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COMPUTER PROGRAM FOR CURVED BRIDGES ON FLEXIBLE BENTS

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ABSTRACT

A computer program is presented for the analysis of continuous prismatic folded plate structures, which are circular in plan and may have up to twelve flexible interior diaphragms or supports. The folded plate structure is considered to be an assemblage of orthotropic plate elements that may, in general, be segments of conical frustra, interconnected at longitudinal joints and simply supported at the two ends. Each plate element is idealized by a number of circumferential finite strips. The finite strip method is used to determine the strip stiffness. Interior diaphragms may be defined by flexible beams, and interior supports may be defined by two-dimensional planar frame bents. A direct stiffness harmonic analysis is used to analyze the assembled folded plate system. The interaction forces between the folded plate system and the interior diaphragms or supports are found using a force method by satisfying the required compatibility conditions. Loads and interaction forces may be approximated by up to 100 non-zero terms of the appropriate Fourier series. The final results are found by summing the solutions for the known loads and the redundant forces. Several numerical examples are presented to demonstrate the use of the program. A user's guide and a FORTRAN listing are also appended to the report.

KEY WORDS

computer program, continuous bridge, curved bridge, curved folded plate, flexible support bent, diaphragm, direct stiffness method, force method, harmonic analysis, finite strip method, shells of revolution, structural analysis.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

In California, straight, skew and curved, multi-cell reinforced and prestressed concrete box girder bridges have been widely used both as simple span and continuous structures (Fig. 1.1). The typical cross-section of a concrete box girder bridge (Fig. 1.1c) consists of a top and bottom slab connected monolithically by vertical webs to form a cellular or box-like structure. In some cases sloping or curved exterior webs are also used. Transverse diaphragms are placed at the end and interior support sections and sometimes, additional interior diaphragms are utilized between supports. Detailed information on research on box girder bridges conducted at the University of California, including listings of computer programs developed, may be found in a series of published research reports [1 - 19] and technical papers [20 - 32]. The analysis of curved box girder bridges forms one part of this research program.

A curved prismatic box girder bridge, circular in plan (Fig. 1.2a), may be considered to be made up of segments of conical frustra (Fig. 1.2b). Because of their complexity and the lack of an available rational analysis, these bridges have been designed using simplified approximate methods. A common procedure is to ignore the curvature and analyze an equivalent straight bridge taking the curved centerline length as the effective span. When curvature is taken into account, elementary curved beam theory is used in which the entire bridge cross-section is treated as a beam section. As an alternative, the curved bridge system may be approximated by a series of short straight one-dimensional beam segments and analyzed as a three-dimensional frame using one of the standard available computer programs for this purpose.

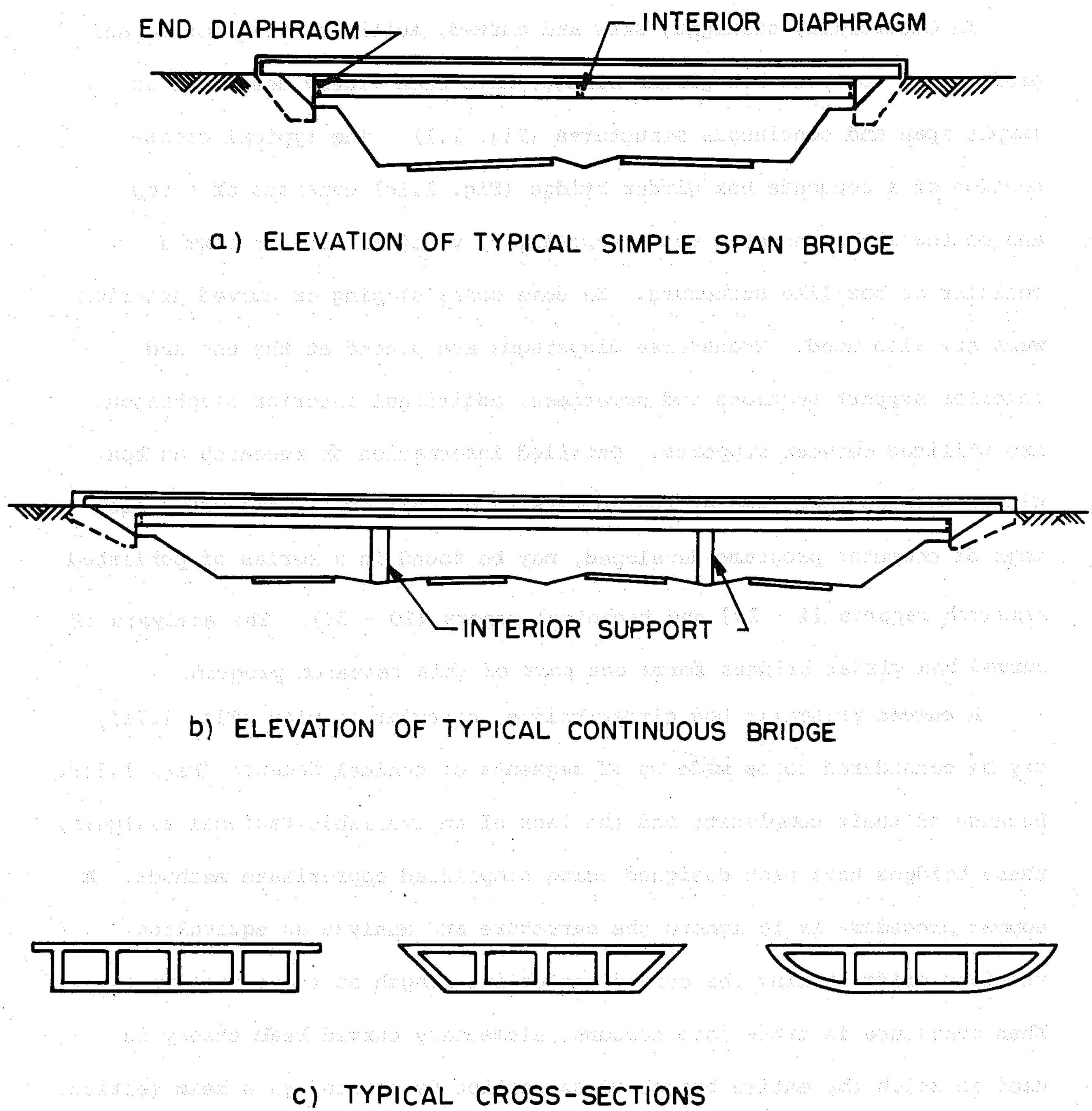


FIG. 1.1 MULTI-CELL BOX GIRDER BRIDGES

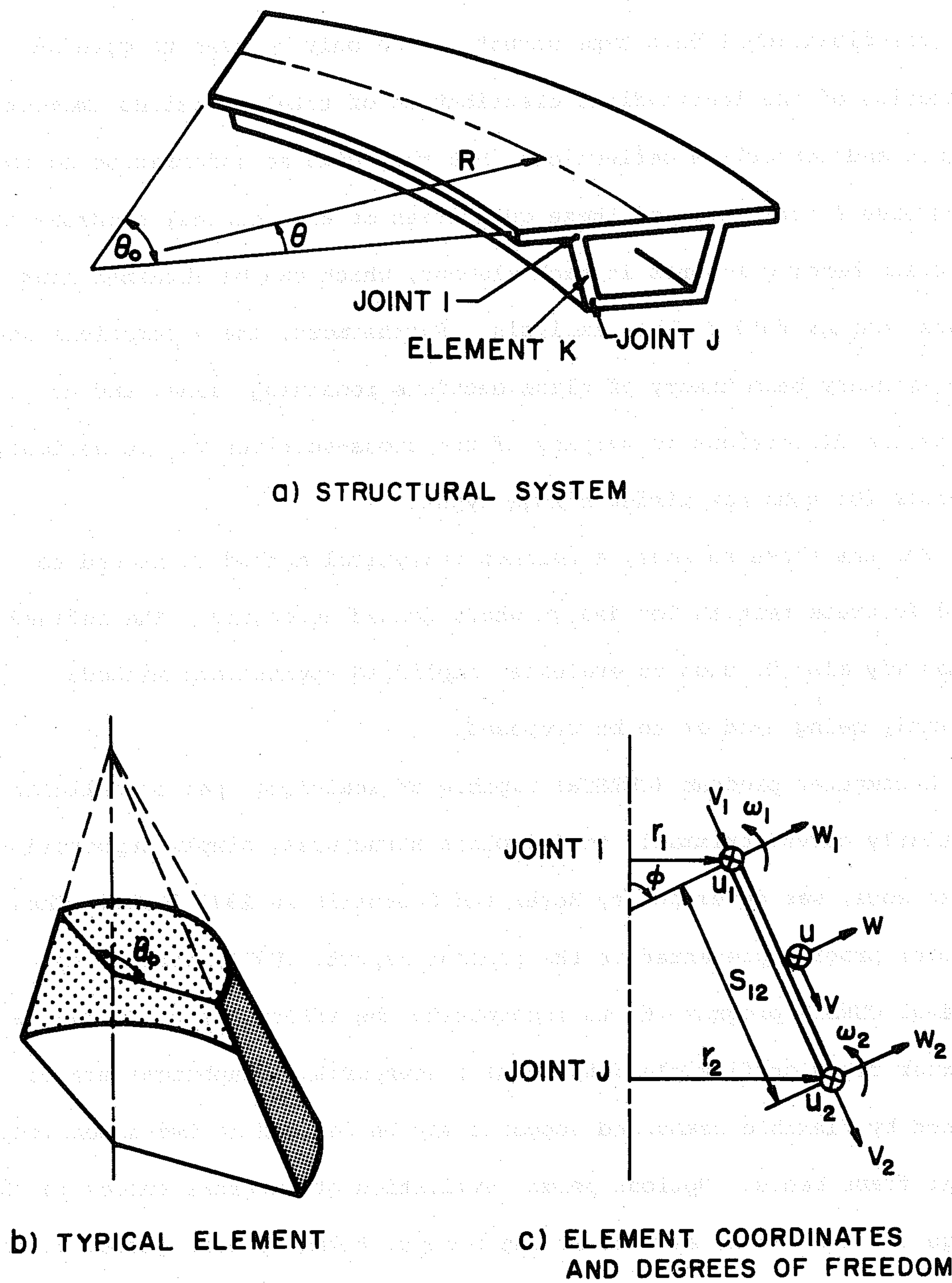


FIG. 1.2 CIRCULARLY CURVED PRISMATIC BOX GIRDER BRIDGE

It is obvious that analyses based on an idealization of the bridge as a one-dimensional beam type structure can only be used to give an indication of the longitudinal distribution of total reactions, moments, torques and centerline deflections, but they give no information on the transverse distribution of these quantities or the internal membrane forces and plate bending moments in each element, which can be obtained from a more complex folded plate analysis. Furthermore, the assumptions used in elementary beam theory of plane sections remaining plane, and no transverse distortions or warping of the cross-sections may be seriously in error for some box girder bridge types.

For the above reasons, a refined analytical method is needed to yield accurate results for design where deemed necessary. The refined method may also be used to evaluate simplified approximate methods presently being used or to be proposed.

A computer program (CURSTR) capable of analyzing open or cellular, circularly curved prismatic folded plate structures, simply supported at two ends, was developed by Meyer and Scordelis in 1970 [6,8]. The computer program presented in the present report, CURDI, extends the original CURSTR program [6] to incorporate the effects of up to twelve interior rigid or flexible diaphragms or supports. Diaphragms may be defined by flexible beams, and supports may be defined by two-dimensional planar frame bents. Options permit evaluation of internal forces in the bridge and the bents, as well as the moments taken by each girder of the bridge cross-section. The program is restricted to the analysis of prismatic structures which may have interior supports, but must be simply supported at the extreme ends by radial diaphragms, rigid in their own plane, but perfectly flexible normal to their own plane. These end diaphragms are restrained against any displacement in their own plane. The material of each plate element making up the cross-section may either be isotropic or orthotropic and is assumed to be homogeneous and linearly elastic.

2. METHOD OF ANALYSIS

2.1 General Remarks

For a curved prismatic box girder bridge (Fig. 1.2a), the problem to be solved is the determination of the internal forces and displacements in a structural system consisting of an assembly of longitudinal plate elements interconnected at joints along their longitudinal edges and simply supported at the two ends by transverse diaphragms. The known quantities input into the problem include the geometry, dimensions and material properties of the plate elements, the surface and joint loadings and the boundary conditions along the longitudinal joints. Each plate element selected is assumed to extend longitudinally over the entire span and transversely between designated joints on the cross-section. A typical element (Fig. 1.1b), in general, may be a segment of a conical frustrum. The simple supports at the two end diaphragms infer that at these radial sections the plate elements experience no horizontal displacements in a radial direction, no vertical displacements and no rotations about a longitudinal axis.

An analysis for applied loads with any arbitrary circumferential distribution along the curved circular bridge may be performed using a harmonic analysis. The applied loads are first resolved into Fourier series components. An analysis is carried out for all loading components of each particular harmonic and then the final results are obtained by summing the results for all harmonics used to represent the load. Once the solution technique, which involves extensive computations, has been developed for a single harmonic, it can be reused for any harmonic, and thus the method is ideally suited to the application of a digital computer.

For each harmonic, each joint has four degrees of freedom; it can displace vertically and horizontally in the plane of the cross-section; it can move longitudinally tangent to the joint; and it can rotate about an axis tangent to the joint. These directions define a global coordinate system for displacements or forces at the joint. The well known direct stiffness method can be used to perform the analysis for each harmonic.

2.2 Solution for a Simply Supported Curved Prismatic Folded Plate Structure

The solution is closely related to the finite strip analysis of plate type structures and also to the finite element analysis of shells of revolution under non-axisymmetric loads. This method is called the "curved strip method" and is described in detail by Meyer [8].

Provided a stiffness matrix can be derived for a typical curved strip element, which relates the generalized joint displacements and forces, it is possible to then apply the direct stiffness method to solve for the unknown generalized joint displacements.

The actual steps in the analysis procedure can be summarized as follows:

1. Replace all surface or line loads distributed across the width of a curved strip element by a set of equivalent nodal joint loads and transform their components to the global system.
2. Resolve all the loads to which the structure is subjected into Fourier series and form the loading vector by adding all load contributions for one typical harmonic of the series. The dimension m of this vector equals four times the number of joints in the structure.

3. Calculate the 8 x 8 stiffness matrix of each curved strip element in the element coordinate system (Fig. 1.2c) for a typical harmonic of the Fourier series.
4. Transform each element stiffness to global coordinates, so that the structure stiffness matrix may be assembled according to the principles of the well known direct stiffness method. This m x m matrix, in conjunction with the loading vector, constitutes the set of equilibrium equations for a typical harmonic of the Fourier series expansion.
5. Solve the system of equations for the unknown joint displacements which actually are the amplitudes of the displacement functions for the respective harmonic term.
6. Transform the joint displacements back to the element coordinates in order to determine the edge displacements to which each curved strip element is subjected.
7. For the edge displacements of this particular harmonic, calculate the internal forces in each curved strip element.
8. Repeat all of the above steps for each harmonic of the Fourier series and sum up the contributions of each term in order to obtain the final displacements and internal stress resultants throughout the structure.

For the analysis, the following assumptions are made:

1. The thickness of each curved strip element is constant and small compared with the other strip dimensions.
2. Straight lines which are perpendicular to the middle surface of the undeformed element remain straight and perpendicular to the deformed middle surface.

3. The material is homogeneous and linearly elastic, with orthotropic properties which are constant throughout any one element.

However, material property and thickness variations in the radial direction may be approximated by further subdividing each plate into curved strips and assigning different properties to each of them such as to simulate the true variation of the element properties.

2.2.1 Element Stiffness Matrix

The key step in the analysis is the derivation of the 8 x 8 stiffness matrix for a general conical shell segment (Fig. 1.2c) in the n'th mode of the harmonic series.

The three displacement components of a general conical shell segment (Fig. 1.1c) are assumed to vary as

$$
\begin{aligned}
u &= \sum_{n=1}^{N} u_n \cos\frac{n\pi\theta}{\theta_o} = \sum_{n=1}^{N} < \Phi_u(\eta) > \{u_i\}_n \cos\frac{n\pi\theta}{\theta_o} \\
v &= \sum_{n=1}^{N} v_n \sin\frac{n\pi\theta}{\theta_o} = \sum_{n=1}^{N} < \Phi_v(\eta) > \{v_i\}_n \sin\frac{n\pi\theta}{\theta_o} \qquad (2.1) \\
w &= \sum_{n=1}^{N} w_n \sin\frac{n\pi\theta}{\theta_o} = \sum_{n=1}^{N} < \Phi_w(\eta) > \{w_i\}_n \sin\frac{n\pi\theta}{\theta_o}
\end{aligned}
$$

where

$$
\{u_i\}_n = \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix}_n \qquad \{v_i\}_n = \begin{Bmatrix} v_1 \\ v_2 \end{Bmatrix}_n \qquad \{w_i\}_n = \begin{Bmatrix} w_1 \\ w_2 \\ \omega_1 = \left.\frac{\partial w}{\partial \eta}\right|_1 \\ \omega_2 = \left.\frac{\partial w}{\partial \eta}\right|_2 \end{Bmatrix}_n \qquad (2.2)
$$

are the displacement amplitudes at the nodal joints 1 and 2 for a typical harmonic term n, and

$$<\Phi_u(\eta)> \;=\; <\Phi_v(\eta)> \;=\; \frac{1}{2} <(1-\eta) \quad (1-\eta)> \tag{2.3a}$$

$$<\Phi_w(\eta)> \;=\; \frac{1}{4} <(2-3\eta+\eta^3) \quad (2+3\eta-\eta^3) \quad \frac{s_{12}}{2}(1-\eta-\eta^2+\eta^3) \quad \frac{s_{12}}{2}(-1-\eta+\eta^2+\eta^3)> \tag{2.3b}$$

are the displacement interpolation polynomials, with the natural coordinate η defined such that $\eta = -1$ at joint 1 and $\eta = +1$ at joint 2.

The accuracy of the analysis can be expected to increase if the linear transverse variation for the in-plane displacements u and v assumed in Eq. 2.3 is changed to vary quadratically over the width of one element, i.e., if

$$\{u_i\}_n = \begin{Bmatrix} u_1 \\ u_2 \\ u_0 \end{Bmatrix}_n \qquad \{v_i\}_n = \begin{Bmatrix} v_1 \\ v_2 \\ v_0 \end{Bmatrix}_n \tag{2.4}$$

and

$$<\Phi_u(\eta)> \;=\; <\Phi_v(\eta)> \;=\; <\frac{1}{2}(1-\eta) \quad \frac{1}{2}(1+\eta) \quad (1-\eta^2)> \tag{2.5}$$

where u_o and v_o are the in-plane displacement degrees of freedom associated with the joint halfway between joints 1 and 2. However, in the computer program version presented in this report, only the theory based on linear in-plane displacement functions is used.

After the displacement shape functions are assumed, the stiffness of each strip for n'th harmonic can be obtained as described in detail by Meyer [8]. The stiffness terms are in integral form and are evaluated numerically by an 8'th order Gaussian quadrature formula.

Similarly the external loads are developed into Fourier series,

$$p \;=\; \sum_{n=1}^{N} p_n(\eta) \sin \frac{n\pi\theta}{\theta_o} \tag{2.6}$$

Distributed surface loads are converted into consistent joint loads such that the work done by these consistent nodal loads going through the joint displacements equals the work done by the distributed loads going through the assumed displacement field.

An important distinction should be noted between the curved strip method, which is essentially a finite element method, and the folded plate elasticity method used previously for straight bridges [1,13]. In the latter case the nodal point loads, R_i, and the element edge forces, S_i, are defined as actual forces in terms of the amplitude intensity of a particular harmonic, therefore in lb per ft or equivalent units. In the curved strip method, R_i and S_i are generalized nodal forces in lbs, which when multiplied by the nodal displacements in ft, do the same virtual work as the actual forces distributed along the longitudinal joints do in going through the joint displacement field. A nodal point displacement, v_i, is the amplitude of the harmonic displacement in ft.

2.3 Solution for a Curved Prismatic Folded Plate Structure Supported by Flexible Planar Frame Bents

The method used previously for straight bridges and described in detail in an earlier report by Lin and Scordelis [13] is also employed for curved bridges. Thus, only a brief outline of the approach will be given here.

A force method is used to analyze the structure, such that compatibility between the folded plate system and the support bent (Fig. 2.1) is maintained. The interaction forces between the folded plates and the supporting frame bent are chosen as the redundants (Fig. 2.1d). Two

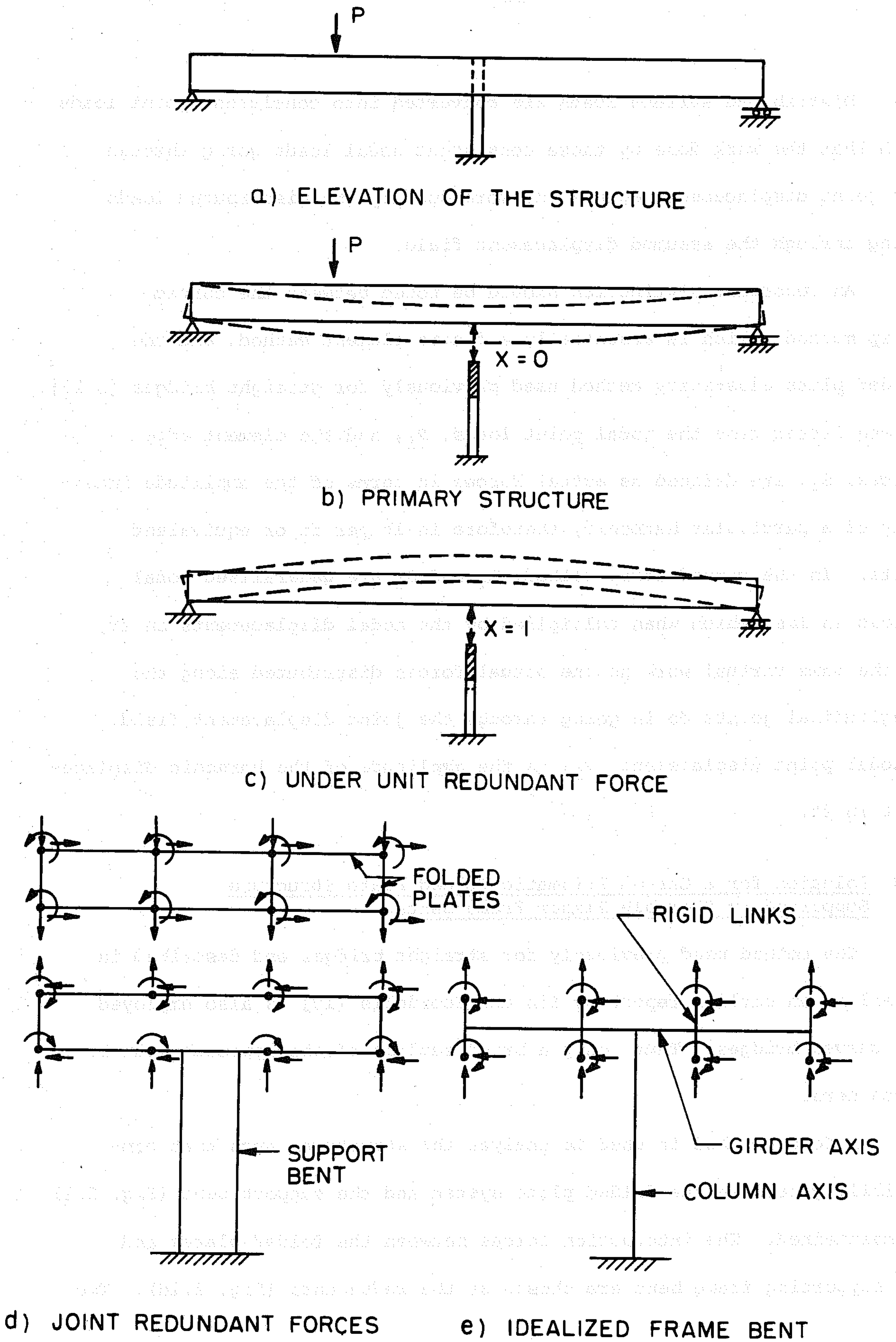


FIG. 2.1 ANALYSIS OF A FOLDED PLATE STRUCTURE ON A FLEXIBLE BENT

approximations have been made to simplify the solution procedure. First, it is assumed that the interaction forces act only at the nodes of the folded plate system, while in reality they are distributed over the contact surface between the folded plates and the bent diaphragms. Second, the longitudinal interaction forces between the folded plates and the bent system are not included. Thus, the interaction forces are represented by a set of three joint forces at each longitudinal joint (Fig. 2.1d), consisting of vertical, horizontal and rotational components in the plane of transverse cross-section.

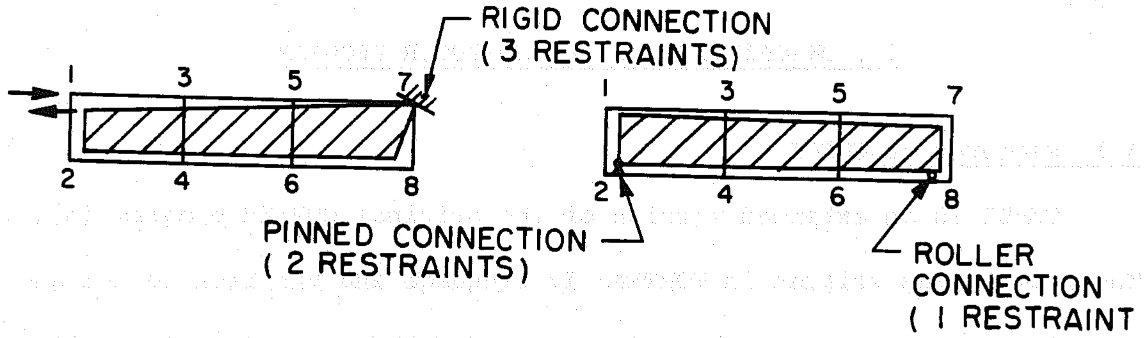
Since the interior support bents are idealized as two-dimensional planar frames, they cannot take loads normal to their plane. The idealization of a typical support bent with a transverse girder (diaphragm) and a single column (Fig. 2.1d) is illustrated in Fig. 2.1e as a planar frame with fictitious vertical rigid links connecting the girder elastic axis to the joints of the folded plate system. In the execution of the solution, very high values of modulus of elasticity may be used for these fictitious elements to simulate rigid links.

2.4 Solution of a Curved Prismatic Folded Plate Structure with Interior Flexible Diaphragms

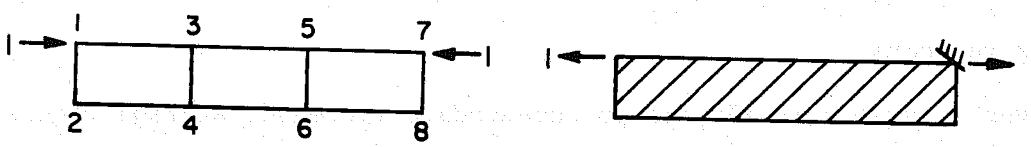
Once again the method used is similar to that described in detail for straight bridges in an earlier report [13]. Only a brief outline will be given here.

Again, a force method is used to analyse the structure, so as to maintain compatibility between the folded plate system and the diaphragms. The diaphragms are idealized as transverse beams in their own plane with zero stiffness normal to their plane. It is assumed that the diaphragms are connected to the folded plate structure at the longitudinal joints only by three interaction forces, namely, the vertical, horizontal and rotational components in the plane of the transverse diaphragm (Fig. 2.3a).

Since the diaphragms are not externally supported they undergo two kinds of displacements when subjected to the interaction forces, first, three degrees of rigid body motion in their own plane, and second, deformations of the diaphragm itself. These conditions require that the interaction forces acting on the diaphragm must be in self-equilibrium. A system of self-equilibrating forces is generated by assuming initial connections between the diaphragm and folded plate system (Fig. 2.2). The diaphragm may be idealized as an assemblage of one dimensional beam elements (Fig. 2.3) having boundary conditions consistent with its initial connection to the folded plate system. Each beam element is defined by the properties along the elastic axis of the diaphragm. It is assumed that plane sections remain plane in defining displacements, at the interaction points at the top and bottom of the diaphragm (Fig. 2.3a). A force method of analysis is used to analyze this total system such that under the action of the applied loads and the interaction forces compatibility of displacement is maintained at the interaction points between the folded plate structure and the diaphragms.



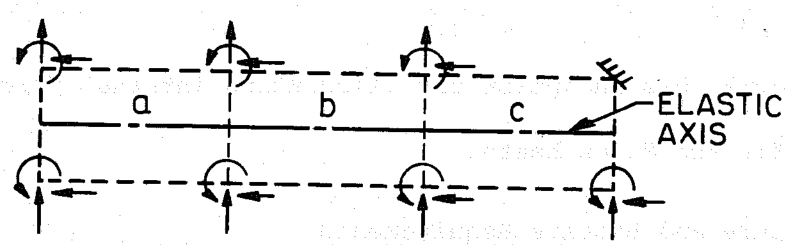
a) TYPES OF INITIAL CONNECTIONS OF DIAPHRAGM TO FOLDED PLATE SYSTEM



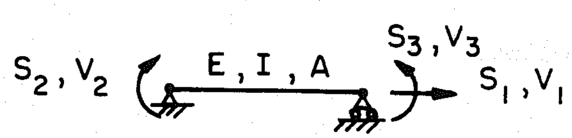
b) INTERACTION FORCES ON FOLDED PLATES

c) INTERACTION FORCES ON DIAPHRAGM

FIG. 2.2 INTERACTION BETWEEN DIAPHRAGM AND FOLDED PLATE SYSTEM



a) IDEALIZED FLEXIBLE DIAPHRAGM



b) TYPICAL BEAM ELEMENT a , b OR c

FIG. 2.3 ANALYSIS OF THE FLEXIBLE DIAPHRAGM

3. DESCRIPTION OF THE COMPUTER PROGRAM

3.1 Features of CURDI

CURDI is an extended version of the original CURSTR program [6]. The program was written in FORTRAN IV language and has been tested on the CDC 6400 computer at the University of California, Berkeley. It provides a rapid solution for a prismatic folded plate structure simply supported at the two ends and having up to 12 interior flexible diaphragms or flexible support bents. This program differs from CURSTR in the following respects.

1. An overlay system is adopted to accommodate increased storage requirements and to make more efficient use of the storage facility.
2. The program can incorporate the effects of interior diaphragms and interior supports (maximum of 12). The diaphragms may be either rigid or flexible. Interior supports for joints of the folded plate system may be rigid or consist of a two-dimensional planar frame bent.
3. The program has an option for calculating internal forces and displacements for the frame bents.

3.2 Structure and Storage Requirements

The program consists of a main overlay and seven primary overlays. Each primary overlay consists of a group of subroutines. Their structure may be outlined as follows:

Main Overlay (0,0)
CURDI

- Overlay (1,0) - Subroutines MAIN, CONE, LOADS, BANSOL
- Overlay (2,0) - Subroutines FORMF, SIMSUM, CORF1
- Overlay (3,0) - Subroutines FRAME, ELSTIF, STIFF, STACON, SYMINV
- Overlay (4,0) - Subroutine FLEXD
- Overlay (5,0) - Subroutines CORF2, ISIMEQ
- Overlay (6,0) - Subroutines EDGDIS, PLFOR, PINVAL, OPRINT, MOMPER, ADDM
- Overlay (7,0) - Subroutine FORCE

The main overlay remains in memory during execution while the seven primary overlays are called consecutively into memory by the main overlay. Loading of a primary overlay onto memory destroys the previously loaded primary overlay. The card decks of the overlays must be in strict order, however, the order of the subroutines within each overlay is immaterial.

The field length required for running the program on the CDC 6400 computer at the University of California, Berkeley is $(130,616)_8 \approx (45,500)_{10}$. The storage allocation for each overlay may be tabulated as follows

TABLE 3.1 - STORAGE REQUIREMENTS FOR CURDI PROGRAM

Overlays	Required Storage for the Overlay	Required Storage for the Execution*
OVERLAY (0,0)	$(23,600)_8$	
OVERLAY (1,0)	$(64,430)_8$	$(110,230)_8$
OVERLAY (2,0)	$(55,424)_8$	$(101,224)_8$
OVERLAY (3,0)	$(43,674)_8$	$(67,474)_8$
OVERLAY (4,0)	$(36,724)_8$	$(62,524)_8$
OVERLAY (5,0)	$(54,671)_8$	$(100,471)_8$
OVERLAY (6,0)	$(64,763)_8$	$(110,563)_8$
OVERLAY (7,0)	$(40,625)_8$	$(64,425)_8$

* Required Storage for the Execution = Required Storage for the Particular Overlay + Required Storage for OVERLAY (0,0).

Required Program Field Length = Max. (Required Storage for the Execution) + Field Length for Loader = $(130,616)_8$

3.3 Descriptions of Overlays and Flow Chart

Brief descriptions of each primary overlay are presented below and a condensed flow chart of the Program is given in Fig. 3.1.

OVERLAY (1,0) - Read and print input data. Resolve external load and unit interaction forces into equivalent nodal loads. Analyze the primary structure for each harmonic. Form the displacement matrix δ_o for the external loads and the interaction forces.

OVERLAY (2,0) - Form the flexibility matrix F_1. Find the transformed $\bar{F}_1$ and $\bar{\delta}_o$ matrices.

OVERLAY (3,0) - Analyze each type of frame bent by direct stiffness method. Form their flexibility matrices F_2.

OVERLAY (4,0) - Form the flexibility matrix $\overline{F}_2$ for each type of flexible interior diaphragm.

OVERLAY (5,0) - Form the total structure flexibility matrix by summing up the flexibility matrices. Solve for redundant forces.

OVERLAY (6,0) - Calculate and print final joint displacements and internal forces for each plate element. Calculate the girder moments by integrating the stresses.

OVERLAY (7,0) - Calculate the joint displacements, member end forces and support reactions for the frame bents.

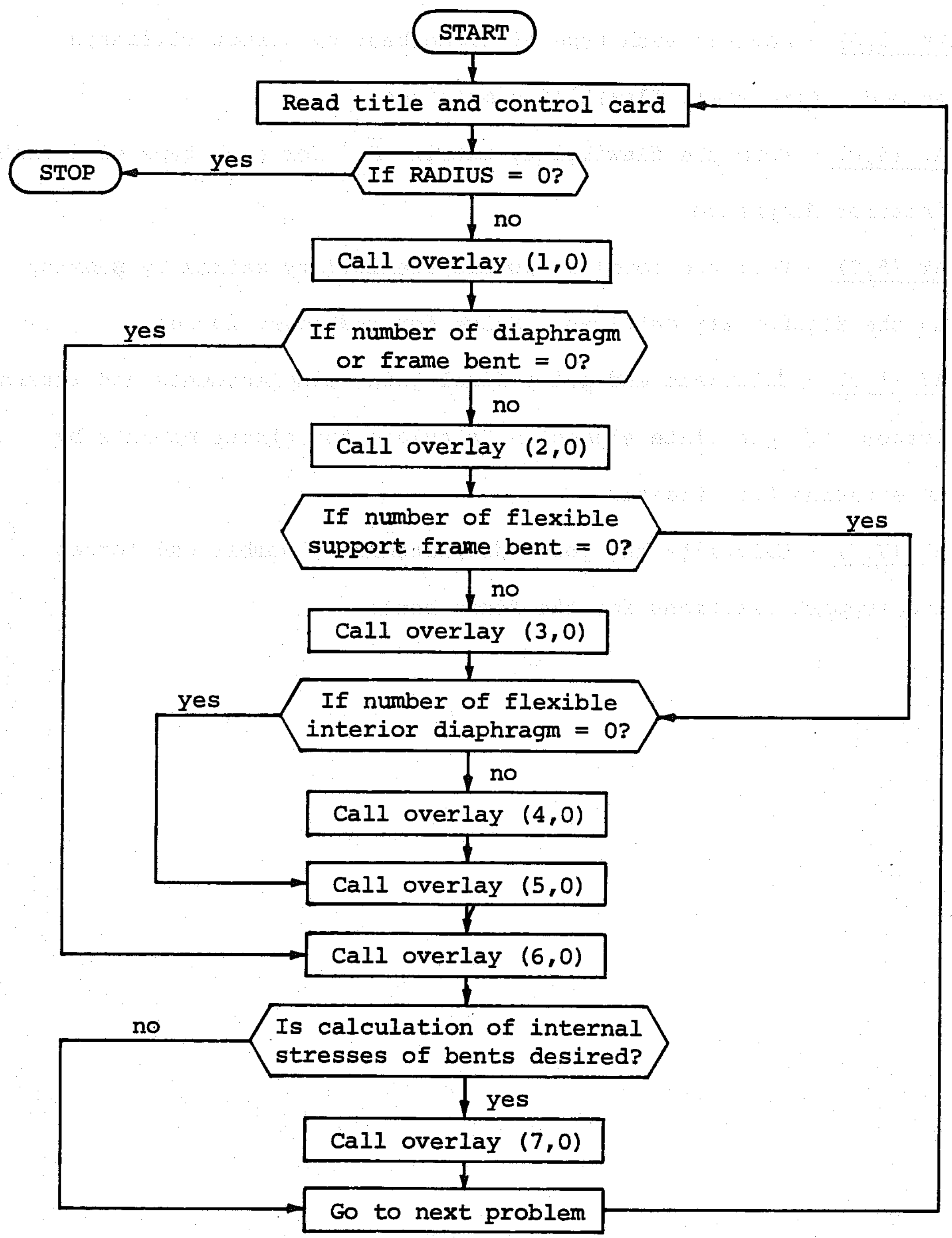


FIG. 3.1 FLOW CHART FOR CURDI

4. COMPUTER PROGRAM USAGE

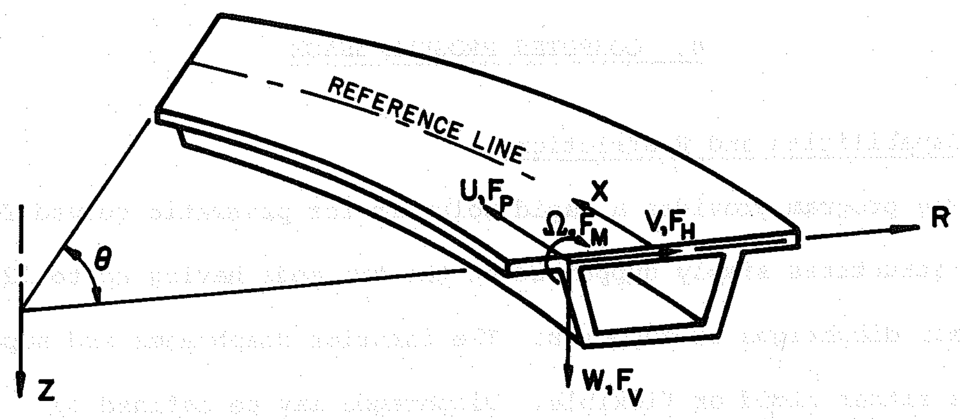
4.1 Capabilities and Restrictions

The program provides a rapid solution for prismatic curved folded plate structures simply supported at the two ends having up to 12 interior diaphragms or supports. The interior diaphragms and supports may be either rigid or flexible. Diaphragms may be defined by flexible beams, and supports may be defined by two-dimensional planar frame bents. The number of interior diaphragms or supports is further restricted by the number of interaction forces which is limited to 120. The two end supports are equivalent to idealized end diaphragms which do not permit any displacements within their plane but offer no resistance to displacements normal to their plane.

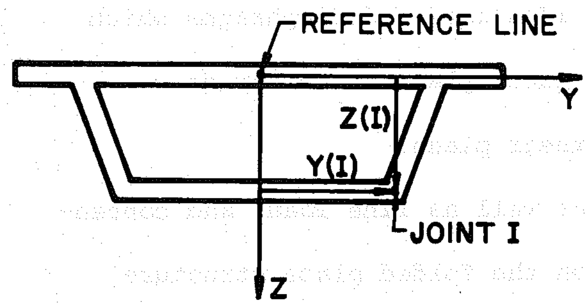
Uniform or partial surface loads, as well as line loads and concentrated loads, may be applied anywhere on the folded plate structure and treated as a single load case. Because of the solution technique used, which involves the summing of the results for all of the harmonics used to represent the loading for a particular load case, each new load case is treated as a new problem. Therefore, multiple load cases on a given structure cannot be analyzed simultaneously in the same problem.

Restrictions as to the maximum number of plates, joints, diaphragms, terms of Fourier series, type of frame bents, etc., are given under user's guide in Appendix A.

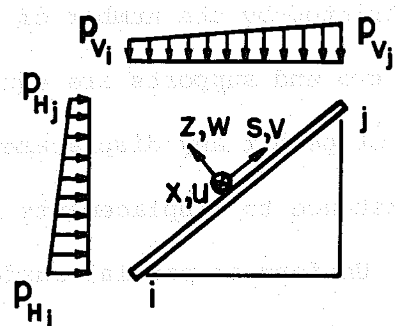
The structure to be analyzed is defined by introducing a circumferential reference line, which may in general have an arbitrary location, provided its radius is nonzero (Fig. 4.1a). The cross-section is



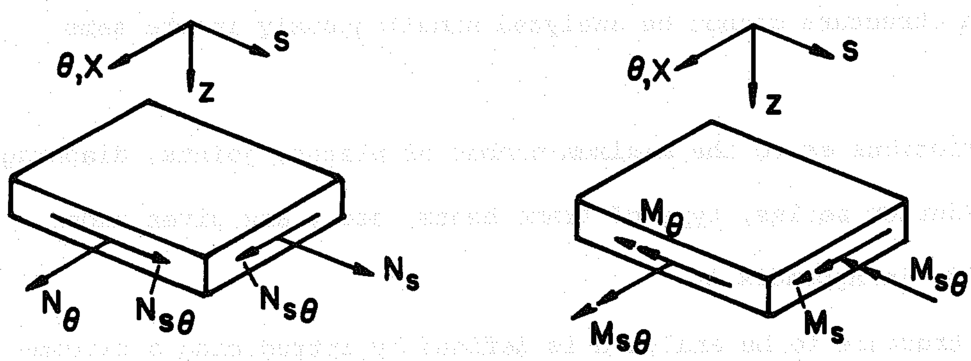
a) GLOBAL JOINT DISPLACEMENTS U,V,W,Ω AND JOINT LOADS F_P, F_H, F_V, F_M



b) JOINT COORDINATES



c) SURFACE LOADS AND ELEMENT DISPLACEMENTS



d) INTERNAL FORCES AND MOMENTS

FIG. 4.1 SIGN CONVENTIONS

then defined by specifying for each nodal joint I a Y- and Z-coordinate as shown in Fig. 4.1b.

A typical element is then defined by specifying the joint numbers I and J. In general, an element is a segment of a conical frustrum. The material law relating stress resultants and strains is assumed to be uniform but polar-orthotropic throughout the element.

$$\begin{Bmatrix} N_s \\ N_\theta \\ N_{s\theta} \\ M_s \\ M_\theta \\ M_{s\theta} \end{Bmatrix} = \begin{bmatrix} \frac{t^m E_s^m}{1-\nu_{s\theta}^m \nu_{\theta s}^m} & \nu_{\theta s}^m \frac{t^m E_\theta^m}{1-\nu_{s\theta}^m \nu_{\theta s}^m} & 0 & 0 & 0 & 0 \\ \nu_{s\theta}^m \frac{t^m E_s^m}{1-\nu_{s\theta}^m \nu_{\theta s}^m} & \frac{t^m E_\theta^m}{1-\nu_{s\theta}^m \nu_{\theta s}^m} & 0 & 0 & 0 & 0 \\ 0 & 0 & t^m G^m & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{(t^b)^3 E_s^b}{12(1-\nu_{s\theta}^b \nu_{\theta s}^b)} & \nu_{\theta s}^b \frac{(t^b)^3 E_\theta^b}{12(1-\nu_{s\theta}^b \nu_{\theta s}^b)} & 0 \\ 0 & 0 & 0 & \nu_{s\theta}^b \frac{(t^b)^3 E_s^b}{12(1-\nu_{s\theta}^b \nu_{\theta s}^b)} & \frac{(t^b)^3 E_\theta^b}{12(1-\nu_{s\theta}^b \nu_{\theta s}^b)} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{(t^b)^3 G^b}{12} \end{bmatrix} \begin{Bmatrix} \varepsilon_s \\ \varepsilon_\theta \\ 2\varepsilon_{s\theta} \\ \kappa_s \\ \kappa_\theta \\ 2\kappa_{s\theta} \end{Bmatrix} \quad (4.1)$$

or symbolically,

$$\begin{Bmatrix} N_s \\ N_\theta \\ N_{s\theta} \\ M_s \\ M_\theta \\ M_{s\theta} \end{Bmatrix} = \begin{bmatrix} d_{11} & d_{12} & 0 & 0 & 0 & 0 \\ d_{21} & d_{22} & 0 & 0 & 0 & 0 \\ 0 & 0 & d_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & d_{44} & d_{45} & 0 \\ 0 & 0 & 0 & d_{54} & d_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & d_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_s \\ \varepsilon_\theta \\ 2\varepsilon_{s\theta} \\ \kappa_s \\ \kappa_\theta \\ 2\kappa_{s\theta} \end{Bmatrix} \quad (4.2)$$

where the superscript "m" denotes "membrane" or in-plane characteristics, and superscript "b" denotes "bending" properties, t is the element thickness, E and G the elastic and shear modulus, and ν Poisson's ratio. Subscripts s and θ indicate the radial and circumferential directions, respectively. Note that symmetry of Eq. (4.1) must be preserved so that

$$\nu^m_{s\theta} = \frac{E^m_\theta}{E^m_s}\nu^m_{\theta s}$$

and (4.3)

$$\nu^b_{s\theta} = \frac{E^b_\theta}{E^b_s}\nu^b_{\theta s}$$

The commonly used isotropic, homogeneous material law follows from Eq. (4.1) by setting

$$E^m_s = E^m_\theta = E^b_s = E^b_\theta = E$$

$$\nu^m_{s\theta} = \nu^m_{\theta s} = \nu^b_{s\theta} = \nu^b_{\theta s} = \nu$$

$$G^m = G^b = G = \frac{E}{2(1+\nu)}, \qquad t^m = t^b = t$$

4.2 Input and Output

The program has been written such that the material law can be input in either of two ways.

a) Input all of the following element properties

$$t^m,\ t^b,\ E^m_s,\ E^b_s,\ E^m_\theta,\ G^m,\ G^b,\ \nu^m_{\theta s},\ \nu^b_{\theta s}$$

for each "plate type" which is defined by a unique set of the above quantities.

b) Input the constitutive relations directly in the form of

$$d_{11},\ d_{12},\ d_{22},\ d_{33},\ d_{44},\ d_{45},\ d_{55},\ d_{66}$$

i.e., specify all independent elements of the constitutive matrix in

Eq. 4.2 directly, thus also completely defining a plate type. The number of different plate types is restricted to a maximum of 30.

This input option gives the user much freedom in defining his constitutive relations. Stiffeners in either direction and different amounts of reinforcement may be taken into account. In complex situations, the d-coefficients may be determined experimentally.

The structure may be subjected to surface or joint loads. Surface loads vary linearly over the width of an element and are constant over a specified portion of the circumferential length of the element. In this case they are referred to as "partial surface loads." Similarly, joint loads may also extend uniformly over the whole length of a joint or over only a fraction of it, in which case they are referred to as "partial joint loads."

The program has an option to suppress all even terms in the Fourier series whenever the applied loads are symmetric about the midspan section. Similarly, if the loads are anti-symmetric about the midspan section, as for example prestress forces applied at the end of the structure, all odd harmonics may be suppressed. If the structure is a full 360° axisymmetric shell subjected to axisymmetric loading, the Fourier analysis degenerates such that only the zero-th harmonic is retained, and the program has been written to incorporate this special case.

For various reasons it might be of interest to study the results not only for a specified final sum of harmonic series contributions, but also intermediate results. For this purpose, it is possible, by specifying, for example, the total number of harmonics to be used as 50, to print internal element forces and displacements also after only say

10 or 20 or 30 terms of the respective Fourier series have been accumulated, or any other combination of harmonics smaller than 50.

The question of how many Fourier terms should be used to represent the loading depends on the type of loading and on the desired output quantities. Deflections usually converge very rapidly, and 5 to 10 nonzero harmonic terms are sufficient to describe most loading types. Stresses and moments do not converge as fast, especially for concentrated loads in which case at least 40 nonzero terms may be necessary for adequate accuracy.

For input/output labelling, the user has the option to specify the circumferential coordinates either in angular degrees or in arc lengths. For strongly curved structures, the user might prefer the angle option, while for large curvature radii, the arc option will usually be more convenient. If use of the arc is made, care has to be taken that the longitudinal position of a concentrated or line load is specified along the joint where the load is acting and not along the reference line unless they coincide.

In analyzing curved bridge structures, it is often useful to know the moment that each individual girder contributes to the total statical moment at any section. In fact, the sum of these girder moments should add up to the statical moment due to the applied loads. This useful check is obtained by means of the "moment integration" option. Individual girder moments due to normal stress resultants as well as longitudinal plate bending moments may be printed out at any section for which stress and displacement output is available, together with the net compressive and tensile stress resultants within each girder.

Detailed descriptions of the input, output, restrictions, and sign conventions are given in Appendix A. A brief description of input and output options is given below.

The required input data includes:

(1) The geometry and dimensions of the structure in terms of the centerline radius, angle in degrees or arc length along reference line between end supports, number of plates, joints, diaphragms, supporting frame bents, and cross-sectional dimensions.

(2) Dimensions and material properties for each plate element.

(3) Magnitudes and locations of uniform and partial surface loads.

(4) Boundary conditions at the longitudinal joints. Any combination of known forces and given zero displacements may be used.

(5) Magnitudes and locations of additional concentrated joint loads.

(6) Location and interaction thickness of each diaphragm or bent, and indices for restraint conditions on each joint.

(7) Geometry, dimensions and material properties of each diaphragm or frame bent.

(8) Desired locations for output of final results.

(9) Neutral axis and division of the cross-section into girders for the calculation of girder moments.

The output consists of the following:

(1) The complete input data is properly labelled and printed as a check.

(2) The interaction joint forces between the diaphragms or bents and the folded plate system are printed.

(3) Resulting joint displacements are given at specified locations.

(4) For each element all internal forces and displacements are printed for each transverse section specified across the plate width and at the X-coordinates (either in terms of arc lengths or angles in degrees) specified along the plate length.

(5) Moment taken by each girder at the specified cross-sections.

(6) For each flexible supporting frame bent the joint displacements, member end forces, applied joint loads and reactions are printed.

4.3 Sign Conventions

The structure is defined in global cylindrical coordinates R,Z,θ as shown in Fig. 4.1a. The Z-axis is defined by the axis of revolution. It has its origin in the plane of the reference line and points downward. The R-axis points from the axis of revolution outward, and the angular θ-coordinate points from one end of the structure towards the other end such that it describes a rotation vector in the negative Z-direction.

External vertical and horizontal loads are positive if acting in the positive Z- and R-directions, respectively. Longitudinal loads and applied moment vectors are positive if acting along a tangential X-axis which is normal to the Z-R plane such that X,R,Z form a right-handed system in that order, Fig. 4.1a.

Joint coordinates within a cross-section are measured in modified global coordinates Y and Z which are positive as shown in Fig. 4.1b.

Joint loads and displacements are positive as shown in Fig. 4.1a. Fig. 4.1c defines positive directions of element surface loads and element displacements, and Fig. 4.1d those of internal forces and moments.

4.4 Special Considerations for the Use of CURDI

If the structure is symmetrical in the longitudinal direction about a transverse midspan plane, a great saving in computing effort may be achieved by taking advantage of the symmetry or anti-symmetry of the loading with respect to this transverse plane, if it exists. For the case of a symmetrical structure subjected to symmetrical loading (Fig. 4.2a), only the odd terms of the Fourier series have to be included. For anti-symmetrical loading (Fig. 4.2b), only the even terms have to be included. This can be accomplished by giving the proper instruction on the control card. It should be noted that the loading includes the external loads as well as the redundant forces from each diaphragm or bent applied individually. Advantage of symmetrical loading can only be taken in a case with only one center bent or diaphragm (Fig. 4.2a). It should be emphasized that no advantage of symmetrical loading may be taken for spans with more than one diaphragm or bent. In these cases all terms of the Fourier series must be used. Advantage of anti-symmetrical loading may be taken only in cases of simple spans with no intermediate diaphragms or bents (Fig. 4.2b).

Since forces are approximated by Fourier coefficients, a suitable number of harmonics must be used to adequately approximate the applied loads and the interaction forces. For design purposes, at least 80 (or 40 nonzero terms in symmetrical cases) should be adopted. A convergence study, in which the problem is run completely two or more times using successively an increasing number of harmonics, is recommended

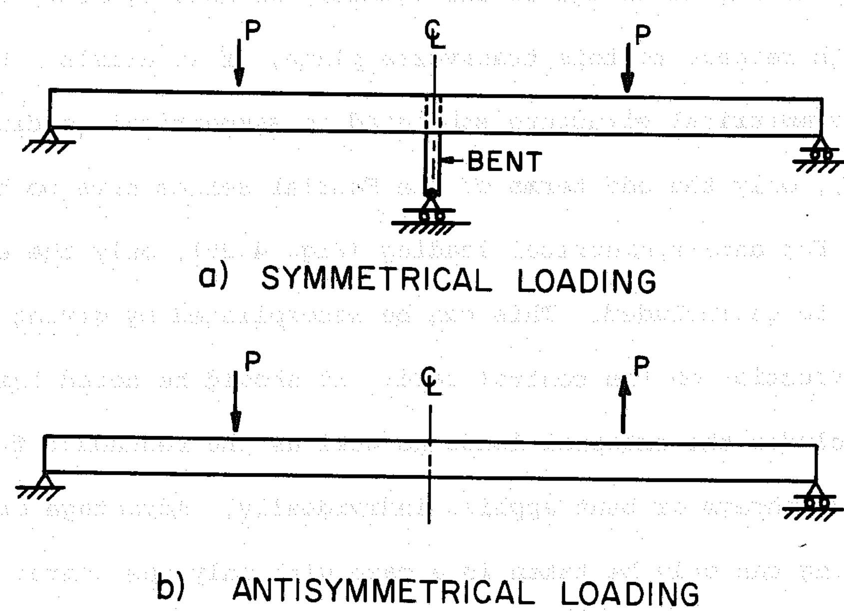


FIG. 4.2 LONGITUDINAL SYMMETRY AND ANTISYMMETRY

whenever detailed information is desired on internal forces and moments in the vicinity of concentrated external loads or interaction redundant forces. See references [8,13] for a further discussion of the convergence problem.

The folded plate system and frame bent are assumed to interact only at discrete points. If the bents are connected continuously to the folded plates, some averaging process has to be used to obtain an appropriate interpretation of the internal forces and moments in the frame bents. This will be illustrated later in Example 4.

Although the program does not give the internal forces in the flexible movable diaphragms, it outputs the interaction forces. The internal forces may be easily calculated by analyzing these diaphragms as beams subjected to the interaction forces. This becomes a simple determinate problem.

5. EXAMPLES

5.1 General Remarks

Four example structures have been analyzed to verify the method of analysis used and the computer program solutions. The examples also demonstrate the capabilities as well as the limitations of the analysis using the computer program CURDI. It should be emphasized that the analysis assumes the structure to be a linear elastic system.

In Example 1, a single span, one cell, box girder bridge model with inclined webs is analyzed. The section consists of a wide concrete top slab acting compositely with a bottom steel box. Comparison of results for a curved bridge, with and without interior diaphragms, and a straight bridge of the same span without interior diaphragms are made to determine the effects of interior diaphragms and bridge curvature.

In Example 2, a straight two-span continuous T-beam bridge is analyzed. Several cases are run, and a comparison of results is made for the bridge with various types of midspan diaphragm conditions and interior support systems. The effects of the flexibility of interior diaphragms or supporting bents is demonstrated. In order to verify the results from CURDI, which is based on a curved strip method, the same cases are run using the previously developed computer program for straight bridges, MUPDI3 [13], which is based on a folded plate elasticity solution. Many previous studies have verified the accuracy of MUPDI3. The CURDI analysis is made assuming a very large radius of curvature for the straight T-beam bridge, so that for all practical purposes it becomes a straight bridge and hence a comparison with the results from MUPDI3 can be made.

In Example 3, a curved, single span, four cell, aluminum box girder bridge model having a midspan diaphragm is analyzed by CURDI. Theoretical results, thus obtained, are then compared with experimental results reported on previously [16]. This serves as an important check on the validity of the analytical model used in CURDI to represent the actual linear elastic system used in the experimental model.

In Example 4, a curved, two span, four cell, continuous concrete box girder bridge is analyzed to demonstrate the practical application of the CURDI program to a typical two lane highway overpass structure. The structure has a single column center bent support and a diaphragm at one midspan but not at the other. The horizontal radius of curvature of the bridge was selected as being the maximum generally encountered in the California highway system.

All computer analyses were made using the CDC 6400 computer at the University of California Computer Center. The CDC 6400 carries approximately 15 significant decimal digits in its arithmetic operations. For computer systems using fewer significant figures, checks should be made with the results given for the Examples in this chapter to determine whether double precision calculations might be necessary. In Section 5.6, a summary for all examples of computer times and costs together with the number of harmonics used is given for comparison purposes. Times and costs on other computer systems will, of course, depend on the computer being used and the rate schedule.

5.2 Example 1 - Single Span, One Cell Box Girder Bridge

A small scale model of a typical composite concrete-steel box girder bridge is analyzed. The cross-sectional dimensions of the model are shown in Fig. 5.1. Note the relatively thick concrete top deck supported by a thin walled steel box, which is typical of this type of construction.

Three cases were analyzed for the same pair of midspan concentrated loads consisting of 0.5 kips above each web.

Example 1A - straight bridge without interior diaphragms

Example 1B - curved bridge without interior diaphragms

Example 1C - curved bridge with interior flexible diaphragms at third points of span

The plan dimensions of the bridges are shown in Fig. 5.3. The straight bridge had a span of 106 in., which was identical to the curved bridge spans measured along the centerline arc. Example 1A was analyzed using a large centerline radius of 10,000 in. in CURDI to closely approximate a straight bridge, while for the curved bridges of Examples 1B and 1C, the actual radius of 187.93 in. was used in CURDI.

The nodal point layout and element properties are given in Fig. 5.2. Centerline dimensions taken from Fig. 5.1 were used, and for simplicity in this study, the steel flange plates at the tops of the webs were omitted in the computer model for ease of comparison. Also indicated in Fig. 5.2 is the division of the cross-section into two girders, an inner girder 1 and an outer girder 2, with reference to the curved bridge. These are used in conjunction with the moment integration options in the computer programs.

Result for displacements, internal forces and moments are presented in Figs. 5.4 to 5.10. The sign conventions for these quantities are given in Fig. 4.1.

The displacements given in Figs. 5.4, 5.5, and 5.6 demonstrate the effects of bridge curvature and the addition of interior diaphragms. The importance of interior diaphragms in curved bridges of this type, which have a rigid top concrete slab on top of a flexible thin walled steel box, is immediately evident in the vertical displacements shown in Figs. 5.4 and 5.5. Comparing the results for the curved (1B) and straight (1A) bridges without diaphragms, it can be seen that the curved bridge has much larger displacements. However, as soon as the interior diaphragms are added to the curved bridge (1C), the results become much closer to those of the straight bridge (1A), with the outer girder of the curved bridge deflecting somewhat more than the inner girder as would be expected. The peculiar result for curved bridge without diaphragms (1B), in which the shorter inner girder has a larger vertical deflection than the longer outer girder, is due to the lack of transverse and torsional stiffness of the flexible thin wall steel box. Fig. 5.6 shows the large horizontal displacement of the bottom steel flange for this case (1B) compared to those in (1A) and (1C). This causes for (1B) larger longitudinal tensile stresses at node 6 and smaller tensile stresses at node 12 as shown in Fig. 5.7. The stress distribution shown in Fig. 5.7 for (1B) is consistent with a larger vertical displacement at the inner girder than at the outer girder. It is evident that there is a complex interaction between the structural elements in bridges of this type, which cannot be predicted by simplified theories. The behavior of a similar cross-section made entirely of concrete with a thick walled, and thus stiff, concrete box on the bottom would be quite different.

The results for the longitudinal forces N_θ (lb/in) shown in

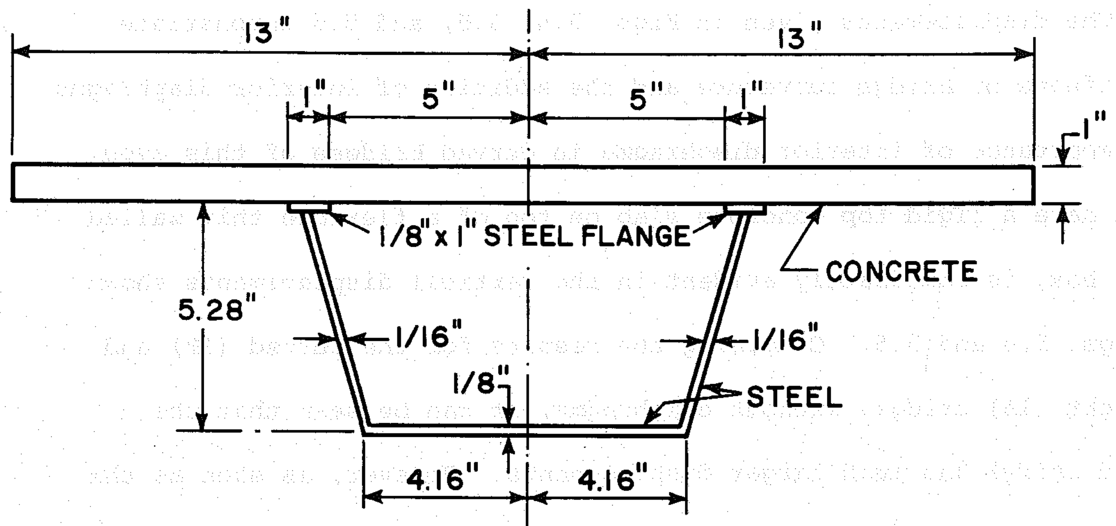


FIG. 5.1 EXAMPLE 1 - TYPICAL MODEL CROSS-SECTION

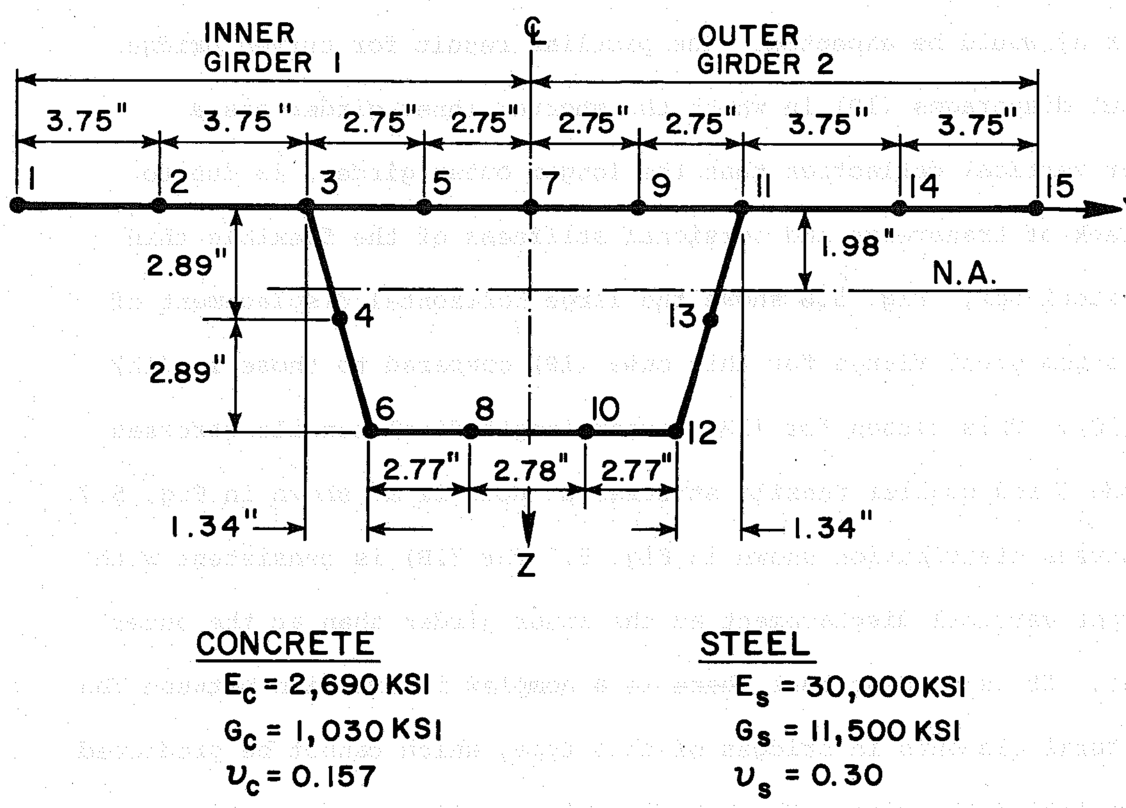
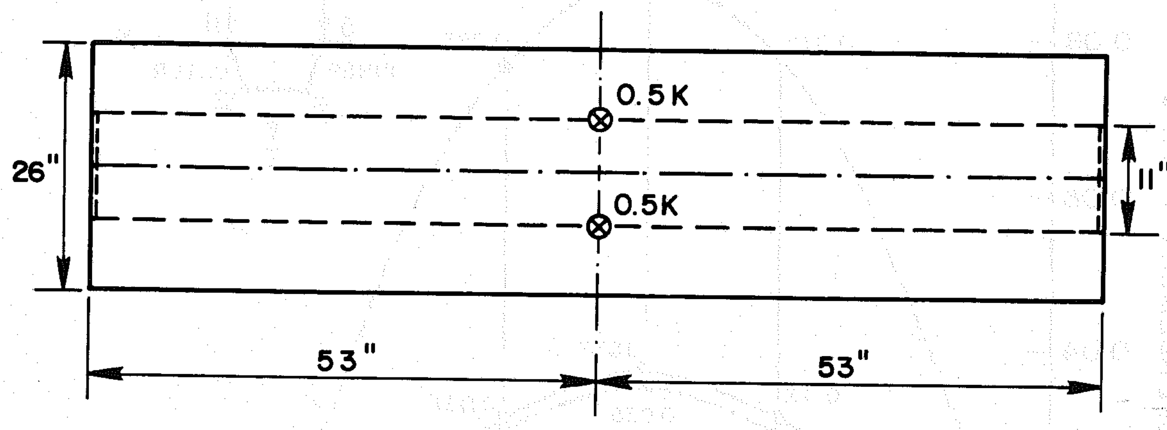
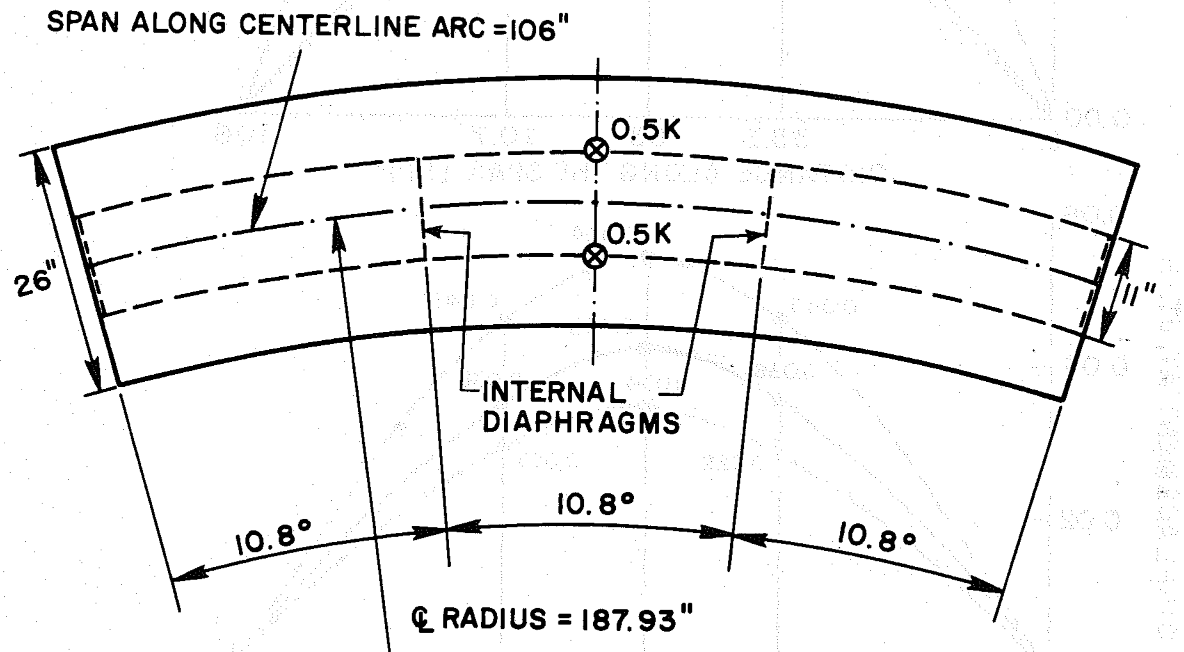


FIG. 5.2 EXAMPLE 1 - NODAL POINT LAYOUT AND MATERIAL PROPERTIES



(a) STRAIGHT BRIDGE



(b) CURVED BRIDGE

FIG. 5.3 EXAMPLE 1 - PLAN VIEWS OF THE MODELS

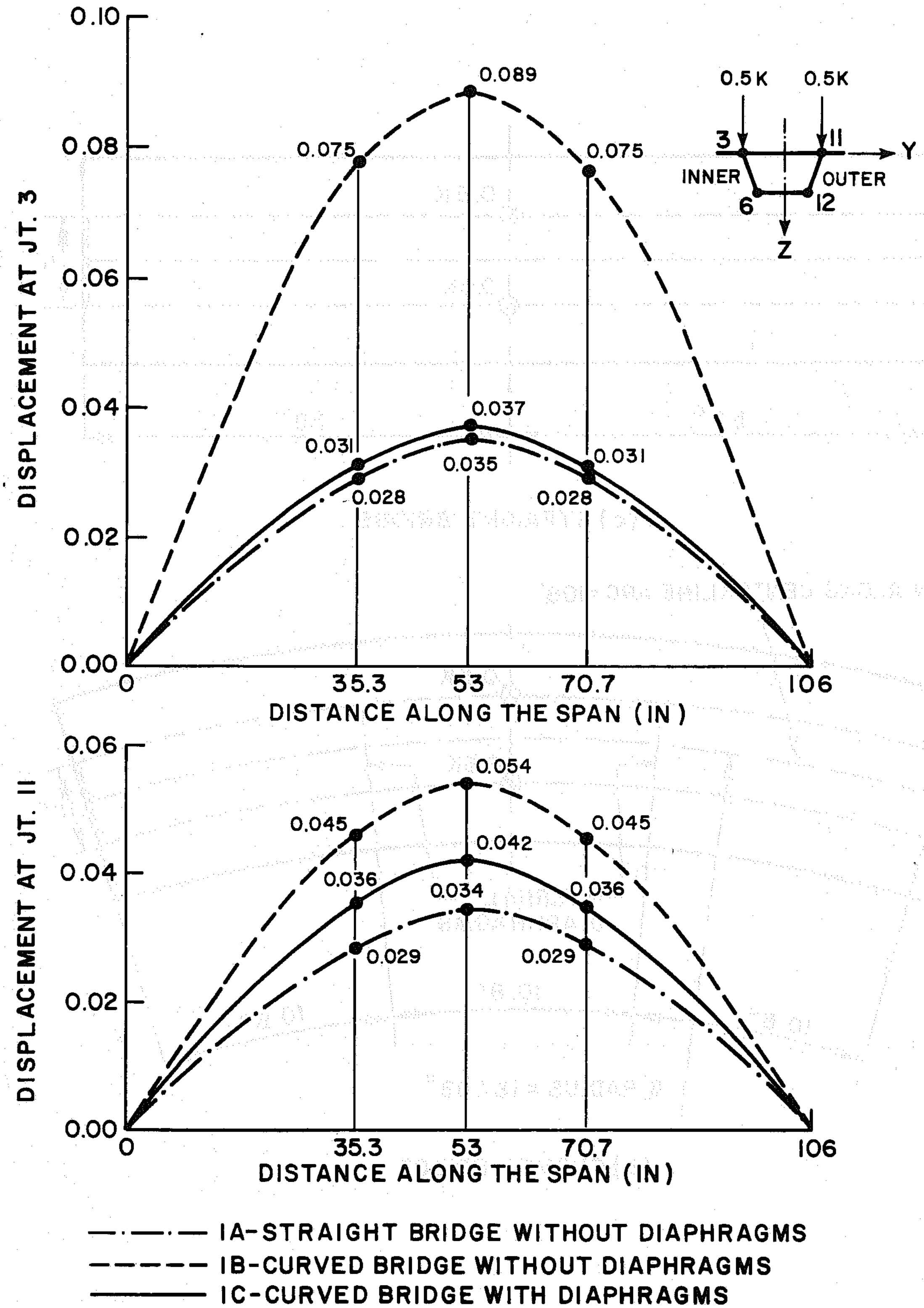
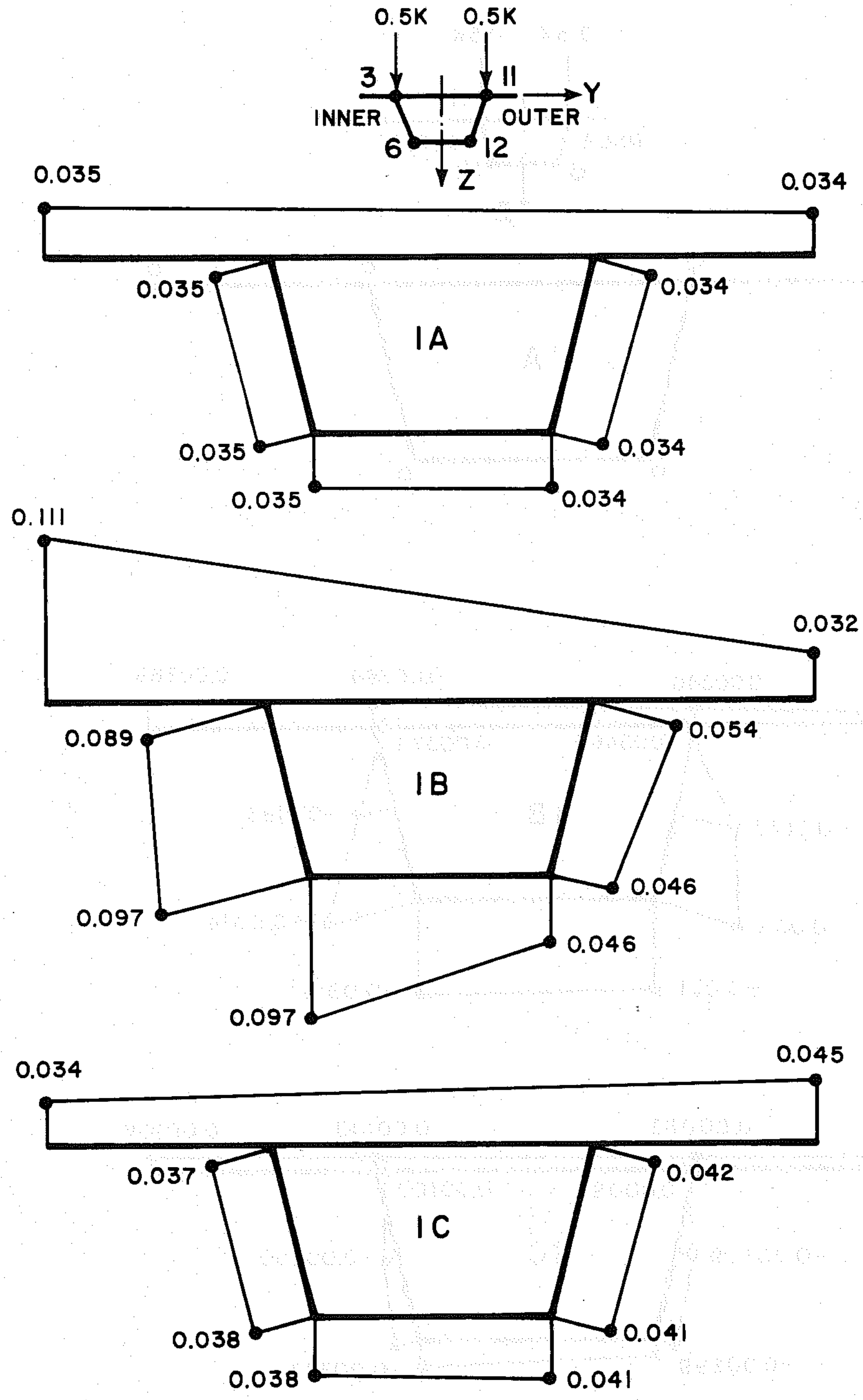
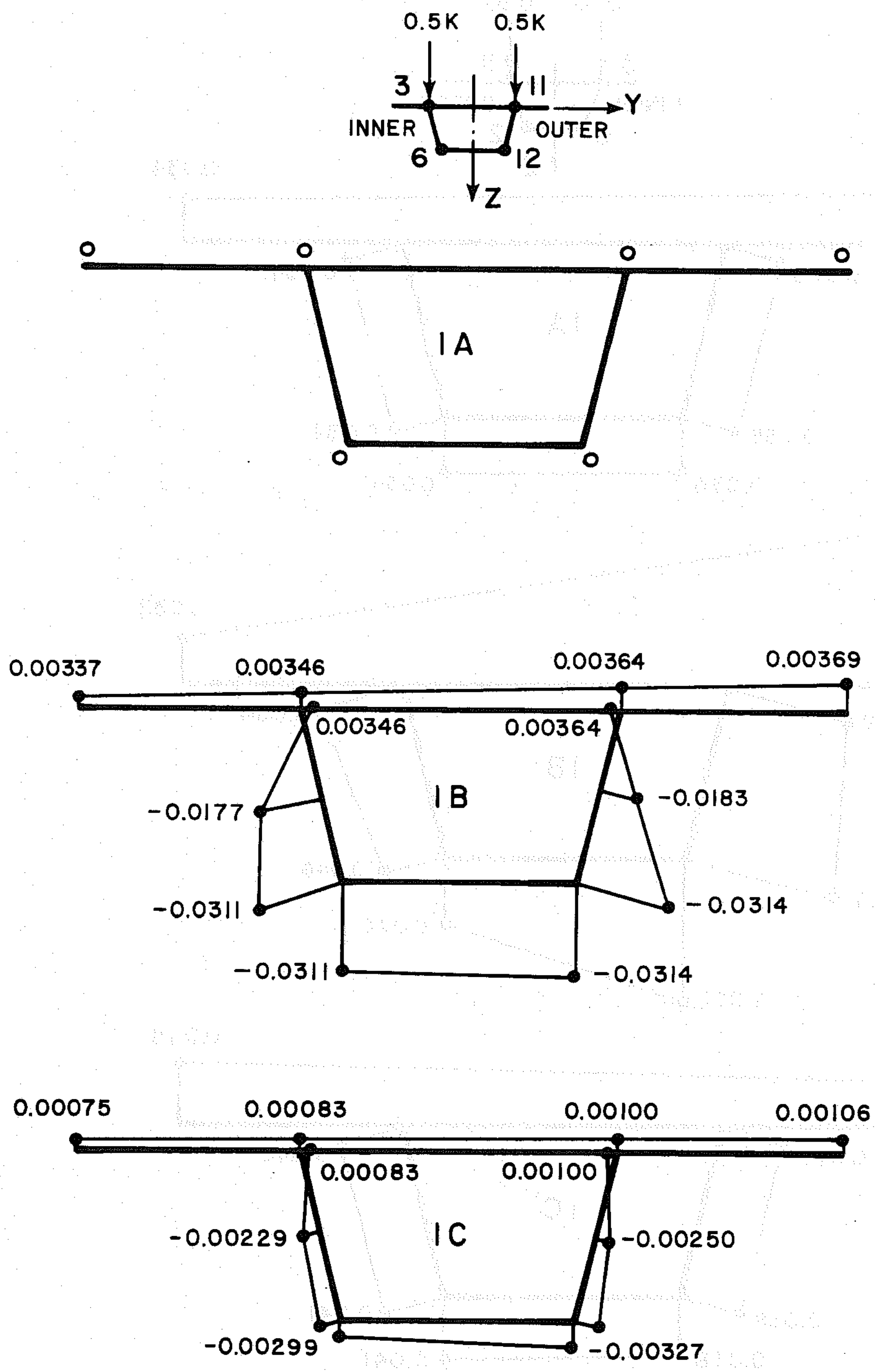


FIG. 5.4 EXAMPLE 1 – LONGITUDINAL DISTRIBUTION OF VERTICAL DEFLECTIONS (INCHES) AT THE TOPS OF THE GIRDER WEBS



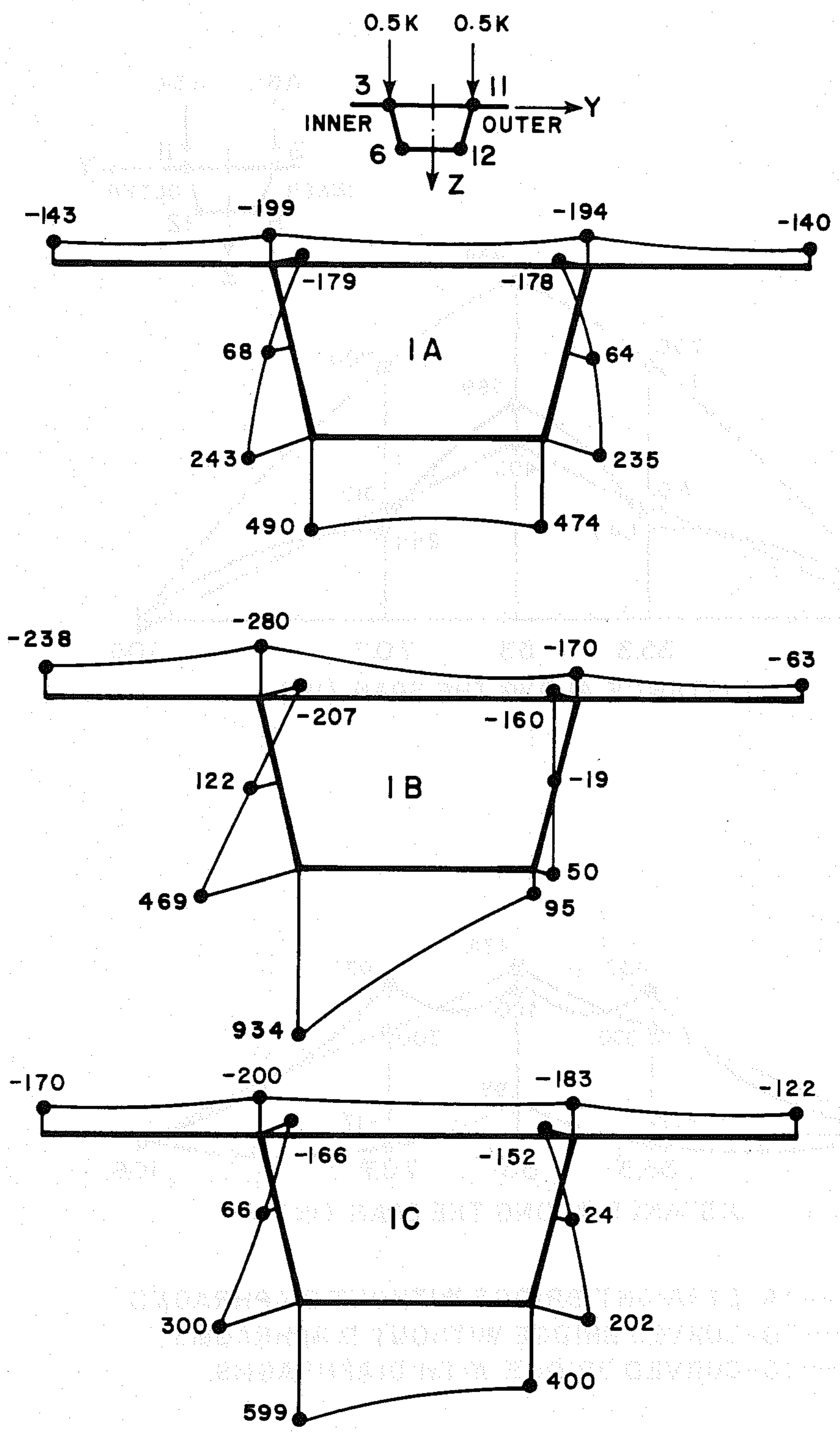
IA-STRAIGHT BRIDGE WITHOUT DIAPHRAGMS
IB-CURVED BRIDGE WITHOUT DIAPHRAGMS
IC-CURVED BRIDGE WITH DIAPHRAGMS

FIG. 5.5 EXAMPLE 1 – TRANSVERSE DISTRIBUTION OF VERTICAL DEFLECTIONS (INCHES) AT MIDSPAN SECTION



IA-STRAIGHT BRIDGE WITHOUT DIAPHRAGMS
IB-CURVED BRIDGE WITHOUT DIAPHRAGMS
IC-CURVED BRIDGE WITH DIAPHRAGMS

FIG. 5.6 EXAMPLE 1 – TRANSVERSE DISTRIBUTION OF HORIZONTAL DEFLECTIONS (INCHES) AT MIDSPAN SECTION



IA-STRAIGHT BRIDGE WITHOUT DIAPHRAGMS
IB-CURVED BRIDGE WITHOUT DIAPHRAGMS
IC-CURVED BRIDGE WITH DIAPHRAGMS

FIG. 5.7 EXAMPLE 1 – TRANSVERSE DISTRIBUTION OF LONGITUDINAL FORCES N_θ (LB/INCH) AT MIDSPAN SECTION

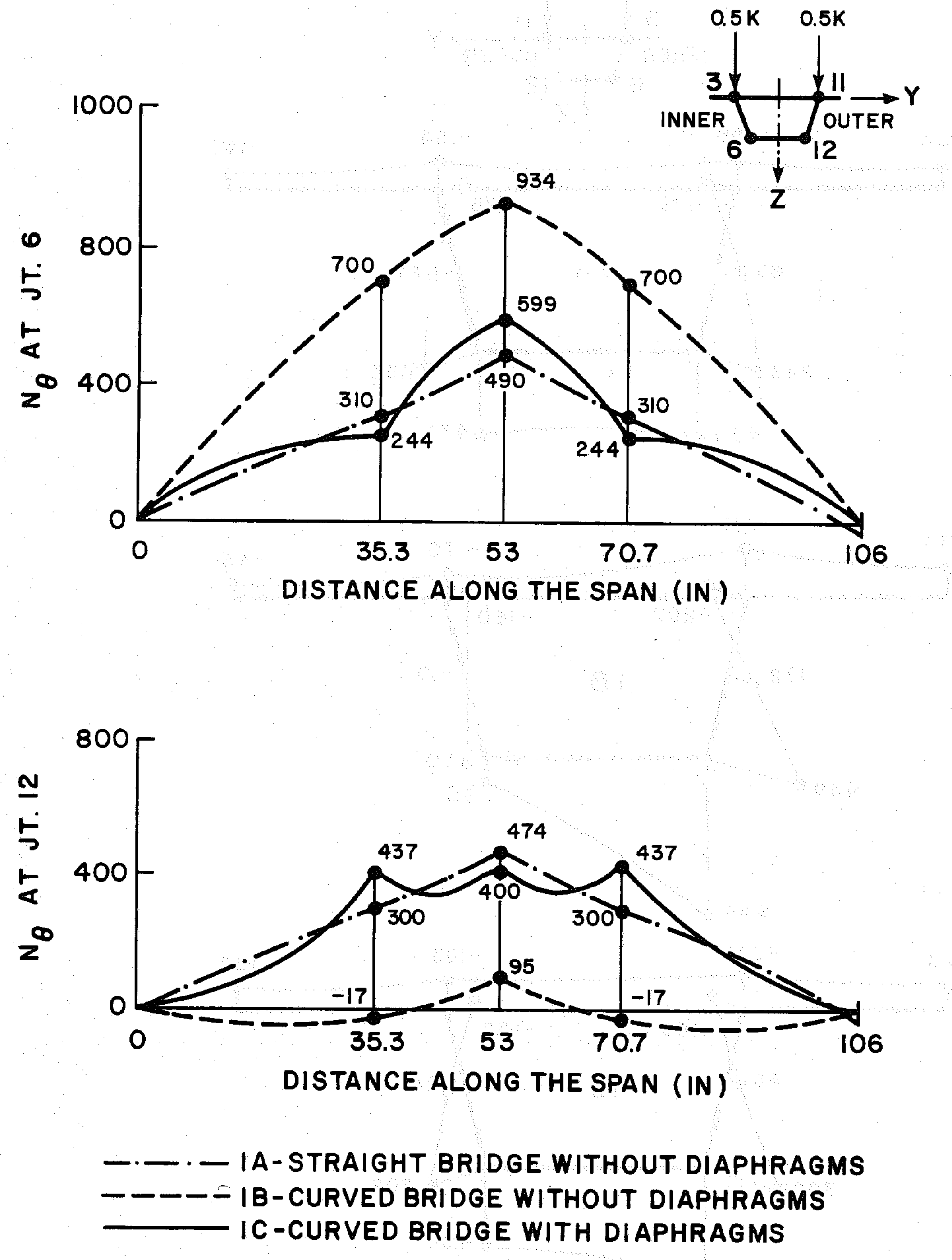


FIG. 5.8 EXAMPLE 1 – LONGITUDINAL DISTRIBUTION OF LONGITUDINAL FORCES N_θ (LB/INCH) IN THE BOTTOM PLATE AT THE BOTTOMS OF THE GIRDER WEBS

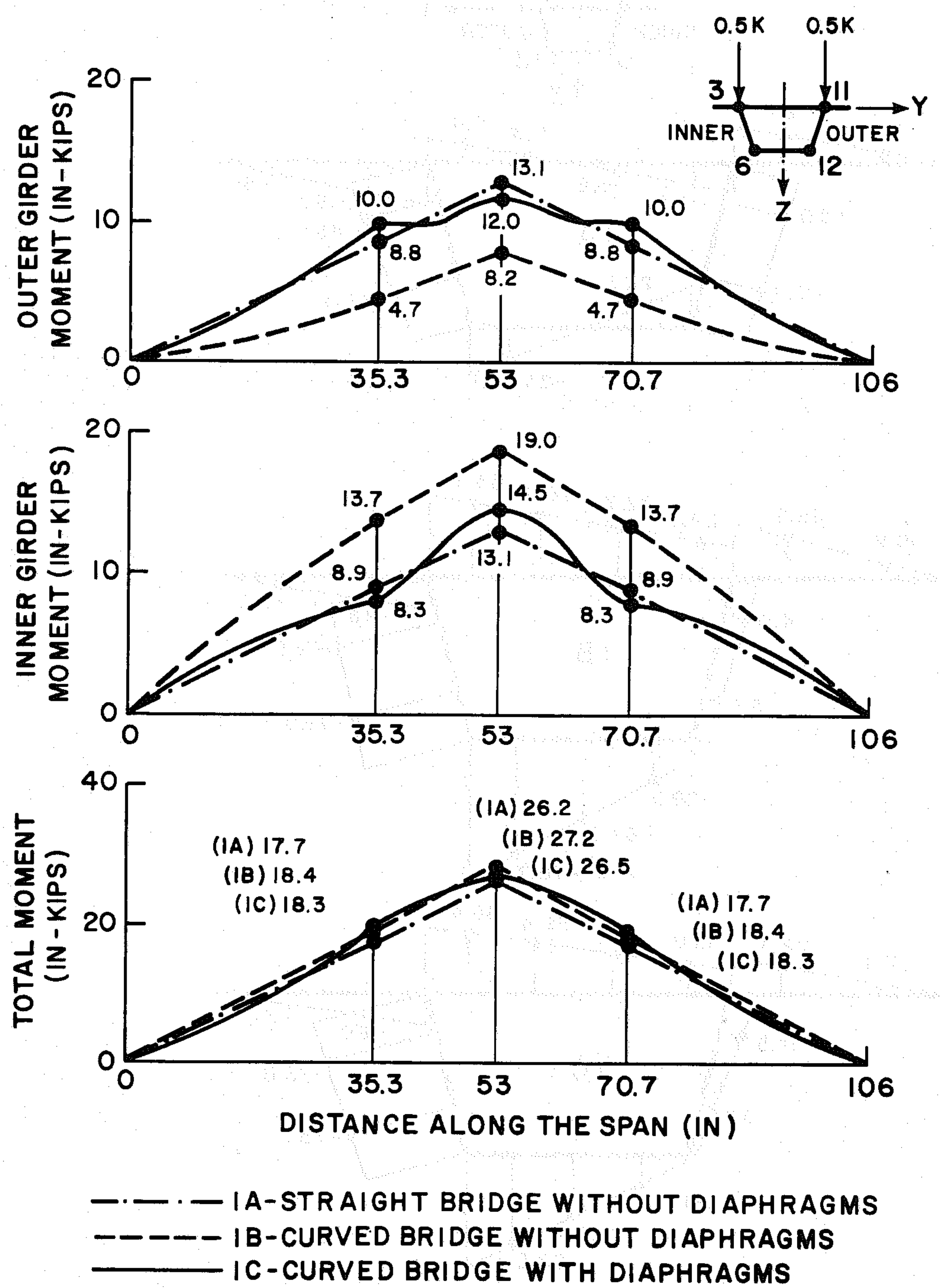
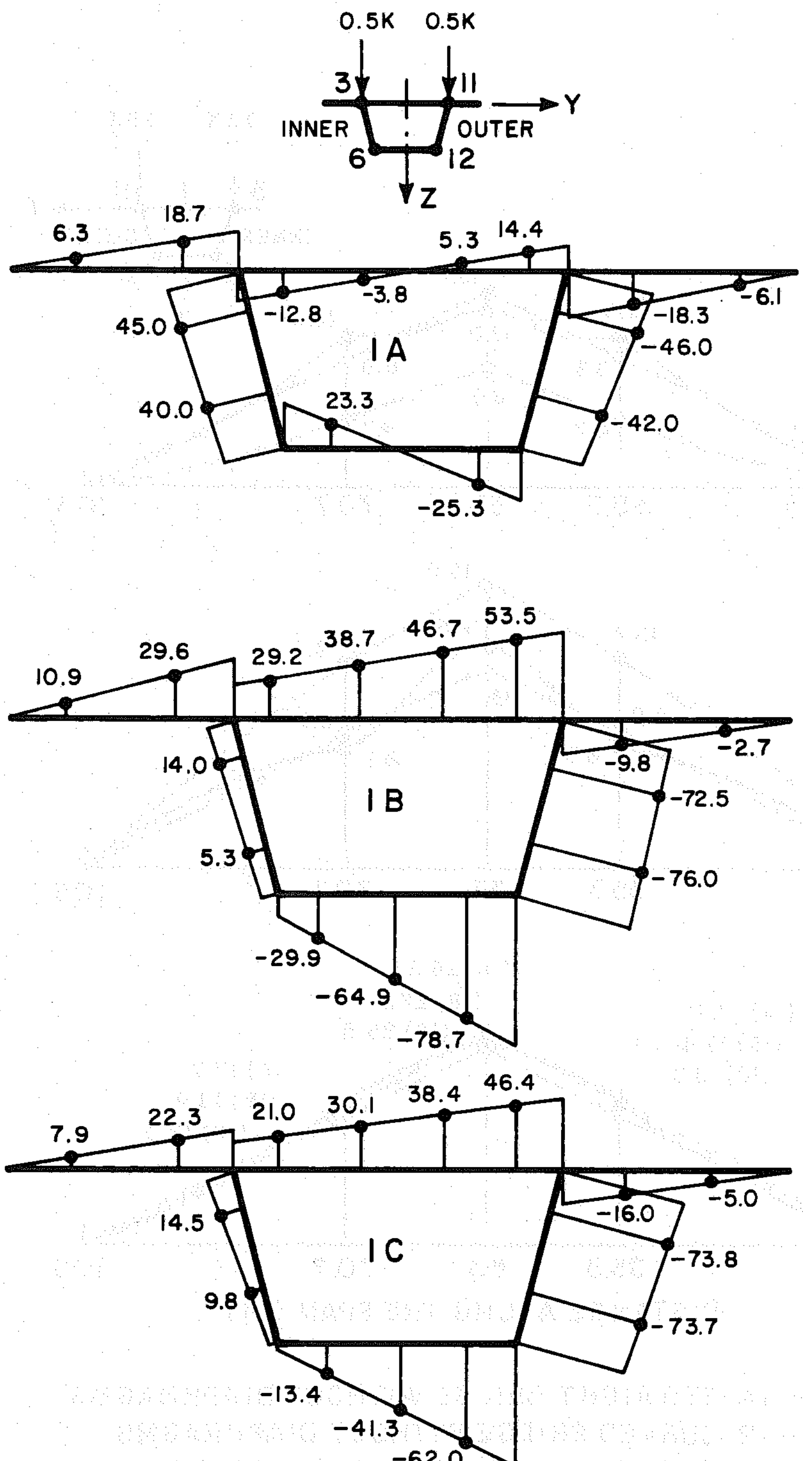


FIG. 5.9 EXAMPLE 1 - LONGITUDINAL DISTRIBUTION OF GIRDER AND TOTAL MOMENTS (INCH-KIPS)



1A - STRAIGHT BRIDGE WITHOUT DIAPHRAGMS
1B - CURVED BRIDGE WITHOUT DIAPHRAGMS
1C - CURVED BRIDGE WITH DIAPHRAGMS

FIG. 5.10 EXAMPLE 1 – TRANSVERSE DISTRIBUTION OF MEMBRANE SHEAR FORCES $N_{s\theta}$ (LB/INCH) AT END SUPPORT SECTION

Figs. 5.7 and 5.8 again demonstrate the need for interior diaphragms to improve the load distributing properties of the curved bridge. The same thing is illustrated in Fig. 5.9, where the moment integration option has been used to evaluate the statical moment taken by the inner and outer girders and also the total of these two, which can be used as a statics check.

Finally, Fig. 5.10 presents the membrane shear forces $N_{s\theta}$ (lb/in) at the end support. For the straight bridge (1A) the results are essentially symmetric about the section's vertical plane of symmetry, with each girder web taking one half of the total end shear. For the curved bridges (1B and 1C), since the end reactions consist of both a torque and vertical force, the membrane shears are larger in the outer web than in the inner web.

5.3 Example 2 - Straight Continuous T-Beam Bridge

To investigate the effects of interior diaphragms and bents, the straight, two span, continuous, concrete T-beam bridge shown in Fig. 5.11 is analyzed with various flexibilities for the midspan diaphragms and the center supporting bent. All cases were analyzed both by the previously developed program for straight bridges, MUPDI3 [13], which is based on a folded plate elasticity solution, and by CURDI, which is based on the curved strip method. For CURDI a large radius of 120,000 ft was input to give for all practical purposes a straight bridge. All cases were run with a modulus of elasticity equal to 432,000 ksf and Poisson's ratio equal to zero. The loading was identical for all cases and consisted of 1 kip midspan concentrated loads in both spans acting on girder 1 only.

Several combinations of midspan diaphragms and center support conditions were used as follows:

Example 2A - Rigid diaphragm at the center support, with three different midspan diaphragm conditions

1. No midspan diaphragms (2A-1)
2. Normal midspan diaphragms (2A-2)
3. Rigid midspan diaphragms (2A-3)

Example 2B - Flexible center support frame bent with a 15 ft high column and normal midspan diaphragms (2B-2)

The nodal point layout is shown in Fig. 5.11c. Normal midspan diaphragm section properties were defined by an 8 by 36 in. cross-section and flexible frame bent properties by the dimensions shown in Fig. 5.11.

The results for girder deflections and moments are presented in Figs. 5.12 to 5.15. Close agreement between the results from CURDI and MUPDI3 is seen to exist, thus giving a good check on the CURDI program.

Comparing the results for Example 2A (Figs. 5.12 and 5.13), very little difference exists for the three types of midspan diaphragm conditions. Comparing the results for Example 2B (Figs. 5.14 and 5.15) with those of Example 2A, slightly larger deflections occur at the loaded girder for 2B due to the use of the flexible center support bent rather than a rigid support, however, the moments change very little.

Figs. 5.16 and 5.17 show the shear-force,axial force and bending moment values found in the center support bent for Example 2B using CURDI and MUPDI3. Again the agreement between the two solutions is very good.

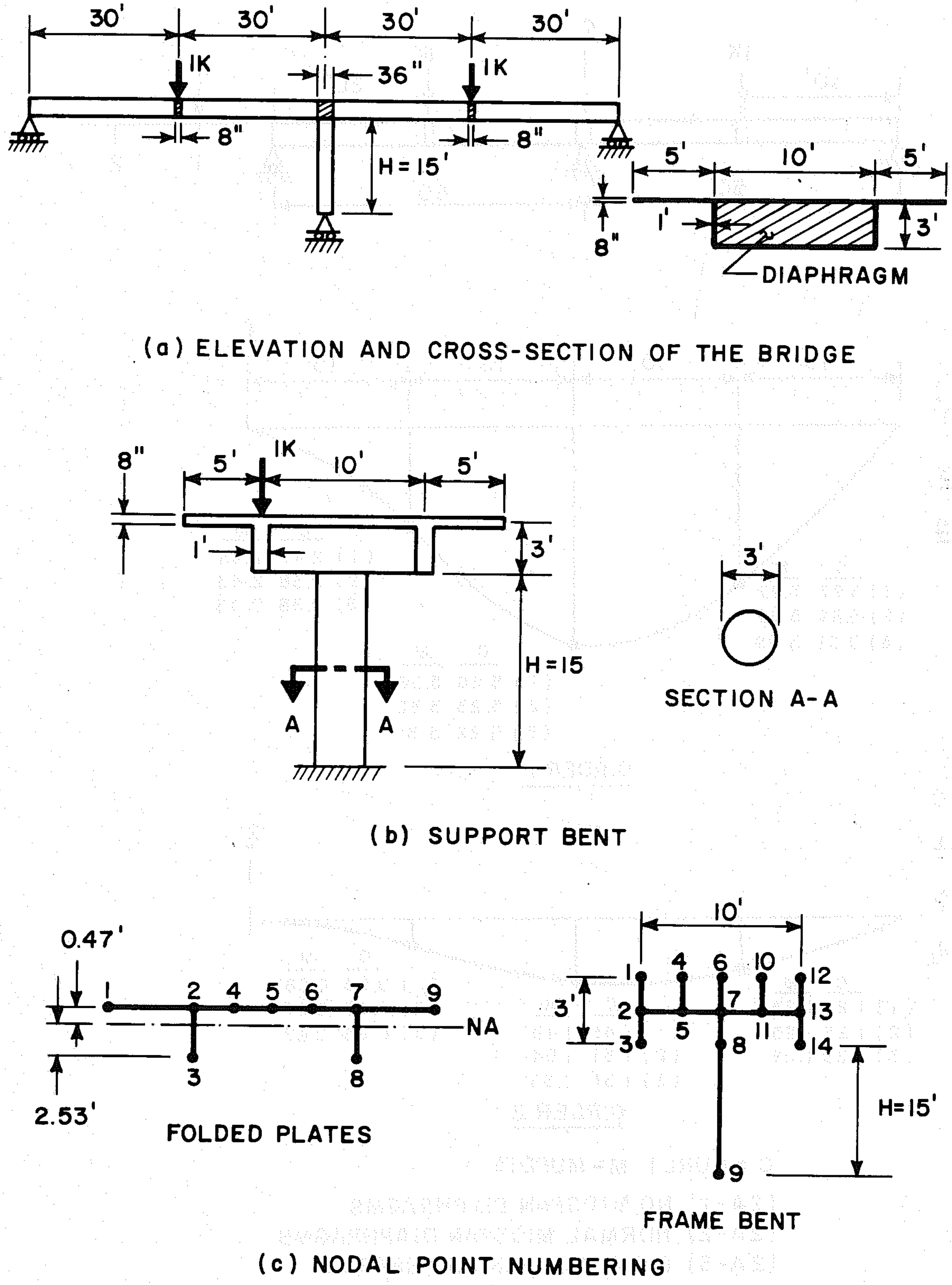


FIG. 5.11 EXAMPLE 2 – STRAIGHT CONTINUOUS T-BEAM BRIDGE

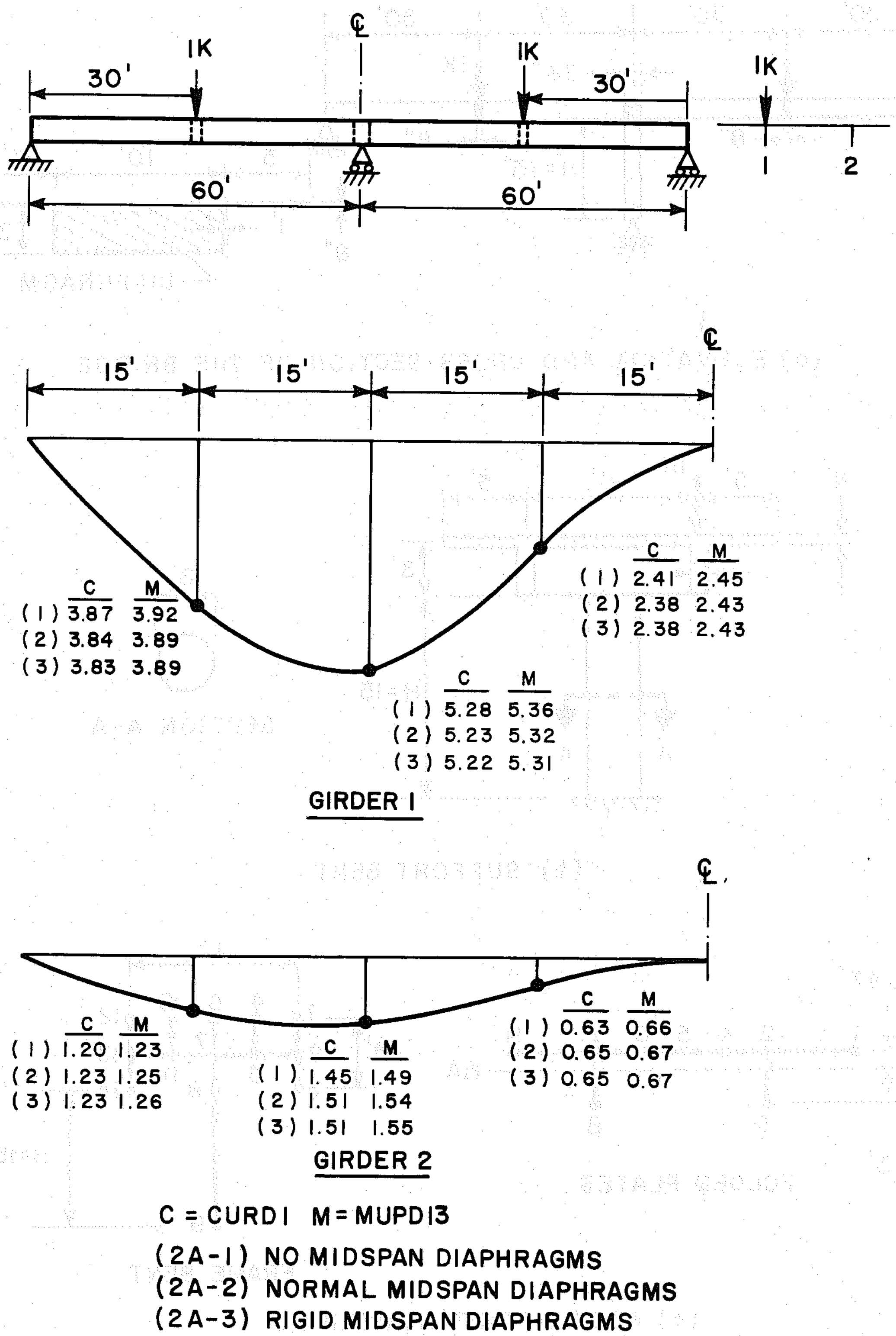


FIG. 5.12 EXAMPLE 2A – LONGITUDINAL DISTRIBUTION OF GIRDER DEFLECTIONS (10^{-4} FT) FROM MUPDI3 AND CURDI ANALYSES

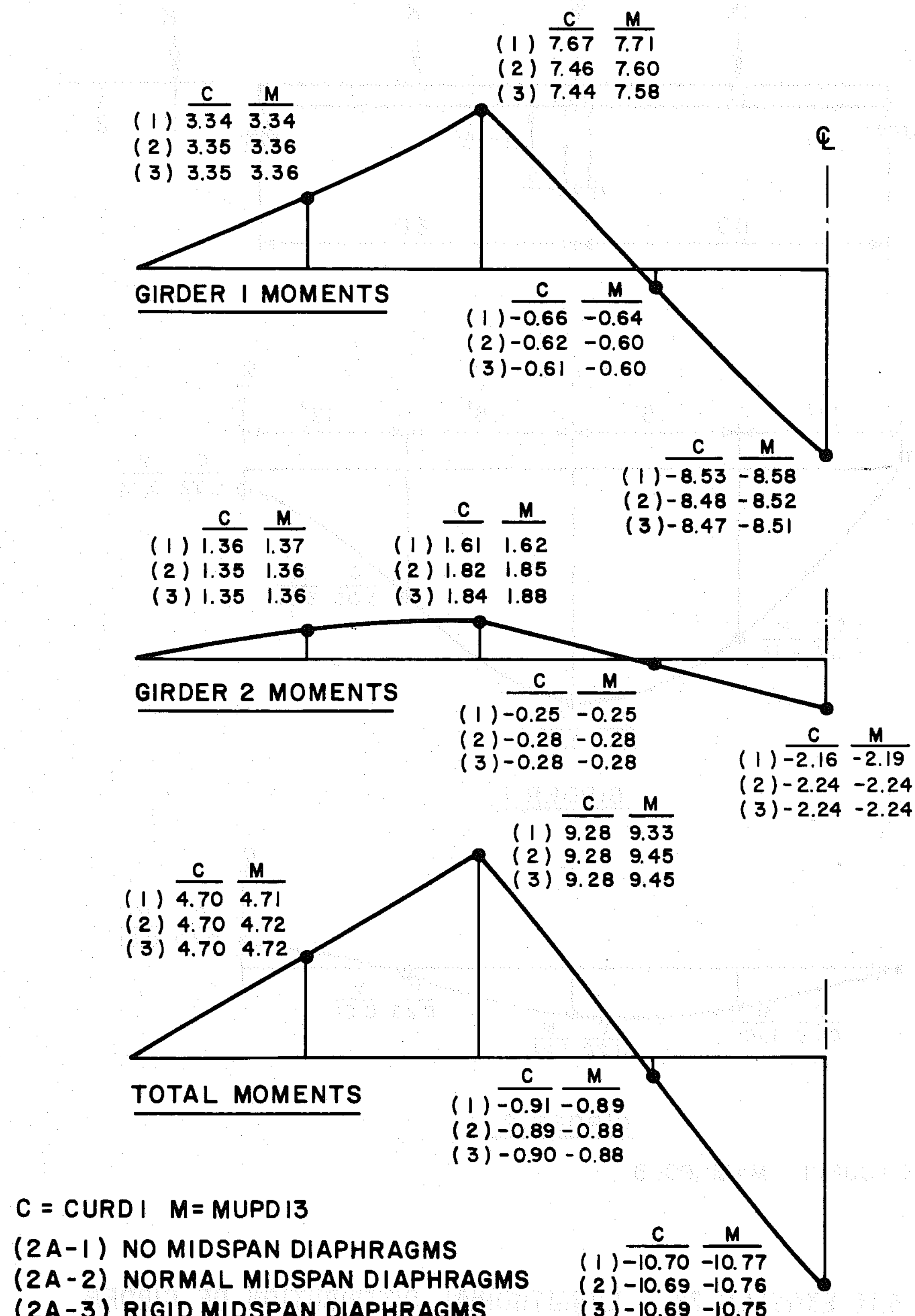


FIG. 5.13 EXAMPLE 2A – LONGITUDINAL DISTRIBUTION OF GIRDER AND TOTAL MOMENTS (FT-KIPS) FROM MUPDI3 AND CURDI ANALYSES

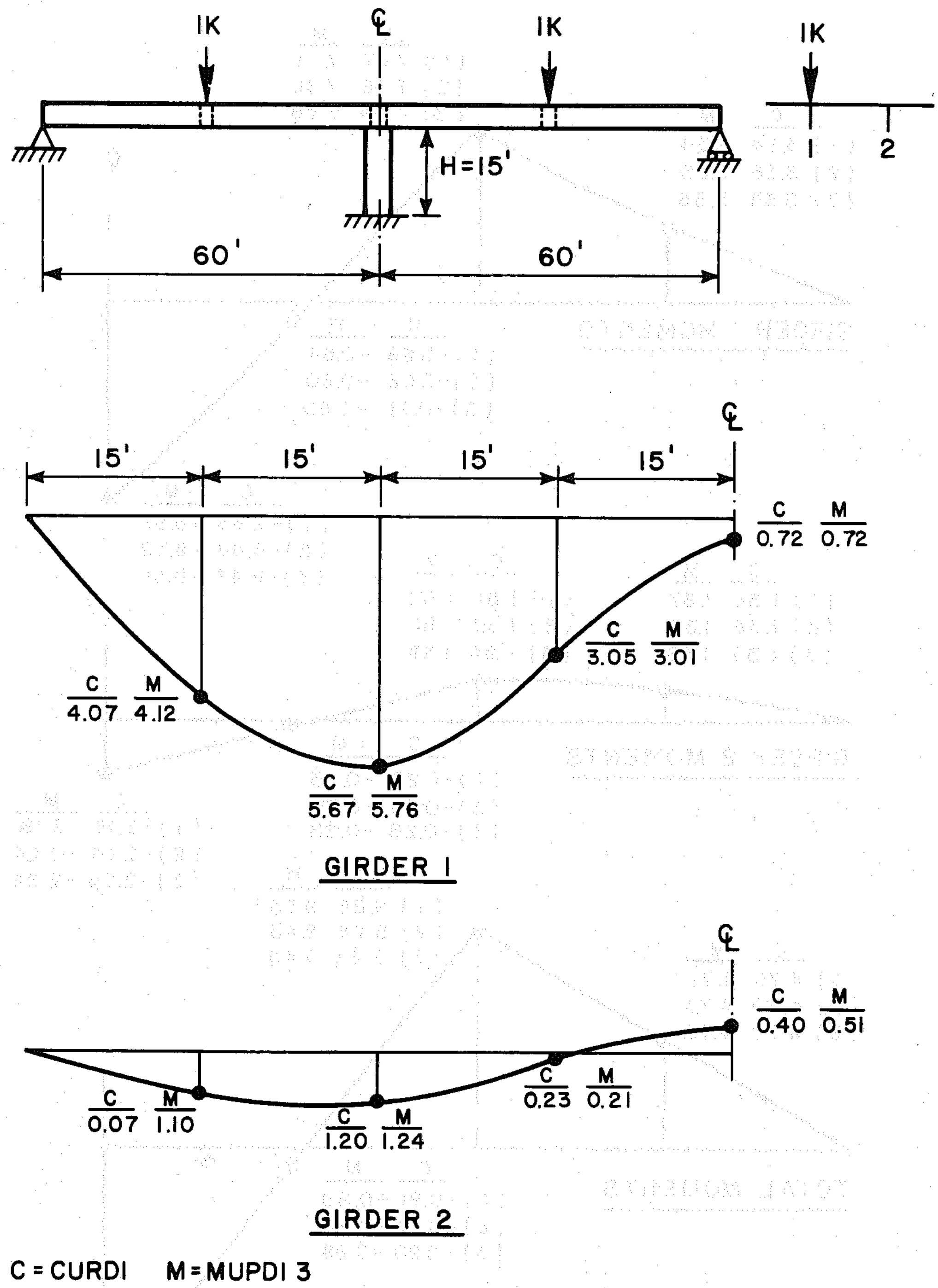


FIG. 5.14 EXAMPLE 2B – LONGITUDINAL DISTRIBUTION OF GIRDER DEFLECTIONS (10^{-4}FT) FROM MUPDI3 AND CURDI ANALYSES

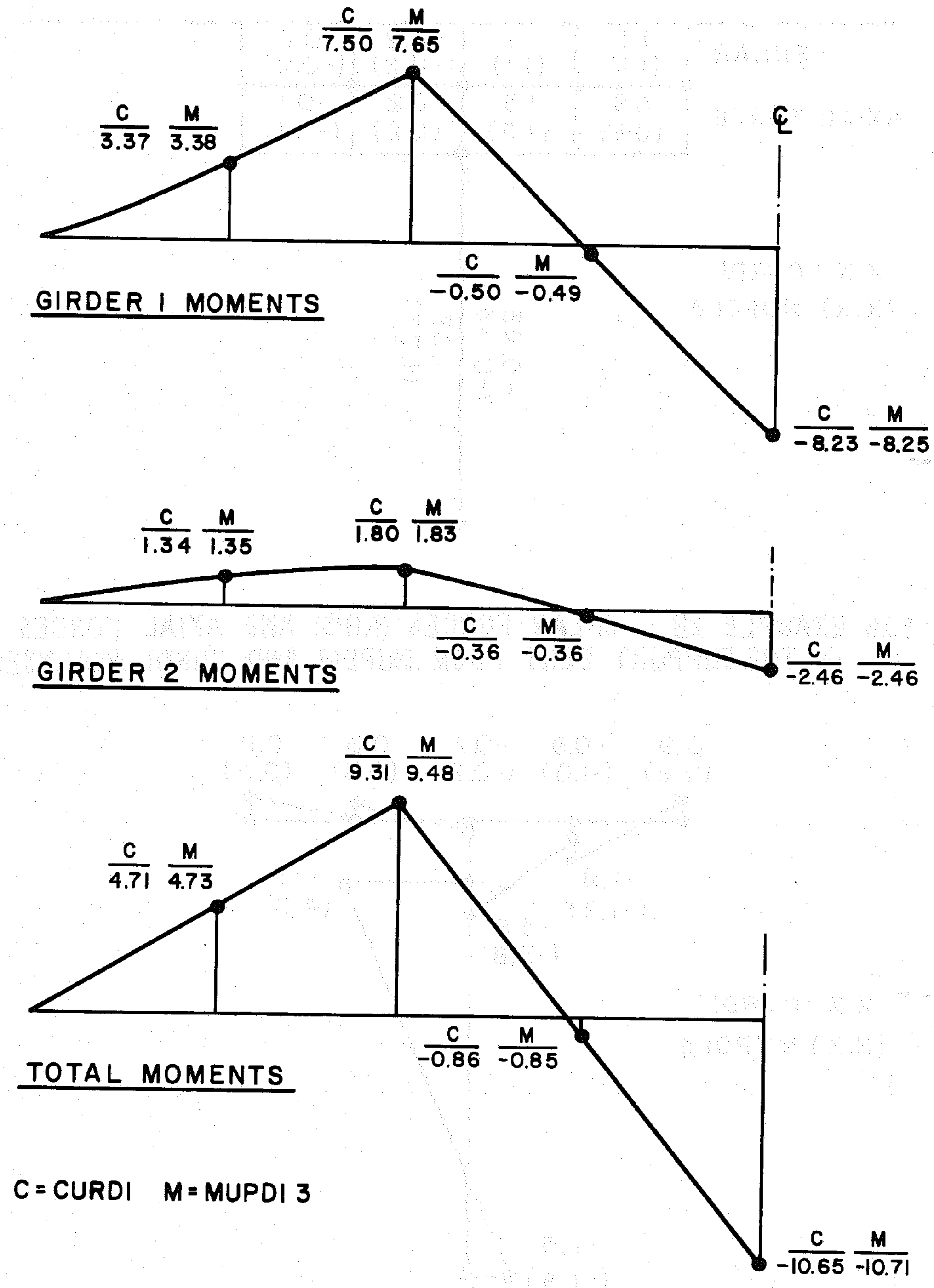


FIG. 5.15 EXAMPLE 2B – LONGITUDINAL DISTRIBUTION OF GIRDER AND TOTAL MOMENTS (FT-KIPS) FROM MUPDI3 AND CURDI ANALYSES

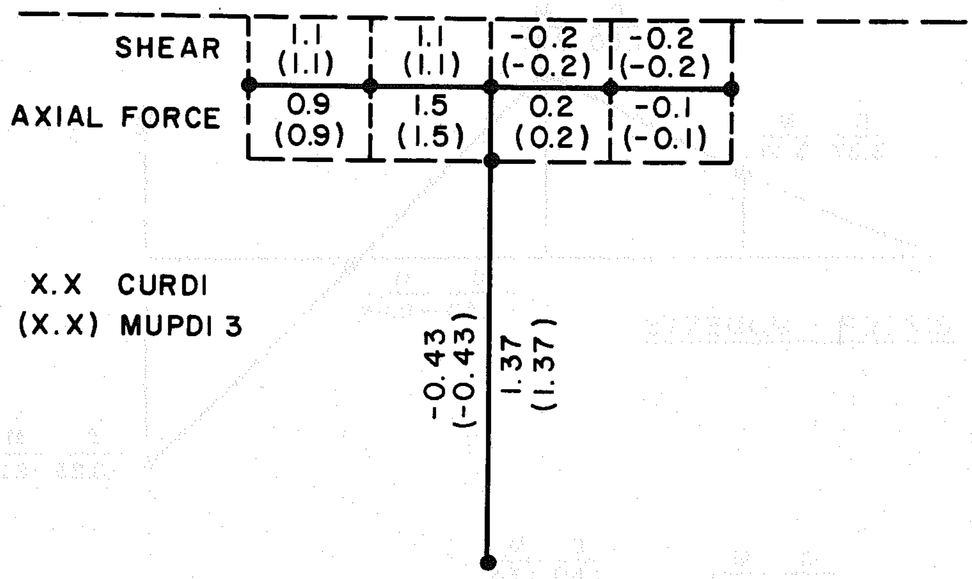


FIG. 5.16 EXAMPLE 2B – SHEAR FORCES (KIPS) AND AXIAL FORCES (KIPS) IN THE SUPPORT BENT FROM MUPDI3 AND CURDI ANALYSES

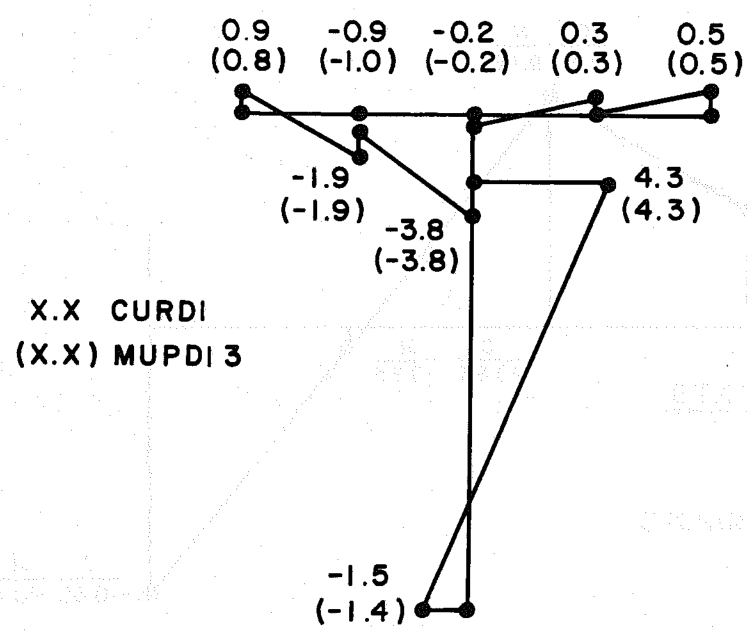


FIG. 5.17 EXAMPLE 2B – BENDING MOMENT (FT–KIPS) DIAGRAM FOR THE SUPPORT BENT FROM MUPDI3 AND CURDI ANALYSES

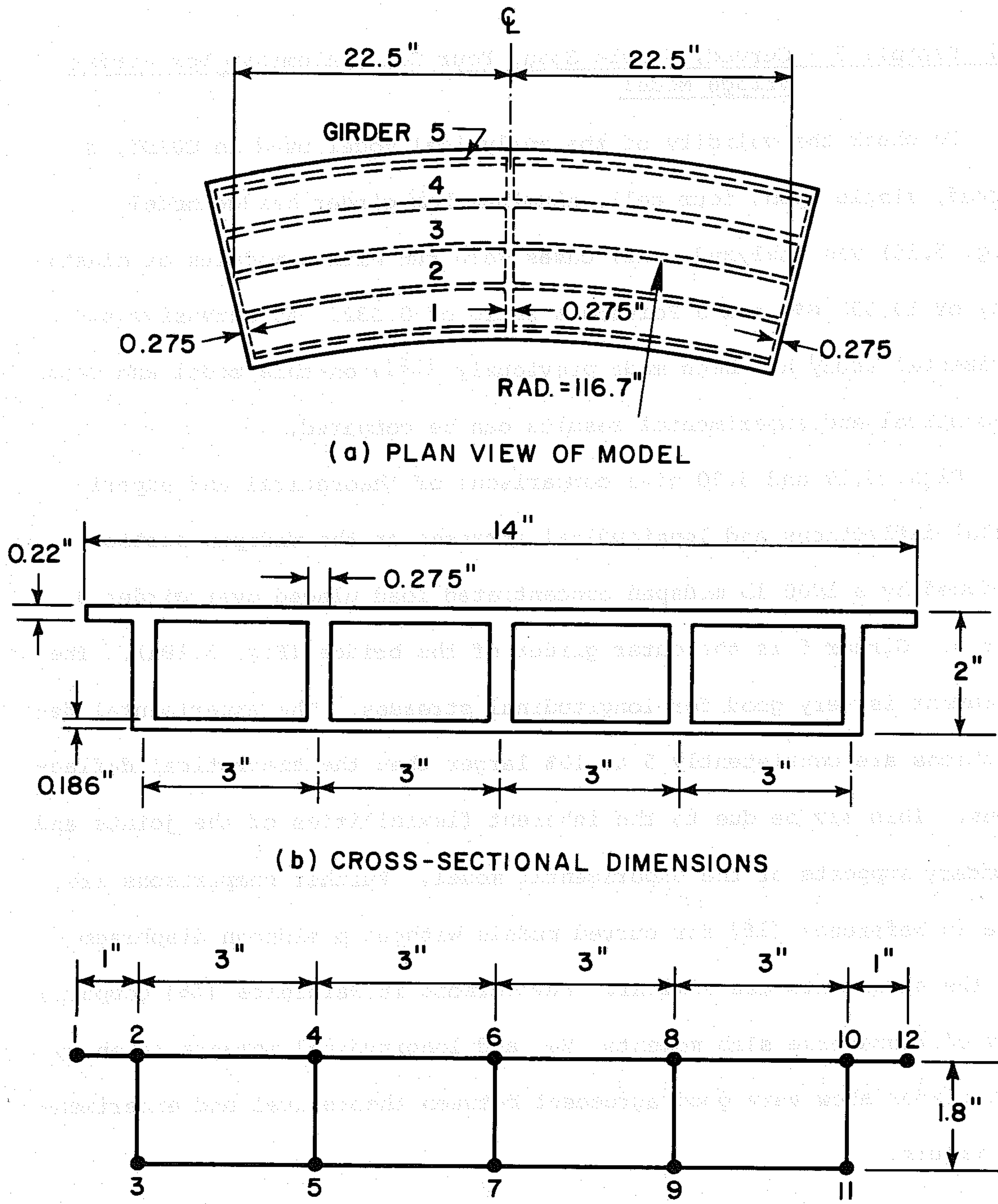
5.4 Example 3 - Curved, Single Span, Four Cell, Aluminum Box Girder Bridge Model

To check the validity of the analytical model used in CURDI, a curved, single span, four cell, aluminum box girder bridge model (Fig. 5.18) was analyzed. All cases were run with a modulus of elasticity of 10,000 ksi and a Poisson's ratio of 0.332. An extensive experimental study has been made previously [16], on this model and thus theoretical and experimental results can be compared.

Figs. 5.19 and 5.20 give comparisons of theoretical and experimental deflections and longitudinal stresses at the midspan section produced by a 1000 lb midspan concentrated load placed over girder 3, 4 or 5. Girder 5 is the outer girder of the bridge (Fig. 5.18a). The agreement is very good for longitudinal stresses. The experimental deflections are consistently 5 to 10% larger than the theoretical deflections. This may be due to the inherent flexibilities of the joints and boundary supports of the experimental model. Further comparisons are made in Reference [16] for curved models without a midspan diaphragm and the agreements are similar. Furthermore in Reference [16] comparisons of transverse slab moments, M_θ, and longitudinal moments taken by each girder show very good agreement between theoretical and experimental values.

5.5 Example 4 - Curved, Two Span, Four Cell, Reinforced Concrete Box Girder Bridge Model

A large scale, curved, two span, four cell, reinforced concrete box girder bridge model is analyzed to demonstrate the practical application of CURDI. The model has been tested at the University of California, Berkeley as part of an extensive study of the elastic,



(a) PLAN VIEW OF MODEL

(b) CROSS-SECTIONAL DIMENSIONS

(c) NODAL POINT NUMBERING

FIG. 5.18 EXAMPLE 3 – MODEL DIMENSIONS AND COMPUTER MODEL LAYOUT

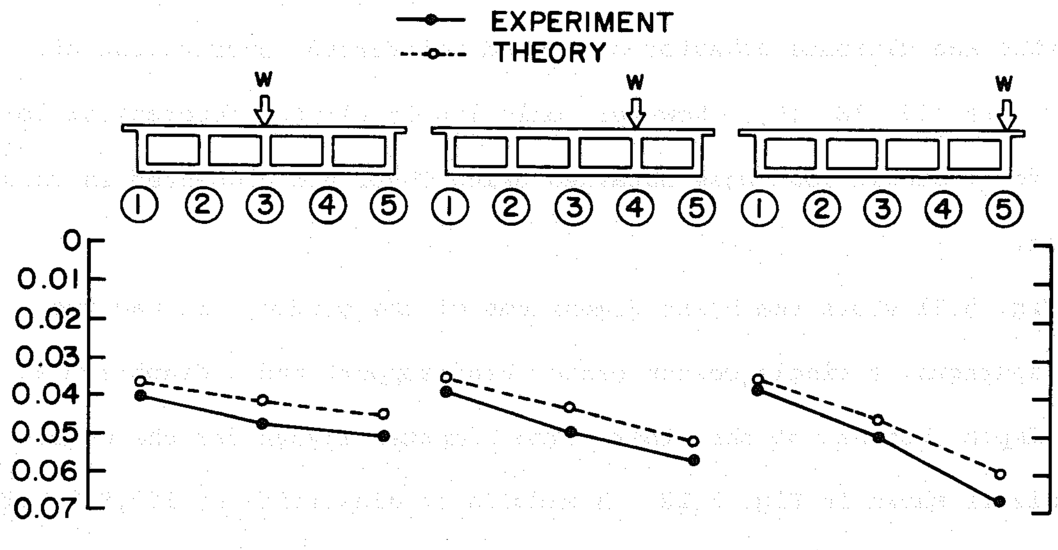


FIG. 5.19 EXAMPLE 3 – TRANSVERSE DISTRIBUTION OF THEORETICAL AND EXPERIMENTAL VERTICAL DEFLECTIONS (INCHES) AT MIDSPAN SECTION DUE TO MIDSPAN 1000 LB LOAD ON GIRDER 3, 4, OR 5

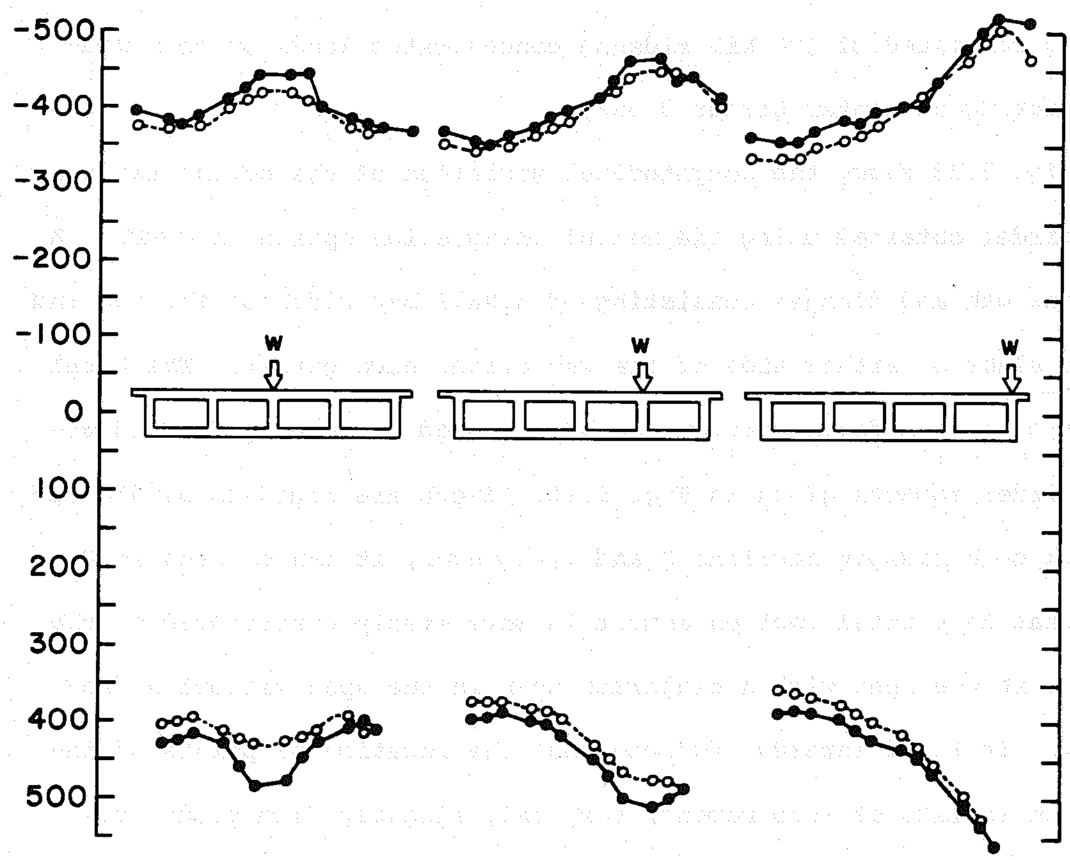


FIG. 5.20 EXAMPLE 3 – TRANSVERSE DISTRIBUTION OF THEORETICAL AND EXPERIMENTAL LONGITUDINAL FORCES N_θ (LB/INCH) AT MIDSPAN SECTION DUE TO MIDSPAN 1000 LB LOAD ON GIRDER 3, 4 OR 5

inelastic and ultimate behavior of curved reinforced concrete box girder bridges [17, 18, 19]. However, only linear elastic theoretical results for a single load case obtained using CURDI are presented in this section.

Fig. 5.21 shows the basic dimensions of the bridge. It had two end diaphragms, a single column center bent support and a diaphragm at one midspan, but not at the other. The computer layout for the CURDI analysis is shown in Fig. 5.22. A modulus of elasticity of 550,800 ksf was used for all top deck elements, while for the rest of the bridge including the center bent support and diaphragms a value of 432,000 ksf was used. For all elements Poisson's ratio was taken as 0.15. The loading consisted of 100 kip midspan concentrated loads at both midspans acting on center girder 3 only.

Fig. 5.23 shows the longitudinal variation of the moment taken by each girder obtained using the moment integration option in CURDI. A vertical web and flanges consisting of a half bay width of the top and bottom slabs on either side of the web define each girder. The total moment at each midspan section can be obtained by summing the individual girder moments given in Fig. 5.23. These are found to be 558 ft-kips at both midspan sections X and Y, however, it can be seen in Fig. 5.23 that this total section moment is more evenly distributed to the girders in the span with a diaphragm than in the span without a diaphragm. It is of interest to note that the location of points of inflection (points of zero moment) vary only slightly from girder to girder.

Fig. 5.24 shows a free body of the portion of the bridge structure between the inflection points on either side of the bridge bent.

A statics check for vertical forces is made by summing the shears in the webs at the inflection points (68.5 + 68.5 = 137.0 kips) and comparing this sum with the computer output for the vertical reaction at the base of the bent column (140.6 kips). The check is good recognizing that the slab transverse shears are neglected. Note also that though the total shears in the two spans are almost identical, the distribution of these shears to individual girders is different in spans I and II, because of the existence of the midspan diaphragm in span I only.

Fig. 5.25 indicates the magnitude and direction of the interaction forces between the folded plate system and the bent. Note that a horizontal, vertical and rotational connection was specified. The forces shown are those acting on the rectangular bent girder isolated as a free body. Again a statics check was made to verify that the sum of the interaction forces equalled the output reaction at the base of the bent column, and the check was excellent.

Fig. 5.26 gives the internal moments, shear forces and axial forces in the bent. Fig. 5.27 graphically illustrates that the computer output should be plotted to make a proper estimate of actual girder moments which would exist if a continuous interaction were used instead of the discretized system needed in the computer program.

If desired, the amount of participation of the top and bottom slabs of the cellular system with the rectangular bent girder section in carrying the transverse moment in the bent can be found by integrating the transverse membrane forces in the top and bottom slab through section A-A in Fig. 5.24.

It should be emphasized that the analytical model treats the center bent as a planar frame which is incapable of taking forces

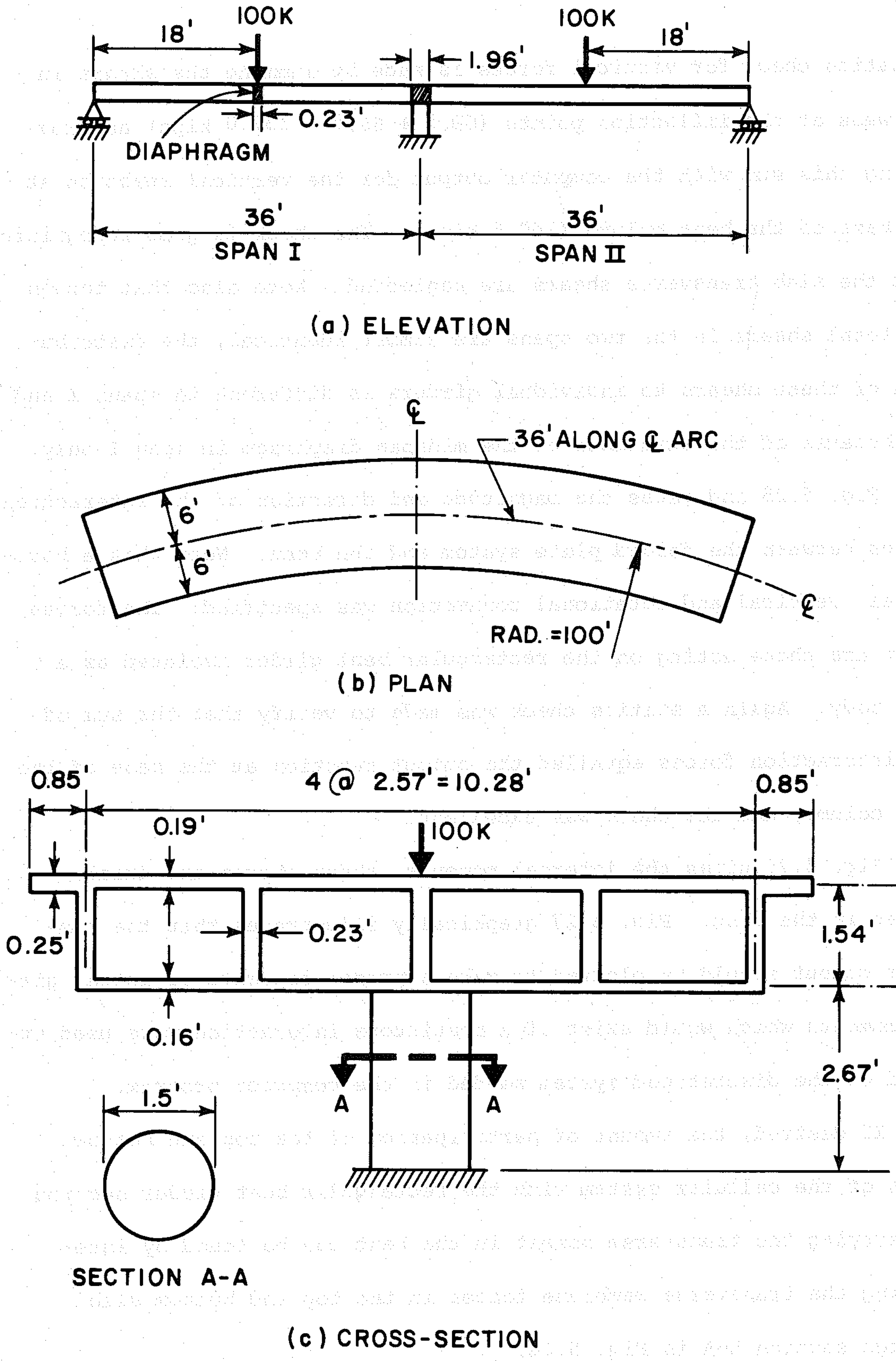


FIG. 5.21 EXAMPLE 4 – DIMENSIONS AND LOADING

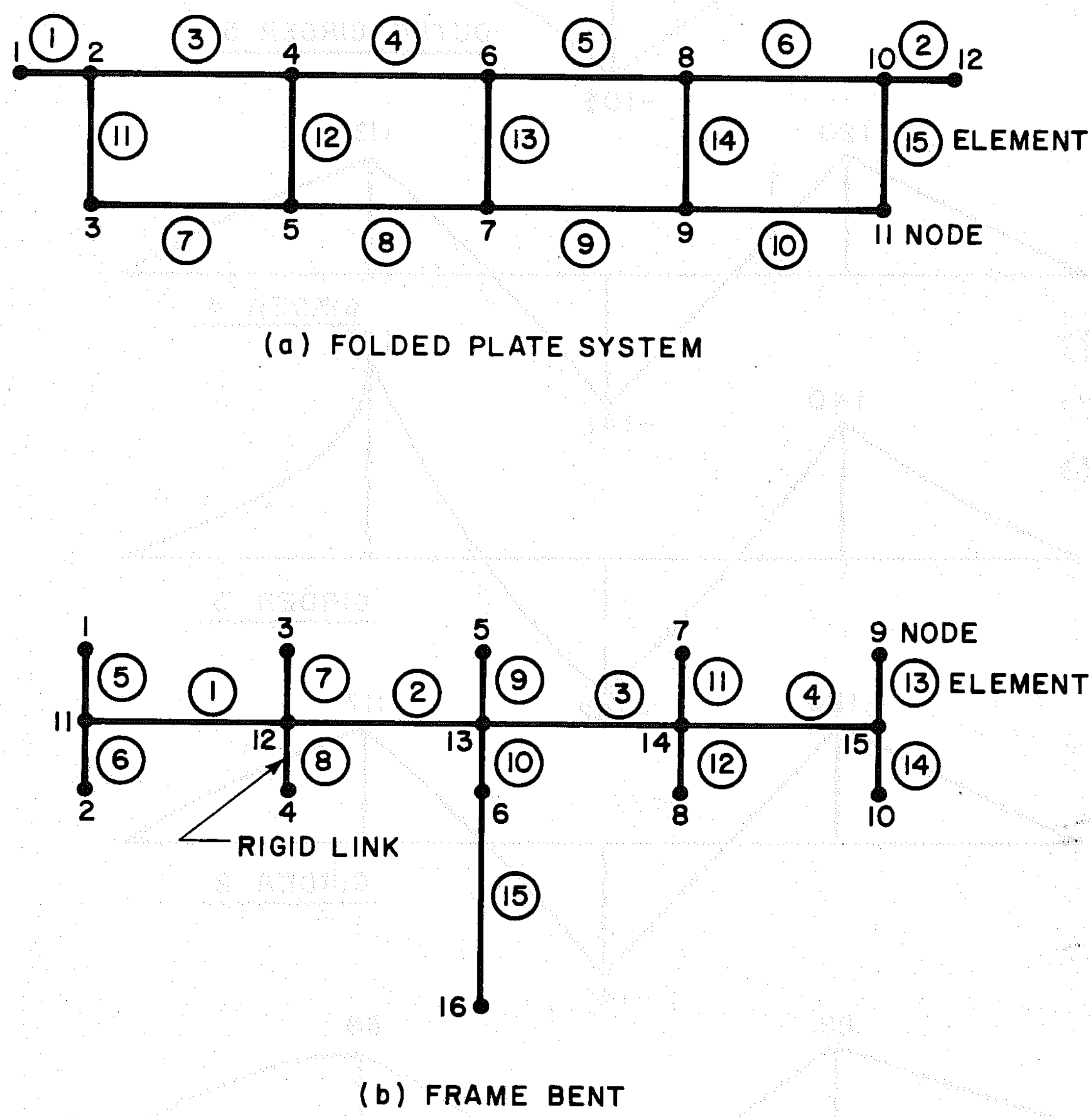


FIG. 5.22 EXAMPLE 4 – NODAL POINT AND ELEMENT NUMBERING

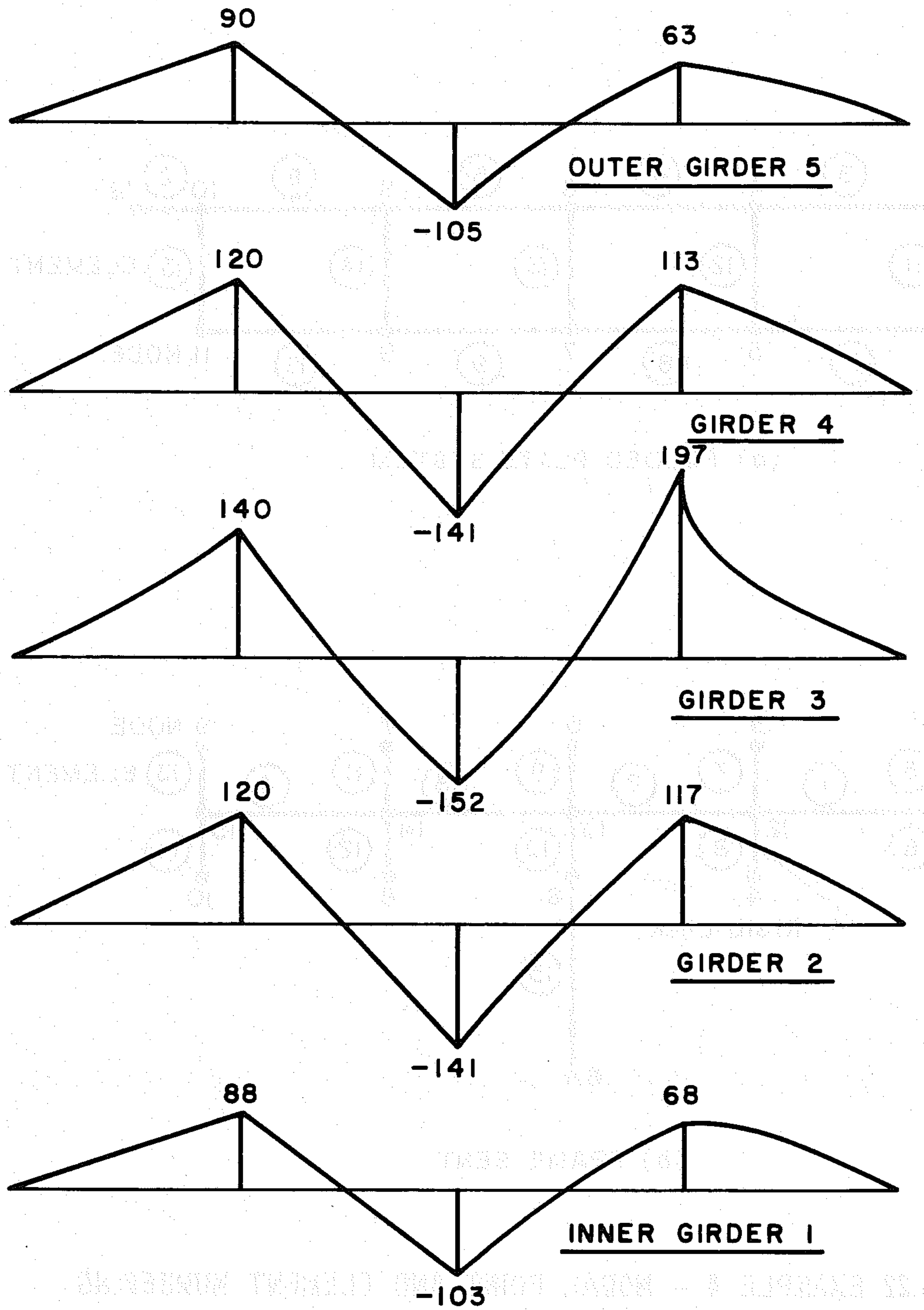


FIG. 5.23 EXAMPLE 4 – LONGITUDINAL DISTRIBUTION OF GIRDER MOMENTS (FT–KIPS)

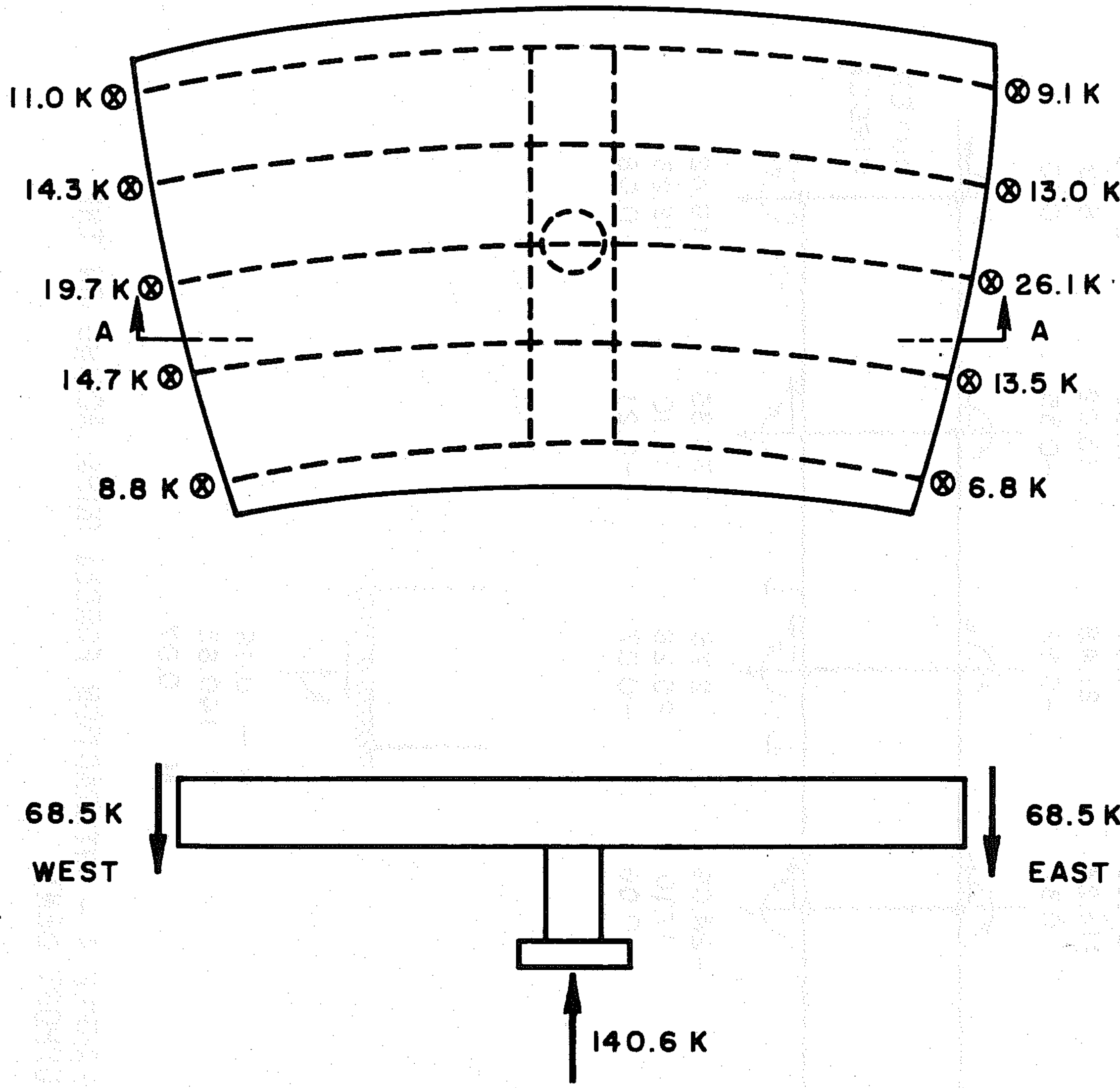


FIG. 5.24 EXAMPLE 4 – VERTICAL FORCES (KIPS) ACTING ON THE CENTER SUPPORT BENT AND AN ADJACENT PORTION OF THE BRIDGE

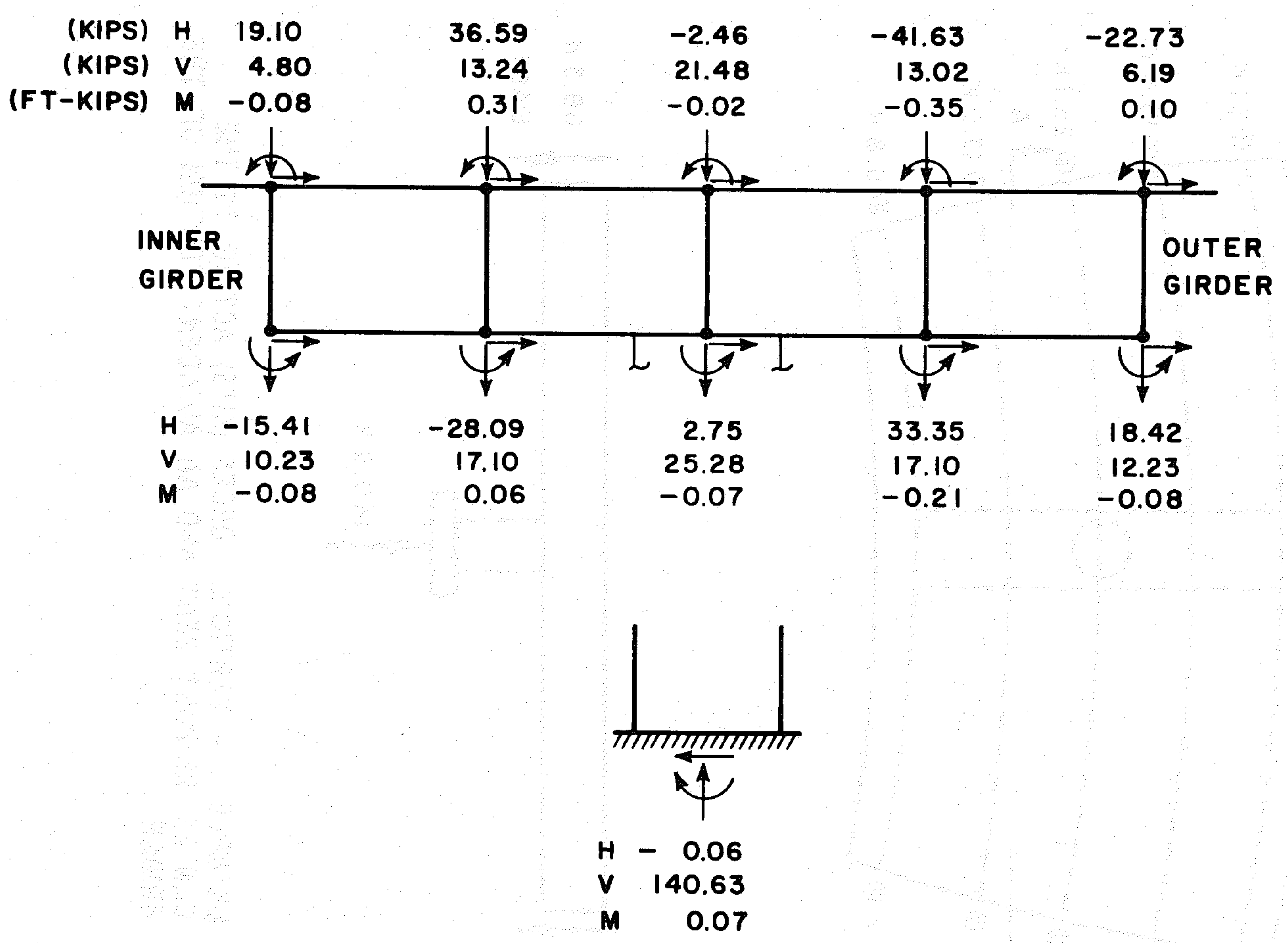


FIG. 5.25 EXAMPLE 4 – INTERACTION FORCES (KIPS) ACTING ON THE SUPPORT BENT

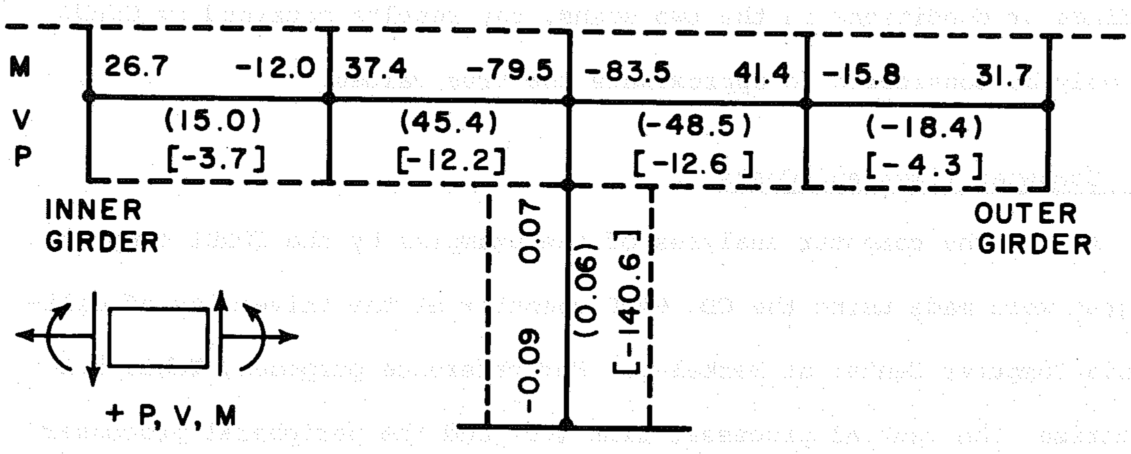


FIG. 5.26 EXAMPLE 4 – MOMENTS (FT-KIPS), SHEAR FORCES (KIPS) AND AXIAL FORCES (KIPS) IN THE SUPPORT BENT

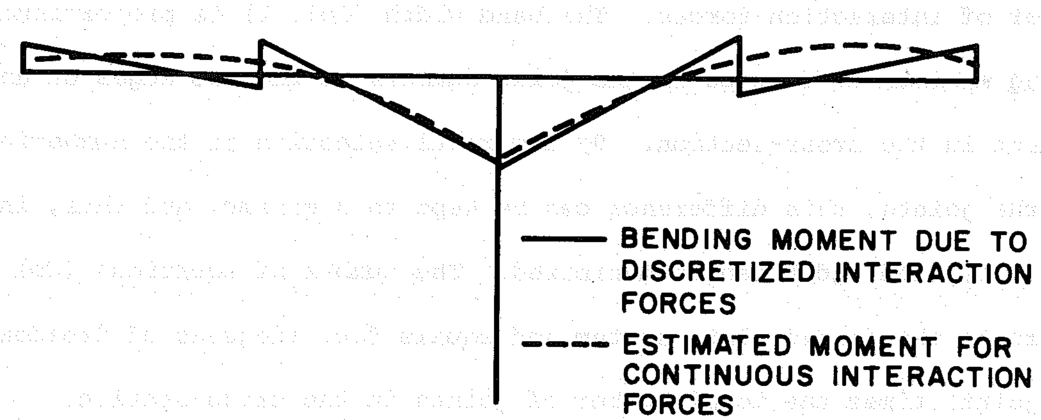


FIG. 5.27 EXAMPLE 4 – BENDING MOMENT DIAGRAM FOR THE SUPPORT BENT

normal to its own plane or longitudinal moments. Thus for unsymmetric loadings or conditions in the two spans, the results obtained by CURDI can only be considered to approximate the true values.

5.6 Computer Times and Costs

All of the computer analyses of the examples by the CURDI computer program were made using the CDC 6400 computer at the University of California Computer Center at Berkeley. For reference purposes, Table 5.1 summarizes the central processer time (CP) and the peripheral processer time (PP) used in running each example. Also indicated is the computer cost for each example. Times and costs on other computer systems will, of course, depend on the computer being used and the corresponding rate schedule.

As can be seen from Table 5.1, the required computer times are a function of the band width, number of harmonics, number of equations and number of interaction forces. The band width (Col. 2) is proportional to the maximum difference in the joint numbers at the two edges of any element in the cross-section. By a careful selection of the numbering for the joints, this difference can be kept to a minimum and thus, in turn, the band width can be minimized. The number of equations (Col. 4) refers to the folded plate system and equals four (degrees of freedom per joint) times the total number of joints in the cross-section.

TABLE 5.1 CDC 6400 CP AND PP COMPUTER TIMES (SECONDS) AND COSTS FOR ANALYSIS OF EXAMPLES BY CURDI COMPUTER PROGRAM

EXAMPLE	BAND WIDTH	NUMBER OF HARMONICS	NUMBER OF EQUATIONS	NUMBER OF INTERACTION FORCES	COMPUTER TIME (SECONDS)		COST ($)
					CP	PP	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1A	16	100	60	0	83	45	9
1B	16	100	60	0	83	45	9
1C	16	100	60	24	131	87	12
2A-1	12	50	36	0	56	41	5
2A-2	12	50	36	42	83	45	9
2A-3	12	50	36	0	56	41	5
2B-2	12	100	36	63	106	96	10
3	12	50	48	30	96	89	9
4	12	100	48	90	204	104	16

CP - CENTRAL PROCESSOR TIME (SECONDS)
PP - PERIPHERAL PROCESSOR TIME (SECONDS)
COST - RATE X (CP + A X PP)
A - FACTOR DEPENDENT ON AMOUNT OF CENTRAL MEMORY USED

6. CONCLUSIONS AND RECOMMENDATIONS FOR IMPLEMENTATION

A computer program has been presented for the linear elastic analysis of circularly curved, continuous highway bridges with flexible interior diaphragms or planar support bents. A complete and detailed description of the response of the structure to an arbitrary loading as well as the interaction between the bridge and the support bents can be obtained by the implementation of the program on a high speed digital computer. The input requires only the geometry and material properties of the structure, magnitudes and locations of the applied loading and the boundary conditions.

The program can be used to establish rational criteria for simplified methods of analysis and design for curved bridges and support bents by analyzing a number of bridge structures, in which important design parameters such as cross-sectional dimensions, radius of curvature, central angle or span along arc length, and flexibility of the support bents are varied to determine their effect on the bridge response. The program can also be used as a direct analytical tool for the design of unusual bridges having cross-sections, supporting bents or diaphragms which do not conform to those covered in the simplified design methods developed for standard cases.

A FORTRAN IV source listing is given in Appendix C for those wishing to implement the program directly onto their available computer. Information on the availability of source decks may be obtained from the authors. It is suggested that the input data given in Appendix B for Example 4 be used as a check case when implementing the program. Finally, it would be appreciated if any inconsistencies or errors are found in the program that they be brought to the attention of the authors.

7. ACKNOWLEDGMENTS

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

From the State of California Division of Highways, G. D. Mancarti, Assistant Bridge Engineer and R. E. Davis, Senior Bridge Engineer of the Research and Development Section, provided close liaison and assistance in the project.

The support of the Computer Center at the University of California, Berkeley, is gratefully acknowledged for providing its facilities.

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Copies of many of the research reports [1-19] in the above reference list have been placed on file with the U. S. Department of Commerce and may be obtained on request for cost of reproducing by writing to the following address:

National Technical Information Service
Operations Division
Springfield, Virginia 22151

The accession number (shown in parenthesis in the reference list) should be specified when ordering a particular report.

APPENDIX A

CURDI User's Guide

UNIVERSITY OF CALIFORNIA
September 1974

Department of Civil Engineering
Faculty Investigator: A. C. Scordelis

Computer Program for Analysis of Curved Prismatic Folded Plates Simply Supported at the Ends with Interior Flexible Diaphragms or Planar Rigid Frame Support Bents

IDENTIFICATION

CURDI - Analysis of Curved Prismatic Folded Plate Structures with Interior Flexible Diaphragms or Planar Rigid Frame Support Bents

Programmed by: A. F. Kabir, University of California, September 1974.

PURPOSE

The program provides a rapid solution for curved cellular or open folded plate structures simply supported at the two ends and having up to twelve interior flexible diaphragms or supporting frame bents between two ends. The structure is assumed to be restrained radially at the two ends. The plate elements may in general be segments of conical frustra. Uniform or partial surface loads, as well as line loads and concentrated loads, may be applied anywhere on the structure. Resulting joint displacements and the internal forces, moments and displacements in the folded plate elements, and the one-dimensional frame elements may be found.

RESTRICTIONS

Restrictions as to the maximum number of plates, joints, diaphragms or frame bents, etc., are given under input data and remarks.

DESCRIPTION

The computer solution uses a direct stiffness method for the folded plate system. Compatibility at the interior flexible diaphragms or supporting frame bents is accomplished by a force (flexibility) method of analysis. The finite strip method is used to evaluate plate edge forces, stiffnesses and final internal forces, moments, and displacements. A harmonic analysis with up to 100 non-zero terms of the appropriate Fourier Series is used for the loads. The flexible transverse diaphragms may be treated either as a beam having a rectangular cross-section or as a beam of arbitrary cross-section with a given cross-sectional area and moment of inertia. The flexible supporting frame bents are analyzed as two-dimensional planar frames. A special moment integration option permits the evaluation of the moment and the percentage of the total moment on a cross section taken by each girder of a box girder bridge. The program is written in FORTRAN IV language.

FORM OF INPUT DATA

Input data are key punched on cards as specified below. It is very important that the sequential order is strictly adhered to and consistent units are used throughout a problem.

1. TITLE CARD (12A6)

Col. 1 to 76 - TITLE(I) = Title of problem to be printed with output for identification

2. CONTROL CARD (2F10.0, 14I4)

Col. 1 to 10 - TETAO = angle of curvature (in degrees) between end supports (360 degrees for axisymmetric shell with axisymmetric loading)

Col. 11 to 20 - R = radius of curvature of structure reference line

Col. 21 to 24 - NPL = number of plate types, max. = 15

Col. 25 to 28 - NEL = number of elements, max. = 30

Col. 29 to 32 - NJT = number of joints, max. = 20

Col. 33 to 36 - NDIAPH = number of diaphragms (includes frame bents), max. = 12

Col. 37 to 40 - NXP = number of x-coordinates at which results are desired, max. = 14

Col. 41 to 44 - MHARM = maximum Fourier series limit
max. = 100 for NCHECK = 0
max. = 200 for NCHECK = +1 or -1

Col. 45 to 48 - NCHECK = check on odd or even harmonics
+1 to work on odd series only (sym.)
0 to include all series
-1 to work on even series only (anti-sym.)

Col. 49 to 52 - MCHECK = moment integration option
0 no moment integration
1 moment integration desired

Col. 53 to 56 - NBT = number of types of flexible supporting frame bents, max. = 8

Col. 57 to 60 - NFMD = number of types of flexible movable diaphragms, max. = 8

Col. 61 to 64 - KFOR = FORCE program option (calculates internal forces and displacements in frame bents)
0 to skip FORCE program
1 to execute FORCE program

Col. 65 to 68 - IO = input/output option indicator
1 sections for input/output given by angular degrees
0 sections for input/output given by arc lengths measured from origin along the reference line or joint under consideration

Col. 69 to 72 - MI = material option indicator
0 for inputting material properties
1 for inputting constitutive relations directly

Col. 73 to 76 - IAX = axisymmetric index
0 for axisymmetric shell only, TETAO = 360°
1 for all other cases

3. CIRCUMFERENTIAL COORDINATE CARD (10F7.2)

Col. 1 to 70 - XP(I) = X-coordinates along reference line, in arc length (if IO=0) or angles measured in degrees (if IO=1) of transverse sections at which results are desired. Use second card if more than 10 sections.

4. DIAPHRAGM CARDS (I10, 2F10.0, 2I4)

One card for each diaphragm or frame bent; omit if NDIAPH = 0

Col. 1 to 10 - I = diaphragm number

Col. 11 to 20 - DIAPHX(I) = X-coordinate at which diaphragm exists, arc length (if IO=0) or angle in degrees (if IO = 1)

Col. 21 to 30 - DIADEL(I) = diaphragm or bent interaction thickness in longitudinal direction

Col. 31 to 34 - KODIA(I) = diaphragm classification code
1 for externally supported rigid diaphragm
2 for movable rigid diaphragm
3 for flexible supporting frame bent
4 for flexible movable diaphragm

Col. 35 to 38 - KDIP(I) = type number of supporting bent or flexible movable diaphragm, leave blank if the diaphragm is rigid, therefore 1 or 2 above. (See paragraphs 14 and 16 for type description.)

5. PLATE TYPE CARDS

If MI = 0, two cards are required for each plate type

a. FIRST CARD - MEMBRANE CHARACTERISTICS (I10, 5F10.0)

Col. 1 to 10 - I = type number

Col. 11 to 20 - THM(I) = effective thickness

Col. 21 to 30 - ETM(I) = modulus of elasticity in hoop direction

Col. 31 to 40 - ESM(I) = modulus of elasticity in meridional direction

Col. 41 to 50 - GM(I) = shear modulus

Col. 51 to 60 - PRM(I) = Poisson's ratio (negative strain in hoop direction for unit strain in meridional direction)

b. SECOND CARD - BENDING CHARACTERISTICS (10X, 5F10.0)

Col. 11 to 20 - THB(I) = effective thickness

Col. 21 to 30 - ETB(I) = modulus of elasticity in hoop direction

Col. 31 to 40 - ESB(I) = modulus of elasticity in meridional direction

Col. 41 to 50 - GB(I) = shear modulus

Col. 51 to 60 = PRB(I) = Poisson's ratio (negative strain in hoop direction for unit strain in meridional direction)

If MI = 1, two cards are required for each plate type

a. FIRST CARD - MEMBRANE CONSTITUTIVE CONSTANTS (I10, 4F10.0)

Col. 1 to 10 - I = type number

Col. 11 to 20 - D11(I)

Col. 21 to 30 - D12(I)

Col. 31 to 40 - D22(I)

Col. 41 to 50 - D33(I)

b. SECOND CARD - PLATE BENDING CONSTITUTIVE CONSTANTS (10X, 4F10.0)

Col. 11 to 20 - D44(I)

Col. 21 to 30 - D45(I)

Col. 31 to 40 - D55(I)

Col. 41 to 50 - D66(I)

6. ELEMENT CARDS (5I4, 5F10.0)

Each element requires one card.

Col. 1 to 4 - I = element number

Col. 5 to 8 - NPI(I) = joint i of element I

Col. 9 to 12 - NPJ(I) = joint j of element I

Col. 13 to 16 - KPL(I) = plate type number

Col. 17 to 20 - NSEC(I) = number of element transverse subdivisions for output of internal forces and displacements, max. = 12. If NSEC(I) = 0, no internal forces and displacements will be output for element I.

Col. 21 to 30 - DL(I) = dead load (force per unit plate area)

Col. 31 to 40 - HLI(I) = horizontal load intensity at joint i (force per unit vertically projected area)

Col. 41 to 50 - HLJ(I) = horizontal load intensity at joint j

Col. 51 to 60 - VLI(I) = vertical load intensity at joint i (force per unit horizontally projected area)

Col. 61 to 70 - VLJ(I) = vertical load intensity at joint j

Note that horizontal and vertical load intensities are uniformly distributed along the entire structure length.

7. NUMBER OF PARTIAL SURFACE LOADS CARD (I4)

Col. 1 to 4 - NSURL = number of partial surface loads, max. = 30

8. PARTIAL SURFACE LOADS CARDS (I10, 6F10.0)

Each partial surface load requires one card. No cards are required if NSURL = 0

Col. 1 to 10 - LEL(I) = element number

Col. 11 to 20 - PHLI(I) = horizontal load intensity at joint i (force per unit vertically projected area or length)

Col. 21 to 30 - PHLJ(I) = horizontal load intensity at joint j

Col. 31 to 40 - PVLI(I) = vertical load intensity at joint i (force per unit horizontally projected area or length)

Col. 41 to 50 - PVLJ(I) = vertical load intensity at joint j

Col. 51 to 60 - SURT(I) = X-coordinate measured along mid-element line (if IO = 0) or angle measured in degrees (if IO = 1) from origin to center of loaded area

Col. 61 to 70 - SURL(I) = length measured along mid-element line (if IO = 0) or angle measured in degrees (if IO = 1) subtended by distributed load. Note that for SURL(I) = 0.0 (transverse line load), loads are input as force per unit length. For SURL(I) $\neq$ 0.0, loads are input as force per unit area.

9. <u>JOINT CARDS</u> (I10, 6F10.0, 7I1)

One card for each joint. All joints require a card.

Col. 1 to 10 - I = joint number

Col. 11 to 20 - Y(I) = Y-coordinate of joint I

Col. 21 to 30 - Z(I) = Z-coordinate of joint I

Col. 31 to 40 - AJFOR (1,I) = applied horizontal joint force or displacement

Col. 41 to 50 - AJFOR (2,I) = applied vertical joint force or displacement

Col. 51 to 60 - AJFOR (3,I) = applied joint moment or rotation

Col. 61 to 70 - AJFOR (4,I) = applied longitudinal joint force or displacement

Col. 71 - LCASE (1,I) = index for horizontal force or displacement (can be 0, 1, 2, or 3)

Col. 72 - LCASE (2,I) = index for vertical force or displacement (can be 0, 1, 2 or 3)

Col. 73 - LCASE (3,I) = index for moment or rotation (can be 0, 1, 2 or 3)

For Cols. 71, 72 and 73, indices are as follows:

0 for given zero force
1 for uniformly distributed force along entire length (input uniform force/unit length for AJFOR)
2 for concentrated force at midspan (input total force for AJFOR)
3 for given zero displacement

Col. 74 - LCASE (4,I) = index for longitudinal force or displacement, can be (0, 2, or 3)

For Col. 74 indices are as follows:

0 for given zero force
2 for prestress P at each end (input total force at one end for AJFOR, + towards midspan)
3 for given zero displacement

The following three indices define whether or not the joint is connected to the interior diaphragm or bents that exist in the structure horizontally, vertically or rotationally and are called joint restraint conditions from diaphragms or bents:

Col. 62 - index for horizontal restraint = JFOR (1,I)

Col. 64 - index for vertical restraint = JFOR (2,I)

Col. 66 - index for rotational restraint = JFOR (3,I)
0 to consider restraint from diaphragms or bents
1 to neglect restraint from diaphragms or bents

10. NUMBER OF PARTIAL JOINT LOADS CARD (I4)

Col. 1 to 4 - NCONL = number of partial joint loads, max. = 30

11. PARTIAL JOINT LOAD CARDS (I10, 6F10.0)

One card is required for each partial joint load. No cards are required if NCONL = 0. More than one location along a joint may be loaded, but each location requires a separate card.

Col. 1 to 10 - LJT(I) = joint number

Col. 11 to 20 - FH(I) = total horizontal force

Col. 21 to 30 - FV(I) = total vertical force

Col. 31 to 40 - FM(I) = total moment

Col. 41 to 50 - FP(I) = total longitudinal force (Note that this force must be balanced by another force FP(I) somewhere on the same joint.)

Col. 51 to 60 - FTL(I) = X-coordinate measured along joint LJT (if IO = 0) or angle measured in degrees (if IO = 1) from origin to center of joint load

Col. 61 to 70 - FTT(I) = length measured along joint LJT (if IO = 0 or angle measured in degrees (if IO = 1) subtended by joint load. For concentrated joint load, FTT(I) = 0.0. Note that each joint may be loaded with more than one joint load, but each joint load requires one separate card.

12. GIRDER MOMENT INTEGRATION CARD DECK

For girder moment integration - no cards required if no moment integration called for on CONTROL CARD (paragraph 2). The accuracy of the integration depends on the number of transverse sections (NSEC) in paragraph 7. Normally, NSEC = 4 is recommended.

a. FIRST CARD (2I4)

Col. 1 to 4 - NOXMP = number of points along X-axis at which girder moments are desired, max. = 14

Col. 5 to 8 - NBOX = number of girders, max. = 10

b. SECOND CARD (10F7.3)

Col. 1 to 70 - XMP(I) = X-coordinates at which girder moments are desired, must be a subset of the coordinates listed in paragraph 3. Use second card if more than 10 sections.

c. NEXT CARDS (3I4, 3F10.0) - one card for each element

Col. 1 to 4 - I = element number

Col. 5 to 8 - NGIEL (I,1) = first girder number to which this element belongs; if it belongs to two, list that which is nearest to node I first; girders are numbered from left to right.

Col. 9 to 12 - NGIEL (I,2) = second girder number to which this element belongs; punch zero if no second girder.

Col. 13 to 22 - DNAI(I) = vertical distance from assumed section neutral axis to node I; downward is positive

Col. 23 to 32 - DNAJ(I) = vertical distance from assumed section neutral axis to node J; downward is positive

Col. 33 to 42 - XDIV(I) = horizontal distance from node I to the dividing point if the element belongs to two girders; rightward is positive

13. FLEXIBLE SUPPORTING FRAME BENT CARD DECK

No cards required if no bents called for on CONTROL CARD (paragraph 2). Otherwise, one set of the following cards required for each type of supporting bent. The type numbers should be ascending consecutive integers starting from 1.

a. CONTROL CARD (6I5)

Col. 1 to 5 - frame type number

Col. 6 to 10 - number of elements

Col. 11 to 15 - number of nodal points (max. = 80)

Col. 16 to 20 - number of materials (max. = 10)

Col. 21 to 25 - number of element section property cards (max. = 200)

Col. 26 to 30 - number of elastic support cards (max. = 40)

b. MATERIAL PROPERTY CARDS (I5, E10.0, F10.0)

Col. 1 to 5 - material identification number (any number from 1 to 10)

Col. 6 to 15 - Young's modulus

Col. 16 to 25 - Poisson's ratio

c. ELASTIC SUPPORT CARDS (I5, 3F10.0) - skip if no elastic supports

Col. 1 to 5 - identification number (any number from 1 to 40)

Col. 6 to 15 - SX (X component of spring stiffness)

Col. 16 to 25 - SY (Y component of spring stiffness)

Col. 26 to 35 - SZ (rotational spring stiffness)

d. SECTION PROPERTY CARDS (I5, 3F10.0)

Col. 1 to 5 - identification number (any number from 1 to 200)

Col. 6 to 15 - axial area

Col. 16 to 25 - shear area (leave blank if shear deformations are to be neglected)

Col. 26 to 35 - moment of inertia

e. NODAL POINT DATA CARDS (2I5, 2F10.0, 2I5) - one for each frame bent node

Col. 1 to 5 - frame nodal point number

Col. 6 to 10 - joint boundary condition code, a three digit number in Cols. 8, 9, 10, use 1 for zero displacement, otherwise use 0, (col. 8 - X displacement, Col. 9 - Y displacement, Col. 10 - Z rotation)

Col. 11 to 20 - global X in frame coordinate system

See page A-14

Col. 21 to 30 - global Y in frame coordinate system

Col. 31 to 35 - elastic support identification number (leave blank if no elastic support)

Col. 36 to 40 - NFP(N) = corresponding nodal point number in the folded plate system (leave blank if not connected to folded plate system)

f. ELEMENT DATA CARDS (5I5, I10) - one for each frame bent element

Col. 1 to 5 - identification number

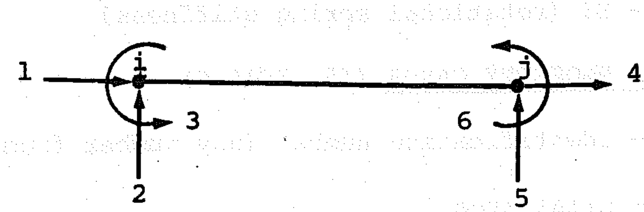
Col. 6 to 10 - node I

Col. 11 to 15 - node J

Col. 16 to 20 - material identification number

Col. 21 to 25 - section property identification number

Col. 26 to 35 - element code - The element code is a six digit number in columns 30 to 35 which permits member end releases (e.g., pin ends). Use 1 for zero member end force, otherwise use 0 or leave blank. The first digit corresponds to member end force 1 in the following diagram. The second digit refers to force 2, etc.



14. REPEAT preceding frame bent card deck for each frame type number.

15. FLEXIBLE MOVABLE DIAPHRAGM CARD DECK

No cards required if no flexible movable diaphragms called for on CONTROL CARD (paragraph 2). Otherwise, one set of the following two cards required for each type of flexible movable diaphragm.

a. FIRST CARD (2I4)

Col. 1 to 4 - type number

Col. 5 to 8 - option code (option for the two ways of inputing data)
1 option one
2 option two

b. SECOND CARD - use either option one or two as designated

1) Option one (5F10.0) diaphragm assumed to have rectangular cross-section

Col. 1 to 10 - DITH = diaphragm thickness

Col. 11 to 20 - DIDP = diaphragm depth (neutral axis is assumed at mid-depth)

Col. 21 to 30 - CODE = code for vertical location of diaphragm neutral axis with respect to joint 1 of folded plate system
+1.0 if neutral axis above joint 1
-1.0 if neutral axis below joint 1

Col. 31 to 40 - DIE = modulus of elasticity

Col. 41 to 50 - DINU = Poisson's ratio

2) Option two (6F10.0)

Col. 1 to 10 - DIPHI = moment of inertia of diaphragm cross-section

Col. 11 to 20 - DIPHA = area of cross-section

Col. 21 to 30 - DIAS = shear area of cross-section (leave blank if shear deformations are to be neglected.)

Col. 31 to 40 - CC = vertical distance from diaphragm neutral axis to joint 1 of folded plate system
\+ if neutral axis above joint 1
\- if neutral axis below joint 1

Col. 41 to 50 - DIE = modulus of elasticity

Col. 51 to 60 - DINU = Poisson's ratio

16. REPEAT preceding card deck for each type of flexible movable diaphragm.

17. ALL of the above data cards (paragraphs 1 to 16) are repeated for next problem to be solved.

18 TWO blank cards are added at the end of the complete data deck.

REMARKS

1. Number all elements of the same plate type in consecutive groups if possible. This will save some computer time when calculating internal forces.

2. Select joint numbering so as to minimize maximum absolute difference between joint numbers for any plate element. See sketches on page A-16.

3. The maximum total number of connections between the folded plate system and all of the diaphragms and bents must be equal to or less than 120. Therefore, assuming there are a total of M zero indices for JFOR, horizontal, vertical or rotational joint restraints, then (M) x NDIAPH $\leq$120.

OUTPUT DESCRIPTION

The output consists of two parts:

1. Input check printout
2. Results

1. Input check printout

The complete input is properly labelled and printed, and may be used to check up on possible errors in punching, field specifications, and order of the cards.

2. Results

The final results consist of the following quantities: (see pages A-14 and A-15 for sign convention).

a. If NDIAPH is not zero, the interaction (restraint) joint forces between each diaphragm or bent and the folded plate system are printed.

b. Resulting displacements at joints - Horizontal, vertical, rotational, and longitudinal displacements of the folded plates are given successively for each joint.

c. Internal element forces and displacements - For each plate element the following quantities are printed:

1) Longitudinal moment per unit length; M_θ
2) Transverse moment per unit length; M_s
3) Torsional moment per unit length; $M_{s\theta}$
4) Longitudinal membrane force per unit length; N_θ
5) Transverse membrane force per unit length; N_s
6) Membrane shear per unit length; $N_{s\theta}$
7) Longitudinal displacement; u
8) Transverse displacement; v
9) Normal displacement; w

Each of these quantities is printed for each transverse section specified across the plate width and at the X-coordinate specified along the plate length.

d. If MCHECK = 1, the following quantities are printed at the specified cross-sections:

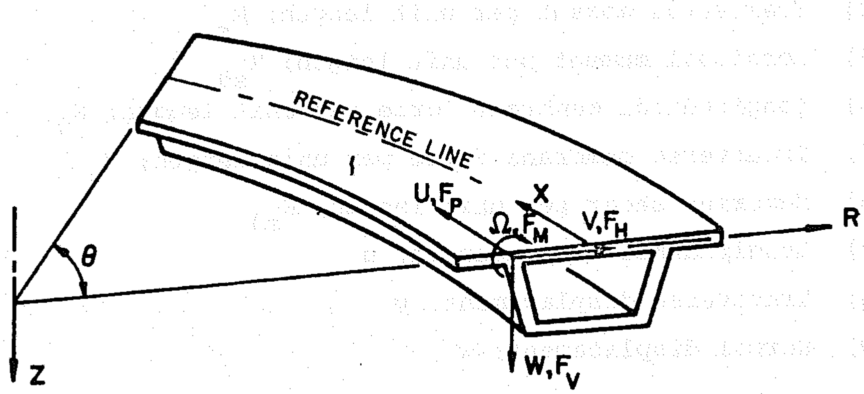
1) Moment taken by each girder
2) Percentages of total moment at the section taken by each girder
3) The resultant longitudinal tensile force and compressive force taken by each girder

e. If KFOR = 1, the following quantities are printed for each flexible supporting frame bent:

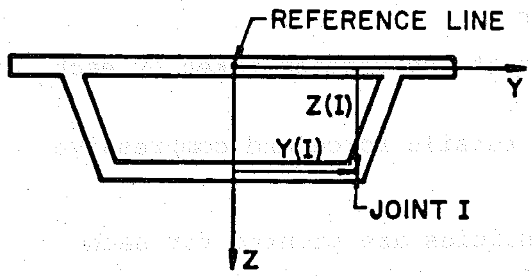
1) Joint displacements
2) Member end forces
3) Applied joint loads (i.e., interaction forces acting on the frame bent) and reactions

SIGN CONVENTIONS

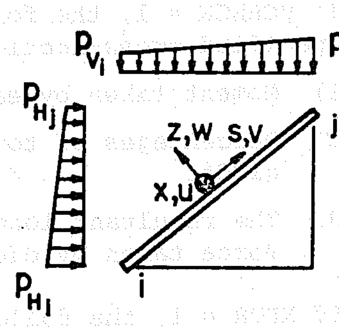
1. SIGN CONVENTIONS FOR THE FOLDED PLATE SYSTEM



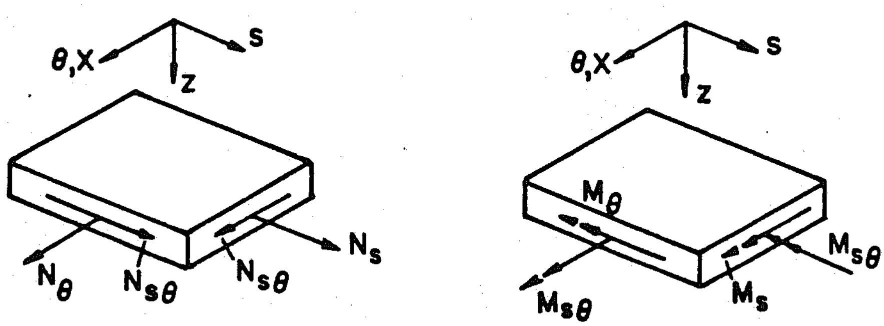
a) GLOBAL JOINT DISPLACEMENTS U,V,W,Ω AND JOINT LOADS F_P, F_H, F_V, F_M



b) JOINT COORDINATES

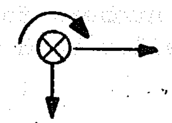


c) SURFACE LOADS AND ELEMENT DISPLACEMENTS



d) INTERNAL FORCES AND MOMENTS

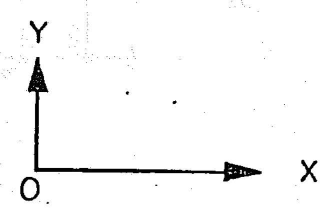
e) EXTERNAL JOINT FORCES OR DISPLACEMENTS (also applicable to the interaction forces between folded plate system and supporting frame bents or diaphragms, acting on the folded plate system)



positive when looking away from the origin of the plate system

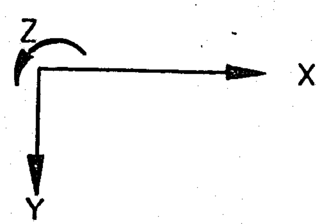
2. SIGN CONVENTIONS FOR THE SUPPORTING FRAME BENTS (assumed looking away from the origin of the folded plate system)

a) COORDINATE SYSTEM FOR THE GEOMETRY OF THE FRAME BENTS (Note this is independent of folded plate coordinate system)

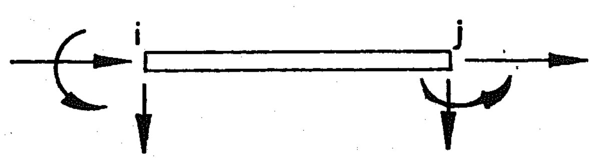


(location of origin can be arbitrary)

b) JOINT FORCES AND DISPLACEMENTS (Joint forces include interaction forces and reactions acting on the supporting frame bent)

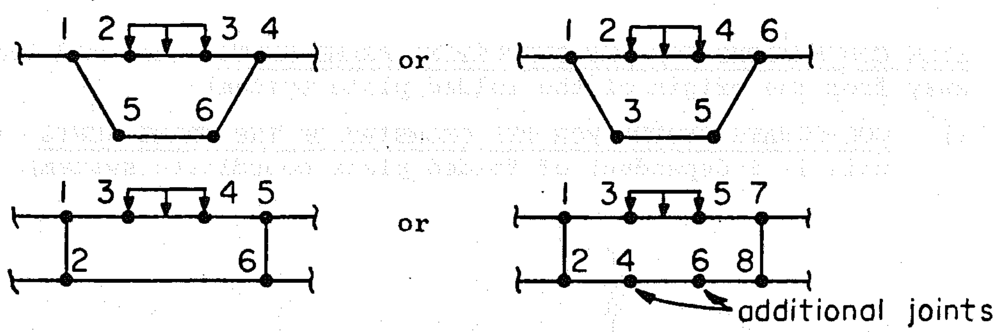


c) POSITIVE MEMBER END FORCES



3. ALTERNATE METHODS OF NUMBERING JOINTS OF THE FOLDED PLATE SYSTEM

The sections shown are assumed looking away from origin of the folded plate system towards the sections. In both cases the joint numbering on the right gives a smaller maximum difference in the joint numbers for any element in the cross-section and thus a smaller band width for the equations to be solved.



APPENDIX B

Listing of Input Data for Example 4

```
EX 4-2SPAN,4CELL,CURVED,RC BRIDGE MODEL (CURDI REPORT)
 41.253    100.0        4   15  12    2  13 100   0    1    1    1    1    0    0    1
0.0     9.0     14.4    18.0    27.0    33.0    36.0    39.0    45.0    54.0
57.6    63.0    72.0
             1  54.0        0.234        4    1
             2  36.0        1.960        3    1
             1 0.255      550800.0   550800.0   239478.2   0.15
               0.255      550800.0   550800.0   239478.2   0.15
             2 0.188      550800.0   550800.0   239478.2   0.15
               0.188      550800.0   550800.0   239478.2   0.15
             3 0.162      432000.0   432000.0   187800.0   0.15
               0.162      432000.0   432000.0   187800.0   0.15
             4 0.234      432000.0   432000.0   187800.0   0.15
               0.234      432000.0   432000.0   187800.0   0.15
    1    1    2    1    4
    2   10   12    1    4
    3    2    4    2    4
    4    4    6    2    4
    5    6    8    2    4
    6    8   10    2    4
    7    3    5    3    4
    8    5    7    3    4
    9    7    9    3    4
   10    9   11    3    4
   11    3    2    4    4
   12    5    4    4    4
   13    7    6    4    4
   14    9    8    4    4
   15   11   10    4    4
    0
             1  -6.0       0.0                                                          111
             2  -5.15      0.0
             3  -5.15      1.539
             4  -2.575     0.0
             5  -2.575     1.539
             6  0.0        0.0
             7  0.0        1.539
             8  2.575       0.0
             9  2.575      1.539
            10  5.15       0.0
            11  5.15       1.539
            12  6.00       0.0                                                          111
    2
             6             100.0                                    18.0       0.0
             6             100.0                                    54.0       0.0
   11    5
  9.0    14.4    18.0    27.0    33.0    36.0    39.0    45.0    54.0    57.6
63.0
    1    1      -0.687     -0.687
    2    5      -0.687     -0.687
    3    1   2 -0.687     -0.687     1.2875
    4    2   3 -0.687     -0.687     1.2875
    5    3   4 -0.687     -0.687     1.2875
    6    4   5 -0.687     -0.687     1.2875
```

```
   7    1    2 0.852       0.852       1.2875
   8    2    3 0.852       0.852       1.2875
   9    3    4 0.852       0.852       1.2875
  10    4    5 0.852       0.852       1.2875
  11    1      0.852      -0.687
  12    2      0.852      -0.687
  13    3      0.852      -0.687
  14    4      0.852      -0.687
  15    5      0.852      -0.687
    1    15    16      2      2      0
    1.432000+06   0.15
    2.432000+11   0.15
    1 3.020       2.520       0.595
    2 1.767       1.590        0.249
    1      0.85        1.539                2
    2      0.85        0.0                  3
    3      3.425       1.539                4
    4      3.425       0.0                  5
    5      6.0         1.539                6
    6      6.0         0.0                  7
    7      8.575       1.539                8
    8      8.575       0.0                  9
    9      11.15       1.539               10
   10      11.15       0.0                 11
   11      0.85        0.7695               0
   12      3.425       0.7695               0
   13      6.0         0.7695               0
   14      8.575       0.7695               0
   15      11.150      0.7695               0
   16   111 6.0       -2.667               0
    1    11    12     1     1
    2    12    13     1     1
    3    13    14     1     1
    4    14    15     1     1
    5     1    11     2     1
    6    11     2     2     1
    7     3    12     2     1
    8    12     4     2     1
    9     5    13     2     1
   10    13     6     2     1
   11     7    14     2     1
   12    14     8     2     1
   13     9    15     2     1
   14    15    10     2     1
   15     6    16     1     2
   1    1
0.234      1.539       -1.0      432000.0    0.15
```

APPENDIX C

FORTRAN IV Listing of CURDI

Considerable time, effort, and expense have gone into the development of the computer program. It is obvious that it should be used only under the conditions and assumptions for which it was developed. These are described in this research report. Although the program has been extensively tested by the authors, no warranty is made regarding the accuracy and reliability of the program and no responsibility is assumed by the authors or by the sponsors of this research project.

```
      OVERLAY(MASTER,0,0)
      PROGRAM CURDI(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1,TAPE2,TA
     1PE3,TAPE4,TAPE7,TAPE8,TAPE9)
C
C     ********************************************************************
C     LINEAR ELASTIC ANALYSIS FOR CURVED FOLDED PLATE STRUCTURES SIMPLY
C     SUPPORTED AT THE ENDS WITH RIGID OR FLEXIBLE INTERIOR DIAPHRAGMS
C     OR SUPPORT BENTS
C                               PROGRAMMED BY AHMAD F. KABIR
C                               UNIVERSITY OF CALIFORNIA,SEPT. 1972
C     ********************************************************************
C
      COMMON TETAO,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMD
     1,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,TITLE(12),SPACE(220)
      COMMON /PLATE/ XP(14),NPI(30),NPJ(30),KPL(30),NSEC(30),PWTH(30),SI
     1NEL(30),COSEL(30),Y(30),Z(30),TP(14)
      COMMON /PROPT/ THM(15),THB(15),ETM(15),ETB(15),ESM(15),ESB(15),GM(
     115),GB(15),PRM(15),PRB(15)
      COMMON /PERM/ NOXMP,NBOX,NGIEL(30,2),BOXMOM(14,10),XDIV(30),DNAI(3
     10),DNAJ(30),MOPX(14),COMP(14,10),TENS(14,10),HS(30),VS(30),XMP(14)
      COMMON /CASE/ AJP(80),LCASE(4,20),JFOR(3,20),XORD(20),YORD(20)
      COMMON /FXDM/ IC(3,2),KTEM(13),MBCOL,NDIA(12),JN1,JN2,INDB(120),XD
     1OD(120),BF(3,120),IT
      COMMON /PARAM/ NUMEL,NUMNP,NEQ,NJMSPR,NP,NUMELT(8),NUMNPT(8),NEQN(
     18),NUSPRG(8),NPT(8),NPR(80)
C
C
   10 READ 50, (TITLE(I),I=1,12)
      READ 60, TETAO,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NF
     1MD,KFOR,IO,MI,IAX
      IF (R) 40,40,20
   20 PRINT 70, (TITLE(I),I=1,12)
      CALL OVERLAY (6HMASTER,1,0)
      IF (NDIAPH.EQ.0) GO TO 30
      CALL OVERLAY (6HMASTER,2,0)
      IF (NBT.NE.0) CALL OVERLAY (6HMASTER,3,0)
      IF (NFMD.NE.0) CALL OVERLAY (6HMASTER,4,0)
      CALL OVERLAY (6HMASTER,5,0)
   30 CALL OVERLAY (6HMASTER,6,0)
      IF (KFOR.EQ.1) CALL OVERLAY (6HMASTER,7,0)
      GO TO 10
   40 STOP
C
   50 FORMAT (12A6)
   60 FORMAT (2F10.0,14I4)
   70 FORMAT (1H1,12A6)
      END
```

```
      OVERLAY(MASTER,1,0)
      PROGRAM MAIN
C
C     ******************************************************************
C     READ AND PRINT INPUT DATA. RESOLVE EXTERNAL LOADS AND UNIT
C     INTERACTION FORCES INTO HARMONIC COMPONENTS. ANALYZE THE PRIMARY
C     STRUCTURE FOR EACH HARMONIC.
C     ******************************************************************
C
      COMMON TETAD,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMD
     1,KFOR,ID,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12)
     2,KDTP(12),CHPLRE,MPC1,MPCOL,MPC,INDMP(60),CF(120)
      COMMON /CASE/ AJP(80),LCASE(4,20),JFOR(3,20),XORD(20),YORD(20)
      COMMON /PLATE/ XP(14),NPI(30),NPJ(30),KPL(30),NSEC(30),PWTH(30),SI
     1NEL(30),COSEL(30),Y(30),Z(30),TP(14)
      COMMON /PROPT/ THM(15),THB(15),ETM(15),ETB(15),ESM(15),ESB(15),GM(
     115),GB(15),PRM(15),PRB(15)
      COMMON /STIFF/ SMALLK(8,8)
      COMMON /PERM/ NDXMP,NBOX,NGIEL(30,2),BOXMOM(14,10),XDIV(30),DNAI(3
     10),DNAJ(30),MCPX(14),COMP(14,10),TENS(14,10),HS(30),VS(30),XMP(14)
      DIMENSION D11(15), D12(15), D22(15), D33(15), D44(15), D45(15), D5
     15(15), D66(15), NPDIF(30), SINKX(200,14), COSKX(200,14), NQ(2), LI
     2ND(80), BIGK(80,20), PTOT(80), PTTT(80,81),      AJFOR(4,20), BK
     3(1600), DISP(80,81)
      DIMENSION LEL(30), PHLI(30), PHLJ(30), PVLI(30), PVLJ(30), SURT(30
     1), SURL(30), LJT(30), FH(30), FV(30), FM(30), FP(30), FTL(30), FTT
     2(30), DL(30), HLI(30), HLJ(30), VLI(30), VLJ(30), H(30), V(30)
      EQUIVALENCE (LIND,LCASE), (AJP,AJFOR)
      EQUIVALENCE (THM,D11), (THB,D12), (ETM,D22), (ETB,D33), (ESM,D44),
     1 (ESB,D45), (GM,D55), (GB,D66)
C
C
C
C     READ AND PRINT INPUT DATA
C
      PRINT 1120, TETAD,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NBT,NFMD
      MH = (MHARM/2)*2
      IF (NCHECK) 10,30,20
   10 PRINT 1090
      IF (MHARM.NE.MH) MHARM=MHARM-1
      GO TO 30
   20 PRINT 1100
      IF (MHARM.EQ.MH)MHARM=MHARM-1
   30 IF (MCHECK.EQ.1) PRINT 1110
      IF (KFOR.EQ.1) PRINT 1080
      READ 1130, (XP(I),I=1,NXP)
      IF (IO.EQ.0) PRINT 1370
      IF (IO.EQ.1) PRINT 1380
      PRINT 1360, (XP(I),I=1,NXP)
C
C
      IF (NDIAPH) 60,60,50
   50 READ 1160, (I,DIAPHX(I),DIADEL(I),KODIA(I),KDTP(I),J=1,NDIAPH)
      PRINT 1170, (I,DIAPHX(I),DIADEL(I),KODIA(I),KDTP(I),I=1,NDIAPH)
```

```
      PRINT 1180
   60 IF (MI.EQ.1) GO TO 80
      DO 70 J=1,NPL
      READ 1290, I,THM(I),ETM(I),ESM(I),GM(I),PRM(I)
   70 READ 1270, THB(I),ETB(I),ESB(I),GB(I),PRB(I)
      PRINT 1400
      PRINT 1410, (I,THM(I),ETM(I),ESM(I),GM(I),PRM(I),TH3(I),ETB(I),ESB
     1(I),GB(I),PRB(I),I=1,NPL)
      GO TO 100
   80 DO 90 J=1,NPL
      READ 1300, I,D11(I),D12(I),D22(I),D33(I)
   90 READ 1260, D44(I),D45(I),D55(I),D66(I)
      PRINT 1340
      PRINT 1350, (I,D11(I),D12(I),D22(I),D33(I),D44(I),D55(I),D66(I),I=
     11,NPL)
C
  100 READ 1280, (I,NPI(I),NPJ(I),KPL(I),NSEC(I),DL(I),HLI(I),HLJ(I),VLI
     1(I),VLJ(I),J=1,NFL)
      PRINT 1420
      PRINT 1430, (I,NPI(I),NPJ(I),KPL(I),NSEC(I),DL(I),HLI(I),HLJ(I),VL
     1I(I),VLJ(I),I=1,NEL)
C
      READ 1140, NSURL
      IF (NSURL) 120,120,110
  110 READ 1320, (LEL(I),PHLI(I),PHLJ(I),PVLI(I),PVLJ(I),SURT(I),SURL(I)
     1,I=1,NSURL)
      PRINT 1460
      PRINT 1470, (LEL(I),PHLI(I),PHLJ(I),PVLI(I),PVLJ(I),SURT(I),SURL(I
     1),I=1,NSURL)
C
  120 DO 130 L=1,NJT
  130 READ 1330, I,Y(I),Z(I),(AJFOR(J,I),J=1,4),(LCASE(K,I),<=1,4),(JFOR
     1(K,I),K=1,3)
      PRINT 1440
      DO 140 I=1,NJT
      PRINT 1450, I,Y(I),Z(I),(AJFOR(J,I),LCASE(J,I),J=1,4),(JFOR(K,I),K
     1=1,3)
  140 CONTINUE
C
      PRINT 1150
      PRINT 1190
      READ 1140, NCCNL
      IF (NCONL) 16C,160,150
  150 READ 1310, (LJT(I),FH(I),FV(I),FM(I),FP(I),FTL(I),FTT(I),I=1,NCONL
     1)
      PRINT 1480
      PRINT 1490, (LJT(I),FH(I),FV(I),FM(I),FP(I),FTL(I),FTT(I),I=1,NCON
     1L)
C
  160 CONTINUE
      IF (MCHECK) 220,220,170
  170 READ 1200, NOXMP,NBOX
      READ 1130, (XMP(I),I=1,NOXMP)
      READ 1220, (I,NGIEL(I,1),NGIEL(I,2),DNAI(I),DNAJ(I),XDIV(I),J=1,NE
     1L)
      PRINT 1230, NCXMP,NBOX
```

```
      PRINT 1240, (XMP(I),I=1,NOXMP)
      PRINT 1250, (I,NGIEL(I,1),NGIEL(I,2),DNAI(I),DNAJ(I),XDIV(I),I=1,N
     1EL)
      DO 200 I=1,NOXMP
      DO 180 J=1,NXP
      IF (XP(J).EQ.XMP(I)) GO TO 190
  180 CONTINUE
      PRINT 1210
      GO TO 200
  190 MOPX(I)=J
  200 CONTINUE
      DO 210 I=1,NOXMP
      DO 210 J=1,NBCX
      BOXMOM(I,J)=0.
      COMP(I,J)=0.
  210 TENS(I,J)=0.
C
  220 CONTINUE
      PI=3.14159265
      MX=4*NJT
C
C
C     COMPUTE PLATE WIDTHS AND SIN AND COS CF INCLINATION ANGLES
C
      DO 230 I=1,NEL
      II=NPI(I)
      IJ=NPJ(I)
      HH=Y(IJ)-Y(II)
      VV=Z(IJ)-Z(II)
      H(I)=HH
      V(I)=-VV
      HS(I)=H(I)
      VS(I)=V(I)
      PWTH(I)=SQRT(HH*HH+VV*VV)
      SINEL(I)=VV/PWTH(I)
  230 COSEL(I)=HH/PWTH(I)
C
C     CALCULATE JOINT RADII    Y(I)=Y(I)+R
C
      FAC=3.14159265/180.
      TETAO=TETAO*FAC
      T2=0.5*TETAO
      HSPAN=R*SIN(T2)
      DO 240 I=1,NJT
  240 Y(I)=Y(I)+R
C
C     CONVERT CIRCUMFERENTEIAL COORDINATES TO RADIAN
C
      S=1./R
      IF (IO.EQ.1) S=FAC
      DO 250 I=1,NXP
  250 TP(I)=XP(I)*S
      IF (NSURL.LE.0) GO TO 270
      DO 260 I=1,NSURL
      IK=LEL(I)
      II=NPI(IK)
```

```
      IJ=NPJ(IK)
      RR=(Y(II)+Y(IJ))/2.
      S=1./RR
      IF (IO.EQ.1) S=FAC
      SURT(I)=SURT(I)*S
  260 SURL(I)=SURL(I)*S
  270 IF (NCONL.LE.C) GO TO 290
      DO 280 I=1,NCCNL
      II=LJT(I)
      S=1./Y(II)
      IF (IO.EQ.1) S=FAC
      FTL(I)=FTL(I)*S
  280 FTT(I)=FTT(I)*S
  290 IF (NDIAPH.LE.0) GO TO 310
      DO 300 I=1,NDIAPH
      S=1.0/R
      DIADEL(I)=DIADEL(I)*S
      IF (IO.EQ.1) S=FAC
  300 DIAPHX(I)=DIAPHX(I)*S
  310 CONTINUE
C     FIND X AND Y COORDINATES WITH ORIGIN AT JOINT 1
C
      IF (NDIAPH) 320,320,330
  320 CHPLRE=1.
      MPC1=1
      GO TO 400
  330 XORD(1)=0.
      YORD(1)=0.
      NPDIF(1)=-1
      DO 340 I=2,NJT
  340 NPDIF(I)=1
      II=1
  350 DO 390 K=1,NEL
      L=K
      I=NPI(K)
      J=NPJ(K)
      IF (NPDIF(I)+NPDIF(J)) 390,360,390
  360 IF (NPDIF(I)+1) 370,370,380
  370 XORD(J)=XORD(I)+H(L)
      YORD(J)=YORD(I)+V(L)
      NPDIF(J)=-1
      II=II+1
      GO TO 390
  380 XORD(I)=XORD(J)-H(L)
      YORD(I)=YORD(J)-V(L)
      NPDIF(I)=-1
      II=II+1
  390 CONTINUE
      IF (II-NJT) 350,400,350
C
C
C     MODIFY SUR. LOADS FOR ELE.(VL=ZL,HL=YL) AND CHECK FOR MAX. BAND WI
C        ALSO SET NPI=NPI*4-4, NPJ=NPJ*4-4
C
  400 NXBAND=0
      DO 410 I=1,NEL
```

```
      H(I)=C
      V(I)=-S
      S=SINEL(I)
      C=COSEL(I)
      AS=ABS(S)
      AC=ABS(C)
      VV=VLI(I)*AC+DL(I)
      HH=HLI(I)*AS
      VLI(I)=S*HH-C*VV
      HLI(I)=C*HH+S*VV
      VV=VLJ(I)*AC+DL(I)
      HH=HLJ(I)*AS
      VLJ(I)=S*HH-C*VV
      HLJ(I)=C*HH+S*VV
      NPDIF(I)=NPJ(I)-NPI(I)
      K=IABS(NPDIF(I))
      IF (K.GT.NXBAND) NXBAND=K
  410 CONTINUE
      MAXJTD=NXBAND
      NXBAND=NXBAND*4+4
C
C     MODIFY PARTIAL SURFACE LOADS (VL=ZL,HL=YL)
C
      IF (NSURL) 440,440,420
  420 DO 430 I=1,NSURL
      K=LEL(I)
      S=SINEL(K)
      C=COSEL(K)
      AS=ABS(S)
      AC=ABS(C)
      VV=PVLI(I)*AC
      HH=PHLI(I)*AS
      PVLI(I)=S*HH-C*VV
      PHLI(I)=C*HH+S*VV
      VV=PVLJ(I)*AC
      HH=PHLJ(I)*AS
      PVLJ(I)=S*HH-C*VV
  430 PHLJ(I)=C*HH+S*VV
C
C     MODIFY LCASE (=LIND) MATRIX
C
  440 DO 450 I=1,MX
  450 LIND(I)=LIND(I)+1
      DO 470 I=1,NJT
      IF (LCASE(4,I)-3) 470,460,470
  460 LCASE(4,I)=LCASE(4,I)+2
  470 CONTINUE
C
C     SET UP INDMP MATRIX AND MPC,MPC1,MPCOL
C
      IF (NDIAPH) 530,530,480
  480 MPCOL=0
      DO 520 I=1,NJT
      DO 520 J=1,3
      IF (LCASE(J,I)-4) 500,490,500
  490 JFOR(J,I)=1
```

```
      GO TO 520
  500 IF (JFOR(J,I)) 520,510,520
  510 MPCOL=MPCOL+1
      INDMP(MPCOL)=(I-1)*4+J
  520 CONTINUE
      MPC1=MPCOL+1
      MPC=MPCOL
C
C     CYCLE FOR EACH HARMONIC IS INITIATED
C
  530 REWIND 3
      IF (NCHECK) 540,550,560
  540 N1=2
      GO TO 570
  550 N1=1
      N2=1
      IF (IAX.EQ.0) MHARM=1
      GO TO 580
  560 N1=1
  570 N2=2
C
  580 MM=0
      DO 1070 NN=N1,MHARM,N2
      MM=MM+1
      DO 590 J=1,NXBAND
      DO 590 I=1,MX
  590 BIGK(I,J)=0.
      IF (IAX.EQ.0) GO TO 610
C
      FN=NN
      FK=FN*PI/TETAO
C
C     HARMONIC AND FOURIER MULTIPLIERS ARE COMPUTED
C
      DO 600 I=1,NXP
      XX=FK*TP(I)
      SINKX(MM,I)=SIN(XX)
  600 COSKX(MM,I)=COS(XX)
      N3=(-1)**NN
      S1=4./(FN*PI)
      S2=(-1.)**((NN+3)/2)
      JT = NN
      GO TO 620
  610 JT = 0
      N3=0
      S1=1.0
      S2=1.0
C
C     CALCULATE ELEMENT STIFFNESSES AND STORE THEM INTO BIGK
C
  620 DO 650 IE=1,NEL
      IJ=KPL(IE)
      I=NPI(IE)
      J=NPJ(IE)
      R1=Y(I)
      R2=Y(J)
```

```
      S=SINEL(IE)
      C=COSEL(IE)
      CALL CONE (IJ,R1,R2,S,C,PWTH(IE),JT)
      NQ(1)=I
      NQ(2)=J
      DO 640 L=1,2
      LL=4*NQ(L)-4
      LV=4*L-4
      DO 640 K=1,2
      KK=4*NQ(K)-4
      IF (KK.LT.LL) GO TO 640
      KH=4*K-4
      DO 630 II=1,4
      LLI=LL+II
      LVI=LV+II
      DO 630 JJ=1,4
      KKJ=KK+JJ
      IF (KKJ.LT.LLI) GO TO 630
      KKJ=KKJ-LLI+1
      KHJ=KH+JJ
      BIGK(LLI,KKJ)=BIGK(LLI,KKJ)+SMALLK(LVI,KHJ)
  630 CONTINUE
  640 CONTINUE
  650 CONTINUE
C
C
C     SET UP LOAD VECTOR
C
      DO 660 I=1,MX
  660 PTOT(I)=0.0
      IF (N3) 670,690,690
C
C     FIND CONSISTENT NODAL LOADS FOR UNIFORM PLATE FORCES
C     AND STORE THESE INTO LOAD VECTOR PTOT
C
  670 DO 680 I=1,NEL
      HI=HLI(I)*S1
      HJ=HLJ(I)*S1
      VI=VLI(I)*S1
      VJ=VLJ(I)*S1
      IF (HI.EQ.0..AND.HJ.EQ.0..AND.VI.EQ.0..AND.VJ.EQ.0.) GO TO 680
      II=NPI(I)
      IJ=NPJ(I)
      R1=Y(II)
      R2=Y(IJ)
      S12=PWTH(I)
      S=SINEL(I)
      C=COSEL(I)
      CALL LOADS (II,IJ,HI,HJ,VI,VJ,R1,R2,S12,S,C,PTOT)
  680 CONTINUE
C
C     ADD CONTRIBUTIONS DUE TO PARTIAL SURFACE LOADS
C
  690 IF (NSURL.LE.0) GO TO 740
      DO 730 I=1,NSURL
      L=LEL(I)
```

```
      II=NPI(L)
      IJ=NPJ(L)
      R1=Y(II)
      R2=Y(IJ)
      IF (SURL(I).EQ.0.) GO TO 700
      C1=S1*SIN(FK*SURT(I))*SIN(.5*FK*SURL(I))
      C2=C1
      GO TO 720
  700 IF (SURT(I).EQ.T2) GO TO 710
      C=SIN(FK*SURT(I))/T2
      C1=C/R1
      C2=C/R2
      GO TO 720
  710 IF (N3.GT.0) GO TO 730
      C1=S2/(R1*T2)
      C2=S2/(R2*T2)
  720 HI=PHLI(I)*C1
      HJ=PHLJ(I)*C2
      VI=PVLI(I)*C1
      VJ=PVLJ(I)*C2
      S12=PWTH(L)
      S=SINEL(L)
      C=COSEL(L)
      CALL LOADS (II,IJ,HI,HJ,VI,VJ,R1,R2,S12,S,C,PTOT)
  730 CONTINUE
C
C     ADD JOINT LOADS INTO PTOT
C
  740 IF (N3.GT.0) GO TO 790
      I=0
      DO 780 J=1,NJT
      R1=Y(J)
      XX=R1*T2
      DO 780 L=1,4
      I=I+1
      K=LIND(I)
      GO TO (780,750,760,780,770), K
  750 PTOT(I)=PTOT(I)+AJP(I)*S1*XX
      GO TO 780
  760 PTOT(I)=PTOT(I)+AJP(I)*S2
      GO TO 780
  770 PTOT(I)=PTOT(I)+AJP(I)*2.
  780 CONTINUE
C
  790 IF (NCONL.LE.0) GO TO 830
      DO 820 I=1,NCONL
      L=LJT(I)
      J=L*4-4
      R1=Y(L)
      C=FK*FTL(I)
      IF (FTT(I).LE.0.) GO TO 800
      XX=FK*FTT(I)/2.
      EQH=S1*R1*T2*SIN(XX)
      EQS=EQH*COS(C)
      EQH=EQH*SIN(C)
      GO TO 810
```

```
  800 EQH=SIN(C)
      EQS=COS(C)
  810 PTOT(J+1)=PTOT(J+1)+EQH*FH(I)
      PTOT(J+2)=PTOT(J+2)+EQH*FV(I)
      PTOT(J+3)=PTOT(J+3)+EQH*FM(I)
  820 PTOT(J+4)=PTOT(J+4)+EQS*FP(I)
C
C     SET UP PTTT MATRIX (WITH 1*S AND 0*S), LAST VECTOR FOR EXTERNAL LO
C
  830 IF (NDIAPH) 870,870,840
  840 DO 860 J=1,MPCOL
      DO 850 I=1,MX
  850 PTTT(I,J)=0.0
      K=INDMP(J)
  860 PTTT(K,J)=1.0*HSPAN
C
C     MODIFY BIGK AND PTOT MATRICES DUE TO BOUNDARY CONDITIONS
C
  870 DO 900 J=1,NJT
      DO 900 I=1,4
      IF (LCASE(I,J).NE.4) GO TO 900
      IL=J*4-4+I
      IJ=IL-NXBAND+1
      IF (IJ.LT.1) IJ=1
      DO 880 L=IJ,IL
      K=IL-L+1
  880 BIGK(L,K)=0.0
      DO 890 L=2,NXBAND
  890 BIGK(IL,L)=0.0
      PTOT(IL)=0.0
  900 CONTINUE
      DO 910 I=1,MX
  910 PTTT(I,MPC1)=PTOT(I)
C
C
C     SOLVE EQUATIONS FOR UNKNOWN JOINT DISPLACEMENTS
C
      MMM=MX*NXBAND
      K=1
      DO 920 J=1,NXBAND
      DO 920 I=1,MX
      BK(K)=BIGK(I,J)
      K=K+1
  920 CONTINUE
      DO 930 I=1,MX
  930 PTOT(I)=PTTT(I,MPC1)
      II=NXBAND+1
      CALL BANSOL (BK,PTOT,BIGK(1,II),MX,NXBAND,1)
      DO 940 I=1,MX
  940 DISP(I,MPC1)=PTOT(I)
      IF (NDIAPH.EQ.0) GO TO 980
      J=1
  950 DO 960 I=1,MX
  960 PTOT(I)=PTTT(I,J)
      CALL BANSOL (BK,PTOT,BIGK(1,II),MX,NXBAND,2)
      DO 970 I=1,MX
```

```
  970 DISP(I,J)=PTOT(I)
      J=J+1
      IF (J.LE.MPCOL) GO TO 950
  980 CONTINUE
      IF (NDIAPH.EQ.0) GO TO 1060
C
C     CHANGE SIGNS TO CONFORM WITH MUPDI3
C
      J=1
  990 DO 1040 I=1,3
      GO TO (1000,1000,1020), I
 1000 DO 1010 K=3,MX,4
      DISP(K,J)=-DISP(K,J)
 1010 DISP(K+1,J)=-DISP(K+1,J)
      J=J+1
      GO TO 1040
 1020 DO 1030 K=1,MX,4
      DISP(K,J)=-DISP(K,J)
 1030 DISP(K+1,J)=-DISP(K+1,J)
      J=J+1
 1040 CONTINUE
      MPC3=MPC-2
      IF (J.LE.MPC3) GO TO 990
      DO 1050 K=3,MX,4
      DISP(K,MPC1)=-DISP(K,MPC1)
 1050 DISP(K+1,MPC1)=-DISP(K+1,MPC1)
C
C     WRITE DISP ON TAPE 3
C
 1060 WRITE (3) ((DISP(I,J),I=1,MX),J=1,MPC1)
 1070 CONTINUE
      RETURN
C
C
C     FORMAT STATEMENTS
C
 1080 FORMAT (94H0EXECUTION OF THE FORCE PROGRAM (INTERNAL FORCES AND DI
     1SPLACEMENTS IN FRAME BENT) IS REQUESTED)
 1090 FORMAT (41H0CALCULATIONS SKIP ALL ODD FOURIER SERIES)
 1100 FORMAT (42H0CALCULATIONS SKIP ALL EVEN FOURIER SERIES)
 1110 FORMAT (41H0INTEGRATION OF GIRDER MOMENTS IS DESIRED)
 1120 FORMAT (28H0ANGLE SUBTENDED AT CENTRE =F8.3/23H0RADIUS OF CENTER L
     1INE=F15.6/28H0NUMBER OF TYPES OF PLATE = I2/22H0NUMBER OF ELEMENTS
     2 = I3/20H0NUMBER OF JOINTS = I3/24H0NUMBER OF DIAPHRAGMS = I2/56H0
     3NUMBER OF X-COORDINATES AT WHICH RESULTS ARE DESIRED = I2/27H0MAXI
     4MUM HARMONIC NUMBER = I3/53H0NUMBER OF TYPES OF FLEXIBLE SUPPORTIN
     5G FRAME BENT = I2/49H0NUMBER OF TYPES OF FLEXIBLE MOVABLE DIAPHRAG
     6M = I2)
 1130 FORMAT (10F7.3)
 1140 FORMAT (I4)
 1150 FORMAT (//37H IH,IV,IM,IS = 0 FOR GIVEN ZERO FORCE/44H
     1     1 FOR UNIF. DISTRIBUTED FORCE/81H                        2 MEANS CONC. F
     2ORCE AT MIDSPAN FOR IH, IV, IM AND PRESTRESS FOR IS/44H
     3     3 FOR GIVEN ZERO DISPLACEMENT)
 1160 FORMAT (I10,2F10.0,2I4)
 1170 FORMAT (/////76H DIAPHRAGM    LOCATION(X-COORD.)   INTERACT. THICK
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```
      1.   CLASSIFICATION    TYPE/(I6,F20.4,F21.6,2I14))                    MAIN 558
 1180 FORMAT (30H0DIAPHRAGM CLASSIFICATION CODE/43H     1  EXTERNALLY SUPMAIN 559
     1PORTED RIGID DIAPHRAGM/30H     2  MOVABLE RIGID DIAPHRAGM/37H    3 MAIN 560
     2 FLEXIBLE SUPPORTING FRAME BENT/33H     4  FLEXIBLE MOVABLE DIAPHRAMAIN 561
     3GM/42H TYPE NUMBER = 0 IF THE DIAPHRAGM  IS RIGID)                 MAIN 562
 1190 FORMAT (//60H RH,RV,RM =       0     - TO CONSIDER RESTRAINT FROM DIAMAIN 563
     1PHRAGMS/59H            NON-ZERO - TO NEGLECT RESTRAINT FROM DIAPHRMAIN 564
     2AGMS)                                                              MAIN 565
 1200 FORMAT (2I4)                                                       MAIN 566
 1210 FORMAT (//51H ERROR- INCOMPATIBLE X-COORDINATE FOR GIRDER MOMENT) MAIN 567
 1220 FORMAT (3I4,3F10.0)                                                MAIN 568
 1230 FORMAT (1H1,70H ADDITIONAL INFORMATION FOR DETERMINATION OF GIRDERMAIN 569
     1 MOMENT PERCENTAGES///,30H NO. OF SECTIONS FOR RESULTS =,I6/,30H NMAIN 570
     2O. OF GIRDERS              = ,I6)                                  MAIN 571
 1240 FORMAT (///29H RESULTS ARE DESIRED AT   X = /,(10F10.3))          MAIN 572
 1250 FORMAT (////56H ELE.NO.  BELONGS TO GIRDERS     DNAI       DNAJ     MAIN 573
     1 XDIV//(I6,8X,2I6,F12.3,F10.3,F10.3))                              MAIN 574
 1260 FORMAT (10X,4F10.0)                                                MAIN 575
 1270 FORMAT (10X,5F10.0)                                                MAIN 576
 1280 FORMAT (5I4,5F10.0)                                                MAIN 577
 1290 FORMAT (I10,5F10.0)                                                MAIN 578
 1300 FORMAT (I10,4F10.0)                                                MAIN 579
 1310 FORMAT (I10,6F10.0)                                                MAIN 580
 1320 FORMAT (I10,6F10.0)                                                MAIN 581
 1330 FORMAT (I10,6F10.0,7I1)                                            MAIN 582
 1340 FORMAT (1H1,50X,20H PLATE ELEMENT TYPES//120HNUMBER        D11     MAIN 583
     1        D12          D22          D33          D44          D45MAIN 584
     2        D55          D66       /)                                  MAIN 585
 1350 FORMAT (I6,2X,7E14.6)                                              MAIN 586
 1360 FORMAT (7F12.5)                                                    MAIN 587
 1370 FORMAT (////42H PRINT RESULTS AT SECTIONS WITH X EQUAL TO/)        MAIN 588
 1380 FORMAT (////46H PRINT RESULTS AT SECTIONS WITH THETA EQUAL TO/)    MAIN 589
 1390 FORMAT (10F7.3)                                                    MAIN 590
 1400 FORMAT (1H1,50X,20H PLATE ELEMENT TYPES//14X,20H MEMBRANE PROPERTIMAIN 591
     1ES,35X,25H PLATE BENDING PROPERTIES/120H     NO.        TH        EMAIN 592
     2-T        E-S        G          NU         TH         E-T        EMAIN 593
     3-S        G          NU      /)                                    MAIN 594
 1410 FORMAT (I7,3X,10E11.4)                                             MAIN 595
 1420 FORMAT (1H2,52X,15H PLATE ELEMENTS//10X,100H  ELE NO    NODE I     MAIN 596
     1NODE J  PLATE TYPE   NSEC       DL        HLI        HLJ        VLI MAIN 597
     2     VLJ     /)                                                    MAIN 598
 1430 FORMAT (6X,5I10,5F10.3)                                            MAIN 599
 1440 FORMAT (39H2INPUT LOADS OR DISPLACEMENTS AT JOINTS//106H JOINT    YMAIN 600
     1-COORD   Z-COORD        HORIZONTAL IH        VERTICAL IV        ROTMAIN 601
     2ATIONAL IM     LONGITUDINAL IS,13H RH    RV    RM/)                MAIN 602
 1450 FORMAT (I6,2F10.2,4(E17.6,I3),3I5)                                 MAIN 603
 1460 FORMAT (22H1PARTIAL SURFACE LOADS//71H ELE        HLI        HLJ   MAIN 604
     1  VLI        VLJ    CENTER COORD  LOAD WIDTH)                      MAIN 605
 1470 FORMAT (I3,4F10.3,2F12.3)                                          MAIN 606
 1480 FORMAT (20H1PARTIAL JOINT LOADS//102H JOINT            H-LOAD      MAIN 607
     1  V-LOAD          MOMENT      LONG. FORCE      CENTER COORD    LOAMAIN 608
     2D WIDTH)                                                           MAIN 609
 1490 FORMAT (I4,6F16.3)                                                 MAIN 610
      END                                                                MAIN 611
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```
      SUBROUTINE CONE (NT,R1,R2,S,C,S12,N)
C
C     ******************************************************************
C     THIS SUBROUTINE CALCULATES THE GLOBAL ELEMENT STIFFNESS OF A
C     THIN SHELL CONICAL SEGMENT, USING LINEAR IN-PLANE AND CUBIC
C     OUT-OF-PLANE DISPLACEMENT FUNCTIONS.
C     BASED ON NOVOZHILOV-S STRAIN-DISPLACEMENT RELATIONS
C
C                             -  INPUT  -
C
C     THM,ESM,ETM,GM,PRM - MATERIAL CONSTANTS FOR MEMBRANE BEHAVIOR
C     THB,ESB,ETB,GB,PRB - MATERIAL CONSTANTS FOR SHELL BENDING BEHAVIOR
C                          IF  MI=1 THEN  THM=D11, THB=D12, ESM=D22,
C                          ESB=D33, ETM=D44, ETB=D45, GM=D55, GB=D66
C                          ARE THE ELEMENTS OF THE CONSTITUTIVE MATRIX
C     R1, R2             - RADII OF CURVATURE OF JOINT 1 AND 2
C     S, C               - SINE AND COSINE OF INCLINATION ANGLE
C     S12                - ELEMENT WIDTH BETWEEN JOINT 1 AND 2
C     N                  - HARMONIC NUMBER
C     TETAO              - SEGMENT ANGLE (IN RADIAN)
C
C                             -  OUTPUT  -
C
C     T(8,8)             - GLOBAL ELEMENT STIFFNESS
C     ******************************************************************
C
      COMMON TETAO,RR,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFM
     1D,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12
     2),KDTP(12),CHPLRE,MPC1,MPCOL,MPC,INDMP(50)
      COMMON /PROPT/ THM(15),THB(15),ETM(15),ETB(15),ESM(15),ESB(15),GM(
     115),GB(15),PRM(15),PRB(15)
      COMMON /STIFF/ T(8,8)
      DIMENSION X(8), W(8), F(3,7)
      EQUIVALENCE (F(1,1),F11), (F(1,2),F12), (F(1,3),F13), (F(1,4),F14)
     1, (F(1,5),F15), (F(1,6),F16), (F(1,7),F17), (F(2,1),F21), (F(2,2),
     2F22), (F(2,3),F23), (F(2,4),F24), (F(2,5),F25), (F(2,6),F26), (F(2
     3,7),F27), (F(3,1),F31), (F(3,2),F32), (F(3,3),F33), (F(3,4),F34),
     4(F(3,5),F35), (F(3,6),F36), (F(3,7),F37)
      DATA X/.183434642495650,-.183434642495650,.525532409916329,-.52553
     12409916329,.796666477413627,-.796666477413627,.960289856497536,-.9
     260289856497536/,W/.362683783378362,.362683783378362,.31370664587788
     387,.313706645877887,.222381034453374,.222381034453374,.10122853629
     40376,.101228536290376/
C
C     SET UP MATRIX OF MATERIAL CONSTANTS
C
      IF (MI.EQ.1) GO TO 10
      FM=PRM(NT)*ETM(NT)/ESM(NT)
      FB=PRB(NT)*ETB(NT)/ESB(NT)
      DM=1./(1.-FM*PRM(NT))
      DB=1./(1.-FB*PRB(NT))
      TH3=THB(NT)**3/12.
      D11=THM(NT)*ESM(NT)*DM
      D22=THM(NT)*ETM(NT)*DM
```

```
      D12=D22*PRM(NT)
      D33=GM(NT)*THM(NT)
      D44=TH3*ESB(NT)*DB
      D55=TH3*ETB(NT)*DB
      D45=D55*PRM(NT)
      D66=GB(NT)*TH3*4.0
      GO TO 20
   10 D11=THM(NT)
      D12=THB(NT)
      D22=ETM(NT)
      D33=ETB(NT)
      D44=ESM(NT)
      D45=ESB(NT)
      D55=GM(NT)
      D66=GB(NT)
C
C     INITIALIZATION
C
   20 A=0.5*(R2-R1)
      B=0.5*(R2+R1)
      SS=S*S
      CC=C*C
      XN=N
      P=XN*PI/TETAO
      PP=P*P
      S2=0.5*S12
      S122=S12*S12
      S123=S12*S122
      S124=S122*S122
C
C     INTEGRALS
C
      F1=2.
      F3=2./3.
      F5=.4
      F7=2./7.
      F8=2.*B
      F9=F3*A
      F10=F3*B
      DO 30 I=1,3
      DO 30 J=1,7
   30 F(I,J)=0.0
      DO 40 K=1,8
      XX=X(K)
      R=A*XX+B
      WR=W(K)
      DO 40 I=1,3
      WR=WR/R
      WX=WR/XX
      DO 40 J=1,7
      WX=WX*XX
   40 F(I,J)=F(I,J)+WX
C
C     STIFFNESS COEFFICIENTS
C
      H1=.25*(D22*PP+D33*CC)
```

```
      H2=.25*(D55*PP+D66*CC)*SS
      H3=C*D33/S12
      H4=D66*C*SS/S12
      H5=D33/S122
      H6=D66*SS/S122
      G1=H5*F8+H6*F11
      G2=H3*F1
      G3=F11-2.*F12+F13
      G4=F11+2.*F12+F13
      G5=F11-F13
      T(1,1)=H1*G3+H2*(F31-2.*F32+F33)+G2-H4*(F22-F21)+G1
      T(1,2)=H1*G5+H2*(F31-F33)+H4*F22-G1
      T(2,2)=H1*G4+H2*(F31+2.*F32+F33)-G2-H4*(F21+F22)+G1
C
      H1=-.25*P*C*(D22+D33)
      H2=P/(2.*S12)
      G1=H2*(D33+D12)*F1
      G2=H2*(D33-D12)*F1
      T(1,3)=H1*G3-G2
      T(1,4)=H1*G5-G1
      T(2,3)=H1*G5+G1
      T(2,4)=H1*G4+G2
C
      H1=.25*(D22*CC+PP*D33)
      G1=C*D12/S12*F1
      G2=D11/S122*F8
      T(3,3)=H1*G3-G1+G2
      T(3,4)=H1*G5-G2
      T(4,4)=H1*G4+G1+G2
C
      H1=-.125*S*P*D22
      H2=.125*S*P*(D55*PP+D66*CC)
      U1=S*C*P/(4.*S12)
      U2=S*P/(2.*S122)
      H3=U1*(D55+D66)
      H4=U2*D45
      H5=U1*D66
      H6=U2*D66
      G1=2.*F11-5.*F12+3.*F13+F14-F15
      G2=2.*F11+F12-3.*F13-F14+F15
      G3=F11-2.*F12+2.*F14-F15
      G4=-F11+2.*F13-F15
      G5=2.*F11-F12-3.*F13+F14+F15
      G6=2.*F11+5.*F12+3.*F13-F14-F15
      G7=-F11-2.*F12+2.*F14+F15
      G8=-F21+F22+F23-F24
      G9=-F21-F22+F23+F24
      T1=H1*S2
      T2=H2*S2
      T3=H3*S2
      T4=H4*S2
      T5=H5*S2
      T6=H6*S2
      U1=3.*H6*(F11-F13)
      U2=6.*H4*(F12-F13)+3.*H3*G8
      U3=6.*H4*(F12+F13)+3.*H3*G9
```

```
      U4=T5*G8-T6*(F11+2.*F12-3.*F13)
      U5=T5*G9+T6*(F11-2.*F12-3.*F13)
      T(1,5)=H1*G1-H2*(2.*F31-5.*F32+3.*F33+F34-F35)+U2+H5*(-2.*F21+3.*F
     122-F24)-U1
      T(1,6)=H1*G2-H2*(2.*F31+F32-3.*F33-F34+F35)-U2+H5*(-2.*F21-3.*F22+
     1F24)+U1
      T(1,7)=T1*G3-T2*(F31-2.*F32+2.*F34-F35)+T3*(-F21-F22+5.*F23-3.*F24
     1)+T4*(-2.*F11+8.*F12-6.*F13)+U4
      T(1,8)=T1*G4-T2*(-F31+2.*F33-F35)+T3*(-F21+3.*F22+F23-3.*F24)+T4*(
     12.*F11+4.*F12-6.*F13)-U5
      T(2,5)=H1*G5-H2*(2.*F31-F32-3.*F33+F34+F35)+U3+H5*(2.*F21-3.*F22+F
     124)+U1
      T(2,6)=H1*G6-H2*(2.*F31+5.*F32+3.*F33-F34-F35)-U3+H5*(2.*F21+3.*F2
     12-F24)-U1
      T(2,7)=-T1*G4-T2*(F31-2.*F33+F35)+T3*(-F21-3.*F22+F23+3.*F24)+T4*(
     1-2.*F11+4.*F12+6.*F13)-U4
      T(2,8)=T1*G7-T2*(-F31-2.*F32+2.*F34+F35)+T3*(-F21+F22+5.*F23+3.*F2
     14)+T4*(2.*F11+8.*F12+6.*F13)+U5
C
      H1=.125*S*C*D22
      H2=S*D12/(4.*S12)
      T1=H1*S2
      T2=H2*S2
      G8=2.*H2*F1
      G9=T2*(F1-F3)
      T(3,5)=H1*G1-G8
      T(3,6)=H1*G2-G8
      T(3,7)=T1*G3-G9
      T(3,8)=T1*G4+G9
      T(4,5)=H1*G5+G8
      T(4,6)=H1*G6+G8
      T(4,7)=G9-T1*G4
      T(4,8)=T1*G7-G9
C
      H1=.0625*SS*D22
      H2=.0625*PP*(D55*PP+D66*CC)
      H3=C*PP*(D55+D66)/(8.*S12)
      H4=PP*D45/(4.*S122)
      H5=(CC*D55+PP*D66)/(4.*S122)
      H6=C*D45/(2.*S123)
      H7=D44/S124
      T1=H1*S2
      T2=H2*S2
      T3=H3*S2
      T4=H4*S2
      T5=H5*S2
      T6=H6*S2
      T7=H7*S2
      U1=T1*S2
      U2=T2*S2
      U3=T3*S2
      U4=T4*S2
      U5=T5*S2
      U6=T6*S2
      U7=T7*S2
      G1=6.*T6*(F1-3.*F3)
```

```
      G2=4.*U6*(F1-9.*F3)
      G3=H5*9.*(F11-2.*F13+F15)+36.*H7*F10
      G4=3.*F11-12.*F13+9.*F15
      G5=12.*T7*(F9-3.*F10)
      G6=12.*T7*(F9+3.*F10)
      G7=6.*(F12-F14)
      G8=F11-F13-F15+F17
      G9=F12-2.*F14+F16
      G10=2.*F11-5.*F13+4.*F15-F17
      G11=F31-F33-F35+F37
      G12=F32-2.*F34+F36
      G13=2.*F31-5.*F33+4.*F35-F37
      T(5,5)=H1*(4.*F11-12.*F12+9.*F13+4.*F14-6.*F15+F17)+H2*(4.*F31-12.
     1*F32+9.*F33+4.*F34-6.*F35+F37)-H3*(-12.*F21+18.*F22+12.*F23-24.*F2
     24+6.*F26)-H4*(24.*F12-36.*F13+12.*F15)+G3
      T(5,6)=H1*(4.*F11-9.*F13+6.*F15-F17)+H2*(4.*F31-9.*F33+6.*F35-F37)
     1-H3*(-18.*F22+24.*F24-6.*F26)-H4*12.*(3.*F13-F15)-G3
      T(5,7)=T1*(2.*F11-5.*F12+F13+6.*F14-4.*F15-F16+F17)+T2*(2.*F31-5.*
     1F32+F33+6.*F34-4.*F35-F36+F37)-T3*(-5.*F21+2.*F22+18.*F23-16.*F24-
     25.*F25+6.*F26)-T4*(-4.*F11+24.*F12-24.*F13-8.*F14+12.*F15)+T5*(G4+
     3G7)+G1-G5
      T(5,8)=T1*(G9-G10)+T2*(G12-G13)-T3*(F21+10.*F22-6.*F23-16.*F24+5.*
     1F25+6.*F26)-T4*(4.*F11-24.*F13+8.*F14+12.*F15)+T5*(G4-G7)-G1+G6
      T(6,6)=H1*(4.*F11+12.*F12+9.*F13-4.*F14-6.*F15+F17)+H2*(4.*F31+12.
     1*F32+9.*F33-4.*F34-6.*F35+F37)-H3*(12.*F21+18.*F22-12.*F23-24.*F24
     2+6.*F26)-12.*H4*(-2.*F12-3.*F13+F15)+G3
      T(6,7)=T1*(G9+G10)+T2*(G12+G13)-T3*(F21-10.*F22-6.*F23+16.*F24+5.*
     1F25-6.*F26)-T4*(-4.*F11+24.*F13+8.*F14-12.*F15)-T5*(G4+G7)-G1+G5
      T(6,8)=T1*(-2.*F11-5.*F12-F13+6.*F14+4.*F15-F16-F17)+T2*(-2.*F31-5
     1.*F32-F33+6.*F34+4.*F35-F36-F37)-T3*(-5.*F21-2.*F22+18.*F23+16.*F2
     24-5.*F25-6.*F26)-T4*(4.*F11+24.*F12+24.*F13-8.*F14-12.*F15)+T5*(G7
     3-G4)+G1-G6
      T(7,7)=U1*(G8-2.*G9)+U2*(G11-2.*G12)-U3*(-2.*F21-2.*F22+12.*F23-4.
     1*F24-10.*F25+6.*F26)-U4*(-4.*F11+16.*F12-8.*F13-16.*F14+12.*F15)+U
     25*(F11+4.*F12-2.*F13-12.*F14+9.*F15)+G2+U7*(4.*F8-24.*F9+36.*F10)
      T(7,8)=U1*(-F11+3.*F13-3.*F15+F17)+U2*(-F31+3.*F33-3.*F35+F37)-U3*
     16.*(F22-2.*F24+F26)-U4*(4.*F11-16.*F13+12.*F15)+U5*(F11-10.*F13+9.
     2*F15)+U7*(-4.*F8+36.*F10)
      T(8,8)=U1*(G8+2.*G9)+U2*(G11+2.*G12)-U3*(2.*F21-2.*F22-12.*F23-4.*
     1F24+10.*F25+6.*F26)-U4*(-4.*F11-16.*F12-8.*F13+16.*F14+12.*F15)+U5
     2*(F11-4.*F12-2.*F13+12.*F14+9.*F15)-G2+U7*(4.*F8+24.*F9+36.*F10)
C
      FAC=0.25*TETAC*S12
      DO 50 I=1,8
      DO 50 J=I,8
      T(I,J)=FAC*T(I,J)
   50 T(J,I)=T(I,J)
C
C     TRANSFORMATION TO GLOBAL COORDINATES
C
      DO 60 I=1,8
      TX=T(I,1)
      T(I,1)=T(I,3)*C+T(I,5)*S
      TY=T(I,2)
      T(I,2)=T(I,3)*S-T(I,5)*C
      T(I,3)=-T(I,7)
```

```
      T(I,5)=T(I,4)*C+T(I,6)*S
      T(I,6)=T(I,4)*S-T(I,6)*C
      T(I,4)=TX
      T(I,7)=-T(I,8)
   60 T(I,8)=TY
      DO 70 I=1,8
      TX=T(1,I)
      T(1,I)=T(3,I)*C+T(5,I)*S
      TY=T(2,I)
      T(2,I)=T(3,I)*S-T(5,I)*C
      T(3,I)=-T(7,I)
      T(5,I)=T(4,I)*C+T(6,I)*S
      T(6,I)=T(4,I)*S-T(6,I)*C
      T(4,I)=TX
      T(7,I)=-T(8,I)
   70 T(8,I)=TY
      RETURN
      END
```

```
      SUBROUTINE LOADS (I,J,HI,HJ,VI,VJ,R1,R2,S12,S,C,PTOT)
C
C     THIS SUBROUTINE TRANSFORMS DISTRIBUTED SURFACE LOADS INTO
C     CONSISTENT NODAL LOADS AND ADDS THEM INTO THE LOAD VECTOR
C
      COMMON TETAO
      EQUIVALENCE (TETAO,T)
      DIMENSION PTOT(1)
      A=.5*(R2-R1)
      B=.5*(R2+R1)
      P=S12*T/120.
      RVI=P*10.*((2.*B-A)*HI+B*HJ)
      RVJ=P*10.*(B*HI+(2.*B+A)*HJ)
      RWI=P*((21.*B-11.*A)*VI+(9.*B-A)*VJ)
      RWJ=P*((9.*B+A)*VI+(21.*B+11.*A)*VJ)
      RTI=P*S12*((3.*B-A)*VI+2.*B*VJ)
      RTJ=-P*S12*(2.*B*VI+(3.*B+A)*VJ)
      K=I*4-4
      L=J*4-4
      PTOT(K+1)=PTOT(K+1)+RVI*C+RWI*S
      PTOT(K+2)=PTOT(K+2)+RVI*S-RWI*C
      PTOT(K+3)=PTOT(K+3)-RTI
      PTOT(L+1)=PTOT(L+1)+RVJ*C+RWJ*S
      PTOT(L+2)=PTOT(L+2)+RVJ*S-RWJ*C
      PTOT(L+3)=PTOT(L+3)-RTJ
      RETURN
      END
```

```
      SUBROUTINE BANSOL (A,B,NBL,NEQ,MBAND,KKK)
C
C     *****************************************************************
C     IN-CORE EQUATION SOLVER FOR BANDED, SYMMETRIC, POSITIVE DEFINITE
C     SYSTEMS, TAKING ACCOUNT OF VARIABLE BAND WIDTH AND AN ARBITRARY
C                         NUMBER OF LOAD VECTORS.
C
C                               - INPUT -
C     A(NEQ*MBAND) - UPPER HALF OF RECTIFIED COEFFICIENT MATRIX BAND
C                    IN ONE-DIMENSIONAL FORM
C     B(NEQ)       - SINGLE LOAD VECTOR
C     NEQ          - NUMBER OF EQUATIONS
C     MBAND        - MAXIMUM WIDTH OF HALF BAND
C     KKK          - LOAD CASE INDICATOR, EQUAL TO
C                     1 FOR FIRST LOAD CASE (REDUCTION OF A AND B WITH
C                       BACKSUBSTITUTION
C                     2 FOR ANY SUBSEQUENT LOAD VECTOR (REDUCTION OF B
C                       WITH BACKSUBSTITUTION)
C
C                               - OUTPUT -
C     B(NEQ)       - SOLUTION VECTOR
C     A(NEQ*MBAND) - REDUCED STIFFNESS MATRIX
C     NBL(NEQ)     - VECTOR DEFINING BAND WIDTH OF EACH EQUATION
C     *****************************************************************
C
      DIMENSION A(1), B(NEQ), NBL(NEQ)
C
      NM=NEQ*MBAND
      NE=NEQ-1
      GO TO (10,90), KKK
C
C         DECOMPOSITION OF BAND MATRIX A
C
   10 DO 80 I=1,NE
      D=A(I)
      IF (D) 20,80,30
   20 PRINT 150, I,D
C
C         ESTABLISH VARIABLE BAND WIDTH
C
   30 DO 40 J=NEQ,NM,NEQ
      IF (A(NM-J+I).NE.0.0) GO TO 50
   40 CONTINUE
   50 NBL(I)=NM-J+I
C
C         REDUCTION OF MATRIX A
C
      JL=I+1
      II=I
      MAX=NBL(I)
      JH=(MAX-1)/NEQ+I
      DO 70 J=JL,JH
      II=II+NEQ
      C=A(II)/D
```

```
      IF (C.EQ.0.0) GO TO 70
      KK=J
      DO 60 JJ=II,MAX,NEQ
      A(KK)=A(KK)-C*A(JJ)
   60 KK=KK+NEQ
   70 A(II)=C
   80 CONTINUE
C
C        REDUCTION OF LOAD VECTOR B
C
   90 DO 110 I=1,NE
      IF (A(I).EQ.0.0) GO TO 110
      JL=I+1
      II=I
      JH=(NBL(I)-1)/NEQ+I
      C=B(I)
      IF (C.EQ.0.0) GO TO 110
      DO 100 J=JL,JH
      II=II+NEQ
  100 B(J)=B(J)-C*A(II)
      B(I)=B(I)/A(I)
  110 CONTINUE
      IF (A(NEQ).EQ.0.0) GO TO 120
      B(NEQ)=B(NEQ)/A(NEQ)
C
C        SOLUTION BY BACKSUBSTITUTION
C
  120 DO 140 I=1,NE
      JI=NEQ-I
      IF (A(JI).EQ.0.0) GO TO 140
      IL=JI+NEQ
      MAX=NBL(JI)
      C=B(JI)
      JN=JI+1
      DO 130 II=IL,MAX,NEQ
      C=C-A(II)*B(JN)
  130 JN=JN+1
      B(JI)=C
  140 CONTINUE
      RETURN
C
  150 FORMAT (//20H PIVOT IS NEGATIVE  /26H DIAGONAL TERM OF EQUATIONI8,
     18H EQUALS E20.6//)
      END
```

```
      OVERLAY(MASTER,2,0)
      PROGRAM FORMF
C
C     ******************************************************************
C     FORM THE FLEXIBILITY MATRIX (FMAT) DUE TO RESTRAINING FORCES FROM
C     THE DIAPHRAGMS OR BENTS
C     ******************************************************************
C
      COMMON TETAO,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMD
     1,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12)
     2,KDTP(12),CHPLRE,MPC1,MPCOL,MPC,INDMP(60)
      COMMON /FOLD/ FMAT(120,120),DINP(120),L1,L2,DISP(80,81)
C
      DIMENSION SINKX(12), D(12)
C
C     INITIATION AND SET F MATRIX = 0
C
      KK=MPC*NDIAPH
      DO 10 I=1,KK
      DINP(I)=0.
      DO 10 J=1,KK
   10 FMAT(I,J)=0.0
      REWIND 3
C
C     CYCLE FOR EACH HARMONIC IS INITIATED
C
      DO 50 NN=N1,MHARM,N2
      FN=NN
      FK=FN*PI/TETAO
C
C     FIND UNIT LOADS≠ COEFFICIENTS AND HARMONIC MULTIPLIERS
C
      DO 40 I=1,NDIAPH
      S=SIN(FK*DIAPHX(I))
      IF (DIADEL(I)) 30,30,20
   20 XX=FK*DIADEL(I)/2.
      D(I)=2./(XX*R*TETAO)*SIN(XX)*S
      GO TO 40
   30 XX=2./(TETAO*R)
      D(I)=XX*S
   40 SINKX(I)=S
C
C     READ DISP FROM TAPE 3
C
      READ (3) ((DISP(I,J),I=1,MX),J=1,MPC1)
C
C     CALCULATE AND SUM UP FMAT AND DINP MATRICES
C
      CALL SIMSUM (SINKX,D)
   50 CONTINUE
      CALL CORF1
      RETURN
      END
```

```
      SUBROUTINE SIMSUM (SINKX,D)
C
C     ************************************************************************
C     CALCULATE AND SUM UP FMAT AND DINP MATRICES
C     ************************************************************************
C
      COMMON TETAO,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMD
     1,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12)
     2,KDTP(12),CHPLRE,MPC1,MPCOL,MPC,INDMP(60)
      COMMON /FOLD/ FMAT(120,120),DINP(120),L1,L2,DISP(80,81)
      DIMENSION SINKX(12), D(12)
C
   10 DO 20 I=1,MPCOL
      K=INDMP(I)
      DO 20 J=1,MPC1
   20 DISP(I,J)=DISP(K,J)
C
      IF (NDIAPH.EQ.1) GO TO 50
      DO 30 L=2,NDIAPH
      C=SINKX(L)
      C1=SINKX(1)*D(L)
      C2=SINKX(L)*D(1)
      M=(L-1)*MPCOL
      DO 30 I=1,MPCOL
      K=M+I
      DINP(K)=DINP(K)+DISP(I,MPC1)*C
      DO 30 J=1,MPCOL
      FMAT(K,J)=FMAT(K,J)+DISP(I,J)*C2
   30 FMAT(J,K)=FMAT(J,K)+DISP(J,I)*C1
      DO 40 M=2,NDIAPH
      IM=(M-1)*MPCOL
      DO 40 N=2,NDIAPH
      IN=(N-1)*MPCOL
      C=SINKX(M)*D(N)
      DO 40 I=1,MPCOL
      K=IM+I
      DO 40 J=1,MPCOL
      L=IN+J
   40 FMAT(K,L)=FMAT(K,L)+DISP(I,J)*C
   50 C=SINKX(1)*D(1)
      C1=SINKX(1)
      DO 60 I=1,MPCOL
      DINP(I)=DINP(I)+DISP(I,MPC1)*C1
      DO 60 J=1,MPCOL
   60 FMAT(I,J)=FMAT(I,J)+DISP(I,J)*C
      RETURN
      END
```

```
      SUBROUTINE CORF1
C
C     ******************************************************************
C     FIND THE TRANSFORMED FMAT AND DINP MATRICES
C     ******************************************************************
C
C
      COMMON TETAO,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMD
     1,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12)
     2,KDTP(12),CHPLRE,MPC1,MPCOL,MPC,INDMP(60)
      COMMON /FOLD/ FMAT(120,120),DINP(120),L1,L2,DISP(80,81)
      COMMON /CASE/ AJP(80),LCASE(4,20),JFOR(3,20),XORD(20),YORD(20)
      COMMON /FXDM/ IC(3,2),KTEM(13),MBCOL,NDIA(12),JN1,JN2,INDB(120),XD
     1OD(120),BF(3,120),IT
      DIMENSION JNUM(2), B(3,120), KB12(3), SD(3), BT(3,120), SFM(3,120)
     1              , KK(3)
C
      EQUIVALENCE (JNUM(1),JN1), (SFM,BT)
C
C
C
C     PRINT INITIAL DISPLACEMENTS
C
      K=MPC*NDIAPH
      PRINT 760, (I,DINP(I),I=1,K)
C
C     CHANGE SIGN OF INITIAL DISPLACEMENTS
      DO 10 I=1,K
   10 DINP(I)=-DINP(I)
C
C     CHECK DIAPHRAGMS WHICH ARE EXTERNALLY SUPPORTED
C
      II=0
      DO 20 I=1,NDIAPH
      IF (KODIA(I).EQ.2.OR.KODIA(I).EQ.4) GO TO 20
      II=II+1
      NDIA(II)=I
   20 CONTINUE
C
C     CHECK IF ALL DIAPHRAGMS ARE EXTERNALLY SUPPORTED
C
      IF ( II.EQ.NDIAPH ) GC TO 730
C
C     GENERATING INITIAL CONNECTIONS
C
      KK(1)=0
      KK(2)=0
      KK(3)=0
      DO 30 I=1,NJT
      DO 30 J=1,3
      IF (LCASE(J,I).EQ.4) GO TO 40
   30 CONTINUE
      GO TO 80
   40 JN1=I
```

```
      JN2=0
      IC(1,1)=1
      IC(2,1)=1
      IC(3,1)=1
      KK(J)=1
      IF (J.EQ.3) GO TO 60
      JJ=J+1
      DO 50 LB=JJ,3
      IF (LCASE(LB,I).EQ.4) KK(LB)=1
   50 CONTINUE
   60 II=I+1
      DO 70 IB=II,NJT
      DO 70 LD=1,3
      IF (LCASE(LD,IB).EQ.4) KK(LD)=1
   70 CONTINUE
      IF (KK(1)*KK(2)*KK(3).EQ.1) GO TO 730
      GO TO 170
C
   80 DO 90 I=1,NJT
      IF (JFOR(2,I).EQ.0) GO TO 100
   90 CONTINUE
  100 JN1=I
      JJ=JN1+1
      C1=XORD(JN1)
      CT=0.
      IC(2,1)=1
      JN2=JJ
      IF (JFOR(1,JN1).EQ.0) GO TO 120
      IC(1,1)=0
      DO 110 I=JJ,NJT
      IF (JFOR(1,I).NE.0.OR.JFOR(2,I).NE.0) GO TO 110
      CT1=ABS(XORD(I)-C1)
      IF (CT1.LE.CT) GO TO 110
      CT=CT1
      JN2=I
  110 CONTINUE
      GO TO 140
  120 IC(1,1)=1
      DO 130 I=JJ,NJT
      IF (JFOR(2,I).NE.0) GO TO 130
      CT1=ABS(XORD(I)-C1)
      IF (CT1.LE.CT) GO TO 130
      CT=CT1
      JN2=I
  130 CONTINUE
  140 IC(2,2)=1
      IF (IC(1,1).EQ.1) GO TO 150
      IC(1,2)=1
      C2=YORD(JN2)
      GO TO 160
  150 IC(1,2)=0
      C2=YORD(JN1)
  160 IC(3,1)=0
      IC(3,2)=0
      IBTYPE=2
      GO TO 290
```

```
C
C     TO FORM TRANSFORMATION MATRIX
C
  170 IBTYPE=1
      C1=XORD(JN1)
      C2=YORD(JN1)
      I=0
      DO 180 J=1,MX,4
      I=I+1
      J1=J+1
      J2=J+2
      B(1,J)=-1.
      B(1,J1)=0.
      B(1,J2)=0.
      B(2,J)=0.
      B(2,J1)=-1.
      B(2,J2)=0.
      B(3,J)=YORD(I)-C2
      B(3,J1)=XORD(I)-C1
  180 B(3,J2)=-1.
      DO 190 I=1,MPCOL
      J=INDMP(I)
      DO 190 K=1,3
  190 B(K,I)=B(K,J)
C
      K=0
      DO 220 I=1,NJT
      IF (I-JN1) 200,230,200
  200 DO 220 J=1,3
      IF (JFOR(J,I)) 220,210,220
  210 K=K+1
      INDB(K)=K
  220 CONTINUE
  230 KB=0
      L=K
      DO 280 J=1,3
      IF (JFOR(J,JN1)) 280,240,280
  240 L=L+1
      IF (IC(J,1)) 260,250,250
  250 K=K+1
      INDB(K)=L
      GO TO 280
  260 KB=KB+1
      KB12(KB)=L
      DO 270 M=1,MPC
  270 B(KB,M)=B(J,M)
  280 CONTINUE
      GO TO 490
C
C
  290 CC=XORD(JN2)-C1
      IF (ABS(CC).LE.0.00001) GO TO 300
      C=1./CC
      GO TO 310
  300 JN2=0
      IC(1,1)=1
```

```
      IC(2,1)=1
      IC(3,1)=1
      GO TO 170
C
  310 I=0
      DO 330  J=1,MX,4
      I=I+1
      J1=J+1
      J2=J+2
      BT(2,J)=-(YORD(I)-C2)*C
      BT(2,J1)=-(XORD(I)-C1)*C
      GO TO (330,320), IBTYPE
C
  320 BT(3,J)=-1.
      BT(1,J)=-BT(2,J)
      BT(1,J1)=-BT(2,J1)-1.
      BT(3,J1)=0.
      BT(1,J2)=-C
      BT(2,J2)=C
  330 BT(3,J2)=0.
      DO 340  I=1,MPCOL
      J=INDMP(I)
      DO 340  K=1,3
  340 BT(K,I)=BT(K,J)
C
      K=0
      L=0
      KB=0
      II=1
      DO 480  IT=1,2
      IJ=JNUM(IT)
      DO 370  I=II,NJT
      IF (I-IJ) 350,380,350
  350 DO 370  J=1,3
      IF (JFOR(J,I)) 370,360,370
  360 L=L+1
      K=K+1
      INDB(K)=L
  370 CONTINUE
  380 DO 470  J=1,3
      IF (JFOR(J,IJ)) 470,390,470
  390 L=L+1
      IF (IC(J,IT)) 410,400,410
  400 K=K+1
      INDB(K)=L
      GO TO 470
  410 KB=KB+1
      KB12(KB)=L
      GO TO (470,420), IBTYPE
C
  420 GO TO (430,450), J
  430 DO 440  M=1,MPC
  440 B(KB,M)=BT(3,M)
      GO TO 470
  450 DO 460  M=1,MPC
  460 B(KB,M)=BT(IT,M)
```

```
  470 CONTINUE
      II=JN1+1
  480 CONTINUE
C
  490 MBCOL=MPC-KB
      IF (K-MBCOL) 500,520,500
  500 K=K+1
      DO 510 I=K,MBCOL
      J=I+KB
  510 INDB(I)=J
  520 DO 530 I=1,MBCOL
      J=INDB(I)
      DO 530 K=1,KB
  530 B(K,I)=B(K,J)
C
C     FIND B TRANSPOSE * FMAT AND B TRANSPOSE * DINP
C
      IT=NDIAPH*MPC
      II=1
      DO 550 I=1,NDIAPH
      IF (II-NDIA(I)) 560,540,560
  540 II=II+1
  550 KTEM(I+1)=MPC*I
C
  560 IJ=(II-1)*MPC
      IK=II
      IL=IJ
      DO 650 IS=II,NDIAPH
      IF (NDIA(IK)-IS) 600,570,600
C
  570 IK=IK+1
      DO 590 J=1,MPC
      K=J+IJ
      M=J+IL
      DO 580 L=1,IT
  580 FMAT(K,L)=FMAT(M,L)
  590 DINP(K)=DINP(M)
      IJ=IJ+MPC
      GO TO 640
C
  600 DO 610 I=1,KB
      J=KB12(I)+IL
      SD(I)=DINP(J)
      DO 610 K=1,IT
  610 SFM(I,K)=FMAT(J,K)
C
      DO 630 I=1,MBCOL
      M=I+IJ
      K=INDB(I)+IL
      DO 620 J=1,IT
      FMAT(M,J)=FMAT(K,J)
      DO 620 L=1,KB
  620 FMAT(M,J)=FMAT(M,J)+B(L,I)*SFM(L,J)
      DINP(M)=DINP(K)
      DO 630 L=1,KB
  630 DINP(M)=DINP(M)+B(L,I)*SD(L)
```

```
      IJ=IJ+MBCOL
  640 IL=IL+MPC
      KTEM(IS+1)=IJ
  650 CONTINUE
      KTEM(1)=0
C
C     FIND B TRANSPOSE* FMAT * B
C
      IT=IJ
      IJ=(II-1)*MPC
      IL=IJ
      IK=II
      DO 720 IS=II,NDIAPH
      IF (NDIA(IK)-IS) 680,660,680
C
  660 IK=IK+1
      DO 670 J=1,MPC
      K=J+IJ
      M=J+IL
      DO 670 L=1,IT
  670 FMAT(L,K)=FMAT(L,M)
      IJ=IJ+MPC
      GO TO 710
C
  680 DO 690 I=1,KB
      J=KB12(I)+IL
      DO 690 K=1,IT
  690 SFM(I,K)=FMAT(K,J)
C
      DO 700 I=1,MBCOL
      M=I+IJ
      K=INDB(I)+IL
      DO 700 J=1,IT
      FMAT(J,M)=FMAT(J,K)
      DO 700 L=1,KB
  700 FMAT(J,M)=FMAT(J,M)+SFM(L,J)*B(L,I)
      IJ=IJ+MBCOL
  710 IL=IL+MPC
  720 CONTINUE
      GO TO 750
  730 IT=NDIAPH*MPC
      DO 740 I=1,NDIAPH
  740 KTEM(I)=(I-1)*MPC
      KTEM(NDIAPH+1)=IT
C
C     SAVE INFORMATION ON TAPE 1
C
  750 REWIND 1
      WRITE (1) ((FMAT(I,J),I=1,IT),J=1,IT),(DINP(I),I=1,IT),KB12,B,KB
      RETURN
C
  760 FORMAT (////45H INITIAL DISPLACEMENTS AT POINTS OF RESTRAINT/(I4,E
     117.8,4(I7,E17.8)))
      END
```

```
      OVERLAY(MASTER,3,0)
      PROGRAM FRAME
C
C     ******************************************************************
C     ANALYZE EACH TYPE OF FRAME BENTS BY DIRECT STIFFNESS METHOD. STORE
C     THE FLEXIBILITY MATRICES AND ELEMENT INFORMATION ON TAPES.
C     ******************************************************************
C
      COMMON TETAO,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMD
     1,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12)
     2,KDTP(12),CHPLRE,MPC1,MPCOL,MPC,INDMP(60)
      COMMON /CASE/ AJP(80),LCASE(4,20),JFOR(3,20),XORD(20),YORD(20)
      COMMON /PARAM/ NUMEL,NUMNP,NEQ,NUMSPR,NP,NUMELT(8),NUMNPT(8),NEQN(
     18),NUSPRG(8),NPT(8),NPR(80)
      COMMON /FBENT/ EFM(10),G(10),LM(6),SA(6,6),ASA(6,6),T(3,3),S(6,6),
     1RF(6),JK(3),NPSTP(80),SP(40,3),X(80),Y(80),KODE(80),COAX(80),COAY(
     280),COAAZ(80),RE(200),B(200),SPF(6),IP(120),ID(120),IQ(120),NPQ(80
     3),NFP(80),A(120,120)
      DIMENSION HHH(14400), LSIZE(8)
      EQUIVALENCE (HHH,A)
C
C     READ AND PRINT CONTROL DATA
C
      WRITE (6,320)
      REWIND 4
      REWIND 7
      REWIND 9
      DO 140 MCOUNT=1,NBT
      READ (5,330) NFT,NUMEL,NUMNP,NUMMAT,NUMETP,NUMSPR
      WRITE (6,380) NFT,NUMEL,NUMNP,NUMMAT,NUMETP,NUMSPR
C
C     READ AND PRINT MATERIAL PROPERTY DATA
C
      WRITE (6,390)
      DO 10 I=1,NUMMAT
      READ (5,340) N,EFM(N),G(N)
      WRITE (6,400) N,EFM(N),G(N)
   10 G(N)=0.5*EFM(N)/(1.0+G(N))
C
C     READ AND PRINT STIFFNESS OF ELASTIC SUPPORTS
C
      IF (NUMSPR.EQ.0) GO TO 30
      WRITE (6,450)
      DO 20 I=1,NUMSPR
      READ (5,360) N,(SP(N,J),J=1,3)
   20 WRITE (6,460) N,(SP(N,J),J=1,3)
   30 CONTINUE
C
C     READ AND PRINT GEOMETRIC PROPERTIES OF COMMON ELEMENTS.
C
      WRITE (6,410)
      DO 50 I=1,NUMETP
      READ (5,350) N,COAX(N),COAY(N),COAAZ(N)
      IF ((COAX(N).NE.0.0).AND.(COAAZ(N).NE.0.0)) GO TO 40
```

```
      WRITE (6,470)
      CALL EXIT
   40 WRITE (6,420) N,COAX(N),COAY(N),COAAZ(N)
   50 CONTINUE
C
C     READ AND PRINT NODAL POINT DATA
C
      WRITE (6,430)
      READ (5,370) (N,KODE(N),X(N),Y(N),NPSTP(N),NFP(N),I=1,NUMNP)
      WRITE (6,440) (N,KODE(N),X(N),Y(N),NPSTP(N),NFP(N),N=1,NUMNP)
C
C     SET UP NPQ AND NPR ARRAYS
C
      INK=NUMNP+1
      INM=0
      DO 70 N=1,NUMNP
      IF (NFP(N).EQ.0) GO TO 60
      INM=INM+1
      NPQ(INM)=N
      GO TO 70
   60 INK=INK-1
      NPQ(INK)=N
   70 CONTINUE
      DO 90 N=2,INM
      NN1=N-1
      DO 80 MM=1,NN1
      M=N-MM
      M1=M+1
      NA=NPQ(M1)
      NB=NPQ(M)
      IF (NFP(NA).GT.NFP(NB)) GO TO 90
      NPQ(M1)=NB
      NPQ(M)=NA
   80 CONTINUE
   90 CONTINUE
      DO 100 I=1,NUMNP
      J=NPQ(I)
      NPR(J)=I
  100 CONTINUE
C
C     SET UP ID ARRAY(ROW NC. OF DEGREES OF FREEDOM ELIMINATED)
C
      NP=0
      DO 110 N=1,INM
      NA=NPQ(N)
      NB=NFP(NA)
      NN1=N-1
      DO 110 M=1,3
      IF (JFOR(M,NB).EQ.0) GO TO 110
      NP=NP+1
      ID(NP)=3*NN1+M
  110 CONTINUE
      INM1=INM+1
      DO 120 N=INM1,NUMNP
      NN1=N-1
      DO 120 M=1,3
```

```
      NP=NP+1
      ID(NP)=3*NN1+M
  120 CONTINUE
C
C     FORM STIFFNESS FOR EACH ELEMENT
C
      REWIND 2
      CALL ELSTIF
C
C     ADD ELEMENT STIFFNESS TO STRUCTURE STIFFNESS
C
      CALL STIFF (A,120)
C
C     STATIC CONDENSATION
C
      CALL STACON (A,ID,IQ,NEQ,120,NP)
C
C     STORE ELASTIC SUPPORT DATA ON TAPE 4
C
      IF (NUMSPR.EQ.0) GO TO 130
      WRITE (4) (NPSTP(I),I=1,NUMNP)
      WRITE (4) ((SP(I,J),I=1,NUMSPR),J=1,3)
C
C     INVERSE THE STIFFNESS MATRIX
C
  130 NMAX=NEQ-NP
      CALL SYMINV (A,NMAX,120)
C
C     STORE THE FLEXIBILITY MATRIX ON TAPE 9
C
      WRITE (9) ((A(I,J),J=1,NMAX),I=1,NMAX)
      NUMELT(NFT)=NUMEL
      NUMNPT(NFT)=NUMNP
      NEQN(NFT)=NEQ
      NUSPRG(NFT)=NUMSPR
      NPT(NFT)=NP
  140 CONTINUE
C
C     STORE INFORMATION ACCORDING TO THE SEQUENCE OF THE BENT
C
      REWIND 2
      REWIND 7
      DO 160 I=1,NBT
      NUMEL=NUMELT(I)
      DO 150 J=1,NUMEL
      K1=1+(J-1)*87
      K2=K1+86
  150 READ (7) (HHH(K),K=K1,K2)
      K3=NUMEL*90
      WRITE (2) (HHH(K),K=1,K3)
  160 CONTINUE
      REWIND 7
      DO 200 I=1,NDIAPH
      IF (KODIA(I).NE.3) GO TO 200
      REWIND 2
      IN=KDTP(I)
```

```
      IF (IN.EQ.1) GO TO 180
      DO 170 J=2,IN
  170 READ (2) HH
  180 NUMEL=NUMELT(IN)
      K3=NUMEL*87
      READ (2) (HHH(K),K=1,K3)
      DO 190 L=1,NUMEL
      K1=1+(L-1)*87
      K2=K1+86
  190 WRITE (7) (HHH(K),K=K1,K2)
  200 CONTINUE
      REWIND 2
      REWIND 4
      DO 230 I=1,NBT
      NEQ=NEQN(I)
      NUMNP=NUMNPT(I)
      NP=NPT(I)
      NUMSPR=NUSPRG(I)
      READ (4) (HHH(J),J=1,NEQ)
      L=NEQ+1
      L1=NEQ-NP
      L2=NEQ
      DO 210 M=1,NP
      L2=L2+L1
      READ (4) (HHH(J),J=L,L2)
      L=L2+1
      L1=L1+1
  210 CONTINUE
      IF (NUMSPR.EQ.0) GO TO 220
      L2=L+NUMNP-1
      READ (4) (HHH(J),J=L,L2)
      L=L2+1
      L2=L+3*NUMSPR-1
      READ (4) (HHH(J),J=L,L2)
  220 WRITE (2) (HHH(J),J=1,L2)
      LSIZE(I)=L2
  230 CONTINUE
      REWIND 4
      DO 270 I=1,NDIAPH
      IF (KODIA(I).NE.3) GO TO 270
      REWIND 2
      IN=KDTP(I)
      IF (IN.EQ.1) GO TO 250
      DO 240 J=2,IN
  240 READ (2) HH
  250 CONTINUE
      ISIZE = LSIZE(IN)
      READ (2) (HHH(J),J=1,ISIZE)
      NEQ=NEQN(IN)
      NP=NPT(IN)
      NUMNP=NUMNPT(IN)
      NUMSPR=NUSPRG(IN)
      WRITE (4) (HHH(J),J=1,NEQ)
      L=NEQ+1
      L1=NEQ-NP
      L2=NEQ
```

```
      DO 260 M=1,NP
      L2=L2+L1
      WRITE (4) (HHH(J),J=L,L2)
      L=L2+1
  260 L1=L1+1
      IF (NUMSPR.EQ.0) GO TO 270
      L2=L+NUMNP-1
      WRITE (4) (HHH(J),J=L,L2)
      L=L2+1
      L2=L+3*NUMSPR-1
      WRITE (4) (HHH(J),J=L,L2)
  270 CONTINUE
      REWIND 2
      DO 310 I=1,NDIAPH
      IF (KODIA(I).NE.3) GO TO 310
      REWIND 9
      IN=KDTP(I)
      IF (IN.EQ.1) GO TO 290
      DO 280 J=2,IN
  280 READ (9) HH
  290 NMAX=NEQN(IN)-NPT(IN)
      N=NMAX*NMAX
      READ (9) (HHH(J),J=1,N)
      NN1=1
      NN2=NMAX
      DO 300 L=1,NMAX
      WRITE (2) (HHH(J),J=NN1,NN2)
      NN1=NN1+NMAX
  300 NN2=NN2+NMAX
  310 CONTINUE
      RETURN
C
C
  320 FORMAT (37H1FRAME BENT PROGRAM IS TO BE EXECUTED/19H INPUT DATA FO
     1LLOWS)
  330 FORMAT (6I5)
  340 FORMAT (I5,E10.0,F10.0)
  350 FORMAT (I5,3F10.0)
  360 FORMAT (I5,3F10.0)
  370 FORMAT (2I5,2F10.0,2I5)
  380 FORMAT (34H2FRAME BENT TYPE NUMBER            =I6/34H NUMBER OF ELEM
     1ENTS                   =I6/34H NUMBER OF NODAL POINTS            =I6/34H
     2NUMBER OF MATERIALS                =I6/34H NUMBER OF ELEMENT TYPES
     3         =I6/34H NUMBER OF ELASTIC SUPPORT TYPES =I6////)
  390 FORMAT (50H1MATERIAL    YOUNG S      POISSON S                  /50H
     1              MODULUS        RATIO                    )
  400 FORMAT (1H ,I5,3X,E13.4,F14.5)
  410 FORMAT (1H1/60H ELEMENT          AXIAL          SHEAR      MOMENT OF
     1           /60H   TYPE           AREA           AREA       INERTIA
     2          )
  420 FORMAT (1H ,I5,3X,3F12.3)
  430 FORMAT (1H1,39H FRAME                 NODAL COORDINATES       54H        ELA
     1STIC SUPPORT     CORRESPONDING NODE             /10H NODE CODE,7X,
     21HX,11X,1HY,20X,4HTYPE,14X,15HIN FOLDED PLATE)
  440 FORMAT (1H ,I4,I5,2F12.3,2I20)
  450 FORMAT (1H1/60H                 SPRING CONSTANTS OF ELASTIC SUPPORTS
```

```
     1          //60H              LINEAR            LINEAR          ROTATIONAL
     2          /60H  TYPE  STIFFNESS  X    STIFFNESS  Y     STIFFNESS  Z
     3      )
 460 FORMAT (1H ,I4,3F16.3)
 470 FORMAT (1H0/60H AXIAL AREA OR FLEXURAL INERTIA CANNOT BE SPECIFIED
     1 AS ZERO.)
      END
```

```
      SUBROUTINE ELSTIF
C
C     ******************************************************************
C     FORM ELEMENT STIFFNESS FOR ONE DIMENSIONAL ELEMENT
C     ******************************************************************
C
      COMMON /PARAM/ NUMEL,NUMNP,NEQ,NUMSPR,NP,NUMELT(8),NUMNPT(8),NEQN(
     18),NUSPRG(8),NPT(8),NPR(80)
      COMMON /FBENT/ EFM(10),G(10),LM(6),SA(6,6),ASA(6,6),T(3,3),S(6,6),
     1RF(6),JK(3),NPSTP(80),SP(40,3),X(80),Y(80),KODE(80),COAX(80),COAY(
     280),COAAZ(80),RE(200),B(200),SPF(6),IP(120),ID(120),IQ(120),NPQ(80
     3),NFP(80),A(120,120)
C
C     INITIALIZATION
C
      NEQ=3*NUMNP
      DO 10 I=1,6
      S(I,1)=0.0
      S(4,I)=0.0
   10 S(I,4)=0.0
      T(3,3)=1.0
      DO 20 I=1,2
      T(3,I)=0.0
   20 T(I,3)=0.0
C
C     READ AND PRINT ELEMENT DATA
C
      WRITE (6,210)
   30 READ (5,200) NEL,NI,NJ,MATTYP,MELTYP,NELKOD
      SIJ=4.0
      SJI=4.0
      CIJ=0.5
      WRITE (6,220) NEL,NI,NJ,MATTYP,MELTYP,NELKOD
C
      AX=COAX(MELTYP)
      AY=COAY(MELTYP)
      AAZ=COAAZ(MELTYP)
C
      DX=X(NJ)-X(NI)
      DY=Y(NJ)-Y(NI)
      DL=SQRT(DX*DX+DY*DY)
      IF (DL) 40,40,50
   40 WRITE (6,240) NEL
      CALL EXIT
   50 COSA=DX/DL
      SINA=DY/DL
C
C     DETERMINE IF SHEAR DEFORMATIONS ARE TO BE INCLUDED.
C
      SHF=0.0
      IF (AY.NE.0.0) SHF=6.*EFM(MATTYP)*AAZ/(G(MATTYP)*AY*DL*DL)
      COMM=EFM(MATTYP)*AAZ/DL
      SHEF=0.5*(2.+SHF)/(1.+2.*SHF)
      COMM=COMM*SHEF
```

```
      SIJ=SIJ*COMM
      SJI=SJI*COMM
      CIJ=(CIJ-0.5*SHF)/(1.+0.5*SHF)
      CJI=CIJ*SIJ/SJI
C
C
C     FORM GLOBAL TO LOCAL COORDINATE TRANSFORMATION.
C
      T(1,1)=COSA
      T(1,2)=-SINA
      T(2,1)=SINA
      T(2,2)=COSA
C
C     FORM ELEMENT STIFFNESS IN LOCAL COORDINATES
C
      S(1,1)=AX*EFM(MATTYP)/DL
      S(4,1)=-S(1,1)
      S(3,2)=-SIJ*(1.+CIJ)/DL
      S(6,2)=-SJI*(1.+CJI)/DL
      S(2,2)=-(S(3,2)+S(6,2))/DL
      S(5,2)=-S(2,2)
      S(3,3)=SIJ
      S(6,3)=CIJ*SIJ
      S(5,3)=(S(3,3)+S(6,3))/DL
      S(4,4)=S(1,1)
      S(5,5)=-S(5,2)
      S(6,5)=-S(6,2)
      S(6,6)=SJI
      DO 60 I=1,5
      M=I+1
      DO 60 J=M,6
   60 S(I,J)=S(J,I)
C
C     MODIFY ELEMENT STIFFNESS FOR KNOWN ZERO MEMBER END FORCES
C
      IF (NELKOD.EQ.0) GO TO 110
      KK=NELKOD
      KD=100000
      DO 100 I=1,6
      IF (KK-KD) 100,70,70
   70 SII=S(I,I)
      DO 80 N=1,6
   80 SA(1,N)=S(I,N)
      DO 90 M=1,6
      COF=S(M,I)/SII
      DO 90 N=1,6
   90 S(M,N)=S(M,N)-COF*SA(1,N)
      KK=KK-KD
  100 KD=KD/10
C
C     OBTAIN SA(6,6) RELATING ELEMENT END FORCES (LOCAL) AND JOINT
C     DISPLACEMENTS (GLOBAL).
C
  110 DO 120 I=1,6
      DO 120 J=1,3
      SA(I,J)=0.0
```

```
      SA(I,J+3)=0.0
      DO 120 K=1,3
      IF (T(K,J).EQ.0.0) GO TO 120
      SA(I,J)=SA(I,J)+S(I,K)*T(K,J)
      SA(I,J+3)=SA(I,J+3)+S(I,K+3)*T(K,J)
  120 CONTINUE
C
C     OBTAIN ELEMENT STIFFNESS ASA(6,6) IN GLOBAL COORDINATES
C
      DO 130 I=1,3
      DO 130 J=1,6
      ASA(I,J)=0.0
      ASA(I+3,J)=0.0
      DO 130 K=1,3
      IF (T(K,I).EQ.0.0) GO TO 130
      ASA(I+3,J)=ASA(I+3,J)+T(K,I)*SA(K+3,J)
      ASA(I,J)=ASA(I,J)+T(K,I)*SA(K,J)
  130 CONTINUE
C
C     FORM LOCAL LOCATION MATRIX FOR ELEMENT
C
      NMI=NPR(NI)
      NMJ=NPR(NJ)
      DO 140 M=1,3
      J=M-3
      LM(M)=3*NMI+J
  140 LM(M+3)=3*NMJ+J
C
C     MODIFY GLOBAL STIFFNESS AND BOUNDARY CONDITIONS FOR KNOWN JOINT
C     DISPLACEMENTS
C
      JK(1)=KODE(NI)
      JK(2)=KODE(NJ)
      DO 170 N=1,2
      KD=100
      KK=JK(N)
      DO 170 M=1,3
      I=3*(N-1)+M
      II=LM(I)
      IF (KK-KD) 170,150,150
  150 DO 160 K=1,6
      ASA(I,K)=0.0
  160 ASA(K,I)=0.0
      ASA(I,I)=1.0
      KK=KK-KD
  170 KD=KD/10
C
C     STORE ELEMENT INFORMATION ON TAPE 2
C
      WRITE (2) LM,SA,ASA,T
C
      WRITE (7) LM,SA,ASA,T
      IF (NUMEL-NEL) 180,190,30
  180 WRITE (6,230) NEL
      CALL EXIT
  190 RETURN
```

```
C
C
  200 FORMAT (5I5,I10)
  210 FORMAT (1H1/60H ELEMENT   NODE   NODE   MATERIAL   ELEMENT   ELEMENT
     1             /60H            I      J      TYPE       TYPE      CODE
     2          )
  220 FORMAT (1H ,I5,I7,I6,I8,I10,I11)
  230 FORMAT (36H0ELEMENT CARD ERROR, ELEMENT NUMBER=I6)
  240 FORMAT (8H0ELEMENT,I5,39H HAS ZERO LENGTH. EXECUTION TERMINATED.)
      END
```

```
      SUBROUTINE STIFF (A,ND)
C
C     ******************************************************************
C     ASSEMBLE THE TOTAL FRAME BENT STIFFNESS MATRIX
C     ******************************************************************
C
      COMMON /PARAM/ NUMEL,NUMNP,NEQ,NUMSPR,NP,NUMELT(8),NUMNPT(8),NEQN(
     18),NUSPRG(8),NPT(8),NPR(80)
      COMMON /FBENT/ EFM(10),G(10),LM(6),SA(6,6),ASA(6,6),T(3,3),S(6,6),
     1RF(6),JK(3),NPSTP(80),SP(40,3),X(80),Y(80),KODE(80),COAX(80),COAY(
     280),COAAZ(80),RE(200),B(200),SPF(6),IP(120),ID(120),IQ(120),NPQ(80
     3),NFP(80)
      DIMENSION A(ND,ND)
C
C     INITIALIZATION
C
      DO 10 I=1,NEQ
      DO 10 J=1,NEQ
   10 A(I,J)=0.0
C
C     ADD ELEMENT STIFFNESS TO STRUCTURE STIFFNESS
C
      REWIND 2
      DO 30 N=1,NUMEL
      READ (2) (LM(I),I=1,87)
      DO 20 I=1,6
      II=LM(I)
      DO 20 J=1,6
      JJ=LM(J)
      IF (JJ.LE.0) GO TO 20
      A(II,JJ)=A(II,JJ)+ASA(I,J)
   20 CONTINUE
   30 CONTINUE
C
C     ADD STIFFNESS OF ELASTIC FOUNDATION TO STRUCTURE STIFFNESS
C
      IF (NUMSPR.EQ.0) GO TO 60
      DO 50 J=1,NUMNP
      MSPR=NPSTP(J)
      IF (MSPR.EQ.0) GO TO 50
      DO 40 K=1,3
      KJ=3*(J-1)+K
   40 A(KJ,1)=A(KJ,1)+SP(MSPR,K)
   50 CONTINUE
   60 RETURN
      END
```

```
      SUBROUTINE STACON (A,ID,IQ,N,ND,NP)
C
C     ******************************************************************
C     STATIC CONDENSATION ROUTINE TO ELIMINATE CERTAIN DEGREES OF
C             FREEDOM FROM A SYMMETRIC SYSTEM OF EQUATIONS
C
C                               -  INPUT  -
C     N    - NUMBER OF EQUATIONS
C     NP   - NUMBER OF DEGREES OF FREEDOM TO BE ELIMINATED
C     ND   - NUMBER OF ROWS IN DIMENSION STATEMENT OF MATRIX  A
C     A    - COEFFICIENT MATRIX OF ORDER N
C     B    - LOAD VECTOR OF ORDER N
C     ID   - ARRAY CONTAINING ROW NUMBERS OF DEGREES OF FREEDOM
C            TO BE ELIMINATED
C
C                               -  OUTPUT  -
C
C     A    - REDUCED COEFFICIENT MATRIX OF ORDER N-NP
C     B    - REDUCED LOAD VECTOR OF ORDER N-NP
C     IQ   - ARRAY CONTAINING SEQUENCE OF UNKNOWNS IN REDUCED SYSTEM
C            OF EQUATIONS
C     ******************************************************************
C
      DIMENSION A(ND,N), ID(NP), IQ(N)
C
C     SET UP  IQ-ARRAY
C
      DO 10 I=1,N
   10 IQ(I)=I
C
C     INTERCHANGE ROWS
C
      DO 70 I=1,NP
      II=NP-I+1
      IJ=ID(II)
      KI=N-I+1
      IF (KI.EQ.IJ) GO TO 70
      MKI=KI-1
      DO 30 J=1,N
      X=A(IJ,J)
      DO 20 M=IJ,MKI
      ML=M+1
   20 A(M,J)=A(ML,J)
   30 A(KI,J)=X
C
C     INTERCHANGE COLUMNS
C
      DO 50 J=1,N
      X=A(J,IJ)
      DO 40 M=IJ,MKI
      ML=M+1
   40 A(J,M)=A(J,ML)
   50 A(J,KI)=X
      IX=IQ(IJ)
```

```
      DO 60 M=IJ,MKI
      ML=M+1
   60 IQ(M)=IQ(ML)
      IQ(KI)=IX
   70 CONTINUE
C
C     STORE IQ ON TAPE 4
C
      WRITE (4) (IQ(I),I=1,N)
C
C     STATIC CONDENSATION
C
      DO 90 M=1,NP
      K=N-M
      L=K+1
      DO 80 I=1,K
      A(L,I)=A(L,I)/A(L,L)
      DO 80 J=I,K
      A(J,I)=A(J,I)-A(L,I)*A(J,L)
   80 A(I,J)=A(J,I)
   90 CONTINUE
C
C     STORE STIFFNESS COEFF. OF ELIMINATED DEG. OF FREEDOM ON TAPE 4
C
      K=N-NP+1
      DO 100 I=K,N
      L=I-1
  100 WRITE (4) (A(I,J),J=1,L)
C
      RETURN
      END
```

```
      SUBROUTINE SYMINV (A,NMAX,NSIZE)
C
C     ***********************************************************************
C     INVERSE A SYMMETRIC MATRIX
C     ***********************************************************************
C
      DIMENSION A(NSIZE,NSIZE)
C
      DO 10 N=1,NMAX
   10 A(N,1)=A(1,N)
C
      DO 80 N=1,NMAX
      PIVOT=A(N,N)
      A(N,N)=-1.
      DO 20 J=1,NMAX
   20 A(N,J)=A(N,J)/PIVOT
      DO 70 I=1,NMAX
      IF (N-I) 30,70,30
   30 IF (A(I,N)) 40,70,40
   40 DO 60 J=I,NMAX
      IF (N-J) 50,60,50
   50 A(I,J)=A(I,J)-A(I,N)*A(N,J)
      A(J,I)=A(I,J)
   60 CONTINUE
   70 CONTINUE
      DO 80 I=1,NMAX
   80 A(I,N)=A(N,I)
C
      DO 90 I=1,NMAX
      DO 90 J=1,NMAX
   90 A(I,J)=-A(I,J)
      RETURN
      END
```

```
      OVERLAY(MASTER,4,0)
      PROGRAM FLEXD
C
C     ******************************************************************
C     ANALYZE EACH TYPE OF THE FLEXIBLE MOVABLE DIAPHRAGMS BY FORCE
C     METHOD. STORE THE FLEXIBILITY MATRICES ON TAPES.
C     ******************************************************************
C
      COMMON TETAO,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMD
     1,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12)
     2,KDTP(12),CHPLRE,MPC1,MPCOL,MPC,INDMP(60)
      COMMON /FXDM/ IC(3,2),KTEM(13),MBCOL,NDIA(12),JN1,JN2,INDB(120),XD
     1DD(120),BF(3,120)
      COMMON /PLATE/ XP(14),NPI(30),NPJ(30),KPL(30),NSEC(30),PWTH(30),SI
     1NEL(30),COSEL(30),Y(30),Z(30),TP(14)
      COMMON /CASE/ AJP(80),LCASE(4,20),JFOR(3,20),XORD(20),YORD(20)
      DIMENSION FE(3,3), FLE(120,120), TB(3), D1(8), D2(8), D3(8), HHH(1
     14400)
      EQUIVALENCE (FLE,HHH)
C
C     READ DIAPHRAGM PROPERTIES
C
      PRINT 480
      DO 50 I=1,NFMD
      READ 470, IN,MOP
      PRINT 490, IN
      GO TO (10,20), MOP
   10 READ 500, DITH,DIDP,CODE,DIE,DINU
      CC=0.5*CODE*DIDP
      PRINT 510, DITH,DIDP,CC,DIE,DINU
      DIPHA=DITH*DIDP
      DIPHI=DIPHA*DIDP*DIDP/12.
      DIAS=DIPHA/1.2
      GO TO 30
   20 READ 500, DIPHI,DIPHA,DIAS,CC,DIE,DINU
      PRINT 520, DIPHI,DIPHA,DIAS,CC,DIE,DINU
      DIDP=SQRT(12.*DIPHI/DIPHA)
C
C     CALCULATE CONSTANTS
C
   30 D1(I)=1./(DIPHA*DIE)
      D3(I)=1./(12.*DIE*DIPHI)
      IF (DIAS.EQ.0.) GO TO 40
      D2(I)=24.*(1.+DINU)*DIPHI/DIAS
      GO TO 50
   40 D2(I)=0.
   50 CONTINUE
C
C     GENERATE COORDINATES OF THE BEAM ELEMENTS
C
      K=0
      DO 70 L=1,NEL
      I=NPI(L)
      J=NPJ(L)
```

```
      IF (JFOR(1,I)*JFOR(2,I)*JFOR(3,I).NE.0) GO TO 60
      K=K+1
      XDOD(K)=XORD(I)
   60 IF (JFOR(1,J)*JFOR(2,J)*JFOR(3,J).NE.0) GO TO 70
      K=K+1
      XDOD(K)=XORD(J)
   70 CONTINUE
      EPSI=0.01*DIDP
      HGH=-99999.
      IBM=0
      DO 100 I=1,K
      G=XDOD(I)
      N=I
      J=I+1
      IF (J.GT.K) GO TO 90
      DO 80 M=J,K
      IF (XDOD(M).GE.G) GO TO 80
      G=XDOD(M)
      N=M
   80 CONTINUE
      XDOD(N)=XDOD(I)
   90 IF ((G-HGH).LE.EPSI) GO TO 100
      IBM=IBM+1
      XDOD(IBM)=G
      HGH=G
  100 CONTINUE
C
C     TO FORM FORCE TRANSFORMATION MATRIX
C
      REWIND 9
      DO 110 I=1,MBCOL
      DO 110 J=1,MBCOL
  110 FLE(I,J)=0.
      DO 120 L=1,NFMD
  120 WRITE (9) ((FLE(I,J),J=1,MBCOL),I=1,MBCOL)
      IF (JN2) 130,130,140
  130 C1=XORD(JN1)
      C2=C1
      C4=YORD(JN1)
      GO TO 180
  140 IF (IC(1,1).EQ.1) GO TO 160
      C4=YORD(JN2)
      IF (XORD(JN2).GT.XORD(JN1)) GO TO 150
      IFTYPE=1
      C1=XORD(JN2)
      C2=XORD(JN1)
      GO TO 180
  150 IFTYPE=2
      C1=XORD(JN1)
      C2=XORD(JN2)
      GO TO 180
  160 C4=YORD(JN1)
      IF (XORD(JN1).GT.XORD(JN2)) GO TO 170
      IFTYPE=1
      C1=XORD(JN1)
      C2=XORD(JN2)
```

```
      GO TO 180
  170 IFTYPE=2
      C1=XORD(JN2)
      C2=XORD(JN1)
  180 EPSI=0.5*EPSI
      IBM1=IBM-1
      KTAPE=-1
      DO 400 JK=1,IEM1
      KTAPE=-KTAPE
      X1=XDOD(JK)-C1
      X2=XDOD(JK+1)-C1
      I=0
      IF (X1.LE.-EPSI) GO TO 290
      C3=C2-C1
      IF (X1.GE.(C3-EPSI)) GO TO 250
      GO TO (190,220), IFTYPE
  190 IMTYPE=3
      DO 210 J=1,MX,4
      I=I+1
      J1=J+1
      J2=J+2
      XX=XORD(I)-C1
      YY=YORD(I)-C4
      IF (XX.LE.(X1+EPSI)) GO TO 200
      BF(1,J)=1.
      BF(1,J1)=0.
      BF(1,J2)=0.
      BF(2,J)=CC-C4-(YY*X1/C3)
      BF(2,J1)=(1.-XX/C3)*X1
      BF(2,J2)=X1/C3
      BF(3,J)=CC-C4-YY*X2/C3
      BF(3,J1)=(1.-XX/C3)*X2
      BF(3,J2)=X2/C3
      GO TO 210
  200 BF(1,J)=0.
      BF(1,J1)=0.
      BF(1,J2)=0.
      BF(2,J)=(C3-X1)*YY/C3
      BF(2,J1)=(C3-X1)*XX/C3
      BF(2,J2)=(X1-C3)/C3
      BF(3,J)=(C3-X2)*YY/C3
      BF(3,J1)=(C3-X2)*XX/C3
      BF(3,J2)=(X2-C3)/C3
  210 CONTINUE
      GO TO 330
  220 IMTYPE=4
      DO 240 J=1,MX,4
      I=I+1
      J1=J+1
      J2=J+2
      XX=XORD(I)-C1
      YY=YORD(I)-C4
      IF (XX.LE.(X1+EPSI)) GO TO 230
      BF(1,J)=0.
      BF(1,J1)=0.
      BF(1,J2)=0.
```

```
      BF(2,J)=-YY*X1/C3
      BF(2,J1)=(1.-XX/C3)*X1
      BF(2,J2)=X1/C3
      BF(3,J)=-YY*X2/C3
      BF(3,J1)=(1.-XX/C3)*X2
      BF(3,J2)=X2/C3
      GO TO 240
  230 BF(1,J)=-1.
      BF(1,J1)=0.
      BF(1,J2)=0.
      BF(2,J)=-CC+C4+YY*(1.-X1/C3)
      BF(2,J1)=XX*(1.-X1/C3)
      BF(2,J2)=-1.+X1/C3
      BF(3,J)=-CC+C4+YY*(1.-X2/C3)
      BF(3,J1)=XX*(1.-X2/C3)
      BF(3,J2)=-1.+X2/C3
  240 CONTINUE
      GO TO 330
  250 IMTYPE=2
      DO 280 J=1,MX,4
      I=I+1
      J1=J+1
      J2=J+2
      XX=XORD(I)-C1
      IF (XX.GE.(X2-EPSI)) GO TO 270
      DO 260 L=1,3
      BF(L,J)=0.
      BF(L,J1)=0.
      BF(L,J2)=0.
  260 CONTINUE
      GO TO 280
  270 BF(1,J)=1.
      BF(1,J1)=0.
      BF(1,J2)=0.
      BF(2,J)=CC-YORD(I)
      BF(2,J1)=X1-XX
      BF(2,J2)=1.
      BF(3,J)=BF(2,J)
      BF(3,J1)=X2-XX
      BF(3,J2)=1.
  280 CONTINUE
      GO TO 330
  290 IMTYPE=1
      DO 320 J=1,MX,4
      I=I+1
      J1=J+1
      J2=J+2
      XX=XORD(I)-C1
      IF (XX.LE.(X1+EPSI)) GO TO 310
      DO 300 L=1,3
      BF(L,J)=0.
      BF(L,J1)=0.
      BF(L,J2)=0.
  300 CONTINUE
      GO TO 320
  310 BF(1,J)=-1.
```

```
      BF(1,J1)=0.
      BF(1,J2)=0.
      BF(2,J)=YORD(I)-CC
      BF(2,J1)=XX-X1
      BF(2,J2)=-1.
      BF(3,J)=BF(2,J)
      BF(3,J1)=XX-X2
      BF(3,J2)=-1.
  320 CONTINUE
C
  330 DO 340 I=1,MPCOL
      J=INDMP(I)
      DO 340 K=1,3
  340 BF(K,I)=BF(K,J)
C
      DO 350 I=1,MBCOL
      J=INDB(I)
      DO 350 K=1,3
  350 BF(K,I)=BF(K,J)
C
C     FIND AND SUM UP B TRANSPOSE * F * B
C
      S=XDOD(JK+1)-XDOD(JK)
      REWIND 8
      REWIND 9
      IF (KTAPE.LT.0) GO TO 360
      MTAPE=9
      NTAPE=8
      GO TO 370
  360 MTAPE=8
      NTAPE=9
  370 DO 400 L=1,NFMD
      FE(1,1)=S*D1(L)
      FE(1,2)=0.
      FE(1,3)=0.
      FE(2,1)=0.
      PHI=D2(L)/S
      FE(2,2)=(4.*S+PHI)*D3(L)
      FE(2,3)=(2.*S-PHI)*D3(L)
      FE(3,1)=0.
      FE(3,2)=FE(2,3)
      FE(3,3)=FE(2,2)
      READ (MTAPE) ((FLE(I,J),J=1,MBCOL),I=1,MBCOL)
      DO 390 I=1,MBCOL
      DO 380 J=1,3
      TB(J)=0.
      DO 380 K=1,3
  380 TB(J)=TB(J)+BF(K,I)*FE(K,J)
      DO 390 J=1,MBCOL
      DO 390 K=1,3
  390 FLE(I,J)=FLE(I,J)+TB(K)*BF(K,J)
      WRITE (NTAPE) ((FLE(I,J),J=1,MBCOL),I=1,MBCOL)
  400 CONTINUE
C
      IF (NTAPE.EQ.9) GO TO 420
      REWIND 8
```

```
      REWIND 9
      DO 410 L=1,NFMD
      READ (8) ((FLE(I,J),J=1,MBCOL),I=1,MBCOL)
  410 WRITE (9) ((FLE(I,J),J=1,MBCOL),I=1,MBCOL)
C
C     STORE FLEXIBILITY MATRICES ON TAPE 8
C
  420 REWIND 8
      DO 460 I=1,NDIAPH
      IF (KODIA(I).NE.4) GO TO 460
      REWIND 9
      IN=KDTP(I)
      N=MBCOL*MBCOL
      IF (IN.EQ.1) GO TO 440
      DO 430 J=2,IN
  430 READ (9) HH
  440 READ (9) (HHH(J),J=1,N)
      NN1=1
      NN2=MBCOL
      DO 450 L=1,MBCOL
      WRITE (8) (HHH(J),J=NN1,NN2)
      NN1=NN1+MBCOL
  450 NN2=NN2+MBCOL
  460 CONTINUE
      RETURN
C
  470 FORMAT (2I4)
  480 FORMAT (46H1PROPERTIES OF THE FLEXIBLE MOVABLE DIAPHRAGMS)
  490 FORMAT (33H3FLEXIBLE MOVABLE DIAPHRAGM TYPE ,I3)
  500 FORMAT (6F10.0)
  510 FORMAT (1H0,8X,9HTHICKNESS,11X,5HDEPTH,13X,12HNEUTRAL AXIS,11X,1HE
     1,16X,1HV/4E20.8,F10.3)
  520 FORMAT (20H0   MOMENT OF INERTIA,10X,4HAREA,13X,10HSHEAR AREA,10X,1
     12HNEUTRAL AXIS,13X,1HE,14X,1HV/5E20.8,F10.3)
      END
```

```
      OVERLAY(MASTER,5,0)
      PROGRAM CORF2
C
C     ******************************************************************
C     SUM UP THE FLEXIBILITY MATRICES OF THE FOLDED PLATES, THE FLEXIBLE
C     BENTS AND THE FLEXIBLE MOVABLE DIAPHRAGMS. SOLVE FOR THE CORREC-
C     TIVE FORCES.
C     ******************************************************************
C
      COMMON TETAO,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMD
     1,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12)
     2,KDTP(12),CHPLRE,MPC1,MPCOL,MPC,INDMP(60),CF(120)
      COMMON /FOLD/ FMAT(120,120),DINP(120),L1,L2,DISP(80,81)
      COMMON /FXDM/ IC(3,2),KTEM(13),MBCOL,NDIA(12),JN1,JN2,INDB(120),XD
     1DD(120),BF(3,120),IT
      DIMENSION RB(120), ERASE(120), DD1(80), T(120), FRAM(120), DD(4,20
     1), KB12(3), B(3,120),TDX(12),TDL(12)
      EQUIVALENCE (FRAM,CF), (DD,DD1)
C
C
C     RESTORE INFORMATION SAVED ON TAPE 1
C
      REWIND 1
      READ (1) ((FMAT(I,J),I=1,IT),J=1,IT),(DINP(I),I=1,IT),KB12,B,KB
C
C     SUM UP THE FLESIBILITIES OF THE FOLDED PLATE AND THE FLEXIBLE BENT
C
      REWIND 2
      REWIND 8
      DO 50 K=1,NDIAPH
      IK=KODIA(K)
      GO TO (50,50,10,30), IK
   10 KMK=KTEM(K)
      DO 20 I=1,MPC
      READ (2) (FRAM(J),J=1,MPC)
      IXYZ=KMK+I
      DO 20 J=1,MPC
      JXYZ=KMK+J
   20 FMAT(IXYZ,JXYZ)=FMAT(IXYZ,JXYZ)+FRAM(J)
      GO TO 50
C
C     ADD THE FLEXIBILITY OF THE FLEXIBLE MOVABLE DIAPHRAGM
C
   30 KMK=KTEM(K)
      DO 40 I=1,MBCCL
      READ (8) (FRAM(J),J=1,MECOL)
      IXYZ=KMK+I
      DO 40 J=1,MBCCL
      JXYZ=KMK+J
   40 FMAT(IXYZ,JXYZ)=FMAT(IXYZ,JXYZ)+FRAM(J)
   50 CONTINUE
C
C     SOLVE FOR CORRECTIVE FORCES
C
```

```
      REWIND 1
      WRITE (1) ((FMAT(I,J),I=1,IT),J=1,IT)
      DO 60 J=1,IT
   60 RB(J)=DINP(J)
      C=0.
      L=ISIMEQ(120,IT,1,FMAT,RB,C,ERASE)
      GO TO (90,70,80), L
   70 PRINT 250
      STOP
   80 PRINT 260
      STOP
   90 DO 100 J=1,IT
  100 RB(J)=FMAT(J,1)
C
C     PRINT DINP AND FMAT*RB FOR CHECK
C
      REWIND 1
      READ (1) ((FMAT(I,J),I=1,IT),J=1,IT)
      PRINT 270
      DO 110 J=1,IT
      ERASE(J)=0.
      DO 110 K=1,IT
  110 ERASE(J)=ERASE(J)+FMAT(J,K)*RB(K)
      PRINT 280, (L,DINP(L),ERASE(L),L=1,IT)
C
C     STORE INTERACTION FORCES ON TAPE 9
C
      REWIND 9
      DO 120 M=1,NDIAPH
      II=KTEM(M)+1
      IJ=KTEM(M+1)
  120 WRITE (9) (RB(J),J=II,IJ)
C
C     PRINT CORRECTIVE JOINT FORCES
C
      PRINT 290
      DO 130 I=1,MX
  130 DD1(I)=0.
      DO 230 M=1,NDIAPH
      IF(IO.EQ.0)PRINT 300,M,DIAPHX(M),DIADEL(M)
      IF(IO.EQ.0)GO TO 320
      TDX(M)=DIAPHX(M)*(180./PI)
      TDL(M)=DIADEL(M)*(180./PI)
      PRINT 310,M,TDX(M),TDL(M)
  320 CONTINUE
      II=KTEM(M)
      IJ=KTEM(M+1)
      IF (IJ-II-MPC) 160,140,160
  140 DO 150 I=1,MPC
      J=I+II
  150 ERASE(I)=RB(J)
      GO TO 200
  160 DO 170 I=1,MBCOL
      K=I+II
      J=INDB(I)
      T(I)=RB(K)
```

```
  170 ERASE(J)=T(I)
      DO 190 I=1,KB
      J=KB12(I)
      C=0.
      DO 180 K=1,MBCOL
  180 C=C+B(I,K)*T(K)
  190 ERASE(J)=C
  200 DO 210 I=1,MPCOL
      J=INDMP(I)
  210 DD1(J)=ERASE(I)
      PRINT 240, (I,(DD(J,I),J=1,3),I=1,NJT)
C
      DO 220 I=1,MPCOL
      K=I+(M-1)*MPCOL
  220 CF(K)=ERASE(I)
  230 CONTINUE
C
      RETURN
C
  240 FORMAT (I5,3E20.8)
  250 FORMAT (27H1OVERFLOW WHEN SOLVING FMAT)
  260 FORMAT (17H1FMAT IS SINGULAR)
  270 FORMAT (64H1CHECK ACCURACY OF SOLVING EQUATIONS, TO COMPARE -DISPL
     1 WITH F*R//17X,7H -DISPL14X,6H F * R)
  280 FORMAT (I4,2E20.6)
  290 FORMAT (40H1FINAL CORRECTIVE JOINT FORCES                        )
  300 FORMAT (////14H DIAPHRAGM NO.I4,8X,4H X =F10.4,8X,12H THICKNESS =F
     110.6//6H JOINT11X,8H H-FORCE12X,8H V-FORCE13X,7H MOMENT)
  310 FORMAT (////14H DIAPHRAGM NO.I4,8X,8H THETA =F10.4,8X,12H THICKNES
     1S =F10.6//6H JOINT11X,8H H-FORCE12X,8H V-FORCE13X,7H MOMENT)
      END
```

```
      FUNCTION ISIMEQ (MAX,NN,LL,A,B,SCALE,ID)
C
C     ******************************************************************
C     SOLVE SYMMETRICAL SIMULTANEOUS EQUATIONS WITH PIVOTING
C     ******************************************************************
C
      DIMENSION A(MAX,MAX), B(MAX,1), ID(1)
C
C     SET I.D. ARRAY
C
      DO 10 N=1,NN
   10 ID(N)=N
C
      DO 140 N=1,NN
      N1=N+1
C
C     LOCATE LARGEST ELEMENT
C
      D=0.0
      DO 30 I=N,NN
      DO 30 J=N,NN
      IF (ABS(A(I,J))-D) 30,20,20
   20 D=ABS(A(I,J))
      II=I
      JJ=J
   30 CONTINUE
C
C     INTERCHANGE COLUMNS
C
      DO 40 I=1,NN
      D=A(I,N)
      A(I,N)=A(I,JJ)
   40 A(I,JJ)=D
C
C     RECORD COLUMN INTERCHANGE
C
      I=ID(N)
      ID(N)=ID(JJ)
      ID(JJ)=I
C
C     INTERCHANGE ROWS
C
      DO 50 J=N,NN
      D=A(N,J)
      A(N,J)=A(II,J)
   50 A(II,J)=D
C
      DO 60 L=1,LL
      D=B(N,L)
      B(N,L)=B(II,L)
   60 B(II,L)=D
C
C     FORM D(N,L)
C
```

```
      DO 70 L=1,LL
   70 B(N,L)=B(N,L)/A(N,N)
C
C     CHECK FOR LAST EQUATION
C
      IF (N-NN) 80,150,80
C
   80 DO 130 J=N1,NN
C
C     FORM H(N,J)
C
      IF (A(N,J)) 90,110,90
   90 A(N,J)=A(N,J)/A(N,N)
C
C     MODIFY A(I,J)
C
      DO 100 I=N1,NN
  100 A(I,J)=A(I,J)-A(I,N)*A(N,J)
C
C     MODIFY B(I,L)
C
  110 DO 120 L=1,LL
  120 B(J,L)=B(J,L)-A(J,N)*B(N,L)
  130 CONTINUE
  140 CONTINUE
C
C     BACK-SUBSTITUTION
C
  150 N1=N
      N=N-1
      IF (N) 180,180,160
C
  160 DO 170 L=1,LL
      DO 170 J=N1,NN
  170 B(N,L)=B(N,L)-A(N,J)*B(J,L)
C
      GO TO 150
C
C     REORDER UNKNOWNS
C
  180 DO 220 N=1,NN
      DO 210 I=N,NN
      IF (ID(I)-N) 210,190,210
  190 DO 200 L=1,LL
      D=B(N,L)
      B(N,L)=B(I,L)
  200 B(I,L)=D
      GO TO 220
  210 CONTINUE
  220 ID(I)=ID(N)
C
      ISIMEQ=1
C
C     PUT ANSWERS IN A ARRAY
C
      DO 230 L=1,LL
```

```
      DO 230 I=1,NN
  230 A(I,L)=B(I,L)
C
      RETURN
C
      END
```

```
      OVERLAY(MASTER,6,0)
      PROGRAM EDGDIS
C
C     ******************************************************************
C     CALCULATE AND PRINT FINAL JOINT DISPLACEMENTS FOR THE FOLDED
C     PLATE STRUCTURE
C     ******************************************************************
C
      COMMON TETAO,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMD
     1,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12)
     2,KDTP(12),CHPLRE,MPC1,MPCOL,MPC,INDMP(60),CF(120)
      COMMON /PERM/ NOXMP,NBOX,NGIEL(30,2),BOXMOM(14,10),XDIV(30),DNAI(3
     10),DNAJ(30),MOPX(14),COMP(14,10),TENS(14,10),HS(30),VS(30),XMP(14)
      COMMON /EDGE/ SINKX(100,14),COSKX(100,14)
      COMMON /PROPT/ THM(15),THB(15),ETM(15),ETB(15),ESM(15),ESB(15),GM(
     115),GB(15),PRM(15),PRB(15)
      COMMON /PLATE/ XP(14),NPI(30),NPJ(30),KPL(30),NSEC(30),PWTH(30),SI
     1NEL(30),COSEL(30),Y(30),Z(30),TP(14)
      DIMENSION RJDIS(80,14), DISP(80), EDP(240), DI(80,81), LIND(80), D
     1(12), P(80)
C
C
C     INITIATION
C
      DO 10 J=1,NXP
      DO 10 I=1,MX
   10 RJDIS(I,J)=0.
      REWIND 1
      REWIND 3
C
C     CYCLE FOR EACH HARMONIC
C
      MM=0
      DO 180 NN=N1,MHARM,N2
      MM=MM+1
      FN=NN
      FK=FN*PI/TETAO
C
C     READ DISPLACEMENT MATRIX FROM TAPE 3
C
      READ (3) ((DI(I,J),I=1,MX),J=1,MPC1)
      IF (NDIAPH) 20,20,40
   20 DO 30 I=1,MX
   30 DISP(I)=DI(I,1)
      GO TO 120
C
C     FOURIER MULTIPLIERS ARE COMPUTED
C
   40 DO 70 I=1,NDIAPH
      XX=FK*DIAPHX(I)
      S=SIN(XX)
      IF (DIADEL(I)) 60,60,50
   50 XX=FK*DIADEL(I)/2.
      C=SIN(XX)
```

```
      D(I)=2./(XX*TETAO*R)*C*S
      GO TO 70
   60 D(I)=2./(TETAO*R)*S
   70 CONTINUE
C
C     FIND FINAL JOINT DISPLACEMENTS (DISP)
C
      DO 80 I=1,MPCOL
      P(I)=0.
      DO 80 J=1,NDIAPH
      K=I+(J-1)*MPCOL
   80 P(I)=P(I)+CF(K)*D(J)
      DO 100 I=1,MX
      C=0.
      DO 90 J=1,MPCOL
   90 C=C+DI(I,J)*P(J)
  100 DISP(I)=C+DI(I,MPC1)
      IF (NDIAPH.EQ.0) GO TO 120
C
C     CHANGE SIGNS TO CONFORM WITH CURSTR
C
      DO 110 I=3,MX,4
      DISP(I)=-DISP(I)
  110 DISP(I+1)=-DISP(I+1)
C
C     CALCULATE AND SUM UP JOINT DISPLACEMENTS AT DIFFERENT POINTS
C
  120 DO 160 II=1,NXP
      IF (IAX.GT.0) GO TO 130
      S=1.0
      C=0.0
      GO TO 140
  130 XX=FK*TP(II)
      C=COS(XX)
      S=SIN(XX)
  140 COSKX(MM,II)=C
      SINKX(MM,II)=S
      DO 160 L=4,MX,4
      I=L-3
      J=L-1
      DO 150 K=I,J
  150 RJDIS(K,II)=RJDIS(K,II)+DISP(K)*S
  160 RJDIS(L,II)=RJDIS(L,II)+DISP(L)*C
C
C     CALCULATE EDGE DISPLACEMENTS FOR EACH ELEMENT AND STORE ON TAPE 1
C
      N=0
      DO 170 L=1,NEL
      K=KPL(L)
      I=NPI(L)*4-4
      J=NPJ(L)*4-4
      C=COSEL(L)
      S=SINEL(L)
      EDP(N+1)=DISP(I+4)
      EDP(N+2)=DISP(J+4)
      EDP(N+3)=DISP(I+1)*C+DISP(I+2)*S
```

```
      EDP(N+4)=DISP(J+1)*C+DISP(J+2)*S
      EDP(N+5)=DISP(I+1)*S-DISP(I+2)*C
      EDP(N+6)=DISP(J+1)*S-DISP(J+2)*C
      EDP(N+7)=-DISP(I+3)
      EDP(N+8)=-DISP(J+3)
  170 N=N+8
      WRITE (1) (EDP(I),I=1,N)
C
C
  180 CONTINUE
C
C     PRINT RESULTS FOR JOINT DISPLACEMENTS
C
      DO 190 I=1,NJT
      J=4*I
      LIND(J)=I
      LIND(J-1)=I
      LIND(J-2)=I
  190 LIND(J-3)=I
      IF (NXP-7) 200,200,210
  200 II=NXP
      IL=1
      GO TO 220
  210 II=7
      IJ=NXP
      IL=2
  220 PRINT 300
      CALL PINVAL (LIND,RJDIS,80,14,XP,MX,II,IJ,IL,IO,1)
      PRINT 310
      CALL PINVAL (LIND,RJDIS,80,14,XP,MX,II,IJ,IL,IO,2)
      PRINT 320
      CALL PINVAL (LIND,RJDIS,80,14,XP,MX,II,IJ,IL,IO,3)
      PRINT 330
      CALL PINVAL (LIND,RJDIS,80,14,XP,MX,II,IJ,IL,IO,4)
C
      CALL PLFOR (MM,II,IJ,IL)
C
      IF (MCHECK.EQ.0) GO TO 260
      DO 250 I=1,NOXMP
      PP=0.0
      TOT=0.0
      TOTEN=0.
      TOCOM=0.
      DO 230 J=1,NBOX
      TOTEN=TOTEN+TENS(I,J)
      TOCOM=TOCOM+COMP(I,J)
  230 TOT=TOT+BOXMOM(I,J)
      IF (TOT.EQ.0.) GO TO 250
      IF(IO.EQ.0)PRINT 270,XMP(I)
C
      IF(IO.EQ.1) PRINT 340,XMP(I)
      DO 240 J=1,NBOX
      PC=BOXMOM(I,J)/TOT*100.
      PP=PP+PC
  240 PRINT 280, J,BOXMOM(I,J),PC,TENS(I,J),COMP(I,J)
      PRINT 290, TOT,PP,TOTEN,TOCOM
```

```
  250 CONTINUE
  260 RETURN
C
  270 FORMAT (1H1,38H MOMENTS TAKEN BY EACH GIRDER AT  X = ,F10.3///,58H
     1 GIRDER NO.    MOMENT    PERCENTAGE    TENSION     COMPRESSION//)
  280 FORMAT (I6,E16.6,F9.2,2E16.6)
  290 FORMAT (//6H TOTAL,E16.6,F9.2,2E16.6)
  300 FORMAT (26H1FINAL JOINT DISPLACEMENTS////10X,25H HORIZONTAL DISPLA
     1CEMENTS)
  310 FORMAT (////10X,23H VERTICAL DISPLACEMENTS)
  320 FORMAT (////10X,10H ROTATIONS)
  330 FORMAT (////10X,27H LONGITUDINAL DISPLACEMENTS)
  340 FORMAT(1H1,42H MOMENTS TAKEN BY EACH GIRDER AT  THETA = ,F10.5///,
     1 58H GIRDER NO.    MOMENT    PERCENTAGE    TENSION    COMPRESSION//)
      END
```

```
      SUBROUTINE PLFOR (MM,II,IJ,IL)
C
C     ******************************************************************
C     CALCULATE AND PRINT FINAL INTERNAL FORCES FOR EACH PLATE ELEMENT
C     ******************************************************************
C
      COMMON TETAO,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMD
     1,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12)
     2,KDTP(12),CHPLRE,MPC1,MFCOL,MPC,INDMP(60),CF(120)
      COMMON /PROPT/ THM(15),THB(15),ETM(15),ETB(15),ESM(15),ESB(15),GM(
     115),GB(15),PRM(15),PRB(15)
      COMMON /EDGE/ SINKX(100,14),COSKX(100,14)
      COMMON /PERM/ NOXMP,NBOX,NGIEL(30,2),BOXMOM(14,10),XDIV(30),DNAI(3
     10),DNAJ(30),MCPX(14),COMP(14,10),TENS(14,10),HS(30),VS(30),XMP(14)
      COMMON /PLATE/ XP(14),NPI(30),NPJ(30),KPL(30),NSEC(30),PWTH(30),SI
     1NEL(30),COSEL(30),Y(30),Z(30),TP(14)
      DIMENSION DI(240), D(8,1500), DIS(8,30), DISP(8)
      DIMENSION U(14,13),VD(14,13),W(14,13),       SN(14,13),TN(14,13)
     1,STN(14,13),SM(14,13),TM(14,13),STM(14,13)
      EQUIVALENCE (DI,DIS)
C
C
      NELINC=12000/(MM*8)-1
      NOFPL=0
      NEL2=0
C
C     READ EDGE DISPLACEMENTS FROM TAPE 1
C
   10 NEL1=NEL2+1
      IF (NEL1-NEL) 20,20,200
   20 NEL2=MINO((NEL1+NELINC),NEL)
      NDI=NEL2*8
      REWIND 1
      L=0
      DO 30 I=1,MM
      READ (1) (DI(J),J=1,NDI)
      DO 30 J=NEL1,NEL2
      L=L+1
      DO 30 K=1,8
   30 D(K,L)=DIS(K,J)
C
C     FOR EACH ELEMENT
C
      NDI=NEL2-NEL1+1
      DO 190 IE=NEL1,NEL2
      FN=NSEC(IE)
      IF (FN) 190,190,40
   40 NUMY=NSEC(IE)+1
      IEPL=KPL(IE)
      XL=2./FN
      ISW=1
      DO 50 J=1,NUMY
      DO 50 K=1,NXP
      U(K,J)=0.
```

```
      VD(K,J)=0.
      W(K,J)=0.
      SN(K,J)=0.
      TN(K,J)=0.
      STN(K,J)=0.
      SM(K,J)=0.
      TM(K,J)=0.
   50 STM(K,J)=0.
      IF (IEPL-NOFPL) 60,80,60
   60 IF (MI.EQ.1) GO TO 70
      FM=PRM(IEPL)*ETM(IEPL)/ESM(IEPL)
      FB=PRB(IEPL)*ETB(IEPL)/ESB(IEPL)
      DM=1.-FM*PRM(IEPL)
      DB=1.-FB*PRB(IEPL)
      TH3=THB(IEPL)**3/12.
      D11=THM(IEPL)*ESM(IEPL)/DM
      D22=THM(IEPL)*ETM(IEPL)/DM
      D12=D22*PRM(IEPL)
      D33=GM(IEPL)*THM(IEPL)
      D44=TH3*ESB(IEPL)/DB
      D55=TH3*ETB(IEPL)/DB
      D45=D55*PRB(IEPL)
      D66=GB(IEPL)*TH3*4.0
      GO TO 80
   70 D11=THM(IEPL)
      D12=THB(IEPL)
      D22=ETM(IEPL)
      D33=ETB(IEPL)
      D44=ESM(IEPL)
      D45=ESB(IEPL)
      D55=GM(IEPL)
      D66=GB(IEPL)
C
   80 S12=PWTH(IE)
      S122=S12*S12
      I=NPI(IE)
      J=NPJ(IE)
      R1=Y(I)
      R2=Y(J)
      A=0.5*(R2-R1)
      B=0.5*(R2+R1)
      SP=SINEL(IE)
      CP=COSEL(IE)
C
C     FOR EACH HARMONIC
C
      N=0
      KJK=1
      DO 180 NN=N1,MHARM,N2
      N=N+1
      I=NDI*(N-1)+(IE-NEL1+1)
      DO 90 J=1,8
   90 DISP(J)=D(J,I)
      FN=NN
      FK=FN*PI/TETAO
C     FOR EACH TRANSVERSE SECTION
```

```
C
      DO 130 IY=1,NUMY
      FY=IY-1
      ETA=XL*FY-1.
      E2=ETA*ETA
      E3=E2*ETA
      PU1=0.5*(1.-ETA)
      PU2=0.5*(1.+ETA)
      PU3=-1./S12
      PU4=-PU3
      P1=PU1*DISP(1)+PU2*DISP(2)
      P2=PU1*DISP(3)+PU2*DISP(4)
      P3=PU3*DISP(1)+PU4*DISP(2)
      P4=PU3*DISP(3)+PU4*DISP(4)
      PU1=.25*(2.-3.*ETA+E3)
      PU2=.25*(2.+3.*ETA-E3)
      PU3=.125*S12*(1.-ETA-E2+E3)
      PU4=.125*S12*(-1.-ETA+E2+E3)
      XW=PU1*DISP(5)+PU2*DISP(6)
      P5=XW+PU3*DISP(7)+PU4*DISP(8)
      PU1=1.5/S12*(E2-1.)
      PU2=-PU1
      PU3=.25*(-1.-2.*ETA+3.*E2)
      PU4=.25*(-1.+2.*ETA+3.*E2)
      P6=PU1*DISP(5)+PU2*DISP(6)+PU3*DISP(7)+PU4*DISP(8)
      PU1=6.*ETA/S122
      PU2=-PU1
      PU3=(3.*ETA-1.)/S12
      PU4=(3.*ETA+1.)/S12
      P7=PU1*DISP(5)+PU2*DISP(6)+PU3*DISP(7)+PU4*DISP(8)
      RR=1./(A*ETA+B)
      SPR=SP*RR
      CPR=CP*RR
      BN=FK*RR
      IF (IAX.EQ.0) BN=0.0
C
      XX=-BN*P1+CPR*P2+SPR*P5
      XNS=D11*P4+D12*XX
      XNT=D12*P4+D22*XX
      XNST=(P3-CPR*P1+BN*P2)*D33
      XX=BN*(BN*P5-SPR*P1)-CPR*P6
      XMS=D45*XX-D44*P7
      XMT=D55*XX-D45*P7
      XMST=D66*(SPR*(P3-CPR*P1)+BN*(CPR*P5-P6))
C
C     SUM UP INTERNAL FORCES AND DISPLACEMENTS
C
      DO 120 I=1,NXP
      IF (IAX.GT.0) GO TO 100
      S=1.0
      C=0.0
      GO TO 110
  100 S=SINKX(N,I)
      C=COSKX(N,I)
  110 U(I,IY)=U(I,IY)+P1*C
      VD(I,IY)=VD(I,IY)+P2*S
```

```
      W(I,IY)=W(I,IY)+XW*S
      SN(I,IY)=SN(I,IY)+XNS*S
      TN(I,IY)=TN(I,IY)+XNT*S
      STN(I,IY)=STN(I,IY)+XNST*C
      SM(I,IY)=SM(I,IY)-XMS*S
      TM(I,IY)=TM(I,IY)-XMT*S
  120 STM(I,IY)=STM(I,IY)-XMST*C
  130 CONTINUE
C
C     PRINT INTERNAL FORCES FOR EACH ELEMENT
C
  160 IF (NN.NE.MHARM) GO TO 180
  170 I=NPI(IE)
      J=NPJ(IE)
      PRINT 210, IE,I,J,NN
      PRINT 220
      CALL OPRINT (SN,14,13,XP,NUMY,II,IJ,IL,IO)
      PRINT 230
      CALL OPRINT (TN,14,13,XP,NUMY,II,IJ,IL,IO)
      PRINT 240
      CALL OPRINT(STN,14,13,XP,NUMY,II,IJ,IL,IO)
      PRINT 250
      CALL OPRINT( SM,14,13,XP,NUMY,II,IJ,IL,IO)
      PRINT 260
      CALL OPRINT( TM,14,13,XP,NUMY,II,IJ,IL,IO)
      PRINT 270
      CALL OPRINT(STM,14,13,XP,NUMY,II,IJ,IL,IO)
      PRINT 280
      CALL OPRINT(  U,14,13,XP,NUMY,II,IJ,IL,IO)
      PRINT 290
      CALL OPRINT( VD,14,13,XP,NUMY,II,IJ,IL,IO)
      PRINT 300
      CALL OPRINT(  W,14,13,XP,NUMY,II,IJ,IL,IO)
C
C     CALCULATE GIRDER MOMENTS
C
      IF (MCHECK.LE.0) GO TO 180
      IF (NN.NE.MHARM) GO TO 180
      PLW=PWTH(IE)
      S=DNAI(IE)
      C=DNAJ(IE)
      HH=R2-R1
      VV=Z(I)-Z(J)
      I=NGIEL(1,IE)
      J=NGIEL(2,IE)
      XX=XDIV(IE)
      CALL MOMPER (TN,TM,PLW,IE,NUMY)
  180 CONTINUE
      NOFPL=IEPL
  190 CONTINUE
      GO TO 10
  200 RETURN
C
  210 FORMAT (1H1,48H INTERNAL FORCES PER UNIT LENGTH FOR ELEMENT NO.I4,
     118H   BETWEEN JOINTS I3,6H   AND I3,9H     AFTERI5,11H  HARMONICS)
  220 FORMAT (////10X,5H N(S))
```

```
230 FORMAT (/////10X,9H N(THETA))
240 FORMAT (/////10X,11H N(S-THETA))
250 FORMAT (/////10X,5H M(S))
260 FORMAT (/////10X,9H M(THETA))
270 FORMAT (/////10X,11H M(S-THETA))
280 FORMAT (/////10X,2H U)
290 FORMAT (/////10X,2H V)
300 FORMAT (/////10X,2H W)
    END
```

```
      SUBROUTINE MOMPER (XN,XM,W,I,NY)
C
C     ******************************************************************
C     FIND THE GIRDER MOMENTS BY INTEGRATING THE MEMBRANE STRESSES AND
C     PLATE BENDING MOMENTS IN EACH GIRDER
C     ******************************************************************
C
      COMMON /PERM/ NOXMP,NBOX,NGIEL(30,2),BOXMOM(14,10),XDIV(30),DNAI( 3
     10),DNAJ(30),MOPX(14),COMP(14,10),TENS(14,10),HS(30),VS(30),XMP(14)
      DIMENSION XN(14,13), XM(14,13), X(14)
      EQUIVALENCE (XMP,X)
      DO 80 J=1,NOXMP
      N1=NGIEL(I,1)
      N2=NGIEL(I,2)
      IX=MOPX(J)
      NSC=NY-1
      SC=NSC
      DEL=W/SC
      DEV=(DNAJ(I)-DNAI(I))/SC
      IF (DEV.EQ.0.) GO TO 10
      DEH=-DEV*HS(I)/VS(I)
      GO TO 20
   10 DEH=HS(I)/SC
   20 X1=DNAI(I)
      IF (N2.NE.0) GO TO 40
      DO 30 NN=1,NSC
      X2=X1+DEV
      CALL ADDM (J,N1,X1,X2,DEL,DEH,XN(IX,NN),XN(IX,NN+1),XM(IX,NN),XM(I
     1X,NN+1))
   30 X1=X2
      GO TO 80
   40 NN=1
      HH=0.
   50 HH=HH+DEH
      AHH=ABS(HH)
      AXDIV=ABS(XDIV(I))
      IF (AHH.GT.AXDIV) GO TO 60
      X2=X1+DEV
      CALL ADDM (J,N1,X1,X2,DEL,DEH,XN(IX,NN),XN(IX,NN+1),XM(IX,NN),XM(I
     1X,NN+1))
      X1=X2
      NN=NN+1
      GO TO 50
   60 FA=(XDIV(I)+DEH-HH)/DEH
      XL=FA*DEL
      XH=FA*DEH
      X2=X1+FA*DEV
      XN2=XN(IX,NN)+FA*(XN(IX,NN+1)-XN(IX,NN))
      XM2=XM(IX,NN)+FA*(XM(IX,NN+1)-XM(IX,NN))
      CALL ADDM (J,N1,X1,X2,XL,XH,XN(IX,NN),XN2,XM(IX,NN),XM2)
      X3=X1+DEV
      XL=DEL-XL
      XH=DEH-XH
      CALL ADDM (J,N2,X2,X3,XL,XH,XN2,XN(IX,NN+1),XM2,XM(IX,NN+1))
```

```
      X1=X3
   70 NN=NN+1
      IF (NN.GT.NSC) GO TO 80
      X2=X1+DEV
      CALL ADDM (J,N2,X1,X2,DEL,DEF,XN(IX,NN),XN(IX,NN+1),XM(IX,NN),XM(I
     1X,NN+1))
      X1=X2
      GO TO 70
   80 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ADDM (J,N,X1,X2,XL,XH,XN1,XN2,XM1,XM2)
C
C     ******************************************************************
C     INTEGRATE THE STRESSES BY TRAPEZOIDAL RULE
C     ******************************************************************
C
      COMMON /PERM/ NOXMP,NBOX,NGIEL(30,2),BOXMOM(14,10),XDIV(30),DNAI(3
     10),DNAJ(30),MCPX(14),COMP(14,10),TENS(14,10),HS(30),VS(30),XMP(14)
      F1=XN1*XL/2.
      XM=F1*(X2+2.*X1)/3.
      F2=XN2*XL/2.
      XM=XM+F2*(X1+2.*X2)/3.
      F=F1+F2
      XM=XM+0.5*(XM1+XM2)*XH
      BOXMOM(J,N)=BOXMOM(J,N)+XM
      IF (F.LT.0.) GO TO 10
      TENS(J,N)=TENS(J,N)+F
      GO TO 20
   10 COMP(J,N)=COMP(J,N)+F
   20 RETURN
      END
```

```
      SUBROUTINE PINVAL (IND,D,M,N,X,MX,K1,K2,NCYC,IO,L)
      DIMENSION IND(M), D(M,N), X(N), IN(2), JN(2)
      DATA IN(1),IN(2)/1,8/
      JN(1)=K1
      JN(2)=K2
      DO 10 K=1,NCYC
      J1=IN(K)
      J2=JN(K)
      IF (IO.EQ.0) PRINT 30, (X(I),I=J1,J2)
      IF (IO.EQ.1) PRINT 40, (X(I),I=J1,J2)
      DO 10 I=L,MX,4
   10 PRINT 20, (IND(I),(D(I,J),J=J1,J2))
      RETURN
C
   20 FORMAT (I6,1P7E16.7)
   30 FORMAT (6H0JOINT,7(6H     X=F10.3))
   40 FORMAT (6H0JOINT,7(6HTHETA=F10.5))
      END
```

```
      SUBROUTINE OPRINT (A,M,N,X,NY,K1,K2,NCYC,IO)
      DIMENSION A(M,N), X(M), IN(2), JN(2)
      DATA IN(1),IN(2)/1,8/
      JN(1)=K1
      JN(2)=K2
      DO 10 K=1,NCYC
      J1=IN(K)
      J2=JN(K)
      IF (IO.EQ.0) PRINT 30, (X(I),I=J1,J2)
      IF (IO.EQ.1) PRINT 40, (X(I),I=J1,J2)
      DO 10 I=1,NY
   10 PRINT 20, (I,(A(J,I),J=J1,J2))
      RETURN
C
   20 FORMAT (I6,1P7E16.7)
   30 FORMAT (6H0SECT.,7(6H     X=F10.3))
   40 FORMAT (6H0SECT.,7(6HTHETA=F10.5))
      END
```

```
      OVERLAY(MASTER,7,0)
      PROGRAM FORCE                                                     FORC
C                                                                       FORC
C     ******************************************************************FORC
C     CALCULATE JOINT DISPLACEMENTS AND MEMBER END FORCES FOR EACH FRAMEFORC
C     BENT                                                              FORC
C     ******************************************************************FORC
C                                                                       FORC
      COMMON TETAD,R,NPL,NEL,NJT,NDIAPH,NXP,MHARM,NCHECK,MCHECK,NBT,NFMDFORC
     1,KFOR,IO,MI,INTRES,PI,MX,N1,N2,IAX,DIAPHX(12),DIADEL(12),KODIA(12)FORC
     2,KDTP(12),CHPLRE,MPC1,MPCOL,MPC,INDMP(60)                         FORC
      COMMON /PARAM/ NUMEL,NUMNP,NEQ,NUMSPR,NP,NUMELT(8),NUMNPT(8),NEQN(FORC
     18),NUSPRG(8),NPT(8),NPR(80)                                       FORC
      COMMON /FBENT/ EFM(10),G(10),LM(6),SA(6,6),ASA(6,6),T(3,3),S(6,6),FORC
     1RF(6),JK(3),NPSTP(80),SP(40,3),X(80),Y(80),KODE(80),COAX(80),COAY(FORC
     280),COAAZ(80),RE(200),B(200),SPF(6),IP(120),ID(120),IQ(120),A(120,FORC
     3120)                                                              FORC
C                                                                       FORC
C                                                                       FORC
C     DETERMINE JOINT DISPLACEMENTS                                     FORC
C                                                                       FORC
      REWIND 2                                                          FORC
      REWIND 4                                                          FORC
      REWIND 7                                                          FORC
      DO 190 IJK=1,NDIAPH                                               FORC
      IF (KODIA(IJK).NE.3) GO TO 190                                    FORC
      REWIND 9                                                          FORC
      IF (IJK.EQ.1) GO TO 20                                            FORC
      DO 10 K=2,IJK                                                     FORC
   10 READ (9) HH                                                       FORC
   20 READ (9) (RE(I),I=1,MPC)                                          FORC
      IN=KDTP(IJK)                                                      FORC
      NUMEL=NUMELT(IN)                                                  FORC
      NUMNP=NUMNPT(IN)                                                  FORC
      NEQ=NEQN(IN)                                                      FORC
      NUMSPR=NUSPRG(IN)                                                 FORC
      NP=NPT(IN)                                                        FORC
      NMAX=NEQ-NP                                                       FORC
      DO 30 I=1,NMAX                                                    FORC
   30 READ (2) (A(I,J),J=1,NMAX)                                        FORC
      DO 50 I=1,NMAX                                                    FORC
      B(I)=0.                                                           FORC
      DO 40 J=1,NMAX                                                    FORC
   40 B(I)=B(I)-A(I,J)*RE(J)                                            FORC
   50 CONTINUE                                                          FORC
      N=NEQ                                                             FORC
      READ (4) (IQ(I),I=1,N)                                            FORC
      L=N-NP-1                                                          FORC
      DO 60 I=1,NP                                                      FORC
      L=L+1                                                             FORC
   60 READ (4) (A(I,J),J=1,L)                                           FORC
      L=N-NP+1                                                          FORC
      DO 80 I=L,N                                                       FORC
      B(I)=0.0                                                          FORC
```

```
      K=I-1
      M=I-NMAX
      DO 70 J=1,K
   70 B(I)=B(I)-A(M,J)*B(J)
   80 CONTINUE
C
C     OUTPUT JOINT DISPLACEMENTS
C
      WRITE (6,200) IJK
      DO 90 I=1,N
      J=IQ(I)
   90 IP(J)=I
      WRITE (6,210)
      DO 100 I=1,NUMNP
      IL=NPR(I)
      JX=IP(3*IL-2)
      JY=IP(3*IL-1)
      JZ=IP(3*IL)
  100 WRITE (6,220) (I,B(JX),B(JY),B(JZ))
C
C     DETERMINE MEMBER END FORCES AND PRINT
C
      DO 110 N=1,NEQ
  110 RE(N)=0.
      WRITE (6,230)
      DO 140 N=1,NUMEL
      READ (7) LM,SA,ASA,T
      DO 130 I=1,6
      RF(I)=0.0
      DO 120 J=1,6
      JJ=LM(J)
      JJJ=IP(JJ)
  120 RF(I)=RF(I)+SA(I,J)*B(JJJ)
  130 CONTINUE
      WRITE (6,240) N,(RF(I),I=1,6)
C
C     OBTAIN CONTRIBUTION OF ELEMENT END FORCES TO APPLIED JOINT LOADS
C     AND STORE IN RE(NEQ)
C
      DO 140 I=1,3
      II=LM(I)
      III=LM(I+3)
      DO 140 J=1,3
      RE(II)=RE(II)+T(J,I)*RF(J)
  140 RE(III)=RE(III)+T(J,I)*RF(J+3)
C
C     DETERMINE AND PRINT ELASTIC SUPPORT REACTIONS
C
      IF (NUMSPR.EQ.0) GO TO 170
      WRITE (6,270)
      READ (4) (NPSTP(I),I=1,NUMNP)
      READ (4) ((SP(I,J),I=1,NUMSPR),J=1,3)
      DO 160 N=1,NUMNP
      MSPR=NPSTP(N)
      IF (MSPR.EQ.0) GO TO 160
      NN=NPR(N)
```

```
      DO 150 K=1,3
      KK=3*(NN-1)+K
      KKK=IP(KK)
      SPF(K)=-SP(MSPR,K)*B(KKK)
  150 RE(KK)=RE(KK)-SPF(K)
      WRITE (6,260) N,(SPF(K),K=1,3)
  160 CONTINUE
C
C     PRINT APPLIED JOINT LOADS AND REACTIONS
C
  170 WRITE (6,250)
      DO 180 I=1,NUMNP
      IL=NPR(I)
      JX=3*IL-2
      JY=3*IL-1
      JZ=3*IL
  180 WRITE (6,260) I,RE(JX),RE(JY),RE(JZ)
  190 CONTINUE
      RETURN
C
C
C
  200 FORMAT(52H1INTERNAL FORCES DISPLACEMENTS FOR DIAPHRAGM NUMBER I5)
  210 FORMAT(1H1/20H JOINT DISPLACEMENTS//
     1 60H JOINT    X-DISPLACEMENT    Y-DISPLACEMENT          Z-ROTATION )
  220 FORMAT(1H ,I4,3E18.5)
  230 FORMAT(1H1/18H MEMBER END FORCES//
     1 60H                                         MEMBER END FORCES     /
     2 56H ELEMENT     AXIAL I     SHEAR I     MOMENT I     AXIAL J
     3 60H       SHEAR J     MOMENT J                                    )
  240 FORMAT(1H ,I5,2X,6E12.4)
  250 FORMAT(1H1/
     1 60H                  APPLIED JOINT LOADS AND REACTIONS            /
     2 60H  NODE            FORCE X           FORCE Y          MOMENT Z  )
  260 FORMAT(1H ,I5,3E15.5)
  270 FORMAT(1H1/
     1 60H                     ELASTIC FOUNDATION REACTIONS              /
     2 60H  NODE            FORCE X           FORCE Y          MOMENT Z  )
      END
```

DISCLAIMER

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16. Abstract

A computer program is presented for the analysis of continuous prismatic folded plate structures, which are circular in plan and may have up to twelve flexible interior diaphragms or supports. The folded plate structure is considered to be an assemblage of orthotropic plate elements that may, in general, be segments of conical frustra, interconnected at longitudinal joints and simply supported at the two ends. Each plate element is idealized by a number of circumferential finite strips. The finite strip method is used to determine the strip stiffness. Interior diaphragms may be defined by flexible beams, and interior supports may be defined by two-dimensional planar frame bents. A direct stiffness harmonic analysis is used to analyze the assembled folded plate system. The interaction forces between the folded plate system and the interior diaphragms or supports are found using a force method by satisfying the required compatibility conditions. Loads and interaction forces may be approximated by up to 100 non-zero terms of the appropriate Fourier series. The final results are found by summing the solutions for the known loads and the redundant forces. Several numerical examples are presented to demonstrate the use of the program. A user's guide and a FORTRAN listing are also appended to the report.

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