,RV,RL,FUNC =  .100000E+01  .154057E+02  .432893E+03 -.208380E+03  .883626E+02 -.572083E+02
X,FF,RH,RV,RL,FUNC = -.100000E+01  .153412E+02  .432887E+03 -.208316E+03  .883457E+02 -.592028E+02
X,FF,RH,RV,RL,FUNC = 0.            .153734E+02  .432890E+03 -.208348E+03  .883539E+02 -.582055E+02
X,FF,RH,RV,RL,FUNC =  .200000E+01  .154380E+02  .432896E+03 -.208412E+03  .883713E+02 -.562110E+02
X,FF,RH,RV,RL,FUNC =  .300000E+01  .154702E+02  .432899E+03 -.208444E+03  .883800E+02 -.552138E+02
X,XM2,XM1,XP1,XP2=  .100000E+01 -.100000E+01 0.          .200000E+01  .300000E+01
HM2,HM1,HP1,HP2= -.592026E+02 -.582055E+02 -.562110E+02 -.552138E+02
FUNCP=  .997261E+00
K,H,HP,XOLD,XNEW,DIFF,TOL,FF=     1 -.572083E+02  .997261E+00  .100000E+01  .583654E+02  .573654E+02  .100000E-01  .154702E+02

X,FF,RH,RV,RL,FUNC =  .583554E+02  .172565E+02  .433078E+03 -.210220E+03  .888620E+02 -.253578E-03
X,FF,RH,RV,RL,FUNC =  .563654E+02  .171920E+02  .433072E+03 -.210155E+03  .888446E+02 -.199476E+01
X,FF,RH,RV,RL,FUNC =  .573654E+02  .172242E+02  .433075E+03 -.210188E+03  .888533E+02 -.997536E+00
X,FF,RH,RV,RL,FUNC =  .593654E+02  .172387E+02  .433081E+03 -.210252E+03  .888707E+02  .996999E+00
X,FF,RH,RV,RL,FUNC =  .603554E+02  .173210E+02  .433085E+03 -.210284E+03  .888794E+02  .199425E+01
X,XM2,XM1,XP1,XP2=  .583654E+02  .563654E+02  .573654E+02  .593654E+02  .603654E+02
HM2,HM1,HP1,HP2= -.199476E+01 -.997506E+00  .996999E+00  .199425E+01
FUNCP=  .997252E+00
K,H,HP,XOLD,XNEW,DIFF,TOL,FF=     2 -.253578E-03  .997252E+00  .583654E+02  .583656E+02  .254276E-03  .100000E-01  .173210E+02

$$$$$$$  RH,RV,RL,RT=  .433078E+03 -.210220E+03  .888620E+02  .481403E+03

$$$$$$$  MR,XNEW,FF=  .583656E+02  .583656E+02  .172565E+02
```

→ *M = 58.3656 k-ft.*   → *F = 17.2565 k.*

Results of XFTWO

F and M for use in design load Combination V

```
MAX,TOL,XSTART=      100     .010     1.000


F,G=   .9816700E-01   .1250000E+00

F1X,F1Y,RX1,RY1,RZ1=   .9405000E+00   .1429240E+01   .4484181E+03  -.1776125E+03   .9010040E+02

F2X,F2Y,RX2,RY2,RZ2=  -.3303040E-04  -.5019480E-04   .6496868E+00  -.1586082E+00   .1141507E+00

F3X,F3Y,RX3,RY3,RZ3=   .1773409E-01   .2694972E-01  -.1773335E-01  -.2694676E-01   .5022425E-02

F1,F2,F3=   .1710926E+01   .6009765E-04   .3226120E-01
X,FF,RH,RV,RL,FUNC =  .100000E+01   .174329E+01   .449533E+03  -.178115E+03   .903044E+02  -.577551E+02
X,FF,RH,RV,RL,FUNC = -.100000E+01   .167877E+01   .449526E+03  -.178032E+03   .902870E+02  -.597501E+02
X,FF,RH,RV,RL,FUNC = 0.             .171103E+01   .449530E+03  -.178084E+03   .902957E+02  -.587526E+02
X,FF,RH,RV,RL,FUNC =  .200000E+01   .177555E+01   .449536E+03  -.178149E+03   .903131E+02  -.567577E+02
X,FF,RH,RV,RL,FUNC =  .300000E+01   .180782E+01   .449539E+03  -.178160E+03   .903218E+02  -.557602E+02
X,XM2,XM1,XP1,XP2=  .100000E+01 -.100000E+01 0.         .200000E+01   .300000E+01
HM2,HM1,HP1,HP2= -.597501E+02 -.587526E+02 -.567577E+02 -.557602E+02
FUNCP=   .997458E+00
K,H,HP,XOLD,XNEW,DIFF,TOL,FF=      1 -.577551E+02   .997458E+00   .100000E+01   .589023E+02   .579023E+02   .100000E-01   .180782E+01

X,FF,RH,RV,RL,FUNC =  .589023E+02   .361140E+01   .449720E+03  -.179973E+03   .906085E+02  -.278279E-03
X,FF,RH,RV,RL,FUNC =  .580023E+02   .354668E+01   .449713E+03  -.179909E+03   .907911E+02  -.199516E+01
X,FF,RH,RV,RL,FUNC =  .579023E+02   .357914E+01   .449717E+03  -.179940E+03   .907998E+02  -.997727E+00
X,FF,RH,RV,RL,FUNC =  .599023E+02   .364367E+01   .449723E+03  -.180003E+03   .908172E+02   .997170E+00
X,FF,RH,RV,RL,FUNC =  .609023E+02   .367593E+01   .449726E+03  -.180037E+03   .908257E+02   .199462E+01
X,XM2,XM1,XP1,XP2=  .569023E+02   .569023E+02   .579023E+02   .599023E+02   .609023E+02
HM2,HM1,HP1,HP2= -.199519E+01 -.997727E+00   .997170E+00   .199462E+01
FUNCP=   .997448E+00
K,H,HP,XOLD,XNEW,DIFF,TOL,FF=      2 -.278279E-03   .997448E+00   .589023E+02   .589026E+02   .278991E-03   .100000E-01   .367593E+01

$$$$$$$  RH,RV,RL,RT=  .449720E+03 -.179973E+03   .903035E+02   .494595E+03

$$$$$$$  MR,XNEW,FF=  .589026E+02   .589026E+02   .361141E+01
```

→ *M = 58.9026 k-ft.*

→ *F = 3.61141 K.*

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Program XFONE source and assembly listings are available separately as provided by Engineer Regulation ER 18-1-6 on request to:

Director
USAE Waterways Experiment Station
ATTN: WESKA
P. O. Box 631
Vicksburg, Mississippi 39180

Results of XFONE

F, Ma, and Mb for Use in Load Combination VI

```
MAX,TOL,X10,Y20=       100      .010      1.000     1.000

F,G=    .9816760E-01    .1250000E+00

RX1A,RY1A,RZ1A,RX1B,RY1,RZ1B,,F1X,F1Y=  .417735E+03 -.206634E+03  .870040E+02  .428829E+03 -.205174E+03 -.861653E+02
                                                                                                          .169617E+02  .257760E+02
RY2A,PY2A,RZ2A,RX2B,RY2B,RZ2B,F2X,F2Y=  .809976E+00 -.196806E+00  .142097E+00 -.160272E+00  .381930E-01  .280190E-01
                                                                                                         -.721000E-04 -.109600E-03
RX3A,RY3A,RZ3A,RX3B,RY3B,RZ3B,F3X,F3Y= -.176330E-01 -.276520E-01  .516020E-02 -.101600E-03  .706000E-03  .148900E-03
                                                                                                          .177360E-01  .269530E-01
RX4A,RY4A,RZ4A,RY4B,RY4B,RZ4B,F4X,F4Y= -.135980E-01  .465100E-02 -.260400E-02 -.414790E-02 -.315969E-01 -.758400E-02
                                                                                                          .177368E-01  .269568E-01

F1,F2,F3,F4=  .308561E+02  .131189E-03  .322650E-01  .322697E-01

*****************************************************************************************************************

X1,X2,FF,RMA,RVA,RLA,M1=  .100000E+01  .100000E+01  .309247E+02  .442752E+03 -.212743E+03  .914008E+02 -.586459E+02
X1,X2,FF,RMA,RVA,RLA,M1= -.100000E+01  .100000E+01  .308602E+02  .442735E+03 -.212675E+03  .913814E+02 -.606390E+02
X1,X2,FF,RMA,RVA,RLA,M1= 0.            .100000E+01  .308925E+02  .442743E+03 -.212709E+03  .913911E+02 -.596425E+02
X1,X2,FF,RMA,RVA,RLA,M1=  .200000E+01  .100000E+01  .309570E+02  .442760E+03 -.212777E+03  .914106E+02 -.576493E+02
X1,X2,FF,RMA,RVA,RLA,M1=  .300000E+01  .100000E+01  .309893E+02  .442769E+03 -.212811E+03  .914203E+02 -.566527E+02
X1,X2,XM2,XM1,XP1,XP2=  .100000E+01  .100000E+01 -.100000E+01 0.             .200000E+01  .300000E+01
M2,M1,MP1,MP2,M1P= -.616390E+02 -.596425E+02 -.576493E+02 -.566527E+02  .996584E+00
K,M1,M1P=   1 -.586459E+02  .956524E+00
X1K,Y1NEW,X2K,DIFF1,TOL,FF=  .100000E+01  .598469E+02  .100000E+01  .588469E+02  .100000E-01  .309893E+02

*****************************************************************************************************************

X1,X2,FF,RMA,RVA,RLA,M1=  .598469E+02  .100000E+01  .328237E+02  .443252E+03 -.214744E+03  .919743E+02 -.250931E-03
X1,X2,FF,RMA,RVA,RLA,M1=  .578469E+02  .100000E+01  .327591E+02  .443237E+03 -.214676E+03  .919549E+02 -.199340E+01
X1,X2,FF,RMA,RVA,RLA,M1=  .588469E+02  .100000E+01  .327914E+02  .443244E+03 -.214710E+03  .919646E+02 -.996826E+00
X1,X2,FF,RMA,RVA,RLA,M1=  .608469E+02  .100000E+01  .328559E+02  .443261E+03 -.214778E+03  .919641E+02  .996324E+00
X1,X2,FF,RMA,RVA,RLA,M1=  .618469E+02  .100000E+01  .328882E+02  .443269E+03 -.214812E+03  .919938E+02  .199290E+01
X1,X2,XM2,XM1,XP1,XP2=  .598469E+02  .100000E+01  .578469E+02  .588469E+02  .608469E+02  .618469E+02
M2,M1,MP1,MP2,M1P= -.199340E+01 -.996826E+00  .996324E+00  .199290E+01  .996575E+00
K,M1,M1P=   2 -.250931E-03  .996575E+00
X1K,X1NEW,X2K,DIFF1,TOL,FF=  .598469E+02  .596472E+02  .100000E+01  .251793E-03  .100000E-01  .328852E+02

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X1,X2,FF,RMB,RVB,RLB,M2=  .594472E+02  .100000E+01  .328237E+02  .422758E+03 -.203910E+03 -.852443E+02 -.557316E+02
X1,X2,FF,RMB,RVB,RLB,M2=  .594472E+02 -.100000E+01  .327591E+02  .422776E+03 -.203849E+03 -.852309E+02 -.577290E+02
X1,X2,FF,RMB,RVB,RLB,M2=  .594472E+02 0.            .327314E+02  .422767E+03 -.203879E+03 -.852376E+02 -.567303E+02
X1,X2,FF,RMB,RVB,RLB,M2=  .594472E+02  .200000E+01  .328560E+02  .422748E+03 -.203940E+03 -.852510E+02 -.547330E+02
X1,X2,FF,RMB,RVB,RLB,M2=  .598472E+02  .300000E+01  .328662E+02  .422739E+03 -.203970E+03 -.852376E+02 -.537343E+02
X1,X2,XM2,XM1,XP1,XP2=  .598472E+02  .100000E+01 -.100000E+01 0.             .200000E+01  .300000E+01
M2,M1,MP1,MP2,M2P= -.577290E+02 -.567303E+02 -.547330E+02 -.537343E+02  .996694E+00
K,M2,M2P=   1 -.557316E+02  .996694E+00
X2K,X2NEW,X1K,DIFF2,TOL,FF=  .100000E+01  .568045E+02  .598472E+02  .558045E+02  .100000E-01  .328882E+02

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X1,X2,FF,RMB,RVB,RLB,M2=  .598472E+02  .568045E+02  .346247E+02  .422237E+03 -.205604E+03 -.856170E+02 -.320869E-03
X1,X2,FF,RMB,RVB,RLB,M2=  .598472E+02  .548045E+02  .345602E+02  .422256E+03 -.205543E+03 -.856037E+02 -.199765E+01
X1,X2,FF,RMB,RVB,RLB,M2=  .598472E+02  .558045E+02  .345924E+02  .422247E+03 -.205574E+03 -.856104E+02 -.999004E+00
X1,X2,FF,RMB,RVB,RLB,M2=  .598472E+02  .578045E+02  .346570E+02  .422228E+03 -.205634E+03 -.856237E+02  .998362E+00
```

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X1,X2,FF,RHB,RVB,PLB,H2=  .598472E+02  .568045E+02  .346893E+02  .422219E+03 -.205665E+03 -.856304E+02  .199704E+01
X1,X2,XM2,XM1,XP1,XP2=  .598472E+02  .568045E+02  .548045E+02  .558045E+02  .578045E+02  .588045E+02
HM2,HM1,HP1,HP2,H2P= -.159769E+01 -.999004E+00  .999362E+00  .199704E+01  .998683E+00
K,H2,H2P=   2 -.320869E-03  .998683E+00
X2K,X2NEW,X1K,DIFF2,TOL,FF=  .568045E+02  .568048E+02  .598472E+02  .321292E-03  .100000E-01  .346893E+02

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X1,X2,FF,RHA,RVA,RLA,H1=  .598472E+02  .568048E+02  .346247E+02  .443953E+03 -.214839E+03  .920850E+02 -.797807E-01
X1,X2,FF,RHB,RVB,PLB,H2=  .598472E+02  .568049E+02  .346247E+02  .422237E+03 -.205604E+03 -.856170E+02 0.
X1K,X2K,H1,H2,TOL=  .598472E+02  .568048E+02 -.797807E-01 0.          .100000E-01

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X1,X2,FF,RHA,RVA,RLA,H1=  .598472E+02  .568045E+02  .346247E+02  .443953E+03 -.214839E+03  .920850E+02 -.797807E-01
X1,X2,FF,RHA,RVA,RLA,H1=  .578472E+02  .568048E+02  .345602E+02  .443936E+03 -.214771E+03  .920655E+02 -.207293E+01
X1,X2,FF,RHA,RVA,RLA,H1=  .588472E+02  .568048E+02  .345925E+02  .443944E+03 -.214805E+03  .920752E+02 -.107636E+01
X1,X2,FF,RHA,RVA,RLA,H1=  .608472E+02  .568046E+02  .346570E+02  .443961E+03 -.214873E+03  .920947E+02  .916796E+00
X1,X2,FF,RHA,RVA,RLA,H1=  .618472E+02  .568048E+02  .346893E+02  .443970E+03 -.214907E+03  .921044E+02  .191337E+01
X1,X2,XM2,XM1,XP1,XP2=  .598472E+02  .568048E+02  .578472E+02  .588472E+02  .608472E+02  .618472E+02
HM2,HM1,HP1,HP2,H1P= -.207293E+01 -.107636E+01  .916796E+00  .191337E+01  .996576E+00
K,H1,H1P=   1 -.797807E-01  .996576E+00
X1K,X1NEW,X2K,DIFF1,TOL,FF=  .598472E+02  .599272E+02  .568048E+02  .800548E-01  .100000E-01  .346893E+02

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X1,X2,FF,RHA,RVA,RLA,H1=  .599272E+02  .568048E+02  .346273E+02  .443954E+03 -.214842E+03  .920857E+02 -.462023E-09
X1,X2,FF,RHA,RVA,RLA,H1=  .579272E+02  .568048E+02  .345628E+02  .443937E+03 -.214774E+03  .920662E+02 -.199315E+01
X1,X2,FF,RHA,RVA,RLA,H1=  .589272E+02  .568048E+02  .345950E+02  .443945E+03 -.214808E+03  .920760E+02 -.996576E+00
X1,X2,FF,RHA,RVA,RLA,H1=  .609272E+02  .568048E+02  .346596E+02  .443962E+03 -.214876E+03  .920955E+02  .996576E+00
X1,X2,FF,RHA,RVA,RLA,H1=  .619272E+02  .568046E+02  .346918E+02  .443971E+03 -.214910E+03  .921052E+02  .199315E+01
X1,X2,XM2,XM1,XP1,XP2=  .599272E+02  .568048E+02  .579272E+02  .589272E+02  .609272E+02  .619272E+02
HM2,HM1,HP1,HP2,H1P= -.199315E+01 -.996576E+00  .996576E+00  .199315E+01  .996576E+00
K,H1,H1P=   2 -.462023E-09  .996576E+00
X1K,X1NEW,X2K,DIFF1,TOL,FF=  .599272E+02  .599272E+02  .568048E+02  .463368E-09  .100000E-01  .346918E+02

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X1,X2,FF,RHB,RVB,PLB,H2=  .599272E+02  .568048E+02  .346273E+02  .422237E+03 -.205604E+03 -.856170E+02  .544671E-04
X1,X2,FF,RHB,RVB,PLB,H2=  .599272E+02  .548048E+02  .345628E+02  .422256E+03 -.205543E+03 -.856036E+02 -.199731E+01
X1,X2,FF,RHB,RVB,PLB,H2=  .599272E+02  .558048E+02  .345950E+02  .422246E+03 -.205574E+03 -.856103E+02 -.998626E+00
X1,X2,FF,RHB,RVB,PLB,H2=  .599272E+02  .578048E+02  .346596E+02  .422228E+03 -.205634E+03 -.856236E+02  .998737E+00
X1,X2,FF,RHB,RVB,PLB,H2=  .599272E+02  .588048E+02  .346919E+02  .422218E+03 -.205665E+03 -.856303E+02  .199742E+01
X1,X2,XM2,XM1,XP1,XP2=  .599272E+02  .568048E+02  .548048E+02  .558048E+02  .578048E+02  .588048E+02
HM2,HM1,HP1,HP2,H2P= -.199731E+01 -.998626E+00  .998737E+00  .199742E+01  .998683E+00
K,H2,H2P=   1  .544671E-04  .998683E+00
X2K,X2NEW,X1K,DIFF2,TOL,FF=  .568048E+02  .568048E+02  .599272E+02 -.545390E-04  .100000E-01  .346919E+02

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X1,X2,FF,RHA,RVA,RLA,H1=  .599272E+02  .568048E+02  .346273E+02  .443954E+03 -.214842E+03  .920857E+02  .779755E-07
X1,X2,FF,RHB,RVB,PLB,H2=  .599272E+02  .568048E+02  .346273E+02  .422237E+03 -.205604E+03 -.856170E+02 -.227374E-12
X1K,X2K,H1,H2,TOL=  .599272E+02  .568048E+02  .779755E-07 -.227374E-12  .10000.E-01

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********************
$$$$$ RHA,RVA,RLA,RTA=  .443954E+03 -.214842E+03  .920857E+02  .493206E+03
$$$$$ RHB,RVB,RLB,RTB=  .422237E+03 -.205604E+03 -.856170E+02  .469635E+03

$$$$$ X1,X2=  .599272E+02  .568048E+02
********************

$$$$$ MRA =  .599272E+02 = Ma
$$$$$ MRB =  .568048E+02 = Mb
$$$$$ FF  =  .346273E+02 = F

********************
```

$F = 34.6273$ K., $M_a = 59.9272$ K-ft., $M_b = 56.8048$ K-ft.

APPENDIX H

Input to XFTWO and XFONE to Compute Values of F, M, M_a, and M_b Shown in Table 8

This Appendix shows the data values input to FORTRAN programs XFTWO and XFONE to compute values of F, M, M_a, and M_b shown in Table 8. The definition of variable names used and FORMAT of data is given in Appendix G. It is assumed that the reader is familiar with the FORTRAN FORMAT conventions.

F and M for Use in Design Load Combination II Using Program XFTWO

Reaction values for STRUDL II loading combinations 101,11, and 12 are used, except that the values from loads 11 and 12 are first divided by 1,000. Also, since behavior is symmetrical, reaction values at joints 'S1' and 'S10', and joints 38 and 1038 respectively were averaged before inputting them.

So, data cards to XFTWO:

Card 1: MAX,TOL,XSTART in (I10,2F10.3) FORMAT

data: 100, 0.01, 1.0

Card 2: F,G in (2F10.3) FORMAT

data: 0.098167, 0.12500

Card 3: F1X,F1Y,RX1,RY1,RZ1 in (5F15.3) FORMAT
(load 101)
data: 8.450312, 12.841577, 422.901856, -205.909798, 86.599009

Card 4: F2X,F2Y,RX2,RY2,RZ2 in (5F15.3) FORMAT
(load (11)/1000)
data: -.0000330304, -.0000501948, .649686768, -.158608231, .114150734

Card 5: F3X,F3Y,RX3,RY3,RZ3 in (5F15.3) FORMAT
(load (12)/1000)
data: .017734085, .026949722, -.017733353, -.026946755, .005022425

Result: F = 17.2565 K., M = 58.3656 K-ft

F and M for Use in Design Load Combination V Using Program XFTWO

Reaction values for STRUDL II loading combinations 102, 11, and 12 are used, except that the values from loads 11 and 12 are first divided by 1,000. Also, since behavior is symmetrical, reaction values at joints 'S1' and 'S10', and joints 38 and 1038 respectively were averaged before inputting them.

So, data cards to XFTWO:

Card 1: same as for Load II

Card 2: same as for Load II

Card 3: F1X,F1Y,RX1,RY1,RZ1 in (5F15.3) FORMAT
(load 102)
data: .940500, 1.429240, 448.418091, -177.812538, 90.100395

Card 4: same as for Load II.

Card 5: same as for Load II

Result: F = 3.61141 K., M = 58.9026 K-ft

F, M_a, and M_b for Use in Design Load Combination VI Using Program XFONE

Reaction values for STRUDL II loading combinations 103, 16, 17, and 18 are used, except that the values from loads 16, 17, and 18 are first divided by 1,000. Reaction values taken from joints 'S1', 38, and 1038. This case includes side support constraints.

So, data cards to XFONE:

Card 1: MAX,TOL,X10,X20 in (I10,3F10.3) FORMAT

data: 100, 0.01, 1.0, 1.0

Card 2: F,G in (2F10.3) FORMAT

data: 0.098167, 0.12500

Card 3: RX1A,RY1A,RZ1A,RX1B,RY1B,RZ1B,F1X,F1Y
(load 103)

data: 417.73486, -206.633791, 87.00398, 428.02856, -205.17385, -86.165301, 16.9617, 25.77599

Card 4: RX2A,RY2A,RZ2A,RX2B,RY2B,RZ2B,F2X,F2Y
(load (16)/1000)

data: .809976, -.196806, .142097, -.160272, .038193, .028019, -.0000721, -.0001096

Card 5: RX3A,RY3A,RZ3A,RX3B,RY3B,RZ3B,F3X,F3Y
(load (17)/1000)

data: -.017633, -.027652, .0051602, -.0001016, .000706, .0001489, .017736, .026953

Card 6: RX4A,RY4A,RZ4A,RX4B,RY4B,RZ4B,F4X,F4Y
(load (18)/1000)

data: -.013588, .004651, -.002604, -.0041479, -.0315969, -.007584, .0177388, .0269568

Result: $F = 34.6273$ K.

$M_a = 59.9272$ K-ft

$M_b = 56.8048$ K-ft