A METHOD OF ANALYSIS FOR NONLINEAR DYNAMIC RESPONSE OF ARCHES

By

JERSON DUARTE GUIMARÃES

Engenheiro Civil
Universidade Federal de Minas Gerais
Belo Horizonte, MG, Brasil
1952

Master of Science
Duke University
Durham, North Carolina
1967

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NOMENCLATURE

A_b, A_{sb}	transverse area of bottom reinforcement
A_i	area of a cross section at joint i
A_i	vector of coefficients in Equation (3.15)
A_j	area of segment j in a given cross section
A_s	transverse area of steel reinforcement
A_t, A_{st}	transverse area of top reinforcement
$(AE)_i$	extensional or axial stiffness of bar i
B_1	width of section at the top
B_2	width of section at an intermediate depth
B_3	width of section at the bottom
B_i	vector of coefficients in Equation (3.15)
C_i	vector of coefficients in Equation (3.15)
C_k	dimensionless constant for the k^{th} mode of vibration
d_b	distance of centroid of bottom reinforcement to the top of the section
$\overline{d}_i$	depth of the centroid of the section at joint i
D_i	vector of coefficients in Equation (3.15)
d_j	distance of centroid of segment j to the top of the section
d_t	distance of centroid of top reinforcement to the top of the section
E	Young's modulus of elasticity

E_c	Young's modulus of elasticity for concrete or compression
E_j	Young's modulus of elasticity for segment j of a given section, initial tangent or secant modulus
E_s	Young's modulus of elasticity for steel
E_t	Young's modulus of elasticity in tension
$(EI)_i$	flexural stiffness at joint i
f	rise of an arch
f_r^i	modulus of rupture of concrete
f_{xj}^i	horizontal force at joint j of bar i
f_{yj}^i	vertical force at joint j of bar i
f_{zj}^i	moment at joint j of bar i
F_j^i	vector of static forces at joint j of bar i
F_m	maximum value or peak of time function
F(t)	dimensionless function of time
F_{xi}	vector of horizontal static and dynamic forces at joint i
F_{yi}	vector of vertical static and dynamic forces at joint i
h_k	distance of bottom of zone k to the top of the section
H	horizontal reaction of an arch
i	an integer index, generally indicator of bar or joint
I	moment of inertia of the cross sectinn
I	impulse
j	an integer index or subscript
k	an interger index or subscript
L	span of an arch or a beam. Length of a bar
L_o	span of a structure or length of a bar
L_{oi}	initial length of bar i
L_i	length of bar i

M	bending moment
M_c	bending moment at the crown of an arch
M_i	bending moment at joint i
m	an integer index or subscript, number of joints
m_i	concentrated point mass at joint i
n	an integer index or subscript, number of bars
P	concentrated applied load
P_i	point indicating location of joint i at the beginning of the dynamic process
P_i'	point indicating location of joint i after some elapsed time
p_o	uniform pressure or pressure pulse
p_{cr}	critical buckling pressure of an arch
p_{max}	maximum value of a pressure pulse
p_{mf}	minimum value of pressure pulse, capable of causing failure of an arch
$p(\alpha)$	pressure pulse at angle α, radial
$p(t,\alpha)$	magnitude of a radial pressure pulse at time t at angle α
Q_i	vector of applied forces at joint i, static
Q_{xi}	horizontal applied force at joint i, static
Q_{yi}	vertical applied force at joint i, static
Q_{zi}	applied moment at joint i, static
Q_{xdi}	horizontal dynamic applied load parameter
Q_{ydi}	vertical dynamic applied load parameter
$Q_{xdi}^{(t)}$	horizontal dynamic applied force at joint i, time i
$Q_{ydi}^{(t)}$	vertical dynamic applied force at joint i, time i
r	radius of gyration of a section

R	radius of a circular arch
$R_i^{(j)}$	residue of equation i at trial j
S	stiffness matrix
S	total length of an arch
$S_{j,k}^i$	stiffness submatrix relating forces at joint j of bar i to the displacement of joint k of bar i
t	elapsed time
t_r	time of rise of a time function
t_d	time of decay of a time function
T	smallest natural period of vibration
T_k	period of the k^{th} mode of vibration
T_o	period of the "breathing" mode of vibration of a circular ring
T_i	thrust in bar i
U	vector of displacements
U_i	vector of displacements of joint i
u_{di}, $u_{di}^{(t)}$	horizontal dynamic displacement of joint i
$\dot{u}_{di}$, $\dot{u}_{di}^{(t)}$	horizontal velocity of point mass m_j
$\ddot{u}_{di}$, $\ddot{u}_{di}^{(t)}$	horizontal acceleration of point mass m_i
$\ddot{u}_{di}^{(r)}$	residual horizontal acceleration at joint i
u_i	horizontal displacement of joint i
u_r	radial displacement
v_c	vertical displacement at the crown of an arch
v_{di}, $v_{di}^{(t)}$	vertical dynamic displacement of joint i
$\dot{v}_{di}$, $\dot{v}_{di}^{(t)}$	vertical velocity of point mass m_i
$\ddot{v}_{di}$, $\ddot{v}_{di}^{(t)}$	vertical acceleration of point mass m_i
$\ddot{v}_{di}^{(r)}$	residual vertical acceleration at joint i

v_i	vertical displacement of joint i
V	vertical reaction of a structure
V_i	shear in bar i
X_i	abcissa of joint i, in global coordinate system
X_{oi}	initial abcissa of joint i
Y_i	ordinate of joint i, in global coordinate system
Y_{oi}	initial ordinate of joint i
Y_j	distance from the centroid of segment j to the centroid of a given section
z_k	a zone of the cross section (see Figure 3.2)
α	angle measuring range of applied dynamic load
α_i	recursion coefficients in Equation (A.2) (Appendix A)
β_i	recursion coefficients in Equation (A.2) (Appendix A)
ΔQ_{xi}	unbalanced horizontal force at joint i
ΔQ_{yi}	unbalanced vertical force at joint i
Δt	time interval
$\Delta\theta_i$	relative rotation at joint i
ε	average axial strain in a bar
ε_{adi}	average dynamic axial strain in bar i
ε_{ai}	average combined static and dynamic strain in bar i
ε_{asi}	average static strain in bar i
ε_j	average strain in segment j of a section
μ	mass per unit length
ϕ_o	angle of opening of a circular arch
ϕ_{oi}	initial average curvature at joint i
ϕ_{di}	increment of curvature at joint i, due to dynamic conditions

ϕ_i	average curvature at joint i
ϕ_{si}	average static curvature at joint i
ϕ_{ti}	average curvature at joint i at time t
σ	average stress
σ_j	average stress in the segment j of a section
θ_i	slope of bar i
θ_{oi}	initial slope of bar i

CHAPTER I

INTRODUCTION

The purpose of this study is to develop a procedure for estimating the effects of nonlinear material characteristics on the behavior of arches under dynamic loads or combined static and dynamic loads.

Much work has been done in the investigation of the behavior of arches under transient loads, considering linear material properties and small displacement theory. Most of this work deals with determination of the lowest natural frequencies of vibration and corresponding mode shapes.

When effects of dynamic loads are combined with nonlinear properties of the materials, large displacements may take place at some points of the structure and the small deformation theory is unable to describe the variation of axial and flexural stiffnesses of the structure where large displacements occur.

The method developed herein takes into account material nonlinearity combined with geometric nonlinearity due to large displacements, by constantly revising the axial and flexural stiffness at selected sections of the structure, as deformations occur under transient loads.

In view of the current importance of dynamic analysis for civil engineering structures, especially with regard to seismic and blast loading, the main application of this study is in the investigation of the resistance of arches under the influence of transient loads, in the inelastic range of behavior of the materials.

A secondary, but no less important, application is to use the method here developed to investigate the effects of a high energy detonation in the vicinity of the structure, thus determining the efficient placement of a detonation to result in catastrophic collapse.

Also, if proper excitation loads are applied, natural modes of vibration, especially the first ones, can be obtained, and hence approximate natural frequencies can be determined for a variety of structures, such as circular, parabolic, elliptic, sinusoidal arches, with constant or variable cross sections of metallic materials or reinforced concrete.

The arches considered are geometrically determined by a given limited number of points forming the joints of a broken line in the plane of the arch, and may also have their axes described by any single-valued functions in the positive quadrant of the X-Y plane, starting at the origin of the coordinate system.

The material of the arch may be a composition of steel, aluminum or other metallic material, or reinforced concrete with top and/or bottom reinforcement, forming, in a specified way, rectangular, I or T sections, with uniform or variable area and mass per unit length.

The analysis is simplified by replacing the actual structure by a discrete framework, consisting of a finite number of bars, joints, concentrated point masses and springs, with properties based on the parameters of the original structure, such as geometry, boundary conditions and material properties.

The loads are applied at the joints as concentrated horizontal and/or vertical loads, and may also be the result of uniform pressure, linear or parabolic, vertical or horizontal, distributed loads. Static loads, if any, are considered only in the linear stage of the behavior of the materials of the structure.

A computer program is then developed in order to make possible the application of the method in the analysis of the replacement structure, with numerical evaluation of bending moments, thrusts, shears and deformations. Also collapse under specified failure criteria is determined.

CHAPTER II

LITERATURE REVIEW

Since Den Hartog (5), in 1928, presented the first study for the lowest frequency of vibration in extensional and inextensional modes for hinged-end and fixed-end circular arches, many investigators have been studying natural frequencies and mode shapes of vibration for circular arches and to a lesser degree noncircular geometries of arches having elastic curves of catenary, cycloidal and parabolic shapes have also been analyzed.

The papers by Wolf (10) and Veletsos et al. (9) give an extensive list of researchers who approached the problem of vibration of elastic arches or rings, using various procedures, such as the Rayleigh-Ritz method, or analytical solution of the differential equations of motion, or different techniques of numerical solution of the differential equations of motion.

Of particular interest is the work done by Eppink & Veletsos (6), where a replacement structure consisting of a series of bars, joints and concentrated point masses was used. The equations of motion were solved numerically by means of a step-by-step method of integration, due to Newmark (7). The material of the arch is linearly elastic, and the effects of shearing deformation and rotatory inertia were neglected. For circular hinged or fixed elastic arches, subjected to a transient normal pressure around the arch, with timewise variation approximated by straight line segments, dynamic responses were obtained. By comparing the solutions with those by the modal method of analysis used by previous researchers, it was shown that excellent results could be obtained with a model structure of only twelve bars.

Wolf (10) used a similar replacement structure, a finite element model, and found the frequencies for the first six modes of vibration for hinged-hinged and fixed-fixed elastic circular arches in free vibration, using a direct-iterative eigensolution method. The effect of rotatory inertia is included, but transverse shear deformations are neglected. Tables of natural frequencies for circular arches of various slenderness ratios and angles of opening were presented.

Veletsos et al.(9) studied free vibration of elastic circular arches of uniform cross section and mass per unit length, either hinged or fixed at both ends. Numerical solutions were presented for the eight lowest natural frequencies of vibration. The associated mode shapes and strain energy distributions were also analyzed. It was shown that vibrational modes may be almost purely flexural, or almost purely extensional, or the extensional and flexural actions may be strongly coupled. Effects of rotatory inertia and shearing deformations were neglected.

Austin and Veletsos (1) extended the method used by Veletsos et al. to include the effects of rotatory inertia and shearing deformations. Numerical solutions were presented for the ten lowest natural frequencies of arches having an angle of opening of ninety degrees. It was shown that the effect of rotatory inertia may be appreciable only for small values of the slenderness ratio (length of the arch divided by the radius of gyration of the cross section), increasing with increasing order of frequency. The effect is most pronounced in the nearly horizontal segments, for which the arch is vibrating in a predominantly flexural mode, and least pronounced in the diagonal seqments, for which the arch is vibrating in a predominantly extensional mode. Rotatory inertia and shearing deformations were shown to have negligible effects in the primarily extensional modes of vibration.

Dawkins (3) used a similar lumped parameter model in the analysis of cylinderical tunnel liner-packing systems of reinforced concrete, sugjected to transient dynamic loading, where inelastic behavior of the constituents was permitted. The equations of motion for the model were solved by the Beta-Method of integration due to Newmark (7).

CHAPTER III

METHOD OF ANALYSIS

Mechanical Model

In order to define a method sufficiently general to handle a wide variety of parameters, it is necessary to represent the structure to be analyzed by a lumped parameter model, composed of straight bars and spring elements, which have force-deformation characteristics derived from the properties of the original members. Consequently, the actual system is represented by n bars and n+1 joints, as shown in Figure 3.1.

Theoretically, the behavior of the model becomes closer to the behavior of the actual structure as the number of bars gets larger. Each bar is considered massless, with its distributed mass concentrated as point masses at the ends of the bar. To every joint, station or node, and to every bar or element an identification number is assigned, from left to right, as indicated in Figure 3.1. Since there are n bars and n+1 joints, bar i is located between joints i and i+1. This model is similar to lumped parameter models used by Dawkins (3) and by Eppink and Veletsos (6).

Assumptions

In addition to the substitution of the mechanical model for the actual structure, the following general assumptions are made:

1. Plane sections remain plane;

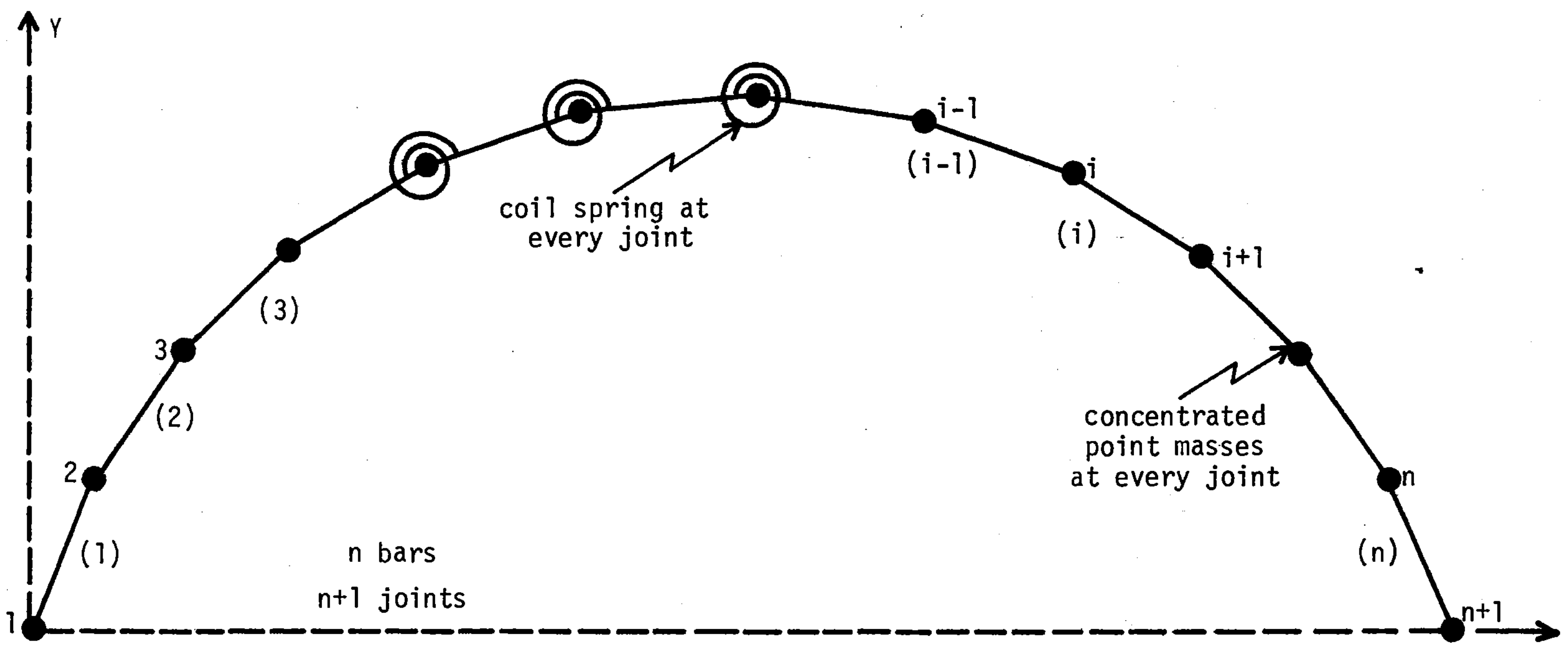


Figure 3.1. Mechanical Model

2. Loads and masses are concentrated at the joints;
3. Loads and displacements occur in the plane of the arch;
4. Linearly elastic behavior is assumed in order to determine the response of the arch to static loads, and then dynamic effects are superimposed on the initial static deformations;
5. Effects of shearing deformation and rotatory inertia are neglected.

Cross Section Description

The general cross section shown in Figure 3.2 is used. It is defined at each joint of the idealized model structure and is divided into nine zones limited by lines parallel to the bases. Each zone may be of a different material, in order to allow a variety of composite sections. Each zone may be subdivided in a given number of fibers or segments, each segment with area A_j and with its centroid located at a distance d_j from the top of the section.

A top and/or bottom reinforcement with transverse areas A_t and A_b may also be provided at distances d_t and d_b, respectively, from the top of the section.

Stress-Strain Curves

A typical stress-strain curve for the materials of the cross section, including the reinforcement, is shown in Figure 3.3. The stress-strain curve is initially divided into ten regions, five for tension and five for compression. To each segment or fiber, as defined in the above description of the cross section, a stress-strain curve is initially assigned, according to the material of the segment, and the stress-strain

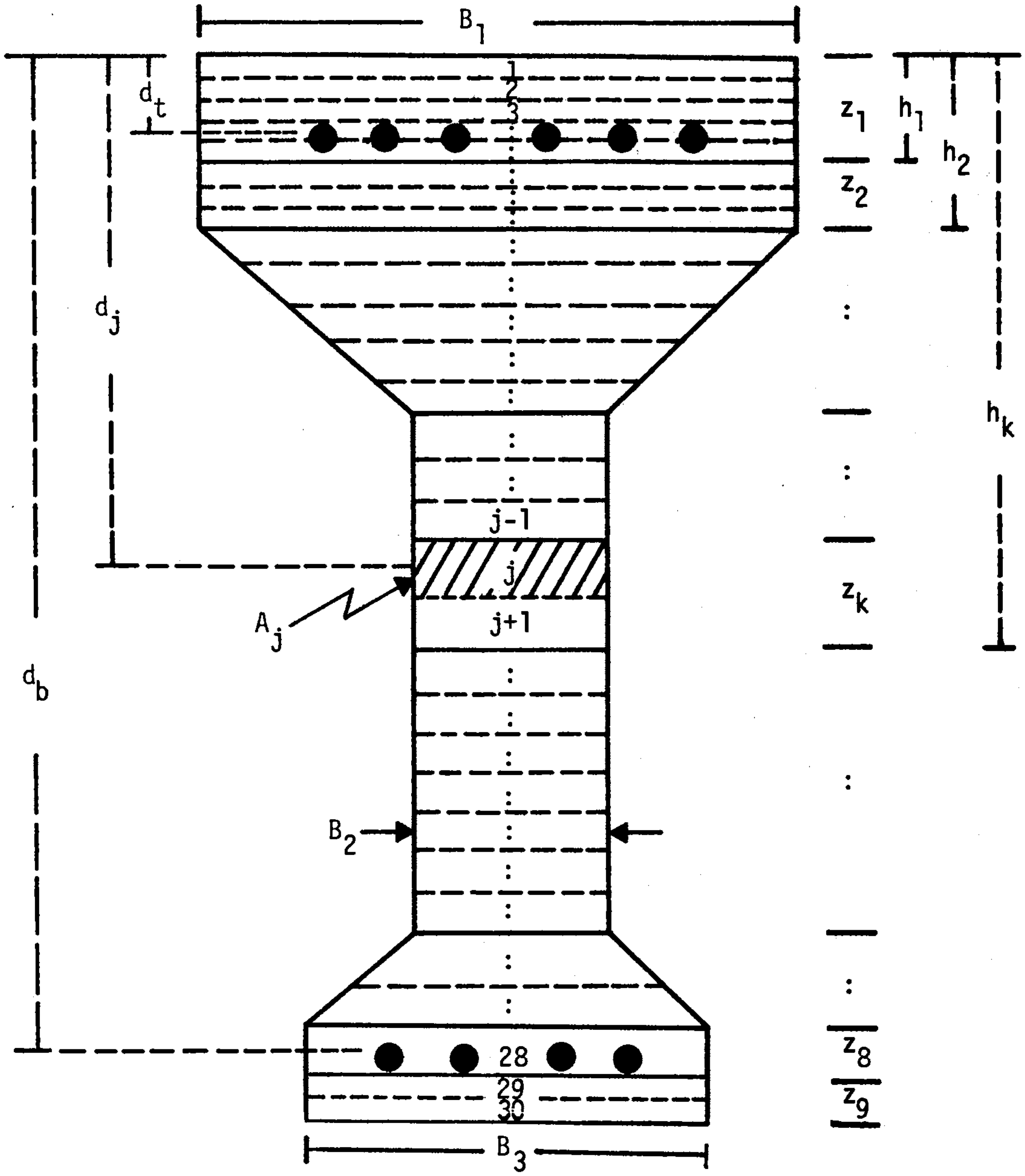


Figure 3.2. Cross Section

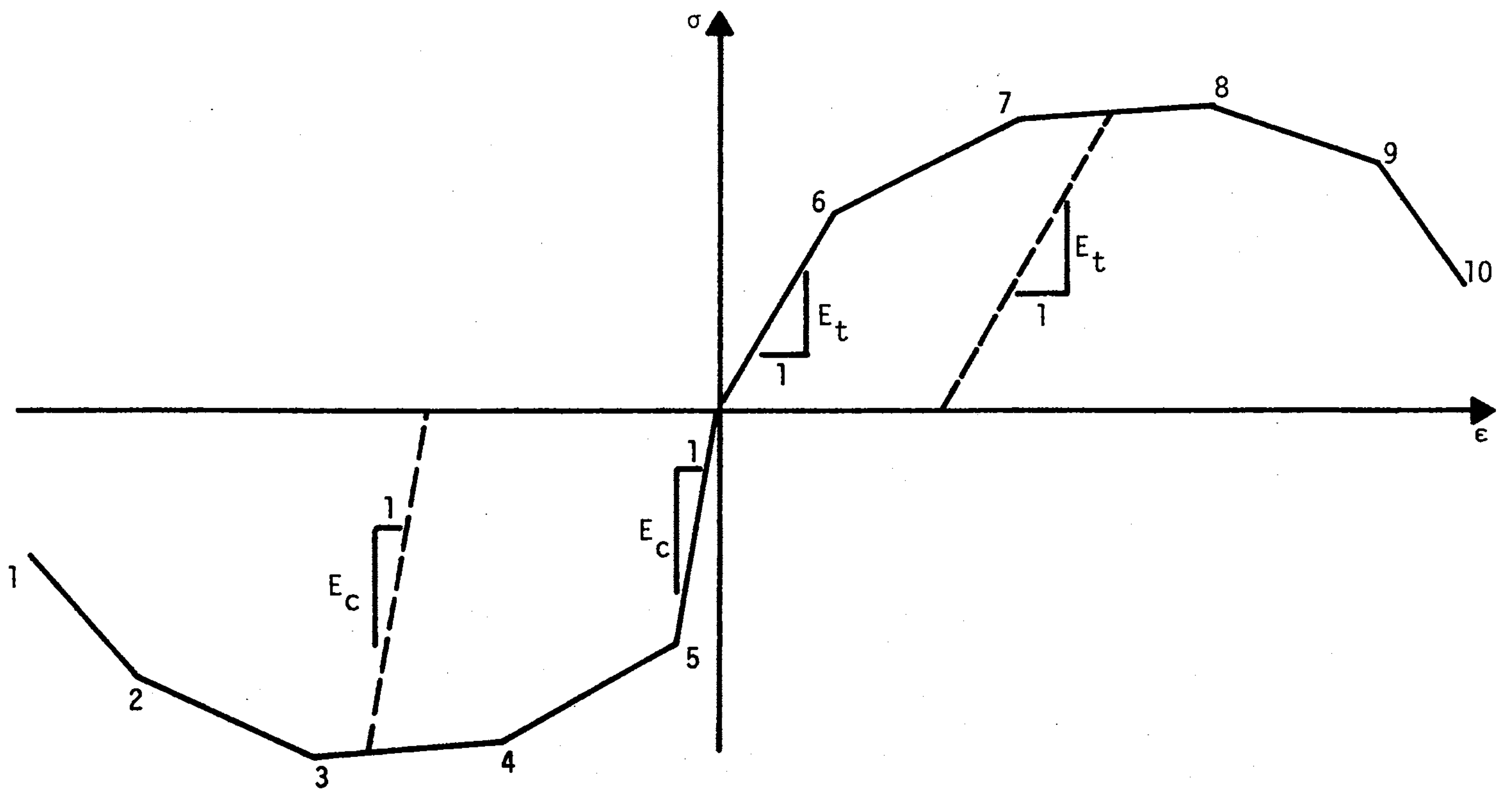


Figure 3.3. Typical Stress-Strain Curve

history of each segment is recorded, accounting for permanent sets, unloadings and reloadings. As the structure deforms, the stress-strain behavior of the material of the segment, in tension or compression, develops along the solid curve shown in Figure 3.3. If the direction of the strain is reversed, the stress-strain behavior is assumed to follow the dashed lines of Figure 3.3, parallel to the initial portion of the curve.

For the static solution, the material is assumed to be linearly elastic, with the stress-strain behavior defined in the initial portion of the curve, with a constant Young's modulus E_j equal to E_c in compression or E_t in tension.

For the dynamic solution, in the inelastic range of behavior of the materials, in order to take into account the modification of the transformed area and consequent shifting of the centroid of the cross section, as cracks and/or plastification are liable to occur, the modulus of elasticity E_j used is either the secant modulus, when the behavior of the material is expressed by the solid line of the stress-strain curve of Figure 3.3, or the initial tangent modulus, when the behavior of the material is expressed by the dashed lines of the stress-strain curve, corresponding to an unloading or reloading situation, with permanent set.

Centroid of the Section

The distance $\overline{d}_i$, measured from the centroid to the top of the cross section at joint i, is calculated considering the transformed area by the formula

$$\overline{d}_i = (\sum_{A_i} E_j\, A_j\, d_j)/(\sum_{A_i} E_j\, A_j) \tag{3.1}$$

with E_j, A_j and d_j as defined in the previous paragraphs and where the above summations are to be extended to all segments of the section A_i plus the top and bottom reinforcement, if any. The area of the material displaced by the steel is subtracted from the area of the segment in which the steel is placed.

Since E_j is constant in the static process, where elastic behavior and uncracked sections are assumed, the depth of the centroid $\overline{d}_i$ does not change, and the centroid is fixed throughout the entire static process. In the dynamic process, however, as plastification or cracks occur, E_j is no longer constant, since the secant modulus is used in the inelastic range, and the depth of the centroid varies, as calculated by Equation (3.1). This shifting of the centroid is described by J. Blaauwandraad (2), who also prescribed the use of the secant modulus in the analysis of nonlinear problems of reinforced concrete framed structures.

Strain and Stress Distribution

In a specified cross section i, if the location of the centroid $\overline{d}_i$, the average strain ε_{ai} and the curvature ϕ_i are known, a strain distribution can be determined, as shown in Figure 3.4.

The strain ε_j at the centroid of a segment can be calculated by

$$\varepsilon_j = \varepsilon_{ai} + \phi_i \, y_j \tag{3.2}$$

where $y_j = d_j - \overline{d}_i$ is the distance from the centroid of the segment to the centroid of the section. Tensile strains are positive. Curvatures are positive if they produce compressive strains at the top of the section.

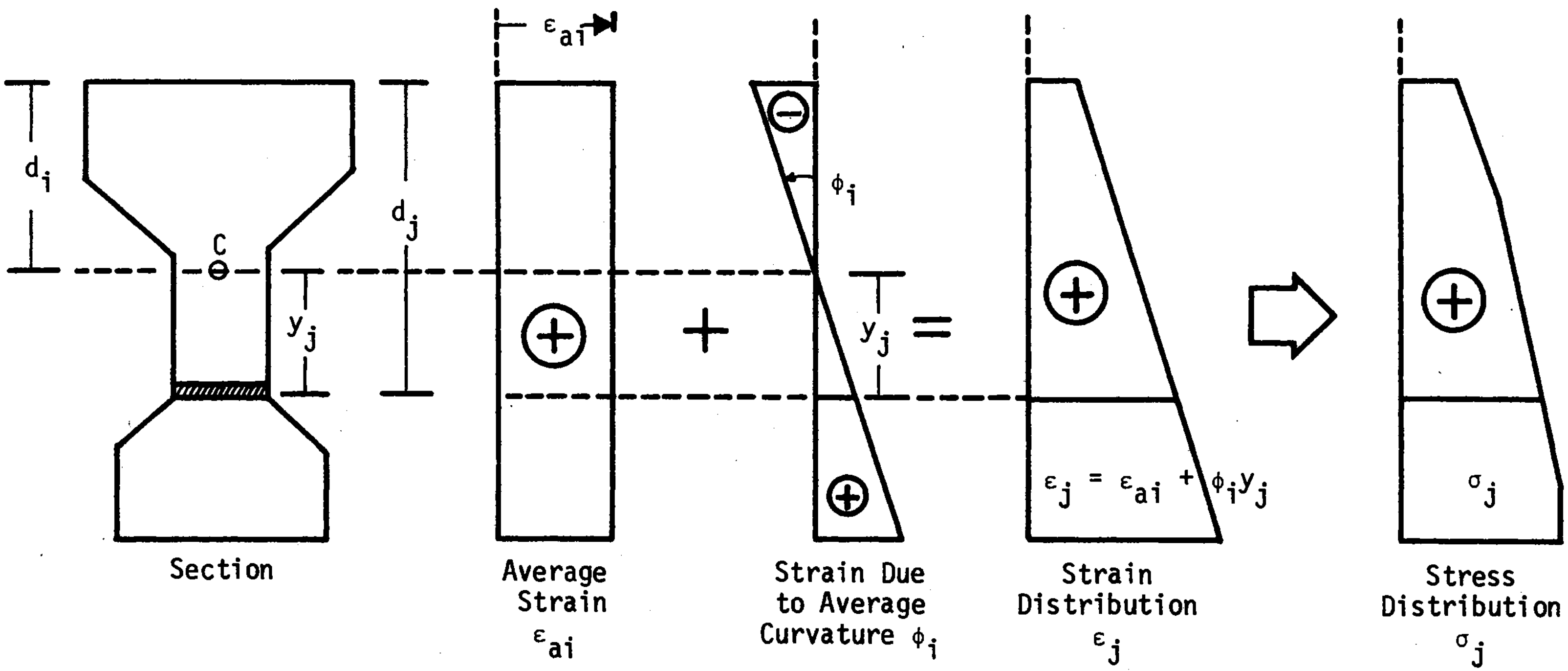


Figure 3.4. Strain and Stress Distributions

Since ε_{ai} is defined in the bar and ϕ_i is defined at the joint, when Equation (3.2) is applied to a bar, ϕ_i is taken as the average between the curvatures of the adjacent joints, and when Equation (3.2) is applied to a joint, ε_{ai} is taken as the average between the strains in adjacent bars.

From the values of ε_j for each segment, a stress distribution can be determined from the stress-strain curve for that particular segment, where, given ε_j and the strain history, the secant modulus E_j and the stress σ_j can be obtained.

If an unloading situation has not yet occurred, the equation

$$\sigma_j = E_j \varepsilon_j \tag{3.3}$$

holds, not only in the linearly elastic behavior, where E_j is constant, but also in the nonlinear range, where E_j is variable.

Thrusts, Moments and Shears

The thrust in bar i can be calculated by the equation

$$T_i = \sum_{A_i} A_j \sigma_j \tag{3.4}$$

where A_i is the cross section at the midpoint of bar i.

The bending moment at joint i can be obtained by the equation

$$M_i = \sum_{A_i} A_j \sigma_j y_j \tag{3.5}$$

where A_i is the cross section at joint i.

Taking Equation (3.4) and substituting σ_j and ε_j for the values in Equations (3.3) and (3.2):

$$T_i = \sum_{A_i} A_j E_j \varepsilon_j = \sum_{A_i} A_j E_j (\varepsilon_{ai} + \phi_i y_j)$$

$$T_i = \varepsilon_{ai} \sum_{A_i} A_j E_j + \phi_i \sum_{A_i} A_j E_j y_j.$$

The second term in the right hand side of the above equation vanishes, since

$$\sum_{A_i} A_j E_j y_j = 0$$

is the condition imposed to obtain the depth of the centroid calculated by Equation (3.1).

As a matter of fact, by substituting into the above equation y_j for $d_j - \overline{d}_i$, one obtains

$$\sum_{A_i} A_j E_j (d_j - \overline{d}_i) = 0$$

from which

$$\overline{d}_i = (\sum_{A_i} A_j E_j d_j)/(\sum_{A_i} A_j E_j)$$

is Equation (3.1) itself.

Then, the value of T_i is given by

$$T_i = \varepsilon_{ai} \sum_{A_i} A_j E_j. \tag{3.6}$$

Now, taking Equation (3.5) and substituting σ_j and ε_j for the values in Equations (3.3) and (3.2)

$$M_i = \sum_{A_i} A_j E_j (\varepsilon_{ai} + \phi_i y_j) y_j$$

or

$$M_i = \varepsilon_{ai} \sum_{A_i} A_j E_j y_j + \phi_i \sum_{A_i} A_j E_j y_j^2;$$

and, since $\sum_{A_i} A_j E_j y_j$ must vanish, the bending moment is given by

$$M_i = \phi_i \sum_{A_i} A_j E_j y_j^2 . \tag{3.7}$$

Shear in bar i is calculated by

$$V_i = (M_{i+1} - M_i)/L_i \tag{3.8}$$

where L_i is the length of bar i.

Extensional and Flexural Stiffnesses

From Equation (3.6), the average extensional or axial stiffness in bar i can be defined as

$$(AE)_i = \sum_{A_i} A_j E_j ,$$

and the thrust in bar i can be expressed as

$$T_i = \varepsilon_{ai} (AE)_i . \tag{3.9}$$

From Equation (3.7), the average flexural stiffness at joint i can be defined by

$$(EI)_i = \sum_{A_i} A_j E_j y_j^2 ,$$

and the bending moment at joint i can be expressed as

$$M_i = \phi_i (EI)_i . \tag{3.10}$$

Equations (3.4) and (3.5) can be used to determine the thrust and the bending moment at any stage of loading or behavior of the material, but Equations (3.9) and (3.10) can be used to advantage when no unloadings and reloadings are taking place or when only linearly elastic behavior is considered.

Static Solution

It is assumed that, under static loads, the deformations of the structure will be small and conventional matrix analysis can be employed. The bars or elements of the structure are considered straight, with constant cross section, although the cross section is allowed to vary along the structure.

Using the notation

$$F_j^i = F_{\text{joint } j}^{\text{bar } i} = \begin{Bmatrix} f_{xj}^i \\ f_{yj}^i \\ f_{zj}^i \end{Bmatrix} ; \qquad U_i = U_{\text{joint } i} = \begin{Bmatrix} u_i \\ v_i \\ \Delta\theta_i \end{Bmatrix}$$

and considering bar i, between joints i and i+1, as shown in Figure 3.5, the following matrix equations can be written:

$$\begin{Bmatrix} F_i^i \\ \hline F_{i+1}^i \end{Bmatrix} = \left[\begin{array}{cc} S_{i,i}^i & S_{i,i+1}^i \\ \hline S_{i+1,i}^i & S_{i+1,i+1}^i \end{array}\right] \begin{Bmatrix} U_i \\ \hline U_{i+1} \end{Bmatrix} \tag{3.11}$$

or symbolically F = SU, where S is the stiffness matrix for bar i, in the global coordinate system X-Y of Figure 3.5(a).

Equation (3.11) relates the forces at the ends of bar i to the respective displacements, through the stiffness coefficients of bar i. $S_{j,k}^i = S_{\text{joint } j, \text{joint } k}^{\text{bar } i}$ is a 3 x 3 submatrix, which relates the forces at joint j of bar i to the displacements of joint k of bar i.

In the calculation of the stiffness matrix S, the bar is considered of constant cross section. Since the cross section is permitted to vary along the structure, and the axial stiffness AE and the flexural stiffness

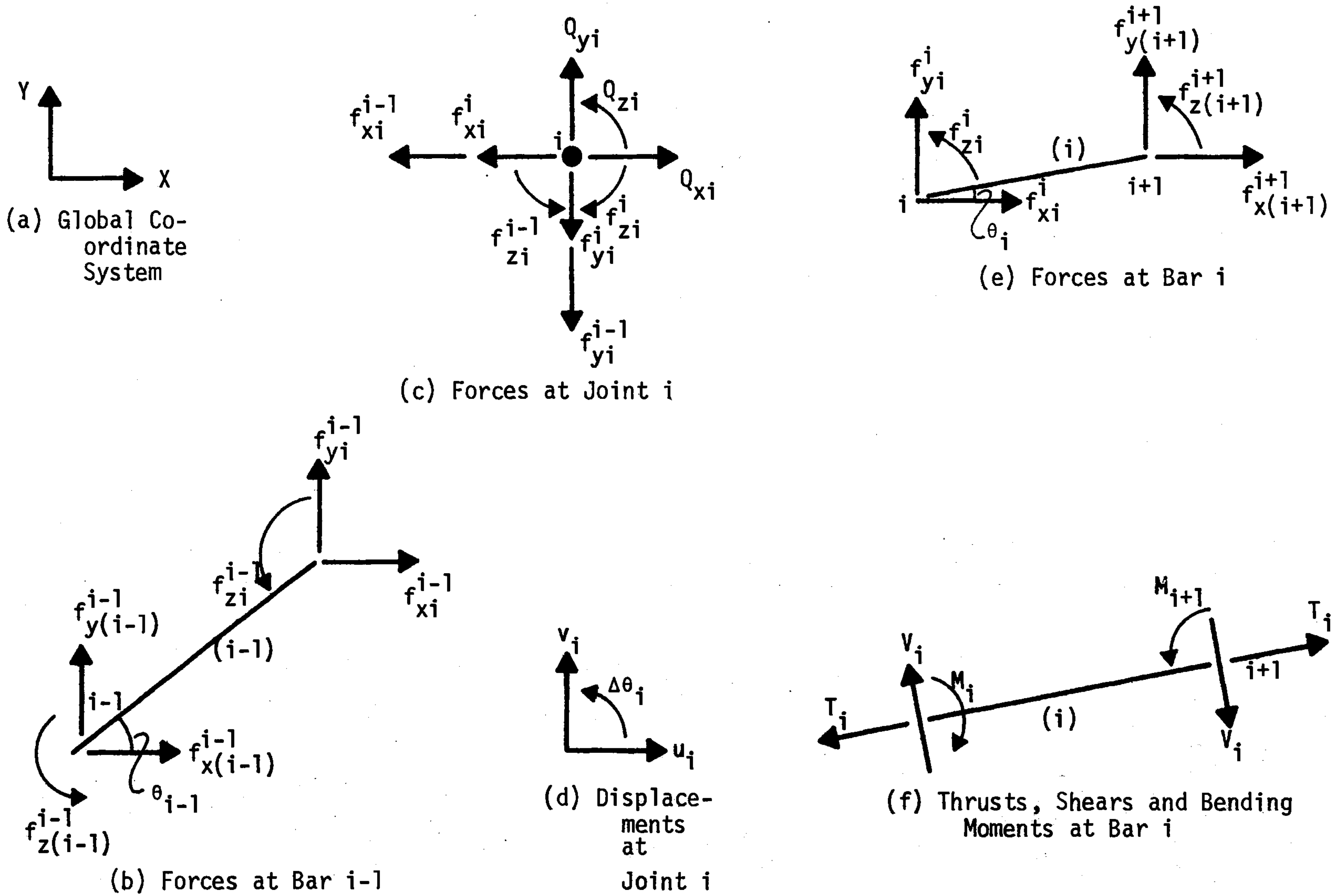


Figure 3.5. Freebody Diagrams of Bars and Joints

EI are defined at the joints, the average values of adjacent joints are considered in the determination of the stiffness matrix S for bar i:

$$(AE)_{bar\ i} = \frac{1}{2}[(AE)_{joint\ i} + (AE)_{joint\ i+1}] ;$$

$$(EI)_{bar\ i} = \frac{1}{2}[(EI)_{joint\ i} + (EI)_{joint\ i+1}] .$$

For bar i-1:

$$\begin{Bmatrix} F_{i-1}^{i-1} \\ ---- \\ F_{i}^{i-1} \end{Bmatrix} = \begin{bmatrix} S_{i-1,i-1}^{i-1} & S_{i-1,i}^{i-1} \\ \hline S_{i,i-1}^{i-1} & S_{i,i}^{i-1} \end{bmatrix} \begin{Bmatrix} U_{i-1} \\ ---- \\ U_{i} \end{Bmatrix} \tag{3.12}$$

For equilibrium of joint i:

$$F_i^{i-1} + F_i^i = Q_i \tag{3.13}$$

where Q_i is the vector of applied forces at joint i:

$$Q_i = \begin{Bmatrix} Q_{xi} \\ Q_{yi} \\ Q_{zi} \end{Bmatrix} .$$

From Equation (3.12), the value of F_i^{i-1} can be expressed as a 3 x 1 submatrix:

$$F_i^{i-1} = S_{i,i-1}^{i-1} U_{i-1} + S_{i,i}^{i-1} U_i .$$

From Equation (3.11), the value of F_i^i can also be expressed as the 3 x 1 submatrix:

$$F_i^i = S_{i,i}^i U_i + S_{i,i+1}^i U_{i+1} .$$

Taking the above values into Equation (3.13),

$$S_{i,i-1}^{i-1} U_{i-1} + [S_{i,i}^{i-1} + S_{i,i}^i] U_i + S_{i,i+1}^i U_{i+1} = Q_i ,$$

which can be written in the form:

$$A_i\ U_{i-1} + B_i\ U_i + C_i\ U_{i+1} + D_i = 0. \tag{3.14}$$

Since A_i, B_i, C_i depend on the stiffnesses of bars i-1 and i, and D_i depends on the applied forces at joint i, these coefficients can be obtained for every joint, given the geometry and physical properties of the bars and the applied loads.

In order to determine the displacements of the joints of the structure, the following system of linear simultaneous equations must be solved:

Joints	Equations
1	$B_1U_1 + C_1U_2 + D_1 = 0$
2	$A_2U_1 + B_2U_2 + C_2U_3 + D_2 = 0$
.	. . . .
i	$A_iU_{i-1} + B_iU_i + C_iU_{i+1} + D_i = 0$
.	. . . .
n	$A_nU_{n-1} + B_nU_n + C_nU_{n+1} + D_n = 0$
m = n+1	$A_mU_n + B_mU_m + D_m = 0$

(3.15)

Using a well known variation of Gauss elimination procedure for solving simultaneous equations, shown in Appendix A, the displacements are determined and the values of forces at the ends of all bars can be found by Equation (3.11). Then, bending moments, shears and thrusts can be determined.

Strains and curvatures, due to the applied static conditions, can now be calculated, by taking thrusts and bending moments, axial and flexural stiffnesses into Equations (3.9) and (3.10) to obtain:

Average static strain in bar i:

$$\varepsilon_{asi} = T_i/(AE)_i. \tag{3.16}$$

Average static curvature at joint i:

$$\phi_{si} = M_i/(EI)_i. \tag{3.17}$$

Dynamic Solution

Initial Structural Configuration

At the beginning of the dynamic process, the structure is already deformed under the static loads, with all acting and resisting forces in equilibrium.

Every joint is defined by its coordinates with respect to a given Cartesian coordinate system X-Y, which include the displacements caused by the static loads.

Let P_{i-1} $(X_{o(i-1)}, Y_{o(i-1)})$, P_i (X_{oi}, Y_{oi}) and P_{i+1} $(X_{o(i+1)}, Y_{o(i+1)})$ be three consecutive joints defining two consecutive bars, Figure 3.6, at the beginning of the dynamic process.

The length of bar i, between joints P_i and P_{i+1}, can be expressed as

$$L_{oi} = \sqrt{(X_{o(i+1)} - X_{oi})^2 + (Y_{o(i+1)} - Y_{oi})^2} .$$

The initial slope of bar i is given by

$$\theta_{oi} = \text{Arcsin} \left[\frac{Y_{o(i+1)} - Y_{oi}}{L_{oi}}\right] .$$

The initial average curvature at joint i is

$$\phi_{oi} = \frac{\theta_{oi} - \theta_{o(i-1)}}{\frac{1}{2}[L_{oi} + L_{o(i+1)}]} .$$

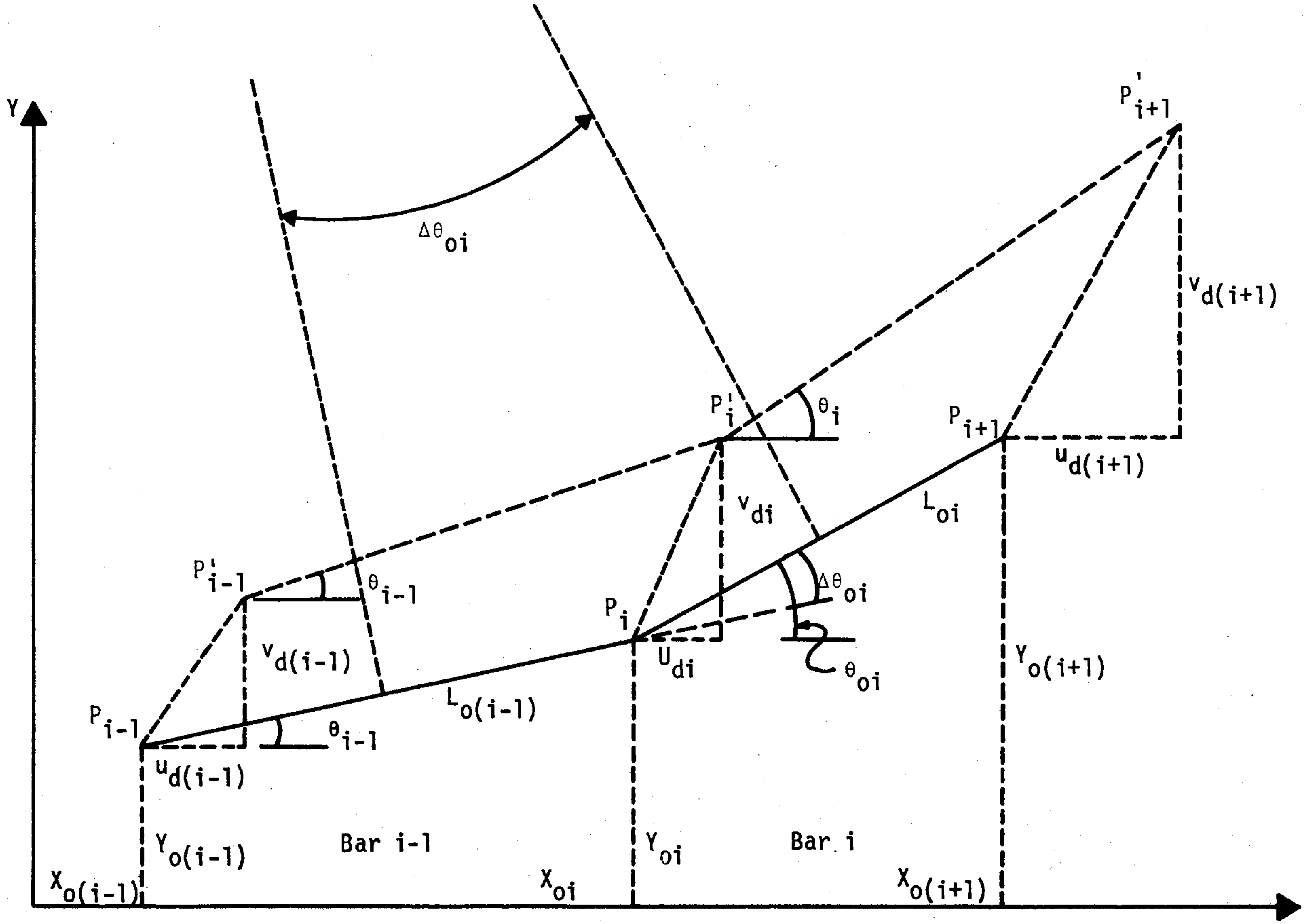


Figure 3.6. Geometric Configurations of Bars

Configuration of the Structure at Time t

After some elapsed time from the moment of application of dynamic forces, the three consecutive joints will occupy positions P'_{i-1}, P'_i and P'_{i+1}, Figure 3.6, in view of the dynamic displacements $u_{d(i-1)}$, u_{di}, $u_{d(i+1)}$ in the horizontal direction and $v_{d(i-1)}$, v_{di}, $v_{d(i+1)}$ in the vertical direction.

Now the length of bar i is expressed as

$$L_i = \sqrt{[X_{(i+1)} + u_{d(i+1)} - X_{oi} - u_{di}]^2 + [Y_{o(i+1)} + v_{d(i+1)} - Y_{oi} - v_{di}]^2}.$$

The slope of bar i at this time is

$$\theta_i = \text{Arcsin}\left[\frac{Y_{o(i+1)} + v_{d(i+1)} - Y_{oi} - v_{di}}{L_i}\right].$$

The average curvature at joint i is

$$\phi_{ti} = \frac{\theta_i - \theta_{i-1}}{\frac{1}{2}[L_i + L_{i-1}]}.$$

The dynamic average axial strain in bar i is

$$\varepsilon_{adi} = \frac{L_i - L_{oi}}{L_{oi}} = L_i/L_{oi} - 1.$$

The increment of curvature at joint i due to the applied dynamic conditions is

$$\phi_{di} = \phi_{ti} - \phi_{oi}.$$

The total average strain and curvature are obtained by adding the contribution of the static process, from Equations (3.16) and (3.17), to the dynamic strain and curvature:

$$\varepsilon_{ai} = \varepsilon_{adi} + \varepsilon_{asi};$$

$$\phi_i = \phi_{di} + \phi_{si}.$$

Strain and Stress Distribution at Time t

With the values of average strain and curvature, ε_{ai} and ϕ_i, a distribution of strains and stresses in the cross section, similar to those of Figure 3.4, necessary for calculation of internal forces, can be determined. One difficulty arises because, since cracking and/or plastification may have occurred, the location of the centroid of the transformed area is not known at time t.

The following iterative procedure is then used to determine an acceptable location of the centroid and consequent distribution of strains and stresses:

1. A position of the centroid of the transformed cross section is assumed, either as the original one used in the static solution or one obtained in a previous step;
2. A trial distribution of strains can be determined for the section, using Equation (3.2), and finding the strains ε_j in each segment;
3. By consulting the stress-strain curves for the materials of the segments of the cross section, the values of the stresses σ_j and the moduli of elasticity E_j can be found;
4. From the new values of E_j and using Equation (3.1) a new location of the centroid can be determined and compared with the assumed position.

The above steps 2. through 4. may be repeated until satisfactory agreement is obtained bwtween assumed and calculated location of the centroid, and ε_j and σ_j will be accepted as strains and stresses in the section.

This iterative procedure is suggested by Zienkiewicz (11) as having been used by other investigators in dealing with nonlinear problems of structures. This process has been found to be convergent in most practical examples and generally three or four iterations of this type lead to an adequate solution.

Differential Equations of Motion

Having obtained the stresses σ_j at every segment of the section, thrusts, bending moments and shears can be determined by use of Equations (3.4), (3.5) and (3.8).

The equations for dynamic equilibrium of all joints can be established. From the freebody diagram of joint i, Figure 3.7(b), the following equilibrium conditions can be verified at time t:

$$\sum F_{xi} = 0$$

$$Q_{xi} + Q_{xdi}^{(t)} + T_i \cos\theta_i - T_{i-1} \cos\theta_{i-1} +$$

$$+ V_i \sin\theta_i - V_{i-1} \sin\theta_{i-1} - m_i \ddot{u}_{di}^{(t)} = 0 \; ;$$

$$\sum F_{yi} = 0$$

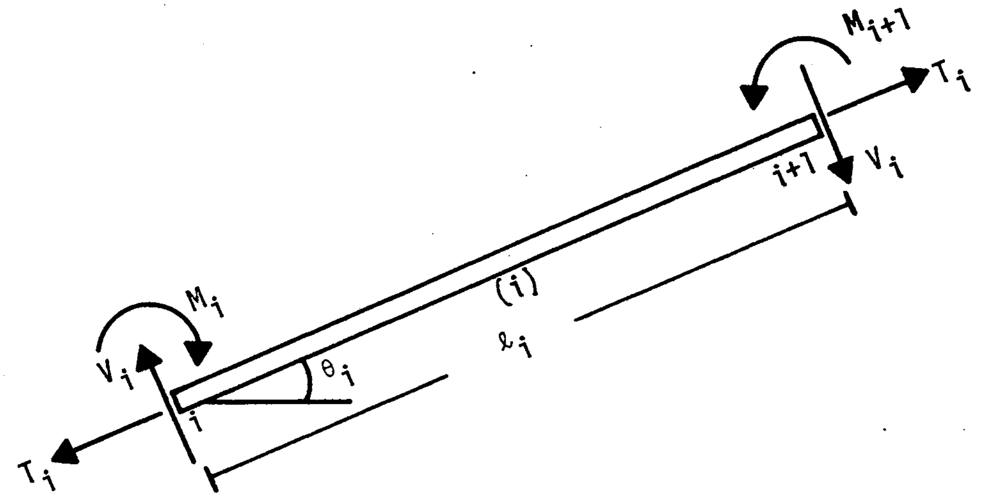
$$Q_{yi} + Q_{ydi}^{(t)} + T_i \sin\theta_i - T_{i-1} \sin\theta_{i-1} +$$

$$- V_i \cos\theta_i + V_{i-1} \cos\theta_{i-1} - m_i \ddot{v}_{di}^{(t)} = 0 \; ;$$

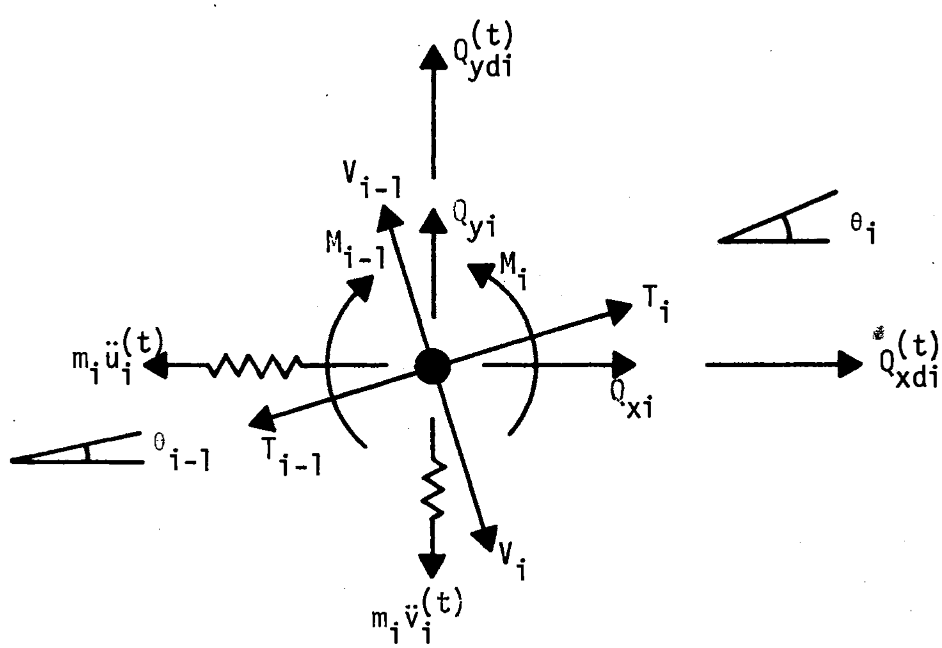
where

$Q_{xdi}^{(t)}$, $Q_{ydi}^{(t)}$ = magnitudes of horizontal and vertical applied dynamic forces at joint i at time t;

$\ddot{u}_{di}^{(t)}$, $\ddot{v}_{di}^{(t)}$ = values of horizontal and vertical components of acceleration of mass m_i at time t.



(a) Freebody of Bar i



(b) Freebody of Joint i

Figure 3.7. Freebody Diagrams for Dynamic Solution

The above equations are the differential equations of motion and if all forces are known at time t, they can be solved for the accelerations:

$$\ddot{u}_{di}^{(t)} = \frac{1}{m_i} [Q_{xi} + Q_{xdi}^{(t)} + T_i \cos\theta_i - T_{i-1} \cos\theta_{i-1} + + V_i \sin\theta_i - V_{i-1} \sin\theta_{i-1}] \ . \quad (3.18)$$

$$\ddot{v}_{di}^{(t)} = \frac{1}{m_i} [Q_{yi} + Q_{ydi}^{(t)} + T_i \sin\theta_i - T_{i-1} \sin\theta_{i-1} + - V_i \cos\theta_i + V_{i-1} \cos\theta_{i-1}] \ . \quad (3.19)$$

Numerical Integration of the Equations of Motion

At the beginning of the dynamic process, when a dynamic force is applied, it will transmit initial accelerations or initial velocities to the point masses of the structure. Initial dynamic displacements are null, because the structure is at rest, although deformed, under the static loads.

Subsequent values of dynamic displacements, velocities and accelerations are found by a step-by-step numerical integration of the differential equations of motion, using the "Beta Method" developed by Newmark (7).

If u_{di} and v_{di} are dynamic displacements of joint i in the X and Y directions, respectively, the numerical integration equations used in the Beta Method are the following, assuming a linear variation of accelerations with time, during a small time interval Δt:

$$\dot{u}_{di}^{(t+\Delta t)} = \dot{u}_{di}^{(t)} + \frac{\Delta t}{2} \ddot{u}_{di}^{(t)} + \frac{\Delta t}{2} \ddot{u}_{di}^{(t+\Delta t)} \ ;$$

$$\dot{v}_{di}^{(t+\Delta t)} = \dot{v}_{di}^{(t)} + \frac{\Delta t}{2} \ddot{v}_{di}^{(t)} + \frac{\Delta t}{2} \ddot{v}_{di}^{(t+\Delta t)} \ ;$$

$$u_{di}^{(t+\Delta t)} = u_{di}^{(t)} + \Delta t\, \dot{u}_{di}^{(t)} + \frac{(\Delta t)^2}{3} \ddot{u}_{di}^{(t)} + \frac{(\Delta t)^2}{6} \ddot{u}_{di}^{(t+\Delta t)} ;$$

$$v_{di}^{(t+\Delta t)} = v_{di}^{(t)} + \Delta t\, \dot{v}_{di}^{(t)} + \frac{(\Delta t)^2}{3} \ddot{v}_{di}^{(t)} + \frac{(\Delta t)^2}{6} \ddot{u}_{di}^{(t+\Delta t)} ;$$

(3.20)

where

$u_{di}^{(t)}$, $v_{di}^{(t)}$ = horizontal and vertical dynamic displacements of joint i at time t, at the beginning of time interval Δt;

$u_{di}^{(t+\Delta t)}$, $v_{di}^{(t+\Delta t)}$ = horizontal and vertical dynamic displacements of joint i at time $t+\Delta t$;

and single dots mean the first derivatives of the displacements with respect to time, or velocities; and the double dots mean the second derivative of the displacements, or accelerations.

For the numerical integration procedure, it is assumed that the values of displacements, velocities and accelerations are known at time t, either as initial conditions of the problem or from the analysis of the preceding time interval Δt.

The accelerations of the masses at time $t+\Delta t$ are assumed, and corresponding velocities and displacements are computed. A new configuration of the system is obtained and internal forces are calculated. By applying conditions of equilibrium at every joint, it is possible to compute the accelerations at time $t+\Delta t$. Calculated and assumed accelerations are compared and, if an acceptable agreement is obtained, the assumed accelerations are correct and the system is in its actual configuration; if not, an improved set of assumed accelerations equal to the newly calculated accelerations is used and the cycle is repeated, until the desired agreement is obtained. A new set of initial conditions is established and the computation proceeds for the next time interval.

The procedure may be outlined as follows:

1. The values of the accelerations are assumed at time $t+\Delta t$, equal to the accelerations at time t;
2. Velocities and displacements at the end of time interval are calculated by Equation (3.20);
3. The configuration of the structure at time $t+\Delta t$ is determined by calculating new lengths and slopes of the bars, average strains and average curvatures;
4. Strain and stress distributions are found for all selected cross sections, using the iterative process described previously, on page 25;
5. Thrusts, bending moments and shears are calculated, using Equations (3.4), (3.5) and (3.8);
6. Conditions of equilibrium of internal forces with static and dynamic loads are established at all joints, and resulting accelerations of the point masses are calculated, by applying Equations (3.18) and (3.19);
7. Steps 2. through 6. are repeated as many times as necessary to obtain a satisfactory agreement between assumed and calculated accelerations, but each time the assumed accelerations are taken equal to the previously calculated ones;
8. When a satisfactory agreement is obtained, the time is incremented by Δt, the next time interval is determined, a new set of initial conditions is established, and the process is resumed, until the total response of the structure is obtained.

Influence of Time Interval

As it was pointed out by Newmark (7), the stability, convergence and accuracy of the numerical procedure depend not only on the characteristics of the structure, but mainly on the interval of time chosen for each set of calculations. With smaller intervals of time better solutions can be obtained, but a very short interval of time will lead to time consuming operations, even in a modern high speed computer. Also the larger the time interval the larger is the number of iterations required for convergence.

For the numerical integration equations here used, the mere convergence of the sequence of calculations is sufficient to insure stability and the rate of convergence will be an adequate criterion for the time interval, because if the time interval is chosen for convergence, the numerical procedure will always be stable.

Newmark also showed that the time interval must be related to the shortest period of vibration, or the period in the highest mode of vibration, for the lumped mass system, and the greater the number of masses the shorter will be the permissible time interval.

Convergence is assured if Δt is less than or equal to 0.389 T, where T is the smallest natural period of vibration. This expression may be used as a guide in the selection of the initial time interval, while not applicable to nonlinear problems, because as a structure goes into the inelastic range, in general the periods of vibration all become longer and the shortest period becomes longer as well. Consequently, the time interval can be considerably longer as plastic action develops in the structure. With continual re-examination of the time interval in terms of the rate of convergence, the change in characteristics of the structure can be taken into account without loss in accuracy, and the results can be obtained with less computational work.

Sometimes difficulty arises in the determination of the smallest natural period of vibration, which may become a troublesome experience, almost impossible in more complex structures.

The best policy is to take a very small value for the initial time interval, and adjust this interval until an optimum value is obtained, thus maintaining the rate of convergence in four or five iterations for each interval of time. At the end of one cycle of iterations, if convergence is not reached in a prescribed number of iterations, the time interval is cut to a half of its value and everything starts again with the initial conditions at time t. If the operation is successfully completed, the time interval is multiplied by a factor, in order to adjust the time interval for the next set of calculations, making it smaller if the number of iterations required for convergence was greater than five, or larger if the required number of iterations was less than four, thus maintaining the rate of convergence in the optimum desired range of four or five iterations for each interval of time.

For circular arches, Veletsos et al. (9), Wolf (10) and Austin and Veletsos (1) used the classical frequency formula which leads to

$$T_k = \frac{2\pi}{C_k} S^2 \sqrt{\frac{\mu}{EI}}$$

where k represents the order of the mode of vibration and T_k is the corresponding period. The dimensionless constant C_k was shown to vary with the slenderness ratio of the arch, and was calculated for the ten lowest modes of vibration, and the highest value obtained was slightly over 1,000 for very flexible fixed arches (slenderness ratio over 300), in the fifth antisymmetrical mode of vibration.

Using these data, a rough approximate value for the initial time interval can be obtained as

$$\Delta t = \frac{0.389 \times 2}{1000} S^2 \sqrt{\frac{\mu}{EI}} .$$

To make the interval of time even smaller to insure convergence from the very beginning of the numerical procedure, the following equation can be used

$$\Delta t = (2 \times 10^{-4}) S^2 \sqrt{\frac{\mu}{EI}}$$

which assigns to the initial interval of time a value approximately twelve times smaller than that given by the preceding expression.

Dynamic Loads as Functions of Time

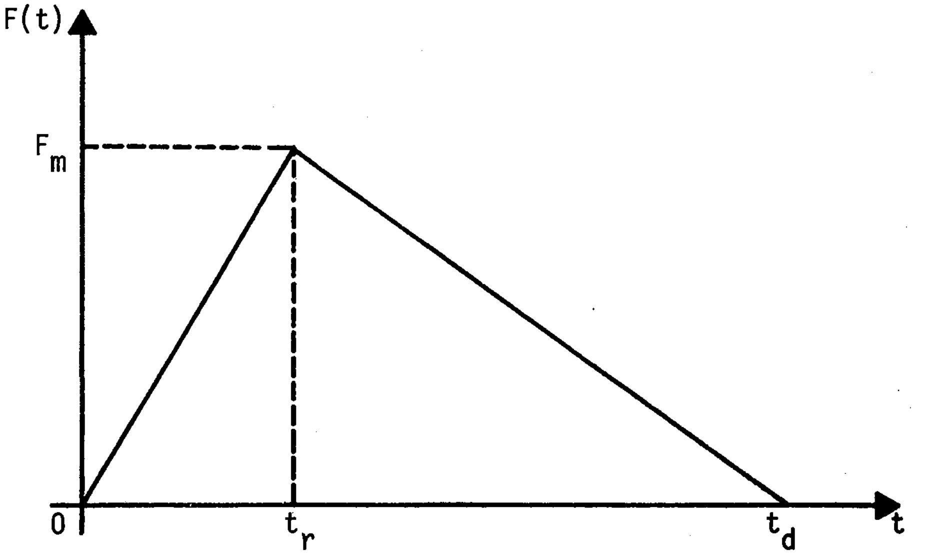
The dynamic forces $Q_{xdi}^{(t)}$ and $Q_{ydi}^{(t)}$ used in Equations (3.18) and (3.19) are variable with time and may be thought of as a product of a dimensionless function of time F(t) by a constant load parameter, i.e.:

$$Q_{xdi}^{(t)} = F(t) \times Q_{xdi} ;$$

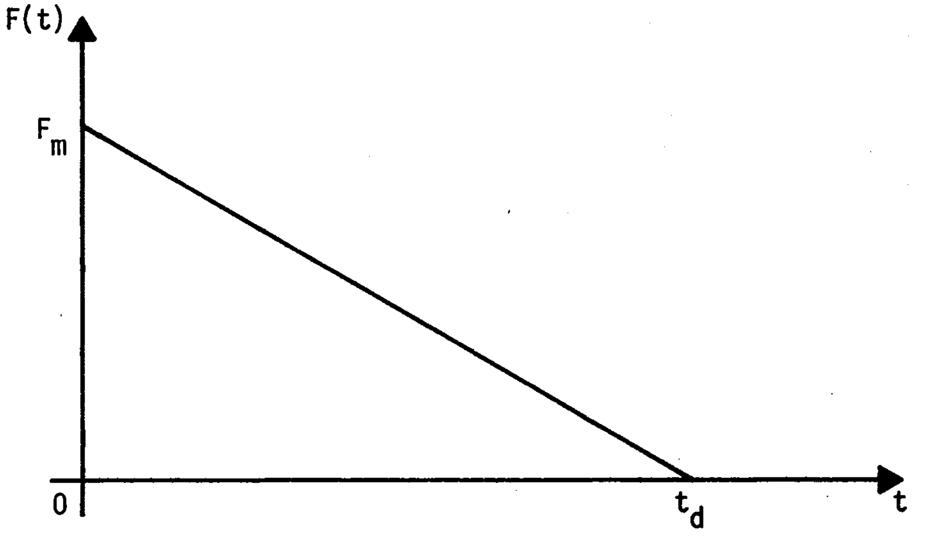
$$Q_{ydi}^{(t)} = F(t) \times Q_{ydi} .$$

The parameters Q_{xdi} and Q_{ydi} at any joint may result in a linear, a parabolic distribution, or a uniform pressure.

The function F(t) considered in this study may be represented by the triangular diagram in Figure 3.8(a), where F_m is the maximum value or peak, t_r is the time of rise, and t_d is the time of decay. The diagram of Figure 3.8(b) may be obtained from the first diagram by setting $t_r = 0$,



(a) Function of Time for a Force Pulse



(b) Time Function for a Force Pulse With $t_r = 0$

Figure 3.8. Types of Time Functions

which will produce a force applied instantaneously at time $t = 0$ with its maximum value.

Other types of time functions may be easily formulated and taken into account, considering the particular problem to be solved.

Two types of dynamic loadings may be used: force pulses and impulses. For the first type of loading, the intensity of the force pulse at time t is given by

$$Q_{xdi}^{(t)} = F(t) \times Q_{xdi} ,$$

$$Q_{ydi}^{(t)} = F(t) \times Q_{ydi} ,$$

where F(t) is evaluated at each time, according to diagrams of Figure 3.8(a) or (b).

The initial conditions at time $t = 0$ for a force pulse are:

Initial dynamic displacements and velocities:

$$u_{di}^{(0)} = 0 ; \qquad \dot{u}_{di}^{(0)} = 0 ;$$

$$v_{di}^{(0)} = 0 ; \qquad \dot{v}_{di}^{(0)} = 0 .$$

Initial accelerations:

$$\ddot{u}_{di}^{(0)} = F(0) \times Q_{xdi}/m_i ;$$

$$\ddot{v}_{di}^{(0)} = F(0) \times Q_{ydi}/m_i .$$

For the second type of loading, F(t) is made equal to zero at all times, and consequently $Q_{xdi}^{(t)} = 0$ and $Q_{ydi}^{(t)} = 0$ at all times, and Q_{xdi} and Q_{ydi} have to have the nature of impulses.

The initial conditions at time $t = 0$ for an impulse are:

Initial dynamic displacements and accelerations:

$$u_{di}^{(0)} = 0 \; ; \qquad \ddot{u}_{di}^{(0)} = 0 \; ;$$

$$v_{di}^{(0)} = 0 \; ; \qquad \ddot{v}_{di}^{(0)} = 0 \; .$$

Initial velocities:

$$\dot{u}_{di}^{(0)} = Q_{xdi}/m_i \; ;$$

$$\dot{v}_{di}^{(0)} = Q_{ydi}/m_i \; .$$

Adjustment of Static Results

For the static solution, as already stated, the bars are flexible and undergo small deformations, whereas for the dynamic solution, the bars are flexurally rigid, and since the dynamic displacements may be very large, the small displacement geometry is no longer applicable.

Also, the rotations of the transverse cross sections have to be concentrated at the joints, in order to make the bars flexurally rigid for the dynamic solution. When this operation is performed over the deformed structure, the equilibrium of the forces at the joints may well not be satisfied, resulting in unbalanced forces, generally small but large enough to interfere with the dynamic solution, by transmitting initial unwanted accelerations to the point masses, concentrated at the joints.

In order to eliminate the unbalanced forces at the joints, first a strain and stress distribution is obtained, by following the procedure described previously on page 25, using the average strains and curvatures caused by static loads and given by Equations (3.16) and (3.17).

This approach will also indicate, for further checking, whether the material at any segment went into the inelastic range during the static process, or was kept in the linearly elastic behavior, with unchanged location of the centroid at all sections, as previously assumed for the static solution.

With the resulting stress distribution, thrusts, bending moments and shears can be determined with Equations (3.4), (3.5) and (3.8), and residual accelerations $\ddot{u}_{di}^{(r)}$ and $\ddot{v}_{di}^{(r)}$ can be obtained by applying Equations (3.18) and (3.19), where $Q_{xdi}^{(t)}$ and $Q_{ydi}^{(t)}$ are null.

The unbalanced forces at the joints can be calculated as

$$\Delta Q_{xi} = m_i \, \ddot{u}_{di}^{(r)} ,$$

$$\Delta Q_{yi} = m_i \, \ddot{v}_{di}^{(r)} ,$$

which are subtracted from the applied static loads.

It was verified that the disturbing forces ΔQ_{xi} and ΔQ_{yi} were very small, but have to be removed anyway, in order to leave all joints in equilibrium at the beginning of the dynamic process.

CHAPTER IV

COMPUTER PROGRAM

The method of analysis described in the preceding chapter was programmed in FORTRAN language for solution in the IBM/360 Model 65 computer of the Oklahoma State University. Only minor changes may become necessary to run the program in other types of computers having a FORTRAN compiler.

According to the program listing presented in Appendix B, a maximum of 24 bars is allowed for the replacement structure. By changing only the dimension statements, an increased number of bars may be taken into account, limited only by the size of the available computing system.

The object code requires approximately 100 K bytes and the array area is approximately 48 K bytes for a maximum of 24 bars, with an additional 5 K bytes required for every additional four bars. An array area slightly over 140 K bytes will be needed to store data and calculated results for a problem with a maximum of one hundred bars in the replacement structure. Double precision arithmetic is used for all real variables, with approximately 16 significant decimal digits.

The program, named DYNARCH, consists of a main driver program, 29 subroutines and one function subprogram. Although some subroutines could be included in the main program or easily incorporated in other subroutines, the program in subroutine form has more flexibility and facilitates changes to take into consideration particular features of specific problems, if necessary.

A summary flow diagram of the program is presented in Figure 4.1. A guide for data input is presented in Appendix C.

The execution starts by reading the identification of the run followed by the identification of the problem. More than one problem can be solved in the same run. Execution terminates, if a card with the first four columns blank is inserted for the identification of problem. A termination message may be written on columns 5 to 80.

Problem data are read and echoed by subroutine INECHO. A function FX must be supplied by the user in order to describe the arch axis in the global coordinate system, starting at the origin. Any kind of continuous and single-valued function in the first quadrant may be used. Thus the program will handle circular, parabolic, catenary, sinusoidal, cycloidal axes, or others. Examples of function FX used in this study are presented in Appendices B and D.

An option for a broken line structure, such as portal frames or arches with initial out-of-roundness is offered. In this case, the coordinates of all joints of the model must be supplied and a dummy function FX must be used. Options for symmetry and for solving a problem only in the linearly elastic range are also offered.

Subroutine GEOM divides the structure described by FX into the specified number of bars with initially equal lengths and determines the coordinates of all joints, or, if the broken line structure option is used, reads the given coordinates of joints and calculated the lengths of all bars; then initial slopes and curvatures are also obtained and stored in common for further use.

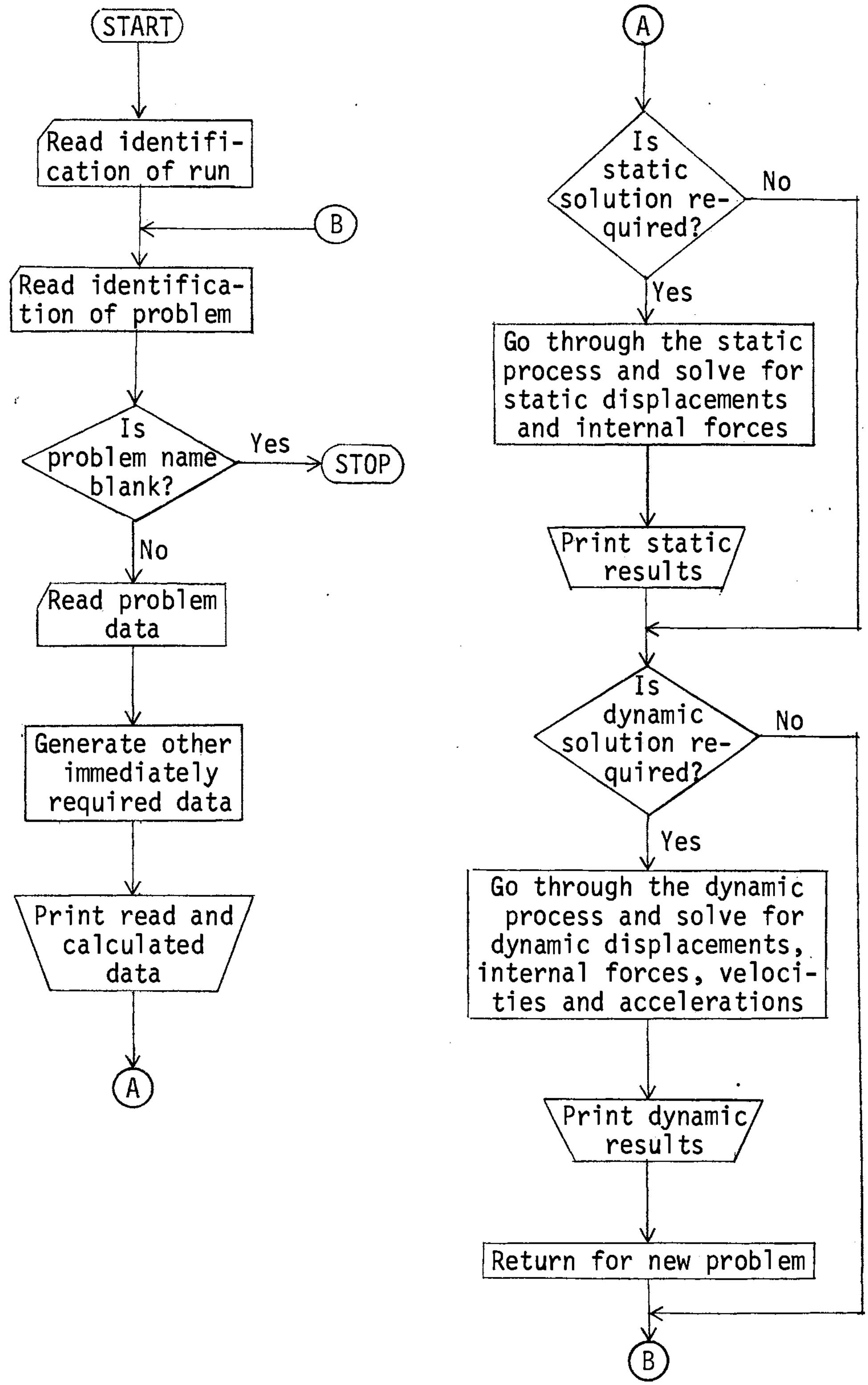


Figure 4.1 Summary Flowchart of Program DYNARCH

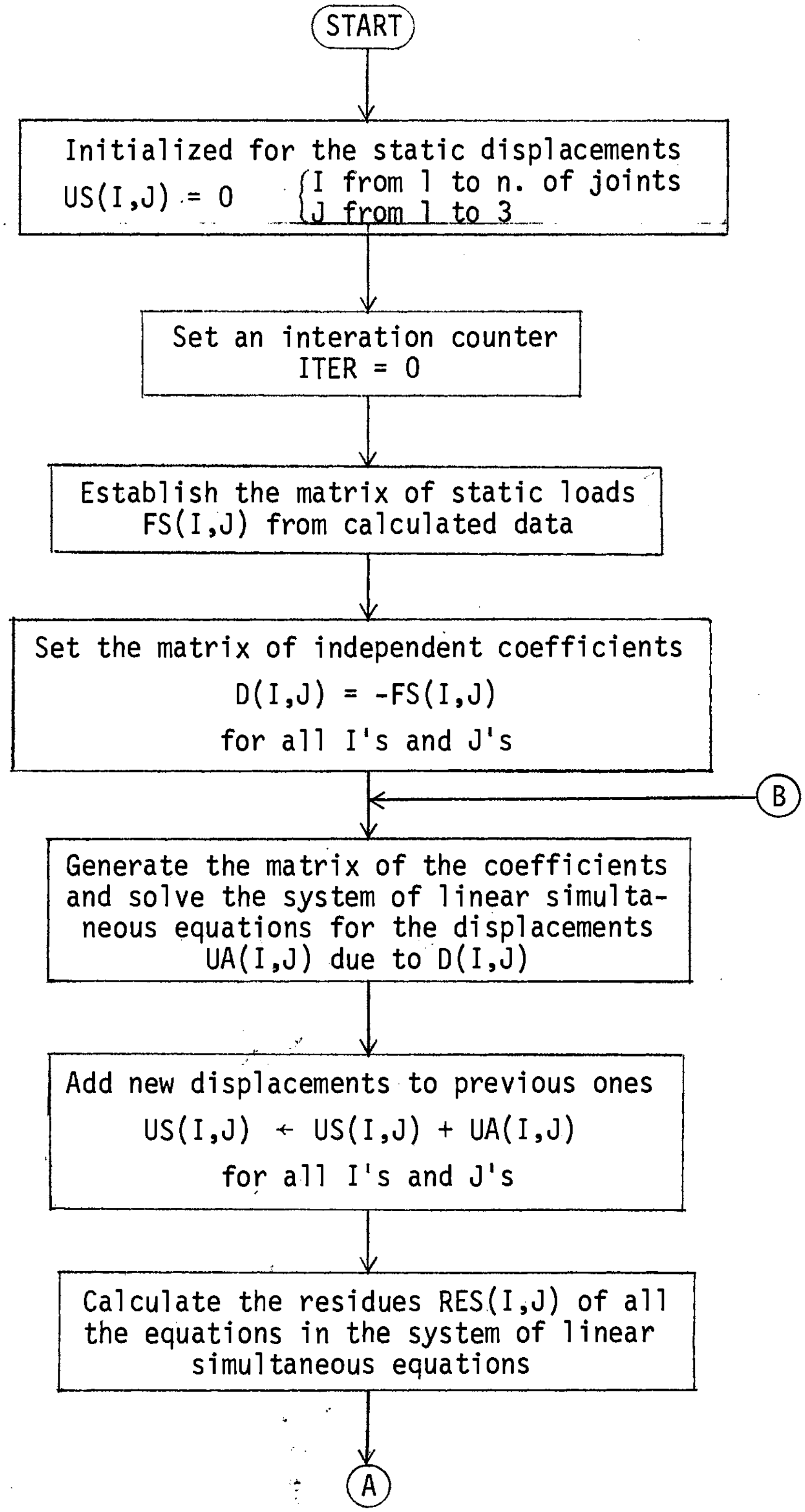
Subroutine DIST, using other subroutines, distributes all input data and calculates concentrated masses, self-weight and applied static loads at the joints as the result of a linear, parabolic distribution or uniform pressure acting in some specified region of the structure. This subroutine, by calling subroutine CENTER, also determines the locations of centroids, axial and flexural stiffnesses at all joint sections. The area of the cross section is allowed to vary from joint to joint.

The static process is controlled by subroutine STATIC, for which the summary flow diagram is shown in Figure 4.2(a) and 4.2(b), on pages 42 and 43.

Subroutine SOLVE calculates the coefficients A_i, B_i, and C_i in equations (3.15), using the axial and flexural stiffnesses of the bars obtained in the local coordinate system by subroutine MSTIF. The independent coefficients D_i are set equal to the respective static forces with signs changed, as described in Chapter III. Then the system of linear simultaneous equations is solved for the displacements.

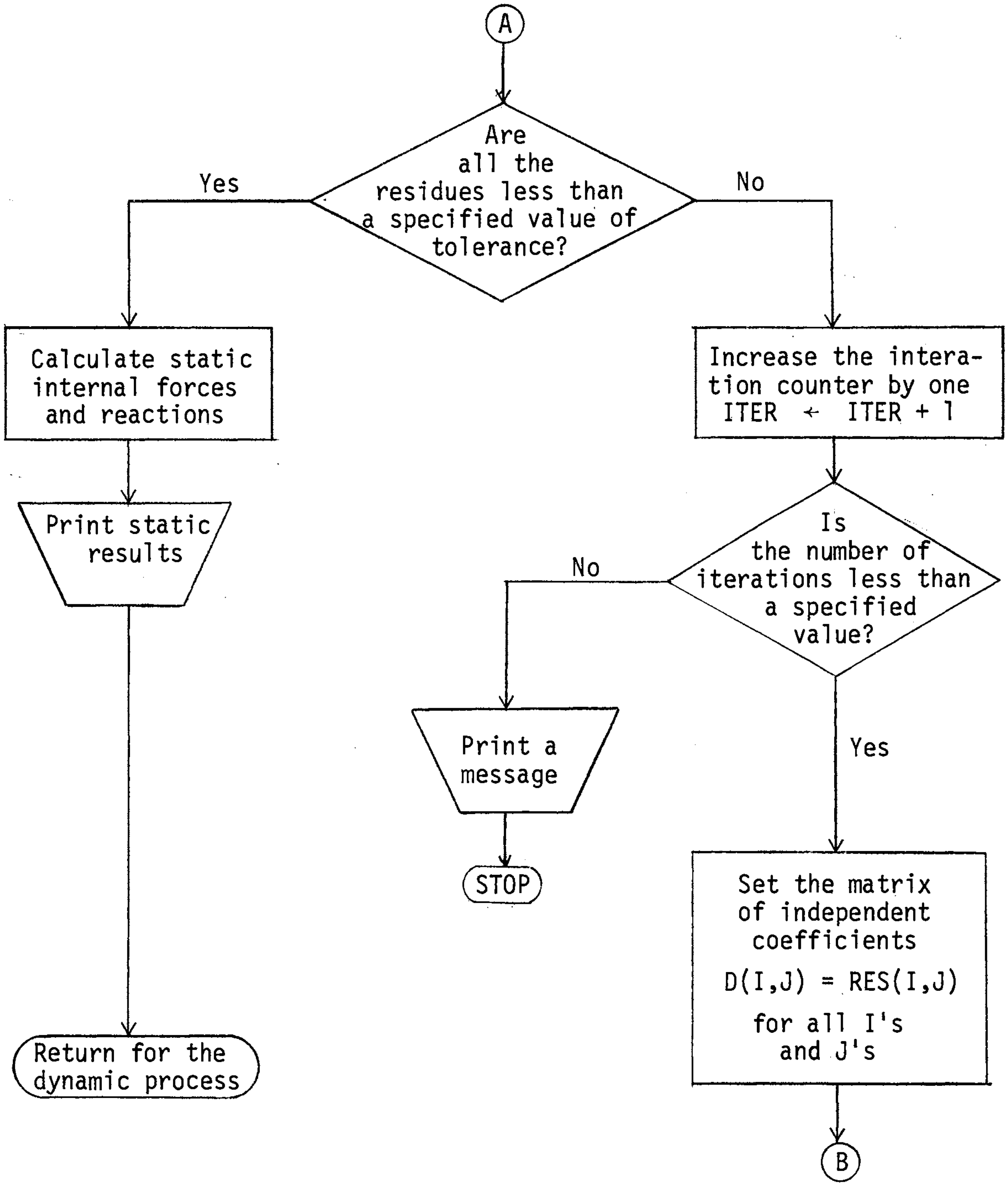
A refinement of the solution is obtained by an iterative procedure, where successive values of additional displacements are calculated, due to the residues of the equations in the system of simultaneous equations. The residues are computed by subroutine RESIDU and the procedure is considered to converge to the best possible solution for the displacements when the residues are kept smaller than a prescribed value of tolerance.

Subroutine STFOR is then called to perform the calculation of static forces at the ends of all bars and convert these forces into thrusts, bending moments and shears in the classical engineering sign convention. Also the reactions resulting from boundary conditions are calculated. Boundary conditions are taken into account by specified



(a)

Figure 4.2. Summary Flowchart for the Static Process



(b)

Figure 4.2. (Continued)

displacements at any joint. Also hinges may be specified at any joint, as described in the guide for data input in Appendix C.

The problem is now ready to go into the dynamic process. Although the structure is assumed to behave linearly in the static process, a response of the structure in the inelastic range under static loads may be obtained by a small modification of the program, which would lead the structure into the dynamic process for just one step with zero dynamic load applied. This would cause a redefinition of location of centroids, axial and flexural stiffnesses, and the collapse of the structure under applied static loads would also be checked. With modified stiffnesses, the static process could be applied again, and a new configuration of the structure would result, with the corresponding internal forces. The operation could be repeated until a satisfactory agreement between two successive configurations of the structure were obtained. Since the response of the structure depends on the location of the centroid at all sections, the depths of the centroids could control the convergence of this iterative procedure.

As a matter of fact, there is no need to go into the dynamic process, but only into part of the preliminary step of adjustment of static results, as described previously, on page 36, and as soon as the locations of centroids, axial and flexural stiffnesses were redefined, and collapse checked, the iterative procedure described above could be applied, thus obtaining the inelastic response of the structure under static loads. Then, if desired, the dynamic loadings could be superimposed. This was not done here, since it was preliminarily assumed that the static process would be applied in the elastic range of behavior of the materials of the structure.

The dynamic process is controlled by subroutine DYNAM, for which the summary flow diagram is shown in Figure 4.3(a) through 4.3(d) on pages 46-49.

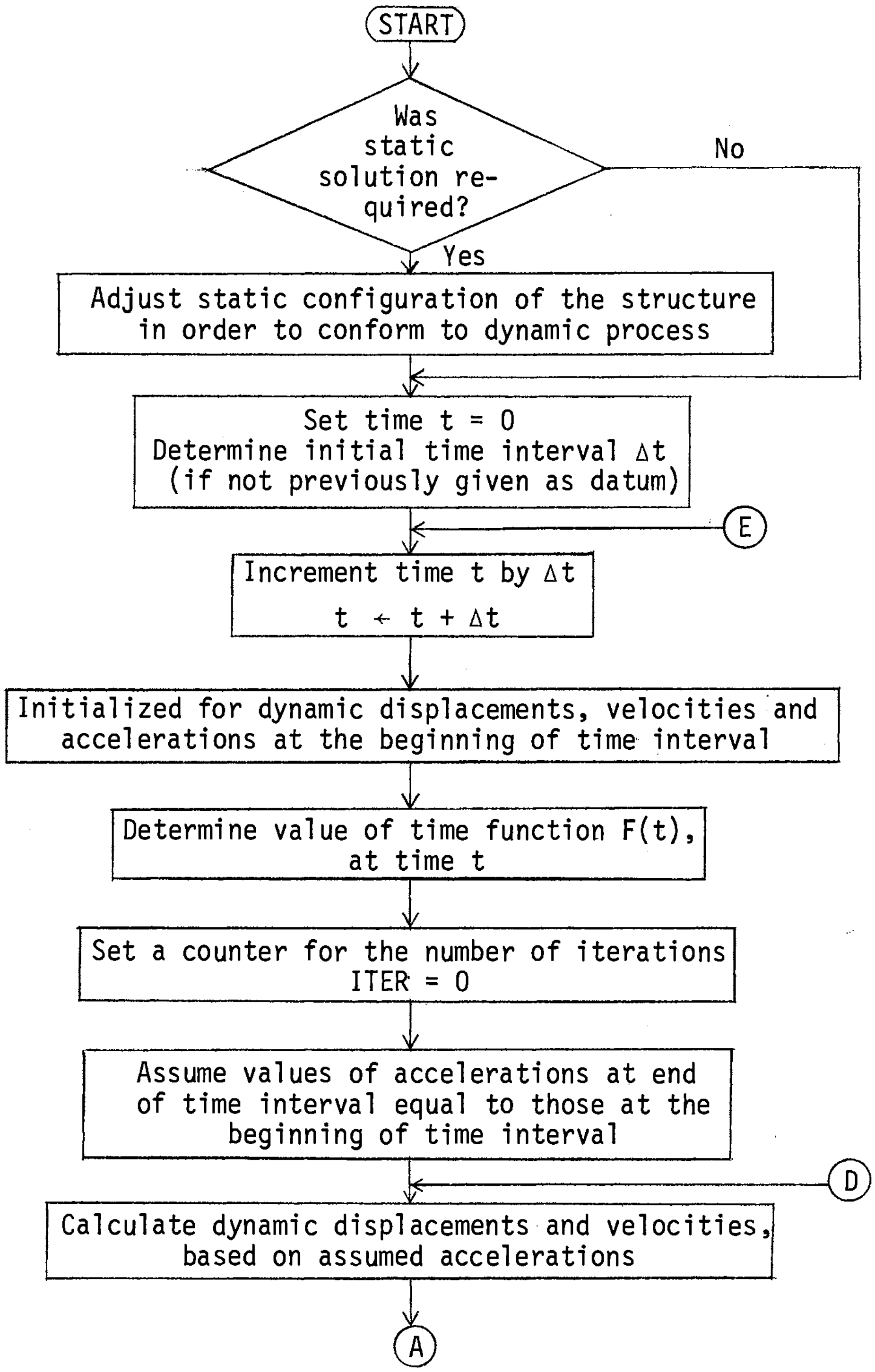
Since the dynamic process is allowed to be applied independently of the static process, a check is first made whether the static solution was required and, if the answer is positive, subroutine ADJUST performs the adjustments of the static results to conform the structure to the dynamic process. For convenience this subroutine also initializes the parameters of the stress-strain curves at all joints.

Time is set to zero and the initial time interval is calculated, if not supplied. Then dynamic displacements, velocities, accelerations are initialized at the beginning of time interval and the dynamic process follows that described in Chapter III. The flow diagrams on pages 46 through 49 are self-explanatory.

Determination of function F(t) at time t is made by subroutine FTIME, which is called if the dynamic response of the structure to a force pulse is desired. If the dynamic loading is an impulse, F(t) is made constantly null. The time functions used are described previously on page 33. This subroutine may be easily modified to allow other types of functions.

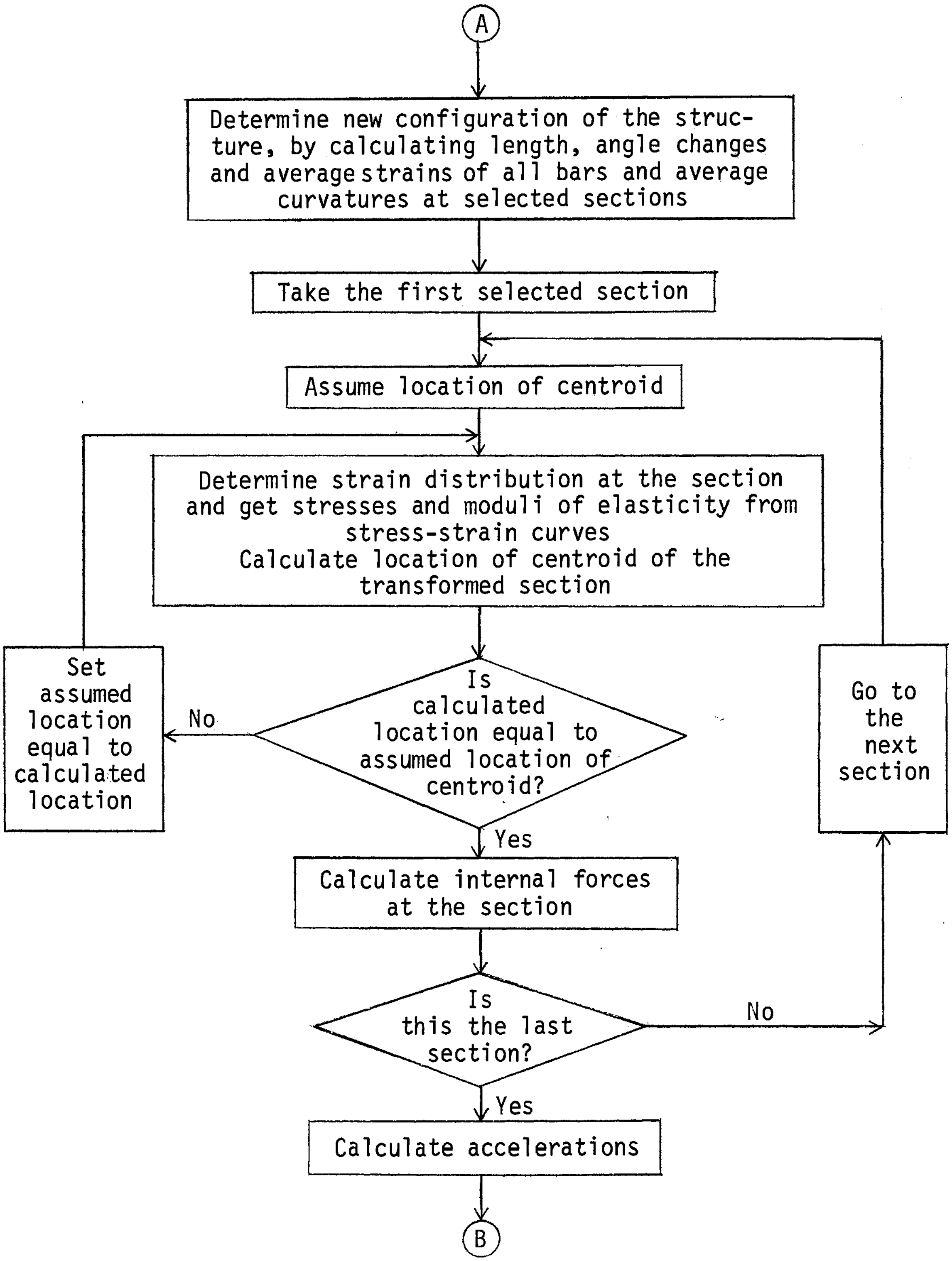
A new configuration of the structure is obtained by subroutine JCURVT, which calculates average curvatures at all joints, lengths, angle changes and average strains at all bars.

Subroutines FORCE and INTERN perform the iterative procedure of determining the new locations of the centroids of the transformed areas of the sections, redefine axial and flexural stiffnesses, and calculate



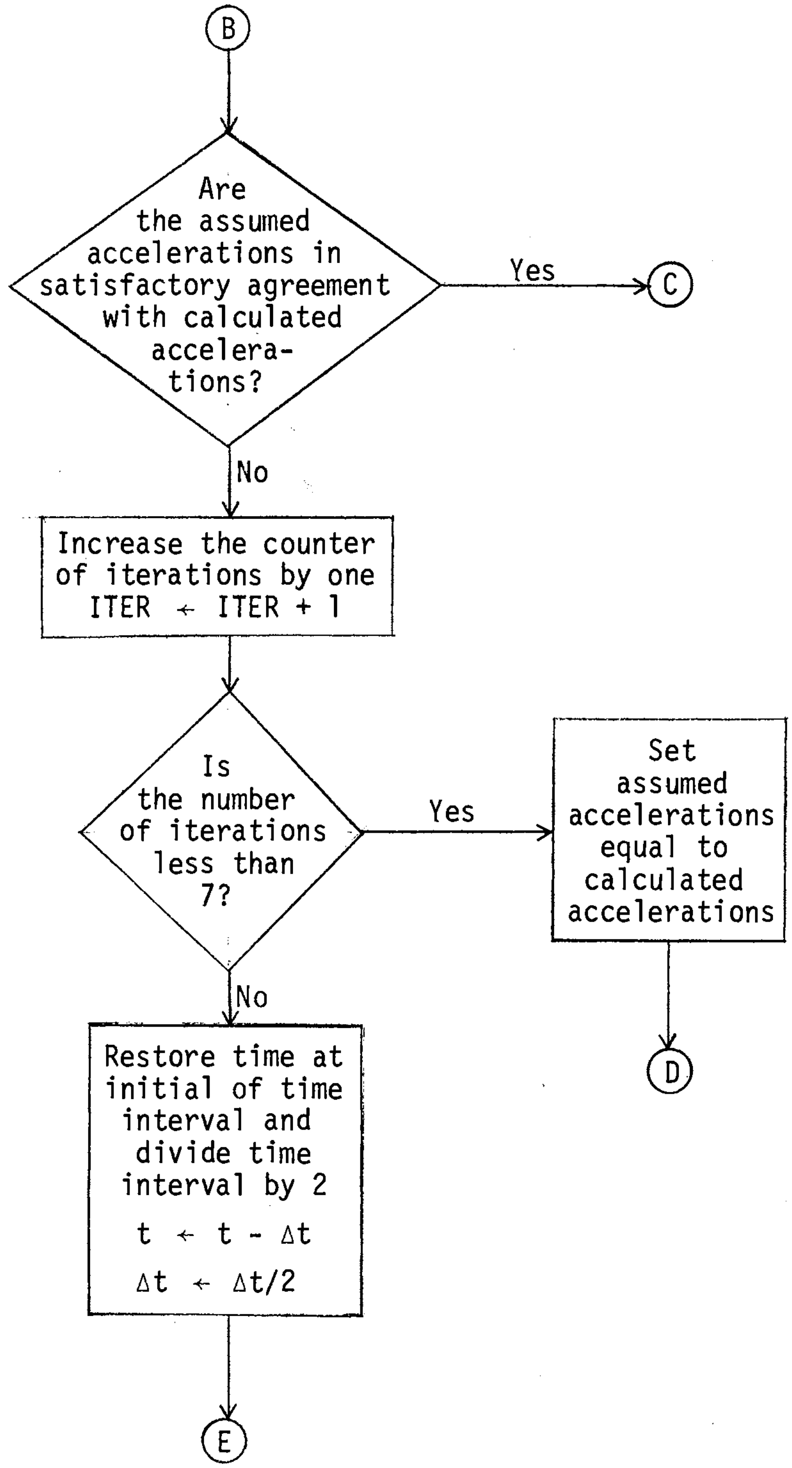
(a)

Figure 4.3. Summary Flowchart for the Dynamic Process



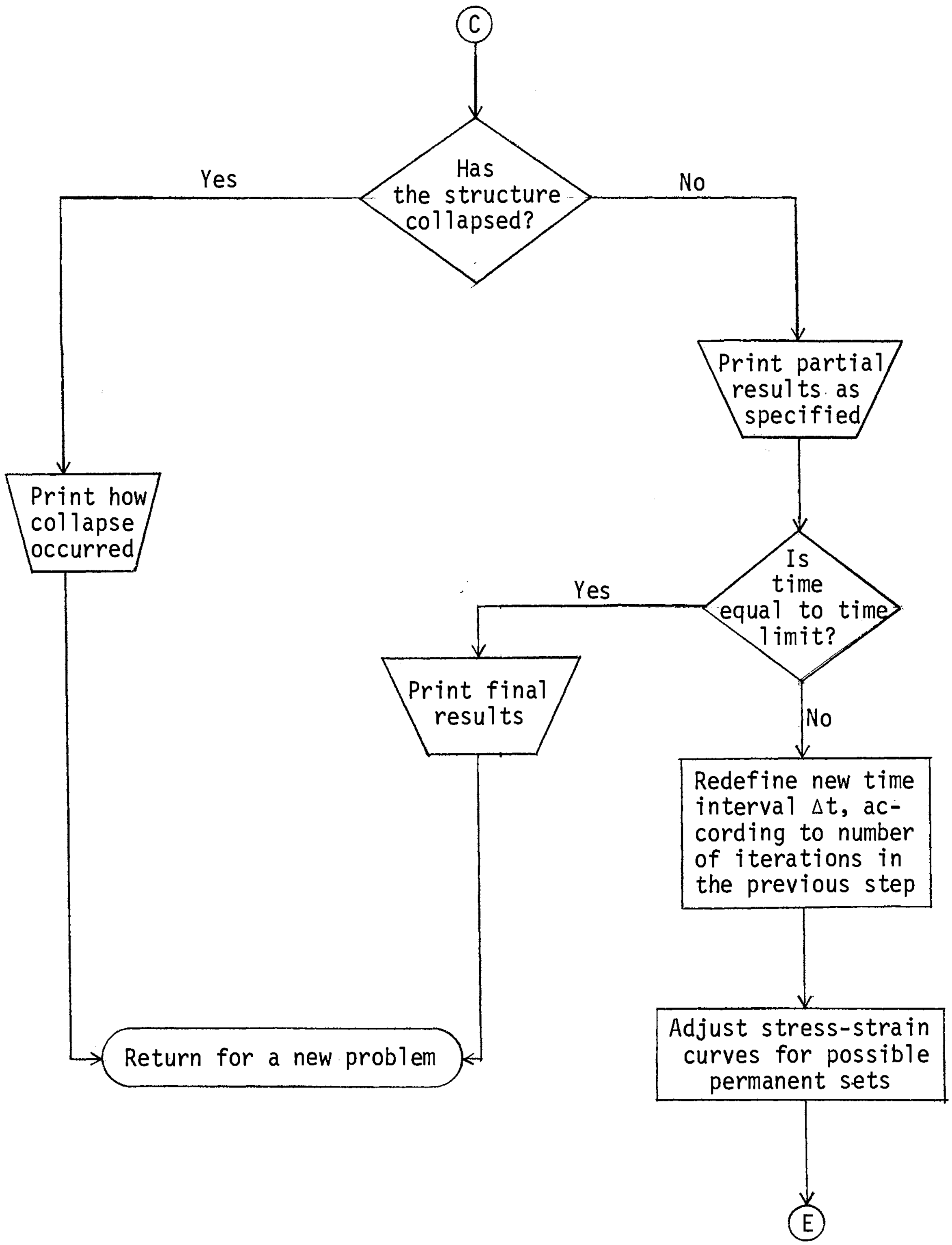
(b)

Figure 4.3. (Continued)



(c)

Figure 4.3. (Continued)



(d)

Figure 4.3 (Continued)

bending moments at all joints, thrusts and shears at all bars, as shown by the flowchart on page 47.

Subroutine SEARCH is used by INTERN to examine the parameters of the stress-strain curves and determine the values for the moduli of elasticity and average stresses at the segments of the section.

Subroutine ACCEL checks the conditions of equilibrium at the joints and calculates the accelerations of all point masses.

After the dynamic solution has converged at the end of the time interval, the parameters of the stress-strain curves are redefined to account for possible permanent sets.

The collapse of the structure is then checked by subroutine FAIL, under the failure criteria of maximum horizontal displacement, maximum vertical displacement, maximum shear, interaction of thrusts and bending moments, and crushing of extreme fibers. If collapse occurred, the circumstances and locations of failure are printed. This subroutine can easily be modified to allow other failure criteria.

Output of final or partial results, either for the static process or for the dynamic process, is made through subroutine OUTPUT. Two printout options are possible: (a) the maximum values of thrusts, shears, bending moments, horizontal and vertical displacements, and where they occurred, and (b) a complete response with values of thrusts, shears in all bars and bending moments, horizontal and vertical displacements at the joints.

CHAPTER V

VERIFICATION OF PROGRAM

In order to illustrate the solution capability of the program and demonstrate its use, and also to verify the accuracy of the method of analysis, several problems have been solved, and the results compared with those obtained by conventional closed form solutions or by methods used by other investigators.

In this chapter, some of those problems are described and the solutions from the computer program are discussed. Sample coding listings for data input and selected printout sheets for all example problems are presented in Appendix D.

The following problems are discussed here (DTP stands for "DYNARCH Test Problems"):

1. Example Problem DTP1: Static solution only.
   Static solution of a reinforced concrete circular arch, having an angle of opening of 180 degrees.
2. Example Problems DTP2: Dynamic solution only--elastic response.
   DTP2.1--Linearly elastic dynamic solution of a wide flange steel two-hinged circular arch, having an angle of opening of 87.21 degrees, subjected to a rectangular pressure pulse of infinite duration.
   DTP2.2--Linearly elastic dynamic solution of a wide flange steel simply supported beam, subjected to a sinusoidal impulse loading.

3. Example Problems DTP3: Combined static and dynamic loading--inelastic response

DTP3.1--Inelastic response of a prismatic reinforced concrete beam, under combined static and dynamic loadings

DTP3.2--Inelastic response of the beam in the previous problem, with dynamic loading reversed.

Example Problem DTP1: Static Solution Only

For this problem, a two-hinged circular arch with an angle of opening of 180 degrees is considered. A central concentrated load P = -2000 lb (downwards) is applied at the crown. The arch has a constant cross section of reinforced concrete with bottom and top reinforcement, as shown in Figure 5.1. The mechanical model consisted of 48 bars.

For a concentrated load at the crown, the closed form solution yields:

Horizontal reactions:

$$H = -P/\pi = 636.62 \text{ lb.}$$

Vertical reactions:

$$V = -P/2 = 1000.00 \text{ lb.}$$

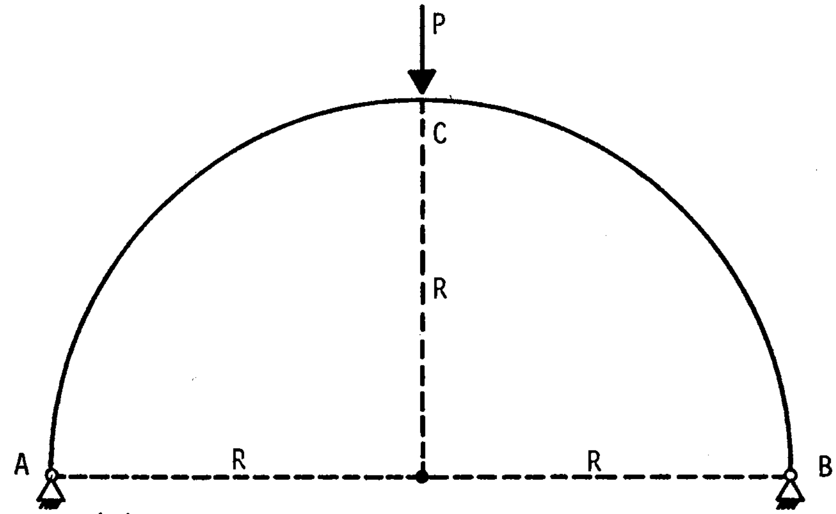
Moment at the crown:

$$M_c = (V - H)R = 6.4186 \times 10^4 \text{ in-lb.}$$

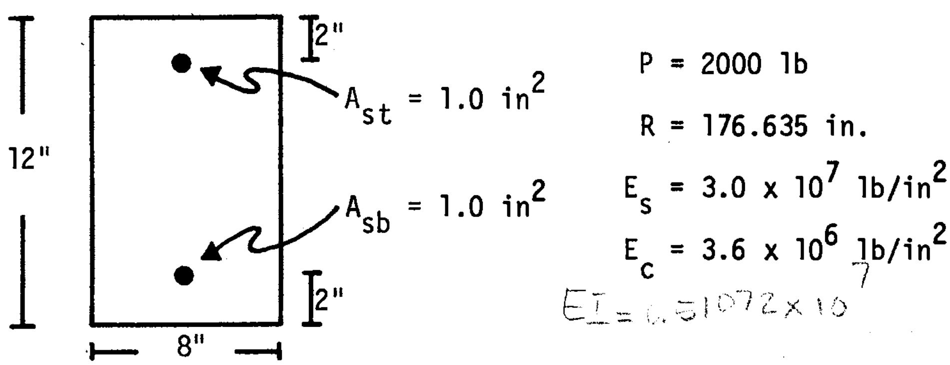
Vertical displacement at the crown:

$$v_c = \frac{PR^3}{8EI} \quad \frac{3\pi^2 - 8\pi - 4}{\pi} = -0.0418 \text{ in.}$$

These values are compared with the computer results in Figure 5.1. It is seen that a very good agreement is obtained.



(a) Two-Hinged Circular Arch of Reinforced Concrete



(b) Cross Section and Problem Data

Quantity	Closed Form Solution	DYNARCH Solution
Horizontal reaction (lb)	636.62	636.56
Vertical reaction (lb)	1000.00	1000.00
Moment at crown (in-lb)	6.4186 x 10^4	6.4196 x 10^4
Deflection at crown (in)	- 0.0418	- 0.0426

(c) Comparison of Results

Figure 5.1. Static Solution--Problem DTP1

Example Problems DTP2: Linearly Elastic Response

Two problems were solved, where only linearly elastic properties of the material were considered: (1) a two-hinged circular arch and (2) a simply supported beam. For both problems no static loads were taken into account, then only the dynamic solution was required.

Problem DTP2.1--Two-Hinged Circular Arch

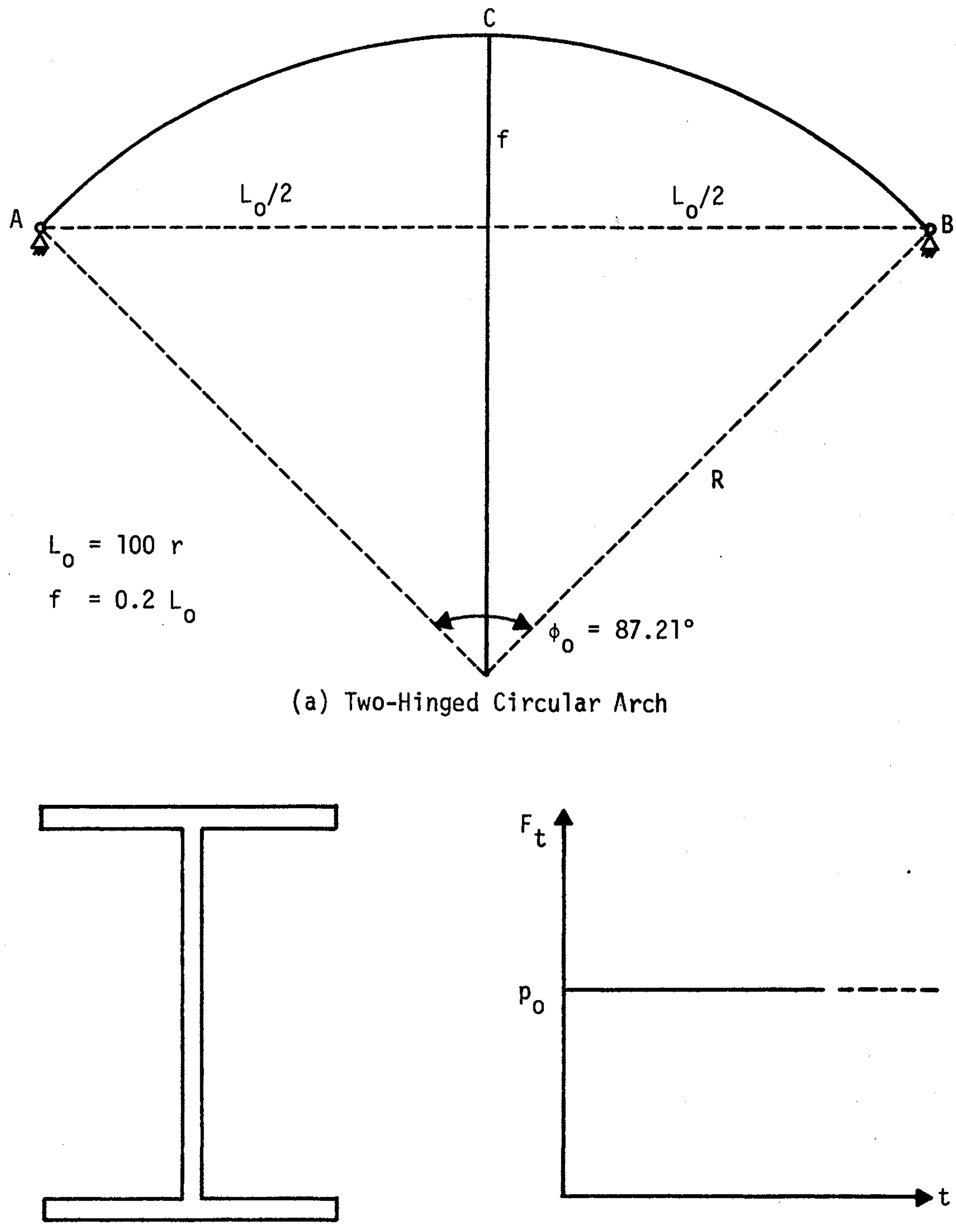
For this problem, a two-hinged circular arch with an angle of opening ϕ_o = 87.21 degrees is considered, Figure 5.2. No static loading is applied. The dynamic loading is taken in the form of a rectangular pressure pulse of infinite duration, uniformly distributed over the entire arch. A similar problem has been solved by Eppink and Veletsos (6).

The wide flange steel section W16X88 used here has a radius of gyration r = 6.78 inches. The span of the arch is L_o = 100r and the rise is f = $0.2L_o$. The uniform pressure pulse has a magnitude p_o = 0.01 p_{cr}, where p_{cr} is the critical buckling pressure of the arch corresponding to an antisymmetrical mode of deformation, defined as

$$p_{cr} = \left[\frac{4\pi^2}{\phi_o^2} - 1\right] \frac{EI}{R^3}$$

The computer results are tabulated in Table D.1 in Appendix D for elapsed times t from 0.1 T_o to 3.0 T_o, where T_o is the period of the "breathing" mode of vibration of a circular ring with the radius of the arch and is given by

$$T_o = 2\pi R \sqrt{\frac{\mu}{EA}}$$



(a) Two-Hinged Circular Arch

(b) Cross Section W 16x88 Wide Flange Steel Section

(c) Rectangular Pressure Pulse p_o of Infinite Duration

Figure 5.2. Data for Problem DTP2.1--Linearly Elastic Dynamic Solution Only

For this particular example p_{cr} = 4711 lb/in and T_o = 1.555 x 10^{-2} sec.

By comparing the values in Table D.1 with those obtained by Eppink and Veletsos (6), one can see that the values for thrusts and vertical displacements at the crown compare very favorably with a difference between 0% and 2%. The values for bending moments at 1/4 point and at the crown present a higher distortion, generally less than 6%, probably due to a different approach in the calculation of bending moments.

Nevertheless, the values given for bending moments in Table D.1, on page 163, closely agree with those calculated by the formula for flexural vibration of a circular ring

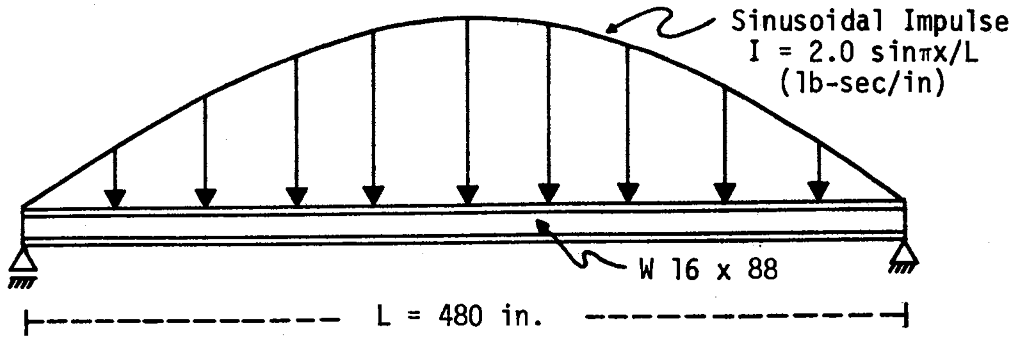
$$M = \frac{EI}{R^2}\left[\frac{\partial^2 u_r}{\partial \theta^2}\right] + u_r$$

given by Timoshenko (8), where u_r is the radial displacement. This equation can be applied at the crown, considering a predominantly flexural mode of vibration of the arch near the midspan.

Taking the above equation and using the second order central finite difference equation as an approximation for the second derivative, the values of bending moments were calculated at the crown and also included in Table D.1 for comparison.

Problem DTP2.2--Simply Supported Beam

For this problem, a simply supported beam is considered, with the same wide flange steel section as the previous problem. No static load is applied. The dynamic loading is taken in the form of a sinusoidal impulse, as shown in Figure 5.3.



(a) Simply Supported Wide Flange Steel Beam

Quantity	Results Obtained by Dawkins (4)		Results From Program DYNARCH
	Closed Form	Program IMPBC	
Maximum moment at midspan (in-kip)	2.7803×10^3	2.7675×10^3	2.7543×10^3
Maximum deflection at midspan (in)	- 1.7715	- 1.7885	- 1.7801
Natural period (sec)	0.1056	0.1062	0.1061

(b) Comparison of Results

Figure 5.3. Problem DTP2.2--Linearly Elastic Dynamic Solution Only

This problem was also solved by Dawkins (4), using both a closed form solution and his program IMPBC for analysis of beam-columns under impulse loadings.

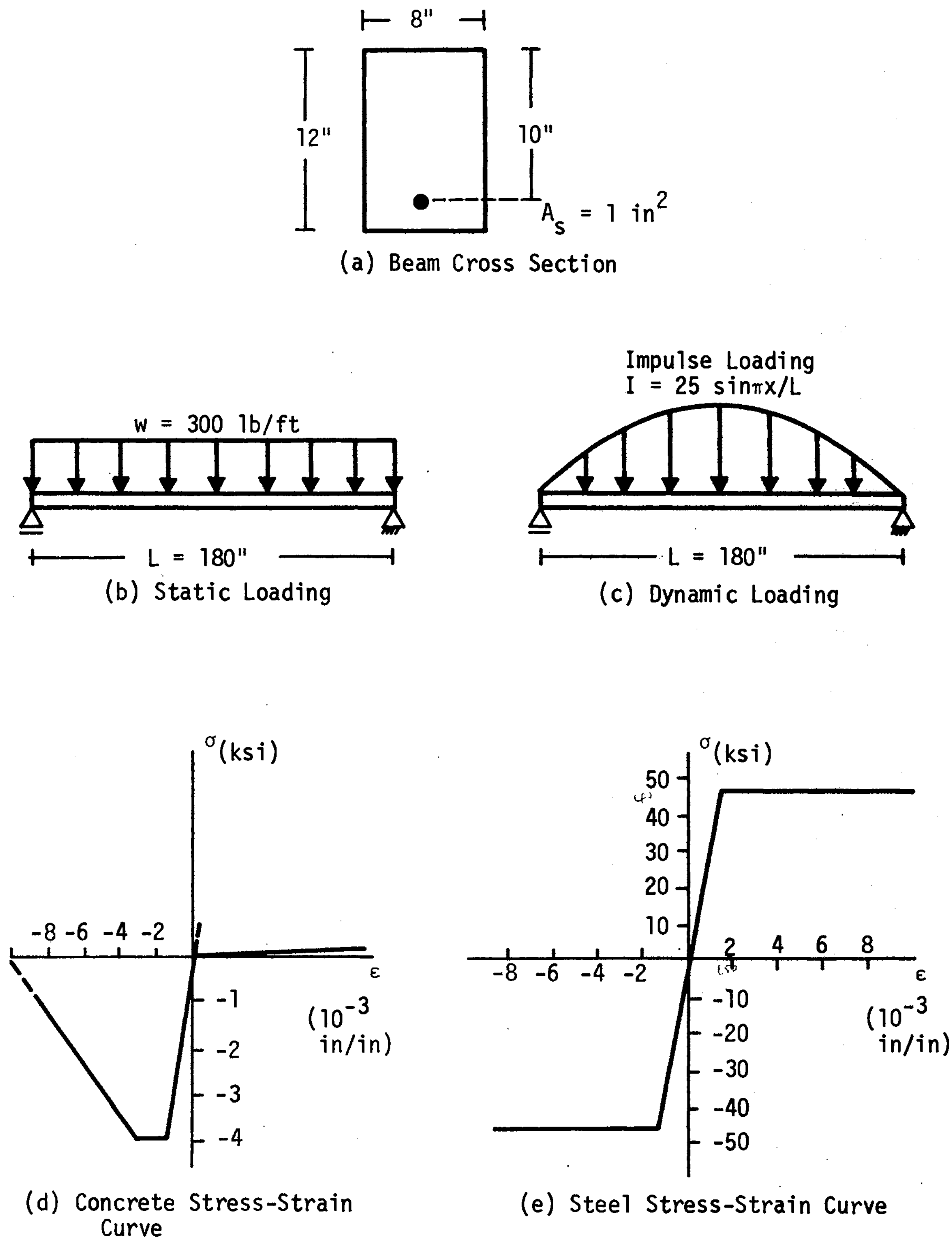
By comparing the results summarized in Figure 5.3, one can see that there is a close agreement between the results obtained by program DYNARCH and those obtained by Dawkins. Differences are less than 1% from closed form solution and about 0.5% from program IMPBC.

Example Problems DTP3:
Inelastic Response

Two problems were also solved to illustrate the application of the computer program and method of analysis to problems where nonlinear properties of the materials are taken into account. The inelastic response of a reinforced concrete beam, under combined static and dynamic loadings, was obtained (1) by superimposing a downward sinusoidal impulse to a uniform static load, and (2) by considering the same static load, but reversing the direction of the impulse.

Problem DTP3.1--Downward Sinusoidal Impulse

For this problem, a prismatic reinforced concrete beam on simple supports, shown in Figure 5.4, was subjected to a uniform static load and to an impulse loading varying sinusoidally over the length of the beam. Beam cross section, loadings and stress-strain curves for concrete and reinforcement are also shown in Figure 5.4. Ultimate strain for concrete is 0.003. Other failure parameters are listed in sample output sheets in Appendix D.



(a) Beam Cross Section

(b) Static Loading

(c) Dynamic Loading

(d) Concrete Stress-Strain Curve

(e) Steel Stress-Strain Curve

Figure 5.4. Data for Problem DTP3.1--Downward Sinusoidal Impulse

The solution indicated failure due to thrust-moment interaction near the center of the beam, at approximately 1.25 milliseconds after the impulse was applied.

Dawkins (4) solved a similar problem using program IMPBC. Numbers can not be compared, because (1) a smaller static load was used here, in order to keep the static solution within the elastic range of the materials, and (2) Dawkins did not consider the shifting of the centroid as inelastic action takes place. Nevertheless, the pattern of behavior of the beam in the two solutions was identical.

Problem DTP3.2--Upward Sinusoidal Impulse

The beam considered for this problem was the same for problem DTP3.1 with the direction of the dynamic loading reversed. This combination of static and dynamic loadings may be the result of a detonation in the interior of a building.

As cracks and consequently large strains should be expected at the top of the section, where no reinforcement was specified, the values in the positive side of the stress-strain curve for the concrete were exaggerated. Also very large values were taken for the maximum allowed negative bending moments in the interaction diagram.

The computer solution indicated failure by maximum prescribed vertical displacement, which occurred at the midspan, at approximately 4.5 milliseconds after the application of the impulse loading. At time of failure, the location of the centroid in the central portion of the span was indicated to be located below the center of gravity of the reinforcement.

CHAPTER VI

APPLICATION OF PROGRAM

In order to demonstrate the applicability of the method of analysis and of the program developed in this study, a two-hinged semi-circular arch of reinforced concrete, Figure 6.1(a), was analyzed under two conditions of dynamic loadings:

1. A forcing pressure pulse of sinusoidal variation, applied at the top of the arch, extending over a region of 30 degrees.

2. The same forcing pressure pulse, applied at the quarter point of the arch, over 30 degrees.

For both problems, the only static loading considered was the self weight of the arch.

Stress-strain diagrams for concrete and steel are shown in Figures 6.1(d) and (e). The time function F(t) was a triangular function with peak F_m, as shown in Figure 6.1(c), having time of rising t_r equal to half of total time of duration t_d.

The uniform cross section is shown in Figure 6.1(b). From stress-strain curves, initial tangent modulus for concrete is $E_c = 3.6 \times 10^6$ pounds per square inch, and for steel $E_s = 3.0 \times 10^7$ pounds per square inch. The transformed area of the cross section is 110.667 in^2 and the moment of inertia is 1386.667 in^4, and the radius of gyration is $r = 3.54$ inches.

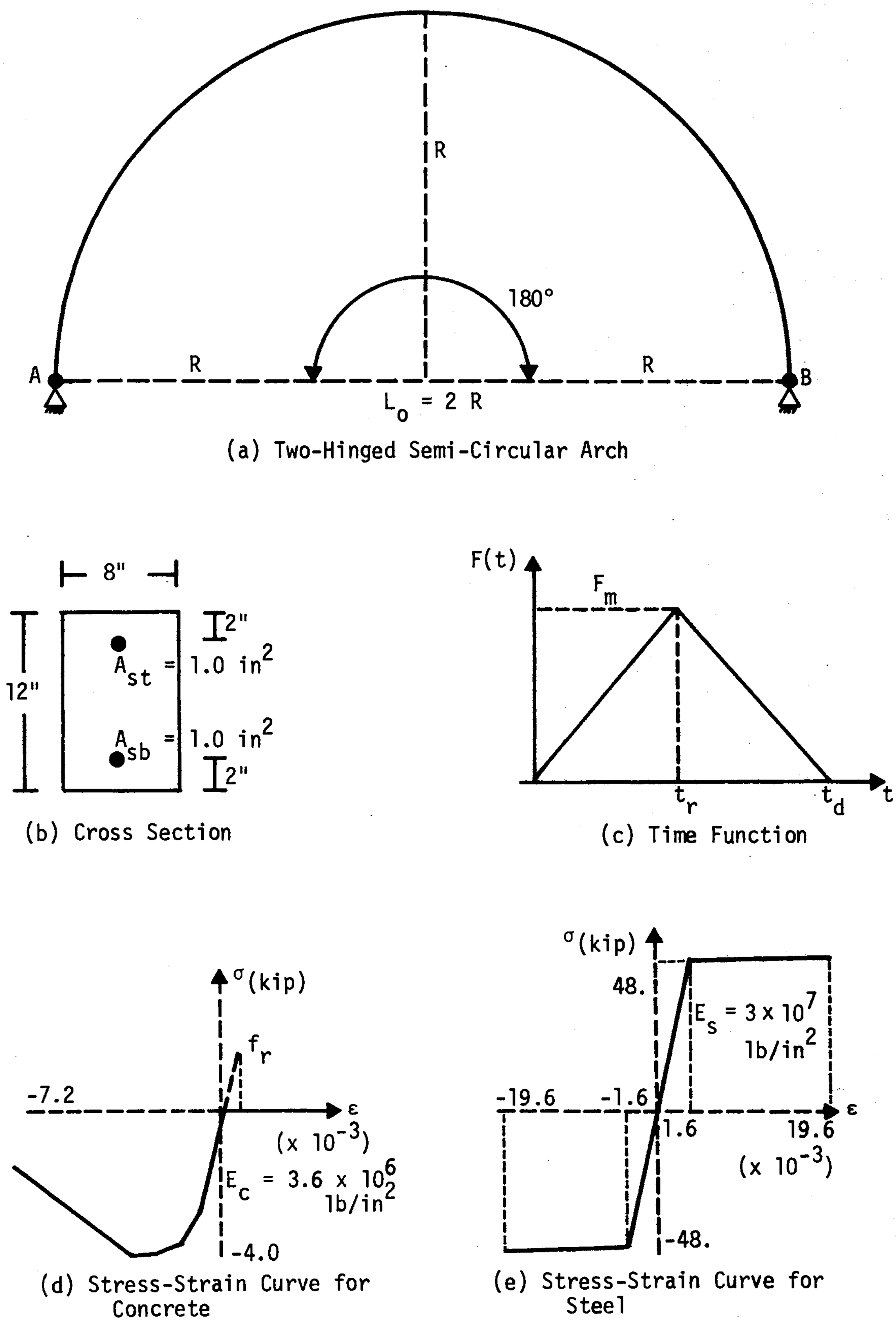


Figure 6.1. Data for DYNARCH Application Problems

The span was taken equal to $L_o = 100\ r = 354$ inches, which corresponds to a radius $R = L_o/2 = 177$ inches for the arch, and a slenderness ratio $S/r = 157.08$, or a value of $R/r = 50$ for the ratio of the radius of the arch to the radius of gyration of the cross section.

Problem DAP1: DYNARCH

Application Problem 1

For this problem, the forcing pressure pulse was applied at the top of the arch, as shown in Figure 6.2(a).

At time t, the magnitude of the pulse is

$$p(t,\alpha) = p(\alpha)\ F(t) = P_o \sin\ [6(\alpha + 15°)]\ F(t)$$

where α, given in degrees, measured from the vertical axis of symmetry, positive clockwise, varies from -15 to +15 degrees, as in Figure 6.2(a), and F(t) is the triangular time function shown in Figure 6.1(c).

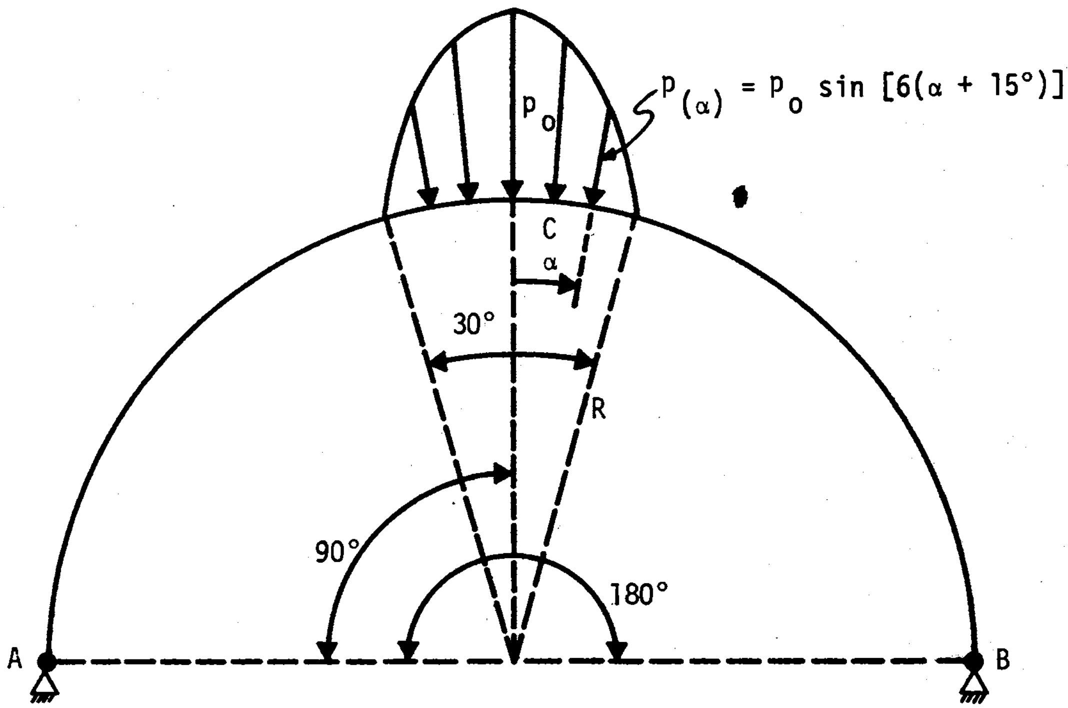
The maximum value of the pressure pulse occurs at the crown of the arch at time t_r:

$$p_{max} = P_o\ F_m$$

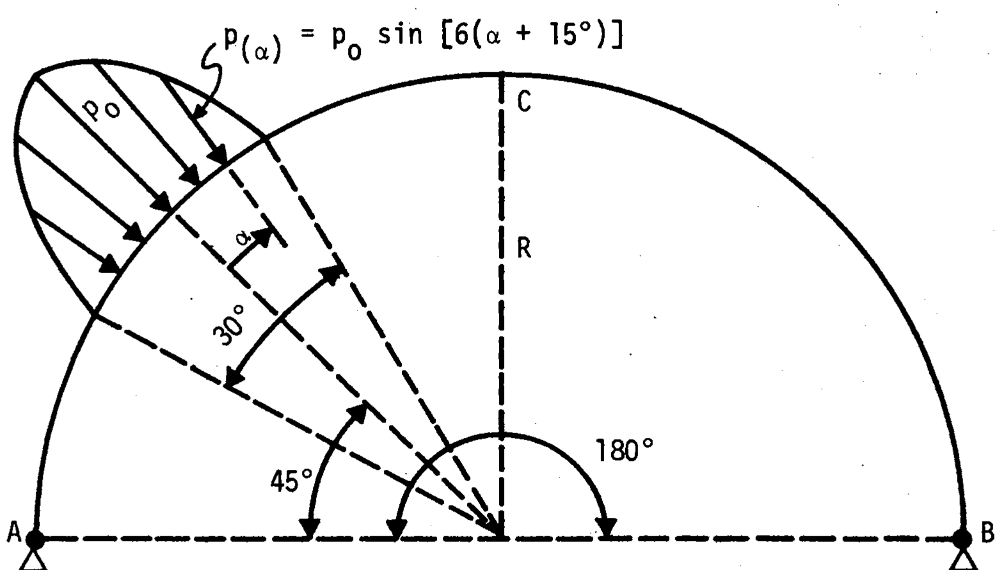
where F_m is the peak of the time function.

The purpose of this analysis was to determine the minimum values of the pressure pulse, p_{mf}, capable of causing the failure of the arch for various times of duration.

A type of iterative procedure was used to attain this goal. For a given time of duration t_d, a forcing pulse of maximum value $p_{max} = p_oF_m$ was initially applied. The program was run and if failure occurred, p_{max} was taken as an upper bound for p_{mf}, the minimum value capable of causing failure of the arch for that particular time of duration; if failure did not occur, p_{max} was taken as a lower bound for p_{mf}.



(a) Dynamic Loading for Problem DAP1



(b) Dynamic Loading for Problem DAP2

Figure 6.2. Dynamic Loadings for DYNARCH Application Problems

Subsequent values of p_{max} were tried until the lower and upper bounds were sufficiently close to each other, and the average of these bounds was taken as p_{mf}.

As an example, a time of duration $t_d = 1.0 \times 10^{-2}$ sec (10 milliseconds) was preliminarily considered and a load p_{max} = 3000 lb/in was applied. Failure occurred at time t = 6.3068 millisec, due to crushing of the top fibers of the section at the crown of the arch. A load p_{max} = 2500 lb/in was then applied and failure occurred at time t = 8.18 millisec, and a new upper bound was established. A smaller load p_{max} = 2000 lb/in was applied and failure did not occur. Then the last value was taken as a lower bound for p_{mf}. Having a lower and an upper bound for p_{mf}, the standard bisection method of analysis was followed until p_{mf} = 2280 lb/in was considered an acceptable value for the minimum load causing failure and having a total time of duration of 10 milliseconds.

Other times of duration t_d for the forcing pressure pulse were considered and the results are summarized in the diagram of Figure 6.3, where the values of p_{mf} were plotted against t_d, curve AA.

For values of t_d smaller than 20 milliseconds, failure occurred after the pulse, and for greater values of t_d, failure occurred during the pulse, at times greater than 70% of the times of duration.

By applying a very small dynamic loading of the same nature, so that the response of the arch would be in the linearly elastic range, an approximate value for the period of vibration of the arch was obtained as 70 milliseconds, which was the maximum value considered for t_d.

For this problem, a model with 24 bars was considered, but advantage was taken of symmetry of shape and loading, and only half the structure was solved. Failure always occurred by crushing of the top fibers of

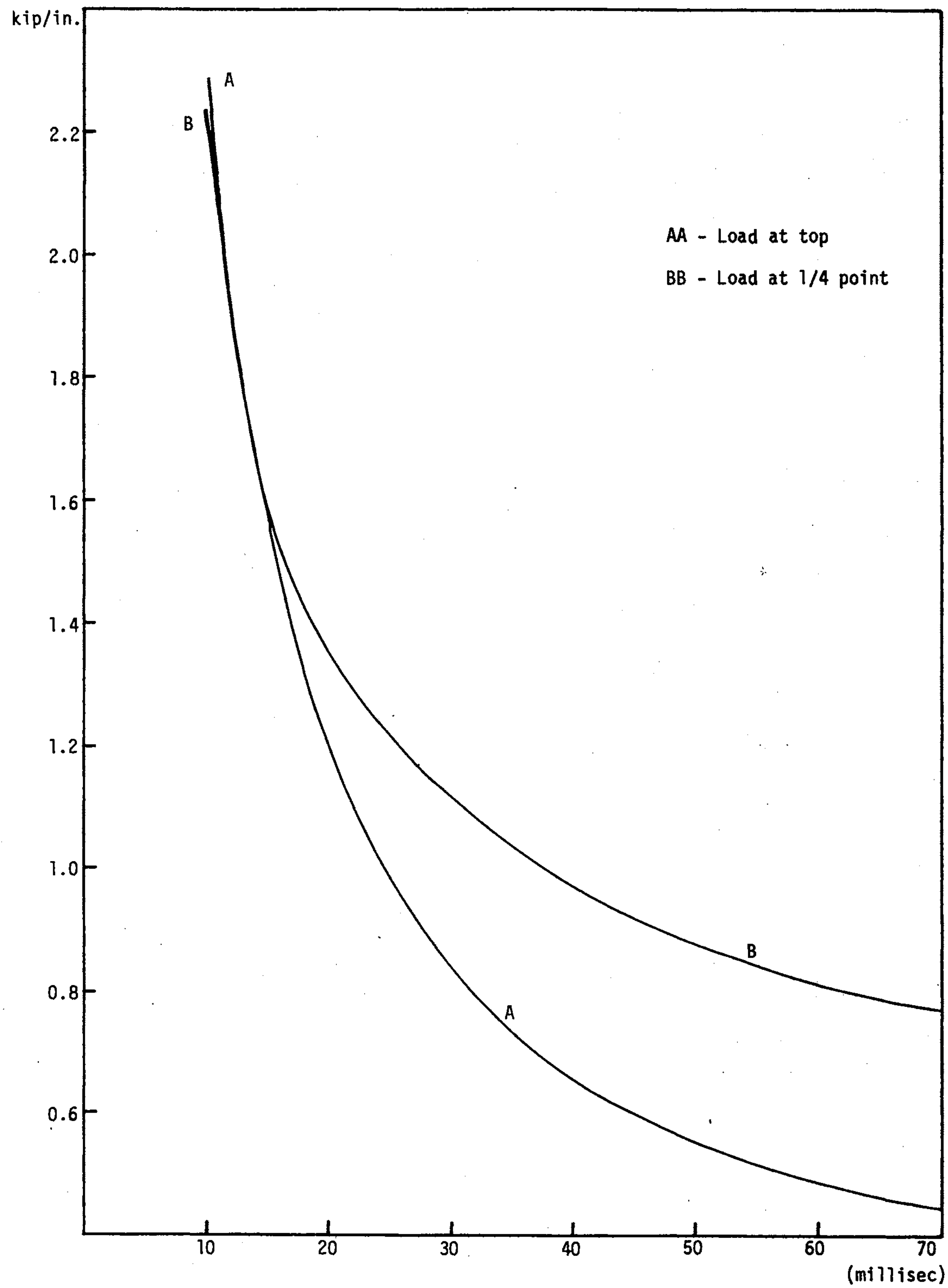


Figure 6.3. Variation of Minimum Failure Load With Time of Duration

the section at the crown, with ultimate strain prescribed as 0.003. Samples of data input and output are shown in Appendix D.

The maximum time spend in the computer for one loading was 16.7 minutes for $t_d = 7.0 \times 10^{-2}$ sec (70 millisec), with time limit of 7.2×10^{-2} sec, the solution progressing at an average of 72 microseconds of elapsed time per second of computer time. For smaller times of duration this average sometimes was as low as 50 microseconds per second.

Problem DAP2: DYNARCH

Application Problem 2

For this problem, the forcing pressure pulse was applied at the quarter region of the arch, as shown in Figure 6.2(b).

At time t, the magnitude of the pulse is

$$p(t,\alpha) = p(\alpha)\ F(t) = p_0 \sin\ [6(\alpha + 15°)]\ F(t)$$

where α varies from -15 to +15 degrees and is measured from the radius at the quarter point; F(t) is the triangular time function shown in Figure 6.1(c).

The maximum value of the pressure occurs at the quarter point of the arch at time t_r.

The same procedure applied to Problem DAP1 was used to find the variation with time of duration of p_{mf}, the minimum value of the pressure to cause failure of the arch, and the results are also symmarized in the diagram of Figure 6.3, where the values of p_{mf} were plotted against t_d, curve BB.

By comparing the results with those obtained for the load applied at the top, one can see that, except for smaller values of t_d, when the loadings have more localized effects at the region of their application, a higher load has to be applied at the quarter region of the arch in order to cause failure, which should be expected.

It was verified that failure occurred during the pulse, at times varying from 60% to 90% of times of duration, this percentage being smaller for larger times of duration.

A model with 24 bars was considered, but in this cause advantage could not be taken of the symmetry of the structure, because the load was not symmetrical. Failure always occurred by crushing of the top fibers of the section at the quarter point, with prescribed ultimate strain of 0.003.

The computer solutions progressed at rates between 30 and 40 microseconds of elapsed time per second of computer time, this rate being smaller for smaller times of duration.

CHAPTER VII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

A method of analysis of arches, beams and portal frames, under dynamic loads or combined static and dynamic loads has been developed in this study, by using a discrete-element mechanical model, representing the actual structure.

For the static loadings, when considered, the deformations of the structure are assumed to be sufficiently small so that conventional matrix analysis of structures is employed. Dynamic effects are superimposed on static results.

The method developed herein takes into account material nonlinearity combined with geometric nonlinearity due to large displacements, by constantly revising the axial and flexural stiffnesses at selected sections of the structure, as deformations occur under transient loads. This is accomplished by considering the modification of the transformed area of the general cross section and consequent relocation of its centroid, as plastification and/or cracks take place. A variable modulus of elasticity, the secant modulus, is used. Failure criteria are also established.

The integration of the equations of motion is made by using a step-by-step iterative numerical procedure, the Newmark's Beta Method, based on the assumption of linear variation of the acceleration during the time-step interval.

A new configuration of the replacement structure is obtained and internal forces are calculated at the end of every time-step interval.

Convergence and stability of the dynamic process are insured by redefining the time-step interval after every cycle of iterations.

Dynamic loadings may be taken in the forms of impulses or time dependent pulses.

A computer program was written in FORTRAN language for solution in the IBM/360 Model 65 computer of the Oklahoma State University. The program in subroutine form is sufficiently general to handle a large variety of parameters, such as material properties, structure shapes and cross sections, collapse criteria, and can easily be changed to take into consideration particular features of specific problems.

In order to illustrate the solution capability of the program and verify the accuracy of the method of analysis, several problems have been solved, and the results compared with known solutions.

The program was used in two application problems to determine a minimum sinusoidal pressure pulse with varying time of duration, capable of inducing collapse of a two-hinged semi-circular arch, when applied over a limited region of the arch.

Conclusions

From the present study the following conclusions can be drawn:

1. The computer results for linearly elastic problems compared satisfactorily with those obtained by conventional closed form solutions, or by methods used by other investigators.

2. The continuous relocation of the centroid of the transformed area of the cross section constitutes a realistic form of treating non-linear problems of structures, and provides a very useful means of redefining axial and flexural stiffnesses as inelastic action takes place.

3. The application problems showed that the program developed can be advantageously used to perform parametric studies in dynamic problems of arches, beams and portal frames, with geometric and material nonlinear characteristics, to determine position, magnitude and time of duration of dynamic loadings capable of inducing collapse of a given structure.

Recommendations

Future extensions of the model and program may include the effects of rotatory inertia and shear deformation, as well as prestressing of concrete members.

Experimental research could be performed, which would have the purpose of evaluating the analytical results obtained with the program. Carefully controlled laboratory or field tests, even in a limited number, would be very helpful in the evaluation of the method of analysis, and would have the merit of supplying additional information on material behavior under dynamic loadings.

A SELECTED BIBLIOGRAPHY

(1) Austin, Walter J., and A. S. Veletsos. "Free Vibration of Arches Flexible in Shear." Journal of the Engineering Mechanics Division, ASCE, Vol. 99 (August, 1973), pp. 735-753.

(2) Blaauwendraad, J. "A Realistic Analysis of Reinforced Concrete Framed Structures." Heron, Vol. 18, No. 4 (1972). Dept. of Civil Engineering, Technological University of Delft, The Netherlands.

(3) Dawkins, William P. "Analysis of Tunnel Liner-Packing Systems." Journal of the Engineering Mechanics Division, ASCE, Vol. 95, No. EM3 (June, 1969), pp. 679-693

(4) Dawkins, William P. "A Method of Analysis for Reinforced Concrete Beam-Columns Subjected to Impulse Loading." Report Submitted to Oklahoma State University (Preliminary Copy), March, 1971.

(5) Den Hartog, J. P. "The Lowest Natural Frequency of Circular Arcs." Philosophical Magazine, Series 7, Vol. 5, No. 28 (February, 1928), pp. 400-408.

(6) Eppink, R. T., and A. S. Veletsos. "Dynamic Analysis of Circular Elastic Arches." Proceedings of the Second Conference on Electronic Computation, ASCE, Pittsburg, September, 1960, pp. 477-502.

(7) Newmark, N. M. "A Method of Computation for Structural Dynamics." Transactions, ASCE, Vol. 127, Part I (1962), pp. 1406-1433.

(8) Timoshenko, S. Vibration Problems in Engineering. Princeton, New Jersey: D. Van Hostrand Co., Inc., 1955.

(9) Veletsos, A. S., et al. "Free In-Plane Vibration of Circular Arches." Journal of the Engineering Mechanics Division, Proceedings, ASCE, Vol. 98, No. EM2 (April, 1972), pp. 311-329.

(10) Wolf, Joseph A. "Natural Frequencies of Circular Arches." Journal of the Structural Division, Proceedings, ASCE, Vol. 97, No. ST9 (September, 1971), pp. 2337-2348.

(11) Zienkiewicz, O. C. The Finite Element Method in Structural and Continuum Mechanics. New York: McGraw-Hill Publishing Co., 1967.

APPENDIX A

SOLUTION OF SIMULTANEOUS EQUATIONS

The system of linear simultaneous equations, on page 21, obtained for the static solution, is solved by a variation of Gauss elimination known as the recursion-inversion procedure.

First it will be shown that the general Equation (3.14) of the system Equation (3.15), on page 21, can be written in the form:

$$U_i = \alpha_{i+1} + \beta_{i+1} U_{i+1} . \quad \text{(A.1)}$$

If Equation (A.1) is supposed to be valid, the following expression for U_{i-1} is also valid:

$$U_{i-1} = \alpha_i + \beta_i U_i . \quad \text{(A.2)}$$

Taking Equation (A.2) into (3.14), it results:

$$A_i (\alpha_i + \beta_i U_i) + B_i U_i + C_i U_{i+1} + D_i = 0 .$$

Solving for U_i:

$$U_i = -(A_i \beta_i + B_i)^{-1} (A_i \alpha_i + D_i) - (A_i \beta_i + B_i)^{-1} C_i U_{i+1} .$$

Then the coefficients α_{i+1} and β_{i+1} of Equation (A.1) can be identified as:

$$\alpha_{i+1} = -(A_i \beta_i + B_i)^{-1} (A_i \alpha_i + D_i); \quad \text{(A.3)}$$

$$\beta_{i+1} = -(A_i \beta_i + B_i)^{-1} C_1 . \quad \text{(A.4)}$$

Since A_i, B_i, C_i, D_i are known, the values of α and β at one station depend only on the values of α and β at previous station.

The first equation of system Equation (3.15) is:

$$B_1 U_1 + C_1 U_2 + D_1 = 0$$

or

$$U_1 = -B_1^{-1} D_1 - B_1^{-1} C_1 U_2$$

where

$$B_1 = S^1_{1,1}, \qquad C_1 = S^1_{1,2} \qquad \text{and} \qquad D_1 = -Q_1 \ .$$

From Equation (A.1):

$$U_1 = \alpha_2 + \beta_2 U_2 \ .$$

Then

$$\alpha_2 = -B_1^{-1} D_1 \qquad \text{and} \qquad \beta_2 = -B_1^{-1} C_1 \ .$$

For purposes of computer programming, it is useful to notice that the last two values can be obtained from Equations (A.3) and (A.4), by setting $\alpha_1 = 0$ and $\beta_1 = 0$, or, which is the same, by setting $A_1 = 0$, as it becomes evident from the first equation of system Equation (3.15).

Subsequent values of α and β can be calculated, until station $m = n+1$ is reached and U_m is established:

$$U_m = \alpha_{m+1} + \beta_{m+1} U_{m+1} \ . \qquad \text{(A.5)}$$

The last equation of system Equation (3.15) is

$$A_m U_n + B_m U_m + D_m = 0$$

from which it is seen that $C_m = 0$ and Equation (A.4) produces $\beta_{m+1} = 0$.

Then, from Equation (A.5):

$$U_m = \alpha_{m+1}$$

and all values of U_{i-1} can be found from Equation (A.2), starting with $i = m$ and proceeding backwards until $i = 2$, when the last vector of displacements U_1 can be determined.

In order to improve the accuracy of the static solution, the values of the displacements are substituted into Equation (3.15), which must be satisfied. Generally, although the program deals with real variables in double precision, the first set of displacements do not satisfy entirely the system of Equation (3.15), which yields some residues R_i in each equation, i.e.:

$$A_i\ U_{i-1}^{(1)} + B_i\ U_i^{(1)} + C_i\ U_{i+1}^{(1)} + D_i = R_i^{(1)} \neq 0 ,$$

the superscript (1) meaning that the values refer to the first trial solution obtained.

Then the entire procedure is repeated using $R_i^{(1)}$ in place of D_i, resulting in the general equation:

$$A_i\ U_{i-1}^{(2)} + B_i\ U_i^{(2)} + C_i\ U_{i+1}^{(2)} + R_i^{(1)} = 0 .$$

The new system is solved and a new set of displacements $U_i^{(2)}$ results in this second operation.

By adding the last two equations together, the residues are eliminated, resulting in:

$$A_i\ (U_{i-1}^{(1)} + U_{i-1}^{(2)}) + B_i\ (U_i^{(1)} + U_i^{(2)}) + C_i\ (U_{i+1}^{(1)} + U_{i+1}^{(2)}) + D_i = 0.$$

It is seen that $U_i = U_i^{(1)} + U_i^{(2)}$ is a better solution. The process goes on until all residues are kept equal or below a specified limit, as close to zero as possible.

Taking the displacements into Equation (3.11), the values of the forces at the ends of all bars can be determined. These forces result in matrix analysis sign convention, Figure 3.5(d), and to calculate bending moments, shears and thrusts in classical engineering sign convention, Figure 3.5(f), the following transformation equations are used:

$$M_{i,i+1} = -f_{zi}^{i} ;$$

$$M_{i+1,i} = f_{z(i+1)}^{i} ;$$

$$T_i = - f^i_{xi} \cos\theta_i - f^i_{yi} \sin\theta_i \;;$$

$$V_i = f^i_{yi} \cos\theta_i - f^i_{xi} \sin\theta_i$$

or, in matrix form:

$$\begin{Bmatrix} T_{bar\ i} \\ V_{bar\ i} \\ M_{joint\ i} \end{Bmatrix} = - \begin{bmatrix} \cos{}_i & \sin{}_i & 0 \\ \sin{}_i & -\cos{}_i & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} f^i_{xi} \\ f^i_{yi} \\ f^i_{zi} \end{Bmatrix} .$$

Values of thrusts and bending moments will be taken into Equations (3.16) and (3.17), in order to calculate the average static strain in bar i and the average static curvature at joint i.

APPENDIX B

LISTING OF PROGRAM DYNARCH

```
C         MAIN PROGRAM DYNARCH
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *      PROGRAM DYNARCH                                              *
C     *                                                                   *
C     *      LANGUAGE:      FORTRAN IV                                    *
C     *                                                                   *
C     *      COMPUTER:      IBM  /360  MODEL 65                           *
C     *                                                                   *
C     *      PROGRAMMER:    JERSON DUARTE GUIMARAES                       *
C     *                     PROFESSOR OF CIVIL ENGINEERING                *
C     *                     UNIVERSIDADE FEDERAL DE GOIAS                 *
C     *                     GOIANIA, GOIAS, BRAZIL                        *
C     *                                                                   *
C     *      PURPOSE:       ANALYSIS AND PREDICTION OF COLLAPSE           *
C     *                     OF ARCHES, BEAMS AND PORTAL FRAMES,           *
C     *                     UNDER DYNAMIC LOADS OR COMBINED               *
C     *                     STATIC AND DYNAMIC LOADINGS                   *
C     *                                                                   *
C     *             DETAILED INFORMATION CAN BE FOUND IN:                 *
C     *              ''A METHOD OF ANALYSIS FOR NONLINEAR                 *
C     *                DYNAMIC RESPONSE OF ARCHES''                       *
C     *                   PH.D.  DISSERTATION                             *
C     *                 BY JERSON DUARTE GUIMARAES                        *
C     *                 OKLAHOMA STATE UNIVERSITY                         *
C     *                       JULY, 1974                                  *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /IDENT/ ID1(40), ID2(19), NPROB
      COMMON /TABL1/ GRAV,TLIM,KEEP(7),ISTAT,ISOPT,NDL,IDOPT,NOUT,ISELFW
      DATA IBLANK, IYES / 4H    , 3HYES /
C
 1000 FORMAT (20A4)
 2000 FORMAT (//24X, 19A4)
C
C>-->    READ RUN IDENTIFICATION  -  TWO CARDS
      READ 1000, ID1
C>-->    READ PROBLEM IDENTIFICATION  -  ONE CARD
  100 READ 1000, NPROB, ID2
C
C>-->    CHECK PROBLEM NAME AND STOP IF BLANK
      IF (NPROB .NE. IBLANK) GO TO 110
C>-->    PRINT TERMINATION MESSAGE AND STOP
         PRINT 2000, ID2
         STOP
C
C>-->    CALL SUBROUTINE INECHO TO READ IN AND ECHO PROBLEM DATA
  110 CALL INECHO
C>-->    CALL SUBROUTINE DIST TO GENERATE AND DISTRIBUTE DATA
      CALL DIST
C
C>-->    CHECK WHETHER STATIC SOLUTION IS REQUIRED
      IF (ISTAT .NE. IYES) GO TO 120
C>-->    CALL SUBROUTINE STATIC TO SOLVE FOR STATIC DISPLACEMENTS
C        AND INTERNAL FORCES AND PRINT STATIC RESULTS
      CALL STATIC
C
C>-->    CHECK WHETHER DYNAMIC SOLUTION IS REQUIRED
  120 IF (NDL .EQ. 0) GO TO 100
C>-->    CALL SUBROUTINE DYNAM TO SOLVE FOR DYNAMIC DISPLACEMENTS
C        INTERNAL FORCES, VELOCITIES AND ACCELERATIONS, CHECK FOR
C        FAILURE AND PRINT DYNAMIC RESULTS
      CALL DYNAM
C
C>-->    RETURN FOR A NEW PROBLEM
      GO TO 100
      END
```

```
C     SUBROUTINE INECHO
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *           THIS SUBROUTINE READS AND ECHOES INPUT DATA           *
C     *       FOR PROGRAM DYNARCH.  IT ALSO CALLS SUBROUTINE GEOM       *
C     *           TO SET UP INITIAL GEOMETRY OF THE STRUCTURE           *
C     *                                                                 *
C     *            DATA ARE ORGANIZED IN TABLES, AS FOLLOWS:            *
C     *                                                                 *
C     *              TABLE 1  -  CONTROL DATA                           *
C     *              TABLE 2  -  CROSS SECTION DESCRIPTION              *
C     *              TABLE 3  -  STRESS-STRAIN CURVES                   *
C     *              TABLE 4  -  SPECIFIED CONDITIONS                   *
C     *              TABLE 5  -  STATIC LOADS                           *
C     *              TABLE 6  -  DYNAMIC LOADS                          *
C     *              TABLE 7  -  COLLAPSE PARAMETERS                    *
C     *              TABLE 8  -  STATION COORDINATES                    *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE INECHO
C
      IMPLICIT REAL * 8(A-H, O-Z)
      EXTERNAL FX
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /CURVS/ EPSN(10,5),SIGN(10,5),EPSMUL(5),SIGMUL(5),EPSPR(5)
      COMMON /FAIL1/ SMAX(25), SMAXN(10), JS7N(10), UMAX, VMAX, NST7
      COMMON /FAIL2/ BMUL(25), PMUL(25), BMULN(10), PMULN(10),
     1               PIAN(9), BIAN(9), EPSU(5), JIA7(10), NIA7
      COMMON /SEGM1/ D(25,9), E(5,2), GAMMA(5), IS(9), MAT(9)
      COMMON /IGEOM/ PHIO(25), THO(24), IBRK, ISYM
      COMMON /TABL1/ GRAV,TLIM,KEEP(7),ISTAT,ISOPT,NDL,IDOPT,NOUT,ISELFW
      COMMON /TABL2/ DN(9,10), B1N(10),B2N(10),B3N(10), DTN(10),ATN(10),
     1               DBN(10), ABN(10), JSN(10), JRN(10), NCT2, NRT2
      COMMON /TABL4/ USN(10), VSN(10), THSN(10), IHINGE(26),
     1               JSDN(10), KU(10), KV(10), KTH(10), NCT4
      COMMON /TABL5/ JI5(20), QXI5(20), QYI5(20), JM5(20), QXM5(20),
     1               QYM5(20), JL5(20), QXL5(20), QYL5(20), NCT5
      COMMON /TABL6/ JI6(20), QXI6(20), QYI6(20), JM6(20), QXM6(20),
     1               QYM6(20), JL6(20), QXL6(20), QYL6(20), NCS(20),NPDL
      COMMON /TIMEF/ FO, TR, TD, FT, TIME, DTIME, TOTIME, IND, INTVL
      DIMENSION II(7)
 1010 FORMAT (5X, 6(1X,A4), 2X, A3, 6I5/5X, 4I5, 5X, 4E10.3)
 1020 FORMAT (5X, I5, 20X, 3E10.3, 2X, A3)
 1030 FORMAT (10X, 3(2I5, E10.3))
 1040 FORMAT (5X, I5, 10X, 4E10.3)
 1050 FORMAT (20X, 3E10.3)
 1060 FORMAT (5X, I5, 7X, 3I1, 10X, 3E10.3, 2X, A3)
 1070 FORMAT (10F8.0)
 1080 FORMAT (3(I5, 2E10.3), 2X, A3)
 2020 FORMAT (//20X, 23HTABLE 1. - CONTROL DATA//)
 2030 FORMAT (31X, 25HNO KEEP OPTIONS EXERCIZED)
 2040 FORMAT (31X, 25HRETAIN PRIOR DATA TABLES , I1, 5(2H, , I1))
 2050 FORMAT (/31X, 27HSTATIC SOLUTION REQUIRED:   , A3//31X,
     1        25HACCELERATION OF GRAVITY   , 1PD10.3)
 2051 FORMAT (/31X, 45HAXIS OF STRUCTURE DESCRIBED BY A SMOOTH CURVE)
 2052 FORMAT (/31X, 21HBROKEN LINE STRUCTURE)
 2054 FORMAT (/31X, 24HSONSYMMETRICAL STRUCTURE)
 2056 FORMAT (/31X, 45HSYMMETRICAL STRUCTURE, NONSYMMETRICAL LOADING)
 2058 FORMAT (/31X, 33HSYMMETRICAL STRUCTURE AND LOADING//31X,
     1        27HSOLUTION FOR HALF STRUCTURE)
 2060 FORMAT (/31X,21HSTATIC OUTPUT OPTION , 13X, I1)
 2062 FORMAT (/31X, 24HSELF WEIGHT NOT INCLUDED)
 2065 FORMAT (/31X, 33HSELF WEIGHT ADDED TO STATIC LOADS)
 2070 FORMAT (/31X,26HNUMBER OF DYNAMIC LOADINGS, 6X, I3//31X,
     1        21HDYNAMIC OUTPUT OPTION, 13X,I1//31X,15HOUTPUT INTERVAL,
     2        18X, I2//31X,10HTIME LIMIT, 15X, 1PD10.3)
 2072 FORMAT (/31X, 38HTYPE OF DYNAMIC LOADING: FORCING PULSE)
```

```
C     SUBROUTINE INECHO                                              (CONTINUED)
C
 2074 FORMAT (/31X, 32HTYPE OF DYNAMIC LOADING: IMPULSE)
 2076 FORMAT (/31X, 43HSOLUTION FOR LINEARLY ELASTIC RESPONSE ONLY)
 2078 FORMAT (/31X, 27HINELASTIC RESPONSE REQUIRED)
 2080 FORMAT (/31X,13HTIME INTERVAL, 12X, 1PD10.3)
 2090 FORMAT (/31X, 35HTIME INTERVAL INTERNALLY CALCULATED)
 2100 FORMAT (//20X,36HTABLE 2. - CROSS SECTION DESCRIPTION)
 2110 FORMAT (/30X, 32HUSING DATA FROM PREVIOUS PROBLEM/)
 2120 FORMAT (//30X, 12HCONTROL DATA//40X, 4HSTA., 10X, 36HTOP FLANGE
     1    WEB       BOT FLANGE/41X, 3HNO., 13X,   31HWIDTH       THICKNESS
     2      WIDTH//40X, I3, 8X, 1P3D13.4)
 2130 FORMAT (//30X, 29HSEGMENT, MATERIAL, DEPTH DATA//37X,
     1              58HSEG   MAT    DEPTH    SEG   MAT    DEPTH    SEG  MAT
     2    DEPTH //(36X, 3(2I4, 1PD12.3)))
 2140 FORMAT (//30X, 25HREINFORCEMENT DESCRIPTION//40X, 4HSTA., 6X,
     1         17HTOP REINFORCEMENT, 5X, 20HBOTTOM REINFORCEMENT/41X,
     2         3HNO., 7X, 14HDEPTH      AREA, 10X, 14HDEPTH      AREA/)
 2150 FORMAT (40X, I3, 1X, 2(4X, 1P2D10.3))
 2160 FORMAT (//20X,31HTABLE 3. - STRESS-STRAIN CURVES//)
 2170 FORMAT (27X, 10HCURVE NO. ,I1//33X, 26HMATERIAL SPECIFIC WEIGHT  ,
     1         1PD12.3/33X, 28HCOMPRESSIVE ULTIMATE STRAIN , 1PD10.3/33X,
     2         28HSTRESS VALUE SCALE FACTOR   , 1PD10.3/33X,
     3         28HSTRAIN VALUE SCALE FACTOR   , 1PD10.3/)
 2180 FORMAT (30X, 19HSTRESS INPUT VALUES/30X, 10F7.3/)
 2190 FORMAT (30X, 19HSTRAIN INPUT VALUES/30X, 10F7.3/)
 2200 FORMAT (//20X,31HTABLE 4. - SPECIFIED CONDITIONS//)
 2210 FORMAT (30X, 10HSTA.  CODE, 11X,
     1         23HSPECIFIED  DISPLACEMENT/48X, 1HU, 11X, 1HV, 10X, 3HROT/)
 2220 FORMAT (30X, I3, 4X, 3I1, 28X, 1PD12.3)
 2230 FORMAT (30X, I3, 4X, 3I1, 16X, 1P2D12.3)
 2240 FORMAT (30X, I3, 4X, 3I1,  4X, 1P3D12.3)
 2250 FORMAT (30X, I3, 4X, 3I1,  4X, 1PD12.3, 12X, 1PD12.3)
 2260 FORMAT (30X, I3, 4X, 5HHINGE)
 2280 FORMAT (//40X, 27HPARAMETERS OF TIME FUNCTION//45X,
     1           21HTIME OF RISING:  TR =, 1PD12.4/45X,
     2           21HTIME OF DECAY:   TD =, 1PD12.4/45X,
     3           21HMAXIMUM VALUE:   FO =, 1PD12.4)
 2290 FORMAT (///20X, 23HTABLE 5. - STATIC LOADS/)
 2300 FORMAT (/35X, 7HINITIAL, 14X, 12HINTERMEDIATE, 17X, 5HFINAL/26X,
     1         4HSTA., 5X, 1HX, 9X, 1HY, 5X, 4HSTA., 5X, 1HX, 9X, 1HY,
     2         5X, 4HSTA., 5X, 1HX, 9X, 1HY/)
 2310 FORMAT (25X, I4,1X,1P2D10.3, I4,1X,1P2D10.3, I4,1X,1P2D10.3)
 2320 FORMAT (/35X, 32HADDITIONAL DATA FOR THIS PROBLEM/)
 2340 FORMAT (/35X, 4HNONE/)
 2330 FORMAT (/35X, 22HUNIDENTIFIABLE LOADING//35X,
     1         20HPROGRAM INTERRUPTED.)
 2350 FORMAT (///20X, 26HTABLE 6. - DYNAMIC LOADING/)
 2360 FORMAT (/31X, 20HDYNAMIC LOADING NO.  , I2/)
 2370 FORMAT (//20X,30HTABLE 7. - COLLAPSE PARAMETERS/)
 2380 FORMAT (/31X, 19HDISPLACEMENT LIMITS//40X,
     1           25HMAXIMUM HORIZONTAL DISPL:, 1PD13.4/40X,
     2           25HMAXIMUM  VERTICAL  DISPL:, 1PD13.4)
 2390 FORMAT (/31X, 12HSHEAR LIMITS/40X, 4HTERM, 13X, 5HSHEAR/40X,
     1           4HSTA., 13X, 5HVALUE)
 2400 FORMAT (/40X, I3, 7X, 1P2D15.4)
 2410 FORMAT (/31X, 24HINTERACTION DIAGRAM DATA//40X 4HTERM,10X,
     1           24HAXIAL FORCE          MOMENT/40X, 4HSTA., 11X,
     2           25HMULTIPLIER      MULTIPLIER)
 2420 FORMAT (/37X, 24HAXIAL FORCE INPUT VALUES/37X, 9F7.3)
 2430 FORMAT (/37X, 19HMOMENT INPUT VALUES/37X, 9F7.3)
 2440 FORMAT (//20X,30HTABLE 8. - STATION COORDINATES//40X,
     1           4HSTA.,12X, 7HX-COORD, 8X, 7HY-COORD)
C
C>-->     INITIALIZE CONSTANT VALUES
      DATA IEND, KEEPI, IYES / 3HEND, 4HKEEP, 3HYES /
      ZERO = 0.0D00
      P5 = 5.0D-01
      ONE = 1.0D00
```

```
C     SUBROUTINE INECHO                                          (CONTINUED)
C
C>-->     ESTABLISH THE HEADING ON THE FIRST PAGE OF OUTPUT
      CALL HEADNG
C>-->     READ AND ECHO TABLE 1  -  PROBLEM CONTROL DATA
      READ 1010, (KEEP(I), I=2,7), ISTAT, ISELFW, ISOPT, NADL, LDTYPE,
     1           IDOPT, NOUT, INEL, IBRK, ISYM, NB,SPAN,GRAV,TLIM,DTIME
      NJ = NB + 1
C>-->     CALL SUBROUTINE GEOM TO CALCULATE OR READ STATION COORDINATES
      CALL GEOM (FX)
         J = 0
         K = 1
      DO 110 I = 2, 7
         II(K) = 0
         IF (KEEP(I) .NE. KEEPI) GO TO 110
         II(K) = I
         J = J + 1
         K = K + 1
  110 CONTINUE
C>-->     PRINT DATA IN TABLE 1
      PRINT 2020
      IF (J .GT. 0) GO TO 120
      PRINT 2030
         GO TO 130
  120 PRINT 2040, (II(I), I = 1, J)
  130 PRINT 2050, ISTAT, GRAV
      IF (IBRK .EQ. 0) PRINT 2051
      IF (IBRK .EQ. 1) PRINT 2052
      IF (ISYM .EQ. 0) PRINT 2054
      IF (ISYM .EQ. 1) PRINT 2056
      IF (ISYM .EQ. 2) PRINT 2058
      IF (ISTAT .NE. IYES) GO TO 140
      PRINT 2060, ISOPT
      IF (ISELFW .EQ. 0) PRINT 2062
      IF (ISELFW .EQ. 1) PRINT 2065
  140 IF (KEEP(6) .EQ. KEEPI) GO TO 145
         NDL = 0
  145 NDL = NDL + NADL
      IF (NDL .EQ. 0) GO TO 160
      PRINT 2070, NDL, IDOPT, NOUT, TLIM
      IF (LDTYPE .EQ. 0) PRINT 2072
      IF (LDTYPE .EQ. 1) PRINT 2074
      IF (INEL .EQ. 0) PRINT 2076
      IF (INEL .EQ. 1) PRINT 2078
      IF (DTIME .EQ. ZERO) GO TO 150
      PRINT 2080, DTIME
         GO TO 160
  150 PRINT 2090
C
C>-->     READ AND ECHO TABLE 2. - CROSS SECTION DESCRIPTION
C
  160 CALL HEADNG
      PRINT 2100
      IF (KEEP(2) .EQ. KEEPI) GO TO 210
         J = 1
  170 READ 1020, JSN(J), B1N(J), B2N(J), B3N(J), IENDN
      DO 180 I = 1, 9, 3
  180 READ 1030, IS(I), MAT(I), DN(I,J), IS(I+1), MAT(I+1),
     1           DN(I+1, J), IS(I+2), MAT(I+2), DN(I+2, J)
      IF (IENDN .EQ. IEND) GO TO 190
         J = J + 1
         GO TO 170
  190    NCT2 = J
         NRT2 = 1
  200 READ 1040, JRN(NRT2), DTN(NRT2), ATN(NRT2), DBN(NRT2), ABN(NRT2)
      IF (JRN(NRT2) .EQ. JSN(NCT2)) GO TO 220
         NRT2 = NRT2 + 1
         GO TO 200
  210 PRINT 2110
```

```
C     SUBROUTINE INECHO                                          (CONTINUED)
C
  220 DO 230 I = 1, NCT2
         PRINT 2120, JSN(I), B1N(I), B2N(I), B3N(I)
         PRINT 2130, (IS(J), MAT(J), DN(J,I), J = 1, 9)
  230 CONTINUE
      PRINT 2140
      PRINT 2150, (JRN(I), DTN(I), ATN(I), DBN(I), ABN(I), I = 1, NRT2)
C
C>-->     READ AND ECHO TABLE 3. - STRESS-STRAIN CURVES
C
      CALL HEADNG
      PRINT 2160
      IF (KEEP(3) .EQ. KEEPI) GO TO 250
      READ 1020, NSSC
      DO 240 I = 1, NSSC
         READ 1050, SIGMUL(I), GAMMA(I)
         READ 1070, (SIGN(J,I), J = 1, 10)
         READ 1050, EPSMUL(I), EPSU(I), EPSPR(I)
         READ 1070, (EPSN(J,I), J = 1, 10)
         EPSU(I) = DABS(EPSU(I))
  240 CONTINUE
         GO TO 260
  250 PRINT 2110
  260 DO 270 I = 1, NSSC
         PRINT 2170, I, GAMMA(I), EPSU(I), SIGMUL(I), EPSMUL(I)
         PRINT 2180, (SIGN(J,I), J = 1, 10)
         PRINT 2190, (EPSN(J,I), J = 1, 10)
  270 CONTINUE
C
C>-->     READ AND ECHO TABLE 4. - SPECIFIED CONDITIONS
C
      CALL HEADNG
      PRINT 2200
      IF (KEEP(4) .NE. KEEPI) GO TO 280
      PRINT 2110
         GO TO 330
  280    J = 1
  290 READ 1060, JSDN(J),KU(J),KV(J),KTH(J),USN(J),VSN(J),THSN(J), IENDN
      IF (IENDN .EQ. IEND) GO TO 300
         J = J + 1
         GO TO 290
  300    NCT4 = J
  330 PRINT 2210
      DO 335 I = 1, NJ
         IHINGE(I) = ZERO
  335 CONTINUE
      IHINGE(NJ+1) = 0
      DO 420 J = 1, NCT4
         KEY = 2 * (2*KU(J) + KV(J)) + KTH(J)
         IF (KEY .GT. 7) KEY = 8
         GO TO (340, 350, 360, 370, 380, 390, 400, 410), KEY
  340    PRINT 2220, JSDN(J), KU(J), KV(J), KTH(J), THSN(J)
         GO TO 420
  350    PRINT 2230, JSDN(J), KU(J), KV(J), KTH(J), VSN(J)
         GO TO 420
  360    PRINT 2230, JSDN(J), KU(J), KV(J), KTH(J), VSN(J), THSN(J)
         GO TO 420
  370    PRINT 2240, JSDN(J), KU(J), KV(J), KTH(J), USN(J)
         GO TO 420
  380    PRINT 2250, JSDN(J), KU(J), KV(J), KTH(J), USN(J), THSN(J)
         GO TO 420
  390    PRINT 2240, JSDN(J), KU(J), KV(J), KTH(J), USN(J), VSN(J)
         GO TO 420
  400    PRINT 2240, JSDN(J), KU(J), KV(J), KTH(J),USN(J),VSN(J),THSN(J)
         GO TO 420
  410    KEY = JSDN(J)
         IHINGE(KEY) = 1
         PRINT 2260, KEY
  420 CONTINUE
```

```
C     SUBROUTINE INECHO                                          (CONTINUED)
C
C>-->      READ AND ECHO TABLE 5. - STATIC LOADING
C
      PRINT 2290
      IF (ISTAT .NE. IYES) GO TO 510
      IF (KEEP(5) .NE. KEEPI) GO TO 430
      PRINT 2110
      PRINT 2300
      PRINT 2310, (JI5(J), QXI5(J), QYI5(J), JM5(J), QXM5(J), QYM5(J),
     1             JL5(J), QXL5(J), QYL5(J), J = 1, NCT5)
      PRINT 2320
         NCI5 = NCT5 + 1
         GO TO 440
  430    NCI5 = 1
  440    NCT5 = NCI5
         K = 0
         IND = 0
  450 READ 1080, JI5(NCT5), QXI5(NCT5), QYI5(NCT5), JM5(NCT5), QXM5(NCT5
     1), QYM5(NCT5), JL5(NCT5), QXL5(NCT5), QYL5(NCT5), IENDN
         K = K + 1
      IF (QXI5(NCT5).EQ.ZERO .AND. QYI5(NCT5).EQ.ZERO) IND = 1
      IF (IENDN .EQ. IEND) GO TO 460
         NCT5 = NCT5 + 1
         GO TO 450
  460 IF (IND .EQ. 1) GO TO 470
      PRINT 2300
      PRINT 2310, (JI5(J), QXI5(J), QYI5(J), JM5(J), QXM5(J), QYM5(J),
     1             JL5(J), QXL5(J), QYL5(J), J = NCI5, NCT5)
         GO TO 540
  470 IF (K - NCT5) 480, 490, 480
  480 IF (K .EQ. 1) GO TO 500
  490 PRINT 2330
      STOP
  500    NCT5 = NCT5 - 1
  510 PRINT 2340
C
C>-->      READ AND ECHO TABLE 6. - DYNAMIC LOADING
C
  540 PRINT 2350
         NCL = 0
      IF (KEEP(6) .EQ. KEEPI) GO TO 550
         NPDL = 0
         GO TO 570
  550 PRINT 2110
      DO 560 I = 1, NPDL
         NCI = NCL + 1
         NCL = NCL + NCS(I)
         PRINT 2360, I
         PRINT 2300
         PRINT 2310, (JI6(J), QXI6(J), QYI6(J), JM6(J), QXM6(J),QYM6(J),
     1                JL6(J), QXL6(J), QYL6(J), J = NCI, NCL)
  560 CONTINUE
      PRINT 2320
  570 IF (NADL .NE. 0) GO TO 580
      PRINT 2340
         GO TO 630
  580    NSI = NPDL + 1
         NPDL = NDL
         NS = NSI
         J = NCL
  590    NCS(NS) = 0
  600    J = J + 1
      READ 1080, JI6(J), QXI6(J), QYI6(J), JM6(J), QXM6(J), QYM6(J),
     1           JL6(J), QXL6(J), QYL6(J), IENDN
         NCS(NS) = NCS(NS) + 1
      IF (IENDN .NE. IEND) GO TO 600
      IF (NS .EQ. NDL) GO TO 610
         NS = NS + 1
         GO TO 590
```

```
C     SUBROUTINE INECHO                                              (CONTINUED)
C
  610     NCL = 0
      DO 620 I = NSI, NDL
         NCI = NCL + 1
         NCL = NCL + NCS(I)
         PRINT 2360, I
         PRINT 2300
         PRINT 2310, (JI6(J), QXI6(J), QYI6(J), JM6(J), QXM6(J),QYM6(J),
     1                JL6(J), QXL6(J), QYL6(J), J = NCI, NCL)
  620 CONTINUE
      IF (LDTYPE .EQ. 1) GO TO 630
      READ 1050, FO, TR, TD
      PRINT 2280, TR, TD, FO
C
C>-->     READ AND ECHO TABLE 7. - COLLAPSE PARAMETERS
C
  630 CALL HEADNG
      PRINT 2370
      IF (NDL .EQ. 0) GO TO 720
      IF (KEEP(7) .NE. KEEPI) GO TO 640
      PRINT 2110
         GO TO 690
  640 READ 1050, UMAX, VMAX
         NST7 = 1
  650 READ 1040,  JS7N(NST7),  SMAXN(NST7)
      IF (JS7N(NST7) .EQ. NJ) GO TO 660
         NST7 = NST7 + 1
         GO TO 650
  660    NIA7 = 1
  670 READ 1040, JIA7(NIA7), PMULN(NIA7), BMULN(NIA7)
      IF (JIA7(NIA7) .EQ. NJ) GO TO 680
         NIA7 = NIA7 + 1
         GO TO 670
  680 READ 1070, PIAN
      READ 1070, BIAN
  690 PRINT 2380, UMAX, VMAX
      PRINT 2390
      DO 700 I = 1, NIA7
         PRINT 2400, JS7N(I), SMAXN(I)
  700 CONTINUE
      PRINT 2410
      DO 710 I = 1, NIA7
         PRINT 2400, JIA7(I), PMULN(I), BMULN(I)
  710 CONTINUE
      PRINT 2420, PIAN
      PRINT 2430, BIAN
         GO TO 730
  720 PRINT 2340
C
C>-->     PRINT TABLE 8. - STATION COORDINATES
C
  730 CALL HEADNG
      PRINT 2440
      DO 740 I = 1, NJ
         PRINT 2400, I, X(I), Y(I)
  740 CONTINUE
      RETURN
      END
```

```
C     SUBROUTINE GEOM
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *  THIS SUBROUTINE ESTABLISHES INITIAL GEOMETRY OF THE STRUCTURE    *
C     *           JOINT COORDINATES ARE READ IN OR CALCULATED.            *
C     *        INITIAL SLOPES AND LENGTHS OF THE BARS AND INITIAL         *
C     *           CURVATURES AT THE JOINTS ARE ALSO DETERMINED            *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE GEOM (FX)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /IGEOM/ PHIO(25), THO(24), IBRK, ISYM
  100 FORMAT (10F8.0)
      DATA DM3 / 1.0D-03 /
C
C>-->     TEST FOR BROKEN LINE STRUCTURE
      IF (IBRK .EQ. 1) GO TO 180
C
C>-->     DIVIDE STRUCTURE IN GIVEN NUMBER OF BARS
C         AND CALCULATE JOINT COORDINATES
C
      JLAST = NB/2
C>-->     TEST FOR SYMMETRICAL STRUCTURE
      IF (ISYM .NE. 1) JLAST = NB
      DN = JLAST
      X(1) = ZERO
      Y(1) = ZERO
      XLAST = P5 * SPAN
      IF (ISYM .NE. 1)  XLAST = SPAN
      YLAST = FX(XLAST)
      DELS = DSQRT (XLAST*XLAST + YLAST*YLAST)/DN
  110 DO 140 I = 1, JLAST
         DX = DELS
  120    XIP1 = X(I) + DX
         YIP1 = FX(XIP1)
         DY = YIP1 - Y(I)
         DXY = DSQRT(DX*DX + DY*DY)
         IF (DABS(DXY-DELS) .LT. DM3) GO TO 130
         DX = DX * DELS / DXY
         GO TO 120
  130    X(I+1) = XIP1
         Y(I+1) = YIP1
  140 CONTINUE
C
      DX = XLAST - X(JLAST+1)
      DY = YLAST - Y(JLAST+1)
      DDELS = DSQRT(DX*DX + DY*DY)
      IF (DDELS .GT. DM3) GO TO 150
         X(JLAST+1) = XLAST
         Y(JLAST+1) = YLAST
         GO TO 160
  150 DDELS = DDELS / DN
      IF (DX .LT. ZERO) DDELS = - DDELS
      DELS = DELS + DDELS
      GO TO 110
  160 IF (ISYM .NE. 1) GO TO 190
      DO 170 I = 1, JLAST
         K = NJ - I + 1
         X(K) = SPAN - X(I)
         Y(K) = Y(I)
  170 CONTINUE
      GO TO 190
C
C>-->     READ JOINT COORDINATES, IF STRUCTURE HAS A BROKEN LINE AXIS
  180 READ 100, (X(I), Y(I), I = 1, NJ)
```

```
C     SUBROUTINE GEOM                                              (CONTINUED)
C
C>-->      CALCULATE INITIAL LENGTHS AND SLOPES OF THE BARS
C          AND INITIAL CURVATURES AT THE JOINTS
  190 DO 200 I = 1, NB
         DX = X(I+1) - X(I)
         DY = Y(I+1) - Y(I)
         XLO(I) = DSQRT(DX*DX + DY*DY)
         THO(I) = DARSIN(DY/XLO(I))
  200 CONTINUE
      PHIO(1) = ZERO
      DO 210 I = 2, NB
         PHIO(I) = (THO(I)-THO(I-1))/P5/(XLO(I)+XLO(I-1))
  210 CONTINUE
      PHIO(NJ) = ZERO
      RETURN
      END



C     SUBROUTINE INTERP
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *    THIS SUBROUTINE DISTRIBUTES DATA  BY LINEAR INTERPOLATION     *
C     *    BETWEEN STATIONS JS(I-1) TO JS(I), I = 2, NC, FOR NC.GE.2     *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE INTERP (NC, JS, ZN, Z)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      DIMENSION JS(1), ZN(1), Z(1)
      DO 100 I = 1, NJ
  100 Z(I) = ZERO
      Z(1) = ZN(1)
      DO 200 I = 2, NC
         HNEL = JS(I) - JS(I-1)
         DZ = (ZN(I)-ZN(I-1)) / HNEL
         JI = JS(I-1) + 1
         JL = JS(I)
         DO 200 J = JI, JL
  200 Z(J) = Z(J-1) + DZ
      RETURN
      END



C     FUNCTION FX
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *              THIS FUNCTION DESCRIBES A HORIZONTAL BEAM,           *
C     *              USED IN PROBLEMS DTP3 AND P2.2 OF SET DTP2           *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      FUNCTION FX (X)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DATA ZERO / 0.0D00 /
            FX = ZERO
      RETURN
      END
```

```
C     FUNCTION FX
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *    THIS FUNCTION DESCRIBES A CIRCULAR ARCH HAVING A CENTRAL     *
C     *    ANGLE OF OPENING OF 87.21 DEGREES, SPAN LO = 687 UNITS OF    *
C     *         LENGTH, RISE OF 0.2 LO, USED IN PROBLEM DTP2.1          *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      FUNCTION FX (X)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DATA A, B, C / 841.575D00, 154.575D00, 360.675D00 /
              FX = DSQRT((A-X)*(B+X)) - C
      RETURN
      END
```

```
C     FUNCTION FX
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *           THIS FUNCTION DESCRIBES A SEMI-CIRCULAR ARCH          *
C     *           HAVING A DIAMETER OF 354.00  UNITS OF LENGTH          *
C     *                 USED IN PROBLEMS DAP1 AND DAP2                  *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      FUNCTION FX (X)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DATA D / 354.0D00 /
              FX = DSQRT (X * (D-X))
      RETURN
      END
```

```
C     SUBROUTINE MABC
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *      THIS IS A MATRIX MULTIPLICATION ROUTINE.  MATRIX A IS      *
C     *         MULTIPLIED BY B AND THE RESULT IS STORED IN C           *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE MABC (A, B, C, N, M)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DIMENSION A(N,N), B(N,M), C(N,M)
      DATA ZERO / 0.0D00 /
C
              DO 110 I = 1, N
              DO 110 J = 1, M
                   TEMP = ZERO
                   DO 100 K = 1, N
  100              TEMP = TEMP + A(I,K)*B(K,J)
                   C(I,J) = TEMP
  110         CONTINUE
              RETURN
              END
```

```
C     SUBROUTINE RTSR
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *              THIS IS A MATRIX MULTIPLICATION ROUTINE              *
C     *              THE SIZE OF ALL MATRICES IS SIX BY SIX               *
C     *        THE TRANSPOSE OF R IS MULTIPLIED BY S AND THEN BY R        *
C     *                  AND THE RESULT IS STORED IN X                    *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE RTSR (R, S, X)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DIMENSION R(6,6), S(6,6), X(6,6), T(6,6)
      DATA ZERO / 0.0D00 /
C
              DO 110 I = 1, 6
              DO 110 J = 1, 6
                   TEMP = ZERO
                   DO 100 K = 1, 6
  100              TEMP = TEMP + R(K,I)*S(K,J)
                   T(I,J) = TEMP
  110         CONTINUE
C
              CALL MABC (T, R, X, 6, 6)
C
              RETURN
              END
```

```
C     SUBROUTINE INVERT
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *                 THIS SUBROUTINE INVERTS A MATRIX                  *
C     *                  INPUT MATRIX IS DESTROYED AND                    *
C     *                   SUBSTITUTED FOR ITS INVERSE                     *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE INVERT (X, N, II)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DIMENSICN X(N,N)
      DATA ZERO, EP, ONE / 0.0D00, 1.0D-10, 1.0D00 /
C
         DO 400 I = 1, N
              IF (DABS(X(I,I)) .LT. EP) GO TO 500
              S = ONE / X(I,I)
              DO 100 J = 1, N
  100         X(I,J) = X(I,J) * S
              X(I,I) = S
              DO 300 J = 1, N
                   IF (J .EQ. I) GO TO 300
                   S = X(J,I)
                   X(J,I) = ZERO
                   DO 200 K = 1, N
  200              X(J,K) = X(J,K) - S * X(I,K)
  300         CONTINUE
  400    CONTINUE
      RETURN
C
  500 PRINT 600, II
      STOP
  600  FORMAT (1H1///, 30X,  27HNO INVERSE EXISTS AT JOINT ,  I3)
      END
```

```
C     SUBROUTINE DIST
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *     THIS SUBROUTINE DISTRIBUTES INPUT DATA TO ALL STATIONS;       *
C     *     CALCULATES MASSES AND SELF WEIGHT, INITIAL LOCATIONS OF       *
C     *     CENTROIDS, AXIAL AND FLEXURAL STIFFNESSES AT THE JOINTS       *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE DIST
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /BMAST/ BMASS(25), BM(25), T(24), SH(24)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL,JF, INEL, LDTYPE
      COMMON /CURVS/ EPSN(10,5),SIGN(10,5),EPSMUL(5),SIGMUL(5),EPSPR(5)
      COMMON /FAIL1/ SMAX(25), SMAXN(10), JS7N(10), UMAX, VMAX, NST7
      COMMON /FAIL2/ BMUL(25), PMUL(25), BMULN(10), PMULN(10),
     1               PIAN(9), BIAN(9), EPSU(5), JIA7(10), NIA7
      COMMON /LOADS/ QX(25), QY(25), QZ(25), QXD(25), QYD(25)
      COMMON /SEGM1/ D(25,9), E(5,2), GAMMA(5), IS(9), MAT(9)
      COMMON /STEEL/ AB(25), AT(25), DB(25), DT(25)
      COMMON /STIFF/ EI(25), AE(25)
      COMMON /TABL1/ GRAV,TLIM,KEEP(7),ISTAT,ISOPT,NDL,IDOPT,NOUT,ISELFW
      COMMON /TABL2/ DN(9,10), B1N(10),B2N(10),B3N(10), DTN(10),ATN(10),
     1               DBN(10), ABN(10), JSN(10), JRN(10), NCT2, NRT2
      COMMON /TABL5/ JI5(20), QXI5(20), QYI5(20), JM5(20), QXM5(20),
     1               QYM5(20), JL5(20), QXL5(20), QYL5(20), NCT5
      COMMON /TABL6/ JI6(20), QXI6(20), QYI6(20), JM6(20), QXM6(20),
     1               QYM6(20), JL6(20), QXL6(20), QYL6(20), NCS(20),NPDL
      COMMON /XSECT/ B1(25), B2(25), B3(25), CG(25), PC(25)
      DIMENSION DUM(10), DZON(9)
      EQUIVALENCE (DUM(1), T(1)), (DZON(1), T(12))
      DATA THREE, SIX, IYES / 3.0D00, 6.0D00, 3HYES /
C>-->     DISTRIBUTE CROSS SECTION DATA
      CALL INTERP (NCT2, JSN, B1N, B1)
      CALL INTERP (NCT2, JSN, B2N, B2)
      CALL INTERP (NCT2, JSN, B3N, B3)
C>-->     DISTRIBUTE REINFORCEMENT DATA
          IF (NRT2 .GT. 1)  GO TO 80
      DO 70 I = 1, NJ
         AB(I) = ABN(1)
         AT(I) = ATN(1)
         DB(I) = DBN(1)
         DT(I) = DTN(1)
   70 CONTINUE
         GO TO 90
   80 CALL INTERP (NRT2, JRN, ABN, AB)
      CALL INTERP (NRT2, JRN, ATN, AT)
      CALL INTERP (NRT2, JRN, DBN, DB)
      CALL INTERP (NRT2, JRN, DTN, DT)
C>-->     DISTRIBUTE ZONE DEPTHS
   90 DO 120 I = 1, 9
          DO 100 J = 1, NCT2
  100     DUM(J) = DN(I,J)
          CALL INTERP (NCT2, JSN, DUM, QZ)
          DO 110 J = 1, NJ
  110     D(J,I) = QZ(J)
  120 CONTINUE
C
C>-->     DISTRIBUTE MASS AND SELF-WEIGHT
      DO 130 I = 1, NJ
         QX(I) = ZERO
         QY(I) = ZERO
         QZ(I) = ZERO
  130 CONTINUE
      I = 1
      DO 135 J = 1, 9
  135 DZON(J) = D(I,J)
```

```
C     SUBROUTINE DIST                                                   (CONTINUED)
C
      CALL MASS (DZON, B1(I), B2(I), B3(I), DB(I), DT(I), AB(I),
     1           AT(I), AGAM)
         AGL = AGAM * XLO(I)
      QY(I) = QY(I) - AGL / THREE
      QY(I+1) = QY(I+1) - AGL / SIX
      DO 140 I = 2, NB
         DO 138 J = 1, 9
  138    DZON(J) = D(I,J)
      CALL MASS (DZON, B1(I), B2(I), B3(I), DB(I), DT(I), AB(I),
     1           AT(I), AGAM)
         AGL = AGAM * XLO(I-1)
         QY(I-1) = QY(I-1) - AGL/SIX
         QY(I) = QY(I) - AGL/THREE
         AGL = AGAM * XLO(I)
         QY(I) = QY(I) - AGL/THREE
         QY(I+1) = QY(I+1) - AGL/SIX
  140 CONTINUE
      I = NJ
      DO 145 J = 1, 9
  145 DZON(J) = D(I,J)
      CALL MASS (DZON, B1(I), B2(I), B3(I), DB(I), DT(I), AB(I),
     1           AT(I), AGAM)
         AGL = AGAM * XLO(NB)
      QY(I-1) = QY(I-1) - AGL / SIX
      QY(I) = QY(I) - AGL/THREE
      SELFW = ISELFW
      DO 150 I = 1, NJ
         BMASS(I) = -QY(I) / GRAV
         QY(I) = SELFW * QY(I)
  150 CONTINUE
C
C>-->     DISTRIBUTE STATIC LOAD DATA
      IF (ISTAT .NE. IYES) GO TO 160
      CALL DFORCE (NCT5, JI5, QXI5, QYI5, JM5, QXM5, QYM5,
     1                   JL5, QXL5, QYL5, QX, QY)
C
C>-->     CALCULATE INITIAL LOCATION OF CENTROID AT EACH
C         CROSS SECTION, AXIAL AND FLEXURAL STIFFNESSES
  160 DO 170 J = 1, NSSC
         E(J,1) = SIGMUL(J)*SIGN(5,J) / (EPSMUL(J)*EPSN(5,J))
         E(J,2) = SIGMUL(J)*SIGN(6,J) / (EPSMUL(J)*EPSN(6,J))
  170 CONTINUE
      DO 190 I = 1, NJ
         DO 180 J = 1, 9
  180    DZON(J) = D(I,J)
         CALL CENTER (DZON, B1(I), B2(I), B3(I), AT(I), DT(I),
     1                AB(I), DB(I), PC(I), AE(I), EI(I))
         CG(I) = PC(I)
  190 CONTINUE
C
C>-->     DISTRIBUTE FAILURE PARAMETERS
      IF (NDL .EQ. 0)  RETURN
      IF (NST7 .GT. 1) GO TO 210
      DO 200 I = 1, NJ
         SMAX(I) = SMAXN(1)
  200 CONTINUE
      GO TO 220
  210 CALL INTERP (NST7, JS7N, SMAXN, SMAX)
  220 IF (NIA7 .GT. 1) GO TO 240
      DO 230 I = 1, NJ
         PMUL(I) = PMULN(1)
         BMUL(I) = BMULN(1)
  230 CONTINUE
      RETURN
  240 CALL INTERP (NIA7, JIA7, PMULN, PMUL)
      CALL INTERP (NIA7, JIA7, BMULN, BMUL)
      RETURN
      END
```

```
C     SUBROUTINE DFORCE
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *       THIS SUBROUTINE DISTRIBUTES STATIC OR DYNAMIC LOADING     *
C     *            AS CONCENTRATED LOADS AT SPECIFIED STATIONS          *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE DFORCE (NC, JI,QIX,QIY, JM,QMX,QMY, JL,QLX,QLY, QX, QY)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      DIMENSION JI(1), QIX(1), QIY(1), JM(1), QMX(1), QMY(1),
     1          JL(1), QLX(1), QLY(1), QX(1), QY(1)
C
      DO 180 J = 1, NC
C
C>-->    DETERMINE TYPE OF SPECIFIED LOADING
         IF (QIX(J).EQ.ZERO .AND. QIY(J).EQ.ZERO) GO TO 160
         IF (QMX(J).EQ.ZERO .AND. QMY(J).EQ.ZERO) GO TO 140
         IF (QLX(J).EQ.ZERO .AND. QLY(J).EQ.ZERO) GO TO 120
C
C>-->    PARABOLIC DISTRIBUTION FROM JI(J) TO JL(J)
         IF (QIX(J) .NE. ZERO)
     1   CALL DPARAB (JI(J), JM(J), JL(J), QIX(J), QMX(J), QLX(J), Y,QX)
         IF (QIY(J) .NE. ZERO)
     1   CALL DPARAB (JI(J), JM(J), JL(J), QIY(J), QMY(J), QLY(J), X,QY)
         GO TO 180
C
C>-->    LINEAR DISTRIBUTION FROM JI(J) TO JM(J)
  120    IF (QIX(J) .NE. ZERO)
     1   CALL LINEAR (JI(J), JM(J), QIX(J), QMX(J), Y, QX)
         IF (QIY(J) .NE. ZERO)
     1   CALL LINEAR (JI(J), JM(J), QIY(J), QMY(J), X, QY)
         GO TO 180
  140    IF (QLX(J) .EQ. ZERO) GO TO 150
C
C>-->    PRESSURE DISTRIBUTION FROM JI(J) TO JL(J)
         JIJ = JI(J) + 1
         JLJ = JL(J)
         DO 145 I = JIJ, JLJ
              DX = X(I) - X(I-1)
              DY = Y(I) - Y(I-1)
              DQX = P5 * QIX(J) * DY
              DQY = P5 * QIX(J) * DX
              QX(I) = QX(I) - DQX
              QX(I-1) = QX(I-1) - DQX
              QY(I) = QY(I) + DQY
              QY(I-1) = QY(I-1) + DQY
  145    CONTINUE
         GO TO 180
C
C>-->    CONCENTRATED LOAD AT JI(J)
  150    JIJ = JI(J)
         QX(JIJ) = QX(JIJ) + QIX(J)
         QY(JIJ) = QY(JIJ) + QIY(J)
         GO TO 180
C
C>-->    PRINT MESSAGE FOR UNIDENTIFIABLE TYPE OF LOADING AND STOP
C
  160    PRINT 170, JI(J)
  170    FORMAT ( ///30X,33HUNIDENTIFIABLE LOAD TYPE AT JOINT, I5,
     1          //30X, 21HPROGRAM DISCONTINUED.)
         STOP
  180 CONTINUE
C
      RETURN
      END
```

```
C     SUBROUTINE DPARAB
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *      THIS SUBROUTINE DISTRIBUTES SPECIFIED PARABOLIC LOADING    *
C     *           AS CONCENTRATED LOADS FROM STATIONS JI TO JL          *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE DPARAB (JI, JM, JL, QIN, QMN, QLN, Z, Q)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DIMENSION Z(1), Q(1)
      DATA TWO, FOUR, TWEL / 2.0D00, 4.0D00, 1.2D01 /
C
              Q1 = QIN
              Q2 = QMN
              Z1 = Z(JI)
              Z2 = Z(JM)
              Z3 = Z(JL)
              FAC1 = (Z2-Z1) * (Z3-Z1)
              FAC2 = (Z2-Z1) * (Z2-Z3)
              FAC3 = (Z3-Z1) * (Z3-Z2)
              FAC1 = Q1 / FAC1
              FAC2 = Q2 / FAC2
              FAC3 = QLN/ FAC3
              A = FAC1 + FAC2 + FAC3
              JIP1 = JI + 1
              DO 100 J = JIP1, JL
                  Q2 = FAC1 * (Z(J)-Z3) * (Z(J)-Z2) +
     1                     FAC2 * (Z(J)-Z1) * (Z(J)-Z3) +
     2                     FAC3 * (Z(J)-Z2) * (Z(J)-Z1)
              DZ = DABS(Z(J)-Z(J-1))
              Q(J-1) = Q(J-1) + DZ*(FOUR*Q1 + TWO*Q2 - A*DZ*DZ) / TWEL
              Q(J) = Q(J) + DZ*(TWO*Q1 + FOUR*Q2 - A*DZ*DZ) / TWEL
  100         Q1 = Q2
      RETURN
      END
```

```
C     SUBROUTINE LINEAR
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *       THIS SUBROUTINE DISTRIBUTES SPECIFIED LINEAR LOADING      *
C     *           AS CONCENTRATED LOADS FROM STATIONS JI TO JL          *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE LINEAR ( JI, JL, QI, QL, Z, Q)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DIMENSION Z(1), Q(1)
      DATA TWO, THREE, SIX / 2.0D00, 3.0D00, 6.0D00 /
C
              QLEFT = QI
              DELQ = (QL-QI) / DABS(Z(JL)-Z(JI))
              JIP1 = JI + 1
              DO 100 I = JIP1, JL
                 DZ = DABS(Z(I)-Z(I-1))
                 DQ = DZ * DELQ
                 Q(I-1) = Q(I-1) + DZ * (THREE*QLEFT + DQ) / SIX
                 Q(I) = Q(I) + DZ * (THREE*QLEFT + TWO*DQ) / SIX
  100         QLEFT = QLEFT + DQ
      RETURN
      END
```

```
C     SUBROUTINE CENTER
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *      THIS SUBROUTINE CALCULATES INITIAL LOCATION OF CENTROID,   *
C     *       AXIAL AND FLEXURAL STIFFNESSES AT GIVEN CROSS SECTION     *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE CENTER (DZON, B1,B2,B3, AT,DT, AB,DB, DBAR, SAE, SEI)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /SEGM1/ D(25,9), E(5,2), GAMMA(5), IS(9), MAT(9)
      COMMON /SEGM2/ DI(30), DA(30), MI(30)
      DIMENSION DZON(1)
C
C>-->    CALCULATE TRANSFORMED AREA OF THE SECTION
C        AND FIRST MOMENT ABOUT THE TOP
      SAE = ZERO
      SEI = ZERO
      SDAE = ZERO
      CALL SEG (DZON, B1, B2, B3)
      DO 100 J = 1, 30
         MM = MI(J)
         DAE = DA(J) * E(MM,1)
         SAE = SAE + DAE
         SDAE = SDAE + DAE*DI(J)
  100 CONTINUE
C>-->    TEST FOR TOP REINFORCEMENT
      IF (AT .EQ. ZERO)  GO TO 130
C>-->    DETERMINE TYPE OF MATERIAL AT THE LEVEL OF TOP REINFORCEMENT
      DO 110 J = 1, 30
         IF (DT .GT. DI(J)) GO TO 110
         MT = MI(J)
         GO TO 120
  110 CONTINUE
C>-->    ADD CONTRIBUTION OF TOP REINFORCEMENT
  120 DAE = AT * (E(NSSC,1) - E(MT,1))
      SAE = SAE + DAE
      SDAE = SDAE + DAE*DT
C>-->    TEST FOR BOTTOM REINFORCEMENT
  130 IF (AB .EQ. ZERO) GO TO 160
C>-->    DETERMINE TYPE OF MATERIAL AT THE LEVEL OF BOTTOM REINFORCEMENT
      DO 140 J = 1, 30
         K = 31 - J
         IF (DB .LT. DI(K)) GO TO 140
         MB = MI(K)
         GO TO 150
  140 CONTINUE
C>-->    ADD CONTRIBUTION OF BOTTOM REINFORCEMENT
  150 DAE = AB * (E(NSSC,1) - E(MB,1))
      SAE = SAE + DAE
      SDAE = SDAE + DAE*DB
C>-->    CALCULATE DEPTH OF CENTROID
  160 DBAR = SDAE / SAE
C>-->    CALCULATE AXIAL AND FLEXURAL STIFFNESSES
      DO 170 J = 1, 30
         MM = MI(J)
         DJ = DI(J) - DBAR
         SEI = SEI + DA(J) * E(MM,1) * DJ * DJ
  170 CONTINUE
      IF (AT .EQ. ZERO) GO TO 180
      DJ = DT - DBAR
      SEI = SEI + AT * (E(NSSC,1)-E(MT,1)) * DJ * DJ
  180 IF (AB .EQ. ZERO) RETURN
      DJ = DB - DBAR
      SEI = SEI + AB * (E(NSSC,1)-E(MB,1)) * DJ * DJ
      RETURN
      END
```

```
C     SUBROUTINE MSTIF
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *           THIS SUBROUTINE CALCULATES MEMBER STIFFNESSES           *
C     *          IN LOCAL COORDINATES AND SETS UP TRANSFORMATION          *
C     *                MATRIX TO GLOBAL COORDINATE SYSTEM                 *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE MSTIF (DELS, IND, EIZ, AEX, COST, SINT, S, R)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DIMENSION S(6,6), R(6,6)
      DATA ZERO, ONE, TWO, SIX / 0.0D00, 1.0D00, 2.0D00, 6.0D00 /
      DATA THREE, FOUR, TWEL / 3.0D00, 4.0D00, 1.2D01 /
C
         DO 100 I = 1, 6
         DO 100 J = 1, 6
              S(I,J) = ZERO
              R(I,J) = ZERO
  100    CONTINUE
         GO TO (110, 120, 130), IND
  110         C22 = THREE
              C26 = THREE
              C33 = ZERO
              C36 = ZERO
              C66  =  THREE
         GO TO 140
  120         C22 = THREE
              C26 = ZERO
              C33 = THREE
              C36 = ZERO
              C66 = ZERO
         GO TO 140
  130         C22 = TWEL
              C26 = SIX
              C33 = FOUR
              C36 = TWO
              C66 = FOUR
  140         AEOL = AEX / DELS
              EIOL = EIZ / DELS
              EIOL2 = EIOL / DELS
              EIOL3 = EIOL2 / DELS
              S(1,1) = AEOL
              S(1,4) = - AEOL
              S(4,4) = AEOL
              S(2,2) = C22 * EIOL3
              S(2,3) = (IND-1) * THREE * EIOL2
              S(2,5) = - S(2,2)
              S(2,6) = C26 * EIOL2
              S(3,3) = C33 * EIOL
              S(3,5) = - S(2,3)
              S(3,6) = C36 * EIOL
              S(5,5) = S(2,2)
              S(5,6) = - S(2,6)
              S(6,6) = C66 * EIOL
              S(4,1) = S(1,4)
         DO 150 I = 2, 5
         DO 150 J = I, 6
              S(J,I) = S(I,J)
  150    CONTINUE
         IF (IND .EQ. 3) GO TO 160
              S(3*IND, 3*IND) = ONE
  160         R(1,1) = COST
              R(2,2) = COST
              R(1,2) = SINT
              R(2,1) = - SINT
              R(3,3) = ONE
              R(4,4) = COST
```

```
C     SUBROUTINE MSTIF                                          (CONTINUED)
C
               R(5,5) = COST
               R(6,6) = ONE
               R(4,5) = SINT
               R(5,4) = - SINT
               RETURN
               END




C     SUBROUTINE SEG
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *           THIS SUBROUTINE DEFINES TYPE OF MATERIAL AND          *
C     *             CALCULATES AREAS AND DEPTHS OF CENTROIDS            *
C     *                 OF EACH SEGMENT IN GIVEN SECTION                *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE SEG (DZON, B1, B2, B3)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /SEGM1/ D(25,9), E(5,2), GAMMA(5), IS(9), MAT(9)
      COMMON /SEGM2/ DI(30), DA(30), MI(30)
      DIMENSION DZON(1)
C
      DO 200 I = 1, 9
         GO TO (100, 150, 110, 120, 150, 150, 130, 140, 150), I
  100    DTOP = ZERO
         BTOP = B1
         BBOT = B1
         ISTRT = 1
         ITOP = 0
         GO TO 160
  110    BBOT = B2
         GO TO 150
  120    BTOP = B2
         GO TO 150
  130    BBOT = B3
         GO TO 150
  140    BTOP = B3
  150    ITOP = IS(I-1)
         DTOP = DZON(I-1)
         ISTRT = IS(I-1) + 1
  160    HN = IS(I) - ITOP
         IF (DZON(I) .LE. DTOP) GO TO 170
         HN = (DZON(I) - DTOP) / HN
         DELB = (BTOP - BBOT) / (DZON(I) - DTOP)
         GO TO 180
  170    HN = ZERO
         DELB = ZERO
  180    M = MAT(I)
         ISTOP = IS(I)
         IF (ISTRT .GT. ISTOP) GO TO 200
         DO 190 J = ISTRT, ISTOP
               DA(J) = HN * (BTOP - P5*DELB*HN)
               DI(J) = DTOP + P5*HN
               MI(J) = M
               DTOP = DTOP + HN
               BTOP = BTOP - DELB*HN
  190    CONTINUE
  200 CONTINUE
      RETURN
      END
```

```
C     SUBROUTINE STATIC
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *            THIS SUBROUTINE CONTROLS THE STATIC SOLUTION           *
C     *            BY CALLING OTHER SUBROUTINES, IT SOLVES FOR            *
C     *            STATIC DISPLACEMENTS, REFINES THE SOLUTION,            *
C     *              SOLVES FOR INTERNAL FORCES AND REACTIONS             *
C     *                      AND PRINTS STATIC RESULTS                    *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE STATIC
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /DISPL/ U(25), V(25), TH(25), UD(25), VD(25)
      COMMON /EPSOY/ XM1(25,32), XM2(25,32), XM3(25,32), ICRAC(25,32)
      COMMON /LOADS/ QX(25), QY(25), QZ(25), QXD(25), QYD(25)
      COMMON /TABL1/ GRAV,TLIM,KEEP(7),ISTAT,ISOPT,NDL,IDOPT,NOUT,ISELFW
      DIMENSION US(25,3), UA(25,3), FS(25,3), F(25,3), RES(25,3)
      EQUIVALENCE (US(1,1),XM1(1,1)), (UA(1,1),XM2(1,1)),
     1            (FS(1,1),XM3(1,1)), (F(1,1),XM3(1,17)),
     2            (RES(1,1), XM3(1,9))
    1 FORMAT(///20X, 35HSUBROUTINES STATIC-RESIDU FAILED TO/20X,
     1       28HCONVERGE AFTER 10 ITERATIONS)
      DATA DM5 / 1.0 D-05 /
C
      DO 130 I = 1, NJ
         FS(I,1) = QX(I)
         FS(I,2) = QY(I)
         FS(I,3) = QZ(I)
      DO 130 J = 1, 3
         F(I,J) = FS(I,J)
  130 CONTINUE
      CALL SOLVE
      DO 140 I = 1, NJ
      DO 140 J = 1, 3
         US(I,J) = UA(I,J)
  140 CONTINUE
         ITER = 0
  150 ITER = ITER + 1
      CALL RESIDU
      DO 160 I = 1, NJ
      DO 160 J = 1, 3
         IF (DABS(RES(I,J)) .GT. DM5)  GO TO 170
  160 CONTINUE
      GO TO 200
  170 DO 180 I = 1, NJ
      DO 180 J = 1, 3
         F(I,J) = RES(I,J)
  180 CONTINUE
      CALL SOLVE
      DO 190 I = 1, NJ
      DO 190 J = 1, 3
         US(I,J) = US(I,J) + UA(I,J)
  190 CONTINUE
      IF (ITER .LT. 10)  GO TO 150
      PRINT 1
      STOP
  200 DO 210 I = 1, NJ
         U(I) = US(I,1)
         V(I) = US(I,2)
         TH(I) = US(I,3)
  210 CONTINUE
      CALL STFOR
      CALL OUTPUT (ISOPT, ZERO, U, V)
      RETURN
      END
```

```
C     SUBROUTINE SOLVE
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                               *
C     *          THIS SUBROUTINE SOLVES FOR STATIC DISPLACEMENTS      *
C     *           USING RECURSION-INVERSION ALGORITHM, BASED ON       *
C     *               GAUSS ELIMINATION FOR BANDED MATRICES           *
C     *                                                               *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE SOLVE
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /EPSOY/ XM1(25,32), XM2(25,32), XM3(25,32), ICRAC(25,32)
      COMMON /STIFF/ EI(25), AE(25)
      COMMON /TABL4/ USN(10), VSN(10), THSN(10), IHINGE(26),
     1               JSDN(10), KU(10), KV(10), KTH(10), NCT4
      DIMENSION A(26,3), B(26,3,3), UA(25,3), F(25,3)
      DIMENSION AA(3,3), BB(3,3), CC(3,3), DD(3,1),S(6,6),R(6,6),ST(6,6)
      DIMENSION AM1(3,1), BM1(3,3), ATM(3,1), BTM(3,3), UP1(3,1)
      EQUIVALENCE (A(1,1), XM1(1,17)), (B(1,1,1), XM2(1,17)),
     1            (UA(1,1), XM2(1,1)), (F(1,1), XM3(1,17)),
     2            (XM3(1,25), S), (XM3(1,27), R), (XM3(1,29), ST)
C
         DO 100 I = 1, 6
         DO 100 J = 1, 6
              S(I,J) = ZERO
  100    CONTINUE
         DO 120 J = 1, 3
              A(1,J) = ZERO
              DO 110 K = 1, 3
  110         B(1,J,K) = ZERO
  120    CONTINUE
C
C>-->    START RECURSION PROCESS
         DO 300 I = 1, NJ
              DO 130 J = 1, 3
              DO 130 K = 1, 3
                   AA(J,K) = S(J+3, K)
                   BB(J,K) = S(J+3, K+3)
  130         CONTINUE
              IND = 3
              IF (IHINGE(I) .EQ. 1) IND = 1
              IF (IHINGE(I+1) .EQ. 1) IND = 2
              IEQ = 8
              DO 140 J = 1, NCT4
                   IF (JSDN(J) .NE. I) GO TO 140
                   KEY = 2 * (2*KU(J) + KV(J)) + KTH(J)
                   IF (KEY .GT. 7) GO TO 140
                   IN = J
                   IEQ = KEY
  140         CONTINUE
              IF (I .LT. NJ) GO TO 160
              DO 150 J = 1, 6
              DO 150 K = 1, 6
                   S(J,K) = ZERO
  150         CONTINUE
              GO TO 166
  160         DX = X(I+1) - X(I)
              DY = Y(I+1) - Y(I)
              CX = DX / XLO(I)
              CY = DY / XLO(I)
              EIZ = P5 * (EI(I)+EI(I+1))
              AEX = P5 * (AE(I)+AE(I+1))
              CALL MSTIF (XLO(I), IND, EIZ, AEX, CX, CY, ST, R)
              CALL RTSR (R, ST, S)
  166         DO 180 J = 1, 3
                   AM1(J,1) = A(I,J)
```

```
C     SUBROUTINE SOLVE                                                  (CONTINUED)
C
                  DO 170 K = 1, 3
                    BB(J,K) = BB(J,K) + S(J,K)
                    CC(J,K) = S(J, K+3)
  170               BM1(J,K) = B(I,J,K)
  180           CONTINUE
                DD(1,1) = - F(I,1)
                DD(2,1) = - F(I,2)
                DD(3,1) = - F(I,3)
                GO TO (240, 210, 210, 190, 190, 190, 190, 260), IEQ
  190           DO 200 J = 1, 3
                  AA(1,J) = ZERO
                  BB(1,J) = ZERO
                  CC(1,J) = ZERO
  200           CONTINUE
                BB(1,1) = ONE
                DD(1,1) = - USN(IN)
                GO TO (240, 210, 210, 260, 240, 210, 210, 260), IEQ
  210           DO 220 J = 1, 3
                  AA(2,J) = ZERO
                  BB(2,J) = ZERO
                  CC(2,J) = ZERO
  220           CONTINUE
                BB(2,2) = ONE
                DD(2,1) = - VSN(IN)
                GO TO (240, 260, 240, 260, 240, 260, 240, 260), IEQ
  240           DO 250 J = 1, 3
                  AA(3,J) = ZERO
                  BB(3,J) = ZERO
                  CC(3,J) = ZERO
  250           CONTINUE
                BB(3,3) = ONE
                DD(3,1) = - THSN(IN)
  260           CALL MABC (AA, BM1, BTM, 3, 3)
                CALL MABC (AA, AM1, ATM, 3, 1)
                DO 270 J = 1, 3
                  ATM(J,1) = ATM(J,1) + DD(J,1)
                  DO 270 K = 1, 3
                  BTM(J,K) = BTM(J,K) + BB(J,K)
  270           CONTINUE
                CALL INVERT (BTM, 3, I)
                CALL MABC (BTM, ATM, AM1, 3, 1)
                CALL MABC (BTM, CC, BB, 3, 3)
                DO 290 J = 1, 3
                  A(I+1,J) = -AM1(J,1)
                  DO 280 K = 1, 3
  280             B(I+1,J,K) = -BB(J,K)
  290           CONTINUE
  300       CONTINUE
C
C>-->       START REVERSION PROCESS (BACKSUBSTITJTION)
            DO 310 J = 1, 3
                UP1(J,1) = A(NJ+1,J)
                UA(NJ,J) = UP1(J,1)
  310       CONTINUE
            DO 340 I = 1, NB
                J = NJ - I
                DO 320 K = 1, 3
                  DO 320 L = 1, 3
                  BTM(K,L) = B(J+1,K,L)
  320           CONTINUE
                CALL MABC (BTM, UP1, ATM, 3, 1)
                DO 330 K = 1, 3
                  UP1(K,1) = ATM(K,1) + A(J+1,K)
                  UA(J,K) = UP1(K,1)
  330           CONTINUE
  340       CONTINUE
            RETURN
            END
```

```
C     SUBROUTINE RESIDU
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                               *
C     *            THIS SUBROUTINE CALCULATES THE RESIDUES            *
C     *            OF THE SYSTEM OF SIMULTANEOUS EQUATIONS            *
C     *                  USED IN THE STATIC SOLUTION                  *
C     *                                                               *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE RESIDU
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /EPSOY/ XM1(25,32), XM2(25,32), XM3(25,32), ICRAC(25,32)
      COMMON /STIFF/ EI(25), AE(25)
      COMMON /TABL4/ USN(10), VSN(10), THSN(10), IHINGE(26),
     1              JSDN(10), KU(10), KV(10), KTH(10), NCT4
      DIMENSION AA(3,3), BB(3,3), CC(3,3), DD(3,1), AUX(3,1), AUXU(3,1)
      DIMENSION US(25,3), FS(25,3), RES(25,3), S(6,6), R(6,6), ST(6,6)
      EQUIVALENCE (US(1,1), XM1(1,1)), (FS(1,1), XM3(1,1)),
     1           (RES(1,1), XM3(1,9)), (XM3(1,25), S(1,1)),
     2           (XM3(1,27), R(1,1)), (XM3(1,29), ST(1,1))
C
C>-->   INITIALIZE AUXILIARY MATRICES
C
        DO 100 I = 1, 3
             AUXU(I,1) = ZERO
        DO 100 J = 1, 3
             AA(I,J) = ZERO
             BB(I,J) = ZERO
  100   CONTINUE
        DO 300 I = 1, NJ
             IND = 3
C
C>-->   SEARCH FOR HINGES
C
             IF (IHINGE(I) .EQ. 1) IND = 1
             IF (IHINGE(I+1) .EQ. 1) IND = 2
             IEQ = 8
             DO 130 J = 1, NCT4
                  IF (JSDN(J) .NE. I) GO TO 130
                  KEY = 2 * (2*KU(J) + KV(J)) + KTH(J)
                  IF(KEY .GT. 7) GO TO 130
                  IJ = J
                  IEQ = KEY
  130        CONTINUE
C
C>-->   DETERMINE MEMBER STIFFNESS MATRIX IN GLOBAL COORDINATE SYSTEM
C
             IF (I .LT. NJ) GO TO 150
             DO 140 J = 1, 6
             DO 140 K = 1, 6
                  S(J,K) = ZERO
  140        CONTINUE
             GO TO 160
  150        DX = X(I+1) - X(I)
             DY = Y(I+1) - Y(I)
             CX = DX / XLO(I)
             CY = DY / XLO(I)
             EIZ = P5 * (EI(I)+EI(I+1))
             AEX = P5 * (AE(I)+AE(I+1))
             CALL MSTIF (XLO(I), IND, EIZ, AEX, CX, CY, ST, R)
             CALL RTSR (R, ST, S)
  160        DO 170 J = 1, 3
             DO 170 K = 1, 3
                  BB(J,K) = BB(J,K) + S(J,K)
                  CC (J,K) = S(J, K+3)
  170        CONTINUE
```

```
C     SUBROUTINE RESIDU                                                (CONTINUED)
C
C>-->        SET UP LOAD FUNCTIONS
C
                  DD(1,1) = - FS(I,1)
                  DD(2,1) = - FS(I,2)
                  DD(3,1) = - FS(I,3)
C
C>-->        CONSIDER SPECIFIED DISPLACEMENT CONDITIONS
C
                  GO TO (230, 200, 200, 180, 180, 180, 180, 250), IEQ
C
C>-->        SPECIFIED HORIZONTAL DISPLACEMENT
  180             DO 190 J = 1, 3
                       AA(1,J) = ZERO
                       BB(1,J) = ZERO
                       CC(1,J) = ZERO
  190             CONTINUE
                  BB(1,1) = ONE
                  DD(1,1) = - USN(IJ)
                  GO TO (230, 200, 200, 250, 230, 200, 200, 250), IEQ
C
C>-->        SPECIFIED VERTICAL DISPLACEMENT
  200             DO 210 J = 1, 3
                       AA(2,J) = ZERO
                       BB(2,J) = ZERO
                       CC(2,J) = ZERO
  210             CONTINUE
                  BB(2,2) = ONE
                  DD(2,1) = - VSN(IJ)
                  GO TO (230, 250, 230, 250, 230, 250, 230, 250), IEQ
C
C>-->        SPECIFIED ROTATION
  230             DO 240 J = 1, 3
                       AA(3,J) = ZERO
                       BB(3,J) = ZERO
                       CC(3,J) = ZERO
  240             CONTINUE
                  BB(3,3) = ONE
                  DD(3,1) = - THSN(IJ)
C
C>-->        CALCULATE RESIDUES
C
  250             CALL MABC (AA, AUXU, AUX, 3, 1)
                  DO 260 J = 1, 3
                  RES(I,J) = -DD(J,1) - AUX(J,1)
  260             AUXU(J,1) = US(I,J)
                  CALL MABC (BB, AUXU, AUX, 3, 1)
                  DO 270 J = 1, 3
  270             RES(I,J) = RES(I,J) - AUX(J,1)
                  IF (I .EQ. NJ) GO TO 300
                  DO 280 J = 1, 3
  280             AUXU(J,1) = US(I+1,J)
                  CALL MABC (CC, AUXU, AUX, 3, 1)
                  DO 290 J = 1, 3
                       RES(I,J) = RES(I,J) - AUX(J,1)
                       AUXU(J,1) = US(I,J)
                       DO 290 K = 1, 3
                         AA(J,K) = S(J+3, K)
                         BB(J,K) = S(J+3, K+3)
  290             CONTINUE
  300        CONTINUE
             RETURN
             END
```

```
C     SUBROUTINE STFOR
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                               *
C     *             THIS SUBROUTINE CALCULATES STATIC INTERNAL        *
C     *              FORCES AND REACTIONS. IT ALSO PRINTS OUT         *
C     *                 STATIC DISPLACEMENTS AND REACTIONS            *
C     *                                                               *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE  STFOR
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /BMAST/ BMASS(25), BM(25), T(24), SH(24)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /EPSOY/ XM1(25,32), XM2(25,32), XM3(25,32), ICRAC(25,32)
      COMMON /STIFF/ EI(25), AE(25)
      COMMON /TABL4/ USN(10), VSN(10), THSN(10), IHINGE(26),
     1              JSDN(10), KU(10), KV(10), KTH(10), NCT4
      DIMENSION US(25,3), FS(25,3), R(10,3), JR(10), S(6,6), RT(6,6)
      DIMENSION UT(6,1), FT(6,1), FL(3), FR(3), RD(2)
      EQUIVALENCE (US(1,1), XM1(1,1)), (FS(1,1), XM3(1,1)),
     1            (XM3(1,25), S), (XM3(1,27), RT), (XM3(1,29), R)
 2020 FORMAT (//20X, 31HTABLE 9. - STATIC DISPLACEMENTS//30X,
     1        4HSTA., 12X, 1HU, 11X, 1HV, 11X, 2HTH/)
 2030 FORMAT (30X, I4, 6X, 1P3D12.4)
 2100 FORMAT (//20X, 28HTABLE 10. - STATIC REACTIONS//30X, 4HSTA., 8X,
     1        33HHORIZONTAL   VERTICAL      MOMENT/)
C
C>-->    PRINT STATIC DISPLACEMENTS
      CALL HEADNG
      PRINT 2020
      DO 80 I = 1,NJ
   80 PRINT 2030, I, (US(I,J), J= 1, 3)
C>-->    INITIALIZE AUXILIARY VECTORS AND REACTIONS
      RD(1) = ZERO
      RD(2) = ZERO
      DO 100 I = 1, 10
              JR(I) = 0
         DO 100 J = 1, 3
              R(I,J) = ZERO
  100 CONTINUE
              M = 0
      DO 200 I = 1, NB
         IND = 3
C>-->    SEARCH FOR HINGES
         IF (IHINGE(I) .EQ. 1) IND = 1
         IF (IHINGE(I+1) .EQ. 1) IND = 2
C>-->    CALCULATE MEMBER STIFFNESSES
         DX = X(I+1) - X(I)
         DY = Y(I+1) - Y(I)
         CX = DX / XLO(I)
         CY = DY / XLO(I)
         EIZ = P5 * (EI(I)+EI(I+1))
         AEX = P5 * (AE(I)+AE(I+1))
         CALL MSTIF (XLO(I), IND, EIZ, AEX, CX, CY, S, RT)
C>-->    CALCULATE INTERNAL FORCES
         DO 130 J = 1, 3
              FT(J,1) = US(I,J)
              FT(J+3,1) = US(I+1,J)
  130    CONTINUE
         CALL MABC (RT, FT, UT, 6, 1)
         CALL MABC ( S, UT, FT, 6, 1)
         FL(1) = - FT(1,1)
         FL(2) =   FT(2,1)
         FL(3) = - FT(3,1)
         FR(1) =   FT(4,1)
         FR(2) = - FT(5,1)
         FR(3) =   FT(6,1)
```

```
C     SUBROUTINE STFOR                                           (CONTINUED)
C
C>-->        CALCULATE STATIC BENDING MOMENTS, THRUSTS AND SHEARS
C
             BM(I) = FL(3)
             T(I) = FR(1)
             SH(I) = FL(2)
C
C>-->        SEARCH FOR SPECIFIED CONDITIONS
C
             DO 190 J = 1, NCT4
                  IF (JSDN(J) .NE. I) GO TO 190
                  K = 2 * (2*KU(J) + KV(J)) + KTH(J)
                  IF (K .GT. 7) GO TO 190
                  M = M + 1
                  JR(M) = JSDN(J)
                  M1 = (K-1) * (K-2) * (K-3)
                  IF (M1 .EQ. 0) GO TO 140
                  R(M,1) = - FS(I,1) + RD(1) + FT(1,1)*CX - FT(2,1)*CY
                  GO TO 150
  140             R(M,1) = ZERO
  150             M2 = (K-1) * (K-4) * (K-5)
                  IF (M2 .EQ. 0) GO TO 160
                  R(M,2) = - FS(I,2) + RD(2) + FT(1,1)*CY + FT(2,1)*CX
                  GO TO 170
  160             R(M,2) = ZERO
  170             M3 = (K-2) * (K-4) * (K-6)
                  IF (M3 .EQ. 0) GO TO 180
                  R(M,3) = - FS(I,3) + FT(3,1)
                  GO TO 190
  180             R(M,3) = ZERO
  190        CONTINUE
             RD(1) = FT(4,1)*CX - FT(5,1)*CY
             RD(2) = FT(4,1)*CY + FT(5,1)*CX
  200   CONTINUE
             BM(NJ) = FR(3)
C
             DO 280 J = 1, NCT4
                  IF (JSDN(J) .NE. NJ) GO TO 280
                  K = 2 * (2*KU(J) + KV(J)) + KTH(J)
                  IF (K .GT. 7) GO TO 270
                  M = M + 1
                  JR(M) = JSDN(J)
                  M1 = (K-1) * (K-2) * (K-3)
                  IF (M1 .EQ. 0) GO TO 210
                  R(M,1) = - FS(NJ,1) + RD(1)
                  GO TO 220
  210             R(M,1) = ZERO
  220             M2 = (K-1) * (K-4) * (K-5)
                  IF (M2 .EQ. 0) GO TO 230
                  R(M,2) = - FS(NJ,2) + RD(2)
                  GO TO 240
  230             R(M,2) = ZERO
  240             M3 = (K-2) * (K-4) * (K-6)
                  IF (M3 .EQ. 0) GO TO 250
                  R(M,3) = - FS(NJ,3) + FT(6,1)
                  GO TO 280
  250             R(M,3) = ZERO
                  GO TO 280
  270             BM(NJ) = ZERO
  280        CONTINUE
C
C>-->        PRINT REACTIONS
C
        CALL HEADNG
        PRINT 2100
             DO 300 I = 1, M
  300        PRINT 2030, JR(I), (R(I,J), J = 1, 3)
        RETURN
        END
```

```
C     SUBROUTINE OUTPUT
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *                THIS SUBROUTINE CONTROLS OUTPUT                    *
C     *                FOR STATIC AND DYNAMIC SOLUTIONS                   *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE OUTPUT (IOPT, TIME, UD, VD)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /BMAST/ BMASS(25), BM(25), T(24), SH(24)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /XSECT/ B1(25), B2(25), B3(25), CG(25), PC(25)
      DIMENSION UD(1), VD(1)
 2000 FORMAT (//20X, 'MAXIMUM RESPONSE,  TIME = ', 1PD12.4//30X,
     1       'QUANTITY',8X,'BAR OR',8X,'VALUE'/46X,'STATION'//30X,
     2       'THRUST',11X,I4,5X,1PD12.4/30X,'MOMENT',11X,I4,5X,
     3       1PD12.4/30X,'SHEAR',12X,I4,5X,1PD12.4/30X,'X DISPL',10X,
     4       I4,5X,1PD12.4/30X,'Y DISPL',10X,I4,5X,1PD12.4)
 2010 FORMAT (//20X, 'COMPLETE RESPONSE,  TIME = ', 1PD12.4//22X,'STA.',
     1       5X,'X DISPL',5X,'Y DISPL',6X,'MOMENT',6X,'SHEAR',
     2       7X, 'THRUST', 4X, 'CENTROID'/)
 2020 FORMAT (22X, I3, 3X, 1P3D12.4, 24X, D12.4)
 2030 FORMAT (64X, 1P2D12.4)
C
C>-->    IF  IOPT = 1,  ONLY MAXIMUM VALUES WILL BE PRINTED
C        IF  IOPT = 2,  COMPLETE RESPONSE WILL BE PRINTED
      CALL HEADNG
      GO TO (100, 160), IOPT
C>-->    SEARCH FOR MAXIMUM VALUES OF DISPLACEMENTS AND INTERNAL FORCES
  100 TMAX = ZERO
      SHMAX = ZERO
      BMMAX = BM(1)
      UMAX = UD(1)
      VMAX = VD(1)
      JB = 1
      JU = 1
      JV = 1
      DO 150 I = 2, NJ
         IF (DABS(T(I-1)) .LT. DABS(TMAX)) GO TO 110
              TMAX = T(I-1)
              JT = I - 1
  110    IF (DABS(SH(I-1)) .LT. DABS(SHMAX))  GO TO 120
              SHMAX = SH(I-1)
              JS = I - 1
  120    IF (DABS(BM(I)) .LT. DABS(BMMAX))  GO TO 130
              BMMAX = BM(I)
              JB = I
  130    IF (DABS(UD(I)) .LT. DABS(UMAX))  GO TO 140
              UMAX = UD(I)
              JU = I
  140    IF (DABS(VD(I)) .LT. DABS(VMAX)) GO TO 150
              VMAX = VD(I)
              JV = I
  150 CONTINUE
C>-->    PRINT MAXIMUM VALUES
      PRINT 2000, TIME, JT,TMAX, JB,BMAX, JS,SHMAX, JU,UMAX, JV,VMAX
      RETURN
C>-->    PRINT COMPLETE RESPONSE
  160 PRINT 2010, TIME
      I = 1
      PRINT 2020, I, UD(I), VD(I), BM(I), CG(I)
      DO 170 I = 2, NJ
         PRINT 2030, SH(I-1), T(I-1)
         PRINT 2020, I, UD(I), VD(I), BM(I), CG(I)
  170 CONTINUE
      RETURN
      END
```

```
C     SUBROUTINE DYNAM
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *           THIS SUBROUTINE CONTROLS THE DYNAMIC PROCESS            *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE DYNAM
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /AKCEL/ DDU(25), DDV(25)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /BMAST/ BMASS(25), BM(25), T(24), SH(24)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /DISPL/ U(25), V(25), TH(25), UD(25), VD(25)
      COMMON /IGEOM/ PHIO(25), THO(24), IBRK, ISYM
      COMMON /LOADS/ QX(25), QY(25), QZ(25), QXD(25), QYD(25)
      COMMON /TABL1/ GRAV,TLIM,KEEP(7),ISTAT,ISOPT,NDL,IDOPT,NOUT,ISELFW
      COMMON /TABL4/ USN(10), VSN(10), THSN(10), IHINGE(26),
     1               JSDN(10), KU(10), KV(10), KTH(10), NCT4
      COMMON /TABL6/ JI6(20), QXI6(20), QYI6(20), JM6(20), QXM6(20),
     1               QYM6(20), JL6(20), QXL6(20), QYL6(20), NCS(20),NPDL
      COMMON /TIMEF/ FO, TR, TD, FT, TIME, DTIME, TDTIME, IND, INTVL
      COMMON /XSECT/ B1(25), B2(25), B3(25), CG(25), PC(25)
      DIMENSION UDO(25), VDO(25), DUO(25), DVO(25), DDUO(25), DDVO(25)
      DIMENSION ADDU(25), ADDV(25), DU(25), DV(25)
      DIMENSION JI(20), QXI(20), QYI(20), JM(20), QXM(20), QYM(20),
     1          JL(20), QXL(20), QYL(20)
C
 2020 FORMAT(//20X, 'SOLUTION FOR DYNAMIC LOADING NO. ',I3///22X,'STA.',
     1       7X,'POINT',8X,'DYNAMIC  LOADS',10X,'STATIC   LOADS',7X,
     2       'DEPTH OF'/23X,'NO.',7X,'MASS',5X,'HORIZONTAL   VERTICAL',
     3       3X,'HORIZONTAL   VERTICAL    CENTROID'//)
 2030 FORMAT (//20X, 'FAILURE DID NOT OCCUR IN SPECIFIED TIME LIMIT',
     1        /20X, 'ELAPSED TIME = ', 1PD12.4)
 2040 FORMAT (22X, I3, 3X, 1P6D12.4)
      DATA DM3, DM1, SIX / 1.0D-03, 1.0D-01, 6.0D00 /
C
C>-->     ADJUST STATIC CONFIGURATION OF THE STRUCTURE
C         TO CONFORM TO DYNAMIC PROCESS  -  INITIALIZE VARIABLES
C
      CALL ADJUST(1)
C
C>-->     START DYNAMIC SOLUTION
C
      NCL = 0
      DO 400 N = 1, NDL
C
C>-->     SET UP DYNAMIC LOADS AT THE JOINTS
          CALL HEADNG
          PRINT 2020, N
          KNOUT = 0
          NCI = NCL + 1
          NCL = NCL + NCS(N)
          NC = 0
          DO 230 I = NCI, NCL
               NC = NC + 1
               JI(NC) = JI6(I)
               JM(NC) = JM6(I)
               JL(NC) = JL6(I)
               QXI(NC) = QXI6(I)
               QYI(NC) = QYI6(I)
               QXM(NC) = QXM6(I)
               QYM(NC) = QYM6(I)
               QXL(NC) = QXL6(I)
               QYL(NC) = QYL6(I)
  230     CONTINUE
C
          CALL DFORCE (NC, JI,QXI,QYI, JM,QXM,QYM, JL,QXL,QYL, QXD,QYD)
```

```
C     SUBROUTINE DYNAM                                          (CONTINUED)
C
C>-->        INITIALIZE FOR DISPLACEMENTS, VELOCITIES AND ACCELERATIONS AND
C            PRINT OUT POINT MASSES, DYNAMIC LOADS AND DEPTHS OF CENTROIDS
             DO 240 I = 1, NJ
                  UDO(I) = ZERO
                  VDO(I) = ZERO
                  DUO(I) = ZERO
                  DVO(I) = ZERO
                  DDUO(I) = ZERO
                  DDVO(I) = ZERO
                  PRINT 2040, I, BMASS(I),QXD(I),QYD(I),QX(I),QY(I),CG(I)
  240        CONTINUE
C
C>-->        CHECK FOR TYPE OF DYNAMIC LOADING
             IF (LDTYPE .NE. 1)  GO TO 260
C
C>-->        IF DYNAMIC LOADING IS AN IMPULSE, SET INITIAL VELOCITIES
             DO 250 I = 1, NJ
                  DUO(I) = QXD(I) / BMASS(I)
                  DVO(I) = QYD(I) / BMASS(I)
  250        CONTINUE
                  GO TO 280
C
C>-->        IF DYNAMIC LOADING IS A PULSE, SET INITIAL ACCELERATIONS
  260        INTVL = 1
             IF (TR .EQ. ZERO) INTVL = 2
             IF (INTVL .NE. 2) GO TO 310
             DO 270 I = 1, NJ
                  DDUO(I) = FO*QXD(I) / BMASS(I)
                  DDVO(I) = FO*QYD(I) / BMASS(I)
  270        CONTINUE
C
C>-->        REVISE VELOCITIES AND ACCELERATIONS FOR UNYIELDING SUPPORTS
  280        DO 300 I = 1, NCT4
                  IF (KU(I) .NE. 1) GO TO 290
                     J = JSDN(I)
                     DUO(J)  = ZERO
                     DDUO(J) = ZERO
  290             IF (KV(I) .NE. 1) GO TO 300
                     J = JSDN(I)
                     DVO(J)  = ZERO
                     DDVO(J) = ZERO
  300        CONTINUE
C
C>-->        START NUMERICAL ITERATIVE PROCEDURE
C>-->        INCREMENT TIME BY TIME INTERVAL
  310        TIME = TIME + DTIME
             IF (LDTYPE .NE. 1) CALL FTIME
C>-->        SET INITIAL ITERATION COUNTER
             ITER = 0
C
C>-->        COMPUTE DYNAMIC DISPL. AND VELOCITIES AND ASSUME ACCELERATIONS
             DO 320 I = 1, NJ
                  UD(I) = UDO(I) + DTIME*DUO(I) + P5*DTIME*DTIME*DDUO(I)
                  VD(I) = VDO(I) + DTIME*DVO(I) + P5*DTIME*DTIME*DDVO(I)
                  DU(I) = DUO(I) + DTIME*DDUO(I)
                  DV(I) = DVO(I) + DTIME*DDVO(I)
                  ADDU(I) = DDUO(I)
                  ADDV(I) = DDVO(I)
  320        CONTINUE
C
C>-->        COMPUTE CURVATURES, STRAINS, INTERNAL FORCES AND ACCELERATIONS
             CALL JCURVT
             CALL FORCE (0)
             CALL ACCEL
C
C>-->        ASSUME CONVERGENCE AND INCREASE ITERATION COUNTER
  330        KONV = 1
             ITER = ITER + 1
```

```
C     SUBROUTINE DYNAM                                              (CONTINUED)
C
          DO 340 I = 1, NJ
C>-->     COMPUTE DIFFERENCE BETWEEN ASSUMED AND COMPUTED ACCELERATIONS
               DELDD = DDU(I) - ADDU(I)
C>-->     CHECK FOR CONVERGENCE OF HORIZONTAL ACCELERATIONS
               COMP = DABS(DM3*DDU(I))
               IF (COMP .LT. DM1)  COMP = DM1
               IF (DABS(DELDD) .GT. COMP)  KONV = 0
C>-->     CALCULATE NEW HORIZONTAL DISPLACEMENTS AND VELOCITIES
               UD(I) = UD(I) + DTIME*DTIME*DELDD/SIX
               DU(I) = DU(I) + P5*DTIME*DELDD
C>-->     SET NEW ASSUMED HORIZONTAL ACCELERATIONS
               ADDU(I) = DDU(I)
C>-->     COMPUTE DIFFERENCE BETWEEN ASSUMED AND CALCULATED ACCELERATIONS
               DELDD = DDV(I) - ADDV(I)
C>-->     CHECK FOR CONVERGENCE OF VERTICAL ACCELERATIONS
               COMP = DABS(DM3*DDV(I))
               IF (COMP .LT. DM1)  COMP = DM1
               IF (DABS(DELDD) .GT. COMP)  KONV = 0
C>-->     CALCULATE NEW VERTICAL DISPLACEMENTS AND VELOCITIES
               VD(I) = VD(I) + DTIME*DTIME*DELDD/SIX
               DV(I) = DV(I) + P5*DTIME*DELDD
C>-->     SET NEW ASSUMED VERTICAL ACCELERATIONS
               ADDV(I) = DDV(I)
  340     CONTINUE
C
C>-->     COMPUTE CURVATURES, STRAINS, INTERNAL FORCES AND ACCELERATIONS
          CALL JCURVT
          CALL FORCE (KONV)
          CALL ACCEL
C>-->     TEST FOR CONVERGENCE AND MAXIMUM NUMBER OF ITERATIONS
          IF (KONV .EQ. 1) GO TO 350
          IF (ITER .LT. 7) GO TO 330
          TIME = TIME - DTIME
          DTIME = P5 * DTIME
          GO TO 310
  350     KNOUT = KNOUT + 1
C
C>-->     SET INITIAL CONDITIONS FOR NEXT STEP
          DO 360 I = 1, NJ
               UDO(I) = UD(I)
               VDO(I) = VD(I)
               DUO(I) = DU(I)
               DVO(I) = DV(I)
               DDUO(I) = DDU(I)
               DDVO(I) = DDV(I)
  360     CONTINUE
C
C>-->     EXAMINE FAILURE CONDITIONS AND TEST FOR FAILURE
          CALL FAIL (TIME)
          IF (IFAIL .EQ. 1) GO TO 390
          IF (KNOUT .LT. NOUT) GO TO 370
C>-->     PRINT OUT DYNAMIC RESULTS
          CALL OUTPUT (IDOPT, TIME, UD, VD)
          KNOUT = 0
C>-->     CHECK FOR TIME LIMIT
  370     IF (TIME .GE. TLIM) GO TO 380
C>-->     REVISE TIME-STEP INTERVAL TO INSURE CONVERGENCE AND STABILITY
          H = 4 - ITER + ITER/5
          DTIME = (ONE + DM1*H) * DTIME
          GO TO 310
C>-->     PRINT OUT ELAPSED TIME AND DYNAMIC RESULTS
  380     PRINT 2030, TIME
  390     CALL OUTPUT (IDOPT, TIME, UD, VD)
C>-->     INITIALIZE VARIABLES FOR NEW DYNAMIC LOADING
          IF (N .LT. NDL) CALL ADJUST(2)
  400 CONTINUE
      RETURN
      END
```

```
C     SUBROUTINE ADJUST
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *  THIS SUBROUTINE ADJUSTS STATIC CONFIGURATION OF THE STRUCTURE  *
C     *    IN ORDER TO CONFORM DEFORMED STRUCTURE TO DYNAMIC PROCESS    *
C     *        CALCULATES INITIAL TIME INTERVAL, IF NOT SUPPLIED        *
C     *                ELIMINATES RESIDUAL ACCELERATIONS                *
C     *                       INITIALIZES VARIABLES                     *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE ADJUST (KEY)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /AKCEL/ DDU(25), DDV(25)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /BMAST/ BMASS(25), BM(25), T(24), SH(24)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /CURVS/ EPSN(10,5),SIGN(10,5),EPSMUL(5),SIGMUL(5),EPSPR(5)
      COMMON /DISPL/ U(25), V(25), TH(25), UD(25), VD(25)
      COMMON /EPPHI/ DPHIJ(25), DPHIJS(25), EPSAB(24), EPSABS(24)
      COMMON /EPSOY/ EPSO(25,32),EPS1P(25,32),EPS1N(25,32),ICRAC(25,32)
      COMMON /IGEOM/ PHIO(25), THO(24), IBRK, ISYM
      COMMON /LOADS/ QX(25), QY(25), QZ(25), QXD(25), QYD(25)
      COMMON /SEGM1/ D(25,9), E(5,2), GAMMA(5), IS(9), MAT(9)
      COMMON /SEGM2/ DI(30), DA(30), MI(30)
      COMMON /STIFF/ EI(25), AE(25)
      COMMON /TABL1/ GRAV,TLIM,KEEP(7),ISTAT,ISOPT,NDL,IDOPT,NOUT,ISELFW
      COMMON /TIMEF/ FO, TR, TD, FT, TIME, DTIME, TDTIME, IND, INTVL
      COMMON /XSECT/ B1(25), B2(25), B3(25), CG(25), PC(25)
      DIMENSION DZON(9)
      DATA PI, IYES / 3.1415926535D00, 3HYES /
      IF (KEY .EQ. 2) GO TO 170
      IF (DTIME .GT. ZERO) GO TO 100
C>-->    COMPUTE INITIAL TIME-STEP INTERVAL
      S = ZERO
      SMASS = ZERO
      SEI = ZERO
      DO 90 I = 1, NB
         S = S + XLO(I)
         SMASS = SMASS + BMASS(I)
         SEI = SEI + EI(I)
   90 CONTINUE
      H = NJ
      SEI = (SEI+EI(NJ)) / H
      SMASS = (SMASS+BMASS(NJ)) / S
      H = H - ONE
      S = S / H
      DTIME = S / H * S * DSQRT(SMASS/SEI)
  100 DTIME1 = DTIME
C>-->    CHECK IF STATIC SOLUTION WAS REQUIRED
      IF (ISTAT .EQ. IYES) GO TO 120
C>-->    IF NOT, SET DISPLACEMENTS, CURVATURES AND STRAINS EQUAL TO ZERO
      DO 110 I = 1, NB
         U(I) = ZERO
         V(I) = ZERO
         DPHIJS(I) = ZERO
         EPSABS(I) = ZERO
  110 CONTINUE
      U(NJ) = ZERO
      V(NJ) = ZERO
      DPHIJS(NJ) = ZERO
      GO TO 170
C>-->    CALCULATE AVERAGE STATIC STRAINS AND CURVATURES
  120 DO 130 I = 1, NB
         AEB = P5 * (AE(I)+AE(I+1))
         EPSABS(I) = T(I) / AEB
         DPHIJS(I) = BM(I) / EI(I)
  130 CONTINUE
```

```
C     SUBROUTINE ADJUST                                                (CONTINUED)
C
      DPHIJS(NJ) = BM(NJ) / EI(NJ)
C>-->    DETERMINE NEW CONFIGURATION OF THE STRUCTURE
      DO 140 I = 1, NJ
         X(I) = X(I) + U(I)
         Y(I) = Y(I) + V(I)
         UD(I) = ZERO
         VD(I) = ZERO
         DPHIJ(I) = DPHIJS(I)
  140 CONTINUE
C>-->    CALCULATE NEW LENGTHS AND SLOPES OF BARS, CURVATURES AT JOINTS
      DO 150 I = 1, NB
         DX = X(I+1) - X(I)
         DY = Y(I+1) - Y(I)
         XLO(I) = DSQRT(DX*DX + DY*DY)
         THO(I) = DARSIN(DY/XLO(I))
         EPSAB(I) = EPSABS(I)
         IF (DX .GE. ZERO)  GO TO 150
              THI = PI
              IF (DY .LT. ZERO) THI = -PI
                 THO(I) = THI - THO(I)
  150 CONTINUE
      DO 160 I = 2, NB
         PHIO(I) = (THO(I)-THO(I-1))/P5/(XLO(I)+XLO(I-1))
  160 CONTINUE
C>-->    INITIALIZE VARIABLES
  170    TIME = ZERO
         DTIME = DTIME1
         IFAIL = 0
         FT = ZERO
         IND = 1
C>-->    INITIALIZE DYNAMIC LOADS, DEPTHS OF CENTROIDS, PARAMETERS
C        OF STRESS-STRAIN CURVES, INDICATORS OF CRACKS
         DO 220 I = 1, NJ
              QXD(I) = ZERO
              QYD(I) = ZERO
              CG(I) = PC(I)
              DO 190 J = 1, 32
                   EPSO(I,J) = ZERO
                   ICRAC(I,J) = 0
  190         CONTINUE
              DO 200 J = 1, 9
                   DZON(J) = D(I,J)
  200         CONTINUE
              CALL SEG (DZON, B1(I), B2(I), B3(I))
              DO 210 J = 1, 30
                   M = MI(J)
                   EPS1N(I,J) = EPSMUL(M) * EPSN(5,M)
                   EPS1P(I,J) = EPSMUL(M) * EPSN(6,M)
  210         CONTINUE
              EPS1N(I,31) = EPSMUL(NSSC) * EPSN(5,NSSC)
              EPS1P(I,31) = EPSMUL(NSSC) * EPSN(6,NSSC)
              EPS1N(I,32) = EPS1N(I,31)
              EPS1P(I,32) = EPS1P(I,31)
  220    CONTINUE
      IF (KEY .EQ. 2) RETURN
      IF (ISTAT .NE. IYES)  RETURN
C
C>-->    ADJUST STATIC FORCES IN ORDER TO ELIMINATE RESIDUAL
C        ACCELERATIONS DUE TO THE NEW CONFIGURATION OF THE STRUCTURE
      CALL FORCE (1)
      CALL OUTPUT (ISOPT, ZERO, U, V)
      CALL ACCEL
      DO 230 I = 1, NJ
         QX(I) = QX(I) - DDU(I) * BMASS(I)
         QY(I) = QY(I) - DDV(I) * BMASS(I)
  230 CONTINUE
      RETURN
      END
```

```
C     SUBROUTINE JCURVT
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *        THIS SUBROUTINE CALCULATES CURVATURES AT THE JOINTS        *
C     *                   AND ALSO STRAINS IN THE BARS                    *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE JCURVT
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /DISPL/ U(25), V(25), TT(25), UD(25), VD(25)
      COMMON /EPPHI/ DPHIJ(25), DPHIJS(25), EPSAB(24), EPSABS(24)
      COMMON /IGEOM/ PHIO(25), THO(24), IBRK, ISYM
      COMMON /TABL4/ USN(10), VSN(10), THSN(10), IHINGE(26),
     1               JSDN(10), KU(10), KV(10), KTH(10), NCT4
      DATA PI / 3.14159265350 00 /
C
         THIM1 = THO(1)
         XLIM1 = XLO(1)
         DO 100 I = 1, NB
               DXU = X(I+1) - X(I) + UD(I+1) - UD(I)
               DYV = Y(I+1) - Y(I) + VD(I+1) - VD(I)
               XLI = DSQRT(DXU*DXU + DYV*DYV)
               EPSAB(I) = XLI / XLO(I) - ONE + EPSABS(I)
               THI = DARSIN (DYV / XLI)
               IF (DXU .GE. ZERO) GO TO 90
               TH = PI
               IF (DYV .LT. ZERO) TH = -PI
                  THI = TH - THI
   90          DPHIJ(I) = (THI-THIM1)/P5/(XLIM1+XLI)-PHIO(I)+DPHIJS(I)
               IF (IHINGE(I) .EQ. 1)  DPHIJ(I) = ZERO
               XLIM1 = XLI
               THIM1 = THI
  100    CONTINUE
         XLI = XLO(NB)
         THI = THO(NB)
      DPHIJ(NJ) = (THI-THIM1) / P5 / (XLIM1+XLI) - PHIO(NJ) + DPHIJS(NJ)
      IF (ISYM .EQ. 2) DPHIJ(NJ) = (THI/XLI-THIM1/XLIM1)/P5 + DPHIJS(NJ)
      IF (IHINGE(NJ) .EQ. 1)  DPHIJ(NJ) = ZERO
      RETURN
      END


C     SUBROUTINE HEADNG
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *      THIS SUBROUTINE ESTABLISHES HEADING ON PAGE OF OUTPUT        *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE HEADNG
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /IDENT/ ID1(40), ID2(19), NPROB
 2000 FORMAT (1H1//20X,15HPROGRAM DYNARCH/20X,
     1        51HANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES/20X,
     2        32HUNDER STATIC AND DYNAMIC LOADING//2(20X,20A4/))
 2010 FORMAT (/20X,8HPROBLEM , A4/24X, 19A4)
C
              PRINT 2000, ID1
              PRINT 2010, NPROB, ID2
      RETURN
      END
```

```
C     SUBROUTINE FORCE
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *            THIS SUBROUTINE CALCULATES INTERNAL FORCES,          *
C     *                 IE., THRUSTS AND BENDING MOMENTS,               *
C     *                  BASED ON STRAINS AND CURVATURES                *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE FORCE (KONV)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /BMAST/ BMASS(25), BM(25), T(24), SH(24)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /EPPHI/ DPHIJ(25), DPHIJS(25), EPSAB(24), EPSABS(24)
      COMMON /EPSOY/ EPSO(25,32),EPS1P(25,32),EPS1N(25,32),ICRAC(25,32)
      COMMON /SEGM1/ D(25,9), E(5,2), GAMMA(5), IS(9), MAT(9)
      COMMON /STEEL/ AB(25), AT(25), DB(25), DT(25)
      COMMON /STIFF/ EI(25), AE(25)
      COMMON /TABL4/ USN(10), VSN(10), THSN(10), IHINGE(26),
     1              JSDN(10), KU(10), KV(10), KTH(10), NCT4
      COMMON /XSECT/ B1(25), B2(25), B3(25), CG(25), PC(25)
      DIMENSION TPEPSO(32), TPEPS1(32), TNEPS1(32), IPCK(32),
     1           TEPSO(32), TEPS1P(32), TEPS1N(32), ICK(32), DZON(9)
    1 FORMAT (//20X, 'VALUES OFF STRESS-STRAIN CURVE AT STATION',
     1           I4, ',  FIBER ', I3)
C
      EPSA1 = P5 * EPSAB(1)
      DO 200 I = 1, NJ
C>-->    TEST IF INELASTIC ACTION IS DESIRED
         IF (INEL .EQ. 1)  GO TO 110
C>-->    IF NOT, CALCULATE THRUSTS AND BENDING MOMENTS,
C        BASED ON ELASTIC STRAINS AND CURVATURES
               IF (I .EQ. NJ)  GO TO 100
                  AEB = P5 * (AE(I)+AE(I+1))
                  T(I) = AEB * EPSAB(I)
  100          BM(I) = EI(I) * DPHIJ(I)
               GO TO 200
  110    IF (I .EQ. NJ) GO TO 120
C>-->    ESTABLISH AVERAGE STRAIN AT THE JOINT
         EPSA2 = P5 * EPSAB(I)
         EPSA = EPSA1 + EPSA2
         EPSA1 = EPSA2
         GO TO 125
  120    EPSA = EPSAB(NB)
C>-->    RECALL DEFORMATION HISTORY OF SEGMENTS OF THE SECTION
  125    DO 130 J = 1, 9
               DZON(J) = D(I,J)
  130    CONTINUE
         DO 140 J = 1, 32
               TPEPSO(J) = EPSO(I, J)
               TPEPS1(J) = EPS1P(I,J)
               TNEPS1(J) = EPS1N(I,J)
               IPCK(J) = ICRAC(I,J)
  140    CONTINUE
C
C>-->    CALL SUBROUTINE INTERN TO FIND NEW DEPTH OF CENTROID,
C        REDEFINE AXIAL AND FLEXURAL STIFFNESSES, DETERMINE A NEW
C        DISTRIBUTION OF STRESSES AND STRAINS, AND CALCULATE
C        BENDING MOMENT  AT JOINT I AND THRUST AT RIGHT OF BAR I-1
C
         CALL INTERN (DZON, EPSA, DPHIJ(I), TPEPSO,TPEPS1,TNEPS1,IPCK,
     1            CG(I), B1(I), B2(I), B3(I), AT(I), DT(I), AB(I),DB(I),
     2            TEPSO,TEPS1P,TEPS1N, ICK, TCG, AE(I),EI(I), BM(I),TJR)
C
         IF (IFAIL - 1) 170, 150, 160
  150    PRINT 1, I, JF
         STOP
  160    IFAIL = 0
```

```
C     SUBROUTINE FORCE                                          (CONTINUED)
C
C>-->      CALCULATE AVERAGE THRUST ACTING ON A BAR
  170      IF (I .EQ. 1)  GO TO 180
                T(I-1) = P5 * (TJL+TJR)
  180      TJL = TJR
           IF (IHINGE(I) .EQ. 1) BM(I) = ZERO
           IF (KONV .EQ. 0)  GO TO 200
C>-->      ESTABLISH NEW DEPTH OF CENTROID AND RECORD NEW PARAMETERS
C          OF STRESS-STRAIN CURVES AND INDICATORS OF CRACKS
                CG(I) = TCG
           DO 190 J = 1, 32
                EPSO(I,J)  = TEPSO(J)
                EPS1P(I,J) = TPEPS1(J)
                EPS1N(I,J) = TNEPS1(J)
                ICRAC(I,J) = ICK(J)
  190      CONTINUE
  200 CONTINUE
      RETURN
      END


C     SUBROUTINE MASS
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *              THIS SUBROUTINE CALCULATES SELF WEIGHT             *
C     *                 PER UNIT LENGTH AT GIVEN SECTION                *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE MASS (DZON, B1, B2, B3, DB, DT, AB, AT, AGAM)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /SEGM1/ D(25,9), E(5,2), GAMMA(5), IS(9), MAT(9)
      COMMON /SEGM2/ DI(30), DA(30), MI(30)
      DIMENSION DZON(1)
C
C>-->      DEFINE PROPERTIES OF THE SEGMENTS IN THE CROSS SECTION
      CALL SEG (DZON, B1, B2, B3)
C
C>-->      CALCULATE SUM OF SEGMENTAL AREAS MULTIPLIED BY SPECIFIC WEIGHT
      AGAM = ZERO
      DO 100 J = 1, 30
         MM = MI(J)
  100 AGAM = AGAM + DA(J)*GAMMA(MM)
      IF (AT .EQ. ZERO) GO TO 130
C
C>-->      ADD CONTRIBUTION OF TOP REINFORCEMENT, IF ANY
      DO 110 J = 1, 30
         IF (DT .GT. DI(J)) GO TO 110
         MM = MI(J)
         GO TO 120
  110 CONTINUE
  120 AGAM = AGAM + AT*(GAMMA(NSSC)-GAMMA(MM))
  130 IF (AB .EQ. ZERO) RETURN
C
C>-->      ADD CONTRIBUTION OF BOTTOM REINFORCEMENT, IF ANY
       DO 140 K = 1, 30
         J = 31 - K
         IF (DB .LT. DI(J)) GO TO 140
         MM = MI(J)
         GO TO 150
  140 CONTINUE
  150 AGAM = AGAM + AB*(GAMMA(NSSC)-GAMMA(MM))
      RETURN
      END
```

```
C     SUBROUTINE ACCEL
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *        THIS SUBROUTINE CALCULATES HORIZONTAL AND VERTICAL         *
C     *           COMPONENTS OF ACCELERATIONS OF POINT MASSES,            *
C     *         BASED ON EQUILIBRIUM OF FORCES ACTING ON JOINTS           *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE ACCEL
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /AKCEL/ DDU(25), DDV(25)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /BMAST/ BMASS(25), BM(25), T(24), SH(24)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /DISPL/ U(25), V(25), TH(25), UD(25), VD(25)
      COMMON /LOADS/ QX(25), QY(25), QZ(25), QXD(25), QYD(25)
      COMMON /TABL4/ USN(10), VSN(10), THSN(10), IHINGE(26),
     1               JSDN(10), KU(10), KV(10), KTH(10), NCT4
      COMMON /TIMEF/ FO, TRISE, TD, FT, TIME, DTIME, TDTIME, IND, INTVL
C
C>-->    CALCULATE ACCELERATIONS
C
      VL = ZERO
      TL = ZERO
      CL = ZERO
      SL = ZERO
      DO 100 I = 1, NB
         DX = X(I+1) - X(I) + UD(I+1) - UD(I)
         DY = Y(I+1) - Y(I) + VD(I+1) - VD(I)
         XL = DSQRT(DX*DX + DY*DY)
         TR = T(I)
         VR = (BM(I+1)-BM(I)) / XL
         CR = DX / XL
         SR = DY / XL
         QU = FT*QXD(I) + QX(I)
         QV = FT*QYD(I) + QY(I)
         DDU(I) = (TR*CR - TL*CL + VR*SR - VL*SL + QU) / BMASS(I)
         DDV(I) = (TR*SR - TL*SL + VL*CL - VR*CR + QV) / BMASS(I)
         VL = VR
         TL = TR
         CL = CR
         SL = SR
  100 CONTINUE
      QU = FT*QXD(NJ) + QX(NJ)
      QV = FT*QYD(NJ) + QY(NJ)
      DDU(NJ) = (- TL*CL - VL*SL + QU) / BMASS(NJ)
      DDV(NJ) = (- TL*SL + VL*CL + QV) / BMASS(NJ)
C
C>-->    REVISE VALUES OF ACCELERATIONS FOR UNYIELDING SUPPORTS
C
      DO 120 I = 1, NCT4
         IF (KU(I) .NE. 1) GO TO 110
           J = JSDN(I)
           DDU(J) = ZERO
  110    IF (KV(I) .NE. 1) GO TO 120
           J = JSDN(I)
           DDV(J) = ZERO
  120 CONTINUE
      RETURN
      END
```

```
C     SUBROUTINE INTERN
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                               *
C     *        THIS SUBROUTINE DETERMINES NEW DEPTH OF CENTROID,      *
C     *            REDEFINES AXIAL AND FLEXURAL STIFFNESSES,          *
C     *      DETERMINES A NEW DISTRIBUTION OF STRESSES AND STRAINS,   *
C     *        AND CALCULATES BENDING MOMENT AND THRUST AT SECTION    *
C     *                                                               *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE INTERN (DZON, EPSA, PHI, PEPSO, PPEPS1, PNEPS1, IPCK,
     1                   PCI, B1, B2, B3, AT, DT, AB, DB, EPSO, EPS1P,
     2                   EPS1N, ICK, DBAR, SAE, SEI, BM, T)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /SEGM2/ DI(30), DA(30), MI(30)
      DIMENSICN DZON(1), PEPSO(1), PPEPS1(1), PNEPS1(1),
     1             IPCK(1), ICK(1), EPSO(1), EPS1P(1), EPS1N(1)
      DATA DM2 / 1.0D-02 /
C
C>-->    DETERMINE PROPERTIES OF THE SEGMENTS OF THE SECTION
      CALL SEG (DZON, B1, B2, B3)
C
C>-->    INITIALIZE ITERATION COUNTER
      ITER = 0
C
C>-->    ASSUME DEPTH OF CENTROID AND INITIALIZE VARIABLES
      XBAR = PCI
  100 DBAR = XBAR
      XBAR = ZERO
      SAE = ZERO
      SEI = ZERO
      BM = ZERO
      T  = ZERO
      MB = 0
      MT = 0
C
C>-->    DETERMINE NEW DISTRIBUTION OF STRAINS AND STRESSES,
C                  AND FIND MODULI OF ELASTICITY
C
      DO 120 J = 1, 30
C>-->    CALCULATE DISTANCE OF SEGMENT TO THE CENTROID OF THE SECTION
         DJ = DI(J) - DBAR
C>-->    CALCULATE AVERAGE STRAIN IN THE SEGMENT
         EPSJ = EPSA + PHI*DJ
C
C>-->    FIND AVERAGE STRESS ACTING ON THE SEGMENT
C        AND DETERMINE MODULUS OF ELASTICITY
         CALL SEARCH (MI(J), PEPSO(J), PPEPS1(J), PNEPS1(J), IPCK(J),
     1                EPSJ, EPSO(J),EPS1P(J),EPS1N(J),ICK(J), EJ, SIGMA)
C
C>-->    TEST IF SEARCH WAS SUCCESSFUL
         IF (IFAIL .EQ. 1) GO TO 170
C>-->    ADD CCNTRIBUTION OF THE SEGMENT
         DAE = DA(J) * EJ
         SAE = SAE + DAE
         XBAR = XBAR + DAE*DI(J)
         SEI = SEI + DAE*DJ*DJ
         DF  = DA(J) * SIGMA
         T  = T + DF
         BM = BM + DF*DJ
         IF (MT .NE. 0)  GO TO 110
C>-->    TEST FOR TOP STEEL IN THE SEGMENT
         IF (DT .GT. DI(J))  GO TO 110
              MT = MI(J)
              EMT = EJ
              SIGT = SIGMA
  110    IF (MB .NE. 0) GO TO 120
```

```
C     SUBROUTINE INTERN                                          (CONTINUED)
C
C>-->      TEST FOR BOTTOM STEEL IN THE SEGMENT
           IF (CB .GT. DI(J))  GO TO 120
                MB = MI(J)
                EMB = EJ
                SIGB = SIGMA
  120 CONTINUE
C
C>-->      CHECK PRESENCE OF TOP REINFORCEMENT
      J = 31
      IF (AT .NE. ZERO) GO TO 130
         EPSO(J)  = PEPSO(J)
         EPS1P(J) = PPEPS1(J)
         EPS1N(J) = PNEPS1(J)
         ICK(J) = IPCK(J)
         GO TO 140
C
C>-->      ADD CONTRIBUTION OF TOP REINFORCEMENT
  130 DJ = DT - DBAR
      EPSJ = EPSA + PHI * DJ
      CALL SEARCH (NSSC, PEPSO(J), PPEPS1(J), PNEPS1(J), IPCK(J), EPSJ,
     1              EPSO(J), EPS1P(J), EPS1N(J), ICK(J), EJ, SIGMA)
      IF (IFAIL .EQ. 1)  GO TO 170
      DAE = AT * (EJ-EMT)
      SAE = SAE + DAE
      XBAR = XBAR + DAE*DT
      SEI = SEI + DAE*DJ*DJ
      DF = AT * (SIGMA-SIGT)
      T  = T + DF
      BM = BM + DF*DJ
C
C>-->      CHECK PRESENCE OF BOTTOM REINFORCEMENT
  140 J = 32
      IF (AB .NE. ZERO) GO TO 150
         EPSO(J)  = PEPSO(J)
         EPS1P(J) = PPEPS1(J)
         EPS1N(J) = PNEPS1(J)
         ICK(J) = IPCK(J)
         GO TO 160
C
C>-->      ADD CONTRIBUTION OF BOTTOM REINFORCEMENT
  150 DJ = DB - DBAR
      EPSJ = EPSA + PHI * DJ
      CALL SEARCH (NSSC, PEPSO(J), PPEPS1(J), PNEPS1(J), IPCK(J), EPSJ,
     1              EPSD(J), EPS1P(J), EPS1N(J), ICK(J), EJ, SIGMA)
      IF (IFAIL .EQ. 1)  GO TO 170
      DAE = AB * (EJ-EMB)
      SAE = SAE + DAE
      XBAR = XBAR + DAE*DB
      SEI = SEI + DAE*DJ*DJ
      DF = AB * (SIGMA - SIGB)
      T  = T + DF
      BM = BM + DF*DJ
C
C>-->      CALCULATE NEW DEPTH OF CENTROID OF THE TRANSFORMED AREA
  160 XBAR = XBAR / SAE
C
C>-->      COMPARE ASSUMED AND CALCULATED DEPTHS OF CENTROID
C          AND RETURN IF AGREEMENT IS ACCEPTABLE
      IF (DABS(DBAR-XBAR) .LT. DM2) RETURN
C>-->      IF NO AGREEMENT, INCREASE ITERATION COUNTER AND START ALL OVER
C          AGAIN, PROVIDED THAT THE ITERATION LIMIT HAS NOT BEEN EXCEEDED
      ITER = ITER + 1
      IF (ITER .LT. 10) GO TO 100
         IFAIL = 2
         RETURN
  170 JF = J
      RETURN
      END
```

```
C     SUBROUTINE FTIME
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *          THIS SUBROUTINE DETERMINES FUNCTION OF TIME FT           *
C     *              IN CASE OF A TRIANGULAR FORCING PJLSE                *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE FTIME
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /TIMEF/ FO, TR, TD, FT, TIME, DTIME, TDTIME, IND, INTVL
      DATA ZERO / 0.0D00 /
C
C>-->    FOR  INTVL = 1,  ELAPSED TIME IS LESS THAN TIME OF RISING
C        FOR  INTVL = 2,  ELAPSED TIME IS GREATER THAN TIME OF RISING,
C                         BUT LESS THAN TIME OF DURATION
C        FOR  INTVL = 3,  ELAPSED TIME IS GREATER THAN TIME OF DURATION,
C                         INDICATING RESPONSE AFTER THE FORCING PULSE
C
C>-->    LOCATE REGION OF PULSE DIAGRAM AT TIME
      GO TO (100, 110, 130), INTVL
  100 IF (TIME .LT. TR) GO TO 150
C
C>-->    REDEFINE REGION OF FORCING PULSE DIAGRAM FOR NEXT STEP
           INTVL = 2
C
C>-->    KEEP INTERVAL OF TIME FOR NEXT STEP AND CALCULATE
C             INTERVAL OF TIME FOR PRESENT STEP
           IND = 0
           TDTIME = DTIME
           DTIME = TR - TIME + DTIME
C
C>-->    REDEFINE ELAPSED TIME AND FUNCTION FT
           TIME = TR
           FT = FO
           RETURN
  110 IF (TIME .LT. TR) GO TO 145
      IF (IND .EQ. 1) GO TO 120
C
C>-->    REDEFINE ELAPSED TIME AND RESTORE INTERVAL OF TIME
           TIME = TIME - DTIME +TDTIME
           DTIME = TDTIME
           IND = 1
  120 IF (TIME .LT. TD) GO TO 160
C>-->    REDEFINE REGION OF FORCING PULSE DIAGRAM FOR NEXT STEP
           INTVL = 3
           IND = 0
           TDTIME = DTIME
           DTIME = TD - TIME + DTIME
           TIME = TD
           FT = ZERO
           RETURN
  130 IF (TIME .LT. TD) GO TO 155
      IF (IND .EQ. 1) GO TO 140
           TIME = TIME - DTIME + TDTIME
           DTIME = TDTIME
           IND = 1
  140 FT = ZERO
      RETURN
  145 INTVL = 1
      IND = 1
  150 FT = FO * TIME / TR
      RETURN
  155 INTVL = 2
      IND = 1
  160 FT = FO * (TD-TIME) / (TD-TR)
      RETURN
      END
```

```
C     SUBROUTINE FAIL
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                 *
C     *      THIS SUBROUTINE CHECKS FOR COLLAPSE OF THE STRUCTURE,      *
C     *         BASED ON MAXIMUM DISPLACEMENTS, MAXIMUM SHEAR,          *
C     *         THRUST-MOMENT INTERACTION AND CRUSHING OF TOP           *
C     *              AND/OR BOTTOM FIBERS OF THE SECTION                *
C     *                                                                 *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE FAIL (TIME)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /ARCXY/ X(25), Y(25), XLO(24), SPAN
      COMMON /BMAST/ BMASS(25), BM(25), T(24), SH(24)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /DISPL/ U(25), V(25), TH(25), UD(25), VD(25)
      COMMON /EPPHI/ DPHIJ(25), DPHIJS(25), EPSAB(24), EPSABS(24)
      COMMON /FAIL1/ SMAX(25), SMAXN(10), JS7N(10), UMAX, VMAX, NST7
      COMMON /FAIL2/ BMUL(25), PMUL(25), BMULN(10), PMULN(10),
     1               PIAN(9), BIAN(9), EPSU(5), JIA7(10), NIA7
      COMMON /SEGM1/ D(25,9), E(5,2), GAMMA(5), IS(9), MAT(9)
      COMMON /XSECT/ B1(25), B2(25), B3(25), CG(25), PC(25)
C
 2010 FORMAT (//20X,'FAILURE DUE TO HORIZONTAL DISPL. AT STATION',I4)
 2020 FORMAT (//20X,'FAILURE DUE TO VERTICAL DEFLECTION AT STATION',I4)
 2030 FORMAT (//20X,'FAILURE DUE TO SHEAR AT BAR', I4)
 2040 FORMAT (//20X,'FAILURE DUE TO THRUST-MOMENT INTERACTION',
     1        ' AT STATION', I4)
 2050 FORMAT (//20X,'FAILURE OCCURRED AT TIME = ', 1PD12.4, '  SECS.')
 2060 FORMAT (//20X,'FAILURE DUE TO CRUSHING OF TOP FIBERS AT BAR',I4)
 2070 FORMAT (/20X,'FAILURE DUE TO CRUSHING OF BOTTOM FIBERS AT BAR',I4)
 2080 FORMAT (//20X,'FAILURE DUE TO CRUSHING OF TOP FIBERS AT JOINT',I4)
 2090 FORMAT (/20X,'FAIL. DUE TO CRUSHING OF BOTTOM FIBERS AT JOINT',I4)
C
C>-->    CHECK FOR FAILURE DUE TO HORIZONTAL DISPLACEMENT
      KEY = 0
      DO 120 I = 1, NJ
         TOTAL = UD(I) + U(I)
         IF (DABS(TOTAL) .LT. UMAX) GO TO 110
               IFAIL = 1
               IF (KEY .EQ. 0)  CALL HEADNG
               KEY = 1
               PRINT 2010, I
C>-->    CHECK FOR FAILURE DUE TO VERTICAL DEFLECTION
  110    TOTAL = VD(I) + V(I)
         IF (DABS(TOTAL) .LT. VMAX) GO TO 120
               IFAIL = 1
               IF (KEY .EQ. 0)  CALL HEADNG
               KEY = 1
               PRINT 2020, I
  120 CONTINUE
C>-->    CHECK FOR FAILURE DUE TO MAXIMUM SHEAR
      DO 130 I = 1, NB
         DX = X(I+1) - X(I) + UD(I+1) - UD(I)
         DY = Y(I+1) - Y(I) + VD(I+1) - VD(I)
         XL = DSQRT (DX*DX + DY*DY)
         SH(I) = (BM(I+1)-BM(I)) / XL
         IF (DABS(SH(I)) .LT. SMAX(I))  GO TO 130
               IFAIL = 1
               IF (KEY .EQ. 0)  CALL HEADNG
               KEY = 1
               PRINT 2030, I
  130 CONTINUE
C>-->    CHECK FOR FAILURE DUE TO THRUST-MOMENT INTERACTION
      TBIM1 = T(1)
      DO 200 I = 1, NJ
         UD(I) = UD(I) + U(I)
         VD(I) = VD(I) + V(I)
```

```
C     SUBROUTINE FAIL                                                  (CONTINUED)
C
          IF (I .EQ. NJ)  GO TO 135
          TBI = T(I)
          GO TO 138
  135     TBI = T(NB)
  138     TJI = P5 * (TBIM1 + TBI)
          TBIM1 = TBI
          BMPC = BM(I) + TJI * (CG(I)-PC(I))
          IF (TJI .GT. ZERO)  TJI = ZERO
          TJI = DABS(TJI) / PMUL(I)
          IF (BMPC .GT. ZERO)  GO TO 160
          DO 140 J = 2, 5
               IF (TJI-PIAN(J))  150, 150, 140
  140     CONTINUE
          GO TO 190
  150     BMMIN = BMUL(I) * (BIAN(J-1) + (TJI-PIAN(J-1)) /
     1                         (PIAN(J)-PIAN(J-1)) * (BIAN(J)-BIAN(J-1)))
          IF (BMPC-BMMIN) 190, 190, 200
  160     DO 170 J = 2, 5
               K = 10 - J
               IF (TJI-PIAN(K))  180, 180, 170
  170     CONTINUE
          GO TO 190
  180     BMMAX = BMUL(I) * (BIAN(K+1) + (TJI-PIAN(K+1)) /
     1                         (PIAN(K)-PIAN(K+1)) * (BIAN(K)-BIAN(K+1)))
          IF (BMPC .LT. BMMAX) GO TO 200
  190          IFAIL = 1
               IF (KEY .EQ. 0) CALL HEADNG
               KEY = 1
               PRINT 2040, I
  200 CONTINUE
C
C>-->      CHECK FOR FAILURE DUE TO CRUSHING OF EXTREME FIBERS
      EPSJ1 = P5 * EPSAB(1)
      DO 260 I = 1, NJ
          IF (I .EQ. NJ) GO TO 230
          PHI = P5 * (DPHIJ(I) + DPHIJ(I+1))
          DZONT = P5 * P5 * (D(I,1)+D(I+1,1))
          DZONB = P5 * P5 * (D(I,8)+D(I,9)+D(I+1,8)+D(I+1,9))
          TCG = P5 * (CG(I) + CG(I+1))
          EPST = EPSAB(I) + PHI*(DZONT-TCG)
          EPSB = EPSAB(I) + PHI*(DZONB-TCG)
C>-->      CHECK FOR FAILURE DUE TO CRUSHING OF TOP FIBERS AT BAR
          IF (EPST .GE. ZERO) GO TO 210
               EPST = - EPST
               J = MAT(1)
               IF (EPST .LT. EPSU(J))  GO TO 210
                  IFAIL = 1
                  IF (KEY .EQ. 0) CALL HEADNG
                  KEY = 1
                  PRINT 2060, I
C>-->      CHECK FOR FAILURE DUE TO CRUSHING OF BOTTOM FIBERS AT BAR
  210     IF (EPSB .GE. ZERO) GO TO 220
               EPSB = - EPSB
               J = MAT(9)
               IF (EPSB .LT. EPSU(J))  GO TO 220
                  IFAIL = 1
                  IF (KEY .EQ. 0) CALL HEADNG
                  KEY = 1
                  PRINT 2070, I
  220     EPSJ2 = P5 * EPSAB(I)
          EPSJ = EPSJ1 + EPSJ2
          EPSJ1 = EPSJ2
          GO TO 240
  230     EPSJ = EPSAB(NB)
  240 DZONT = P5 * D(I,1)
      DZONB = P5 * (D(I,8) + D(I,9))
      EPST = EPSJ + DPHIJ(I)*(DZONT-CG(I))
      EPSB = EPSJ + DPHIJ(I)*(DZONB-CG(I))
```

```
C     SUBROUTINE FAIL                                            (CONTINUED)
C
C>-->     CHECK FOR FAILURE DUE TO CRUSHING OF TOP FIBERS AT JOINT
          IF (EPST .GE. ZERO) GO TO 250
               EPST = - EPST
               J = MAT(1)
               IF (EPST .LT. EPSU(J))  GO TO 250
                  IFAIL = 1
                  IF (KEY .EQ. 0) CALL HEADNG
                  KEY = 1
                  PRINT 2080, I
C>-->     CHECK FOR FAILURE DUE TO CRUSHING OF BOTTOM FIBERS AT JOINT
  250     IF (EPSB .GE. ZERO) GO TO 260
               EPSB = - EPSB
               J = MAT(9)
               IF (EPSB .LT. EPSU(J))  GO TO 260
                  IFAIL = 1
                  IF (KEY .EQ. 0) CALL HEADNG
                  KEY = 1
                  PRINT 2090, I
  260 CONTINUE
C>-->     IF FAILURE HAVE OCCURRED, PRINT TIME OF FAILURE
      IF (IFAIL .EQ. 1) PRINT 2050, TIME
      RETURN
      END


C     SUBROUTINE SEARCH
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                                                   *
C     *      THIS SUBROUTINE SEARCHES FOR AVERAGE STRESS AND MODULUS     *
C     *            OF ELASTICITY IN THE SEGMENT OF THE SECTION,           *
C     *          BY CONSULTING THE STRESS-STRAIN CURVE AND TAKING         *
C     *          INTO ACCOUNT THE STRAIN HISTORY OF THE SEGMENT;          *
C     *            DEFINES TEMPORARY INDICATOR OF CRACKING AND            *
C     *               PARAMETERS OF THE STRESS-STRAIN CURVE               *
C     *                                                                   *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE SEARCH (MAT, PEPSO, PPEPS1, PNEPS1, IPCK, EPSJ,
     1                    EPSO, EPS1P, EPS1N, ICK, E, SIGMA)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      COMMON /CONST/ ZERO, P5, ONE, NB, NJ, NSSC, IFAIL, JF, INEL,LDTYPE
      COMMON /CURVS/ EPSN(10,5),SIGN(10,5),EPSMUL(5),SIGMUL(5),EPSPR(5)
      DIMENSION EPS(5), SIG(5)
C
      EPSO  = PEPSO
      EPS1P = PPEPS1
      EPS1N = PNEPS1
      ICK = IPCK
C
C>-->     CALCULATE INITIAL TANGENT MODULUS IN COMPRESSION
      FAC = SIGMUL(MAT) / EPSMUL(MAT)
      ECI = FAC * SIGN(5,MAT) / EPSN(5,MAT)
      ENTER = EPSJ - PEPSO
C>-->     CHECK FOR TENSION OR COMPRESSION
      IF (ENTER .LT. ZERO)  GO TO 170
C>-->     CHECK FOR PREVIOUS CRACKING
      IF (IPCK .EQ. 1) GO TO 110
      IF (ENTER .GT. EPSPR(MAT))  GO TO 100
C>-->     DEFINE MODULUS OF ELASTICITY AND STRESS FOR UNCRACKED SECTION
      E = ECI
      SIGMA = ECI * ENTER
      RETURN
  100 ICK = 1
```

```
C     SUBROUTINE SEARCH                                            (CONTINUED)
C
C>-->     CALCULATE INITIAL TANGENT MODULUS IN TENSION
  110 ETI = FAC * SIGN(6,MAT) / EPSN(6,MAT)
C>-->     GENERATE ACTUAL STRESS-STRAIN CURVE, TENSION SIDE
      TEPS = PPEPS1 / EPSMUL(MAT)
      DO 120 J = 1, 4
         K = J + 6
         IF (TEPS .LT. EPSN(K,MAT)) GO TO 130
  120 CONTINUE
      GO TO 230
  130 EK = FAC * (SIGN(K,MAT)-SIGN(K-1,MAT))/(EPSN(K,MAT)-EPSN(K-1,MAT))
      SIG(1) = SIGMUL(MAT)*SIGN(K-1,MAT) +
     1           EK * (PPEPS1-EPSN(K-1,MAT)*EPSMUL(MAT))
      EPS(1) = SIG(1) / ETI
      IF (ENTER .GT. EPS(1)) GO TO 140
C>-->     DEFINE AVERAGE STRESS AND INITIAL TANGENT MODULUS OF ELASTICITY
      SIGMA = ETI * ENTER
      E = ETI
      RETURN
  140 DO 150 J = K, 10
         L = J - K + 2
         SIG(L) = SIGN(J,MAT) * SIGMUL(MAT)
         EPS(L) = EPS(1) + EPSN(J,MAT)*EPSMUL(MAT) - PPEPS1
         IF (ENTER .LT. EPS(L)) GO TO 160
  150 CONTINUE
C>-->     WARNING:  VALUES OFF STRESS-STRAIN CURVE
      GO TO 230
  160 EK = (SIG(L)-SIG(L-1)) / (EPS(L)-EPS(L-1))
C>-->     DEFINE AVERAGE STRESS AND SECANT MOD. OF ELASTICITY IN TENSION
      SIGMA = SIG(L-1) + EK * (ENTER-EPS(L-1))
      EPS1P = PPEPS1 + ENTER - EPS(1)
      E = SIGMA / EPS1P
      EPSO = PEPSO + ENTER - SIGMA/ETI
      RETURN
C>-->     GENERATE ACTUAL STRESS-STRAIN CURVE, COMPRESSION SIDE
  170 TEPS = PNEPS1 / EPSMUL(MAT)
      DO 180 J = 1, 4
         K = 5 - J
         IF (TEPS .GT. EPSN(K,MAT)) GO TO 190
  180 CONTINUE
C>-->     WARNING:  VALUES OFF STRESS-STRAIN CURVE
      GO TO 230
  190 EK = FAC * (SIGN(K,MAT)-SIGN(K+1,MAT))/(EPSN(K,MAT)-EPSN(K+1,MAT))
      SIG(1) = SIGMUL(MAT) * SIGN(K+1,MAT) +
     1           EK * (PNEPS1 - EPSN(K+1,MAT)*EPSMUL(MAT))
      EPS(1) = SIG(1) / ECI
      IF (ENTER .LT. EPS(1)) GO TO 200
C>-->     DEFINE AVERAGE STRESS AND INITIAL TANGENT MODULUS OF ELASTICITY
      SIGMA = ECI * ENTER
      E = ECI
      RETURN
  200 DO 210 J = 1, K
         L = K - J + 1
         SIG(J+1) = SIGN(L,MAT) * SIGMUL(MAT)
         EPS(J+1) = EPS(1) + EPSN(L,MAT)*EPSMUL(MAT) - PNEPS1
         IF (ENTER .GT. EPS(J+1))  GO TO 220
  210 CONTINUE
C>-->     WARNING:  VALUES OFF STRESS-STRAIN CURVE
      GO TO 230
  220 EK = (SIG(J+1)-SIG(J)) / (EPS(J+1)-EPS(J))
C>-->     DEFINE AVERAGE STRESS AND SECANT MOD. OF ELAST. IN COMPRESSION
      SIGMA = SIG(J) + EK * (ENTER-EPS(J))
      EPS1N = PNEPS1 + ENTER - EPS(1)
      E = SIGMA / EPS1N
      EPSO = PEPSO + ENTER - SIGMA/ECI
      RETURN
  230 IFAIL = 1
      RETURN
      END
```

APPENDIX C

PROGRAM DYNARCH: GUIDE FOR DATA INPUT

IDENTIFICATION OF RUN

Two alphameric cards

(20A4)

1	80

(20A4)

1	80

IDENTIFICATION OF PROBLEM

One alphameric card each problem
Program terminates execution, if NPROB (Problem Name) is blank

NPROB	Description of Problem (20A4)
1–4	10–80

TABLE 1--PROBLEM CONTROL DATA

Two cards each problem
First card

2	3	4	5	6	7	a	b	c	d	e	f	g
7–10	12–15	17–20	22–25	27–30	32–35	38–40	45	50	55	60	65	70

Where:

2 to 7 - Enter "KEEP" to retain data from previous problem for TABLES 2 to 7

a) ISTAT (A3) - Option for static solution
Enter "YES" or "NO", cols. 38-40

b) ISELFW (I5) - Option to consider self-weight
= 0, Self-weight will not be taken into account
= 1, Self-weight will be calculated internally and added to static loads

c) ISOPT (I5) - Option for output of static results
= 1, Only maximum values will be printed
= 2, Complete response

TABLE 1 (Continued)

d) NADL (I5) - Number of dynamic loadings for the problem or number of additional dynamic loadings, if TABLE 6 is retained from previous problem. Maximum: 20

e) LDTYPE (I5) - Option for type of dynamic loading
= 0, Forcing pulse
= 1, Impulse

f) IDOPT (I5) - Dynamic results output option
= 1, Only maximum values printed
= 2, Complete response

g) NOUT (I5) - Output interval for dynamic solution
Enter 1 if output is desired at the end of every time interval

Second Card

INEL	IBRK	ISYM	NB	SPAN	GRAV	TLIM	DTIME
6 10	15	20	25	31 40	50	60	70

Where:

INEL (I5) - Option for range of response
= 0, Elastic response only
= 1, Inelastic response desired

IBRK (I5) - Option for geometry of structure
= 0, Axis defined by a supplied function FX
= 1, Broken line structure, for example, a portal frame. A dummy function FX must be used. Coordinates of all joints must be supplied on next cards

ISYM (I5) - Definition of symmetry
= 0, Nonsymmetric structure
= 1, Structure symmetric about a vertical axis
Symmetric or nonsymmetric load
SPAN = total span of the structure
= 2, Symmetric structure and load
Only half structure is solved
SPAN = Half span of the structure
Last station at the crown of the arch

NB (I5) - Number of bars in the model structure
Maximum: 24 (For program as now written)

SPAN (E10.3) - Span of the structure

GRAV (E10.3) - Acceleration of gravity, necessary for calculation of concentrated point masses. Compatible units must be used

TLIM (E10.3) - Time limit for the dynamic solution
Unit of time is always the second

DTIME (E10.3) - Initial interval of time for the dynamic solution
If left blank, an approximate tentative value will be internally calculated

If IBRK is left blank, the station coordinates are calculated internally, by using supplied function FX. The next set of cards are needed only if IBRK is set equal to 1, and the joint coordinates are read in ten values per card (10F8.0):

X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)	...	...	...	...
1–8	16	24	32	40	48	56	64	72	80

TABLE 2--CROSS SECTION DESCRIPTION

Minimum of nine cards per problem
No card, if TABLE 2 is retained from previous problem

A) Control Card

Minimum of two cards: one for the first station and one for the last station. Maximum of ten cards.

JS	B1	B2	B3	IEND
6 10	31 40	50	60	63-65

Where:

JS (I5) - Station number: enter "1" on the first card and the number of last station (NB + 1) on the last card

B1 (E10.3) - Width of top flange at station JS. See Figure 3.2

B2 (E10.3) - Thickness of the web at station JS

B3 (E10.3) - Width of bottom flange at station JS

IEND (A3) - Enter "END" if JS is the number of last station

B) Zone Data Cards

Three cards for each control card. See Figure 3.2

IS(1)	MAT(1)	DZN(1)	IS(2)	MAT(2)	DZN(2)	...	...	...
11 15	20	30	35	40	50	55	60	70

Where:

IS(K) (I5) - Number of the segment at the bottom of zone K. Segments are numbered 1 to 30, from top to bottom of the section, as shown in Figure 3.2, page 10. IS(9), the last segment at end of zone 9, must be entered as "30"

MAT(K) (I5) - Material identification of zone K. Varies from 1 to 4. Must be equal to the number of the corresponding stress-strain curve entered in TABLE 3

DZN(K) (E10.3) - Depth of the bottom of zone K, from the top of the section. DZN(9) must be equal to the total depth of the section at station JS

Remark: Depths may change from station to station, but segment numbers and material identification <u>may not</u>. For this reason, IS(K) and MAT(K) may be entered only for the last station.

C) Reinforcement Description

Minimum of one card; maximum of ten cards for all problems.

JRN		DTN	ATN	DBN	ABN
6 10	21	30	40	50	60

Where:

JRN (I5) - Number of station where a change in reinforcement occurs. For uniform distribution of reinforcement all over the structure, set JRN equal to the last station number and enter only one card. If there is no reinforcement, leave columns 21 to 60 blank

DTN (E10.3) - Depth of centroid of top reinforcement from top

ATN (E10.3) - cross section area of top reinforcement

DBN (E10.3) - Depth of centroid of bottom reinforcement from top

ABN (E10.3) - Cross section area of bottom reinforcement

Remarks: All cards in TABLE 2 must be in ascending order of station numbers, starting with station 1;

Values for omitted stations will be linearly interpolated between input stations;

Omitted segments are assumed to be equally spaced within the zone.

TABLE 3--STRESS-STRAIN CURVES

Minimum of five cards; maximum of 21 cards
No card, if TABLE 3 is retained from previous problem
Specification according to Figure 3.3

A) Control Card

Only one card required

NSSC
6 10

Where:

NSSC (I5) - Number of stress-strain curves to be input. Maximum of five curves allowed. Curves must be input according to material identification in TABLE 2. Last curve input is used for all reinforcement, if any

B) Specific Weight and Stress Values

Two cards for each curve

SIGMUL	GAMMA
21 30	40

SIGN(1) SIGN(2) ... ... SIGN(J),J=1,10 (10F8.0)

1	8	16	24	32	40	48	56	64	72	80

Where:

SIGMUL (E10.3) - Stress multiplier; may not be zero or blank

GAMMA (E10.3) - Specific weight of the material, necessary for calculation of self-weight of the structure and concentrated point masses

SIGN(J) (F8.0) - Factor to be internally multiplied by the stress multiplier, in order to obtain the stress at the j^{th} point of the stress-strain curve. Input must proceed from most negative to most positive value. Ten values must be supplied

C) Strain Values

Two cards for each curve

EPSMUL	EPSU	EPSPR
21–30	31–40	41–50

EPSN(1)	EPSN(2)	...	...	EPSN(J),J=1,10					(10F8.0)
1–8	16	24	32	40	48	56	64	72	80

Where:

EPSMUL (E10.3) - Strain multiplier; may not be zero or blank

EPSU (E10.3) - Ultimate strain in compression for the material

EPSPR (E10.3) - Ultimate strain in tension for concrete. If resistance of concrete in tension is not to be considered, specify a very small value, for instance, 1.0 E-8. Leave blank for other materials

EPSN(J) (F8.0) - Factor to be internally multiplied by the strain multiplier, in order to obtain the strain at the j^{th} point of the stress-strain curve. Input must proceed from most negative to most positive value. Ten values must be supplied

Remarks: At least one stress-strain curve must be available;

Program terminates execution if any strain limit is exceeded, i.e., if points fall off stress-strain curve.

TABLE 4--SPECIFIED CONDITIONS

Minimum of one card each problem. For stability of structure, at least three displacements must be specified.
No card, if TABLE 4 is retained from previous problem.

JSDN	Code	USN	VSN	THSN	IEND
6–10	18-20	31–40	50	60	63-65

Where:

TABLE 4 (Continued)

JSDN (I5) - Station number where a displacement is to be specified

USN (E10.3) - Value of specified horizontal displacement. May be left blank if displacement is zero

VSN (E10.3) - Value of specified vertical displacement

THSN (E10.3) - Value of specified rotation

IEND (A3) - Enter "END" if last card in TABLE 4

Code - Enter "1" in column 18 to specify horizontal displacement, "1" in column 19 or 20 to specify vertical displacement or rotation. Then 001 will specify only a rotation.

A hinge may be specified at joint JSDN, by entering a code number greater than 111. Generally 999 is used.

If ISYM is set equal to 2 in TABLE 1, Code must be 101 for the last station

TABLE 5--STATIC LOADS

Minimum of one card; maximum of twenty cards per run.
No card, if static solution is not required, i.e., if ISTAT in TABLE 1 is set different from "YES".
Data in TABLE 5 are cumulative. If TABLE 5 is retained, present specification is added to previous table; if no additional load is added to previous table, a blank card is used with "END" in columns 78-80.

JI5	QXI5	QYI5	JM5	QXM5	QYM5	JL5	QXL5	QYL5	IEND
1 5	15	25	30	40	50	55	65	75	78-80

Where:

JI5 (I5) - Number of station

QXI5 (E10.3) - Magnitude of horizontal load at station JI5

QYI5 (E10.3) - Magnitude of vertical load at station JI5

JM5 (I5) - Number of station

QXM5 (E10.3) - Magnitude of horizontal load at station JM5

TABLE 5 (Continued)

QYM5 (E10.3) - magnitude of vertical load at station JM5

JL5 (I5) - Number of station

QXL5 (E10.3) - Magnitude of horizontal load at station JL5

QYL5 (E10.3) - Magnitude of vertical load at station JL5

IEND (A3) - Enter "END" if last card in TABLE 5

Remarks: A parabolic load distribution is assumed from station JI5 to station JL5, if all three values in the same direction are not zero;

A linear load distribution is assumed from station JI5 to station JM5, if only magnitudes of load at station JL5 are set to zero or left blank;

A uniform pressure distribution of load is assumed from station JI5 to station JL5, if QXI5 is set equal to QXL5 and all other magnitudes are set to zero or left blank;

A concentrated load is assumed at station JI5, if QXI5 and/or QYI5 are/is not zero or blank, and all other magnitudes of load are zero or blank;

Except when no additional load is added to previous TABLE 5, QXI5 and QYI5 may never be both zero or left blank;

If the magnitude of load is zero at the beginning or end of a parabolic or linear distribution, specify a very small value, for instance, 1.0 E-20;

A horizontal load is positive from left to right, a vertical load is positive acting upwards, and a uniform pressure distribution is positive if acting outwards.

TABLE 6--DYNAMIC LOADS

Minimum of one card; maximum of twenty cards per run.
No card is necessary if number of additional loadings (NADL in TABLE 1) is zero.
Data in TABLE 6 is arranged in sets. A set may contain any number of cards, provided that the limit for the run is observed.
If previous table is retained, a card may not be added to pre-existing set, but new sets (NADL in TABLE 1) of dynamic loadings may be added.
All remarks for TABLE 5, with appropriate changes, are valid here.

TABLE 6 (Continued)

JI6	QXI6	QYI6	JM6	QXM6	QYM6	JL6	QXL6	QYL6		IEND
1	5	15	25	30	40	50	55	65	75	78-80

Where:

JI6 (I5) - Number of station

QXI6 (E10.3) - Magnitude of horizontal load at station JI6

QYI6 (E10.3) - Magnitude of vertical load at station JI6

JM6 (I5) - Number of station

QXM6 (E10.3) - Magnitude of horizontal load at station JM6

QYM6 (E10.3) - Magnitude of vertical load at station JM6

JL6 (I5) - Number of station

QXL6 (E10.3) - Magnitude of horizontal load at station JL6

QYL6 (E10.3) - Magnitude of vertical load at station JL6

IEND (A3) - Enter "END" if last card in the set

The next card is necessary to define the time function, if and only if the dynamic loadings are to be considered as pulses, i.e., if LDTYPE is not set equal to 1 in TABLE 1. See Figure 3.8.

FO	TR	TD	
21	30	40	50

Where:

FO (E10.3) - Maximum value of time function (peak)

TR (E10.3) - Time of rise in seconds

TD (E10.3) - Time of decay in seconds

TABLE 7--COLLAPSE PARAMETERS

Only for dynamic solution
No card if dynamic solution is not required.

A) Maximum Displacements

One card

TABLE 7 (Continued)

UMAX	VMAX
21 – 30	– 40

Where:

UMAX (E10.3) - Maximum allowable horizontal displacement

VMAX (E10.3) - Maximum allowable vertical displacement

B) Maximum Shear

Minimum of one card; maximum of ten cards

JS7	SMAXN
6 – 10	21 – 30

Where:

JS7 (I5) - Number of station where a change in allowable shear occurs. For uniform maximum allowable shear all over the structure, set JS7 equal to the last station and enter only one card

SMAXN (E10.3) - Ultimate shear at station JS7

Remarks: Ultimate shear is linearly interpolated between input stations;

All cards must be in ascending order of station numbers, starting with station 1;

Last card must contain the last station number of the structure.

C) Thrust-Moment Interaction Diagram

Minimum three cards; maximum twelve cards
Multipliers (minimum one card, maximum ten cards)

JIA7	PMULN	BMULN
6 – 10	21 – 30	– 40

Where:

JIA7 (I5) - Number of station

PMULN (E10.3) - Thrust multiplier at station JIA7

BMULN (E10.3) - Moment multiplier at station JIA7

TABLE 7 (Continued)

Remarks: Multipliers are linearly interpolated between input stations;

All cards must be in ascending order of station numbers, starting with station 1;

Last card must contain the last station number of the structure;

For constant values for multipliers over the entire structure, set JIA7 equal to the last station and enter only one card.

Thrust-Moment Values (Two cards only; see Figure C.1)

First card--Thrust Values

P(2)	P(3)	...	...	P(J),J=2,8		...
9–16	16–24	24–32	32–40	40–48	48–56	56–64

Second card--Moment Values

M(1)	M(2)	M(3)	M(4)	M(6)	M(7)	M(8)	M(9)
1–8	8–16	16–24	24–32	41–48	48–56	56–64	64–72

Where:

P(J) (F8.0) - Value to be multiplied by the thrust multiplier to obtain the value of thrust at point J of the thrust-moment interaction diagram

M(J) (F8.0) - Value to be multiplied by the moment multiplier to obtain the value of moment at point J of the thrust-moment interaction diagram

END OF RUN

One card. This is the last card in the data deck. It may be left blank or a termination message may be punched in columns 5 to 80 (alphameric). This message will be printed as the last line of the output.

5–80

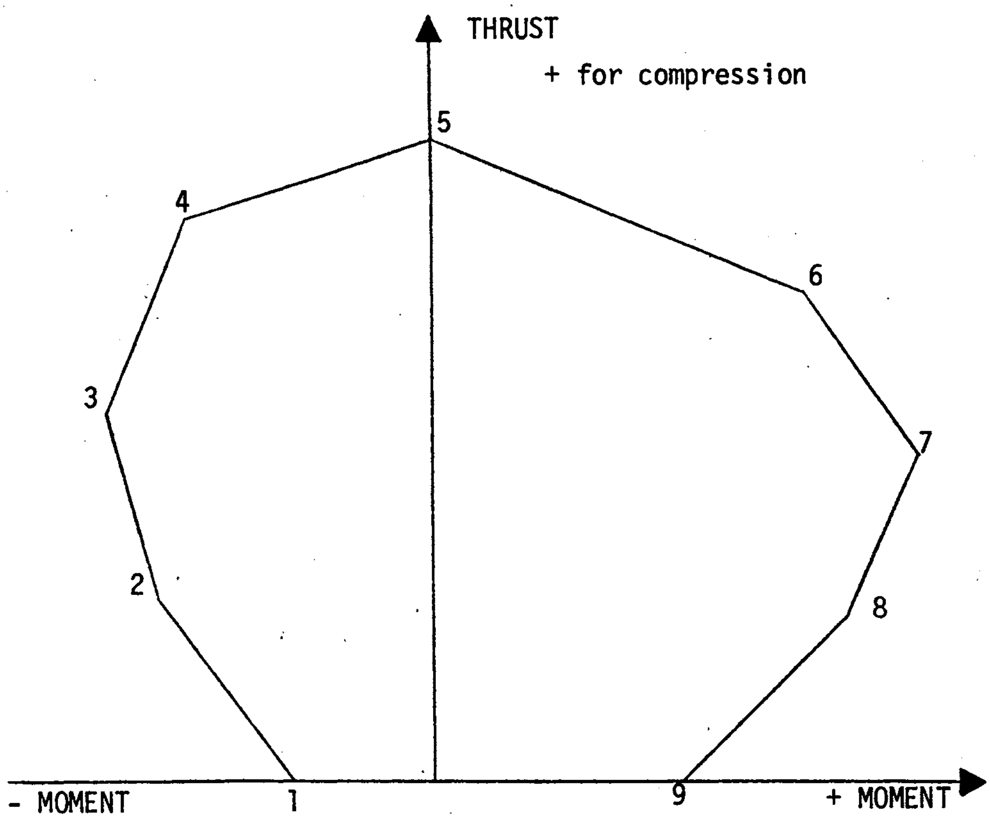


Figure C.1. Typical Thrust-Moment Interaction Diagram

APPENDIX D

PROGRAM DYNARCH: CODING LISTINGS AND PRINTOUT SHEETS

PROGRAM DYNARCH - MOUNTING FOR PROBLEM DTP1

```
COLUMNS #
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

//DYNARCH  JOB (13446,238-82-2628,1),'JERSON GUIMARAES',CLASS=B
/*PASSWORD GOIA
/*ROUTE PRINT HOLD
//   EXEC FORTGCG,REGION.GO=148K
//FORT.SYSIN DD *
C    FUNCTION FX
C
C    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C    *                                                                 *
C    *          THIS FUNCTION DESCRIBES A SEMI-CIRCULAR ARCH           *
C    *          HAVING A DIAMETER OF 353.27  UNITS OF LENGTH           *
C    *                     USED IN PROBLEM DTP1                        *
C    *                                                                 *
C    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      FUNCTION FX (X)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DATA D / 3.5327D 02 /
              FX = DSQRT (X * (D-X))
      RETURN
      END
//GO.HEXIN DD *

         (INSERT OBJECT CODE DECK FOR
          MAIN PROGRAM AND SUBROUTINES)

//GO.SYSIN DD *
JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - TWO HINGED CIRCULAR ARCH OF REINFORCED CONCRETE
DTP1     CIRC. ARCH - 180 DEGREES - STATIC SOLUTION ONLY - CENTRAL LOAD
                                      YES         2
                   2   24       176.635   386.4
         1                      8.          8.         8.
                       0.3                2.2                 2.2
                       4.1                7.9                 9.8
                       9.8                11.7               12.0
        25                      8.          8.         8.       END
              2    1   0.3        6    1   2.2        7    1   2.2
             11    1   4.1       19    1   7.9       23    1   9.8
             24    1   9.8       28    1  11.7       30    1  12.0
        25             2.0      1.0        10.0      1.0
         2
                      1.0   E3  8.694E-2
  -1.5    -3.9   -4.0    -3.8    -2.88 0.0001   0.0002   0.0003   0.0004   0.0005
                       1.0 E-3   3.0 E-3  1.75 E-4
  -7.2   -2.4    -1.9    -1.35   -0.8       20.     21.     22.       23.       24.
                     1.0    E4  2.861E-1
  -4.84  -4.83   -4.82   -4.81    -4.8      4.8      4.81   4.82   4.83     4.84
                       1.0 E-3   2.0 E-2
 -19.6   -15.1   -10.6    -6.1    -1.6     1.6     6.1     10.6    15.1     19.6
         1       11
         1       222
        25       1 1                                            END
   25            -1000.                                                       END
                   NORMAL TERMINATION OF EXECUTION
//

         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - TWO HINGED CIRCULAR ARCH OF REINFORCED CONCRETE

PROBLEM DTP1
CIRC. ARCH - 180 DEGREES - STATIC SOLUTION ONLY - CENTRAL LOAD

TABLE 1. - CONTROL DATA

NO KEEP OPTIONS EXERCIZED

STATIC SOLUTION REQUIRED: YES

ACCELERATION OF GRAVITY 3.864D 02

AXIS OF STRUCTURE DESCRIBED BY A SMOOTH CURVE

SYMMETRICAL STRUCTURE AND LOADING

SOLUTION FOR HALF STRUCTURE

STATIC OUTPUT OPTION 2

SELF WEIGHT NOT INCLUDED

TABLE 9. - STATIC DISPLACEMENTS

STA.	U	V	TH
1	0.0	0.0	0.0
2	-4.6813D-03	1.2364D-04	3.9974D-04
3	-9.1621D-03	5.3413D-04	3.7639D-04
4	-1.3262D-02	1.1790D-03	3.3964D-04
5	-1.6831D-02	1.9779D-03	2.9138D-04
6	-1.9752D-02	2.8293D-03	2.3360D-04
7	-2.1943D-02	3.6182D-03	1.6828D-04
8	-2.3360D-02	4.2228D-03	9.7453D-05
9	-2.3993D-02	4.5223D-03	2.3187D-05
10	-2.3868D-02	4.4039D-03	-5.2452D-05
11	-2.3042D-02	3.7596D-03	-1.2739D-04
12	-2.1600D-02	2.5422D-03	-1.9955D-04
13	-1.9652D-02	6.7100D-04	-2.6686D-04
14	-1.7324D-02	-1.8635D-03	-3.2730D-04
15	-1.4754D-02	-5.0462D-03	-3.7883D-04
16	-1.2086D-02	-8.8243D-03	-4.1950D-04
17	-9.4595D-03	-1.3107D-02	-4.4738D-04
18	-7.0052D-03	-1.7762D-02	-4.6058D-04
19	-4.8353D-03	-2.2621D-02	-4.5730D-04
20	-3.0364D-03	-2.7478D-02	-4.3580D-04
21	-1.6628D-03	-3.2096D-02	-3.9443D-04
22	-7.2912D-04	-3.6209D-02	-3.3159D-04
23	-2.0445D-04	-3.9528D-02	-2.4581D-04
24	-7.0902D-06	-4.1748D-02	-1.3571D-04
25	0.0	-4.2558D-02	0.0

TABLE 10. - STATIC REACTIONS

STA.	HORIZONTAL	VERTICAL	MOMENT
1	6.3656D 02	1.0000D 03	0.0
25	-6.3656D 02	0.0	6.4196D 04

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - TWO HINGED CIRCULAR ARCH OF REINFORCED CONCRETE

PROBLEM DTP1
CIRC. ARCH - 180 DEGREES - STATIC SOLUTION ONLY - CENTRAL LOAD

COMPLETE RESPONSE, TIME = 0.0

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			6.0000D 00
				-6.0350D 02	-1.0203D 03	
2	-4.6813D-03	1.2364D-04	-6.9759D 03			6.0000D 00
				-5.3548D 02	-1.0576D 03	
3	-9.1621D-03	5.3413D-04	-1.3165D 04			6.0000D 00
				-4.6516D 02	-1.0903D 03	
4	-1.3262D-02	1.1790D-03	-1.8542D 04			6.0000D 00
				-3.9285D 02	-1.1184D 03	
5	-1.6831D-02	1.9779D-03	-2.3083D 04			6.0000D 00
				-3.1886D 02	-1.1417D 03	
6	-1.9752D-02	2.8293D-03	-2.6769D 04			6.0000D 00
				-2.4351D 02	-1.1601D 03	
7	-2.1943D-02	3.6182D-03	-2.9583D 04			6.0000D 00
				-1.6711D 02	-1.1736D 03	
8	-2.3360D-02	4.2228D-03	-3.1515D 04			6.0000D 00
				-8.9994D 01	-1.1820D 03	
9	-2.3993D-02	4.5223D-03	-3.2555D 04			6.0000D 00
				-1.2496D 01	-1.1854D 03	
10	-2.3868D-02	4.4039D-03	-3.2700D 04			6.0000D 00
				6.5056D 01	-1.1836D 03	
11	-2.3042D-02	3.7696D-03	-3.1948D 04			6.0000D 00
				1.4233D 02	-1.1768D 03	
12	-2.1600D-02	2.5422D-03	-3.0302D 04			6.0000D 00
				2.1900D 02	-1.1650D 03	
13	-1.9652D-02	6.7100D-04	-2.7771D 04			6.0000D 00
				2.9472D 02	-1.1482D 03	
14	-1.7324D-02	-1.8635D-03	-2.4365D 04			6.0000D 00
				3.6918D 02	-1.1265D 03	
15	-1.4754D-02	-5.0462D-03	-2.0097D 04			6.0000D 00
				4.4207D 02	-1.0999D 03	
16	-1.2086D-02	-8.8243D-03	-1.4988D 04			6.0000D 00
				5.1306D 02	-1.0686D 03	
17	-9.4595D-03	-1.3107D-02	-9.0574D 03			6.0000D 00
				5.8185D 02	-1.0328D 03	
18	-7.0052D-03	-1.7762D-02	-2.3319D 03			6.0000D 00
				6.4815D 02	-9.9253D 02	
19	-4.8353D-03	-2.2621D-02	5.1598D 03			6.0000D 00
				7.1168D 02	-9.4801D 02	
20	-3.0364D-03	-2.7478D-02	1.3386D 04			6.0000D 00
				7.7216D 02	-8.9944D 02	
21	-1.6628D-03	-3.2096D-02	2.2311D 04			6.0000D 00
				8.2933D 02	-8.4701D 02	
22	-7.2912D-04	-3.6209D-02	3.1896D 04			6.0000D 00
				8.8295D 02	-7.9096D 02	
23	-2.0445D-04	-3.9528D-02	4.2103D 04			6.0000D 00
				9.3279D 02	-7.3151D 02	
24	-7.0902D-06	-4.1748D-02	5.2884D 04			6.0000D 00
				9.7864D 02	-6.6894D 02	
25	0.0	-4.2558D-02	6.4196D 04			6.0000D 00

NORMAL TERMINATION OF EXECUTION

PROGRAM DYNARCH - MOUNTING FOR PROBLEM DTP2.1

```
COLUMNS #
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

//DYNARCH  JOB (13446,238-82-2628,1),'JERSON GUIMARAES',CLASS=B
/*PASSWORD GOIA
/*ROUTE PRINT HOLD
//  EXEC FORTGCG,PARM.FORT=(NOSOURCE),REGION.GO=148K
//FORT.SYSIN DD *
C    FUNCTION FX
C
C    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C    *                                                               *
C    *    THIS FUNCTICN DESCRIBES A CIRCULAR ARCH HAVING A CENTRAL    *
C    *    ANGLE OF OPENING OF 87.21 DEGREES, SPAN LO = 687 UNITS OF   *
C    *          LENGTH, RISE OF 0.2 LO, USED IN PROBLEM DTP2.1        *
C    *                                                               *
C    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      FUNCTION FX (X)
C
      IMPLICIT REAL * 8(A-H, O-Z)
      DATA A, B, C / 841.575D00, 154.575D00, 360.675D00 /
            FX = DSQRT((A-X)*(B+X)) - C
      RETURN
      END
  GO.HEXIN DD *

        (INSERT OBJECT CODE DECK FOR
         MAIN PROGRAM AND SUBROUTINES)

//GO.SYSIN DD *
JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - LINEARLY ELASTIC DYNAMIC SOLUTION ONLY
DTP2    P2.1 - CIRC. ARCH - 87.21 DEG. - SYM. DYNAMIC UNIFORM PRESSURE - ELASTIC
                                              NO             1         2   10
                 2    6       343.5     386.4        4.67E-2  1.555E-4
        1                      11.502        .504      11.502
                       0.318               0.795                  0.795
                       4.795              11.365                 15.365
                      15.365              15.842                 16.16
        7                      11.502        .504      11.502    END
             2    1    0.318      5    1   0.795      6    1   0.795
            11    1    4.795     19    1  11.365     24    1  15.365
            25    1   15.365     28    1  15.842     30    1  16.16
        7
        1
                        1.0 E4  .28618
  -4.84  -4.83    -4.82   -4.81    -4.8      4.8      4.81    4.82    4.83     4.84
                       1.0 E-3   2.0 E-2
 -19.6   -15.1    -10.6   -6.1     -1.6     1.6      6.1     10.6    15.1     19.6
        1       11
        1       222
        7        1 1                                                 END
    1   -1.0                                                7   -1.0             END
                       47.11                    1.0 E16
                       3.        4.
        7             3.0    E5
        7             1.0    E5   1.0  E5
         0.8     1.8       3.2    4.72      3.2     1.8      0.8
  -4.5   -10.5   -16.5    -12.              12.     16.5     10.5    4.5
                 NORMAL TERMINATION OF EXECUTION
//


         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - LINEARLY ELASTIC DYNAMIC SOLUTION ONLY

PROBLEM DTP2
P2.1 - CIRC. ARCH - 87.21 DEG. - SYM. DYNAMIC UNIFORM PRESSURE - ELASTIC

TABLE 2. - CROSS SECTION DESCRIPTION

CONTROL DATA

STA. NO.	TOP FLANGE WIDTH	WEB THICKNESS	BOT FLANGE WIDTH
1	1.1502D 01	5.0400D-01	1.1502D 01

SEGMENT, MATERIAL, DEPTH DATA

SEG	MAT	DEPTH	SEG	MAT	DEPTH	SEG	MAT	DEPTH
2	1	3.180D-01	5	1	7.950D-01	6	1	7.950D-01
11	1	4.795D 00	19	1	1.137D 01	24	1	1.537D 01
25	1	1.537D 01	28	1	1.584D 01	30	1	1.616D 01

CONTROL DATA

STA. NO.	TOP FLANGE WIDTH	WEB THICKNESS	BOT FLANGE WIDTH
7	1.1502D 01	5.0400D-01	1.1502D 01

SEGMENT, MATERIAL, DEPTH DATA

SEG	MAT	DEPTH	SEG	MAT	DEPTH	SEG	MAT	DEPTH
2	1	3.180D-01	5	1	7.950D-01	6	1	7.950D-01
11	1	4.795D 00	19	1	1.137D 01	24	1	1.537D 01
25	1	1.537D 01	28	1	1.584D 01	30	1	1.616D 01

REINFORCEMENT DESCRIPTION

STA. NO.	TOP REINFORCEMENT DEPTH	TOP REINFORCEMENT AREA	BOTTOM REINFORCEMENT DEPTH	BOTTOM REINFORCEMENT AREA
7	0.0	0.0	0.0	0.0

TABLE 3. - STRESS-STRAIN CURVES

CURVE NO. 1

MATERIAL SPECIFIC WEIGHT	2.862D-01
COMPRESSIVE ULTIMATE STRAIN	2.000D-02
STRESS VALUE SCALE FACTOR	1.000D 04
STRAIN VALUE SCALE FACTOR	1.000D-03

STRESS INPUT VALUES
-4.840 -4.830 -4.820 -4.810 -4.800 4.800 4.810 4.820 4.830 4.840

STRAIN INPUT VALUES
-19.600-15.100-10.600 -6.100 -1.600 1.600 6.100 10.600 15.100 19.600

PROGRAM DYNARCH
ANALYSIS AND PREDICTICN OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - LINEARLY ELASTIC DYNAMIC SOLUTION ONLY

PROBLEM DTP2
P2.1 - CIRC. ARCH - 87.21 DEG. - SYM. DYNAMIC UNIFORM PRESSURE - ELASTIC

TABLE 4. - SPECIFIED CONDITIONS

STA.	CODE	SPECIFIED DISPLACEMENT U	V	ROT
1	110	0.0	0.0	
1	HINGE			
7	101	0.0		0.0

TABLE 5. - STATIC LOADS

NONE

TABLE 6. - DYNAMIC LOADING

DYNAMIC LOADING NO. 1

INITIAL STA.	X	Y	INTERMEDIATE STA.	X	Y	FINAL STA.	X	Y
1	-1.0000D 00	0.0	0	0.0	0.0	7	-1.0000D 00	0.0

PARAMETERS OF TIME FUNCTION

TIME OF RISING: TR = 0.0
TIME OF DECAY: TD = 1.0000D 16
MAXIMUM VALUE: FO = 4.7110D 01

TABLE 8. - STATION COORDINATES

STA.	X-COORD	Y-COORD
1	0.0	0.0
2	4.8383D 01	4.0554D 01
3	1.0151D 02	7.4662D 01
4	1.5852D 02	1.0178D 02
5	2.1850D 02	1.2146D 02
6	2.8050D 02	1.3340D 02
7	3.4350D 02	1.3740D 02

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - LINEARLY ELASTIC DYNAMIC SOLUTION ONLY

PROBLEM DTP2
P2.1 - CIRC. ARCH - 87.21 DEG. - SYM. DYNAMIC UNIFORM PRESSURE - ELASTIC

COMPLETE RESPONSE, TIME = 7.7750D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			8.0800D 00
				6.4060D 01	-4.4937D 04	
2	7.2584D-03	-1.4406D-02	4.0439D 03			8.0800D 00
				9.5197D 02	-4.4634D 04	
3	1.2166D-02	-2.8835D-02	6.4140D 04			8.0800D 00
				2.2993D 02	-4.4247D 04	
4	1.2015D-02	-3.6977D-02	7.8655D 04			8.0800D 00
				-1.0209D 03	-4.4156D 04	
5	8.0061D-03	-3.6389D-02	1.4209D 04			8.0800D 00
				-6.6886D 02	-4.4287D 04	
6	3.7114D-03	-3.3316D-02	-2.8015D 04			8.0800D 00
				2.6620D 01	-4.4357D 04	
7	0.0	-3.2334D-02	-2.6334D 04			8.0800D 00

UNDIMENSIONAL COEFFICIENTS FOR

	T/TO	Y-DISPL(CR)	THRUST(CR)	MOMENT(1/4)	MOMENT(CR)	M(CROWN)-T
5	5.0000D-01	-2.1276D 00	-1.8904D 00	4.8793D-01	-1.6336D-01	-1.6294D-01

PROBLEM DTP2
P2.1 - CIRC. ARCH - 87.21 DEG. - SYM. DYNAMIC UNIFORM PRESSURE - ELASTIC

COMPLETE RESPONSE, TIME = 1.5550D-02

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			8.0800D 00
				4.3189D 01	-5.3218D 03	
2	-3.1226D-03	3.0450D-03	2.7265D 03			8.0800D 00
				-8.6665D 02	-5.4756D 03	
3	-6.0376D-03	6.7529D-03	-5.1986D 04			8.0800D 00
				-7.3749D 02	-5.7079D 03	
4	-6.0506D-03	5.6889D-03	-9.8544D 04			8.0800D 00
				8.0401D 02	-5.7568D 03	
5	-2.8474D-03	-5.5914D-03	-4.7786D 04			8.0800D 00
				2.0443D 03	-5.4222D 03	
6	-8.9693D-05	-2.2277D-02	8.1272D 04			8.0800D 00
				9.9201D 02	-5.0306D 03	
7	0.0	-3.0214D-02	1.4390D 05			8.0800D 00

UNDIMENSIONAL COEFFICIENTS FOR

	T/TO	Y-DISPL(CR)	THRUST(CR)	MOMENT(1/4)	MOMENT(CR)	M(CROWN)-T
10	1.0000D 00	-1.9881D 00	-2.1439D-01	-6.1132D-01	8.9267D-01	8.9001D-01

PROGRAM DYNARCH
ANALYSIS AND PREDICTICN OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - LINEARLY ELASTIC DYNAMIC SOLUTION ONLY

PROBLEM DTP2
P2.1 - CIRC. ARCH - 87.21 DEG. - SYM. DYNAMIC UNIFORM PRESSURE - ELASTIC

COMPLETE RESPONSE, TIME = 2.3325D-02

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			8.0800D 00
				-1.4164D 03	-4.0196D 04	
2	6.1541D-04	-5.8719D-03	-8.9416D 04			8.0800D 00
				1.1309D 03	-3.9977D 04	
3	5.5759D-03	-1.9676D-02	-1.8023D 04			8.0800D 00
				1.8638D 03	-3.9400D 04	
4	9.4652D-03	-3.5390D-02	9.9637D 04			8.0800D 00
				-8.7727D 01	-3.8979D 04	
5	7.8316D-03	-4.0677D-02	9.4099D 04			8.0800D 00
				-1.8365D 03	-3.9113D 04	
6	3.5008D-03	-3.5171D-02	-2.1838D 04			8.0800D 00
				-9.3572D 02	-3.9447D 04	
7	0.0	-3.1148D-02	-8.0909D 04			8.0800D 00

UNDIMENSIONAL COEFFICIENTS FOR

	T/TO	Y-DISPL(CR)	THRUST(CR)	MOMENT(1/4)	MOMENT(CR)	M(CROWN)-T
15	1.5000D 00	-2.0495D 00	-1.6812D 00	6.1810D-01	-5.0191D-01	-5.0047D-01

PROBLEM DTP2
P2.1 - CIRC. ARCH - 87.21 DEG. - SYM. DYNAMIC UNIFORM PRESSURE - ELASTIC

COMPLETE RESPONSE, TIME = 3.1100D-02

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			8.0800D 00
				1.7446D 03	-8.7858D 03	
2	6.1592D-03	-8.4725D-03	1.1014D 05			8.0800D 00
				-9.3378D 02	-9.0069D 03	
3	4.5985D-03	-7.4104D-03	5.1187D 04			8.0800D 00
				-1.8836D 03	-9.6329D 03	
4	6.8209D-04	-1.0179D-03	-6.7725D 04			8.0800D 00
				-7.7554D 01	-1.0125D 04	
5	-1.4544D-04	-1.1622D-03	-7.2621D 04			8.0800D 00
				1.5846D 03	-1.0071D 04	
6	5.0749D-04	-8.9272D-03	2.7418D 04			8.0800D 00
				8.8802D 02	-9.7761D 03	
7	0.0	-1.3603D-02	8.3479D 04			8.0800D 00

UNDIMENSIONAL COEFFICIENTS FOR

	T/TO	Y-DISPL(CR)	THRUST(CR)	MOMENT(1/4)	MOMENT(CR)	M(CROWN)-T
20	2.0000D 00	-8.9508D-01	-4.1664D-01	-4.2013D-01	5.1786D-01	5.1631D-01

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - LINEARLY ELASTIC DYNAMIC SOLUTION ONLY

PROBLEM DTP2
P2.1 - CIRC. ARCH - 87.21 DEG. - SYM. DYNAMIC UNIFORM PRESSURE - ELASTIC

COMPLETE RESPONSE, TIME = 3.8875D-02

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			8.0800D 00
				-7.8326D 01	-3.3549D 04	
2	5.5977D-03	-1.0968D-02	-4.9446D 03			8.0800D 00
				6.6052D 02	-3.3489D 04	
3	9.8718D-03	-2.2716D-02	3.6753D 04			8.0800D 00
				7.8121D 02	-3.3363D 04	
4	1.0753D-02	-3.0948D-02	8.6070D 04			8.0800D 00
				-3.9329D 02	-3.3333D 04	
5	7.5332D-03	-2.9914D-02	6.1242D 04			8.0800D 00
				-1.5675D 03	-3.3573D 04	
6	3.1128D-03	-2.1540D-02	-3.7712D 04			8.0800D 00
				-9.7395D 02	-3.3912D 04	
7	0.0	-1.6457D-02	-9.9196D 04			8.0800D 00

UNDIMENSIONAL COEFFICIENTS FOR

	T/TO	Y-DISPL(CR)	THRUST(CR)	MOMENT(1/4)	MOMENT(CR)	M(CROWN)-T
25	2.5000D 00	-1.0829D 00	-1.4452D 00	5.3393D-01	-6.1536D-01	-6.1356D-01

COMPLETE RESPONSE, TIME = 4.6650D-02

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			8.0800D 00
				-2.7451D 02	-1.5013D 04	
2	-1.5277D-03	-9.6132D-05	-1.7330D 04			8.0800D 00
				-5.2348D 02	-1.5220D 04	
3	-2.1266D-03	-1.4763D-03	-5.0378D 04			8.0800D 00
				3.0504D 02	-1.5415D 04	
4	-6.0257D-04	-7.6282D-03	-3.1120D 04			8.0800D 00
				9.0641D 02	-1.5385D 04	
5	1.1484D-03	-1.7017D-02	2.6101D 04			8.0800D 00
				2.1914D 02	-1.5302D 04	
6	1.1326D-03	-2.3580D-02	3.9935D 04			8.0800D 00
				-1.0935D 02	-1.5289D 04	
7	0.0	-2.5552D-02	3.3095D 04			8.0800D 00

UNDIMENSIONAL COEFFICIENTS FOR

	T/TO	Y-DISPL(CR)	THRUST(CR)	MOMENT(1/4)	MOMENT(CR)	M(CROWN)-T
30	3.0000D 00	-1.6813D 00	-6.5159D-01	-1.9305D-01	2.0531D-01	2.0466D-01

FAILURE DID NOT OCCUR IN SPECIFIED TIME LIMIT
ELAPSED TIME = 4.6805D-02

```
                PROGRAM DYNARCH  -  EXAMPLE OF DATA INPUT
COLUMNS #
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

//GO.SYSIN DD *
JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS  -  SIMPLY SUPPORTED HORIZONTAL BEAM
DTP2     P2.2 - WIDE FLANGE STEEL BEAM - ELASTIC RESPONSE ONLY - SINUS. IMPULSE
                                     NO               1    1    2   60
                   2    10       240.        386.4      2.8 E-2 8.1906E-5
         1                         11.502      .504    11.502
                        0.318                0.795               0.795
                        4.795               11.365              15.365
                       15.365               15.842              16.16
        11                         11.502      .504    11.502    END
             2     1    0.318       5    1   0.795       6    1  0.795
            11     1    4.795      19    1  11.365      24    1 15.365
            25     1   15.365      28    1  15.842      30    1 16.16
        11
         1
                         1.0 E4   .28618
  -4.74   -4.73   -4.72   -4.71   -4.70    4.70    4.71    4.72    4.73    4.74
                        1.0 E-3   2.0 E-2
  -15.7   -12.2   -8.64   -5.10   -1.57    1.57    5.10    8.64    12.2    15.7
         1       1
         1      222
        11      1 1                                               END
    1           -1.0E-15    3                -0.618      5             -1.1756
    5           -1.1756     8                -1.782     11               -2.0      END
                        10.       10.
        11              1.0 E10
        11              1.0 E10   1.0 E10
      0.2     0.4     0.6      1.0     0.6     0.4     0.2
 -1.0    -1.0    -1.0    -1.0            1.0     1.0     1.0     1.0
DTP3     RC BEAM - COMBINED STATIC LOAD AND DOWNWARD/UPWARD SINUSOIDAL IMPULSE
                KEEP                 YES               2    2    1    2   10
         1         2    10        90.        386.4      1.0 E-2 4.7874E-5
         1                        8.          8.        8.
                        0.3                  2.2                 2.2
                        4.1                  7.9                 9.8
                        9.8                 11.7                12.0
        11                        8.          8.        8.       END
             2     1    0.3         6    1   2.2         7    1  2.2
            11     1    4.1        19    1   7.9        23    1  9.8
            24     1    9.8        28    1  11.7        30    1 12.0
        11                                  10.0        1.0
         2
                      1.0   E3 0.0848433
       -2.0    -4.0    -4.01    -4.0   0.001   0.002   0.003   0.004   0.005
                        1.0 E-3   3.0 E-3  1.75 E-4
  -10.0   -6.25   -2.5    -2.0    -1.5    6.0    12.0    18.0    24.0    30.0
                        1.0  E4 0.2861235
  -4.74   -4.73   -4.72   -4.71   -4.70    4.70    4.71    4.72    4.73    4.74
                        1.0 E-3   2.0 E-2
  -15.7   -12.2   -8.64   -5.10   -1.57    1.57    5.10    8.64    12.2    15.7
    1           -25.0       11               -25.0                                END
    1           -1.0E-15    3                -7.725      5              -14.69
    5           -14.69      8               -22.275     11               -25.0     END
    1            1.0E-15    3                 7.725      5               14.69
    5            14.69      8                22.275     11                25.0     END
                        1.0       5.0
        11              3.0  E4
        11              1.0  E5   1.0  E5
     1.2     2.0     3.05    4.27    2.5     1.1     0.55
 -6.6    -6.6    -6.6    -5.5            5.3     7.7     6.5     4.35
                   NORMAL TERMINATION OF EXECUTION
//
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - SIMPLY SUPPORTED HORIZONTAL BEAM

PROBLEM DTP2
P2.2 - WIDE FLANGE STEEL BEAM - ELASTIC RESPONSE ONLY - SINUS. IMPULSE

COMPLETE RESPONSE, TIME = 4.9144D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	6.6522D-04	0.0	0.0			8.0800D 00
				5.2842D 03	1.7637D 01	
2	5.3330D-04	-7.9741D-02	1.2682D 05			8.0800D 00
				4.8932D 03	1.3224D 01	
3	4.0785D-04	-1.5747D-01	2.4426D 05			8.0800D 00
				4.5729D 03	6.8777D 00	
4	2.9448D-04	-2.3131D-01	3.5401D 05			8.0800D 00
				4.5853D 03	2.9338D 00	
5	1.9764D-04	-2.9952D-01	4.6405D 05			8.0800D 00
				4.1382D 03	-5.2034D-01	
6	1.2054D-04	-3.6034D-01	5.6337D 05			8.0800D 00
				3.2951D 03	-3.2613D 00	
7	6.4383D-05	-4.1221D-01	6.4245D 05			8.0800D 00
				2.5030D 03	-4.5659D 00	
8	2.8097D-05	-4.5387D-01	7.0252D 05			8.0800D 00
				1.8253D 03	-6.2314D 00	
9	8.5481D-06	-4.8435D-01	7.4633D 05			8.0800D 00
				1.2411D 03	-7.3797D 00	
10	1.1024D-06	-5.0296D-01	7.7612D 05			8.0800D 00
				4.9525D 02	-9.0914D 00	
11	0.0	-5.0922D-01	7.8800D 05			8.0800D 00

PROBLEM DTP2
P2.2 - WIDE FLANGE STEEL BEAM - ELASTIC RESPONSE ONLY - SINUS. IMPULSE

COMPLETE RESPONSE, TIME = 1.5071D-02

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	4.9012D-03	0.0	0.0			8.0800D 00
				1.3825D 04	1.2273D 02	
2	3.9292D-03	-2.1642D-01	3.3180D 05			8.0800D 00
				1.3706D 04	1.1099D 02	
3	3.0039D-03	-4.2756D-01	6.6075D 05			8.0800D 00
				1.3141D 04	9.3120D 01	
4	2.1681D-03	-6.2820D-01	9.7613D 05			8.0800D 00
				1.1998D 04	6.8203D 01	
5	1.4564D-03	-8.1331D-01	1.2641D 06			8.0800D 00
				1.0538D 04	4.0326D 01	
6	8.9036D-04	-9.7832D-01	1.5170D 06			8.0800D 00
				8.9746D 03	8.3857D 00	
7	4.7712D-04	-1.1192D 00	1.7324D 06			8.0800D 00
				7.4541D 03	-2.2683D 01	
8	2.0883D-04	-1.2325D 00	1.9113D 06			8.0800D 00
				5.3420D 03	-5.0575D 01	
9	6.3951D-05	-1.3155D 00	2.0395D 06			8.0800D 00
				2.9076D 03	-7.2233D 01	
10	8.5641D-06	-1.3660D 00	2.1093D 06			8.0800D 00
				9.4280D 02	-8.2378D 01	
11	0.0	-1.3829D 00	2.1319D 06			8.0800D 00

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - SIMPLY SUPPORTED HORIZONTAL BEAM

PROBLEM DTP2
P2.2 - WIDE FLANGE STEEL BEAM - ELASTIC RESPONSE ONLY - SINUS. IMPULSE

COMPLETE RESPONSE, TIME = 2.5227D-02

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	8.0624D-03	0.0	0.0			8.0800D 00
				1.8167D 04	1.9708D 02	
2	6.4616D-03	-2.7773D-01	4.3601D 05			8.0800D 00
				1.7463D 04	1.6257D 02	
3	4.9390D-03	-5.4852D-01	8.5513D 05			8.0800D 00
				1.6319D 04	1.2414D 02	
4	3.5647D-03	-8.0571D-01	1.2468D 06			8.0800D 00
				1.5326D 04	8.2913D 01	
5	2.3935D-03	-1.0431D 00	1.6146D 06			8.0800D 00
				1.3776D 04	4.1795D 01	
6	1.4612D-03	-1.2548D 00	1.9452D 06			8.0800D 00
				1.1570D 04	6.9632D 00	
7	7.8077D-04	-1.4355D 00	2.2229D 06			8.0800D 00
				9.2003D 03	-2.0716D 01	
8	3.3968D-04	-1.5809D 00	2.4437D 06			8.0800D 00
				6.8599D 03	-4.2404D 01	
9	1.0191D-04	-1.6874D 00	2.6086D 06			8.0800D 00
				4.4060D 03	-5.7093D 01	
10	1.1969D-05	-1.7525D 00	2.7143D 06			8.0800D 00
				1.5454D 03	-6.3806D 01	
11	0.0	-1.7744D 00	2.7514D 06			8.0800D 00

PROBLEM DTP2
P2.2 - WIDE FLANGE STEEL BEAM - ELASTIC RESPONSE ONLY - SINUS. IMPULSE

COMPLETE RESPONSE, TIME = 2.6538D-02

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	8.0970D-03	0.0	0.0			8.0800D 00
				1.8129D 04	2.0638D 02	
2	6.4860D-03	-2.7864D-01	4.3509D 05			8.0800D 00
				1.7516D 04	1.9091D 02	
3	4.9538D-03	-5.5035D-01	8.5548D 05			8.0800D 00
				1.6631D 04	1.6878D 02	
4	3.5710D-03	-8.0847D-01	1.2546D 06			8.0800D 00
				1.5371D 04	1.4451D 02	
5	2.3939D-03	-1.0466D 00	1.6235D 06			8.0800D 00
				1.3631D 04	1.1561D 02	
6	1.4581D-03	-1.2590D 00	1.9507D 06			8.0800D 00
				1.1595D 04	8.7531D 01	
7	7.7592D-04	-1.4403D 00	2.2290D 06			8.0800D 00
				9.3698D 03	5.8147D 01	
8	3.3446D-04	-1.5862D 00	2.4538D 06			8.0800D 00
				6.9285D 03	3.4606D 01	
9	9.7715D-05	-1.6930D 00	2.6201D 06			8.0800D 00
				4.1917D 03	1.6550D 01	
10	9.7430D-06	-1.7582D 00	2.7207D 06			8.0800D 00
				1.3996D 03	8.0272D 00	
11	0.0	-1.7801D 00	2.7543D 06			8.0800D 00

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - SIMPLY SUPPORTED HORIZONTAL BEAM

PROBLEM DTP2
P2.2 - WIDE FLANGE STEEL BEAM - ELASTIC RESPONSE ONLY - SINUS. IMPULSE

COMPLETE RESPONSE, TIME = 2.7193D-02

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	8.0962D-03	0.0	0.0			8.0800D 00
				1.8017D 04	1.9778D 02	
2	6.4874D-03	-2.7841D-01	4.3242D 05			8.0800D 00
				1.7520D 04	1.7074D 02	
3	4.9566D-03	-5.4995D-01	8.5291D 05			8.0800D 00
				1.6638D 04	1.4068D 02	
4	3.5745D-03	-8.0792D-01	1.2522D 06			8.0800D 00
				1.5326D 04	1.0714D 02	
5	2.3972D-03	-1.0460D 00	1.6200D 06			8.0800D 00
				1.3831D 04	7.5588D 01	
6	1.4606D-03	-1.2583D 00	1.9520D 06			8.0800D 00
				1.1749D 04	4.5059D 01	
7	7.7756D-04	-1.4395D 00	2.2339D 06			8.0800D 00
				9.1706D 03	2.1805D 01	
8	3.3583D-04	-1.5853D 00	2.4540D 06			8.0800D 00
				6.7468D 03	3.5994D 00	
9	9.8772D-05	-1.6920D 00	2.6160D 06			8.0800D 00
				4.2090D 03	-6.3270D 00	
10	1.0304D-05	-1.7570D 00	2.7170D 06			8.0800D 00
				1.4457D 03	-1.0531D 01	
11	0.0	-1.7789D 00	2.7517D 06			8.0800D 00

COMPLETE RESPONSE, TIME = 2.8012D-02

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	8.0669D-03	0.0	0.0			8.0800D 00
				1.7787D 04	1.9231D 02	
2	6.4681D-03	-2.7754D-01	4.2690D 05			8.0800D 00
				1.7506D 04	1.5996D 02	
3	4.9458D-03	-5.4829D-01	8.4705D 05			8.0800D 00
				1.6732D 04	1.2195D 02	
4	3.5706D-03	-8.0557D-01	1.2486D 06			8.0800D 00
				1.5383D 04	7.9299D 01	
5	2.3987D-03	-1.0430D 00	1.6178D 06			8.0800D 00
				1.3674D 04	3.4862D 01	
6	1.4661D-03	-1.2547D 00	1.9460D 06			8.0800D 00
				1.1680D 04	-1.2511D 01	
7	7.8509D-04	-1.4354D 00	2.2263D 06			8.0800D 00
				9.2948D 03	-5.2491D 01	
8	3.4336D-04	-1.5808D 00	2.4494D 06			8.0800D 00
				6.7659D 03	-8.6388D 01	
9	1.0486D-04	-1.6872D 00	2.6118D 06			8.0800D 00
				4.0202D 03	-1.1126D 02	
10	1.3772D-05	-1.7520D 00	2.7083D 06			8.0800D 00
				1.2625D 03	-1.2443D 02	
11	0.0	-1.7738D 00	2.7386D 06			8.0800D 00

FAILURE DID NOT OCCUR IN SPECIFIED TIME LIMIT
ELAPSED TIME = 2.8012D-02

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - SIMPLY SUPPORTED HORIZONTAL BEAM

PROBLEM DTP3
RC BEAM - COMBINED STATIC LOAD AND DOWNWARD/UPWARD SINUSOIDAL IMPULSE

TABLE 1. - CONTROL DATA

RETAIN PRIOR DATA TABLES 4,

STATIC SOLUTION REQUIRED: YES

ACCELERATION OF GRAVITY 3.864D 02

AXIS OF STRUCTURE DESCRIBED BY A SMOOTH CURVE

SYMMETRICAL STRUCTURE AND LOADING

SOLUTION FOR HALF STRUCTURE

STATIC OUTPUT OPTION 2

SELF WEIGHT NOT INCLUDED

NUMBER OF DYNAMIC LOADINGS 2

DYNAMIC OUTPUT OPTION 2

OUTPUT INTERVAL 10

TIME LIMIT 1.000D-02

TYPE OF DYNAMIC LOADING: IMPULSE

INELASTIC RESPONSE REQUIRED

TIME INTERVAL 4.787D-05

TABLE 7. - COLLAPSE PARAMETERS

DISPLACEMENT LIMITS

MAXIMUM HORIZONTAL DISPL: 1.0000D 00
MAXIMUM VERTICAL DISPL: 5.0000D 00

SHEAR LIMITS

TERM STA.	SHEAR VALUE
11	3.0000D 04

INTERACTION DIAGRAM DATA

TERM STA.	AXIAL FORCE MULTIPLIER	MOMENT MULTIPLIER
11	1.0000D 05	1.0000D 05

AXIAL FORCE INPUT VALUES
0.0 1.200 2.000 3.050 4.270 2.500 1.100 0.550 0.0

MOMENT INPUT VALUES
-6.600 -6.600 -6.600 -5.500 0.0 5.300 7.700 6.500 4.350

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PROBLEM DTP3
RC BEAM - COMBINED STATIC LOAD AND DOWNWARD/JPWARD SINUSOIDAL IMPULSE

COMPLETE RESPONSE, TIME = 0.0

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			6.3851D 00
				2.1375D 03	-2.7786D-01	
2	0.0	-1.5680D-02	1.9235D 04			6.3851D 00
				1.9125D 03	-8.0433D-01	
3	0.0	-3.0917D-02	3.6446D 04			6.3851D 00
				1.6875D 03	-1.2723D 00	
4	0.0	-4.5310D-02	5.1632D 04			6.3851D 00
				1.4625D 03	-1.6818D 00	
5	0.0	-5.8502D-02	6.4793D 04			6.3851D 00
				1.2375D 03	-2.0328D 00	
6	0.0	-7.0185D-02	7.5930D 04			6.3851D 00
				1.0125D 03	-2.3253D 00	
7	0.0	-8.0100D-02	8.5041D 04			6.3851D 00
				7.8750D 02	-2.5592D 00	
8	0.0	-8.8033D-02	9.2128D 04			6.3851D 00
				5.6250D 02	-2.7347D 00	
9	0.0	-9.3818D-02	9.7190D 04			6.3851D 00
				3.3750D 02	-2.8517D 00	
10	0.0	-9.7336D-02	1.0023D 05			6.3851D 00
				1.1250D 02	-2.9102D 00	
11	0.0	-9.8516D-02	1.0124D 05			6.3851D 00

PROBLEM DTP3
RC BEAM - COMBINED STATIC LOAD AND DOWNWARD/JPWARD SINUSOIDAL IMPULSE

COMPLETE RESPONSE, TIME = 4.7874D-04

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	1.0470D-03	0.0	0.0			6.3851D 00
				4.1236D 03	1.7203D 03	
2	5.1019D-04	-1.0099D-01	3.7112D 04			6.3851D 00
				7.7113D 03	3.4075D 03	
3	1.3616D-04	-2.0112D-01	1.0652D 05			4.5713D 00
				3.4097D 03	4.3837D 03	
4	-1.3075D-04	-2.9605D-01	1.3720D 05			4.3271D 00
				5.2322D 03	5.0986D 03	
5	-2.1561D-04	-3.8391D-01	1.8430D 05			4.2287D 00
				4.5280D 03	4.9160D 03	
6	-2.3521D-04	-4.6214D-01	2.2505D 05			4.1507D 00
				4.5183D 03	4.0385D 03	
7	-1.9653D-04	-5.2851D-01	2.6571D 05			4.1507D 00
				4.3982D 02	2.9972D 03	
8	-1.5802D-04	-5.8087D-01	2.6967D 05			4.1507D 00
				1.2079D 03	2.0256D 03	
9	-1.0594D-04	-6.1902D-01	2.8054D 05			4.1507D 00
				1.6668D 03	1.3390D 03	
10	-5.5461D-05	-6.4239D-01	2.9555D 05			4.1507D 00
				2.2693D 01	9.8060D 02	
11	0.0	-6.5019D-01	2.9575D 05			4.1507D 00

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - SIMPLY SUPPORTED HORIZONTAL BEAM

PROBLEM DTP3
RC BEAM - COMBINED STATIC LOAD AND DOWNWARD/UPWARD SINUSOIDAL IMPULSE

COMPLETE RESPONSE, TIME = 9.5748D-04

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	5.1613D-03	0.0	0.0			6.3851D 00
				7.0543D 03	1.6440D 03	
2	3.2442D-03	-1.8614D-01	6.3489D 04			6.3851D 00
				1.1600D 04	4.4325D 03	
3	1.5887D-03	-3.7080D-01	1.6789D 05			4.2287D 00
				9.1537D 03	6.3794D 03	
4	3.1218D-04	-5.4670D-01	2.5028D 05			4.1507D 00
				1.2302D 04	7.5122D 03	
5	-6.1730D-04	-7.0941D-01	3.6100D 05			4.0982D 00
				3.8235D 03	7.4194D 03	
6	-1.2061D-03	-8.5303D-01	3.9541D 05			4.0220D 00
				1.2195D 03	5.0173D 03	
7	-1.5346D-03	-9.7490D-01	4.0639D 05			4.0382D 00
				1.5392D 03	-1.4060D 02	
8	-1.5777D-03	-1.0733D 00	4.2024D 05			3.9894D 00
				9.9399D 02	-4.6701D 03	
9	-1.0226D-03	-1.1447D 00	4.2919D 05			3.9694D 00
				-1.3875D 02	-6.2145D 03	
10	-4.8961D-04	-1.1870D 00	4.2794D 05			3.9781D 00
				4.2167D 02	-6.1767D 03	
11	0.0	-1.2011D 00	4.3174D 05			4.0149D 00

COMPLETE RESPONSE, TIME = 1.2447D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	9.4050D-03	0.0	0.0			6.3851D 00
				1.0257D 04	1.9535D 03	
2	6.2905D-03	-2.3848D-01	9.2311D 04			5.1881D 00
				1.3907D 04	3.7951D 03	
3	3.4464D-03	-4.7330D-01	2.1747D 05			4.1507D 00
				1.3937D 04	3.5047D 03	
4	1.0924D-03	-6.9666D-01	3.4292D 05			4.1507D 00
				5.3468D 03	1.7859D 03	
5	-1.3428D-03	-9.0195D-01	3.9104D 05			4.0982D 00
				5.3032D 03	-4.1644D 03	
6	-2.9489D-03	-1.0866D 00	4.3877D 05			4.0335D 00
				7.4401D 02	-1.0427D 04	
7	-3.9312D-03	-1.2426D 00	4.4546D 05			4.0252D 00
				7.7950D 01	-1.1114D 04	
8	-4.1792D-03	-1.3683D 00	4.4617D 05			3.9894D 00
				5.9908D 02	-1.1371D 04	
9	-2.4546D-03	-1.4598D 00	4.5156D 05			3.9694D 00
				6.9549D 02	-1.3775D 04	
10	-1.0552D-03	-1.5139D 00	4.5782D 05			3.9781D 00
				-1.1352D 02	-1.5879D 04	
11	0.0	-1.5315D 00	4.5680D 05			3.9915D 00

FAILURE DUE TO THRUST-MOMENT INTERACTION AT STATION 10

FAILURE OCCURRED AT TIME = 1.2447D-03 SECS.

PROGRAM DYNARCH
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JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - SIMPLY SUPPORTED HORIZONTAL BEAM

PROBLEM DTP3
RC BEAM - COMBINED STATIC LOAD AND DOWNWARD/UPWARD SINUSOIDAL IMPULSE

SOLUTION FOR DYNAMIC LOADING NO. 2

STA. NO.	POINT MASS	DYNAMIC LOADS HORIZONTAL	DYNAMIC LOADS VERTICAL	STATIC LOADS HORIZONTAL	STATIC LOADS VERTICAL	DEPTH OF CENTROID
1	9.7200D-02	0.0	6.0075D 00	4.0014D 00	-1.1250D 02	6.3851D 00
2	1.9440D-01	0.0	3.5475D 01	4.0558D-02	-2.2498D 02	6.3851D 00
3	1.9440D-01	0.0	6.9382D 01	-7.1337D-02	-2.2498D 02	6.3851D 00
4	1.9440D-01	0.0	1.0158D 02	-1.4533D-01	-2.2498D 02	6.3851D 00
5	1.9440D-01	0.0	1.3201D 02	-1.8616D-01	-2.2498D 02	6.3851D 00
6	1.9440D-01	0.0	1.5942D 02	-1.9856D-01	-2.2498D 02	6.3851D 00
7	1.9440D-01	0.0	1.8217D 02	-1.8728D-01	-2.2498D 02	6.3851D 00
8	1.9440D-01	0.0	2.0007D 02	-1.5704D-01	-2.2498D 02	6.3851D 00
9	1.9440D-01	0.0	2.1310D 02	-1.1259D-01	-2.2498D 02	6.3851D 00
10	1.9440D-01	0.0	2.2128D 02	-5.8664D-02	-2.2498D 02	6.3851D 00
11	9.7200D-02	0.0	1.1215D 02	0.0	-1.1249D 02	6.3851D 00

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - SIMPLY SUPPORTED HORIZONTAL BEAM

PROBLEM DTP3
RC BEAM - COMBINED STATIC LOAD AND DOWNWARD/UPWARD SINUSOIDAL IMPULSE

COMPLETE RESPONSE, TIME = 4.7874D-04

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	3.6898D-04	0.0	0.0			6.3851D 00
				-7.3149D 03	1.0192D 03	
2	1.0785D-04	7.0289D-02	-6.5835D 04			6.3851D 00
				4.1601D 02	3.2192D 03	
3	-1.1442D-05	1.3903D-01	-6.2090D 04			6.7568D 00
				6.0781D 03	3.2969D 03	
4	-8.3202D-05	2.0599D-01	-7.3863D 03			1.0138D 01
				-1.8605D 03	2.8108D 03	
5	-6.0838D-05	2.6586D-01	-2.4132D 04			8.9662D 00
				1.9366D 03	2.5335D 03	
6	-6.8263D-05	3.2192D-01	-6.7017D 03			1.0302D 01
				1.2172D 02	1.3791D 03	
7	-3.1999D-05	3.6869D-01	-5.6062D 03			1.0447D 01
				-1.4611D 02	8.8631D 02	
8	-1.8467D-05	4.0457D-01	-6.9212D 03			1.0302D 01
				2.8344D 01	5.0519D 02	
9	-1.2367D-05	4.3084D-01	-6.6661D 03			1.0302D 01
				6.9538D 01	2.4930D 02	
10	-6.4181D-06	4.4786D-01	-6.0393D 03			1.0447D 01
				-1.7587D 02	1.2374D 02	
11	0.0	4.5315D-01	-7.6221D 03			1.0302D 01

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - SIMPLY SUPPORTED HORIZONTAL BEAM

PROBLEM DTP3
RC BEAM - COMBINED STATIC LOAD AND DOWNWARD/UPWARD SINUSOIDAL IMPULSE

COMPLETE RESPONSE, TIME = 9.5748D-04

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	3.0897D-03	0.0	0.0			6.3851D 00
				7.3263D 03	1.9129D 03	
2	1.9235D-03	1.5202D-01	6.5938D 04			6.3851D 00
				-3.3967D 02	3.9082D 03	
3	5.5709D-04	3.0558D-01	6.2881D 04			6.3851D 00
				-8.1630D 03	5.9349D 03	
4	-2.3535D-04	4.6061D-01	-1.0591D 04			1.0626D 01
				4.0897D 03	6.4650D 03	
5	-4.1003D-04	5.8744D-01	2.6220D 04			7.0095D 00
				-3.9491D 03	6.5626D 03	
6	-1.3413D-03	7.1496D-01	-9.3215D 03			1.0626D 01
				4.9258D 01	5.4395D 03	
7	-5.9329D-04	8.1768D-01	-8.8781D 03			1.0626D 01
				1.2155D 02	4.4849D 03	
8	-6.2541D-04	8.9675D-01	-7.7841D 03			1.0626D 01
				-5.3900D 01	2.8968D 03	
9	-3.4595D-04	9.5510D-01	-8.2692D 03			1.0568D 01
				-1.8033D 02	2.2548D 03	
10	-1.9268D-04	9.9295D-01	-9.8922D 03			1.0626D 01
				6.5982D 01	1.6400D 03	
11	0.0	1.0045D 00	-9.2984D 03			1.0568D 01

PROBLEM DTP3
RC BEAM - COMBINED STATIC LOAD AND DOWNWARD/UPWARD SINUSOIDAL IMPULSE

COMPLETE RESPONSE, TIME = 1.9150D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	1.8551D-02	0.0	0.0			6.3851D 00
				4.8016D 03	1.3510D 03	
2	1.2896D-02	3.1945D-01	4.3215D 04			6.3851D 00
				2.0751D 01	4.0460D 03	
3	7.3652D-03	6.3990D-01	4.3402D 04			6.3851D 00
				-6.7449D 03	6.7478D 03	
4	1.8196D-03	9.6136D-01	-1.7304D 04			1.0646D 01
				1.3021D 03	8.1380D 03	
5	-1.7735D-05	1.2366D 00	-5.5818D 03			1.0626D 01
				-1.1698D 03	8.2248D 03	
6	-3.9093D-03	1.4969D 00	-1.6110D 04			1.0646D 01
				-3.1475D 02	8.7852D 03	
7	-3.7901D-03	1.7142D 00	-1.8944D 04			1.0646D 01
				2.8795D 02	9.5752D 03	
8	-5.0806D-03	1.8808D 00	-1.6352D 04			1.0646D 01
				-6.6056D 01	1.1154D 04	
9	-3.0589D-03	2.0036D 00	-1.6947D 04			1.0646D 01
				-2.5366D 02	1.1663D 04	
10	-2.2621D-03	2.0810D 00	-1.9230D 04			1.0646D 01
				-2.0937D 01	1.2625D 04	
11	0.0	2.1070D 00	-1.9419D 04			1.0646D 01

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH TEST PROBLEMS - SIMPLY SUPPORTED HORIZONTAL BEAM

PROBLEM DTP3
RC BEAM - COMBINED STATIC LOAD AND DOWNWARD/UPWARD SINUSOIDAL IMPULSE

COMPLETE RESPONSE, TIME = 3.3512D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	7.3289D-02	0.0	0.0			6.3851D 00
				3.4029D 03	2.3408D 03	
2	5.5278D-02	5.6898D-01	3.0626D 04			6.3851D 00
				-3.7159D 03	7.7899D 03	
3	3.7604D-02	1.1387D 00	-2.8183D 03			1.0646D 01
				-1.4625D 03	1.2281D 04	
4	2.2923D-02	1.7010D 00	-1.5985D 04			1.0646D 01
				-1.3336D 03	1.4910D 04	
5	9.6012D-03	2.2206D 00	-2.7990D 04			1.0646D 01
				6.3635D 02	1.6743D 04	
6	1.8594D-03	2.6654D 00	-2.2261D 04			1.0646D 01
				-8.1772D 02	1.8124D 04	
7	-3.9014D-03	3.0506D 00	-2.9622D 04			1.0646D 01
				-3.3864D 02	1.8680D 04	
8	-5.7831D-03	3.3567D 00	-3.2671D 04			1.0646D 01
				1.1993D 02	1.9429D 04	
9	-5.6738D-03	3.5753D 00	-3.1592D 04			1.0646D 01
				-8.9257D 01	2.0555D 04	
10	-3.1583D-03	3.7093D 00	-3.2395D 04			1.0646D 01
				-3.2807D 02	2.1012D 04	
11	0.0	3.7566D 00	-3.5349D 04			1.0646D 01

FAILURE DUE TO VERTICAL DEFLECTION AT STATION 11

FAILURE OCCURRED AT TIME = 4.4523D-03 SECS.

COMPLETE RESPONSE, TIME = 4.4523D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	1.5204D-01	0.0	0.0			6.3851D 00
				1.7092D 03	1.6482D 03	
2	1.1970D-01	7.6205D-01	1.5383D 04			6.3851D 00
				-2.5269D 03	5.6195D 03	
3	8.7669D-02	1.5245D 00	-7.3600D 03			1.0646D 01
				-1.1211D 03	8.3523D 03	
4	5.8849D-02	2.2674D 00	-1.7452D 04			1.0646D 01
				-1.9646D 03	1.1856D 04	
5	3.3130D-02	2.9637D 00	-3.5136D 04			1.0646D 01
				-2.1349D 02	1.4477D 04	
6	1.6115D-02	3.5664D 00	-3.7058D 04			1.0646D 01
				3.4466D 02	1.6764D 04	
7	3.6428D-03	4.0700D 00	-3.3955D 04			1.0646D 01
				-1.0838D 03	1.8764D 04	
8	-1.5743D-03	4.4829D 00	-4.3714D 04			1.0646D 01
				-4.0076D 01	1.8557D 04	
9	-4.6350D-03	4.7786D 00	-4.4075D 04			1.0646D 01
				-2.7702D 01	1.9370D 04	
10	-2.4938D-03	4.9559D 00	-4.4324D 04			1.0646D 01
				8.8782D 01	1.8863D 04	
11	0.0	5.0144D 00	-4.3525D 04			1.0646D 01

NORMAL TERMINATION OF EXECUTION

PROGRAM DYNARCH - EXAMPLE OF DATA INPUT

```
COLUMNS #
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

//GO.SYSIN DD *
JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH APPLICATION PROBLEMS - TWO-HINGED CIRCULAR ARCH OF REINFORCED CONCRETE
DAP1      CIRCULAR ARCH - 180 DEG. - SYM. DYN. LOAD AND SELF WEIGHT - INELASTIC
                                        YES     1    2    1         2   10
         1         2    12       177.      386.4        1.2 E-2   1.2 E-4
         1                        8.         8.         8.
                        0.3                  2.2                  2.2
                        4.1                  7.9                  9.8
                        9.8                 11.7                 12.0
        13                        8.         8.         8.       END
              2    1    0.3        6    1    2.2         7    1   2.2
             11    1    4.1       19    1    7.9        23    1   9.8
             24    1    9.8       28    1   11.7        30    1  12.0
        13              2.0       1.0       10.0        1.0
         2
                        1.0  E3   8.694E-2
 -1.5     -3.9    -4.0    -3.8     -2.88     0.0001  0.0002  0.0003  0.0004  0.0005
                        1.0 E-3   3.0 E-3   1.75 E-4
 -7.2     -2.4    -1.9    -1.35    -0.8     20.      21.      22.      23.      24.
                        1.0  E4   2.861E-1
 -4.84    -4.83   -4.82   -4.81    -4.8      4.8      4.81     4.82     4.83     4.84
                        1.0 E-3   2.0 E-2
-19.6    -15.1   -10.6    -6.1     -1.6      1.6      6.1     10.6     15.1     19.6
         1       11
         1       222
        13       1 1                                             END
    1   1.0E-15                                                                 END
   11 1.0 E-15 -1.0 E-15   12.70710678 -.70710678   13   1.0      -1.0          END
                      2400.       5.0 E-3   1.0 E-2
                        3.        4.
        13              3.0  E5
        13              1.0  E5   1.0  E5
          0.8      1.8     3.2     4.72      3.2      1.8      0.8
 -4.5    -10.5   -16.5   -12.                12.      16.5     10.5     4.5
DAP2      CIRC. ARCH - 180 DEG. -  NONSYM. DYN. LOAD AND SELF WEIGHT - INELASTIC
            KEEP                        YES     1    2    1         2   10
         1         1    24       354.      386.4        2.0 E-2
         1                        8.         8.         8.
                        0.3                  2.2                  2.2
                        4.1                  7.9                  9.8
                        9.8                 11.7                 12.0
        25                        8.         8.         8.       END
              2    1    0.3        6    1    2.2         7    1   2.2
             11    1    4.1       19    1    7.9        23    1   9.8
             24    1    9.8       28    1   11.7        30    1  12.0
        25              2.0       1.0       10.0        1.0
         1       11
         1       222
        25       222
        25       11                                              END
    1            -1.0 E-15
   25            -1.0 E-15                                                      END
    5 1.0 E-15 -1.0 E-15    6.70710678 -.70710678    7   1.0      -1.0
    7   1.0      -1.0       8.70710678 -.70710678    9 1.0 E-15 -1.0 E-15       END
                      4000.       5.0 E-3   1.0 E-2
                        3.        4.
        25              3.0  E5
        25              1.0  E5   1.0  E5
          0.8      1.8     3.2     4.72      3.2      1.8      0.8
 -4.5    -10.5   -16.5   -12.                12.      16.5     10.5     4.5
                    NORMAL TERMINATION OF EXECUTION
//
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH APPLICATION PROBLEMS - TWO-HINGED CIRCULAR ARCH OF REINFORCED CONCRETE

PROBLEM DAP1
CIRCULAR ARCH - 180 DEG. - SYM. DYN. LOAD AND SELF WEIGHT - INELASTIC

TABLE 1. - CONTROL DATA

NO KEEP OPTIONS EXERCIZED

STATIC SOLUTION REQUIRED: YES

ACCELERATION OF GRAVITY 3.864D 02

AXIS OF STRUCTURE DESCRIBED BY A SMOOTH CURVE

SYMMETRICAL STRUCTURE AND LOADING

SOLUTION FOR HALF STRUCTURE

STATIC OUTPUT OPTION 2

SELF WEIGHT ADDED TO STATIC LOADS

NUMBER OF DYNAMIC LOADINGS 1

DYNAMIC OUTPUT OPTION 2

OUTPUT INTERVAL 10

TIME LIMIT 1.200D-02

TYPE OF DYNAMIC LOADING: FORCING PULSE

INELASTIC RESPONSE REQUIRED

TIME INTERVAL 1.200D-04

TABLE 5. - STATIC LOADS

	INITIAL			INTERMEDIATE			FINAL	
STA.	X	Y	STA.	X	Y	STA.	X	Y
1	1.0000D-15	0.0	0	0.0	0.0	0	0.0	0.0

TABLE 6. - DYNAMIC LOADING

DYNAMIC LOADING NO. 1

	INITIAL			INTERMEDIATE			FINAL	
STA.	X	Y	STA.	X	Y	STA.	X	Y
11	1.0000D-15	-1.0000D-15	12	7.071D-01	-7.071D-01	13	1.0000D 00	-1.0000D 00

PARAMETERS OF TIME FUNCTION

TIME OF RISING: TR = 5.0000D-03
TIME OF DECAY: TD = 1.0000D-02
MAXIMUM VALUE: FO = 2.4000D 03

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH APPLICATION PROBLEMS - TWO-HINGED CIRCULAR ARCH OF REINFORCED CONCRETE

PROBLEM DAP1
CIRCULAR ARCH - 180 DEG. - SYM. DYN. LOAD AND SELF WEIGHT - INELASTIC

TABLE 7. - COLLAPSE PARAMETERS

DISPLACEMENT LIMITS

MAXIMUM HORIZONTAL DISPL: 3.0000D 00
MAXIMUM VERTICAL DISPL: 4.0000D 00

SHEAR LIMITS

TERM STA.	SHEAR VALUE
13	3.0000D 05

INTERACTION DIAGRAM DATA

TERM STA.	AXIAL FORCE MULTIPLIER	MOMENT MULTIPLIER
13	1.0000D 05	1.0000D 05

AXIAL FORCE INPUT VALUES
0.0 0.800 1.800 3.200 4.720 3.200 1.800 0.800 0.0

MOMENT INPUT VALUES
-4.500-10.500-16.500-12.000 0.0 12.000 16.500 10.500 4.500

TABLE 8. - STATION COORDINATES

STA.	X-COORD	Y-COORD
1	0.0	0.0
2	1.5143D 00	2.3104D 01
3	6.0313D 00	4.5812D 01
4	1.3474D 01	6.7736D 01
5	2.3714D 01	8.8501D 01
6	3.6577D 01	1.0775D 02
7	5.1843D 01	1.2516D 02
8	6.9250D 01	1.4042D 02
9	8.8501D 01	1.5329D 02
10	1.0927D 02	1.6353D 02
11	1.3119D 02	1.7097D 02
12	1.5390D 02	1.7549D 02
13	1.7700D 02	1.7700D 02

PROGRAM DYNARCH
ANALYSIS AND PREDICTICN OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH APPLICATION PROBLEMS - TWO-HINGED CIRCULAR ARCH OF REINFORCED CONCRETE

PROBLEM DAP1
CIRCULAR ARCH - 180 DEG. - SYM. DYN. LOAD AND SELF WEIGHT - INELASTIC

COMPLETE RESPONSE, TIME = 0.0

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			6.0000D 00
				-6.2099D 02	-2.3740D 03	
2	-6.8170D-03	3.0856D-04	-1.4378D 04			6.0000D 00
				-3.4531D 02	-2.2362D 03	
3	-1.2130D-02	1.2328D-03	-2.2373D 04			6.0000D 00
				-1.1555D 02	-2.0704D 03	
4	-1.5086D-02	2.1092D-03	-2.5048D 04			6.0000D 00
				6.6129D 01	-1.8862D 03	
5	-1.5549D-02	2.2157D-03	-2.3517D 04			6.0000D 00
				1.9928D 02	-1.6931D 03	
6	-1.3933D-02	1.0171D-03	-1.8903D 04			6.0000D 00
				2.8507D 02	-1.5004D 03	
7	-1.0978D-02	-1.6904D-03	-1.2303D 04			6.0000D 00
				3.2625D 02	-1.3168D 03	
8	-7.5325D-03	-5.7350D-03	-4.7496D 03			6.0000D 00
				3.2700D 02	-1.1505D 03	
9	-4.3531D-03	-1.0614D-02	2.8212D 03			6.0000D 00
				2.9279D 02	-1.0084D 03	
10	-1.9582D-03	-1.5603D-02	9.6000D 03			6.0000D 00
				2.3019D 02	-8.9650D 02	
11	-5.5213D-04	-1.9907D-02	1.4930D 04			6.0000D 00
				1.4667D 02	-8.1929D 02	
12	-2.1935D-05	-2.2816D-02	1.8325D 04			6.0000D 00
				5.0330D 01	-7.7989D 02	
13	0.0	-2.3844D-02	1.9491D 04			6.0000D 00

COMPLETE RESPONSE, TIME = 0.0

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			6.0000D 00
				-6.2099D 02	-2.3383D 03	
2	-6.8170D-03	3.0856D-04	-1.4385D 04			6.0000D 00
				-3.4531D 02	-2.2260D 03	
3	-1.2130D-02	1.2328D-03	-2.2383D 04			6.0000D 00
				-1.1555D 02	-2.0617D 03	
4	-1.5086D-02	2.1092D-03	-2.5060D 04			6.0000D 00
				6.6129D 01	-1.8798D 03	
5	-1.5549D-02	2.2157D-03	-2.3528D 04			6.0000D 00
				1.9928D 02	-1.6895D 03	
6	-1.3933D-02	1.0171D-03	-1.8912D 04			6.0000D 00
				2.8507D 02	-1.5000D 03	
7	-1.0978D-02	-1.6904D-03	-1.2309D 04			6.0000D 00
				3.2625D 02	-1.3197D 03	
8	-7.5325D-03	-5.7350D-03	-4.7519D 03			6.0000D 00
				3.2700D 02	-1.1564D 03	
9	-4.3531D-03	-1.0614D-02	2.8225D 03			6.0000D 00
				2.9279D 02	-1.0170D 03	
10	-1.9582D-03	-1.5603D-02	9.6045D 03			6.0000D 00
				2.3019D 02	-9.0728D 02	
11	-5.5213D-04	-1.9907D-02	1.4937D 04			6.0000D 00
				1.4667D 02	-8.3160D 02	
12	-2.1935D-05	-2.2816D-02	1.8334D 04			6.0000D 00
				5.0330D 01	-7.9299D 02	
13	0.0	-2.3844D-02	1.9500D 04			6.0000D 00

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH APPLICATION PROBLEMS - TWO-HINGED CIRCULAR ARCH OF REINFORCED CONCRETE

PROBLEM DAP1
CIRCULAR ARCH - 180 DEG. - SYM. DYN. LOAD AND SELF WEIGHT - INELASTIC

COMPLETE RESPONSE, TIME = 2.8205D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			6.0000D 00
				-6.4449D 02	-7.2549D 03	
2	-6.9837D-03	4.4137D-05	-1.4922D 04			6.0000D 00
				-3.0635D 02	-7.6824D 03	
3	-1.2486D-02	6.8117D-04	-2.2014D 04			6.0000D 00
				-1.1608D 02	-8.5634D 03	
4	-1.5760D-02	1.2891D-03	-2.4702D 04			6.0000D 00
				6.0126D 01	-9.8717D 03	
5	-1.6712D-02	1.1008D-03	-2.3310D 04			6.0000D 00
				3.3281D 02	-1.1489D 04	
6	-1.5726D-02	-3.2656D-04	-1.5605D 04			6.0000D 00
				6.0640D 02	-1.3389D 04	
7	-1.3871D-02	-3.0210D-03	-1.5656D 03			6.0000D 00
				-5.4546D 01	-1.5679D 04	
8	-1.2398D-C2	-6.0167D-03	-2.8284D 03			6.0000D 00
				-2.1068D 03	-1.8686D 04	
9	-1.1424D-02	-9.4643D-03	-5.1605D 04			6.0000D 00
				-2.8552D 03	-2.2538D 04	
10	-8.6582D-03	-1.7934D-02	-1.1771D 05			6.0000D 00
				1.8404D 03	-2.6002D 04	
11	-3.3385D-03	-3.8635D-02	-7.5098D 04			6.0000D 00
				9.0017D 03	-2.8017D 04	
12	8.0413D-04	-6.7598D-02	1.3330D 05			6.0000D 00
				1.8841D 03	-2.7293D 04	
13	0.0	-8.2403D-02	1.7692D 05			5.1257D 00

COMPLETE RESPONSE, TIME = 5.9583D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			6.0000D 00
				-4.5804D 03	-5.1678D 04	
2	-2.6369D-02	-1.1010D-03	-1.0604D 05			6.0000D 00
				7.2945D 02	-5.1443D 04	
3	-4.2136D-02	-1.6265D-03	-8.9152D 04			6.0000D 00
				4.0285D 03	-5.0385D 04	
4	-4.8670D-02	-1.4988D-03	4.1126D 03			6.0000D 00
				3.1036D 03	-5.0334D 04	
5	-5.6910D-02	-2.0854D-03	7.5958D 04			6.0000D 00
				-2.2880D 03	-5.1371D 04	
6	-7.0733D-02	5.4843D-03	2.2985D 04			6.0000D 00
				-6.2802D 03	-5.5213D 04	
7	-8.8030D-02	1.3982D-02	-1.2239D 05			6.0000D 00
				-4.3311D 03	-5.9388D 04	
8	-9.2994D-02	1.7460D-02	-2.2266D 05			6.0000D 00
				-1.5974D 03	-6.2534D 04	
9	-8.8172D-02	-4.3380D-04	-2.5963D 05			6.5339D 00
				-4.1351D 03	-6.6033D 04	
10	-6.6425D-02	-4.9126D-02	-3.5536D 05			8.0323D 00
				1.2338D 04	-7.3652D 04	
11	-2.8883D-02	-1.9806D-01	-6.9836D 04			6.0000D 00
				1.4035D 04	-7.2032D 04	
12	4.6316D-03	-3.5468D-01	2.5515D 05			5.1257D 00
				1.1960D 04	-7.4185D 04	
13	0.0	-4.7257D-01	5.3191D 05			3.6922D 00

PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH APPLICATION PROBLEMS - TWO-HINGED CIRCULAR ARCH OF REINFORCED CONCRETE

PROBLEM DAP1
CIRCULAR ARCH - 180 DEG. - SYM. DYN. LOAD AND SELF WEIGHT - INELASTIC

COMPLETE RESPONSE, TIME = 8.8356D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			6.0000D 00
				3.1812D 02	-2.7810D 04	
2	-6.5191D-02	2.2423D-03	7.3648D 03			6.0000D 00
				-3.3478D 03	-2.7603D 04	
3	-1.3032D-01	1.4431D-02	-7.0143D 04			6.0000D 00
				-3.7495D 03	-2.8067D 04	
4	-1.8728D-01	3.0341D-02	-1.5694D 05			6.0000D 00
				1.6419D 03	-2.7788D 04	
5	-2.2514D-01	4.9484D-02	-1.1893D 05			6.0000D 00
				2.7201D 03	-2.7582D 04	
6	-2.5238D-01	6.2586D-02	-5.5959D 04			6.0000D 00
				-9.8126D 02	-2.8033D 04	
7	-2.6949D-01	7.9656D-02	-7.8679D 04			6.0000D 00
				-6.3002D 03	-3.4802D 04	
8	-2.8407D-01	8.8040D-02	-2.2451D 05			7.7568D 00
				-1.1171D 04	-4.1823D 04	
9	-2.6296D-01	5.4945D-02	-4.8315D 05			8.4520D 00
				2.5631D 03	-4.5562D 04	
10	-1.8222D-01	-1.4122D-01	-4.2384D 05			8.3210D 00
				2.0658D 04	-4.2576D 04	
11	-7.1718D-02	-4.6999D-01	5.4475D 04			6.0000D 00
				1.0523D 04	-3.6825D 04	
12	-1.3960D-02	-8.0578D-01	2.9803D 05			3.8011D 00
				7.3854D 03	-3.4698D 04	
13	0.0	-1.0557D 00	4.6901D 05			3.2112D 00

COMPLETE RESPONSE, TIME = 8.9298D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			6.0000D 00
				4.9593D 02	-2.5633D 04	
2	-6.7073D-02	2.5335D-03	1.1481D 04			6.0000D 00
				-3.6804D 03	-2.6165D 04	
3	-1.3449D-01	1.5158D-02	-7.3728D 04			6.0000D 00
				-3.8752D 03	-2.5783D 04	
4	-1.9322D-01	3.1861D-02	-1.6344D 05			6.0000D 00
				1.8296D 03	-2.5676D 04	
5	-2.3209D-01	5.1690D-02	-1.2108D 05			6.0000D 00
				2.6615D 03	-2.6007D 04	
6	-2.6016D-01	6.5299D-02	-5.9466D 04			6.0000D 00
				-6.7258D 02	-2.6565D 04	
7	-2.7753D-01	8.2953D-02	-7.5039D 04			6.0000D 00
				-6.7041D 03	-3.3706D 04	
8	-2.9286D-01	9.1954D-02	-2.3022D 05			7.9138D 00
				-1.0942D 04	-4.1047D 04	
9	-2.6953D-01	5.5616D-02	-4.8354D 05			8.4520D 00
				2.8519D 03	-4.3742D 04	
10	-1.8598D-01	-1.4603D-01	-4.1754D 05			8.3210D 00
				1.9926D 04	-3.9692D 04	
11	-7.3600D-02	-4.7879D-01	4.3842D 04			6.0000D 00
				1.0647D 04	-3.3124D 04	
12	-1.5124D-02	-8.2005D-01	2.9027D 05			3.6766D 00
				9.1292D 03	-4.4022D 04	
13	0.0	-1.0752D 00	5.0163D 05			3.4362D 00

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PROGRAM DYNARCH
ANALYSIS AND PREDICTION OF COLLAPSE OF PLANE ARCHES
UNDER STATIC AND DYNAMIC LOADING

JERSON DUARTE GUIMARAES - OSU - STILLWATER, OKLAHOMA, APRIL 1974
DYNARCH APPLICATION PROBLEMS - TWO-HINGED CIRCULAR ARCH OF REINFORCED CONCRETE


PROBLEM DAP2
         CIRC. ARCH - 180 DEG. -  NONSYM. DYN. LOAD AND SELF WEIGHT - INELASTIC

TABLE 3. - STRESS-STRAIN CURVES


       CURVE NO. 1

             MATERIAL SPECIFIC WEIGHT       8.694D-02
             COMPRESSIVE ULTIMATE STRAIN   3.000D-03
             STRESS VALUE SCALE FACTOR      1.000D 03
             STRAIN VALUE SCALE FACTOR      1.000D-03

          STRESS INPUT VALUES
           -1.500 -3.900 -4.000 -3.800 -2.880  0.000  0.000  0.000  0.000  0.000

          STRAIN INPUT VALUES
           -7.200 -2.400 -1.900 -1.350 -0.800 20.000 21.000 22.000 23.000 24.000

       CURVE NO. 2

             MATERIAL SPECIFIC WEIGHT       2.861D-01
             COMPRESSIVE ULTIMATE STRAIN   2.000D-02
             STRESS VALUE SCALE FACTOR      1.000D 04
             STRAIN VALUE SCALE FACTOR      1.000D-03

          STRESS INPUT VALUES
           -4.840 -4.830 -4.820 -4.810 -4.800  4.800  4.810  4.820  4.830  4.840

          STRAIN INPUT VALUES
          -19.600-15.100-10.600 -6.100 -1.600  1.600  6.100 10.600 15.100 19.600

TABLE 5. - STATIC LOADS


              INITIAL                     INTERMEDIATE                    FINAL
      STA.     X          Y       STA.     X           Y        STA.     X          Y

        1  0.0       -1.000D-15    0  0.0         0.0            0  0.0        0.0
       25  0.0       -1.000D-15    0  0.0         0.0            0  0.0        0.0


TABLE 6. - DYNAMIC LOADING


          DYNAMIC LOADING NO.  1


              INITIAL                     INTERMEDIATE                    FINAL
      STA.     X          Y       STA.     X           Y        STA.     X          Y

        5  1.000D-15-1.000D-15    6  7.071D-01-7.071D-01    7  1.000D 00-1.000D 00
        7  1.000D 00-1.000D 00    8  7.071D-01-7.071D-01    9  1.000D-15-1.000D-15

                     PARAMETERS OF TIME FUNCTION

                          TIME OF RISING:  TR =  5.0000D-03
                          TIME OF DECAY:   TD =  1.0000D-02
                          MAXIMUM VALUE:   FO =  4.0000D 03
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DYNARCH APPLICATION PROBLEMS - TWO-HINGED CIRCULAR ARCH OF REINFORCED CONCRETE

PROBLEM DAP2
CIRC. ARCH - 180 DEG. - NONSYM. DYN. LOAD AND SELF WEIGHT - INELASTIC

COMPLETE RESPONSE, TIME = 3.7969D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			6.0000D 00
				-8.5132D 03	-8.5910D 04	
2	-3.1996D-02	-2.6037D-03	-1.9707D 05			6.0000D 00
				-5.2346D 03	-8.8313D 04	
3	-4.4321D-02	-6.2357D-03	-3.1823D 05			6.0000D 00
				-4.3465D 02	-9.0190D 04	
4	-2.4685D-02	-1.7073D-02	-3.2830D 05			6.5339D 00
				4.2487D 03	-9.3792D 04	
5	3.1725D-02	-5.4183D-02	-2.2996D 05			6.0000D 00
				1.7369D 04	-9.4834D 04	
6	1.0588D-01	-1.0696D-01	1.7215D 05			6.0000D 00
				1.1492D 04	-9.0176D 04	
7	1.5392D-01	-1.6094D-01	4.3811D 05			4.0113D 00
				-1.1065D 04	-8.6390D 04	
8	1.0756D-01	-1.2139D-01	1.8202D 05			6.0000D 00
				-1.6694D 04	-8.4145D 04	
9	6.1256D-02	-5.5451D-02	-2.0446D 05			6.0000D 00
				-2.2063D 03	-7.4554D 04	
10	2.8391D-02	-5.7151D-03	-2.5553D 05			6.9266D 00
				1.2364D 03	-6.3888D 04	
11	2.0893D-02	9.0246D-03	-2.2691D 05			6.0000D 00
				7.4715D 03	-5.4516D 04	
12	1.8161D-02	7.1608D-04	-5.3955D 04			6.0000D 00
				4.9004D 03	-4.5541D 04	
13	1.7293D-02	-1.2434D-02	5.9494D 04			6.0000D 00
				-1.4860D 02	-3.9023D 04	
14	1.4037D-02	-1.8657D-02	5.6054D 04			6.0000D 00
				-1.4342D 03	-3.4985D 04	
15	1.2376D-02	-1.8480D-02	2.2852D 04			6.0000D 00
				-6.1217D 02	-3.0242D 04	
16	1.1322D-02	-1.5481D-02	8.6799D 03			6.0000D 00
				-1.9929D 02	-2.6831D 04	
17	1.1632D-02	-1.1595D-02	4.0660D 03			6.0000D 00
				-2.8083D 02	-2.3001D 04	
18	1.2821D-02	-7.3104D-03	-2.4355D 03			6.0000D 00
				-3.4903D 02	-1.9984D 04	
19	1.4692D-02	-3.4760D-03	-1.0516D 04			6.0000D 00
				-3.0643D 02	-1.7064D 04	
20	1.6381D-02	-6.5075D-04	-1.7610D 04			6.0000D 00
				-2.1160D 02	-1.4524D 04	
21	1.7074D-02	8.0331D-04	-2.2509D 04			6.0000D 00
				-7.4667D 01	-1.2267D 04	
22	1.5956D-02	1.0526D-03	-2.4238D 04			6.0000D 00
				9.8966D 01	-1.0455D 04	
23	1.2593D-02	5.3634D-04	-2.1947D 04			6.0000D 00
				2.9344D 02	-9.1988D 03	
24	7.0391D-03	-2.9312D-05	-1.5153D 04			6.0000D 00
				6.5447D 02	-8.5910D 03	
25	0.0	0.0	0.0			6.0000D 00

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DYNARCH APPLICATION PROBLEMS - TWO-HINGED CIRCULAR ARCH OF REINFORCED CONCRETE

PROBLEM DAP2
CIRC. ARCH - 180 DEG. - NONSYM. DYN. LOAD AND SELF WEIGHT - INELASTIC

FAILURE DUE TO CRUSHING OF TOP FIBERS AT JOINT 7

FAILURE OCCURRED AT TIME = 5.1878D-03 SECS.

COMPLETE RESPONSE, TIME = 5.1878D-03

STA.	X DISPL	Y DISPL	MOMENT	SHEAR	THRUST	CENTROID
1	0.0	0.0	0.0			6.0000D 00
				-1.6146D 04	-1.2255D 05	
2	-7.4027D-02	-1.4998D-03	-3.7374D 05			6.0000D 00
				-4.9721D 02	-1.2359D 05	
3	-1.1003D-01	-4.3916D-03	-3.8524D 05			7.5499D 00
				-1.4396D 03	-1.2344D 05	
4	-5.4768D-02	-3.3247D-02	-4.1856D 05			7.5274D 00
				8.3854D 03	-1.3119D 05	
5	9.9060D-02	-1.2994D-01	-2.2457D 05			6.0000D 00
				2.6196D 04	-1.3153D 05	
6	2.7015D-01	-2.4115D-01	3.8205D 05			6.0000D 00
				7.7020D 03	-1.2645D 05	
7	3.7848D-01	-3.6294D-01	5.6022D 05			3.8494D 00
				-7.0453D 03	-1.2186D 05	
8	2.6716D-01	-2.7230D-01	3.9727D 05			6.0000D 00
				-2.6495D 04	-1.2098D 05	
9	1.7059D-01	-1.1383D-01	-2.1639D 05			6.0000D 00
				-8.5766D 03	-1.0979D 05	
10	7.8711D-02	2.2361D-02	-4.1477D 05			7.8644D 00
				3.7209D 03	-9.7023D 04	
11	6.5422D-02	5.7038D-02	-3.2863D 05			6.1297D 00
				5.1134D 03	-8.6566D 04	
12	5.6604D-02	5.5450D-02	-2.1028D 05			6.0000D 00
				6.7769D 03	-7.7341D 04	
13	5.6989D-02	3.3607D-02	-5.3390D 04			6.0000D 00
				6.5510D 03	-6.9179D 04	
14	4.8261D-02	7.0459D-03	9.8236D 04			6.0000D 00
				4.1488D 02	-6.3660D 04	
15	4.4014D-02	-8.4676D-03	1.0784D 05			6.0000D 00
				-3.1511D 03	-5.7702D 04	
16	3.7434D-02	-1.0521D-02	3.4901D 04			6.0000D 00
				-1.6611D 03	-5.2806D 04	
17	3.6459D-02	-9.9331D-03	-3.5553D 03			6.0000D 00
				-4.9606D 01	-4.7811D 04	
18	3.2804D-02	-7.4237D-03	-4.7036D 03			6.0000D 00
				-5.3015D 00	-4.3393D 04	
19	3.1906D-02	-6.7633D-03	-4.8263D 03			6.0000D 00
				-3.0193D 02	-4.0627D 04	
20	2.9411D-02	-4.3894D-03	-1.1816D 04			6.0000D 00
				-2.4332D 02	-3.9179D 04	
21	2.7565D-02	-3.8519D-03	-1.7449D 04			6.0000D 00
				-1.4163D 02	-3.7920D 04	
22	2.3850D-02	-2.6362D-03	-2.0728D 04			6.0000D 00
				-3.5585D 02	-3.8156D 04	
23	1.8835D-02	-2.3562D-03	-2.8966D 04			6.0000D 00
				-3.4134D 02	-3.7977D 04	
24	1.1099D-02	-1.4645D-03	-3.6868D 04			6.0000D 00
				1.5925D 03	-3.8457D 04	
25	0.0	0.0	0.0			6.0000D 00

NORMAL TERMINATION OF EXECUTION

TABLE D.1

NONDIMENSIONAL RESULTS--PROBLEM DTP2.1

Elapsed Time	Vertical Displ. Crown	Thrust Crown	Moment ¼ Point	Moment Crown	Moment Crown
t/T_o	$\frac{v_{dc}}{p_o R^2/AE}$	$\frac{T_c}{p_o R}$	$\frac{M_{1/4}}{p_o Rr}$	$\frac{M_c}{p_o Rr}$	$\frac{EI}{p_o R^3 r}\left[\frac{\partial^2 u_r}{\partial\theta^2} + u_r\right]_c$
0.1	-0.1906	-0.1896	-0.0060	-0.0026	-0.0026
0.2	-0.6920	-0.6335	-0.0257	-0.0097	-0.0097
0.3	-1.3310	-1.2002	0.0386	-0.0138	-0.0138
0.4	-1.8783	-1.6766	0.2711	-0.0321	-0.0321
0.5	-2.1276	-1.8904	0.4879	-0.1634	-0.1629
0.6	-2.0428	-1.8139	0.5038	-0.4226	-0.4213
0.7	-1.8336	-1.4362	0.3847	-0.4964	-0.4950
0.8	-1.7526	-0.9484	0.1798	-0.1139	-0.1136
0.9	-1.8304	-0.4858	-0.1773	0.4699	0.4685
1.0	-1.9881	-2.2144	-0.6113	0.8927	0.8900
1.1	-2.1864	-0.2288	-0.8684	1.1000	1.0967
1.2	-2.3454	-0.4691	-0.7592	1.0333	1.0302
1.3	-2.3705	-0.8968	-0.3277	0.6202	0.6183
1.4	-2.2546	-1.3319	0.2122	0.0354	0.0353
1.5	-2.0495	-1.6812	0.6181	-0.5019	-0.5005
1.6	-1.8269	-1.8201	0.7265	-0.8076	-0.8053
1.7	-1.6753	-1.6818	0.5628	-0.6402	-0.6384
1.8	-1.5604	-1.3444	0.2728	-0.0760	-0.0758
1.9	-1.3132	-0.8560	-0.0863	0.4040	0.4028
2.0	-0.8951	-0.4166	-0.4201	0.5179	0.5163
2.1	-0.4716	-0.1361	-0.4572	0.3861	0.3850
2.2	-0.2312	-0.1249	-0.1416	0.1502	0.1498
2.3	-0.2558	-0.4168	0.2271	-0.1740	-0.1735
2.4	-0.5533	-0.8927	0.4494	-0.4978	-0.4963
2.5	-1.0829	-1.4452	0.5339	-0.6154	-0.6136
2.6	-1.6854	-1.8219	0.4858	-0.4546	-0.4533
2.7	-2.1279	-1.9152	0.3603	-0.1621	-0.1617
2.8	-2.2456	-1.6823	0.2264	0.0968	0.0964
2.9	-2.0355	-1.1896	0.0358	0.2148	0.2141
3.0	-1.6813	-0.6516	-0.1931	0.2053	0.2047

VITA

Jerson Duarte Guimarães

Candidate for the Degree of

Doctor of Philosophy

Thesis: A METHOD OF ANALYSIS FOR NONLINEAR DYNAMIC RESPONSE OF ARCHES

Major Field: Civil Engineering

Biographical:

Personal Data: Born in Pitangui, State of Minas Gerais, Brazil, on January 25, 1923, son of Joao Antonio Guimaraes and Izaura Maria Duarte.

Education: Graduated from Colegio Estadual de Minas Gerais, Belo Horizonte, Brazil, in February, 1944, junior high school; graduated from Colegio Anchieta de Belo Horizonte, Minas Gerais, Brazil, in December, 1946, high school; graduated accountant from Escola Technica de Comercio Brasileira, Belo Horizonte, Brazil, in December, 1944; received Civil Engineering degree from Escola de Engenharia da Universidade Federal de Minas Gerais, Belo Horizonte, Brazil, in December, 1952; received Master of Science degree in Civil Engineering from Duke University, Durham, North Carolina, USA, in June, 1967.

Professional Experience: Worked for Mrs. A. J. Diniz & Cia., auto dealers, Belo Horizonte, Minas Gerais, Brazil, from 1941 to 1952, first as an auxiliary bookkeeper and then, from 1945, as Chief Accountant; Assistant Civil Engineer for Sociedade Brasileira de Eletrificação and for Construtora Walter Coscarelli, Belo Horizonte, Minas Gerais, Brazil, from 1953 to 1955; Consultant Structural Engineer and Professor of Civil Engineering in Goiania, State of Goias, Brazil, since 1957; Executive Director of the Escola de Engenharia da Universidade Federal de Goias, Goiania, Brazil, from 1959 to 1962; graduate teaching assistant at Duke University, Durham, North Carolina, from September, 1965 to March, 1967, and at Oklahoma State University for the academic year of 1973-1974.

Honorary: Vice-President for the Clube de Engenharia de Goias, Goiania, Goias, Brazil, 1959/60; member of the first University Council of the Universidade Federal de Goias, representing the

Escola de Engenharia, Goiania, Goias, Brazil, 1961; Vice-President of the Goias State branch of the Conselho Federal de Engenharia, Arquitetura e Agronomia, Goiania, Goias, Brazil, 1968.