NONLINEAR AND LARGE DISPLACEMENT BEHAVIOR OF PORTAL FRAMES SUBJECTED TO IMPULSE LOADING

By

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NOMENCLATURE

A_j	area of j^{th} segment of cross section
AB	area of bottom reinforcing steel
$(AE)_i$	axial stiffness of i^{th} cross section
AT	area of top reinforcing steel
a_i, b_i, c_i, d_i, e_i	coefficients in governing equations for static displacements
$[A_i]$, $[B_i]$, $[C_i]$, $[D_i]$, $[E_i]$	matrix coefficients in governing equations for static displacements
B	width of cross section
D	depth of cross section
d	depth to bottom steel
d'	depth to top steel
d_j	depth from top of section to center of j^{th} segment
d_k	distance from centroid of cross section to center of k^{th} segment
$\overline{d}$	depth from top of section to centroid of section
E_j	modulus of elasticity of j^{th} segment of cross section
EC1	modulus of elasticity of concrete
$(EI)_e$	equivalent flexural stiffness
$(EI)_i$	flexural stiffness of i^{th} cross section
ES1	modulus of elasticity of top steel
ES2	modulus of elasticity of bottom steel

F_{xi}	foundation force in the x direction at station i
F_{yi}	foundation force in the y direction at station i
i	station number
I	moment of inertia
kd	depth from top of section to neutral axis
L_i	length of i^{th} bar
ΔL_i	change in length of i^{th} bar
m_i	mass at joint i
M_i	bending moment at joint i
n	ratio of modulus of elasticity of steel to that of concrete
NSNS	number of segments in section
p	percentage of bottom steel
p'	percentage of top steel
Q_{xi}	applied static load at joint i in the x direction
Q_{yi}	applied static load at joint i in the y direction
S_{xi}	foundation stiffness at station i in the x direction
S_{yi}	foundation stiffness at station i in the y direction
T_i	axial thrust in bar i
T_ℓ	the period of free vibration of equivalent uniform beam
u_i	the deflection of joint i in the x direction
$\dot{u}_i$	the velocity of joint i in the x direction
$\ddot{u}_i$	the acceleration of joint i in the x direction
v_i	the deflection of joint i in the y direction
$\dot{v}_i$	the velocity of joint i in the y direction
$\ddot{v}_i$	the acceleration of joint i in the y direction

V_i	the shear in bar i
x_i	x coordinate of station i
y_i	y coordinate of station i
α_i, β_i, γ_i, δ_i, ρ_i	coefficients at station i in the solution for static effects
ε_a	strain at the centroid of the cross section
ε_j	the level of strain in the j^{th} segment
ε_i	axial strain in the i^{th} bar
θ_i	the slope of bar i
$\Delta\theta_i$	the change in slope of bar i
ϕ_i	the average change in curvature between midpoints of adjacent bars at joint i
ψ	the curvature of the cross section
σ	the axial stress
σ_j	the stress in the j^{th} segment
μ	mass per unit length

CHAPTER I

INTRODUCTION

1.1 General Discussion

Structures may be subjected to the effects of high energy detonations in the vicinity of the structure or to the effects of explosions, chemical or otherwise, within the structure. Either of these effects results in imparting initial velocities to the structure. The safety of the structure depends on the ability of the various structural elements to withstand the maximum deformations and forces due to these initial velocities. In addition, the integrity of the structure as a whole is dependent on the interactions of the various structural components.

A knowledge of the behavior of a structure under impulsive loading is necessary to determine if the structure is capable of withstanding different types of explosions. This knowledge is also necessary to efficiently place a detonation to cause the collapse of a structure.

1.2 Statement of the Problem and Objectives

The purpose of this study is to develop a method of analysis, considering nonlinear and large displacement behavior, for plane reinforced concrete portal and gabled frames subjected to the effects of impulse loading.

A lumped parameter model of the frame is developed using a bar spring analogy. Any static loading and distributed impulse loads are considered. Linear and small deflection theories are used to solve for static deflections. Nonlinear and large displacement behavior are considered for the dynamic response. The history of the response of the frame to collapse is traced.

1.3 Previous Work

There has been very little reported on the effects of impulse loading of reinforced concrete frames. Work has been reported on impulse loading of beams, arches, plates, rings and shells, and on underground structures such as arches and rings.

Dynamic testing of engineering materials is documented as early as 1872 (1). One of the earlier tests of impact on reinforced concrete beams was performed by T. D. Mylrea in 1940 (2). He investigated the impact resistance of reinforcing steels of various grades by tests of simple beams. Results indicated the great value of even small amounts of reinforcement in beams subjected to impact. World War II and the atomic era increased the interest in dynamic loading, and procedures and equipment for testing were greatly improved.

In 1953 N. M. Newmark presented an approach for preliminary design of structures to resist blast loadings (3).

J. Penzien, in a paper "Dynamic Reponse of Elasto-Plastic Frames" (4), presents the results of an analytical investigation involving a single mass system that has an idealized elasto-plastic resistance deformation relationship. The system is subjected to the ground motion measured during the El Centro earthquake.

The behavior of a rigid portal frame subjected to a pulse of loading is analyzed by Rawlings (5) making the assumption that the material has rigid plastic characteristics. An examination of the influence of strain hardening and of large changes in structural geometry is made.

Dawkins (6) reported on the "Dynamic Response of a Tunnel Liner Packing System." In this study he considers large displacements and nonlinear behavior of reinforced concrete liners.

Haltiwanger and Blackburn (7) made use of the study performed by Dawkins to investigate the effects of nuclear blast loading on a buried arch.

A computer oriented method is described by Lionberger and Weaver (8) for determining the dynamic response of rectangular plane frames with nonrigid beam to column connections. The moment-rotation relationships for the nonrigid connections are assumed to be bilinear and the effects of elasto-plastic behavior in the columns, finite joint sizes and initial vertical loads are included in the analysis.

F. Y. Cheng (9) presents a general matrix formulation suitable for use of the digital computer for dynamic analysis of frameworks composed of prismatic members. Dynamic stiffness coefficients are derived in the form of nondimensional parameters.

Walpole and Shepherd presented a paper on the "Elasto-Plastic Seismic Response of Reinforced Concrete Frames" (10). Elasto-plastic analysis is achieved by the step-by-step numerical integration of the differential equations of motion. The structure is assumed to behave in a linearly elastic manner within each short step interval of time. The elastic properties of the structure are changed from one interval to the next.

Dawkins presented "A Method of Analysis for Reinforced Concrete Beam-Columns Subjected to Impulse Loading" (11). This paper provided the basis for the approach used in the frame analysis which follows.

1.4 Method of Approach

The solution method used herein is to treat the reinforced concrete frame as a lumped parameter model made up of bar and spring elements which have force-deformation characteristics derived from the properties of the frame. The bars are axially deformable, flexurally rigid and are connected at the nodes (joints) by flexural hinges. The characteristics of a joint are determined from the characteristics of the real frame between midpoints of adjoining segments. Loads are replaced by equivalent concentrated loads at the nodes, and the distributed mass is also concentrated at the nodes. The response of the frame to static loads is determined and the dynamic effects are superimposed on the initial static displacements.

The static solution of the lumped parameter model of the frame is obtained by using a back-and-forth recursion solution technique (12). Deflections are assumed to be small and stresses and strains are assumed to be within the elastic range for the static solution.

In the dynamic solution, deflections may be large and stresses and strains may be in the nonlinear range. A step-by-step numerical integration procedure is used to solve the governing dynamic equations (13).

CHAPTER II

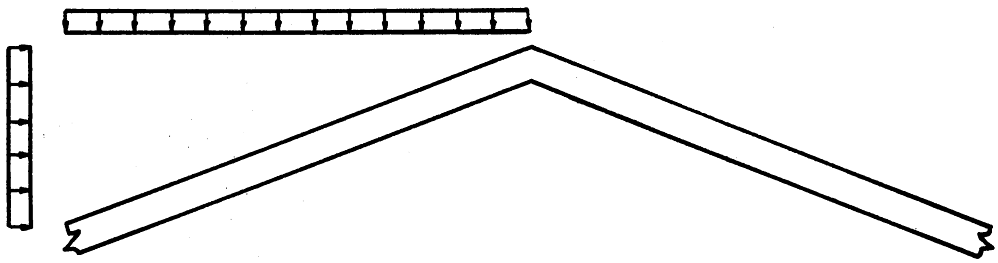
METHOD OF ANALYSIS

2.1 General

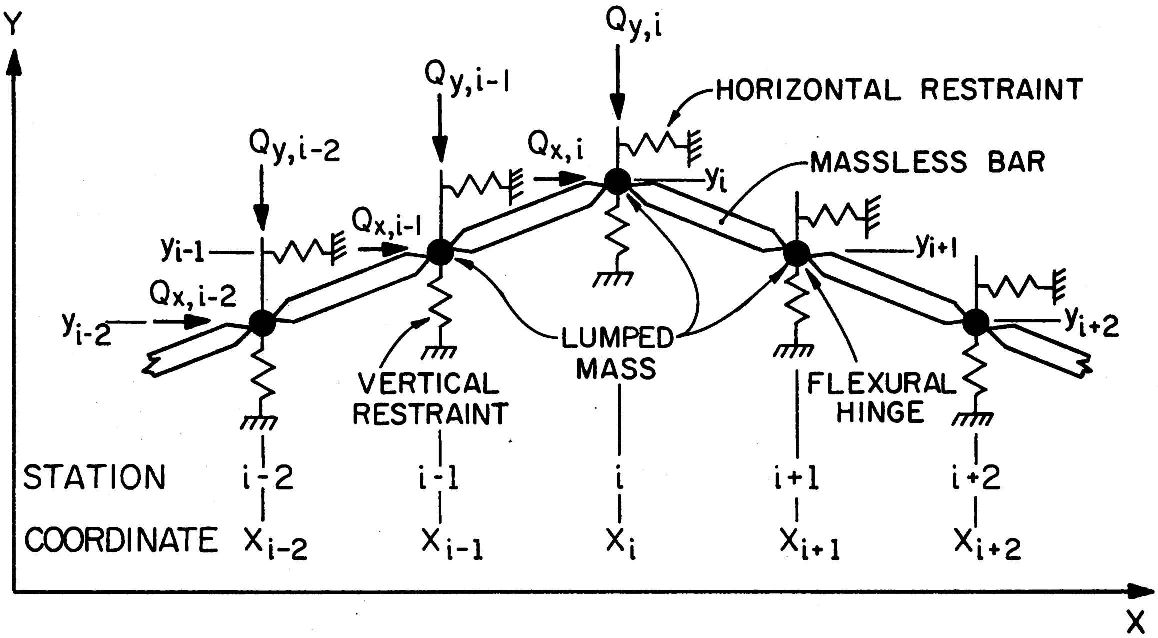
The response of frames to impulse loading is dependent on the material behavior, the geometry of the frame and the time history of the response. A procedure combining a lumped parameter model with numerical integration of the resulting differential equations of motion may be used to account for the effects of all the above variables. Lumped parameter models have been used successfully for the analysis of linearly elastic beam-columns subjected to both static and dynamic loads (12). This procedure has also been applied to tunnel liner-packing systems in which nonlinear material properties and the time history of the response are taken into account (6). These methods were successfully combined in a study which analyzed nonlinear, nonprismatic beam-columns (11) and can be adapted to analyze portal and gabled frames subjected to impulse loads.

2.2 Development of the Model

The lumped parameter model is developed by replacing the frame with a mechanical model composed of a series of bar and spring elements which have force deformation characteristics derived from the properties of the original members. A typical arrangement of bars and springs is shown in Figure 1.



(a) PORTION OF GABLED FRAME WITH LOAD



(b) MECHANICAL MODEL

Figure 1. Lumped Parameter Model

The frame is initially undeflected. It is assumed to lie in the X-Y plane with loads and displacements occurring in the X-Y plane. The frame is divided into regions and the terminus of each region is assigned a station, or node, number as indicated in Figure 1(b). Each region of the frame is replaced by an axially-deformable, flexurally-rigid, massless bar with adjacent bars connected at the nodes by flexural hinges. The distributed mass of the frame is concentrated as point masses at the stations of the model as shown in Figure 1(b). Loads on the frame are replaced by equivalent horizontal and vertical concentrated loads acting at the nodal points of the model.

The geometry of the model is completely defined in the unloaded state by the X and Y coordinates of the nodes. In a deflected condition, the geometry depends on deflections in the X and Y directions as well as the original coordinates. A typical segment of the frame showing typical displacements of the model is shown in Figure 2.

The internal deformations of the frame are related to the displacements of the nodes. The response of the frame to static loads is determined and the dynamic effects are superimposed on the initial static displacements.

2.3 Static Solution

2.3.1 Support Conditions

For the static solution process, all supports are assumed to be linear, elastic springs. Translation restraints are accounted for at the joints of the structure by applying linear springs having stiffnesses S_{xi} in the X direction and S_{yi} in the Y direction. Large stiffness

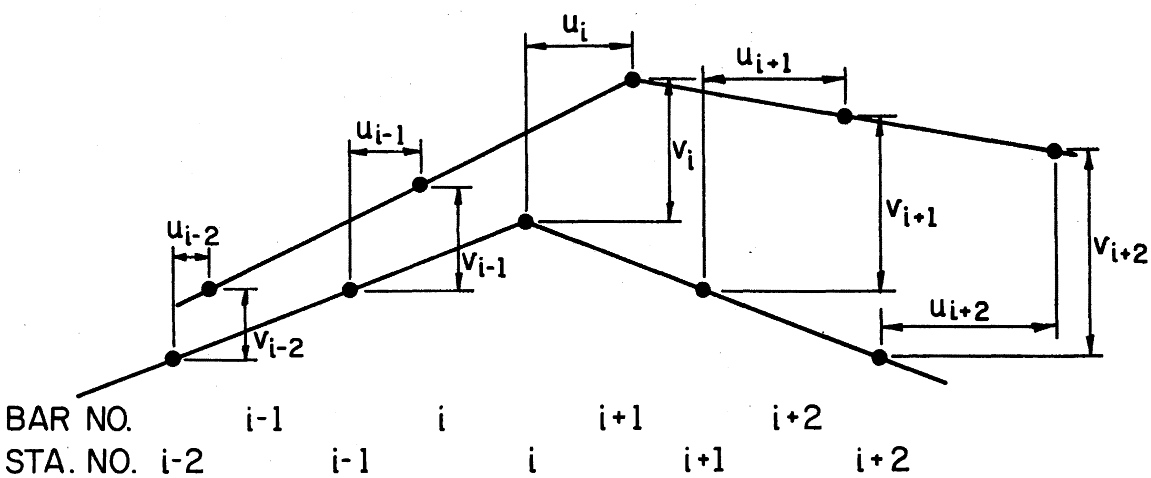


Figure 2. Displacements of Model

values are assigned to these springs to approximate unyielding supports. If there is a need to approximate the effects of distributed supports, springs can be applied at every joint in the region of the distributed support. A fixed end condition can be approximated by applying appropriate springs at two adjacent nodes.

2.3.2 Applied Loads

Any type of static loading may be applied to the frame. Loads are replaced by equivalent concentrated loads at the nodes. The loading is assumed to be such that horizontal and vertical deflections of the frame are small and that linear and small deflection theory may be used in the solution process.

2.3.3 Strain-Displacement Relations

The original length of the i^{th} bar, Figures 1 and 2, is:

$$L_i = [(X_i - X_{i-1})^2 + (Y_i - Y_{i-1})^2]^{1/2} \tag{2.1}$$

and the change in length of the i^{th} bar may be expressed as

$$\Delta L_i = (u_i - u_{i-1}) \cos \theta_i + (v_i - v_{i-1}) \sin \theta_i \tag{2.2}$$

where

ΔL_i = the change in length of the i^{th} bar;

u_i = the deflection of joint i in the X direction;

v_i = the deflection of joint i in the Y direction; and

θ_i = the slope of bar i.

The average axial strain in the i^{th} bar is

$$\varepsilon_i = \frac{\Delta L_i}{L_i} = \frac{(u_i - u_{i-1}) \cos \theta_i + (v_i - v_{i-1}) \sin \theta_i}{[(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2]^{1/2}} \tag{2.3}$$

The change in slope of bar i is

$$\Delta\theta_i = \frac{(-u_i + u_{i-1}) \sin \theta_i - (-v_i + v_{i-1}) \cos \theta_i}{L_i} \tag{2.4}$$

and the change in angle between two adjacent bars at joint i is obtained from

$$\Delta\theta_{i+1} - \Delta\theta_i = \frac{(-u_{i+1} + u_i) \sin \theta_{i+1} + (v_{i+1} - v_i) \cos \theta_{i+1}}{L_{i+1}} - \frac{(-u_i + u_{i-1}) \sin \theta_i + (v_i - v_{i-1}) \cos \theta_i}{L_i} \tag{2.5}$$

The average change in curvature over the length of beam between midpoints of adjacent bars at joint i is

$$\begin{aligned} \phi_i &= \frac{\Delta\theta_{i+1} - \Delta\theta_i}{1/2\,(L_i + L_{i+1})} \\ &= \frac{(-u_{i+1} + u_i) \sin \theta_{i+1} + (v_{i+1} - v_i) \cos \theta_{i+1}}{1/2\,(L_{i+1})(L_i + L_{i+1})} \\ &\quad - \frac{(-u_i + u_{i-1}) \sin \theta_i + (v_i - v_{i-1}) \cos \theta_i}{1/2\,(L_i)(L_i + L_{i+1})} \, . \end{aligned} \tag{2.6}$$

The average bar strain, ε_i, and the average change in curvature, ϕ_i, are used for determining the axial thrusts and joint moments in the model due to static loads.

2.3.4 Beam-Column Cross Section and Material Description

Cross sections of members are limited to rectangular reinforced concrete similar to that shown in Figure 3. The cross section is defined at each joint in the model. Materials in the cross section have stress-strain characteristics as illustrated in Figure 4. For the static solution, the deflections are assumed to be small and small displacement geometry relations can therefore be used in the solution process.

The neutral axis of the cross section is determined using the equation for a transformed rectangular reinforced concrete section, which is assumed to be cracked, from Gerstle (14) which follows:

$$kd = d \{-[np + (2n - 1)\, p'] + \sqrt{[np + (2n - 1)\, p']^2 + 2[np + (2n - 1)\, p' \tfrac{d'}{d}]}\}, \quad (2.7)$$

where

kd = depth from top of section to neutral axis;

n = ratio of modulus of elasticity of steel to that of concrete;

p = percentage of bottom steel;

p' = percentage of top steel;

d' = depth to top steel; and

d = depth to bottom steel.

After the location of the neutral axis is determined, the axial and flexural stiffnesses of the cross section can be readily determined from

$$(AE)_i = (AT)\,(ES1) + (AB)\,(ES2) + (\bar{d})\,(B)\,(EC1) \qquad (2.8)$$

where

$(AE)_i$ = axial stiffness of the i^{th} cross section;

AT = area of top reinforcing steel;

AB = area of bottom reinforcing steel;

ES1 = modulus of elasticity of top steel;

ES2 = modulus of elasticity of bottom steel;

$\bar{d}$ = depth from top of section to centroid of section;

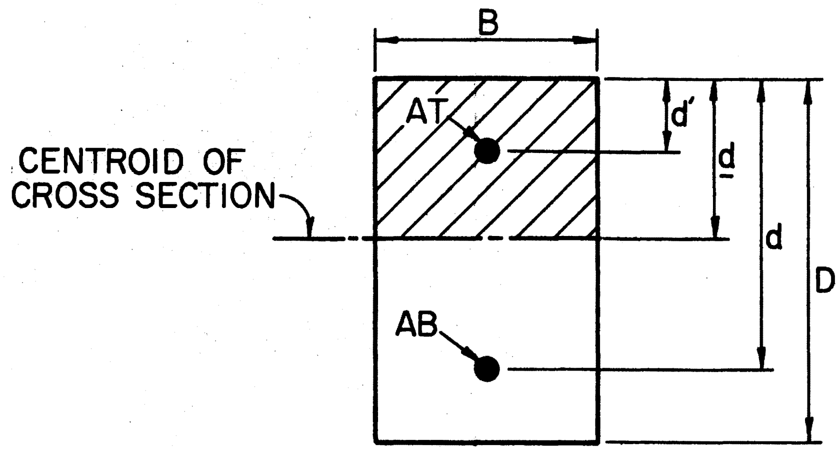


Figure 3. Cross Section

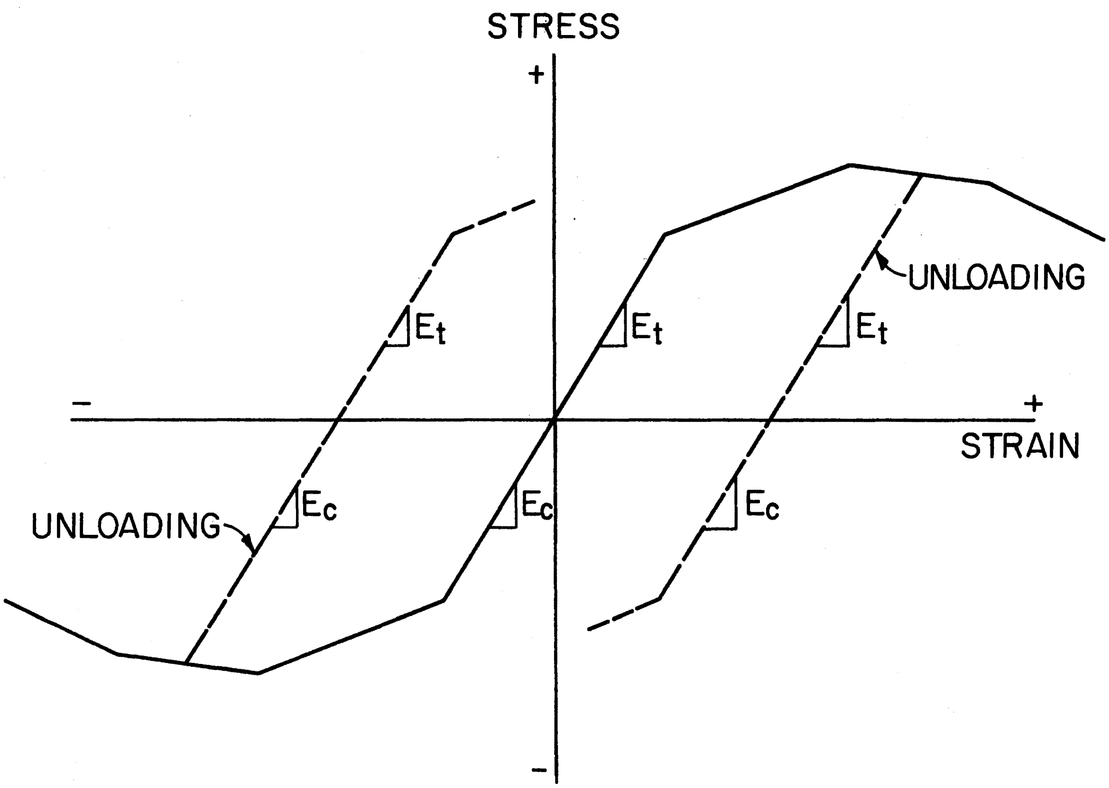


Figure 4. Stress-Strain Curve

B = width of cross section;

EC1 = modulus of elasticity of concrete;

and

$$(EI)_i = (AT)\ (ES1)\ \left(\frac{\overline{d} - d}{\overline{d}}\right)^2 + (AB)\ (ES2)\ \left(\frac{d - \overline{d}}{\overline{d}}\right)^2$$

$$+ (\overline{d})\ (B)\ (EC1)\ \left(\frac{\overline{d}}{2}\right)^2, \qquad (2.9)$$

where

$(EI)_i$ = flexural stiffness of the i^{th} cross section;

d' = depth to top steel; and

d = depth to bottom steel.

2.3.5 Force Deformation Relations

The axial thrust in each bar and bending moment at each joint in the model are obtained from the average bar strains and average joint curvatures.

The thrust in bar i is calculated as follows:

$$T_i = 1/2\ [(AE)_{i-1} + (AE)_i]\ \varepsilon_i \qquad (2.10)$$

and the bending moment occurring at joint i is obtained from

$$M_i = (EI)_i\ \phi_i. \qquad (2.11)$$

Forces introduced by the translation restraints are obtained from the foundation spring stiffnesses and joint displacements by

$$F_{xi} = -S_{xi}\ u_i \qquad (2.12)$$

where

F_{xi} = the foundation resistance at joint i in the x direction, and

$$F_{yi} = -S_{yi}\ v_i \qquad (2.13)$$

where

F_{yi} = the foundation resistance at joint i in the y direction.

These forces, F_{xi} and F_{yi}, are opposite in direction to the displacements u_i and v_i, respectively.

2.3.6 Equilibrium Equations

Free body diagrams of bar i and joint i are shown in Figure 5. For equilibrium of bar i:

$$\Sigma M = 0$$

leads to

$$V_i = \frac{1}{L_i}(M_i - M_{i-1}), \tag{2.14}$$

where

V_i = shear in bar i.

For the equilibrium of joint i:

$$\Sigma F_x = 0$$

leads to

$$-T_i \cos\theta_i + T_{i+1}\cos\theta_{i+1} - V_i \sin\theta_i + V_{i+1}\sin\theta_{i+1} + F_{xi} + Q_{xi} = 0; \tag{2.15}$$

and

$$\Sigma F_y = 0$$

leads to

$$-T_i \sin\theta_i + T_{i+1}\sin\theta_{i+1} + V_i \cos\theta_i - V_{i+1}\cos\theta_{i+1} + F_{yi} + Q_{yi} = 0, \tag{2.16}$$

where

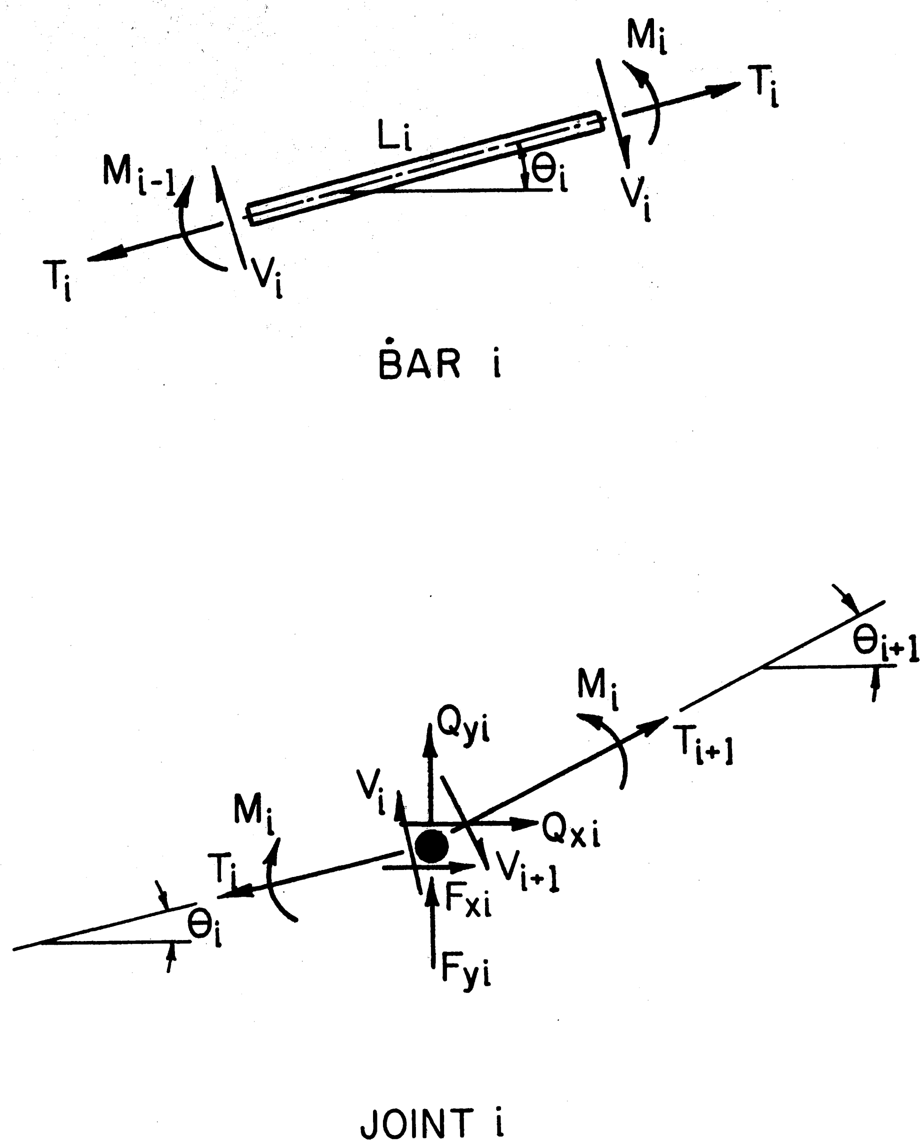


Figure 5. Free Body Diagrams--Static Solution

Q_{xi} = applied static load at joint i in the x direction; and

Q_{yi} = applied static load at joint i in the y direction.

2.3.7 Governing Equations

Two governing equations are obtained by combining the strain displacement and force deformation relations with the equilibrium equations. This gives joint displacements in terms of applied loads.

Combining Equations (2.3, 2.6, 2.10, 2.11, 2.12, 2.13, 2.14, and 2.15) gives an equation of the form:

$$a_{i,11} u_{i-2} + a_{i,12} v_{i-2} + b_{i,11} u_{i-1} + b_{i,12} v_{i-1} + c_{i,11} u_i + c_{i,12} v_i + d_{i,11} u_{i+1} + d_{i,12} v_{i+1} + e_{i,11} u_{i+2} + e_{i,12} v_{i+2} = -Q_{xi}. \qquad (2.17)$$

Combining Equations (2.3, 2.6, 2.10, 2.11, 2.12, 2.13, 2.14, and 2.16) gives an equation of the form:

$$a_{i,21} u_{i-2} + a_{i,22} v_{i-2} + b_{i,21} u_{i-1} + b_{i,22} v_{i-1} + c_{i,21} u_i + c_{i,22} v_i + d_{i,21} u_{i+1} + d_{i,22} v_{i+1} + e_{i,21} u_{i+2} + e_{i,22} v_{i+2} = -Q_{yi}. \qquad (2.18)$$

The detailed equations showing the values of the coefficients (a_n, b_n, c_n, d_n, e_n) for Equations (2.17) and (2.18) may be found in Appendix A.

These equations may be written in matrix form as follows:

$$\begin{bmatrix} a_{i,11} & a_{i,12} \\ a_{i,21} & a_{i,22} \end{bmatrix} \begin{bmatrix} u_{i-2} \\ v_{i-2} \end{bmatrix} + \begin{bmatrix} b_{i,11} & b_{i,12} \\ b_{i,21} & b_{i,22} \end{bmatrix} \begin{bmatrix} u_{i-1} \\ v_{i-1} \end{bmatrix}$$

$$+ \begin{bmatrix} c_{i,11} & c_{i,12} \\ c_{i,21} & c_{i,22} \end{bmatrix} \begin{bmatrix} u_i \\ v_i \end{bmatrix} + \begin{bmatrix} d_{i,11} & d_{i,12} \\ d_{i,21} & d_{i,22} \end{bmatrix} \begin{bmatrix} u_{i+1} \\ v_{i+1} \end{bmatrix}$$

$$+ \begin{bmatrix} d_{i,11} & d_{i,12} \\ d_{i,21} & d_{i,22} \end{bmatrix} \begin{bmatrix} u_{i+1} \\ v_{i+1} \end{bmatrix} + \begin{bmatrix} e_{i,11} & e_{i,12} \\ e_{i,21} & e_{i,22} \end{bmatrix} \begin{bmatrix} u_{i+2} \\ v_{i+2} \end{bmatrix}$$

$$= \begin{bmatrix} -Q_{xi} \\ -Q_{yi} \end{bmatrix} \qquad (2.19)$$

or

$$[A_i]\ [U_{i-2}] + [B_i]\ [U_{i-1}] + [C_i]\ [U_i] + [D_i]\ [U_{i+1}]$$

$$+ [E_i]\ [U_{i+2}] = -[Q_i]. \qquad (2.20)$$

The coefficients of the governing equations are stiffness coefficients related only to the cross section, material and initial geometry of the frame.

2.3.8 Solution of Equations

The governing equations must be satisfied at every joint in the frame. This leads to a set of simultaneous matrix equations in the unknown joint displacements u and v. These u and v displacements are interrelated and must be solved for simultaneously. The values of the coefficients are calculated for each joint in the frame in the STATIC subroutine of the computer program and will be discussed later.

The governing equations can be written for each joint in the frame and will be of the form shown in Figure 6. These equations are efficiently solved by a two-pass elimination procedure. On the initial pass,

$$[C_o]\,[U_o] + [D_o]\,[U_1] + [E_o]\,[U_2] = -[Q_o]$$

$$[B_1]\,[U_o] + [C_1]\,[U_1] + [D_1]\,[U_2] + [E_1]\,[U_3] = -[Q_1]$$

$$[A_2]\,[U_o] + [B_2]\,[U_1] + [C_2]\,[U_2] + [D_2]\,[U_3] + [E_2]\,[U_4] = -[Q_2]$$

$$+ [A_3]\,[U_1] + [B_3]\,[U_2] + [C_3]\,[U_3] + [D_3]\,[U_4] + [E_3]\,[U_5] = -[Q_3]$$

$$[A_i]\,[U_{i-2}] + [B_i]\,[U_{i-1}] + [C_i]\,[U_i] + [D_i]\,[U_{i+1}] + [E_i]\,[U_{i+2}] = -[Q_i]$$

$$[A_{m-2}]\,[U_{m-4}] + [B_{m-2}]\,[U_{m-3}] + [C_{m-2}]\,[U_{m-2}] + [D_{m-2}]\,[U_{m-1}] + [E_{m-2}]\,[U_m] = -[Q_{m-2}]$$

$$[A_{m-1}]\,[U_{m-3}] + [B_{m-1}]\,[U_{m-2}] + [C_{m-1}]\,[U_{m-1}] + [D_{m-1}]\,[U_m] = -[Q_{m-1}]$$

$$+ [A_m]\,[U_{m-2}] + [B_m]\,[U_{m-2}] + [C_m]\,[U_m] = -[Q_m]$$

Figure 6. Simultaneous Governing Equations for Each Joint

the equations are reduced to the form

$$[U_i] = [\alpha_i] + [\beta_i] [U_{i+1}] + [\gamma_i] [U_{i+2}] \tag{2.21}$$

where

$$[\alpha_i] = [\delta_i] \{[Q_i] + [A_i] [\alpha_{i-2}] + [\rho_i] [\alpha_{i-1}]\} \tag{2.22}$$

$$[\beta_i] = [\delta_i] \{[\rho_i] [\gamma_{i-1}] + [D_i]\} \tag{2.23}$$

$$[\gamma_i] = [\delta_i] [E_i] \tag{2.24}$$

and

$$[\delta_i] = -\{[\rho_i] [\beta_{i-1}] + [A_i] [\gamma_{i-2}] + [C_i]\}^{-1} \tag{2.25}$$

$$[\rho_i] = [A_i] [\beta_{i-2}] + [B_i]. \tag{2.26}$$

At the initial station, o, of the frame, $[A_o]$ and $[B_o]$ are both equal to zero. The values of $[\alpha_i]$, $[\beta_i]$ and $[\gamma_i]$ may therefore be obtained from the known values of the coefficients of Equation (2.20) starting at the initial station and proceeding to the final station. At the final station, m, the coefficients $[D_m]$ and $[E_m]$ are zero, resulting in zero values for both $[\gamma_m]$ and $[\beta_m]$. A solution for $[U_m]$ is then obtained from Equation (2.21). Likewise, at the next to last station, m-1, γ_{m-1} will be zero and $[U_{m-1}]$ may be obtained from Equation (2.21). All other values of $[U_i]$ are calculated by using Equation (2.21) and proceeding back to the initial station.

This solution process is particularly convenient for a computer solution since it can be summarized as a set of equations which are solved repeatedly at station after station along the frame. For beam-column problems, the coefficients α_i, β_i and γ_i may be thought of as expressing the physical continuity of the system. All of the known input data are included in these coefficients. These coefficients at any one station depend not only on the load and stiffness data at that station, but also on effects from all previous stations and have, therefore, been termed "Continuity Coefficients."

In the computer program to further simplify the complete solution, three fictitious nodes are added at each end of the frame. No load or stiffness data exists for these fictitious nodes. In the computation of the continuity coefficients, the fictitious extensions to the frame automatically generate the required zeroes at the ends of the matrix equations. These zero terms are the means by which the recursion process is enabled to get under way and then to get turned around at the far end so that deflections may be calculated. This process eliminates the necessity for specializing the coefficients for the end conditions (12).

After the u and v displacements of every joint have been determined, the internal moment, shear and axial thrust can be calculated for each bar and joint in the frame using these displacements and the equations developed earlier.

2.4 Dynamic Solution

2.4.1 General

The effects of the impulse loadings are superimposed on the displacements due to the static load. Since the dynamic displacements may be very large, the small displacement geometry relations used in the static solution are no longer applicable. In addition, the stresses and strains do not remain in the initial linear region of the stress-strain curves. Inertia forces are also developed at the nodes of the model and must be included in the equilibrium expressions.

To facilitate programming the solution for the computer, the changes in deformations which occur in the time interval Δt are restricted to small deformations.

2.4.2 Support Conditions

For convenience in the static solution process, unyielding supports are approximated by very stiff elastic springs. However, because of the high frequencies associated with these large stiffness values, unyielding supports must be specified as such for the dynamic solution. The velocities and accelerations of the joints at unyielding supports remain identically zero for all time after the impulse load is applied. This procedure necessitates dual specification of some support conditions; however, the efficiency of the solution process is greatly increased.

As in the static solution, a fixed end condition can be approximated by applying appropriate conditions at two adjacent nodes.

2.4.3 Applied Loads

The impulse loads can be applied in either the horizontal or vertical direction, or both. The impulse loads vary sinusoidally over portions of the frame. These loads are replaced by equivalent concentrated loads at the nodes.

2.4.4 Strain-Displacement Relations

At any instant in time, the deflections of the model are represented as shown in Figure 2. The length of the i^{th} bar at that time is

$$L_i = [(x_i + u_i - x_{i-1} - u_{i-1})^2 + (y_i + v_i - y_{i-1} - v_{i-1})^2]^{1/2} \tag{2.27}$$

where x_i and y_i are the original coordinates of the node, and u_i and v_i are the displacements from these original coordinates.

The axial strain in bar i is

$$\varepsilon_i = \frac{L_i - [(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2]^{1/2}}{[(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2]^{1/2}} . \tag{2.28}$$

The slope of bar i is given by

$$\theta_i = \text{Arctan} \left[\frac{y_i + v_i - y_{i-1} - v_{i-1}}{x_i + u_i - x_{i-1} - u_{i-1}}\right] \tag{2.29}$$

and the change in slope of bar i is

$$\Delta\theta_i = \frac{(-u_i + u_{i-1}) \sin \theta_i + (v_i - v_{i-1}) \cos \theta_i}{L_i} . \tag{2.30}$$

The change in angle between two adjacent bars at joint i is obtained from

$$\Delta\theta_{i+1} - \Delta\theta_i = \frac{(-u_{i+1} + u_i) \sin \theta_{i+1} (v_{i+1} - v_i) \cos \theta_{i+1}}{L_{i+1}} - \frac{(-u_i + u_{i-1}) \sin \theta_i + (v_i - v_{i-1}) \cos \theta_i}{L_i} \tag{2.31}$$

and the average change in curvature at joint i is

$$\phi_i = \frac{\Delta\theta_{i+1} - \Delta\theta_i}{1/2\ (L_i + L_{i+1})} . \tag{2.32}$$

2.4.5 Force-Deformation Relations

In the static solution it was assumed that loads were such that the materials of the beams and columns remained in the initial linear region of the stress-strain curve. To account for nonlinear stress-strain behavior and to include the effects of strain history (15), the force-deformation response of the beam-column must be determined from the distribution of stresses over the cross section. The segmented cross section shown in Figure 7 is utilized with each segment initially having a stress-strain curve as shown in Figure 4. For monotonically increasing deformations, the stress in each segment corresponding to a given strain is obtained from the curve. When the deformations begin to reverse, it is assumed that the stress diminishes with diminishing strain along a line parallel to the initial linear portion of the curve, slope E_t or E_c, as shown in Figure 4. The stress will follow the dashed line until a zero stress level is reached at which point, with continued decrease in strain, it is assumed the stress will follow a curve parallel to the initial stress-strain curve for strain in the opposite direction. If a subsequent reversal in strain occurs before the stress level is zero, the stress will increase along the unloading line, E_t or E_c in Figure 4, until the point on the curve where the stress is equal to that where a change in slope of the original curve occurs. At this point, the stress will follow the slope of the next portion of the original curve until the original curve is reached, at which time the original stress-strain curve will be used.

Although the location of the centroid of the cross section, Figure 7, is dependent on material properties, it is assumed that the centroid of the cross section remains at the position given in the static solution by Equation (2.7). The segmented cross section is shown in Figure 7 along with typical strain and stress distributions. The strain distribution shown is determined by denoting the strain at the centroid as ε_a and the curvature at the cross section as ψ. The depth from the centroid of the cross section to the center of the j^{th} segment (d_j) is

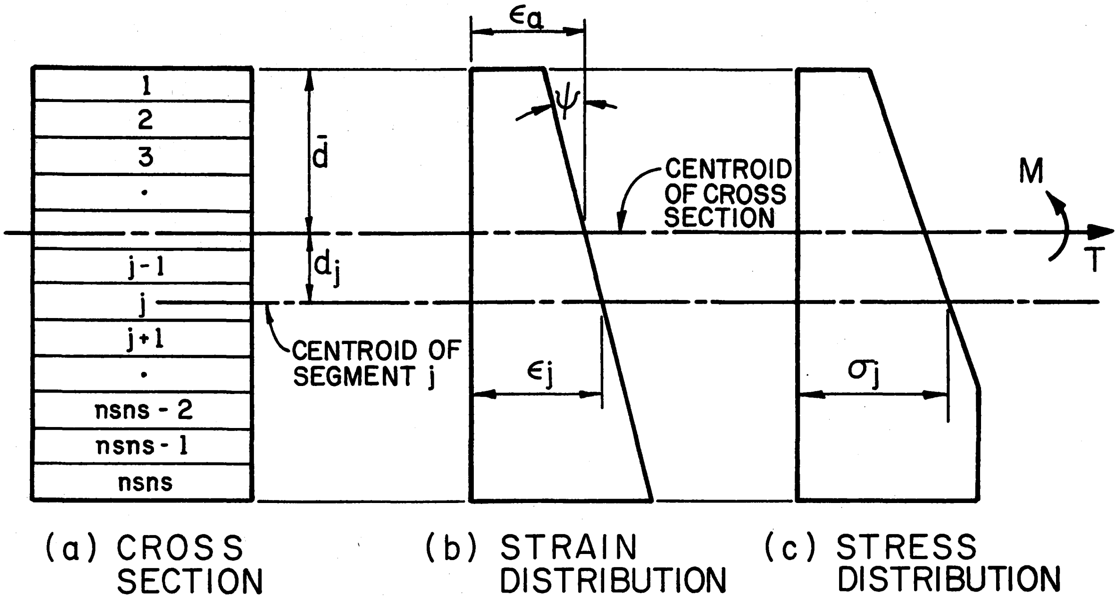


Figure 7. Stress and Strain Distribution at Cross Section

readily determined. The level of strain in this j^{th} segment is obtained from the strain distribution and is written:

$$\varepsilon_j = \varepsilon_a + d_j\psi. \tag{2.33}$$

The stress in the j^{th} segment is determined from the stress-strain curve for the segment which has been adjusted according to the procedure outlined earlier to account for the strain history. The stress distribution for the entire cross section is calculated and may be as shown in Figure 7.

The thrust and moment at the cross section are now calculated by integration of the stress distribution. The thrust is given by

$$T = \sum_{k=1}^{n} \sigma_k A_k, \tag{2.34}$$

where

T = thrust at the cross section;

σ_x = stress in the k^{th} segment;

A_k = area of k^{th} segment; and

n = total number of segments in cross section.

The bending moment corresponding to the stress distribution is

$$M = \sum_{k=1}^{n} \sigma_k A_k d_k,$$

where

M = bending moment at the cross section; and

d_k = distance from the centroid of the cross section to the k^{th} segment.

Since the average strain has only been defined for the bars in the model, while the curvature has been determined at the joint, the following averaging process must be used to obtain the complete strain distribution required for calculation of thrust and moment. The thrust in each bar is determined from a strain distribution with $\varepsilon_a = \varepsilon_i$, where ε_i is the strain given by Equation (2.28) and $\psi = 1/2\ (\ _{i-1} + \phi_i)$, where ϕ_{i-1} and ϕ_i are given by Equation (2.32). Similarly, the moment at each joint is that resulting from a strain distribution with $\psi = \phi_i$ from Equation (2.32) and the average strain $\varepsilon_a = 1/2\ (\varepsilon_i + \varepsilon_{i+1})$ where ε_i and ε_{i+1} are given by Equation (2.28).

2.4.6 Equilibrium Equations

Free body diagrams of bar i and joint i for the dynamic solution, at any instant in time, are shown in Figure 8. For equilibrium of bar i,

$\Sigma M = 0$:

$$V_i = \frac{1}{L_i} (M_i - M_{i-1}). \tag{2.36}$$

For equilibrium of joint i,

$\Sigma F_x = 0$:

$$-T_i \cos \theta_i + T_{i+1} \cos \theta_{i+1} - V_i \sin \theta_i + V_{i+1} \sin \theta_{i+1} + F_{xi} + Q_{xi} - m_i \ddot{u}_i = 0, \tag{2.37}$$

where

F_{xi} = foundation resistance in the x direction;

Q_{xi} = applied external static load in the x direction;

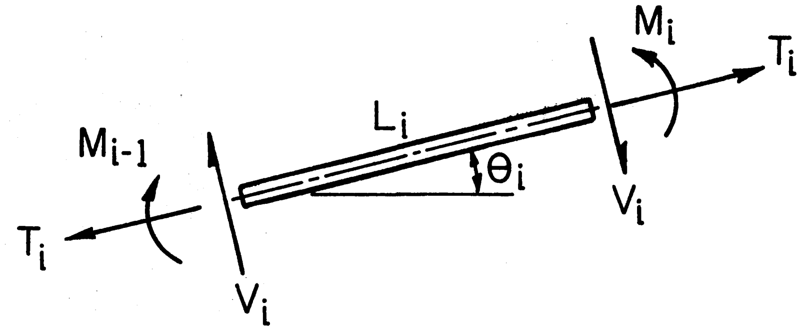
m_i = mass at joint i; and

$\ddot{u}_i$ = acceleration of joint i in the x direction.

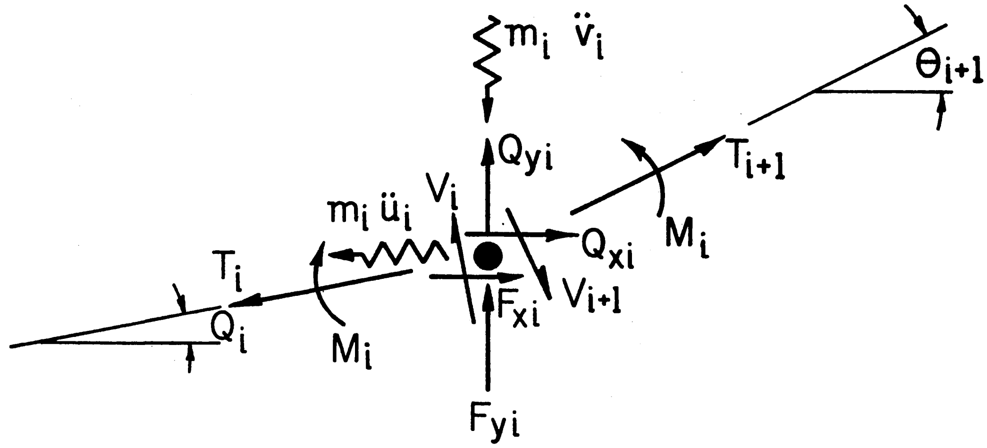
And

$\Sigma F_y = 0$:

$$-T_i \sin \theta_i + T_{i+1} \sin \theta_{i+1} + v_i \cos \theta_i - v_{i+1} \cos \theta_{i+1}$$



BAR i



JOINT i

Figure 8. Free Body Diagrams--Dynamic Solution

$$+ F_{yi} + Q_{yi} - m_i \ddot{v}_i = 0, \tag{2.38}$$

where

F_{yi} = foundation resistance in the y direction;

Q_{yi} = applied external static load in the y direction; and

$\ddot{v}_i$ = acceleration of joint in the y direction.

All of the terms in Equations (2.36, 2.37 and 2.38), except Q_{xi} and Q_{yi}, are functions of the joint displacements u and v. Values of u and v must, therefore, be found before these expressions can be evaluated.

2.4.7 Solution of Dynamic Equations

Equation (2.36) can be written in terms of u and v displacements and the result substituted into Equations (2.37) and (2.38) giving two equations in two unknowns, u and v. These two equations of motion represented by Equations (2.37) and (2.38) are solved by a step-by-step numerical integration procedure as developed by Newmark (13) and adapted for computers by Melin (16) and Wilson and Clough (17). It is assumed that the accelerations of the joints vary linearly with time during a small time interval Δt. If the values of acceleration, velocity and displacement are known at any time t, the values at time $t + \Delta t$ can be determined from

$$u_{t+\Delta t} = u_t + \frac{\Delta t}{2} (\ddot{u}_t + \ddot{u}_{t+ t}), \tag{2.39}$$

and

$$u_{t+\Delta t} = u_t + \Delta t \, \dot{u}_t + \frac{1}{3} (\Delta t)^2 \, \ddot{u}_t + \frac{1}{6} (\Delta t)^2 \, \ddot{u}_{t+\Delta t}. \tag{2.40}$$

For the y direction,

$$\dot{v}_{t+ t} = \dot{v}_t + \frac{\Delta t}{2} (\ddot{v}_t + \ddot{v}_{t+\Delta t}), \tag{2.41}$$

and

$$v_{t+\Delta t} = v_t + \Delta t\ \dot{v}_t + \frac{1}{3}(\Delta t)^2\ \ddot{v}_t + \frac{1}{6}(\Delta t)^2\ \ddot{v}_{t+\Delta t}. \qquad (2.42)$$

The solution is started by assuming values of acceleration, $\ddot{u}_{t+\Delta t}$ and $\ddot{v}_{t+\Delta t}$, at every joint in the frame. These assumed values enable values of $\dot{u}_{t+\Delta t}$, $u_{t+\Delta t}$, $\dot{v}_{t+\Delta t}$, and $v_{t+\Delta t}$ to be obtained from the above equations (2.39 through 2.42). The displacements calculated are then used to calculate thrusts, shears, moments and reactions. New estimates of the accelerations $\ddot{u}_{t+\Delta t}$ and $\ddot{v}_{t+\Delta t}$ are now obtained using Equations (2.37) and (2.38). These calculated values of acceleration are compared with the initial assumed values, and if the agreement is not satisfactory, the process is repeated with the calculated accelerations being used as the new assumed values. This process is repeated until the desired agreement between the assumed and calculated acceleration is reached. When satisfactory agreement is obtained, the stress-strain curves for each element of the cross section are adjusted to account for strain history and the iterative process is repeated for the next time interval.

2.4.8 Stability and Convergence of Numerical Integration

The stability and convergence of the iterative process outlined in Section 2.4.7 above is governed by the length of the time interval Δt. Newmark (13) has shown that stability and convergence are assured if Δt is approximately 1/5 to 1/6 of the shortest natural period of vibration of the model.

An equivalent uniform beam is utilized to determine the required time interval Δt. This equivalent beam has a bending stiffness given by

$$(EI)_e = \frac{1}{m} \sum_{k=1}^{m} (EI)_k, \tag{2.43}$$

where

$(EI)_e$ = bending stiffness of equivalent uniform beam;

m = total number of joints in the model; and

$(EI)_k$ = bending stiffness of joint k obtained from Equation (2.9).

The mass per unit length of the equivalent beam is

$$\mu = \frac{1}{L} \sum_{k=1}^{m} (m_k), \tag{2.44}$$

where

μ = mass per unit length of equivalent beam;

L = total length of beam; and

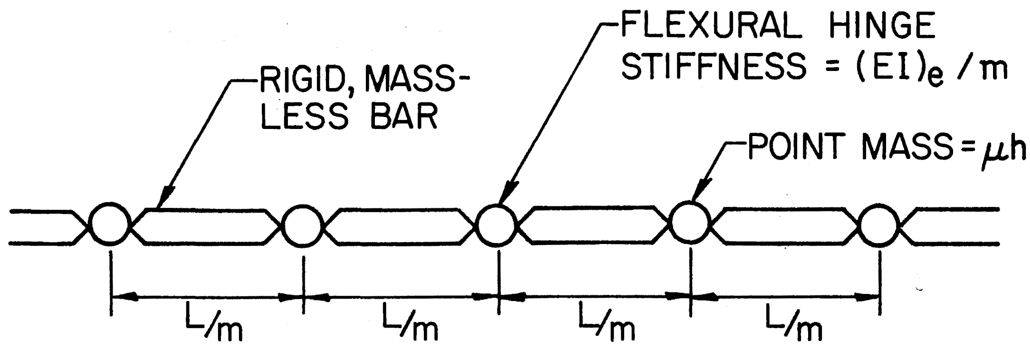
m_k = concentrated mass at joint k.

If the equivalent beam is replaced by a lumped parameter model having m joints as shown in Figure 9(a), the highest mode of lateral vibration of this model for small deflections will be as shown in Figure 9(b). The period of vibration for this mode can be written as

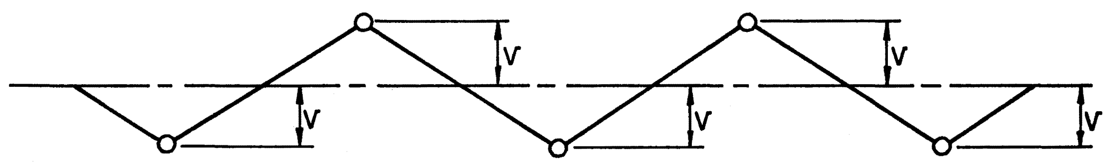
$$T_\ell = \frac{\pi L^2}{2\,(m-1)^2} \sqrt{\frac{\mu}{(EI)_e}}\;. \tag{2.45}$$

The time interval is taken as $T_\ell/10$.

This procedure will suffice for those frames which have limited variations in cross section geometry throughout and for which the spacing between nodes in the model is sufficiently small. For other cases, the time interval should be calculated from a more complete estimate of true structural behavior as shown by Dawkins (6). A trial and error procedure can also be used as recommended by Clough (17); however, this could be costly in terms of computer time.



(a) LUMPED PARAMETER MODEL OF EQUIVALENT UNIFORM FRAME



(b) ASSUMED DISPLACEMENTS

Figure 9. Equivalent System for Estimating Shortest Period of Vibration

2.4.9 Adjustment for Dynamic Solution Process

It is assumed that the frame is at rest under the external static loads. The initial displacements of the system for the dynamic solution will be the static displacements, u and v, of each joint. However, since small deflection theory is utilized in the static solution, and large deflection theory is assumed for the dynamic solution, the initial strains as calculated by Equations (2.3) and (2.38) differ. This difference, if not accounted for, results in spurious initial dynamic forces.

To eliminate these spurious dynamic forces, the force in the X and Y direction at each station is adjusted, and the accelerations at time zero are set equal to zero. In adjusting the forces at each station, an acceleration for each node in the frame is calculated based on the initial static displacements. The force on each node is then adjusted by subtracting this acceleration times the mass of each node from the applied force. The acceleration at time zero is then set equal to zero, and the solution process may proceed without the spurious dynamic forces (18, 19).

2.4.10 Collapse Criteria

The primary purpose of this study is to determine the magnitude of the impulsive load required to cause collapse of the frame. It is, therefore, necessary to establish limits on the response of the frame which constitute collapse. Excessive horizontal displacement, excessive vertical displacement, shear failure and failure due to interaction of bending moment and axial load are selected as the four collapse modes. The limits on these collapse modes must be provided as input data for the computer program discussed in Chapter III. Each limit is compared with the calculated response of the frame at every station at the end of each time step. If any one of the limits is exceeded, the frame is assumed to have collapsed, and the computer printout designates the location and type of collapse.

CHAPTER III

DESCRIPTION OF COMPUTER PROGRAM

3.1 General

The analytical procedure described in the preceding chapter has been programmed for solution on a digital computer. The program is written in the ASA FORTRAN language and should require only minor revisions to be operable on any computer having a storage capacity of 25,000 word equivalents. On a machine operating with a word size of less than 60 binary bits (15 significant decimal figures), double precision arithmetic must be used. A summary flow diagram for the program is shown in Figure 10. A complete FORTRAN listing of the program is included in Appendix C.

3.2 Input Information

The program has been developed to generate automatically as much of the required data as possible in order to minimize the amount of input data and to permit the solution of as many problems as desired on a single run. The specific formats of the input data are given in Appendix D. The input data are arranged in tabular form, and the general input sequence is described below.

3.2.1 Run Identification

Two alphanumeric cards are required at the beginning of each run.

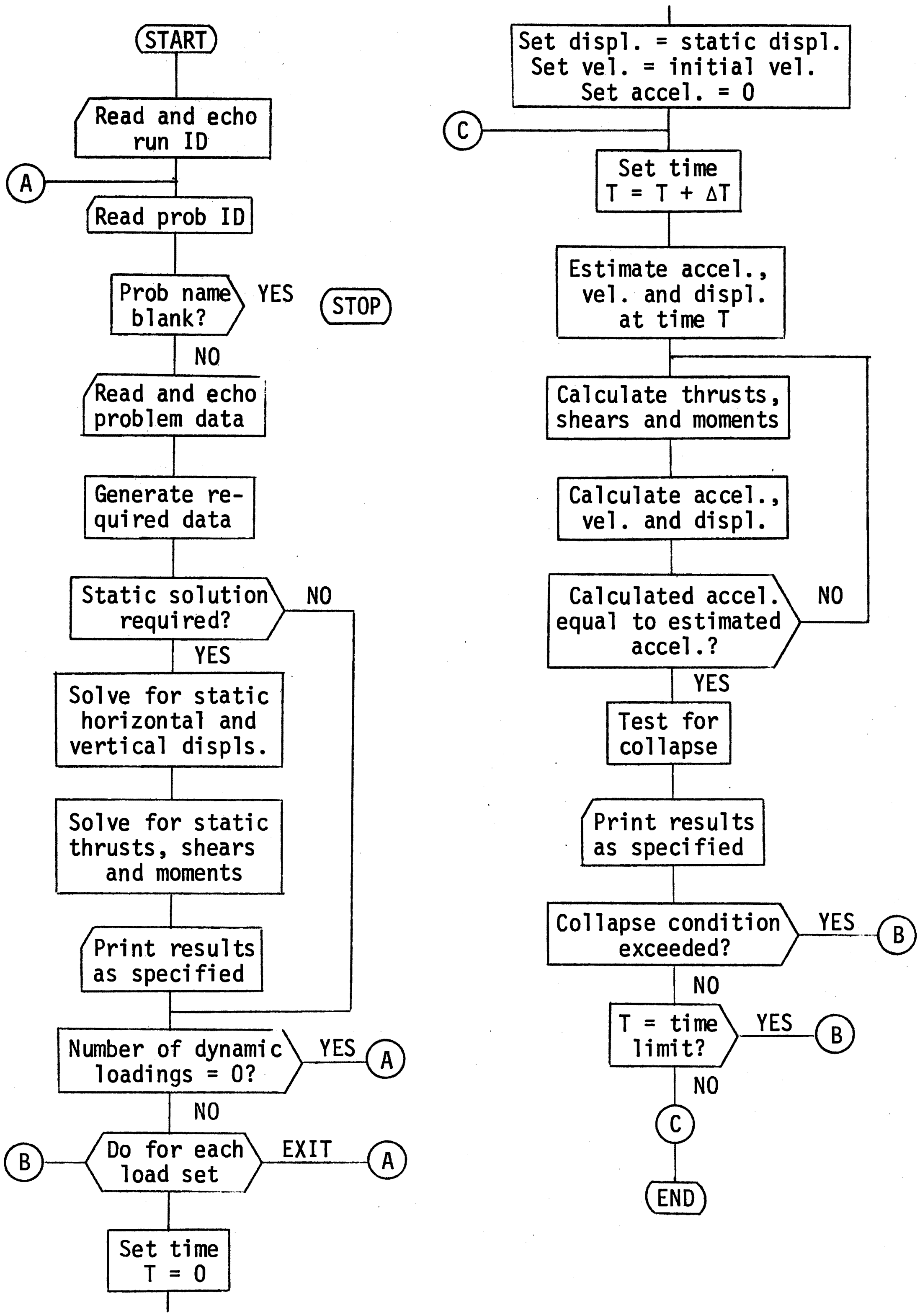


Figure 10. Summary Flow Diagram

3.2.2 Problem Identification

One alphanumeric card is required at the beginning of each problem. The program stops if the Problem Name identifier is blank.

3.2.3 Table 1--Control Data

One card containing the problem control data is required.

3.2.4 Table 2--Joint Coordinates and Cross Section Description

The initial station on the frame is assumed to be located at coordinates x = 0, y = 0. Data giving the location at which a change in direction of the members of the frame must be provided. Data giving the location of each station at which a change in the cross section description occurs is also required. The general form of the cross section is assumed to be rectangular and is divided into a suitable number of segments. The depth of each segment is equal to the depth of the section divided by the number of segments. A reinforced concrete cross section is assumed, and a description of reinforcement must be provided for every cross section.

3.2.5 Table 3--Stress Strain Curves

A maximum of five different material stress-strain curves may be specified. The continuous curve is represented by straight lines between the stress and strain values input. The curve is assumed to pass through the point stress equals zero, strain equals zero, and this point cannot be included as input. The ten points required for each curve must include the coordinates of five points in the negative region and five points in the positive region. The final coordinate value used by the program is the product of the multiplier and the input value. Nonzero multipliers must be included for each curve. The last curve input is used for the reinforcement.

3.2.6 Table 4--Beam-Column Mass and Supports

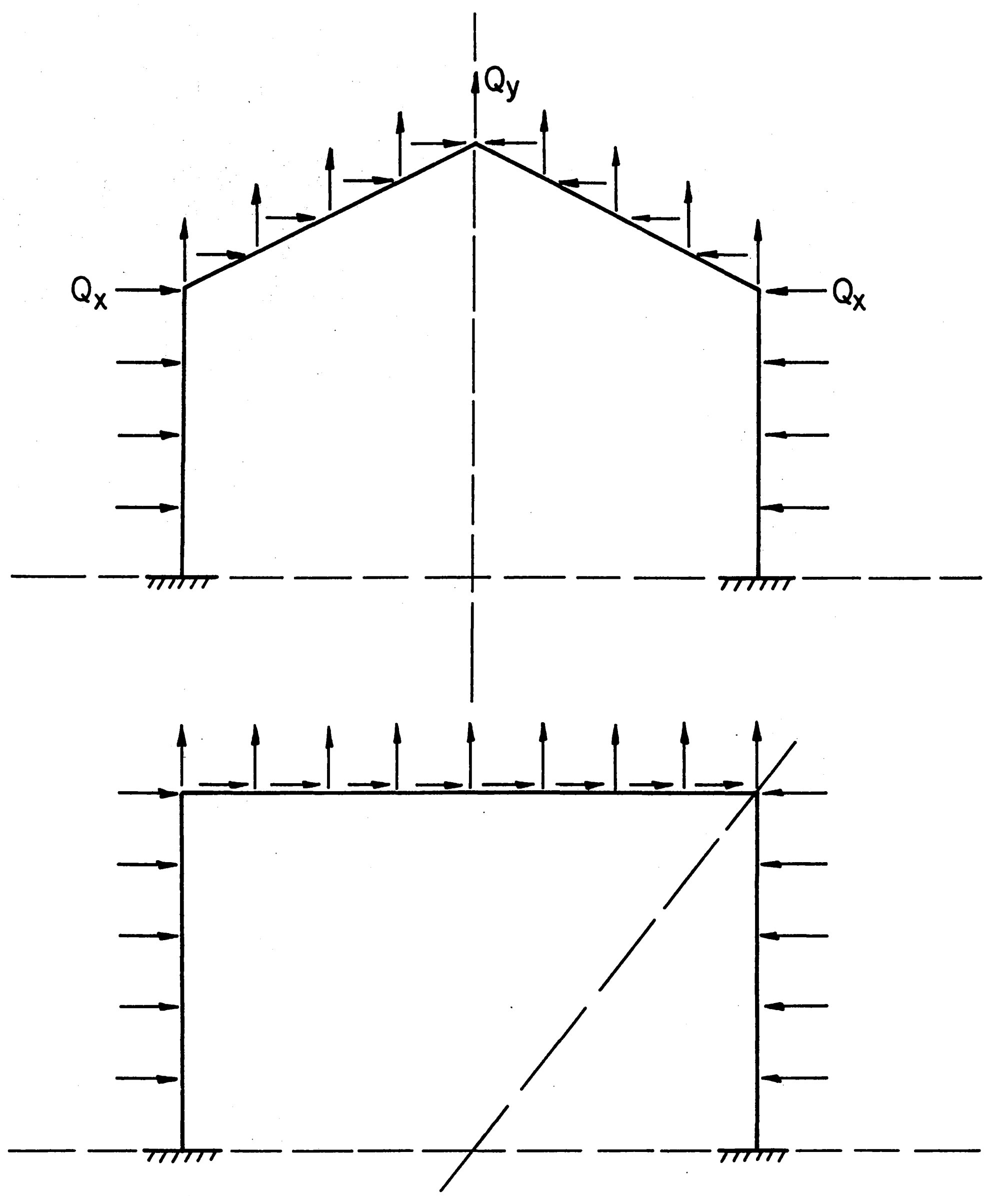
A nonzero, positive mass must be assigned to every station on the frame if a dynamic solution is to be performed. The mass may be specified as either distributed or concentrated. A sufficient number of supports must be provided to restrain all possible displacements of the frame as a rigid body. A fixed end condition can be approximated by specifying the appropriate restraints at two adjacent stations. Horizontal and vertical restraints are applied to the stations of the frame and may be either distributed or concentrated. Unyielding supports must be specified. The accelerations and velocities of the masses at unyielding supports are set to zero.

3.2.7 Table 5--Static Loads

Static loads are applied to the stations and may be either distributed or concentrated. The sign convention for loads is shown in Figure 11.

3.2.8 Table 6--Impulse Loadings

The effects of impulse loading are superimposed on the displacements due to static loads. Impulse loads may be concentrated or distributed with either linear or parabolic variation along the horizontal or



NOTES:

1) LOADS ARE POSITIVE AS SHOWN ABOVE.

2) VERTICAL LOADS ARE ALWAYS POSITIVE UP.

3) HORIZONTAL LOADS ARE POSITIVE TOWARD A VERTICAL LINE THRU APEX OF GABLED FRAME AND TOWARD A LINE FROM CENTERLINE AT BASE THRU RIGHT CORNER OF PORTAL FRAME.

Figure 11. Sign Convention for Loads

vertical direction of the frame. Distributed values are lumped as equivalent concentrated values at the nodes of the frame. The solution process is extremely sensitive to abrupt changes in slope of distributed impulse loading curves. The program is arranged to permit the solution of a number of different impulse loadings on a given frame. Each dynamic solution is treated independently of other dynamic loadings. The sign convention for impulse loads is also shown in Figure 11.

3.2.9 Table 7--Collapse Parameters

The frame is assumed to collapse when any one of the limits on horizontal displacement, vertical displacement, or total shear on a cross section is exceeded. Collapse is also assumed to occur whenever the combination of bending moment and thrust at any station exceeds the limits of the thrust-moment interaction diagram for that station. Interaction diagrams must be provided for every station on the frame and are specified in two parts. A single general shape for the diagram is specified in nondimensional form for the entire frame. Multipliers for thrust and moment are supplied for every beam station. The final values of the ordinates of the interaction diagram at each station will be the product of the multipliers for that station and the nondimensional interaction diagram values.

It is assumed that the interaction diagram is defined for moments about the plastic centroid of the cross section (20). Since moments are defined about the elastic centroid by the analytical process described herein, it is necessary that the location of the plastic centroid for each station be determined in order to correlate computed thrusts and moments with values supplied by the interaction diagram. The location of the plastic centroid for each cross section is determined from the uniform compressive strain condition used to establish P-ultimate (15), (21). The value of the uniform strain for P-ultimate must be supplied as input data.

3.2.10 <u>End of Run</u>

A blank card is required at the end of the data deck to terminate the program.

The arrangement of a typical data deck for one run is shown in Figure 12.

3.3 Output Information

The complete list of input data is printed in tabular form as the data are read. Calculated results are output according to an option specified by the user.

Two options are provided for output of effects due to static loads. The first option includes a complete printing of the horizontal and vertical displacements at each station, the bending moment at every station, and the thrust and shear in each bar of the model. The second option for static loads will provide only a printout of the location and magnitude of the maximum value of each of the above quantities.

Three options are available for output of the calculated dynamic response. The first two options are the same as those described above for the static effects except the data are printed for each time step. The third option results only in the location, time and mode of collapse.

Sample output for the example problems of Chapter IV is included in Appendix D.

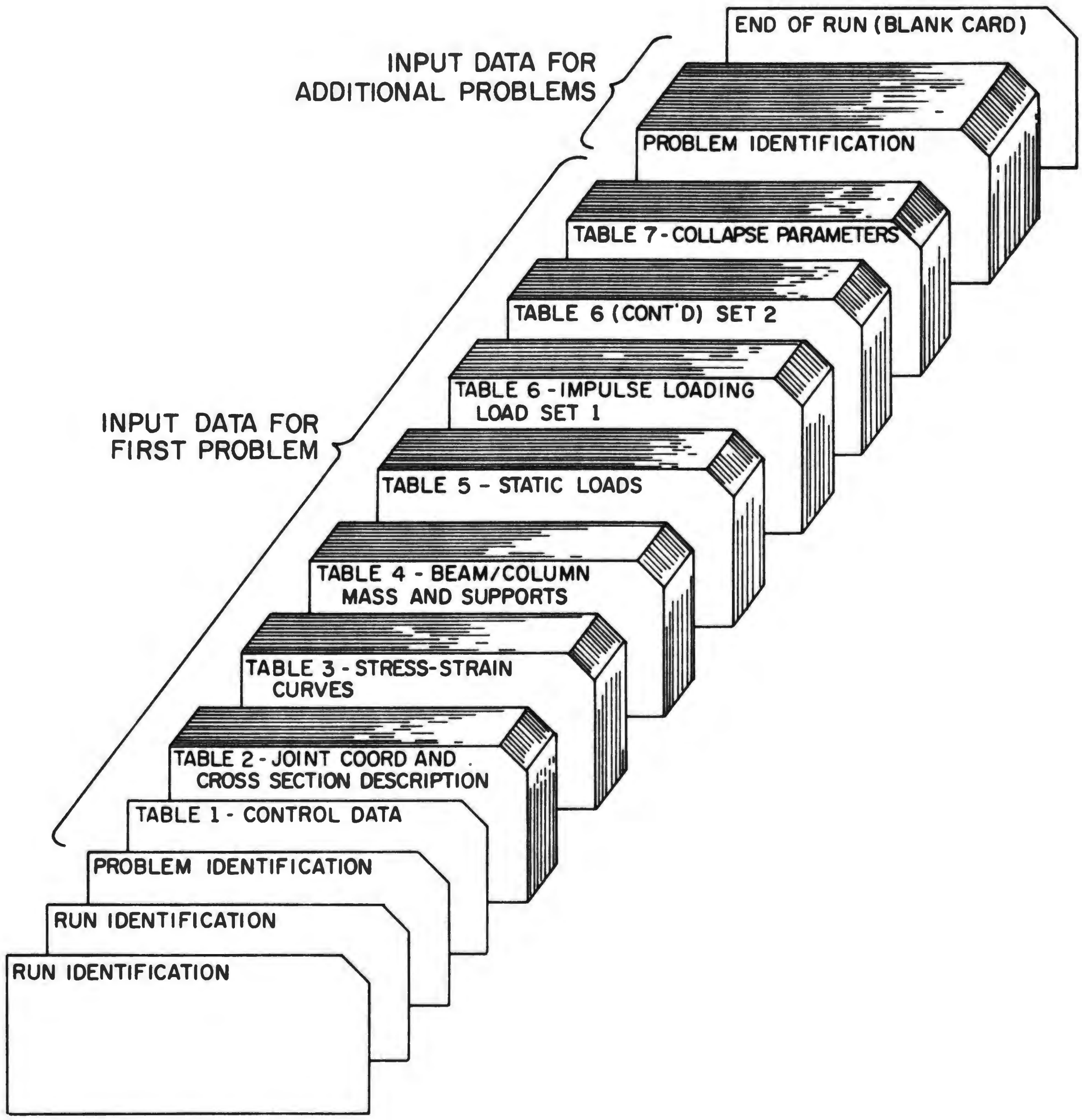


Figure 12. Arrangement of Input Data

CHAPTER IV

DEMONSTRATION OF PROGRAM

4.1 General

Several problems involving plane portal and gabled frames subjected to static and dynamic loads have been solved to verify the computer program and to demonstrate its use. These problems are described and the results discussed in the following sections of this chapter. Sample output data from problems run is included in Appendix D.

4.2 Verification of Static Solution

4.2.1 Problem IPF1--Portal Frame With Uniform Load on Beam

The static solution for a reinforced concrete portal frame with dimensions, cross section and loading as shown in Figure 13 was obtained using the computer program developed. The frame was hinged at its supports and loaded with a uniform static load on the beam. The frame model used contained 61 nodes. Stress-strain curves for concrete and steel in the cross section are shown in Figure 14.

The results of the solution obtained are compared with the results obtained using a computer program for plane frames (22) in Figure 15. The slight differences, approximately 2 percent for deflection and less than one-half percent for moment at the center of the frame, could be

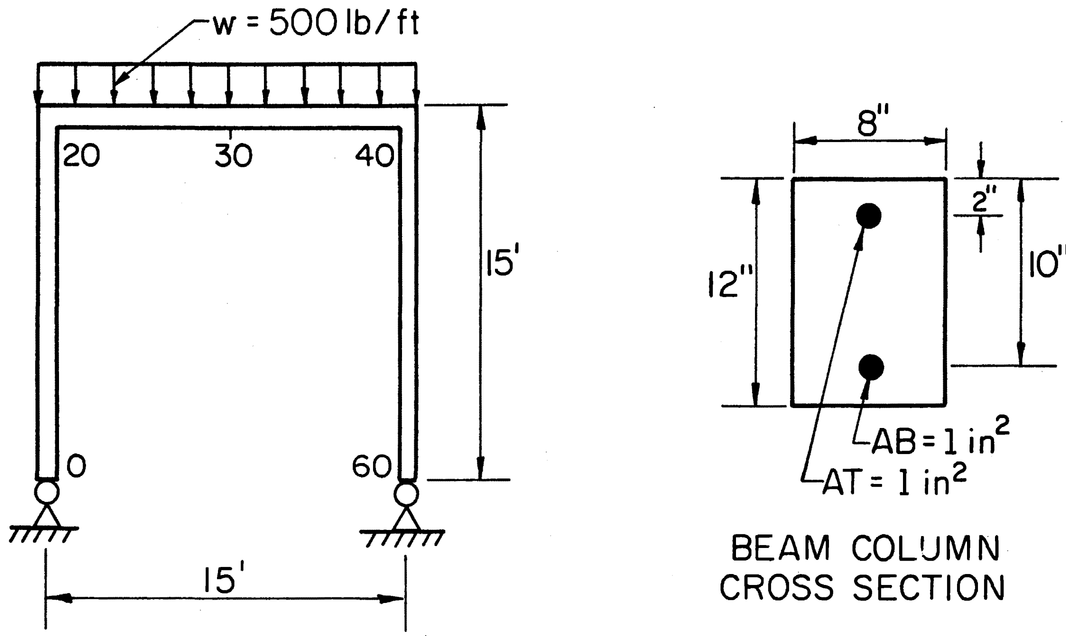


Figure 13. Frame Data for Problem IPF1

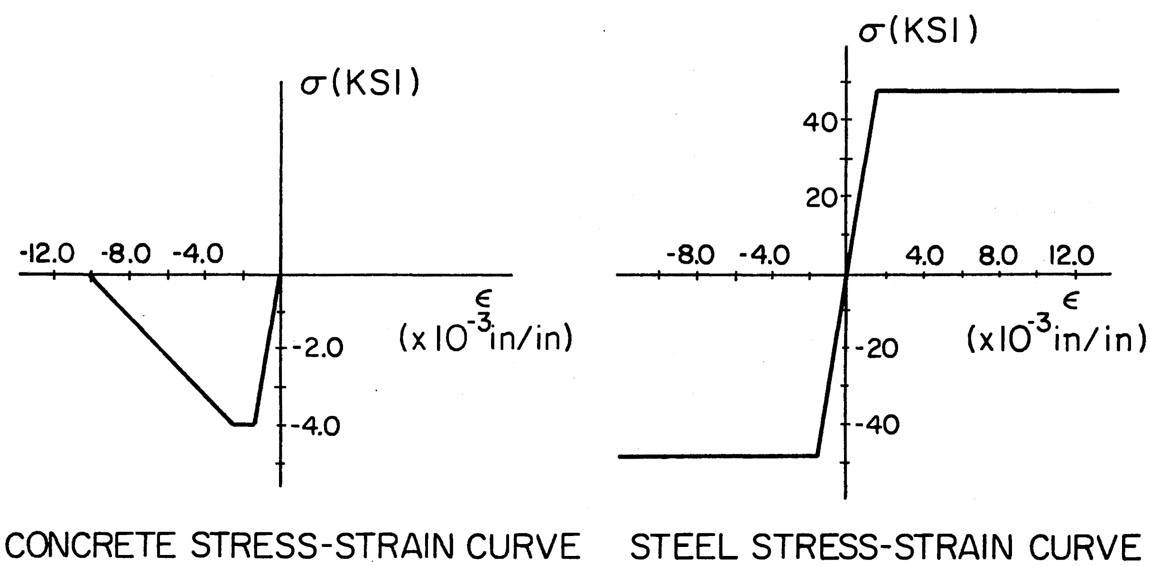


Figure 14. Concrete and Steel Stress-Strain Curves

Node	Description	Plane Frame Program	Developed Program
20	x-displ.	2.634×10^{-4} in.	2.616×10^{-4} in.
	y-displ.	-5.323×10^{-3} in.	-5.249×10^{-3} in.
	moment	-6.681×10^{4} lb-in.	-6.729×10^{4} lb-in.
30	x-displ.	-2.895×10^{-13} in.	6.508×10^{-12} in.
	y-displ.	-1.874×10^{-1} in.	-1.918×10^{-1} in.
	moment	1.019×10^{5} lb-in.	1.015×10^{5} lb-in.
40	x-displ.	-2.634×10^{-4} in.	-2.616×10^{-4} in.
	y-displ.	-5.323×10^{-3} in.	-5.249×10^{-3} in.
	moment	-6.681×10^{4} lb-in.	-6.729×10^{4} lb-in.

(a) Problem IPF1--Portal Frame With Uniform Load on Beam

Node	Description	Plane Frame Program	Developed Program
20	x-displ.	4.958×10^{-1} in.	5.019×10^{-1} in.
	y-displ.	-3.076×10^{-3} in.	-3.032×10^{-3} in.
	moment	-7.358×10^{3} lb-in.	-7.356×10^{3} lb-in.
30	x-displ.	5.948×10^{-1} in.	6.025×10^{-1} in.
	y-displ.	-2.039×10^{-1} in.	-2.071×10^{-1} in.
	moment	1.558×10^{5} lb-in.	1.558×10^{5} lb-in.
40	x-displ.	5.632×10^{-1} in.	5.703×10^{-1} in.
	y-displ.	-1.409×10^{-1} in.	-1.429×10^{-1} in.
	moment	1.896×10^{4} lb-in.	1.899×10^{4} lb-in.
50	x-displ.	6.308×10^{-1} in.	6.389×10^{-1} in.
	y-displ.	-1.656×10^{-3} in.	-1.633×10^{-3} in.
	moment	-1.274×10^{5} lb-in.	-1.274×10^{5} lb-in.

(b) Problem IPF2--Gabled Frame With Two Concentrated Loads

Figure 15. Static Solutions for Verification of Programs

reduced by increasing the number of nodal points in the frame. The results do demonstrate that the static solution is working properly.

4.2.2 Problem IPF2--Gabled Frame With Two Concentrated Loads

The static solution for a reinforced concrete gabled frame with dimensions, cross section and loading as shown in Figure 16 was obtained using the computer program developed. The frame was hinged at its supports and loaded with a 1-kip static horizontal load at the top of the left column and a 5-kip static vertical load at the center of the left beam. Eighty-one nodes were used in the frame model. Stress-strain curves for steel and concrete are shown in Figure 14.

The results of the solution obtained are compared with the results obtained using a computer program for plane frames (22) in Figure 15. The slight differences in the two solutions of approximately 1.2 percent in the worst case indicate, as in the first problem, that the computer program developed for the static solution is working properly.

4.3 Verification of Dynamic Solution

4.3.1 Problem IPF3--Simple Reinforced Concrete Beam With Static and Dynamic Loads

A rectangular, singly reinforced concrete beam on simple supports with a span of 15 feet was subjected to a uniform static load of 500 lb/ft and to an impulse loading varying sinusoidally over the length of the beam. The beam, cross section and loading are shown in Figure 17. Stress-strain curves for concrete and reinforcement are shown in Figure

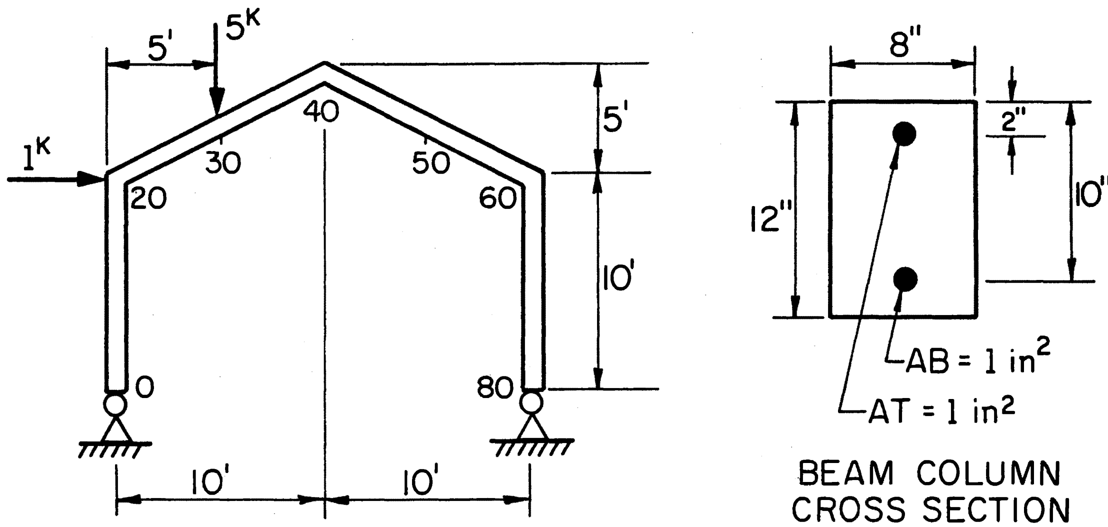


Figure 16. Frame Data for Problem IPF2

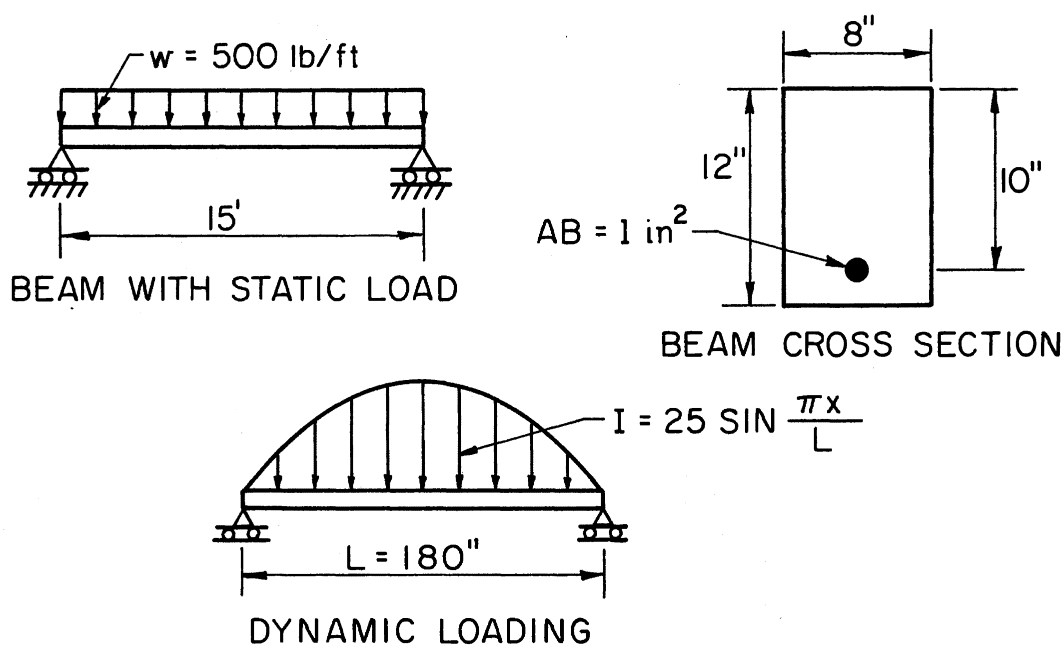


Figure 17. Beam Data for Problem IPF3

14. The beam model used contained 21 nodes, and the cross section was divided into 12 segments.

The static and dynamic solutions for the beam were obtained using the computer program developed. The results are compared with the solution obtained by Dawkins (11) using a program he developed for impulse loading of reinforced concrete beam columns. This comparison is shown in Figure 18.

The differences in the two solutions are due to the use of a cracked section in calculating the properties of the reinforced concrete cross section in the solution developed. Dawkins used an uncracked section in his solution. The computer program developed was run inputting the values for axial stiffness and flexural stiffness calculated in Dawkins' program, and the results were identical. The dynamic solution process developed will, therefore, solve reinforced concrete beams loaded with an impulse load varying sinusoidally over the length of the beam.

4.3.2 Problem IPF4--Portal Frame With Sinusoidally Varying Impulse Load on Beam and Columns

The dynamic solution for a symmetric portal frame with dimensions, cross section and loading as shown in Figure 19 was obtained using the computer code developed. The frame was hinged at its supports and subjected to an impulse loading varying sinusoidally over the beam and two columns. The frame model consisted of 61 nodes and the cross section was divided into six segments. The stress-strain curve shown in Figure 19 was used. The impulse loading applied was of such a magnitude to ensure that deflections were small and that stresses and strains

Quantity	Dawkins' Solution	Thesis Solution
Max. defl. at midspan	-0.3741 in.	-0.3956 in.
Max. mom. at midspan	1.6876×10^2 kip-in.	1.6876×10^2 kip-in.

(a) Static Solution

Quantity	Dawkins' Solution	Thesis Solution
Max. defl. at midspan	-1.537 in.	-1.704 in.
Max. mom. at midspan	4.6726×10^2 kip-in.	4.530×10^2 kip-in.
Failure time	0.0010054 sec	0.0011324 sec

(b) Dynamic Solution

Figure 18. Static and Dynamic Solutions for Verification of Program--Problem IPF3

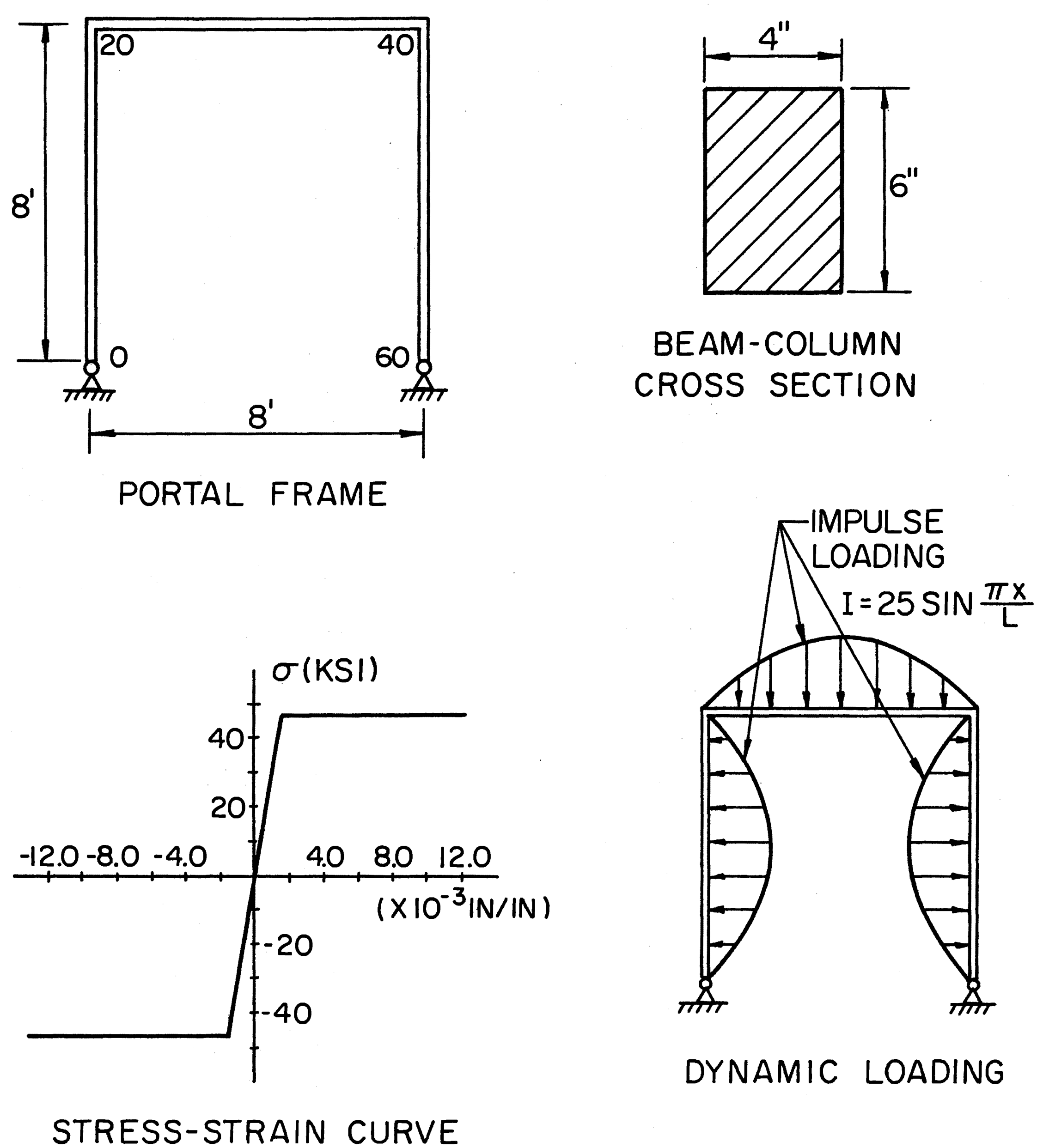


Figure 19. Frame and Loading Data for Problem IPF4

remained in the linear region of the curve. Failure parameters were adjusted to ensure failure of the frame did not occur during the time of the solution process.

The purpose of this solution was to observe the deflected shape of the symmetric structure under the dynamic loading applied and to determine the period of vibration of the structure.

The deflected shape from the sinusoidally varying impulse loading remained symmetric for the beam and columns throughout the time of the applied loading. The frame deflected in the manner expected for the loading applied. The deflected shape of the frame at different time steps in the solution process is shown in Figure 20. A graph of displacement versus time for different points on the frame is shown in Figure 21.

In determining the period of vibration for the frame, it was not practical to carry the solution process through the entire period due to the large amount of computer time required. The solution was carried beyond the quarter period of vibration rather than the full period desired. Establishing this quarter period of vibration did provide the data needed to compare the period of vibration of the computer solution to that of a calculated period of vibration. The calculated period of vibration and that obtained by the computer solution developed differed by approximately 3.8 percent. This difference could be reduced by increasing the number of nodes in the frame and the number of segments in the section. This would increase the computer time required considerably. The solution is accurate enough to indicate the solution process is working properly.

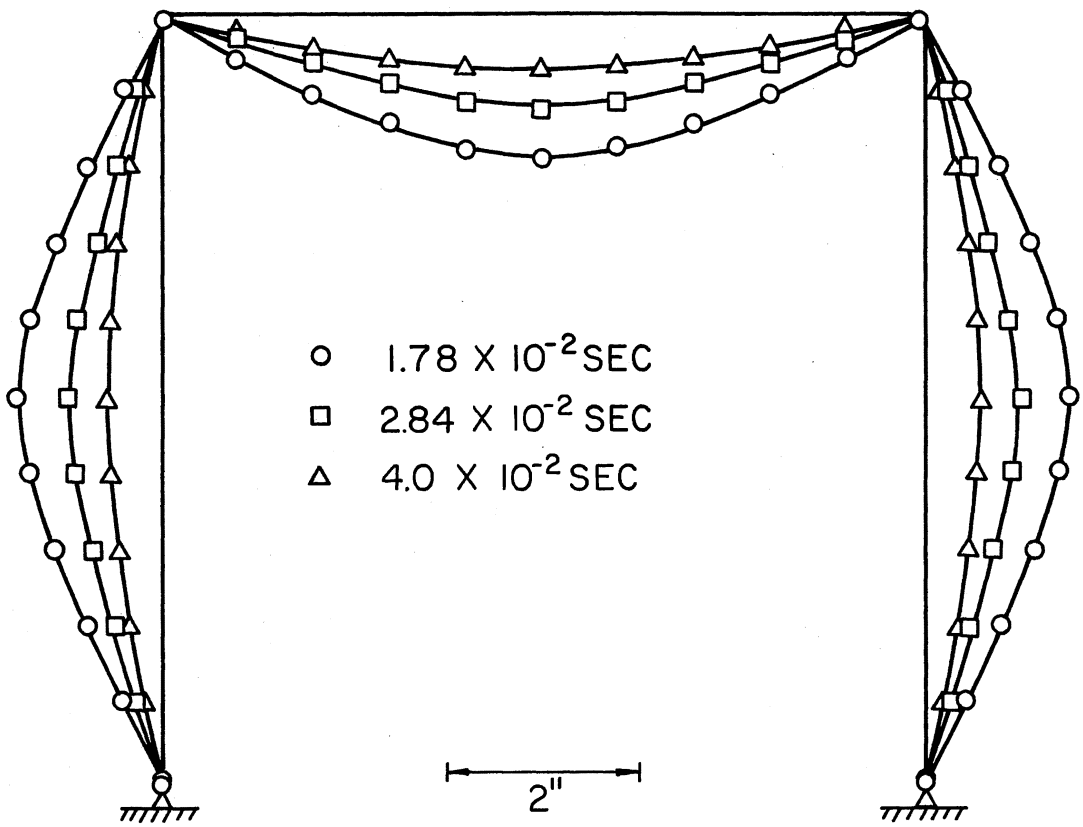


Figure 20. Deflected Shape of Portal Frame at Selected Time Steps

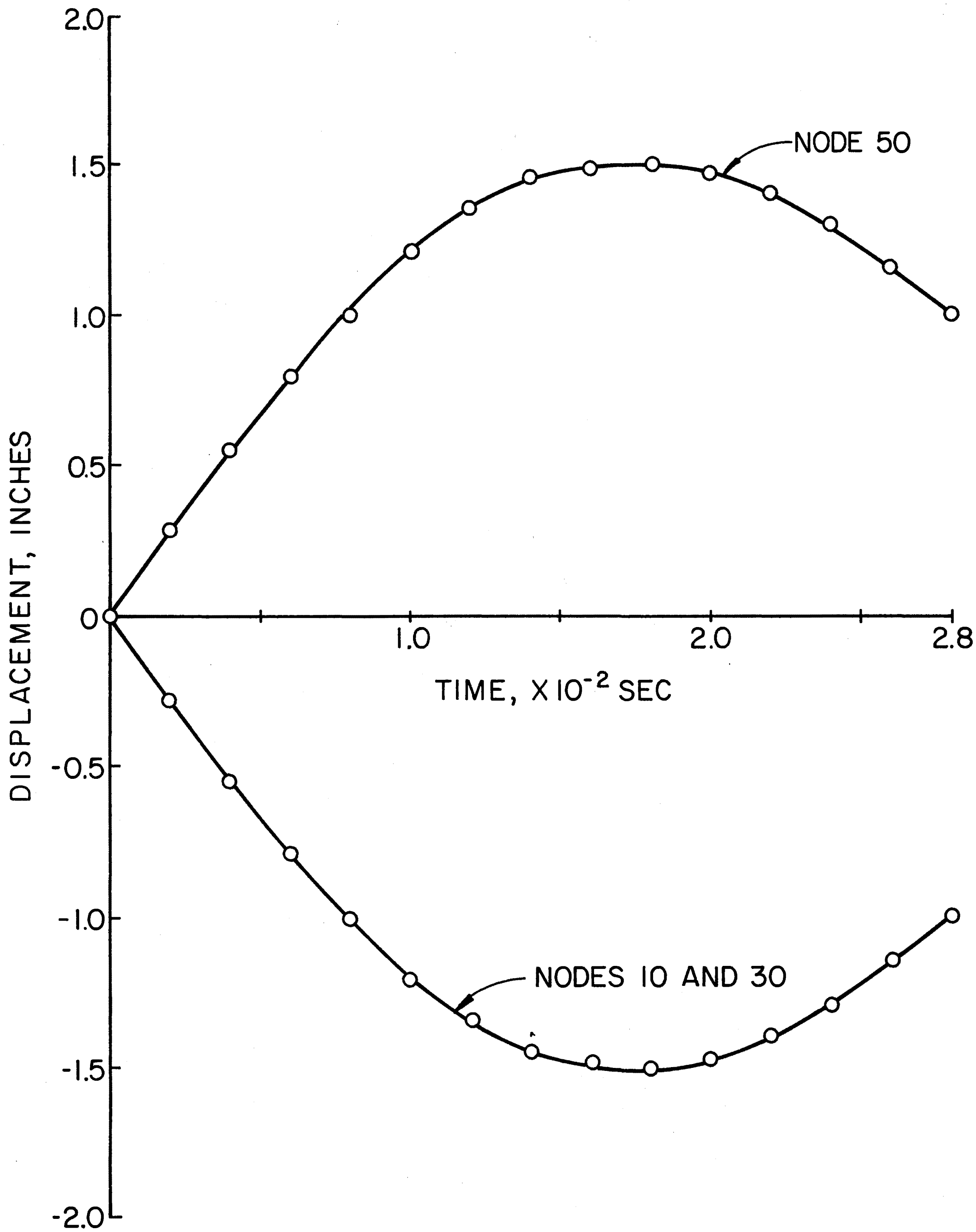


Figure 21. Displacement-Time Diagrams for Specific Nodes of the Frame Throughout Applied Loading

4.4 Application of Program

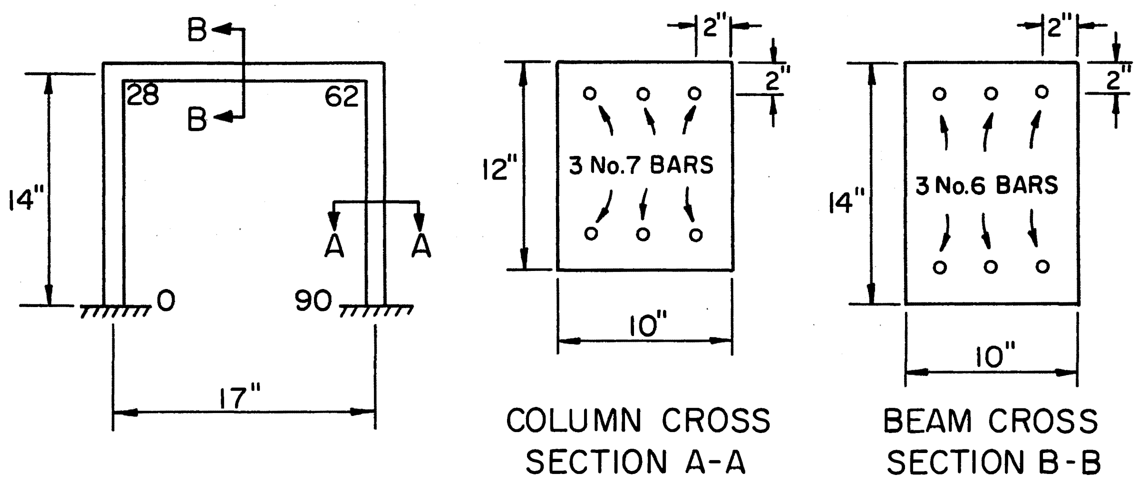
The computer program developed has been utilized in the analysis of a plane reinforced concrete portal frame fixed at its supports and subjected to combined static and dynamic loads. The dimensions, cross section and physical properties of the frame are as shown in Figure 22. The frame model contained 91 nodes and the cross section was divided into 12 segments.

The static load applied for these solutions was the dead load of the frame itself. Three separate dynamic loads were applied, each simulating a blast pressure from a different direction to the frame. Loadings applied for the three cases are shown in Figure 23.

The problems solved and results of each solution are discussed below. A listing of input data and portions of the output data for these problems are included in Appendix D.

4.4.1 Problem IPF6--Portal Frame With Sinusoidally Varying Impulse Load on Beam

In this problem the reinforced concrete portal frame was subjected to an impulse loading varying sinusoidally over the length of the beam. This loading simulates a detonation at some distance above the frame. The solution from the dynamic loading indicated very high moments were developed at the corners of the frame as can be seen in Figure 24. This in turn resulted in high shears and with the collapse parameters established, the solution indicates the frame will fail due to shear in the bar at the top of the right column of the frame at approximately 1.65 $\times 10^{-5}$ seconds after the impulse is applied. Although failure in the



PROPERTIES:

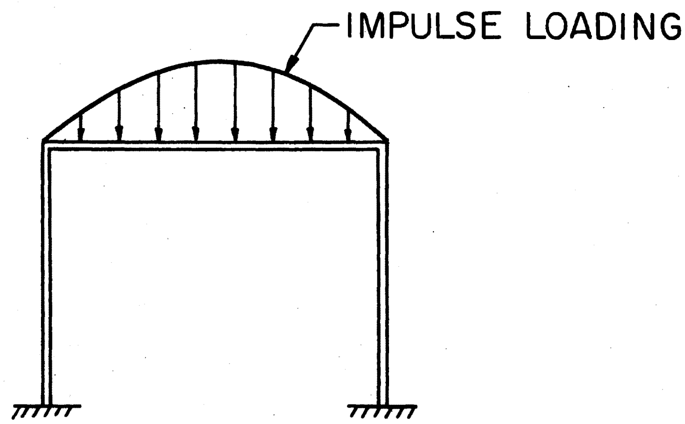
CONCRETE: DYNAMIC STRENGTH = 5 KSI

MODULUS OF ELASTICITY = 4×10^3 KSI

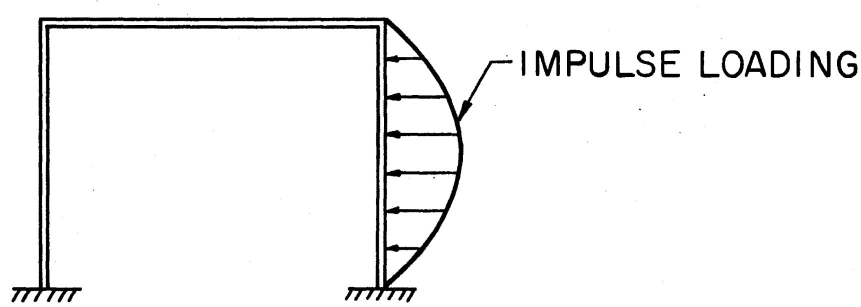
STEEL: DYNAMIC STRENGTH = 60 KSI

MODULUS OF ELASTICITY = 3×10^4 KSI

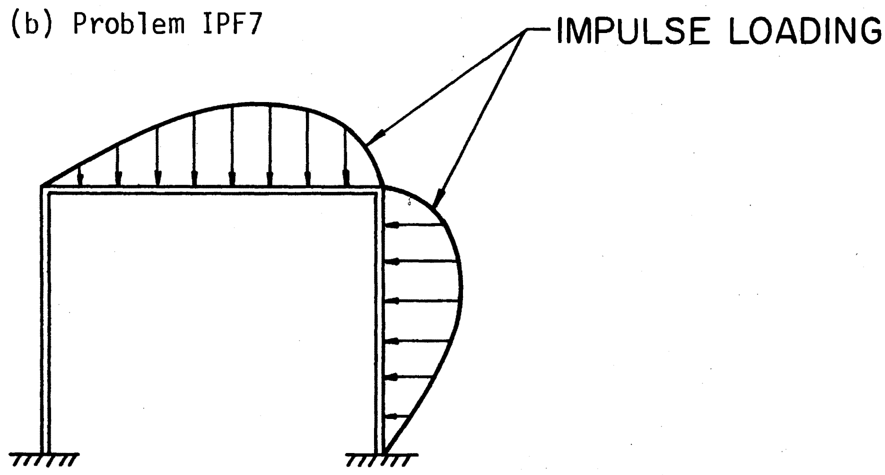
Figure 22. Frame Data for Problems IPF6, IPF7 and IPF8



(a) Problem IPF6



(b) Problem IPF7



(c) Problem IPF8

Figure 23. Dynamic Loadings for Problems IPF6, IPF7 and IPF8

Node	x-Displacement (in.)		y-Displacement (in.)		Moment (k-in.)	
	Static	Dynamic Failure	Static	Dynamic Failure	Static	Dynamic Failure
5	-.00156	-.00156	-.00017	-.00017	+ 7.6220	+ 7.170
10	-.00548	-.00548	-.00033	-.00033	- 0.5778	- 11.560
15	-.00922	-.00922	-.00050	-.00050	- 8.7780	- 45.340
20	-.01024	-.01024	-.00066	-.00067	-16.9800	- 78.280
25	-.00600	-.00600	-.00084	-.00084	-25.1800	-110.500
30	-.00012	-.00012	-.00670	-.00865	-15.2400	- 83.220
35	-.00008	-.00008	-.02275	-.02918	+13.7900	+ 11.490
40	-.00004	-.00004	-.03543	-.04620	+31.2000	+ 44.390
45	≈ 0.0	≈ 0.0	-.04017	-.05251	+37.0100	+ 50.370
50	-.00004	-.00004	-.03543	-.04620	+31.2000	+ 44.390
55	-.00008	-.00008	-.02275	-.02918	+13.7900	+ 11.490
60	-.00012	-.00012	-.00670	-.00865	-15.2400	- 83.220
65	+.00600	+.00600	-.00084	-.00084	-25.1800	-110.500
70	+.01024	+.01024	-.00067	-.00067	-16.9800	- 78.280
75	+.00922	+.00922	-.00050	-.00050	- 8.7780	- 45.340
80	+.00548	+.00548	-.00033	-.00033	- 0.5778	- 11.560
85	+.00156	+.00156	-.00017	-.00017	+ 7.6220	+ 7.170

Figure 24. Problem IPF6--Displacements and Moments

left column did not occur, the shear in the corresponding bar to that of the failed column is high and approaching failure. Several attempts were made to reduce the high moments at the corners of the frame in the dynamic solution. The impulse loading was stopped short of the corner of the frame by one, two and then three nodes. Moments at the corners of the frame continued to increase rapidly even with these changes in the loading condition. The corners of the frame were then restrained but the moments were not significantly reduced under this condition either. The dynamic loading was then applied as a force-time function. This led to a slight but not significant reduction in the moment values.

4.4.2 Problem IPF7--Portal Frame With Sinusoidally Varying Impulse Load on Right Column

The frame from the previous problems was subjected to an impulse loading varying sinusoidally over the length of the right column. This loading simulates a detonation at some distance to the right of the frame. The solution indicates the frame will fail due to shear at the top of the right column of the frame at approximately 2.5×10^{-6} seconds after the impulse is applied. The moments were again large as shown in Figure 25 and resulted in rapid failure of the frame.

4.4.3 Problem IPF8--Portal Frame With Sinusoidally Varying Impulse Load on Beam and Right Column

In this problem, the frame used in the two previous problems was subjected to an impulse loading varying sinusoidally over the length of

Node	x-Displacement (in.)		y-Displacement (in.)		Moment (k-in.)	
	Static	Dynamic Failure	Static	Dynamic Failure	Static	Dynamic Failure
5	-.00156	-.00156	-.00017	-.00017	+ 7.6220	+ 7.170
10	-.00548	-.00548	-.00033	-.00033	- 0.5778	- 11.560
15	-.00922	-.00922	-.00050	-.00050	- 8.7780	- 45.340
20	-.01024	-.01024	-.00067	-.00067	-16.9800	- 78.280
25	-.00600	-.00600	-.00084	-.00084	-25.1800	-111.100
30	-.00012	-.00012	-.00670	-.00670	-15.2400	- 89.500
35	-.00008	-.00008	-.02275	-.02275	+13.7900	+ 14.110
40	-.00004	-.00004	-.03543	-.03543	+31.2000	+ 32.050
45	≈ 0.0	≈ 0.0	-.04017	-.04017	+37.0100	+ 38.020
50	-.00004	-.00004	-.03543	-.03543	+31.2000	+ 32.050
55	-.00008	-.00008	-.02275	-.02275	+13.7900	+ 14.110
60	-.00012	-.00012	-.00670	-.00670	-15.2400	- 89.460
65	+.00600	+.00535	-.00084	-.00084	-25.1800	-108.900
70	+.01024	+.00863	-.00067	-.00067	-16.9800	- 69.490
75	+.00922	+.00713	-.00050	-.00050	- 8.7780	- 36.460
80	+.00548	+.00359	-.00033	-.00033	- 0.5778	- 2.457
85	+.00156	+.00103	-.00017	-.00017	+ 7.6220	- 84.930

Figure 25. Problem IPF7--Displacements and Moments

the beam and right column. In order to simulate a detonation above and to the right of the frame, the loading peaked toward the right end of the beam and toward the top of the column as shown in Figure 23(c). The solution indicates the frame will fail due to shear at the top of the right column of the frame at approximately 2.5 x 10^{-6} seconds after the impulse is applied. The results of the static and dynamic loading is shown in Figure 26. The same condition with high moments experienced in the two previous problems occurred with this problem.

Node	x-Displacement (in.)		y-Displacement (in.)		Moment (k-in.)	
	Static	Dynamic Failure	Static	Dynamic Failure	Static	Dynamic Failure
5	-.00156	-.00156	-.00017	-.00017	+ 7.6220	+ 7.170
10	-.00548	-.00548	-.00033	-.00033	- 0.5778	- 11.560
15	-.00922	-.00922	-.00050	-.00050	- 8.7780	- 45.340
20	-.01024	-.01024	-.00067	-.00067	-16.9800	- 78.280
25	-.00600	-.00600	-.00084	-.00084	-25.1800	-111.100
30	-.00012	-.00012	-.00670	-.00671	-15.2400	- 89.400
35	-.00008	-.00008	-.02275	-.02280	+13.7900	+ 14.180
40	-.00004	-.00004	-.03543	-.03550	+31.2000	+ 32.010
45	≈ 0.0	≈ 0.0	-.04017	-.04026	+37.0100	+ 37.990
50	-.00004	-.00004	-.03543	-.03556	+31.2000	+ 32.010
55	-.00008	-.00008	-.02275	-.02299	+13.7900	+ 15.380
60	-.00012	-.00012	-.00670	-.00690	-15.2400	- 77.400
65	+.00600	+.00566	-.00084	-.00084	-25.1800	- 93.130
70	+.01024	+.00998	-.00067	-.00067	-16.9800	- 79.220
75	+.00922	+.00910	-.00050	-.00050	- 8.7780	- 46.320
80	+.00548	+.00542	-.00033	-.00033	- 0.5778	- 12.560
85	+.00156	+.00151	-.00017	-.00017	+ 7.6220	+ 7.414

Figure 26. Problem IPF8--Displacements and Moments

CHAPTER V

SUMMARY AND CONCLUSION

5.1 Summary

A mathematical model for analysis of frames subjected to both static and dynamic loads has been developed. The model permits a wide variety of static and dynamic loads and accounts for members of different cross sections. A computer program has been written based on the model. Solutions obtained using the program have compared satisfactorily with known solutions for static loading of reinforced concrete frames and for static and dynamic loading of reinforced concrete beams. The dynamic loading of a symmetric reinforced concrete frame was used to determine the period of vibration of the frame. Results were compared with that of a calculated period of vibration for the frame and indicated that the solution process was working properly. In addition, the deflected shape of the frame was correct and results remained symmetric for the beam and columns throughout the time of the applied loading. The application of the computer program developed to a plane reinforced concrete portal frame with fixed supports and subjected to combined static and dynamic loads led to very high moments and shears at the corners of the frame. Several attempts were made to reduce these high values at the corners with no significant changes. The impulse loading was stopped at different distances, in terms of nodes, from the corners but without significant changes. The corners of the frame were restrained with similar results.

The dynamic loading was then applied as a force-time function. This resulted in a slight but not significant reduction in values of moments and shears at the corners.

5.2 Conclusion

Results indicate that very high moments and shears exist at the corners of reinforced concrete portal frames under impulse loading. Since it is not known whether this actually occurs or is a result of the bar-spring model developed, it is recommended that additional research be accomplished using a different type model, perhaps with a continuous mass. Experimental testing is also recommended to verify the analytical results obtained with the model and program.

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APPENDIX A

GOVERNING EQUATIONS FOR THE STATIC SOLUTION

In the static solution process two governing equations for each joint in the frame are obtained by combining the strain displacement and force deformation relations with the equilibrium equations. These equations give joint displacements in terms of applied loads.

Combining Equations (2.3, 2.6, 2.10, 2.11, 2.12, 2.13, 2.14, and 2.15) gives:

$$- \frac{(EI)_{i-1} \sin \theta_i}{1/2\ (L_i)(L_{i-1})(L_{i-1} + L_i)} [\sin \theta_{i-1}\ (u_{i-2}) - \cos \theta_{i-1}\ (v_{i-2})]$$

$$+ \frac{(EI)_{i-1} \sin \theta_i}{1/2\ (L_i)(L_{i-1})(L_{i-1} + L_i)} [\sin \theta_{i-1}\ (u_{i-1}) - \cos \theta_{i-1}\ (v_{i-1})]$$

$$+ \frac{(EI)_{i-1} \sin \theta_i}{1/2\ (L_i)^2\ (L_{i-1} + L_i)} [\sin \theta_i\ (u_{i-1}) - \cos \theta_i\ (v_{i-1})]$$

$$+ \frac{(EI)_i \sin \theta_i}{1/2\ (L_i)^2\ (L_i + L_{i+1})} [\sin \theta_i\ (u_{i-1}) - \cos \theta_i\ (v_{i-1})]$$

$$+ \frac{(EI)_i \sin \theta_{i+1}}{1/2\ (L_i)(L_{i+1})(L_i + L_{i+1})} [\sin \theta_i\ (u_{i-1}) - \cos \theta_i\ (v_{i-1})]$$

$$+ \frac{[(AE)_{i-1} + (AE)_i] \cos \theta_i}{2L_i} [\cos \theta_i\ (u_{i-1}) + \sin \theta_i\ (v_{i-1})]$$

$$- \frac{(EI)_{i-1} \sin \theta_i}{1/2\ (L_i)^2\ (L_{i-1} + L_i)} [\sin \theta_i\ (u_i) - \cos \theta_i\ (v_i)]$$

$$- \frac{(EI)_i \sin \theta_i}{1/2\ (L_i)^2\ (L_i + L_{i-1})} [\sin \theta_i\ (u_i) - \cos \theta_i\ (v_i)]$$

$$- \frac{(EI)_i \sin \theta_i}{1/2\ (L_i)(L_{i+1})(L_i + L_{i+1})} [\sin \theta_{i+1}\ (u_i) - \cos \theta_{i+1}\ (v_i)]$$

$$- \frac{(EI)_i \sin \theta_{i+1}}{1/2\ (L_i)(L_{i+1})(L_i + L_{i+1})} [\sin \theta_i\ (u_i) - \cos \theta_i\ (v_i)]$$

$$- \frac{(EI)_i \sin\theta_{i+1}}{1/2\ (L_{i+1})^2\ (L_i + L_{i+1})} [\sin\theta_{i+1}\ (u_i) - \cos\theta_{i+1}\ (v_i)]$$

$$- \frac{(EI)_{i+1} \sin\theta_{i+1}}{1/2\ (L_{i+1})^2\ (L_{i+1} + L_{i+2})} [\sin\theta_{i+1}\ (u_i) - \cos\theta_{i+1}\ (v_i)]$$

$$- \frac{[(AE)_{i-1} + (AE)_i] \cos\theta_i}{2L_i} [\cos\theta_i\ (u_i) + \sin\theta_i\ (v_i)]$$

$$- \frac{[(AE)_i + (AE)_{i+1}] \cos\theta_{i+1}}{2L_{i+1}} [\cos\theta_{i+1}\ (u_i) + \sin\theta_{i+1}\ (v_i)]$$

$$- S_{xi}\ u_i$$

$$+ \frac{(EI)_i \sin\theta_i}{1/2\ (L_i)(L_{i+1})(L_i + L_{i+1})} [\sin\theta_{i+1}\ (u_{i+1}) - \cos\theta_{i+1}\ (v_{i+1})]$$

$$+ \frac{(EI)_i \sin\theta_{i+1}}{1/2\ (L_{i+1})^2\ (L_i + L_{i+1})} [\sin\theta_{i+1}\ (u_{i+1}) - \cos\theta_{i+1}\ (v_{i+1})]$$

$$+ \frac{(EI)_{i+1} \sin\theta_{i+1}}{1/2\ (L_{i+1})^2\ (L_{i+1} + L_{i+2})} [\sin\theta_{i+1}\ (u_{i+1}) - \cos\theta_{i+1}\ (v_{i+1})]$$

$$+ \frac{(EI)_{i+1} \sin\theta_{i+1}}{1/2\ (L_{i+1})(L_{i+2})(L_{i+1} + L_{i+2})} [\sin\theta_{i+2}\ (u_{i+1})$$

$$- \cos\theta_{i+2}\ (v_{i+1})]$$

$$+ \frac{[(AE)_i + (AE)_{i+1}] \cos\theta_{i+1}}{2L_{i+1}} [\cos\theta_{i+1}\ (u_{i+1})$$

$$+ \sin\theta_{i+1}\ (v_{i+1})]$$

$$- \frac{(EI)_{i+1} \sin\theta_{i+1}}{1/2\ (L_{i+1})(L_{i+2})(L_{i+1} + L_{i+2})} [\sin\theta_{i+2}\ (u_{i+2})$$

$$- \cos\theta_{i+2}\ (v_{i+2})]$$

$$+ Q_{xi} = 0. \qquad \text{(A.1)}$$

Combining Equations (2.3, 2.6, 2.10, 2.11, 2.12, 2.13, 2.14, and 2.16) gives:

$$+ \frac{(EI)_{i-1} \cos \theta_i}{1/2\ (L_i)(L_{i-1})(L_{i-1} + L_i)} [\sin \theta_{i-1}\ (u_{i-2}) - \cos \theta_{i-1}\ (v_{i-2})]$$

$$- \frac{(EI)_{i-1} \cos \theta_i}{1/2\ (L_i)(L_{i-1})(L_{i-1} + L_i)} [\sin \theta_{i-1}\ (u_{i-1}) - \cos \theta_{i-1}\ (v_{i-1})]$$

$$- \frac{(EI)_{i-1} \cos \theta_i}{1/2\ (L_i)^2\ (L_{i-1} + L_i)} [\sin \theta_i\ (u_{i-1}) - \cos \theta_i\ (v_{i-1})]$$

$$- \frac{(EI)_i \cos \theta_i}{1/2\ (L_i)^2\ (L_i + L_{i+1})} [\sin \theta_i\ (u_{i-1}) - \cos \theta_i\ (v_{i-1})]$$

$$- \frac{(EI)_i \cos \theta_{i+1}}{1/2\ (L_i)(L_{i+1})(L_i + L_{i+1})} [\sin \theta_i\ (u_{i-1}) - \cos \theta_i\ (v_{i-1})]$$

$$+ \frac{[(AE)_{i-1} + (AE)_i] \sin \theta_i}{2L_i} [\cos \theta_i\ (u_{i-1}) + \sin \theta_i\ (v_{i-1})]$$

$$+ \frac{(EI)_{i-1} \cos \theta_i}{1/2\ (L_i)^2\ (L_{i-1} + L_i)} [\sin \theta_i\ (u_i) - \cos \theta_i\ (v_i)]$$

$$+ \frac{(EI)_i \cos \theta_i}{1/2\ (L_i)^2\ (L_i + L_{i+1})} [\sin \theta_i\ (u_i) - \cos \theta_i\ (v_i)]$$

$$+ \frac{(EI)_i \cos \theta_i}{1/2\ (L_i)(L_{i+1})(L_i + L_{i+1})} [\sin \theta_{i+1}\ (u_i) - \cos \theta_{i+1}\ (v_i)]$$

$$+ \frac{(EI)_i \cos \theta_{i+1}}{1/2\ (L_i)(L_{i+1})(L_i + L_{i+1})} [\sin \theta_i\ (u_i) - \cos \theta_i\ (v_i)]$$

$$+ \frac{(EI)_i \cos \theta_{i+1}}{1/2\ (L_{i+1})^2\ (L_i + L_{i+1})} [\sin \theta_{i+1}\ (u_i) - \cos \theta_{i+1}\ (v_i)]$$

$$+ \frac{(EI)_{i+1} \cos \theta_{i+1}}{1/2\ (L_{i+1})^2\ (L_{i+1} + L_{i+2})} [\sin \theta_{i+1}\ (u_i) - \cos \theta_{i+1}\ (v_i)]$$

$$- \frac{[(AE)_{i-1} + (AE)_i] \sin \theta_i}{2L_i} [\cos \theta_i (u_i) + \sin \theta_i (v_i)]$$

$$- \frac{[(AE)_i + (AE)_{i+1}] \sin \theta_{i+1}}{2L_{i+1}} [\cos \theta_{i+1} (u_i) + \sin \theta_{i+1} (v_i)]$$

$$- S_{yi} v_i$$

$$- \frac{(EI)_i \cos \theta_i}{1/2 (L_i)(L_{i+1})(L_i + L_{i+1})} [\sin \theta_{i+1} (u_{i+1}) - \cos \theta_{i+1} (v_{i+1})]$$

$$- \frac{(EI)_i \cos \theta_{i+1}}{1/2 (L_{i+1})^2 (L_i + L_{i+1})} [\sin \theta_{i+1} (u_{i+1}) - \cos \theta_{i+1} (v_{i+1})]$$

$$- \frac{(EI)_{i+1} \cos \theta_{i+1}}{1/2 (L_{i+1})^2 (L_{i+1} + L_{i+2})} [\sin \theta_{i+1} (u_{i+1}) - \cos \theta_{i+1} (v_{i+1})]$$

$$- \frac{(EI)_{i+1} \cos \theta_{i+1}}{1/2 (L_{i+1})(L_{i+2})(L_{i+1} + L_{i+2})} [\sin \theta_{i+2} (u_{i+1})$$

$$- \cos \theta_{i+2} (v_{i+1})]$$

$$+ \frac{[(AE)_i + (AE)_{i+1}] \sin \theta_{i+1}}{2L_{i+1}} [\cos \theta_{i+1} (u_{i+1})$$

$$+ \sin \theta_{i+1} (v_{i+1})]$$

$$+ \frac{(EI)_{i+1} \cos \theta_{i+1}}{1/2 (L_{i+1})(L_{i+2})(L_{i+1} + L_{i+2})} [\sin \theta_{i+2} (u_{i+2})$$

$$- \cos \theta_{i+2} (v_{i+2})]$$

$$+ Q_{yi} = 0. \qquad \text{(A.2)}$$

These two governing equations for joint i are of the form:

$$a_{i,11}\, u_{i-2} + a_{i,12}\, v_{i-2} + b_{i,11}\, u_{i-1} + b_{i,12}\, v_{i-1} + c_{i,11}\, u_i$$

$$+ c_{i,12}\, v_i + d_{i,11}\, u_{i+1} + d_{i,12}\, v_{i+1} + e_{i,11}\, u_{i+2}$$

$$+ e_{i,12}\, v_{i+2} = -Q_{xi}, \tag{A.3}$$

and

$$a_{i,21}\, u_{i-2} + a_{i,22}\, v_{i-2} + b_{i,21}\, u_{i-1} + b_{i,22}\, v_{i-1} + c_{i,21}\, u_i$$

$$+ c_{i,22}\, v_i + d_{i,21}\, u_{i+1} + d_{i,22}\, v_{i+1} + e_{i,21}\, u_{i+2}$$

$$+ e_{i,22}\, v_{i+2} = -Q_{yi}. \tag{A.4}$$

By letting,

$$\text{Con } 1 = \frac{2(EI)_{i-1}}{(L_{i-1})(L_i)(L_{i-1} + L_i)}$$

$$\text{Con } 2 = \frac{2(EI)_{i-1}}{(L_i)^2\,(L_{i-1} + L_i)}$$

$$\text{Con } 3 = \frac{2(EI)_i}{(L_i)^2\,(L_i + L_{i+1})}$$

$$\text{Con } 4 = \frac{2(EI)_i}{(L_i)(L_{i+1})(L_i + L_{i+1})}$$

$$\text{Con } 5 = \frac{[(AE)_{i-1} + (AE)_i]}{2L_i}$$

$$\text{Con } 6 = \frac{2(EI)_i}{(L_{i+1})^2\,(L_i + L_{i+1})}$$

$$\text{Con } 7 = \frac{2(EI)_{i+1}}{(L_{i+1})^2\,(L_{i+1} + L_{i+2})}$$

$$\text{Con } 8 = \frac{[(AE)_i + (AE)_{i+1}]}{2L_{i+1}}$$

$$\text{Con } 9 = \frac{2(EI)_{i+1}}{(L_{i+1})(L_{i+2})(L_{i+1} + L_{i+2})}$$

and by using the appropriate trigonometric relations, the coefficients of Equations (A.3) and (A.4) can be written as follows:

$$a_{i,11} = -\text{Con } 1 \,(\sin \theta_i)(\sin \theta_{i-1})$$

$$a_{i,12} = \text{Con } 1 \,(\sin \theta_i)(\cos \theta_{i-1})$$

$$a_{i,21} = \text{Con } 1 \,(\cos \theta_i)(\sin \theta_{i-1})$$

$$a_{i,22} = -\text{Con } 1 \,(\cos \theta_i)(\cos \theta_{i-1})$$

$$b_{i,11} = \text{Con } 1 \,(\sin \theta_i)(\sin \theta_{i-1}) + (\text{Con } 2 + \text{Con } 3)\,(\sin \theta_i)^2 + \text{Con } 4 \,(\sin \theta_{i+1})(\sin \theta_i) + \text{Con } 5 \,(\cos \theta_i)^2$$

$$b_{i,12} = -\text{Con } 1 \,(\sin \theta_i)(\cos \theta_{i-1}) - (\text{Con } 2 + \text{Con } 3)\,(\sin \theta_i)(\cos \theta_i) - \text{Con } 4 \,(\sin \theta_{i+1})(\cos \theta_i) + \text{Con } 5 \,(\cos \theta_i)(\sin \theta_i)$$

$$b_{i,21} = -\text{Con } 1 \,(\cos \theta_i)(\sin \theta_{i-1}) - (\text{Con } 2 + \text{Con } 3)(\cos \theta_i)(\sin \theta_i) - \text{Con } 4 \,(\cos \theta_{i+1})(\sin \theta_i) + \text{Con } 5 \,(\sin \theta_i)(\cos \theta_i)$$

$$b_{i,22} = \text{Con } 1 \,(\cos \theta_i)(\cos \theta_{i-1}) + (\text{Con } 2 + \text{Con } 3)\,(\cos \theta_i)^2 + \text{Con } 4 \,(\cos \theta_{i+1})(\cos \theta_i) + \text{Con } 5 \,(\sin \theta_i)^2$$

$$c_{i,11} = -(\text{Con } 2 + \text{Con } 3)(\sin \theta_i)^2 - 2\,(\text{Con } 4)(\sin \theta_i)(\sin \theta_{i+1}) - (\text{Con } 6 + \text{Con } 7)(\sin \theta_{i+1})^2 - \text{Con } 5 \,(\cos \theta_i)^2 - \text{Con } 8 \,(\cos \theta_{i+1})^2 - S_{xi}$$

$$c_{i,12} = (\text{Con } 2 + \text{Con } 3)(\sin \theta_i)(\cos \theta_i) + \text{Con } 4 \,(\sin \theta_i)(\cos \theta_{i+1}) + \text{Con } 4 \,(\sin \theta_{i+1})(\cos \theta_i) + (\text{Con } 6 + \text{Con } 7)(\sin \theta_{i+1})(\cos \theta_{i+1}) - \text{Con } 5 \,(\cos \theta_i)(\sin \theta_i)$$

$$- \text{Con } 8 (\cos \theta_{i+1})(\sin \theta_{i+1})$$

$$c_{i,21} = c_{i,12}$$

$$c_{i,22} = -(\text{Con } 2 + \text{Con } 3)(\cos \theta_i)^2 - 2 (\text{Con } 4)(\cos \theta_i)(\cos \theta_{i+1})$$
$$- (\text{Con } 6 + \text{Con } 7)(\cos \theta_{i+1})^2 - \text{Con } 5 (\sin \theta_i)^2$$
$$- \text{Con } 8 (\sin \theta_{i+1})^2 - S_{yi}$$

$$d_{i,11} = \text{Con } 4 (\sin \theta_i)(\sin \theta_{i+1}) + (\text{Con } 6 + \text{Con } 7)(\sin \theta_{i+1})^2$$
$$+ \text{Con } 9 (\sin \theta_{i+1})(\sin \theta_{i+2}) + \text{Con } 8 (\cos \theta_{i+1})^2$$

$$d_{i,12} = -\text{Con } 4 (\sin \theta_i)(\cos \theta_{i+1}) - (\text{Con } 6 + \text{Con } 7) (\sin \theta_{i+1})$$
$$(\cos \theta_{i+1}) - \text{Con } 9 (\sin \theta_{i+1})(\cos \theta_{i+2})$$
$$+ \text{Con } 8 (\cos \theta_{i+1})(\sin \theta_{i+1})$$

$$d_{i,21} = -\text{Con } 4 (\cos \theta_i)(\sin \theta_{i+1}) - (\text{Con } 6 + \text{Con } 7) (\cos \theta_{i+1})$$
$$(\sin \theta_{i+1}) - \text{Con } 9 (\cos \theta_{i+1})(\sin \theta_{i+2})$$
$$+ \text{Con } 8 (\sin \theta_{i+1})(\cos \theta_{i+1})$$

$$d_{i,22} = \text{Con } 4 (\cos \theta_i)(\cos \theta_{i+1}) + (\text{Con } 6 + \text{Con } 7)(\cos \theta_{i+1})^2$$
$$+ \text{Con } 9 (\cos \theta_{i+1})(\cos \theta_{i+2}) + \text{Con } 8 (\sin \theta_{i+1})^2$$

$$e_{i,11} = -\text{Con } 9 (\sin \theta_{i+1})(\sin \theta_{i+2})$$

$$e_{i,12} = \text{Con } 9 (\sin \theta_{i+1})(\cos \theta_{i+2})$$

$$e_{i,21} = \text{Con } 9 (\cos \theta_{i+1})(\sin \theta_{i+2})$$

$$e_{i,22} = -\text{Con } 9 (\cos \theta_{i+1})(\cos \theta_{i+2})$$

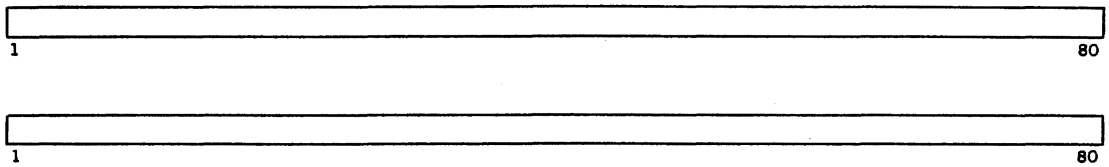
The governing Equations (A.3) and (A.4) can be solved using the above matrix coefficients and the back and forth recursion technique described in Chapter II.

APPENDIX B

GUIDE FOR DATA INPUT

RUN IDENTIFICATION

Two alphanumeric cards at beginning of run.



PROBLEM IDENTIFICATION

One card at the beginning of each problem. Program stops if problem name is left blank.

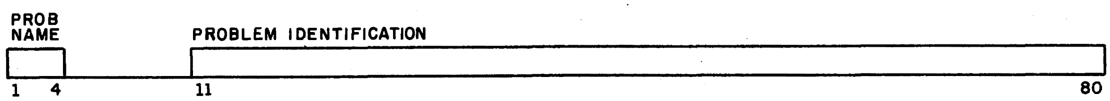
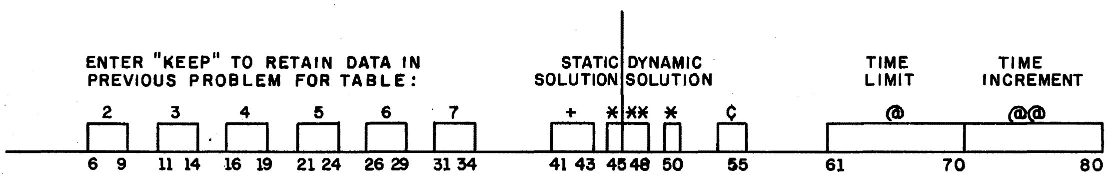


TABLE 1--CONTROL DATA

One card for each problem.



+--Enter "YES" or "NO" for static solution.

*--Output Option:

1 - maximum bending moment, shear and deflection only.

2 - bending moment, shear and deflection at every station.

3 - indication of collapse only (for dynamic solution).

**--Enter only the number of additional impulse loading sets input with each problem.

¢--The number entered determines the time interval for which the dynamic response is printed.

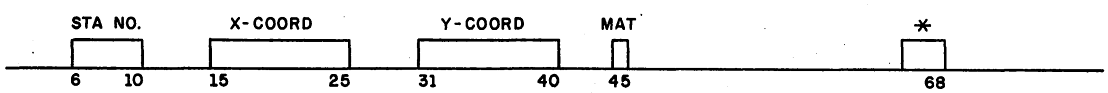
@--The maximum time limit to which the dynamic solution is to be carried for each dynamic loading.

@@--The time interval which is to be used in the numerical integration process in the dynamic solution. If this time increment is left blank, the interval is estimated internally in the program. If more than 10 iterations are required during any time step before convergence of the numerical integration is achieved, the program will terminate. This condition is usually caused by too large a time interval and can be corrected by reducing the time interval.

TABLE 2--JOINT COORDINATES AND CROSS SECTION DESCRIPTION

A rectangular cross section is assumed in the solution.

1. Joint coordinates and material. Minimum of three cards for new Table 2A for a frame. See Figure 27 for a typical frame.

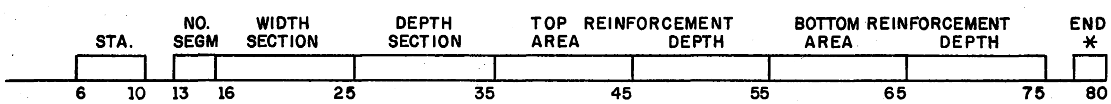


Station Number--There are three fictitious station numbers off each end of the frame to simplify the static solution. Station #4 is the first station on the frame and is assumed at coordinates x = 0, y = 0. A maximum of 105 stations are permitted including the six fictitious stations automatically generated. A station number with coordinates is required at each location where a member changes direction. Omitted stations and coordinates are assigned at equal intervals between input stations.

Material--The option is included for using different materials at a later date.

*--Enter "END" if station number is last station on frame.

2. Cross section and reinforcement description. Minimum of two cards for new Table 2B and a maximum of 10 cards for all problems. See Figure 28 for a general cross section.



Station--For constant values through frame, give start and end station. For varying values, give station and values at each change.

Number of Segments--The number of segments the cross section is to be divided into. A maximum of 30 segments is allowed.

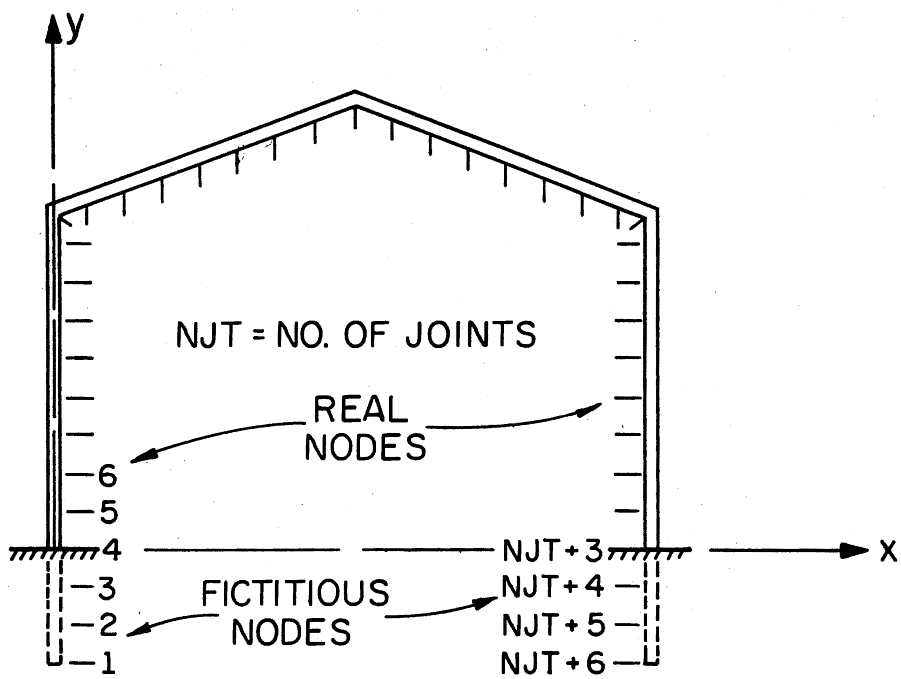


Figure 27. Typical Frame

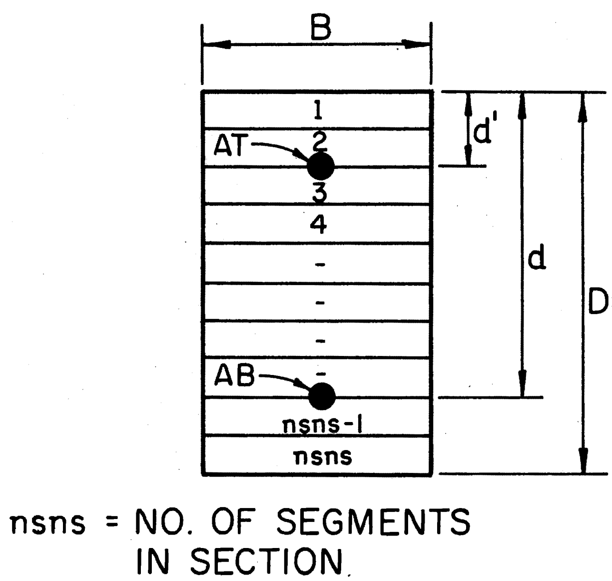


Figure 28. General Cross Section

Reinforcement Description--Values for omitted stations are linearly interpolated between input values.

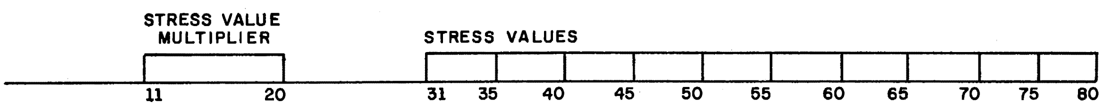
*--Enter "END" if station number is last station on frame.

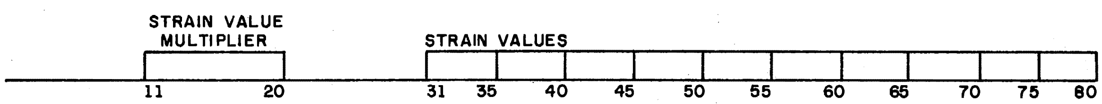
TABLE 3--STRESS-STRAIN CURVES

A minimum of three cards is required and a maximum of 11 cards is permitted for a new Table 3. No cards are permitted if preceding Table 3 is retained. The general form of the curve is shown in Figure 29.

1. Control card. One required for new Table 3.

2. Stress-strain values. Two cards for each curve.



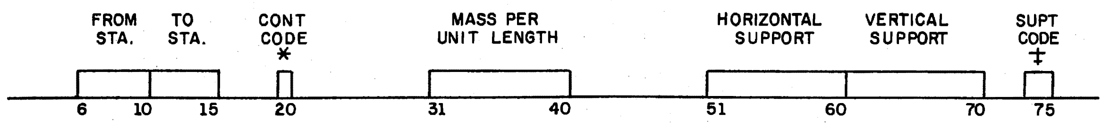


Maximum of five curves is allowed. Curve stress and strain values must proceed from the most negative to the most positive values. Ten stress and strain values are required. A nonzero multiplier must also be input.

The last curve input is used for all reinforcement.

TABLE 4--BEAM/COLUMN MASS AND ELASTIC SUPPORTS

A minimum of one card is required for each problem, and a maximum of 10 cards is permitted for all problems. If no data is included, insert a blank card.



* Code = 0 for last card in Table 4.

= 1 if data varies linearly between values at "FROM STA" on this card and values at "TO STA" on next card.

= 2 for end of distribution sequence.

= 3 if data is uniformly distributed between "FROM STA" and "TO STA."

Remarks: If "FROM STA" = "TO STA" and Code = 0 or 3, values are assumed to be concentrated; otherwise, all values are assumed to be given per unit length. Overlapping distributions and concentrated values are cumulative.

Data values are linearly interpolated between input values and are lumped at each station according to station coordinates.

A nonzero value of beam/column mass must be provided for every real station in the frame if a dynamic solution is to be performed.

‡ Undeflecting supports at "FROM STA" for dynamic solution only.

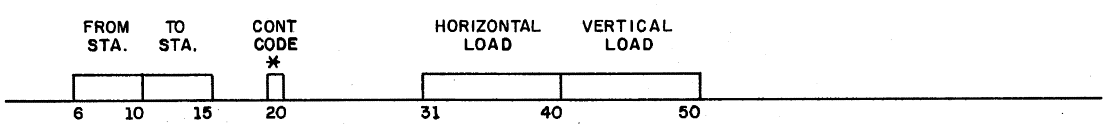
Code = "SL" for vertical support only.

= "SA" for horizontal support only.

= "AL" for horizontal and vertical support.

TABLE 5--STATIC LOADS

A minimum of one card is required for each problem and a maximum of 10 cards is permitted for all problems. A blank card must be inserted if no additional data is to be provided.



* Code designated in Table 4 applies.

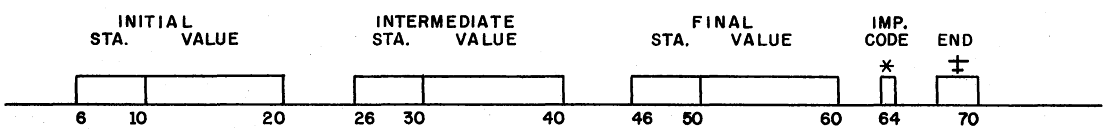
Data in Table 5 are cumulative.

Data values are linearly interpolated between input values and are lumped at each station according to station coordinates.

TABLE 6--IMPULSE LOADING

The number of sets of data is according to the number of dynamic loadings specified in Table 1. No cards are required if no dynamic loading is specified. A minimum of one card per dynamic loading set is required. A maximum of 20 cards per set and a maximum of 20 sets is permitted.

Each data set is treated as an independent dynamic loading and is superimposed on the static loading specified in Table 5. Data are cumulative for each data set.



Concentrated Impulse: enter data at initial station only.

Distributed Impulse:

Linear Variation: enter data for initial and final station only, leaving intermediate station blank.

Parabolic Variation: enter data for initial and final stations and data for one.

* Impulse Code = 1 for vertical impulse.

= 2 for horizontal impulse.

‡ Enter "END" on last card in each data set. Leave blank otherwise.

Remarks: Data values may be concentrated or distributed with either linear or parabolic variation. Distributed values are lumped as equivalent concentrated values.

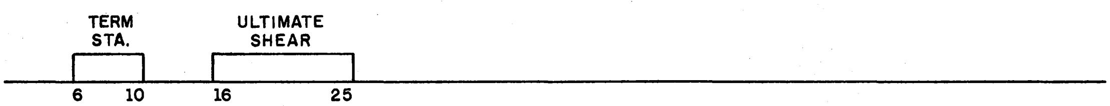
The solution process is extremely sensitive to abrupt changes in slope of distributed impulse loading curves. Such changes should be avoided. Straight lines are not acceptable approximations of curved distributions for impulse loadings.

TABLE 7--COLLAPSE PARAMETERS

The number of cards required is specified below with each major heading. No cards are required if there are no dynamic loads or if Table 7 is retained.

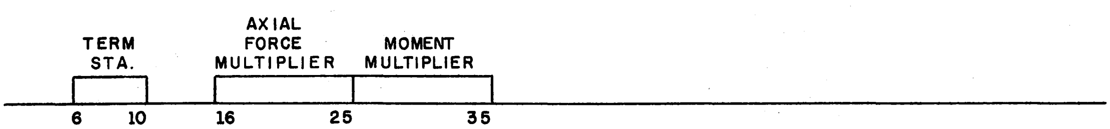
1. Deflection limits. One card is required for a new Table 7.

2. Shear limits. A minimum of one card is required for a new Table 7 and a maximum of 10 cards is permitted.



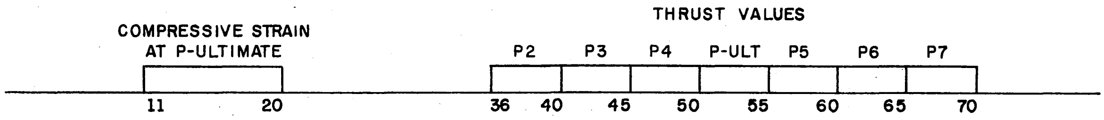
The ultimate shear capacity is assumed constant over the region between input stations. Enter terminal station number for each region. The last station number input must be the end station number for the frame. For constant value throughout frame, the end station would be used and only one card is required.

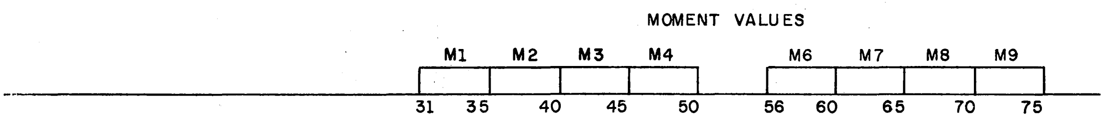
3. Thrust-moment interaction diagram data. Multipliers: A minimum of one card for a new Table 7 and a maximum of 10 cards is permitted.



Multipliers are assumed constant over region of frame between input stations. Enter terminal station number for each region. The last station input must be the End Station No. for the frame.

4. Nondimensional thrust-moment values. A minimum of two cards is required for a new Table 7. See Figure 30 for typical nondimensional interaction diagram.





Remarks: The frame is assumed to collapse when the horizontal or vertical deflection, the total shear on the cross section or a combination of axial thrust and bending moment at any station exceeds the limits specified in Table 7.

The uniform level of strain corresponding to P-ultimate is used to compute the location of the plastic centroid in order to compare computed thrusts and moments with values on the interaction diagram for each station.

END OF RUN

One blank card is required at the end of the data.

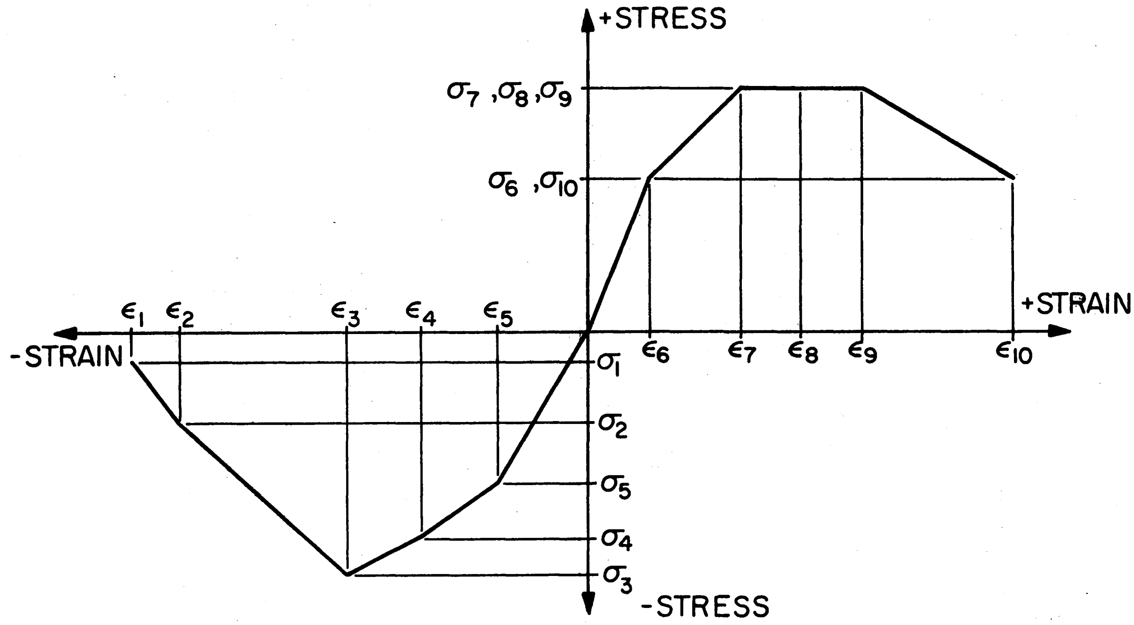


Figure 29. Typical Stress-Strain Curve

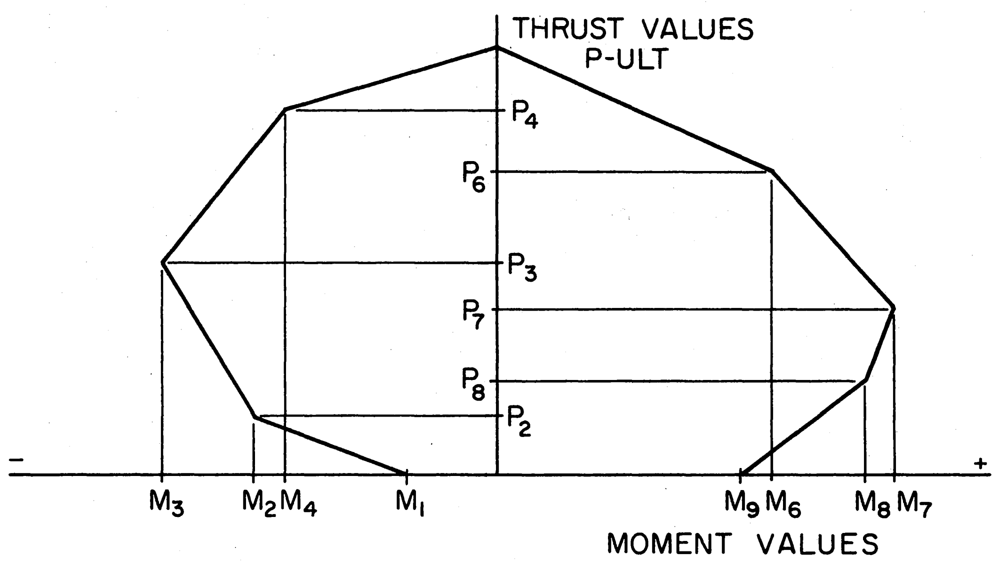


Figure 30. Typical Nondimensional Interaction Diagram

APPENDIX C

FORTRAN LISTING OF COMPUTER PROGRAM

```
      PROGRAM ZPOLE(INPUT,OUTPUT)
C-----MAIN PROGRAM FOR IMPFM
C
C
C
      COMMON /ID/ ID1(40), ID2(19), NPROB
      COMMON /CONT/ TLIM, DTIME, IDOPT, ISOPT, ISTAT, KEEP(7), NDL, NOUT
     0COMMON /XSECTN/ XN(10), YN(10), BN(10), DN(10), ATN(10), DTN(10),
     1                ABN(10), DBN(10), JSN(10), JSNB(10), MATN(10),
     2                NCT2A, NCT2B, NSNS, IENDN
      COMMON /CURVES/ EPSMUL(5), EPSN(10,5), SIGMUL(5), SIGN(10,5),NSSC
     0COMMON /BEAMN/ BMASSN(10),           SXN(10), SYN(10),ISC (10),
     1               JI4(10), JL4(10), KONT4(10), NCT4
      COMMON /LOADN/ QN(10,2), JI5(10), JL5(10), KONT5(10), NCT5
     0COMMON /IMPN/ QI1N(20), QI2N(20), QI3N(20), IPCODN(20), JI6(20),
     1              JM6(20), JL6(20), NCS(20), NSETS
     0COMMON /XSECT/ B(105), D(105), AT(105), DT(105), AB(105), DB(105),
     1               CG(105), AE(105), EI(105), MAT(105)
     0COMMON /BEAM/ X(105), Y(105), XYL(105), SX(105), SY(105), HI(105),
     1              BMASS(105), DPC(105), U(105), V(105), UD(105),
     2              VD(105), Q(105,2), QI(105,2), NJT
      COMMON /FORCEN/ BM(105), T(105)
      DATA ITEST / 4H    /, NO / 3H NO /, ZERO / 0.0E00 /
 1000 FORMAT ( 1H1 )
C-----READ AND ECHO INPUT INFORMATION
  100 CALL INECHO
C-----DISTRIBUTE INPUT DATA TO BEAM/COLUMN STATIONS
      CALL DIST
C-----SOLVE FOR STATIC EFFECTS IF REQUIRED
         IF ( ISTAT .EQ. NO ) GO TO 110
      CALL STATIC
      PRINT 1000
            TIME = ZERO
C-----PRINT STATIC RESULTS
      CALL OUTPUT ( ISOPT, TIME, T, BM, X, Y, XYL, U, V, NJT )
C-----SOLVE FOR DYNAMIC EFFECTS
         IF ( NDL .EQ. 0 ) GO TO 100
  110 PRINT 1000
      CALL DYNAM
C-----RETURN FOR NEW PROBLEM
         IF ( NPROB .NE. ITEST ) GO TO 100
      STOP
      END
```

```
      SUBROUTINE INECHO
C
C-----READ AND ECHO INPUT DATA FOR IMPFM
C
C
      COMMON /ID/ ID1(40), ID2(19), NPROB
      COMMON /CONT/ TLIM, DTIME, IDOPT, ISOPT, ISTAT, KEEP(7), NDL, NOUT
     0COMMON /XSECTN/ XN(10), YN(10), BN(10), DN(10), ATN(10), DTN(10),
     1                ABN(10), DBN(10), JSN(10), JSNB(10), MATN(10),
     2                NCT2A, NCT2B, NSNS, IENDN
      COMMON /CURVES/ EPSMUL(5), EPSN(10,5), SIGMUL(5), SIGN(10,5),NSSC
     0COMMON /BEAMN/ BMASSN(10),           SXN(10), SYN(10),ISC (10),
     1               JI4(10), JL4(10), KONT4(10), NCT4
      COMMON /LOADN/ QN(10,2), JI5(10), JL5(10), KONT5(10), NCT5
     0COMMON /IMPN/ QI1N(20), QI2N(20), QI3N(20), IPCODN(20), JI6(20),
     1              JM6(20), JL6(20), NCS(20), NSETS
     0COMMON /XSECT/ B(105), D(105), AT(105), DT(105), AB(105), DB(105),
     1               CG(105), AE(105), EI(105), MAT(105)
     0COMMON /BEAM/ X(105), Y(105), XYL(105), SX(105), SY(105), HI(105),
     1              BMASS(105), DPC(105), U(105), V(105), UD(105),
     2              VD(105), Q(105,2), QI(105,2), NJT
     0COMMON / FAILN/ UMAX, VMAX, SMAXN(10), PMULN(10), BMULN(10),
     1       SMAX(105), PMUL(105), BMUL(105), PIAN(9), BIAN(9), EPSU,
     2       JS7N(10), NST7, JIA7(10), NIA7
      COMMON /FORCEN/ BM(105), T(105)
      DIMENSION II(7)
      DATA IEND, ITEST, IYES, KEEPI / 3HEND, 4H    , 3HYES, 4HKEEP /
      DATA NEW, KNEW / 4H NEW, 4H NEW /, ZERO / 0.0E00 /
C
 1000 FORMAT ( 20A4 )
 1010 FORMAT ( 5X, 6(A4, 1X), 5X, A3, I2,      I3,I2,3X,I2,5X,2E10.3 )
 1015 FORMAT ( 5X, I5, 2(5X, E10.3), 4X, I1, 20X, A3 )
 1020 FORMAT ( 5X, I5, E10.3, 10X, 3E10.3, 5X, A3 )
 1030 FORMAT ( 5X, I5, 2X, I3, 6E10.3, 2X, A3 )
 1040 FORMAT ( 5X, I5, 5X, 4E10.3 )
 1050 FORMAT ( 10X, E10.3, 10X, 10F5.0 )
 1060 FORMAT ( 5X, 3I5, 10X, E10.3, 10X, 2E10.3, 3X, A2 )
 1070 FORMAT ( 5X, 3I5, 10X, 4E10.3 )
 1080 FORMAT (10X, 4E10.3 )
 1090 FORMAT ( 3( 5X, I5, E10.3 ), 3X, I1, 3X, A3 )
20000FORMAT (     1H1, //,
    1           47H     PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION
    2           28H OF COLLAPSE OF PLANE FRAMES
    3   /       51H                         UNDER STATIC OR IMPULSE LOADS
    4   ///, 2( 5X, 20A4, / ) )
 2010 FORMAT ( / 13H      PROBLEM , A4, //, 10X, 19A4 )
20200FORMAT (///35H      TABLE 1. PROGRAM CONTROL DATA
    1 //        35H           RETAIN PRIOR DATA TABLES , 6( I1, 2H , ) )
 2030 FORMAT (   35H           STATIC SOLUTION REQUIRED , 5X, A5 )
 2040 FORMAT (   35H           STATIC OUTPUT OPTION     , 9X, I1 )
20500FORMAT (    36H           NUMBER OF DYNAMIC LOADINGS, 6X, I3,
    1   /       35H           DYNAMIC OUTPUT OPTION    , 9X, I1,
    2   /       35H           OUTPUT INTERVAL          , 8X, I2,
    3   /       35H           TIME LIMIT               ,   E10.3 )
20600FORMAT (///50H      TABLE 2. JOINT COORDINATES AND CROSS SECTION
    1           11HDESCRIPTION )
 2070 FORMAT ( / 45H           USING DATA FROM PREVIOUS PROBLEM   /  )
20800FORMAT (///40H         A.JOINT COORDINATES AND MATERIAL ,
    1 //        51H               JT.NO.        X-COORD         Y-COORD
    2           17H          MATERIAL /)
 2090 FORMAT (16X, I3, 7X,   E10.3, 6X, E10.3, 9X, I3)
21000FORMAT (// 41H         B.CROSS SECTION AND REINFORCEMENT
    1           12H DESCRIPTION
    2 //        48H                STA    WIDTH    DEPTH         TOP
    3           35H REINF          BOTTOM REINF    NO.
    4   /       47H                       SECT.    SECT.       AREA
    5           37H    DEPTH       AREA       DEPTH  SEGM.   , // )
 2105 FORMAT ( 14X, I5,   6E10.3, 1X, I3 )
 2120 FORMAT (///35H      TABLE 3. STRESS-STRAIN CURVES      )
21300FORMAT (// 20H          CURVE NO. , I1,
```

```
    1  /         40H               STRESS VALUE SCALE FACTOR,     E12.3,
    2  /         40H               STRAIN VALUE SCA‹- FACTOR,     E12.3 )
2140 FORMAT ( / 30H          STRESS INPUT VALUES    /, 15X, 10F7.3 )
2150 FORMAT (    30H          STRAIN INPUT VALUES , /, 15X, 10F7.3 )
21600FORMAT (///52H       TABLE 4. BEAM/COLUMN MASS AND ELASTIC SUPPORTS
    1  //        52H             FROM  TO  CONT         MASS
    2            35H   HORIZONTAL   VERTICAL   SUPPORT
    3  /         52H             STA  STA  CODE
    4            35H    SUPPORT      SUPPORT      CODE    /)
2170 FORMAT (   9X, 3I5, 4X,   E12.3, 12X,   2E12.3, 5X, A2 )
2180 FORMAT ( / 45H          ADDITIONAL DATA FOR THIS PROBLEM   / )
21900FORMAT (///30H       TABLE 5. STATIC LOADS
    1  //        52H             FROM  TO  CONT      HORIZONTAL   VERTICAL
    2  /         50H             STA  STA  CODE        LOAD        LOAD /)
22000FORMAT (///30H       TABLE 6. IMPULSE LOADING      )
22100FORMAT (// 33H           IMPULSE LOADING NUMBER , I2,
    1  //        46H              INITIAL           INTERMEDIATE
    2            30H         FINAL          LOADING
    3  /         46H             STA   IMPULSE       STA   IMPULSE
    4            30H       STA   IMPULSE     CODE    ,/)
2220 FORMAT ( / 19H                NONE / )
22300FORMAT (///35H       TABLE 1. PROGRAM CONTROL DATA
    1  //        35H           NO KEEP OPTIONS EXERCISED       / )
2240 FORMAT ( 9X, 3I5, 4X,   4E12.3 )
2250 FORMAT (///35H       TABLE 7. COLLAPSE PARAMETERS  )
22600FORMAT (// 30H           DISPLACEMENT LIMITS ,
    1  //        46H               MAX HORIZONTAL      MAX VERTICAL  ,
    2  /         42H                    DEFL                 DEFL  ,
    3  /, 18X,   E12.3, 5X, E12.3)
2270 FORMAT (    35H          TIME INTERVAL             ,   E10.3 )
2280 FORMAT (    46H          TIME INTERVAL              INTERNAL    )
22900FORMAT (// 25H           SHEAR LIMITS    ,
    1  //        35H                     TERM      SHEAR  ,
    2  /         35H                      STA      VALUE,
    3  /, 20X, I5,   E12.3 )
2300 FORMAT ( 20X, I5,   E12.3, 3X, E12.3 )
23100FORMAT (// 35H           INTERACTION DIAGRAM DATA ,
    1  //        30H               MULTIPLIERS     ,
    2  /         52H                     TERM AXIAL FORCE       MOMENT
    3  /         52H                      STA  MULTIPLIER     MULTIPLIER
    4      )
23200FORMAT (// 43H               COMPRESSIVE STRAIN AT P-ULT ,  E12.3,
    1  //        40H               AXIAL FORCE INPUT VALUES ,
    2  /, 20X, 0P9F7.3 )
23300FORMAT (    35H               MOMENT INPUT VALUES ,
    1   /, 20X, 9F7.3 )
 2340 FORMAT ( 9X, I4,   E12.3, 4X, I4, E12.3, 4X, I4, E12.3, 6X, I1)
C
C-----READ AND ECHO RUN AND PROBLEM IDENTIFICATION
C
         IF ( KNEW .NE. NEW ) GO TO 100
     READ 1000, ( ID1(I), I= 1, 40 )
              KNEW = ITEST
  100 READ 1000, NPROB, ( ID2(I), I= 1, 19 )
     PRINT 2000, ( ID1(I), I = 1, 40 )
     PRINT 2010, NPROB, ( ID2(I), I = 1, 19 )
C
C-----TEST FOR END OF RUN
C
         IF ( NPROB .EQ. ITEST ) GO TO 9999
C
C-----READ AND ECHO TABLE 1. PROGRAM CONTROL DATA
C
     0READ 1010, (KEEP(I), I=2,7), ISTAT, ISOPT, NDL, IDOPT, NOUT,
     1            TLIM, DTIME
              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
          IF ( J .GT. 0 ) GO TO 114
      PRINT 2230
          GO TO 116
  114 PRINT 2020, ( II(I), I = 1, J )
  116 PRINT 2030, ISTAT
          IF ( ISTAT .NE. IYES ) GO TO 120
      PRINT 2040, ISOPT
  120     IF ( NDL .EQ. 0 ) GO TO 130
      PRINT 2050, NDL, IDOPT, NOUT, TLIM
          IF ( DTIME .EQ. ZERO) GO TO 122
  123 PRINT 2270, DTIME
          GO TO 125
  122 PRINT 2280
  125     CONTINUE
C
C     READ AND ECHO TABLE 2. JOINT COORDINATES AND CROSS SECTION DATA
C
  130 PRINT 2060
          IF ( KEEP(2) .EQ. KEEPI ) GO TO 150
C
C-----INITILIZE
C
          DO 132 I = 1, 105
               X(I) = ZERO
               Y(I) = ZERO
               XYL(I) = ZERO
               HI(I) = ZERO
               B(I) = ZERO
               D(I) = ZERO
               AT(I) = ZERO
               DT(I) = ZERO
               AB(I) = ZERO
               DB(I) = ZERO
               CG(I) = ZERO
               AE(I) = ZERO
               EI(I) = ZERO
               Q(I,1) = ZERO
               Q(I,2) = ZERO
               QI(I,1) = ZERO
               QI(I,2) = ZERO
               BMASS(I) = ZERO
               SX(I) = ZERO
               SY(I) = ZERO
               T(I) = ZERO
               BM(I) = ZERO
               UD(I) = ZERO
               VD(I) = ZERC
  132 CONTINUE
C
               NCT2A = 1
C
C     READ CONTROL POINT DATA
C
               JN = 4
               X(JN) = ZERO
               Y(JN) = ZERO
          GO TO 140
  135          JN = JSN(NCT2A)
               X(JN) = XN(NCT2A)
               Y(JN) = YN(NCT2A)
C
C     PROGRAM ASSUMES NODE 4 AT 0,0 AND GENERATES FICTITIOUS NODES
C     ONLY NODES WHERE CHANGES IN DIRECTIONS OCCUR NEED BE READ IN
C
C     READ JOINT COORDINATE DATA
C
```

```
  140 READ 1015, JSN(NCT2A), XN(NCT2A), YN(NCT2A), MATN(NCT2A), IENON
C
C-----NJT = NUMBER OF ACTUAL JOINTS(NODES) IN STRUCTURE
C
            NJT = JSN(NCT2A) - 3
        IF ( JSN(NCT2A) .EQ. JN ) GO TO 135
        IF ( IENON .EQ. IENO ) GO TO 160
            NCT2A = NCT2A + 1
        GO TO 140
  150 PRINT 2070
C
C-----ECHO JOINT COORDINATES AND MATERIAL DATA
C
  160 PRINT 2080
        DO 170 I = 1, NCT2A
      PRINT 2090, JSN(I), XN(I), YN(I), MATN(I)
  170 CONTINUE
        IF ( KEEP(2) .EQ. KEEPI ) GO TO 180
C
C     READ CROSS SECTION AND REINFORCEMENT DESCRIPTION
C
            NCT2B = 1
  1480READ 1030, JSNB(NCT2B), NSNS, BN(NCT2B), DN(NCT2B), ATN(NCT2B),
     1          DTN(NCT2B), ABN(NCT2B), DBN(NCT2B), IENON
C
C     FINAL NODE DOES NOT INCLUDE FICTITIOUS NODES AT THAT END
C
        IF ( IENON .EQ. IEND ) GO TO 180
            NCT2B = NCT2B + 1
        GO TO 148
C
C-----ECHO CROSS SECTION DATA
C
  180 PRINT 2180
        DO 190 I = 1, NCT2B
     0PRINT 2105, JSNB(I), BN(I), DN(I), ATN(I), DTN(I), ABN(I), DBN(I),
     1          NSNS
  190   CONTINUE
C
C-----READ AND ECHO TABLE 3. STRESS--STRAIN CURVES
C
      PRINT 2120
        IF ( KEEP(3) .EQ. KEEPI ) GO TO 210
      READ 1020, NSSC
        DO 200 I = 1, NSSC
      READ 1050, SIGMUL(I), ( SIGN(J,I), J = 1, 10 )
      READ 1050, EPSMUL(I), ( EPSN(J,I), J = 1, 10 )
  200   CONTINUE
        GO TO 220
  210 PRINT 2070
  220   DO 230 I = 1, NSSC
      PRINT 2130, I, SIGMUL(I), EPSMUL(I)
      PRINT 2140, ( SIGN(J,I), J = 1,10 )
      PRINT 2150, ( EPSN(J,I), J = 1, 10)
  230   CONTINUE
C
C-----READ AND ECHO TABLE 4. BEAM/COLUMN MASS AND ELASTIC SUPPORTS
C
      PRINT 2160
        IF ( KEEP(4) .NE. KEEPI ) GO TO 240
      PRINT 2070
     0PRINT 2170, (JI4(I), JL4(I), KONT4(I), BMASSN(I),
     1          SXN(I), SYN(I),ISC(I), I = 1, NCT4 )
      PRINT 2180
        IF ( NCT4 .EQ. 1 ) GO TO 234
        IF ( KONT4(NCT4 - 1) .EQ. 1 ) GO TO 236
  234       KONT4 ( NCT4 ) = 3
        GO TO 238
  236       KONT4 ( NCT4 ) = 2
  238   CONTINUE
            NCI4 = NCT4 + 1
      GO TO 250
  240       NCI4 = 1
  250       NCT4 = NCI4
  2600READ 1060, JI4(NCT4), JL4(NCT4), KONT4(NCT4), BMASSN(NCT4),
     1                SXN(NCT4), SYN(NCT4),ISC(NCT4)
        IF ( KONT4(NCT4) .LE. 0 ) GO TO 270
            NCT4 = NCT4 + 1
        GO TO 260
  2700PRINT 2170, ( JI4(I), JL4(I), KONT4(I), BMASSN(I),
     1          SXN(I), SYN(I), ISC(I), I = NCI4, NCT4 )
C
C-----READ AND ECHO TABLE 5. STATIC LOADS
C
      PRINT 2190
        IF ( KEEP(5) .NE. KEEPI ) GO TO 280
      PRINT 2070
        DO 275 I = 1, NCT5
      PRINT 2240, JI5(I), JL5(I), KONT5(I), QN(I,1), QN(I,2)
  275   CONTINUE
      PRINT 2180
        IF ( NCT5 .EQ. 1 ) GO TO 276
        IF ( KONT5(NCT5 - 1) .EQ. 1 ) GO TO 277
  276       KONT5 ( NCT5 ) = 3
        GO TO 278
  277       KONT5 ( NCT5 ) = 2
  278   CONTINUE
            NCI5 = NCT5 + 1
        GO TO 290
  280       NCI5 = 1
  290       NCT5 = NCI5
  3000READ 1070, JI5(NCT5), JL5(NCT5), KONT5(NCT5), QN(NCT5,1),
     1          QN(NCT5,2)
        IF ( KONT5(NCT5) .LE. 0 ) GO TO 310
            NCT5 = NCT5 + 1
        GO TO 300
  310   DO 315 I = NCI5, NCT5
      PRINT 2240, JI5(I), JL5(I), KONT5(I), QN(I,1), QN(I,2)
  315   CONTINUE
C
C-----READ AND ECHO TABLE 6. IMPULSE LOADING
C
      PRINT 2200
        IF ( KEEP(6) .EQ. KEEPI ) GO TO 320
            NSETS = 0
            NSI = 1
            NCL = 0
        GO TO 350
  320 PRINT 2070
            NCL = 0
        DO 330 I = 1, NSETS
            NCI = NCL + 1
            NCL = NCL + NCS(I)
      PRINT 2210, I
     0PRINT 2340, ( JI6(N), QI1N(N), JM6(N), QI2N(N), JL6(N), QI3N(N),
     1          IPCODN(N), N = NCI, NCL )
  330   CONTINUE
  340   IF ( NDL .EQ. 0 ) GO TO 400
      PRINT 2180
  350   IF ( NDL .EQ. 0 ) GO TO 400
            NSI = NSETS + 1
            NSETS = NSETS + NDL
            NS = NSI
            N = NCL
  360       NCS(NS) = 0
  370       N = N + 1
     0READ 1090, JI6(N), QI1N(N), JM6(N), QI2N(N), JL6(N), QI3N(N),
     1          IPCODN(N), KODE
            NCS(NS) = NCS(NS) + 1
        IF ( KODE .NE. IEND ) GO TO 370
```

```
      IF ( NS .EQ. NSETS ) GO TO 380
           NS = NS + 1
      GO TO 360
380        NCL = 0
      DO 390 I = NSI, NSETS
           NCI = NCL + 1
           NCL = NCL + NCS(I)
  PRINT 2210, I
      DO 388 N = NCI, NCL
 0PRINT 2340,    JI6(N), QI1N(N), JM6(N), QI2N(N), JL6(N), QI3N(N),
1            IPCODN(N)
388   CONTINUE
390   CONTINUE
      GO TO 410
400 PRINT 2220
410   CONTINUE
C
C     READ AND ECHO TABLE 7. COLLAPSE PARAMETERS
C
    PRINT 2250
      IF ( NSETS .EQ. 0 ) GO TO 460
411   IF ( KEEP(7) .NE. KEEPI ) GO TO 412
    PRINT 2070
      GO TO 430
412 READ 1080, UMAX, VMAX
         NST7 = 1
414 READ 1040, JS7N(NST7),SMAXN(NST7)
      IF (JS7N(NST7) .EQ. NJT+3) GO TO 416
         NST7 = NST7 + 1
      GO TO 414
416   NIA7 = 1
418 READ 1040, JIA7(NIA7), PMULN(NIA7), BMULN(NIA7)
      IF (JIA7(NIA7) .EQ. NJT+3) GO TO 420
         NIA7 = NIA7 + 1
      GO TO 418
420 READ 1050, EPSU, ( PIAN(I), I = 1,9 )
    READ 1050, DUM,  ( BIAN(I), I = 1,9 )
430 PRINT 2260, UMAX, VMAX
    PRINT 2290
      DO 440 I = 1, NST7
    PRINT 2300, JS7N(I), SMAXN(I)
440   CONTINUE
    PRINT 2310
      DO 450 I = 1, NIA7
    PRINT 2300, JIA7(I), PMULN(I), BMULN(I)
450   CONTINUE
    PRINT 2320, EPSU, ( PIAN(I), I = 1, 9 )
    PRINT 2330,       ( BIAN(I), I = 1, 9 )
          EPSU = -  ABS(EPSU)
      GO TO 470
460 PRINT 2220
470   CONTINUE
C
    RETURN
9999 CONTINUE
    STOP
    END
```

```
      SUBROUTINE DIST
C
C-----DISTRIBUTE INPUT DATA FOR IMPFM
C
C
      COMMON /ID/ ID1(40), ID2(19), NPROB
      COMMON /CONT/ TLIM, DTIME, IDOPT, ISOPT, ISTAT, KEEP(7), NDL, NOUT
     0COMMON /XSECTN/ XN(10), YN(10), BN(10), DN(10), ATN(10), DTN(10),
     1               ABN(10), DBN(10), JSN(10), JSNB(10), MATN(10),
     2               NCT2A, NCT2B, NSNS, IENDN
      COMMON /CURVES/ EPSMUL(5), EPSN(10,5), SIGMUL(5), SIGN(10,5),NSSC
     0COMMON /BEAMN/ BMASSN(10),        SXN(10), SYN(10),ISC (10),
     1               JI4(10), JL4(10), KONT4(10), NCT4
      COMMON /LOADN/ QN(10,2), JI5(10), JL5(10), KONT5(10), NCT5
     0COMMON /IMPN/ QI1N(20), QI2N(20), QI3N(20), IPCODN(20), JI6(20),
     1              JM6(20), JL6(20), NCS(20), NSETS
     0COMMON /XSECT/ B(105), D(105), AT(105), DT(105), AB(105), DB(105),
     1               CG(105), AE(105), EI(105), MAT(105)
     0COMMON /BEAM/ X(105), Y(105), XYL(105), SX(105), SY(105), HI(105),
     1              BMASS(105), DPC(105), U(105), V(105), UD(105),
     2              VD(105), Q(105,2), QI(105,2), NJT
     0COMMON / FAILN/ UMAX, VMAX, SMAXN(10), PMULN(10), BMULN(10),
     1         SMAX(105), PMUL(105), BMUL(105), PIAN(9), BIAN(9), EPSU,
     2         JS7N(10), NST7, JIA7(10), NIA7
     0DIMENSION DUM(10), DUM2(10), DUM3(5,2), DUM5(30), DUM6(30)
      DATA  ZERO / 0.0E00 /, NO / 3H NO /
C
C-----CALCULATE JOINT COORDINATES FOR EACH STATION
C
              NJP2 = NJT + 2
              NJP3 = NJT + 3
              NJP4 = NJT + 4
              NJP5 = NJT + 5
              NJP6 = NJT + 6
              NCT2A = 1
              JN = 4
  100         NSTOP = JSN(NCT2A) - JN
              DX = (XN(NCT2A) - X(JN)) / NSTOP
              DY = (YN(NCT2A) - Y(JN)) / NSTOP
              ISTART = JN + 1
              ISTOP = JSN(NCT2A)
         DO 110 I = ISTART, ISTOP
              X(I) = X(I - 1) + DX
              Y(I) = Y(I - 1) + DY
  110 CONTINUE
              JN = JSN(NCT2A)
              NCT2A = NCT2A + 1
         IF (JN .NE. NJT + 3) GO TO 100
              X(3) = -X(5)
              X(2) = X(3) - X(5)
              X(1) = X(2) + X(3)
              Y(3) = -Y(5)
              Y(2) = Y(3) - Y(5)
              Y(1) = Y(2) + Y(3)
              DX = X(JN) - X(JN-1)
              DY = Y(JN) - Y(JN-1)
              X(JN+1) = X(JN) + DX
              X(JN+2) = X(JN+1) + DX
              X(JN+3) = X(JN+2) + DX
              Y(JN+1) = Y(JN) + DY
              Y(JN+2) = Y(JN+1) + DY
              Y(JN+3) = Y(JN+2) + DY
  115 CONTINUE
C
C-----DISTRIBUTE MATERIAL DATA
C
         DO 118 I = 4, NJP3
              MAT(I) = MATN(1)
  118 CONTINUE
C
```

```
C-----SET UP CROSS SECTION DATA FOR EACH STATION
C
      CALL INTRP1 ( JSN8, BN, B, NCT28 )
      CALL INTRP1 ( JSN8, DN, D, NCT28 )
      CALL INTRP1 ( JSN8, ATN, AT, NCT28 )
      CALL INTRP1 ( JSN8, DTN, DT, NCT28 )
      CALL INTRP1 ( JSN8, ABN, AB, NCT28 )
      CALL INTRP1 ( JSN8, DBN, DB, NCT28 )
C
C-----DISTRIBUTE BEAM/COLUMN STATIC LOAD DATA
C
C-----DETERMINE LENGTH OF MEMBERS FOR MASS CALCULATION
C
          DO 125 I = 2, NJP6
               XL = X(I) - X(I-1)
               YL = Y(I) - Y(I-1)
               XYL(I) =  SQRT((XL * XL) + (YL * YL))
               HI(I) = XYL(I)
  125 CONTINUE
C
C-----DETERMINE COORDINATES AT NODES ALONG FRAME MEMBERS
C
               XYL(1) = ZERO
          DO 126 I = 1, NJP5
               XYL(I+1) = XYL(I+1) + XYL(I)
  126 CONTINUE
      CALL INTRP2 (JI4, JL4, KONT4, BMASSN, BMASS, XYL, NCT4)
      CALL INTRP2 (JI4, JL4, KONT4, SXN, SX, Y, NCT4)
      CALL INTRP2 (JI4, JL4, KONT4, SYN, SY, X, NCT4)
          IF ( ISTAT .EQ. NO ) GO TO 128
      CALL INTRP2 (JI5, JL5, KONT5, QN(1,1), Q(1,1), Y, NCT5)
      CALL INTRP2 (JI5, JL5, KONT5, QN(1,2), Q(1,2), X, NCT5)
C
C-----CALCULATE CG OF EACH CROSS SECTION
C
C-----CALCULATE INITIAL MODULI
C
  128     DO 130 I = 1, NSSC
               DUM3(I,1)=SIGMUL(I)* SIGN(5,I) / ( EPSMUL(I) * EPSN(5,I))
               DUM3(I,2)=SIGMUL(I)* SIGN(6,I) / ( EPSMUL(I) * EPSN(6,I))
  130     CONTINUE
               EC1 = DUM3(1,1)
               EC2 = DUM3(1,2)
               ES1 = DUM3(NSSC, 1)
               ES2 = DUM3(NSSC, 2)
          DO 150 I = 4, NJP3
     0CALL CENTER ( B(I), D(I), AT(I), DT(I), AB(I), DB(I), EC1, ES1,
     1                  ES2, CG(I), AE(I), EI(I) )
  150     CONTINUE
C
C-----DISTRIBUTE FAILURE PARAMETERS
C
          IF ( NSETS .EQ. 0 ) GO TO 250
          IF ( NST7 .GT. 1 ) GO TO 170
          DO 160 I = 1, NJP6
               SMAX(I) = SMAXN(1)
  160     CONTINUE
          GO TO 180
  170 CALL INTRP1 ( JS7N, SMAXN, SMAX, NST7 )
  180     IF ( NIA7 .GT. 1 ) GO TO 200
          DO 190 I = 1, NJP6
               BMUL(I) = BMULN(1)
               PMUL(I) = PMULN(1)
  190     CONTINUE
          GO TO 210
  200 CALL INTRP1 ( JIA7, PMULN, PMUL, NIA7 )
      CALL INTRP1 ( JIA7, BMULN, BMUL, NIA7 )
  210     CONTINUE
C
C---------CALCULATE LOCATION OF PLASTIC CENTROID AT EACH CROSS SECTION
C
          DO 240 J = 5, NJP2
          DO 220 I = 1, 30
               DUM5(I) = ZERO
               DUM6(I) = ZERO
  220          CONTINUE
               PEPSA = ZERO
               PPHI = ZERO
               PHI = ZERO
               EPSOT = ZERO
               EPSOB = ZERO
               TEORT = ZERO
               TEORB = ZERO
      CALL IFORCE (PEPSA, PPHI, DUM5, BM, T, EPSU, PHI, D(J), AT(J),
     1             DT(J), AB(J), DB(J), B(J), CG(J), NSNS, EPSMUL, EPSN,
     2             SIGMUL, SIGN, NSSC, MAT, EPSOT, EPSOB, DUM6, TEORT,
     3             TEORB)
               DPC(J) = CG(J) + BM / T
  240     CONTINUE
               DPC(4) = CG(4)
               DPC(NJP3) = CG(NJP3)
  250     CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE INTRP1 ( JS, ZN, Z, NC )
C
C-----LINEAR INTERPOLATION ROUTINE
C
C
      DIMENSION JS(10), ZN(10), Z(105)
      DATA ZERO / 0.0E00 /
          DO 100 I = 1, 105
               Z(I) = ZERO
  100     CONTINUE
               Z(4) = ZN(1)
          DO 200 N = 2, NC
               NEL = JS(N) - JS(N-1)
               DENOM = NEL
               DELZ = ( ZN(N) - ZN(N-1) ) / DENOM
               ISTRT = JS(N-1) + 1
               ISTOP = JS(N)
          DO 200 I = ISTRT, ISTOP
               Z(I) = Z(I-1) + DELZ
  200     CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE INTRP2  ( JI, JL, KONT, ZN, Z, X, NC )
C
C-----LINEAR INTERPOLATION ROUTINE
C
C
      DIMENSION JI(10), JL(10), KONT(10), ZN(10), Z(105), X(105)
      DATA ZERO, TWO, SIX / 0.0E00, 2.0E00, 6.0E00 /
          DO 100 I = 1,105
               Z(I) = ZERO
  100     CONTINUE
               IS = 0
               I = 1
  110          K = KONT(I) + 1
          GO TO ( 120, 160, 145, 190 ), K
  120     IF ( IS .NE. 0 ) GO TO 230
           IF ( JL(I) .NE. JI(I) ) GO TO 200
  130          J = JI(I)
               Z(J) = Z(J) + ZN(I)
  140     IF ( K .EQ. 1 ) GO TO 230
          GO TO 150
  145          IS = 0
  150          I = I + 1
          GO TO 110
  160     IF ( IS.EQ. 0 ) GO TO 170
               JSTRT = JL(I)
          GO TO 180
  170          JSTRT = JI(I)
               IS = 1
  180          JSTOP = JL(I+1)
               ZL = ZN(I)
               ZR = ZN(I+1)
          GO TO 210
  190     IF ( JL(I) .EQ. JI(I) ) GO TO 130
  200          JSTRT = JI(I)
               JSTOP = JL(I)
               ZL = ZN(I)
               ZR = ZN(I)
  210          DENOM = X(JSTOP) - X(JSTRT)
          IF ( DENOM .EQ. ZERO ) GO TO 215
               DZ = ( ZR - ZL ) / DENOM
          GO TO 218
  215          DZ = ZERO
C
  218          JSTOP = JSTOP - 1
          DO 220 J = JSTRT, JSTOP
               H = X(J+1) - X(J)
               ZR = ZL + H * DZ
               Z(J) = Z(J) + H * ( TWO * ZL + ZR ) / SIX
               Z(J+1) = Z(J+1) + H * ( ZL + TWO * ZR ) / SIX
               ZL = ZR
  220     CONTINUE
          IF ( K .NE. 1 ) GO TO 150
  230     CONTINUE
C
      RETURN
      END
```

```
      0SUBROUTINE CENTER ( B, D, AT, DT, AB, DB, EC1, ES1, ES2, DBAR, A,
      1                   SM)
C
       DATA  ZERO, P5, ONE, TWO / 0.0E00, 0.5E00, 1.0E00, 2.0E00 /
               RN = ES2 / EC1
               BD = B * D
               P = AB / BD
               PP = AT / BD
               RNP = RN * P
               TEMP1 = RNP + (( TWO * RN - ONE ) * PP )
C
C-----WITH NO BOTTOM STEEL SECTION MUST BE SYMMETRIC AS CG TAKEN AT D/2
C
          IF ( AB .EQ. ZERO ) GO TO 100
     0         RATIOK = - TEMP1 +  SQRT (( TEMP1 * TEMP1 ) + TWO * ( RNP
     1                + (( TWO * RN - ONE ) * PP ) * ( DT / DB )))
               DBAR = RATIOK * DB
          GO TO 110
  100          DBAR = P5 * D
C
C-----CALCULATE AXIAL AND FLEXURAL STIFFNESS AT EACH SECTION
C
  110          T = ZERO
               A = ZERO
               C = ZERO
               SM = ZERO
          IF (DT .GT. DBAR) GO TO 221
               DAE = AT * ES1
               DEP = DBAR - DT
               C = C + DAE * DEP / DBAR
               A = A + DAE
               SM = SM + C * DEP * DBAR
          GO TO 222
  221          DAE = AT * ES2
               DEP = DT - DBAR
               DET = DAE * DEP / DBAR
               T = T + DET
               A = A + DAE
               SM = SM + DET * DEP * DBAR
  222          DAE = AB * ES2
               DEP = DB - DBAR
               DET = DAE * DEP / DBAR
               T = T + DET
               A = A + DAE
               SM = SM + DET * DEP * DBAR
               DAE = DBAR * B * EC1
               DEP = DBAR / TWO
               DC = DAE / TWO
               C = C + DC
               SM = SM + DC * DEP * DBAR
               A = A + DAE
C
       RETURN
       END
```

```
      SUBROUTINE STATIC
C     MACK RIDDLE
C
      COMMON /ID/ ID1(40), ID2(19), NPROB
     0COMMON /XSECT/BB(105), D(105), AT(105), DT(105), AB(105), DB(105),
     1           CG(105), AE(105), EI(105), MAT(105)
     0COMMON /BEAM/ X(105), Y(105), XYL(105), SX(105), SY(105), HI(105),
     1          BMASS(105), DPC(105), U(105,2) , UD(105),
     2          VD(105), Q(105,2), QI(105,2), NJT
      COMMON /FORCEN/ BM(105), T(105)
      DIMENSION A(105,2), B(105,2,2), C(105,2,2)
      DATA  ZERO, ONE, TWO / 0.0E00, 1.0E00, 2.0E00 /
      DATA  P5 / 0.5E 00 /
C
C     NJT = NUMBER OF JOINTS IN FRAME(DOES NOT INCLUDE FICTITIOUS NODES)
C
C     INITILIZE
C
              NJP6 = NJT + 6
          DO 240 I = 1, NJP6
              U(I,1) = ZERO
              U(I,2) = ZERO
              A(I,1) = ZERO
              A(I,2) = ZERO
              B(I,1,1) = ZERO
              B(I,1,2) = ZERO
              B(I,2,1) = ZERO
              B(I,2,2) = ZERO
              C(I,1,1) = ZERO
              C(I,1,2) = ZERO
              C(I,2,1) = ZERO
              C(I,2,2) = ZERO
  240 CONTINUE
C
C     START OF SOLUTION FOR STATIC LOADS
C
C     CALCULATE DISPLACEMENTS DUE TO STATIC LOADS
C
              NJP4 = NJT + 4
          DO 250 I = 3, NJP4
C     COMPUTE LENGTHS, TRIG FUNCTIONS AND CONSTANTS AT EACH STATION
              DXIM1 = X(I-1) - X(I-2)
              DYIM1 = Y(I-1) - Y(I-2)
              HIM1 =  SQRT((DXIM1 * DXIM1) + (DYIM1 * DYIM1))
              STHIM1 = DYIM1 / HIM1
              CTHIM1 = DXIM1 / HIM1
              DXI = X(I) - X(I-1)
              DYI = Y(I) - Y(I-1)
              HI(I) =  SQRT( (DXI * DXI) + (DYI * DYI) )
              HISQ = HI(I) * HI(I)
              STHI = DYI / HI(I)
              STHISQ = STHI * STHI
              CTHI = DXI / HI(I)
              CTHISQ = CTHI * CTHI
              DXIP1 = X(I+1) - X(I)
              DYIP1 = Y(I+1) - Y(I)
              HIP1 =  SQRT((DXIP1 * DXIP1) + (DYIP1 * DYIP1))
              HIP1SQ = HIP1 * HIP1
              STHIP1 = DYIP1 / HIP1
              SIP1SQ = STHIP1 * STHIP1
              CTHIP1 = DXIP1 / HIP1
              CIP1SQ = CTHIP1 * CTHIP1
              DXIP2 = X(I+2) - X(I+1)
              DYIP2 = Y(I+2) - Y(I+1)
              HIP2 =  SQRT((DXIP2 * DXIP2) + (DYIP2 * DYIP2))
              STHIP2 = DYIP2 / HIP2
              CTHIP2 = DXIP2 / HIP2
              CON1 = (TWO * EI(I-1)) / (HI(I) * HIM1 * (HIM1 + HI(I)))
              CON2 = (TWO * EI(I-1)) / (HISQ * (HIM1 + HI(I)))
              CON3 = (TWO * EI(I)) / (HISQ * (HI(I) + HIP1))
              CON4 = (TWO * EI(I)) / (HI(I) * HIP1 * (HI(I) + HIP1))
              CON5 = (AE(I-1) + AE(I)) / (TWO * HI(I))
              CON6 = (TWO * EI(I)) / (HIP1SQ * (HI(I) + HIP1))
              CON7 = (TWO * EI(I+1)) / (HIP1SQ * (HIP1 + HIP2))
              CON8 = (AE(I) + AE(I+1)) / (TWO * HIP1)
              CON9 = (TWO * EI(I+1)) / (HIP1 * HIP2 * (HIP1 + HIP2))
C
C     COMPUTE MATRIX COEFFICIENTS AT EACH STATION
C
              AA11 =-CON1 * STHI * STHIM1
              AA12 = +CON1 * STHI * CTHIM1
              AA21 = +CON1 * CTHI * STHIM1
              AA22 =-CON1 * CTHI * CTHIM1
     0        BB11 = +CON1 * STHI * STHIM1 + (CON2 + CON3) * STHISQ
     1             + CON4 * STHIP1 * STHI + CON5 * CTHISQ
     0        BB12 =-CON1 * STHI * CTHIM1 - (CON2 + CON3) * STHI * CTHI
     1             - CON4 * STHIP1 * CTHI + CON5 * CTHI * STHI
     0        BB21 =-CON1 * CTHI * STHIM1 - (CON2 + CON3) * CTHI * STHI
     1             - CON4 * CTHIP1 * STHI + CON5 * STHI * CTHI
     0        BB22 = +CON1 * CTHI * CTHIM1 + (CON2 + CON3) * CTHISQ
     1             + CON4 * CTHIP1 * CTHI + CON5 * STHISQ
     0        CC11 =-(CON2 + CON3) * STHISQ - TWO *CON4 * STHI * STHIP1
     1             - (CON6 + CON7) * SIP1SQ - CON5 * CTHISQ
     2             - CON8 * CIP1SQ - SX(I)
     0        CC12 = +(CON2 + CON3) * STHI *CTHI + CON4 * STHI * CTHIP1
     1             + CON4 * STHIP1 * CTHI + (CON6 + CON7)*STHIP1*CTHIP1
     2             - CON5 * CTHI * STHI - CON8 * CTHIP1 * STHIP1
              CC21 = CC12
     0        CC22 =-(CON2 + CON3) * CTHISQ - TWO *CON4 * CTHI * CTHIP1
     1             - (CON6 + CON7) * CIP1SQ - CON5 * STHISQ
     2             - CON8 * SIP1SQ - SY(I)
     0        DD11 = +CON4 * STHI * STHIP1 + (CON6 + CON7) * SIP1SQ
     1             + CON9 * STHIP1 * STHIP2 + CON8 * CIP1SQ
     0        DD12 =-CON4 * STHI * CTHIP1 - (CON6 + CON7)*STHIP1*CTHIP1
     1             - CON9 * STHIP1 * CTHIP2 + CON8 * CTHIP1 * STHIP1
     0        DD21 =-CON4 * CTHI * STHIP1 - (CON6 + CON7)*CTHIP1*STHIP1
     1             - CON9 * CTHIP1 * STHIP2 + CON8 * STHIP1 * CTHIP1
     0        DD22 = +CON4 * CTHI * CTHIP1 + (CON6 + CON7) * CIP1SQ
     1             + CON9 * CTHIP1 * CTHIP2 + CON8 * SIP1SQ
              EE11 =-CON9 * STHIP1 * STHIP2
              EE12 = +CON9 * STHIP1 * CTHIP2
              EE21 = +CON9 * CTHIP1 * STHIP2
              EE22 =-CON9 * CTHIP1 * CTHIP2
C
C     COMPUTE CONTINUITY COEFFICIENTS AT EACH STATION
C
C     CALCULATING RHO
C
              RO11 = (AA11 * B(I-2,1,1) + AA12 * B(I-2,2,1)) + BB11
              RO12 = (AA11 * B(I-2,1,2) + AA12 * B(I-2,2,2)) + BB12
              RO21 = (AA21 * B(I-2,1,1) + AA22 * B(I-2,2,1)) + BB21
              RO22 = (AA21 * B(I-2,1,2) + AA22 * B(I-2,2,2)) + BB22
C
C     CALCULATING DELTA
C
     0        FF11 = (RO11 * B(I-1,1,1) + RO12 * B(I-1,2,1))
     1             + (AA11 * C(I-2,1,1) + AA12 * C(I-2,2,1)) + CC11
     0        FF12 = (RO11 * B(I-1,1,2) + RO12 * B(I-1,2,2))
     1             + (AA11 * C(I-2,1,2) + AA12 * C(I-2,2,2)) + CC12
     0        FF21 = (RO21 * B(I-1,1,1) + RO22 * B(I-1,2,1))
     1             + (AA21 * C(I-2,1,1) + AA22 * C(I-2,2,1)) + CC21
     0        FF22 = (RO21 * B(I-1,1,2) + RO22 * B(I-1,2,2))
     1             + (AA21 * C(I-2,1,2) + AA22 * C(I-2,2,2)) + CC22
C
C     INVERTING DELTA AND NEGATING
C
              DENOM = (FF11 * FF22 - FF12 * FF21)
  300         DENOM = -ONE / DENOM
  320         TEMP = FF11
              FF11 = FF22 * DENOM
```

```
            FF22 = TEMP * DENOM
            FF12 = -FF12 * DENOM
            FF21 = -FF21 *DENOM
C
C     COMPUTING CONTINUITY COEFFICIENTS
C
     0      A(I,1) = FF11 * ((AA11 * A(I-2,1)) + (AA12 * A(I-2,2))
     1             + (RO11 * A(I-1,1)) + (RO12 * A(I-1,2)) + Q(I,1))
     2             + FF12 * ((AA21 * A(I-2,1)) + (AA22 * A(I-2,2))
     3             + (RO21 * A(I-1,1)) + (RO22 * A(I-1,2)) + Q(I,2))
     0      A(I,2) = FF21 * ((AA11 * A(I-2,1)) + (AA12 * A(I-2,2))
     1             + (RO11 * A(I-1,1)) + (RO12 * A(I-1,2)) + Q(I,1))
     2             + FF22 * ((AA21 * A(I-2,1)) + (AA22 * A(I-2,2))
     3             + (RO21 * A(I-1,1)) + (RO22 * A(I-1,2)) + Q(I,2))
     0      B(I,1,1) = FF11 * ((RO11 * C(I-1,1,1)) + (RO12
     1             * C(I-1,2,1)) + DD11)
     2             + FF12 * ((RO21 * C(I-1,1,1)) + (RO22
     3             * C(I-1,2,1)) + DD21)
     0      B(I,1,2) = FF11 * ((RO11 * C(I-1,1,2)) + (RO12
     1             * C(I-1,2,2)) + DD12)
     2             + FF12 * ((RO21 * C(I-1,1,2)) + (RO22
     3             * C(I-1,2,2)) + DD22)
     0      B(I,2,1) = FF21 * ((RO11 * C(I-1,1,1)) + (RO12
     1             * C(I-1,2,1)) + DD11)
     2             + FF22 * ((RO21 * C(I-1,1,1)) + (RO22
     3             * C(I-1,2,1)) + DD21)
     0      B(I,2,2) = FF21 * ((RO11 * C(I-1,1,2)) + (RO12
     1             * C(I-1,2,2)) + DD12)
     2             + FF22 * ((RO21 * C(I-1,1,2)) + (RO22
     3             * C(I-1,2,2)) + DD22)
            C(I,1,1) = (FF11 * EE11) + (FF12 * EE21)
            C(I,1,2) = (FF11 * EE12) + (FF12 * EE22)
            C(I,2,1) = (FF21 * EE11) + (FF22 * EE21)
            C(I,2,2) = (FF21 * EE12) + (FF22 * EE22)
  250 CONTINUE
C
C     BACK SUBSTITUTE FOR DEFLECTIONS
C
        DO 260 I = 3, NJP4
            L = NJP4 + 3 - I
            U(L,1) = A(L,1) + (B(L,1,1) * U(L+1,1)) + (B(L,1,2)
     1             * U(L+1,2)) + (C(L,1,1) * U(L+2,1)) + (C(L,1,2)
     2             * U(L+2,2))
     0      U(L,2) = A(L,2) + (B(L,2,1) * U(L+1,1)) + (B(L,2,2)
     1             * U(L+1,2)) + (C(L,2,1) * U(L+2,1)) + (C(L,2,2)
     2             * U(L+2,2))
  260 CONTINUE
        DO 330 I = 3, NJP4
            DXI = X(I) - X(I-1)
            DYI = Y(I) - Y(I-1)
            STHI = DYI / HI(I)
            CTHI = DXI / HI(I)
     0      DL = (U(I,1) - U(I-1,1)) * CTHI + (U(I,2) - U(I-1,2))
     1             * STHI
            T(I) = P5 * (AE(I-1) + AE(I)) * DL / HI(I)
            DXIP1 = X(I+1) -  X(I)
            DYIP1 = Y(I+1) - Y(I)
            HIP1 =  SQRT((DXIP1 * DXIP1) + (DYIP1 * DYIP1))
            STHIP1 = DYIP1 / HIP1
            CTHIP1 = DXIP1 / HIP1
     0      THI = ((-U(I,1) + U(I-1,1)) * STHI + (U(I,2) - U(I-1,2))
     1          * CTHI) / HI(I)
     0      THIP1 = ((-U(I+1,1) + U(I,1)) * STHIP1 + (U(I+1,2)
     1             - U(I,2)) * CTHIP1) / HIP1
            BM(I) = TWO * EI(I) * ((THIP1 - THI) / (HI(I) + HIP1))
  330 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE OUTPUT ( IOPT, TIME, T, BM, X, Y, XYL, U, V, NJT )
C
C-----OUTPUT SUBROUTINE
C
C
      COMMON /ID/ ID1(40), ID2(19), NPROB
     0DIMENSION T(105), BM(105), X(105), Y(105), XYL(105), U(105),
     1          V(105)
      DATA  ZERO, P5 / 0.0E00, 0.5E00 /
 1000FORMAT (     1H1, //,
     1           47H      PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION
     2           28H OF COLLAPSE OF PLANE FRAMES
     3   /       50H                   UNDER STATIC OR IMPULSE LOADS
     4   ///, 2( 5X, 20A4, / ) )
 1010 FORMAT ( / 13H      PROBLEM , A4, //, 10X, 19A4 )
 1020FORMAT (///30H      MAXIMUM RESPONSE, TIME = ,   E12.4 ,
     1  //       42H           QUANTITY        BAR OR      X COORD
     2           27H      Y COORD          VALUE ,
     3   /       31H                    STATION ,
     4  //       20H           THRUST     , 5X, I5, 3( 3X,   E12.4 ),
     5   /       20H           MOMENT     , 5X, I5, 3( 3X,   E12.4 ),
     6   /       20H           SHEAR      , 5X, I5, 3( 3X,   E12.4 ),
     7   /       20H           X DISP     , 5X, I5, 3( 3X,   E12.4 ),
     8   /       20H           Y DISP     , 5X, I5, 3( 3X,   E12.4 ) )
 1030FORMAT (///31H      COMPLETE RESPONSE, TIME = ,   E12.4,
     1  //       49H        STA     X COORD          Y COORD          THRUST
     2           29H         MOMENT          SHEAR  , //)
 1040 FORMAT ( 5X, I5, 2(2X,   E12.4), 16X,   E12.4 )
 1042 FORMAT ( 40X,   E12.4, 16X,   E12.4 )
 1045FORMAT (    1H1 , ///,
     1           41H        STA          X DISP             Y DISP , ///)
 1050 FORMAT (5X, I5, 2(5X,  E12.4))
C
      PRINT 1000, ( ID1(I), I = 1, 40 )
      PRINT 1010, NPROB, ( ID2(I), I = 1, 19 )
              NJP3 = NJT + 3
              NJP4 = NJT + 4
              NJP6 = NJT + 6
          GO TO ( 100, 180, 200 ), IOPT
C
C-----PRINT MAXIMUM VALUE ONLY
C
  100         TMIN = ZERO
              BMMIN = ZERO
              SMIN = ZERO
              UMIN = ZERO
              VMIN = ZERO
          DO 150 J = 4, NJP3
          IF (  ABS( T(J) ) .LT.  ABS( TMIN ) ) GO TO 110
              TMIN = T(J)
              JT = J
              XT =  P5 * ( X(J) + X(J-1) )
              YT = P5 * ( Y(J) + Y(J-1) )
  110     IF (  ABS( BM(J) ) .LT.  ABS( BMMIN ) ) GO TO 120
              BMMIN = BM(J)
              JB = J
              XB = X(J)
              YB = Y(J)
  120         SHEAR = ( BM(J) - BM(J-1) ) / ( XYL(J) - XYL(J-1) )
          IF (  ABS( SHEAR ) .LT.  ABS( SMIN ) ) GO TO 130
              SMIN = SHEAR
              JS = J
              XS =  P5 * ( X(J) + X(J-1) )
              YS = P5 * ( Y(J) + Y(J-1) )
  130     IF (  ABS( U(J) ) .LT.  ABS( UMIN) ) GO TO 140
              UMIN = U(J)
              JU = J
              XU = X(J)
              YU = Y(J)
  140     IF (  ABS( V(J) ) .LT.  ABS( VMIN ) ) GO TO 150
```

```
            VMIN = V(J)
            JV = J
            XV = X(J)
            YV = Y(J)
  150     CONTINUE
  1700PRINT 1020, TIME, JT, XT, YT, TMIN, JB, XB, YB, BMMIN, JS, XS, YS,
     1      SHEAR, JU, XU, YU, UMIN, JV, XV, YV, VMIN
          GO TO 200
C
C-----PRINT COMPLETE OUTPUT
C
  180           J = 0
      PRINT 1030, TIME
      PRINT 1040, J, X(4), Y(4), BM(4)
          DO 190 J = 5, NJP3
            SHEAR = ( BM(J) - BM(J-1) ) / ( XYL(J) - XYL(J-1) )
      PRINT 1042, T(J), SHEAR
            JJ = J - 4
      PRINT 1040, JJ, X(J), Y(J), BM(J)
  190 CONTINUE
      PRINT 1045
          DO 195 J = 4, NJP3
            JJ = J - 4
      PRINT 1050, JJ, U(J), V(J)
  195 CONTINUE
C
  200 RETURN
      END
```

```
      SUBROUTINE DYNAM
C
C-----SOLUTION FOR DYNAMIC DISPLACEMENTS
C
C
      COMMON /ID/ ID1(40), ID2(19), NPROB
      COMMON /CONT/ TLIM, DTIME, IDOPT, ISOPT, ISTAT, KEEP(7), NDL, NOUT
     0COMMON /XSECTN/ XN(10), YN(10), BN(10), DN(10), ATN(10), DTN(10),
     1                ABN(10), DBN(10), JSN(10), JSN9(10), MATN(10),
     2                NCT2A, NCT28, NSNS, IENON
      COMMON /CURVES/ EPSMUL(5), EPSN(10,5), SIGMUL(5), SIGN(10,5),NSSC
     0COMMON /BEAMN/ BMASSN(10),          SXN(10), SYN(10),ISC (10),
     1               JI4(10), JL4(10), KONT4(10), NCT4
      COMMON /LOADN/ QN(10,2), JI5(10), JL5(10), KONT5(10), NCT5
     0COMMON /IMPN/ QI1N(20), QI2N(20), QI3N(20), IPCODN(20), JI6(20),
     1              JM6(20), JL6(20), NCS(20), NSETS
     0COMMON /XSECT/ B(105), D(105), AT(105), DT(105), AB(105), DB(105),
     1               CG(105), AE(105), EI(105), MAT(105)
     0COMMON /BEAM/ X(105), Y(105), XYL(105), SX(105), SY(105), HI(105),
     1              BMASS(105), DPC(105), U(105), V(105), UD(105),
     2              VD(105), Q(105,2), QI(105,2), NJT
     0COMMON / FAILN/ UMAX, VMAX, SMAXN(10), PMULN(10), BMULN(10),
     1        SMAX(105), PMUL(105), BMUL(105), PIAN(9), BIAN(9), EPSU,
     2        JS7N(10), NST7, JIA7(10), NIA7
      COMMON /FORCEN/ BM(105), T(105)
     0DIMENSION TQ1(20), DV(105), DDV(105),  ADDV(105), DU(105),TQ2(20),
     1          DDU(105), ADDU(105),TQ3(20),  PEPSAB(105), PPHIJ(105),
     2          EPSOB(30,105), EPSOJ(30,105), EPORBT(105), EPORBB(105),
     3          EPORJT(105), EPORJB(105), EPSAB(105), PHIJ(105),
     4                 TEPSOB(30,105), TEPSOJ(30,105), TEORBT(105),
     5          TEORBB(105), TEORJT(105), TEORJB(105), JI(20), JL(20),
     6          DQ(105,2), KONT(20), JM(20)
     0DATA ZERO, P5, ONE, TWO, PI / 0.0E00, 0.5E00, 1.0E00, 2.0E00,
     1                            3.14159E00 /
      DATA SIX, TEN / 6.0E00, 1.0E01 /
      DATA ALIM / 0.1E00 /
      DATA ISL, IAL / 2HSL, 2HAL /, NO / 3H NO /, ISA / 2HSA /
 10000FORMAT (    1H1, // 1X,  88(1H*) / 1X, 1H*, 86X, 1H* /
     1           47H *   PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION
     2           28H OF COLLAPSE OF PLANE FRAMES  , 13X, 1H*,
     3   /       40H *          UNDER STATIC OR IMPULSE LOADS    ,
     4         48X, 1H*,2( / 1X, 1H*, 86X, 1H* ) ,
     5         2( / 2H *, 3X, 20A4, 3X, 1H* ), 2( / 1X, 1H*, 86X,1H* ) )
 10100FORMAT (   13H *   PROBLEM , A4, 71X, 1H* / 1X, 1H*, 86X, 1H* /
     1         1X, 1H*, 8X, 19A4, 2X, 1H*,2( / 1X, 1H*,86X, 1H* ) )
 10200FORMAT (   37H *   SOLUTION FOR DYNAMIC LOADING NO. , I3,
     1         48X, 1H*, / 1X, 1H*, 86X, 1H* / 1X, 88(1H*) )
               NJP3 = NJT + 3
               NJP4 = NJT + 4
               NJP6 = NJT + 6
          IF ( DTIME .GT. ZERO ) GO TO 102
C
C-----CALCULATE TIME INTERVAL
C
C-----CALCULATE AVERAGE FLEXURAL STIFFNESS AND AVG MASS
C
               AEI = ZERO
               AMASS = ZERO
          DO 100 I = 1, NJP6
               AEI = AEI + EI(I)
               AMASS = AMASS + BMASS(I)
  100     CONTINUE
               AMAX = NJT
               H = ( XYL(NJP3) - XYL(4) ) /( AMAX - ONE )
               AMASS = AMASS / ( XYL(NJP3) - XYL(4) )
               AEI = AEI / AMAX
               DTIME = PI *  SQRT ( AMASS / AEI ) * H * H / TEN / TWO
C
  102     IF ( ISTAT .NE. NO ) GO TO 106
          DO 104 I = 1, NJP6
```

```
            U(I) = ZERO
            V(I) = ZERO
            UD(I) = ZERO
            VD(I) = ZERO
  104     CONTINUE
  106     CONTINUE
C
C-----CALCULATE IMPULSE AT EACH STATION
C
            NCL = 0
        DO 260 N = 1, NSETS
C
C-----INITILIZE
C
        DO 108 I = 1, 105
            QI(I,1) = ZERO
            QI(I,2) = ZERO
  108 CONTINUE
      PRINT 1000, ( ID1(I), I = 1, 40 )
      PRINT 1010, NPROB, ( ID2(I), I = 1, 19 )
      PRINT 1020, N
            I = NCL + 1
            NCL = NCL + NCS(N)
  109       NC = 0
            IPCODT = IPCODN(I)
  110   IF ( IPCODN(I) .NE. IPCODT ) GO TO 113
            NC = NC + 1
            JI(NC) = JI6(I)
            JM(NC) = JM6(I)
            JL(NC) = JL6(I)
            TQ1(NC) = QI1N(I)
            TQ2(NC) = QI2N(I)
            TQ3(NC) = QI3N(I)
            I = I + 1
        IF ( I .LE. NCL ) GO TO 110
  113   IF ( IPCODT .EQ. 2 ) GO TO 114
      CALL IMPULS (JI, JM, JL, TQ1, TQ2, TQ3, QI(1,2), X, NC)
        GO TO 115
  114 CALL IMPULS (JI, JM, JL, TQ1, TQ2, TQ3, QI(1,1), Y, NC)
  115   IF ( I .LE. NCL ) GO TO 109
C
C-----CALCULATE INITIAL DISPLACEMENTS, VELOCITIES AND ACCELERATIONS
C
        DO 120 I = 4, NJP3
            VD(I) = V(I)
            DV(I) = QI(I,2) / BMASS(I)
            DDV(I) = ZERO
            ADDV(I) = ZERO
            UD(I) = U(I)
            DU(I) = QI(I,1) / BMASS(I)
            DDU(I) = ZERO
            ADDU(I) = ZERO
  120   CONTINUE
C
C-----REVISE DISPLACEMENTS AND VELOCITIES FOR UNYIELDING SUPPORTS
C
        DO 125 I = 1, NCT4
        IF ( ISC(I) .NE. ISL .AND. ISC(I) .NE. IAL ) GO TO 123
            IJ = JI4(I)
            VD(IJ) = ZERO
            DV(IJ) = ZERO
  123   IF ( ISC(I) .NE. ISA .AND. ISC(I) .NE. IAL ) GO TO 125
            IJ = JI4(I)
            UD(IJ) = ZERO
            DU(IJ) = ZERO
  125   CONTINUE
C
C-----CALCULATE INITIAL AVERAGE STRAINS AND CURVATURES
C
      CALL GEOM (X, Y, UD, VD, HI, NJT, PEPSAB, PPHIJ)
C
C-----SET ZERO POINT ON STRESS-STRAIN CURVES AT TIME ZERO
C
        DO 140 J = 1, NJP6
        DO 130 I = 1, 30
            EPSOB(I,J) = ZERO
            EPSOJ(I,J) = ZERO
            TEPSOB(I,J) = ZERO
            TEPSOJ(I,J) = ZERO
  130 CONTINUE
            EPORBT(J) = ZERO
            EPORBB(J) = ZERO
            EPORJT(J) = ZERO
            EPORJB(J) = ZERO
            TEORBT(J) = ZERO
            TEORJT(J) = ZERO
            TEORBB(J) = ZERO
            TEORJB(J) = ZERO
  140   CONTINUE
C
C-----ADJUST FORCES TO CONFORM TO DYNAMIC SOLUTION PROCESS
C
     0CALL FORCE ( BM, T, EPSOB, TEPSOB, PPHIJ, PPHIJ, PEPSAB, EPORBT,
     1           EPORBB, TEORBT, TEORBB, PEPSAB, EPSOJ, TEPSOJ,
     2           TEORJT, TEORJB, EPORJT, EPORJB )
     0CALL ACCEL (X, Y, UD, DDU, VD, DDV, BM, T, SY, SX, Q, BMASS, ISC,
     1           NJT, NCT4, JI4)
        DO 142 I = 4, NJP3
            DQ(I,1) = Q(I,1) - DDU(I) * BMASS(I)
            DQ(I,2) = Q(I,2) - DDV(I) * BMASS(I)
            DDU(I) = ZERO
            DDV(I) = ZERO
  142   CONTINUE
C
C-----START DYNAMIC SOLUTION
C
            KNOUT = 0
            TIME = ZERO
  150       TIME = TIME + DTIME
            NIT = 0
C
C-----ESTIMATE DISPL. AND VEL. AT TIME
C
        DO 160 I = 4, NJP3
     0      VD(I) = VD(I) + DTIME * DV(I) + P5 * DTIME * DTIME
     1            * DDV(I)
            DV(I) = DV(I) + DTIME * DDV(I)
     0      UD(I) = UD(I) + DTIME * DU(I) + P5 * DTIME * DTIME
     1            * DDU(I)
            DU(I) = DU(I) + DTIME * DDU(I)
  160   CONTINUE
C
C-----CALCULATE STRAINS AND CURVATURES AT TIME
C
  170 CALL GEOM ( X, Y, UD, VD, HI, NJT,EPSAB, PHIJ )
            NIT = NIT + 1
C
C-----CALCULATE BAR THRUSTS AND JOINT MOMENTS
C
     0CALL FORCE ( BM, T, EPSOB, TEPSOB, PHIJ, PPHIJ, PEPSAB, EPORBT,
     1           EPORBB, TEORBT, TEORBB, EPSAB, EPSOJ, TEPSOJ,
     2           TEORJT, TEORJB, EPORJT, EPORJB )
C
C-----CALCULATE ACCELERATIONS
C
     0CALL ACCEL ( X, Y, UD, DDU, VD, DDV, BM, T, SY, SX, DQ, BMASS,
     1           ISC, NJT, NCT4, JI4)
C
C-----TEST FOR CONVERGENCE
C
```

```
         DO 180 I = 4, NJP3
                DELDD =  ABS    ( DDV(I) - ADDV(I) )
         IF ( DELDD .GT. ALIM ) GO TO 190
                DELDD =  ABS ( DDU(I) - ADDU(I) )
         IF ( DELDD .GT. ALIM ) GO TO 190
  180    CONTINUE
                KONVER = 1
         GO TO 200
  190           KONVER = 0
C
C-----REVISE DISPL. AND VEL.
C
  200    DO 210 I = 4, NJP3
                DELDD = DDV(I) - ADDV(I)
                VD(I) = VD(I) + DTIME * DTIME * DELDD / SIX
                DV(I) = DV(I) +  P5 * DTIME * DELDD
                ADDV(I) = DDV(I)
                DELDD = DDU(I) - ADDU(I)
                UD(I) = UD(I) + DTIME * DTIME * DELDD / SIX
                DU(I) = DU(I) +  P5    * DTIME * DELDD
                ADDU(I) = DDU(I)
  210    CONTINUE
         IF ( NIT .GT. 10 ) GO TO 270
         IF ( KONVER .EQ. 0 ) GO TO 170
C
C-----REVISE FOR NEXT TIME INTERVAL
C
         DO 230 J = 4, NJP3
         DO 220 I = 1, NSNS
                EPSOB(I,J) = TEPSOB(I,J)
                EPSOJ(I,J) = TEPSOJ(I,J)
  220 CONTINUE
                EPORBT(J) = TEORBT(J)
                EPORBB(J) = TEORBB(J)
                EPORJT(J) = TEORJT(J)
                EPORJB(J) = TEORJB(J)
                PPHIJ(J) = PHIJ(J)
                PEPSAB(J) = EPSAB(J)
  230    CONTINUE
C
C-----TEST FOR END OF RUN
C
                KNOUT = KNOUT + 1
C
C-----TEST FOR COLLAPSE
C
      CALL FAIL ( UD, VD, BM, T, X, Y, XYL, CG, TIME, DPC, NJT, K )
         IF ( K .NE. 1 ) GO TO 240
      CALL OUTPUT ( IDOPT, TIME, T, BM, X, Y, XYL, UD, VD, NJT )
         GO TO 260
  240    IF ( KNOUT .NE. NOUT ) GO TO 250
      CALL OUTPUT ( IDOPT, TIME, T, BM, X, Y, XYL, UD, VD, NJT )
                KNOUT = 0
  250    IF ( TIME .LT. TLIM ) GO TO 150
C-----TIME LIMIT EXCEEDED
      PRINT 9010
      CALL OUTPUT ( IDOPT, TIME, T, BM, X, Y, XYL, UD, VD, NJT )
      PRINT 9010
  260    CONTINUE
C-----THIS IS THE ONLY RETURN STATEMENT
      RETURN
  270 PRINT 9000, DTIME
                IDOPT = 2
      CALL OUTPUT ( IDOPT, TIME, T, BM, X, Y, XYL, UD, VD, NJT )
      PRINT 9000, DTIME
      STOP
 9000OFORMAT (   46H1    SOLUTION FAILED TO CLOSE IN 10 ITERATIONS
    1            22H     TIME INTERVAL IS ,    E12.4   )
 9010OFORMAT (   48H1     BEAM/COLUMN DID NOT FAIL IN SPECIFIED TIME
    1             6H LIMIT   )
      END
```

```
      OSUBROUTINE FORCE ( BM, T, EPSOB, TEPSOB, PHIJ, PPHIJ, PEPSAB,
      1          EPORBT, EPORBB, TEORBT, TEORBB, EPSAB, EPSOJ, TEPSOJ,
      2          TEORJT, TEORJB, EPORJT, EPORJB )
C
C-----SOLVE FOR BAR THRUSTS AND JOINT MOMENTS
C
C
       COMMON /ID/ ID1(40), ID2(19), NPROB
       COMMON /CONT/ TLIM, DTIME, IDOPT, ISOPT, ISTAT, KEEP(7), NDL, NOUT
      OCOMMON /XSECTN/ XN(10), YN(10), BN(10), DN(10), ATN(10), DTN(10),
      1               ABN(10), DBN(10), JSN(10), JSNB(10), MATN(10),
      2               NCT2A, NCT2B, NSNS, IENDN
       COMMON /CURVES/ EPSMUL(5), EPSN(10,5), SIGMUL(5), SIGN(10,5),NSSC
      OCOMMON /BEAMN/ BMASSN(10),          SXN(10), SYN(10),ISC (10),
      1              JI4(10), JL4(10), KONT4(10), NCT4
       COMMON /LOADN/ QN(10,2), JI5(10), JL5(10), KONT5(10), NCT5
      OCOMMON /IMPN/ QI1N(20), QI2N(20), QI3N(20), IPCODN(20), JI6(20),
      1             JM6(20), JL6(20), NCS(20), NSETS
      OCOMMON /XSECT/ B(105), D(105), AT(105), DT(105), AB(105), DB(105),
      1               CG(105), AE(105), EI(105), MAT(105)
      OCOMMON /BEAM/ X(105), Y(105), XYL(105), SX(105), SY(105), HI(105),
      1              BMASS(105), DPC(105), U(105), V(105), UD(105),
      2              VD(105), Q(105,2), QI(105,2), NJT
      ODIMENSION BM(105), T(105), EPSOB(30,105), TEPSOB(30,105),
      1         PHIJ(105), PPHIJ(105), PEPSAB(105), EPORBT(105),
      2         EPORBB(105), TEORBT(105), TEORBB(105), EPSAB(105),
      3         EPSOJ(30,105), TEPSOJ(30,105), TEORJT(105), TEORJB(105),
      4         EPORJT(105), EPORJB(105), DEPSO(50), TEPSO(50)
       DATA ZERO, P5 / 0.0E00, 0.5E00 /
                ISTOP = NSNS
                NJP2 = NJT + 2
                NJP3 = NJT + 3
                NJP4 = NJT + 4
                NJP6 = NJT + 6
                T(3) = ZERO
                BM(4) = ZERO
           DO 160 J = 5, NJP3
C
C-----SET UP TEMPORARY DATA FOR EACH CROSS SECTION
C
           DO 100 I = 1, ISTOP
                DEPSO(I) = EPSOB(I,J)
                TEPSO(I) = TEPSOB(I,J)
  100 CONTINUE
                PHI =  P5 * ( PHIJ(J) + PHIJ(J-1) )
                PPHI =  P5 * ( PPHIJ(J) + PPHIJ(J-1) )
                TAT =  P5 * ( AT(J) + AT(J-1) )
                TD = P5 * ( D(J) + D(J-1) )
                TDT =  P5 * ( DT(J) + DT(J-1) )
                TAB =  P5 * ( AB(J) + AB(J-1 ) )
                TDB =  P5 * ( DB(J) + DB(J-1) )
                TB = P5 * ( B(J) + B(J-1) )
                TCG =  P5 * ( CG(J) + CG(J-1 ) )
C
C-----CALCULATE THRUST IN BAR
C
      OCALL IFORCE ( PEPSAB(J), PPHI, DEPSO, DUM, T(J), EPSAB(J), PHI,
      1            TD, TAT, TDT, TAB, TDB, TB, TCG, NSNS,
      2            EPSMUL, EPSN, SIGMUL, SIGN, NSSC, MAT, EPORBT(J),
      3            EPORBB(J), TEPSO, TEORBT(J), TEORBB(J) )
           DO 120 I = 1, ISTOP
                TEPSOB(I,J) = TEPSO(I)
  120 CONTINUE
C
C-----CALCULATE MOMENT IN JOINT
C
                EPSA =  P5 * ( EPSAB(J) + EPSAB(J+1) )
                PEPSA =  P5 * ( PEPSAB(J) + PEPSAB(J+1) )
           DO 130 I = 1, ISTOP
                DEPSO(I) = EPSOJ(I,J)
```

```
            TEPSO(I) = TEPSOJ(I,J)
  130 CONTINUE
            TCG = CG(J)
     0CALL IFORCE ( PEPSA, PPHIJ(J), DEPSO, BM(J), DUM, EPSA, PHIJ(J),
     1          TD, AT(J), DT(J), AB(J), DB(J), B(J),
     2          TCG, NSNS, EPSMUL, EPSN, SIGMUL, SIGN, NSSC,
     3          MAT, EPORJT(J), EPORJB(J), TEPSO, TEORJT(J),
     4          TEORJB(J) )
        DO 150 I = 1, ISTOP
            TEPSOJ(I,J) = TEPSO(I)
  150 CONTINUE
  160 CONTINUE
            BM(NJP3) = ZERO
            T(NJP4) = ZERO
C
      RETURN
      END
```

```
      0SUBROUTINE ACCEL (X, Y, U, DDU, V, DDV, BM, T, SY, SX, Q, BMASS,
      1                    ISC, NJT, NCT4, JI4)
C
C-----CALCULATE X AND Y ACCELERATIONS OF EACH NODE
C
C
      0DIMENSION X(105), Y(105), U(105), V(105), DDU(105), DDV(105),
      1         BM(105), T(105), SX(105), SY(105), Q(105,2), BMASS(105),
      2         ISC(10), JI4(10)
       DATA  ZERO / 0.0E00 /
       DATA  ISA, ISL, IAL / 2HSA, 2HSL, 2HAL /
                NJP3 = NJT + 3
C
C-----CALCULATE VALUES AT RIGHT END OF BAR 3
C
                DX = X(4) + U(4) - X(3) - U(3)
                DY = Y(4) + V(4) - Y(3) - V(3)
                XLR =  SQRT((DX * DX) + (DY * DY))
                STHR = DY / XLR
                CTHR = DX / XLR
                VR = (BM(4) - BM(3)) / XLR
           DO 100 I = 4, NJP3
                XLL = XLR
                STHL = STHR
                CTHL = CTHR
                VL = VR
                DX = X(I+1) + U(I+1) - X(I) - U(I)
                DY = Y(I+1) + V(I+1) - Y(I) - V(I)
                XLR =  SQRT((DX * DX) + (DY * DY))
                VR = (BM(I+1) - BM(I)) / XLR
                STHR = DY / XLR
                CTHR = DX / XLR
      0         DDU(I) = (T(I+1) * CTHR - T(I) * CTHL + VR * STHR - VL
      1                * STHL + Q(I,1) - SX(I) * U(I)) / BMASS(I)
      0         DDV(I) = (T(I+1) * STHR - T(I) * STHL - VR * CTHR + VL
      1                * CTHL + Q(I,2) - SY(I) * V(I)) / BMASS(I)
  100 CONTINUE
           DO 130 I = 1, NCT4
           IF (ISC(I) .NE.ISA ) GO TO 110
                IJ = JI4(I)
                DDU(IJ) = ZERO
  110      IF (ISC(I) .NE.ISL ) GO TO 120
                IJ = JI4(I)
                DDV(IJ) = ZERO
  120      IF ( ISC(I) .NE. IAL ) GO TO 130
                IJ = JI4(I)
                DDU(IJ) = ZERO
                DDV(IJ) = ZERO
  130      CONTINUE
C
       RETURN
       END
```

```
      SUBROUTINE GEOM (X, Y, U, V, HI, NJT, EPSAB, PHIJ)
C
C     CALCULATE AVERAGE STRAIN IN BARS AND CURVATURE IN JOINTS
C
C
     0DIMENSION  X(105), Y(105), U(105), V(105), HI(105), EPSAB(105),
     1           PHIJ(105)
      DATA  ZERO, ONE, TWO / 0.0E00, 1.0E00, 2.0E00 /
              NJP3 = NJT + 3
              NJP4 = NJT + 4
              NJP6 = NJT + 6
          DO 100 I = 1, NJP6
              EPSAB(I) = ZERO
              PHIJ(I) = ZERO
  100 CONTINUE
C
C     U AND V DISPLACEMENTS FROM STATIC SOLUTION OR SET EQUAL TO ZERO IN
C     DYNAM
C
              DXIM1 = X(5) + U(5) - X(4) - U(4)
              DYIM1 = Y(5) + V(5) - Y(4) - V(4)
              XLIM1 =  SQRT( (DXIM1 * DXIM1) + (DYIM1 * DYIM1) )
              THIM1 =   ASIN( DYIM1 / XLIM1 )
     0        DTHIM1 = ( ( -U(5) + U(4) ) *  SIN(THIM1)
     1              + ( V(5) - V(4) ) *  COS(THIM1) ) / XLIM1
              EPSAB(5) = XLIM1 / HI(5) - ONE
          DO 110 I = 6, NJP3
              DXI = X(I) + U(I) - X(I-1) - U(I-1)
              DYI = Y(I) + V(I) - Y(I-1) - V(I-1)
              XLI =  SQRT( (DXI * DXI) + (DYI * DYI) )
              THI =   ASIN( DYI / XLI )
     0        DTHI = ( ( -U(I) + U(I-1) ) *  SIN(THI)
     1             + ( V(I) - V(I-1) ) *  COS(THI) ) / XLI
              EPSAB(I) = XLI / HI(I) - ONE
              PHIJ(I-1) = TWO * ( DTHI - DTHIM1 ) / ( XLIM1 + XLI )
              XLIM1 = XLI
              DTHIM1 = DTHI
  110 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE FAIL ( UD, VD, BM, T, X, Y, XYL, CG, TIME, DPC, NJT, K)
C
C
C
     0COMMON / FAILN/ UMAX, VMAX, SMAXN(10), PMULN(10), BMULN(10),
     1       SMAX(105), PMUL(105), BMUL(105), PIAN(9), BIAN(9), EPSU,
     2       JS7N(10), NST7, JIA7(10), NIA7
     0DIMENSION UD(105), VD(105), BM(105), T(105), X(105), Y(105),
     1          XYL(105), CG(105), DPC(105)
      DATA ZERO, P5 / 0.0E00, 0.5E00 /
 1000 0FORMAT ( //47H     FAILURE DUE TO VERTICAL DEFLECTION AT X = ,
     1          E12.4, 8H    Y = ,   E12.4 )
 1010 0FORMAT ( //49H     FAILURE DUE TO HORIZONTAL DEFLECTION AT X = ,
     1          E12.4, 8H    Y = ,   E12.4 )
 1020 0FORMAT ( //33H     FAILURE DUE TO SHEAR AT X = ,   E12.4,
     1          8H    Y = ,   E12.4 )
 1030 0FORMAT (// 45H     FAILURE DUE TO THRUST-MOMENT INTERACTION
     1          8H AT X = ,   E12.4, 6H  Y = ,   E12.4 )
 1070 FORMAT ( //23H     FAILURE AT TIME = ,   E12.4 )
 1080 FORMAT ( 1H1 )
C
C-----CHECK FOR FAILURE AT EACH STATION AND IN EACH BAR
C
              KK = 0
              K = 0
              NJP3 = NJT + 3
C
C-----CHECK FOR FAILURE DUE TO EXCESSIVE DEFLECTION
C
          DO 120 J = 4, NJP3
          IF (  ABS( VD(J) ) .LT. VMAX ) GO TO 110
          IF ( KK .EQ. 0 ) PRINT 1080
              KK = 1
              K = 1
      PRINT 1000, X(J), Y(J)
  110     IF (  ABS( UD(J) ) .LT. UMAX ) GO TO 120
          IF ( KK .EQ. 0 ) PRINT 1080
              KK = 1
              K = 1
      PRINT 1010, X(J), Y(J)
  120     CONTINUE
C
C-----CHECK FOR FAILURE DUE TO SHEAR
C
          DO 130 J = 4, NJP3
              SHEAR = ( BM(J) - BM(J-1) ) / ( XYL(J) - XYL(J-1) )
          IF (  ABS (SHEAR) .LT. SMAX(J) ) GO TO 130
              K = 1
              XB = P5 * ( X(J) + X(J-1 ) )
              YB = P5 * ( Y(J) + Y(J-1) )
          IF ( KK .EQ. 0 ) PRINT 1080
              KK = 1
      PRINT 1020, XB, YB
  130     CONTINUE
C
C-----CHECK FOR FAILURE DUE TO THRUST - MOMENT INTERACTION
C
          DO 190 J = 4, NJP3
              TJ = P5 * ( T(J) + T(J+1) )
          IF ( TJ .GT. ZERO ) TJ = ZERO
              TJ =  ABS (TJ )
              BMPC = BM(J) + TJ*( DPC(J) - CG(J) )
          IF ( BMPC .GT. ZERO ) GO TO 160
C
C-----SEARCH NEGATIVE PART OF I/A DIAGRAM
C
              I = 1
  140     IF ( TJ .LT. (PMUL(J) * PIAN(I+1))) GO TO 150
              I = I + 1
          GO TO 140
```

```
 1500         BMMAX= BMUL(J) * (BIAN(I) + ( TJ/PMUL(J) - PIAN(I) )
    1              / (PIAN(I+1) - PIAN(I) ) * (BIAN(I+1) - BIAN(I) ) )
        IF ( BMPC  .GT. BMMAX ) GO TO 190
             K = 1
        IF ( KK .EQ. 0 ) PRINT 1080
             KK = 1
    PRINT 1030, X(J), Y(J)
        GO TO 190
C
C-----SEARCH POSITIVE PART OF I/A DIAGRAM
C
  160        I = 9
  170   IF ( TJ .LT. (PMUL(J) * PIAN(I-1))) GO TO 180
             I = I - 1
        GO TO 170
 1800        BMMAX = BMUL(J) * (BIAN(I) + (TJ/PMUL(J) - PIAN(I) )
    1              / (PIAN(I-1) - PIAN(I) ) * ( BIAN(I-1) - BIAN(I) ))
        IF ( BMPC  .LT. BMMAX ) GO TO 190
             K = 1
        IF ( KK .EQ. 0 ) PRINT 1080
             KK = 1
    PRINT 1030, X(J), Y(J)
  190   CONTINUE
        IF ( K .EQ. 1 ) PRINT 1070, TIME
C
      RETURN
      END
```

```
      SUBROUTINE IMPULS  ( JI, JM, JL, TQ1, TQ2, TQ3, QI, X, NC )
C-----CALCULATE EQUIVALENT CONCENTRATED IMPULSE FROM PARABOLIC DIST.
C
     0DIMENSION TQ1(20), TQ2(20), TQ3(20), QI(105), X(105),
     1         JI(20), JM(20), JL(20)
     0DATA ZERO, TWO, FOUR, SIX, TWEL / 0.0E00, 2.0E00, 4.0E00, 6.0E00,
     1         1.2E01 /
C
        DO 150 N = 1, NC
        IF ( JM(N) .GT. JI(N) ) GO TO 130
  105   IF ( JL(N) .GT. JI(N) ) GO TO 110
C-----CONCENTRATED IMPULSE AT JI(N)
             J = JI(N)
             QI(J) = TQ1(N)
        GO TO 150
C-----LINEAR DISTRIBUTION FROM JI(N) TO JL(N)
  110        JSTRT = JI(N)
             JSTOP = JL(N)
             QL = TQ1(N)
             QR = TQ3(N)
             XL = X(JSTRT)
             XR = X(JSTOP)
             DQ = ( QR - QL ) / ( XR - XL )
             JSTOP = JSTOP - 1
        DO 120   J= JSTRT, JSTOP
             H = X(J+1) - X(J)
             QR = QL + H*DQ
             QI(J) = QI(J) + H * ( TWO * QL + QR ) / SIX
             QI(J+1) = QI(J+1) + H * ( QL + TWO * QR ) / SIX
             QL = QR
  120   CONTINUE
        GO TO 150
C-----PARABOLIC DISTRIBUTION FROM JI(N) TO JL(N)
  130        J1 = JI(N)
             J2 = JM(N)
             J3 = JL(N)
             Q1 = TQ1(N)
             Q2 = TQ2(N)
             Q3 = TQ3(N)
             X1 = X(J1)
             X2 = X(J2)
             X3 = X(J3)
             TEMP1 = Q1 / ( ( X2 - X1 ) * ( X3 - X1 ) )
             TEMP2 = Q2 / ( ( X1 - X2 ) * ( X3 - X2 ) )
             TEMP3 = Q3 / ( ( X1 - X3 ) * ( X2 - X3 ) )
             XL = X1
             XM = X(J1+1)
             H2 = XM - XL
             Q2 = Q1
     0       Q3 = ( X2 - XM ) * ( X3 - XM ) * TEMP1
     1          + ( X1 - XM ) * ( X3 - XM ) * TEMP2
     2          + ( X1 - XM ) * ( X2 - XM ) * TEMP3
             JSTRT = J1
             JSTOP = J3 - 2
        DO 140 J = JSTRT, JSTOP
             Q1 = Q2
             Q2 = Q3
             H1 = H2
             XR = X(J+2)
             H2 = XR - X(J + 1 )
     0       Q3 = ( X2 - XR ) * ( X3 - XR ) * TEMP1
     1          + ( X1 - XR ) * ( X3 - XR ) * TEMP2
     2          + ( X1 - XR ) * ( X2 - XR ) * TEMP3
             A = ( H1 + TWO*H2 ) / ( H1 + H2 )
             B = H1 * H1 / ( H2 * ( H1 + H2 ) )
     0       QI(J) = QI(J) + H1 * (( A + TWO ) * Q1 + ( TWO+H1/H2 ) *
     1               Q2 - B * Q3 ) / TWEL
     0       QI(J+1) = QI(J+1) + H1 * ( A * Q1 + ( FOUR + H1 / H2 ) *
     1                 Q2 - B * Q3 ) / TWEL
  140   CONTINUE
```

```
          A = ( H2 + TWO * H1 ) / ( H1 + H2 )
          B = H2 * H2 / ( H1 * ( H1 + H2 ) )
     0    QI(JSTOP+1) = QI(JSTOP+1) + H2 * ( A * Q3 + ( FOUR +
     1               H2 / H1 ) * Q2 - B * Q1 ) / THEL
     0    QI(JSTOP+2) = QI(JSTOP+2) + H2 * (( A + TWO ) * Q3 +
     1               ( TWO + H2 / H1 ) * Q2 - B * Q1 ) / THEL
  150     CONTINUE
C
      RETURN
      END
```

```
      0SUBROUTINE IFORCE ( PEPSA, PPHI, EPSO, BM, T, EPSA, PHI,
      1                    D, AT, DT, AB, DB, B, CG, NSNS,
      2                    EPSMUL, EPSN, SIGMUL, SIGN, NSSC, MAT,
      3                    EPSOT, EPSOB, TEPSO, TEORT, TEORB )
C
C-----CALCULATE BENDING MOMENT AND THRUST AT CROSS SECTION
C
C
      0DIMENSION ST(10), EP(10), EPSO(30), TEPSO(30),
      1          EPSMUL(5), EPSN(10,5),SIGMUL(5), SIGN(10,5), MAT(9)
       DATA ZERO, P5 / 0.0E00, 0.5E00 /
                BM = ZERO
                T = ZERO
C
C-----SET UP DIMENSIONS FOR EACH SECTION
C
  100           DTOP = ZERO
C-----NSNS = NUMBER OF SEGMENTS IN SECTION
                HN = D / NSNS
                M = 1
           DO 180 I = 1, NSNS
C
C-----SET UP STRESS-STRAIN CURVE
C
           DO 170 N = 1, 10
                ST(N) = SIGMUL(M) * SIGN(N,M)
                EP(N) = EPSMUL(M) * EPSN(N,M)
  170      CONTINUE
C
C-----CALCULATE CONTRIBUTION TO MOMENT AND THRUST
C
                DA = HN * B
                DEP = DTOP +  P5 * HN - CG
C
C-----CALCULATE PREVIOUS AND CURRENT STRAIN LEVELS
C
                PEPS = PEPSA + DEP * PPHI
                EPS = EPSA + DEP *  PHI
       CALL SEARCH ( ST, EP, PEPS, EPSO(I), EPS, SIG, TEPSO(I) )
                DF = DA * SIG
                T = T + DF
                BM = BM + DF * DEP
                DTOP = DTOP + HN
  180      CONTINUE
C
C-----CALCULATE CONTRIBUTION OF REINFORCEMENT
C
           DO 190 N = 1, 10
                ST(N) = SIGMUL(NSSC) * SIGN(N,NSSC)
                EP(N) = EPSMUL(NSSC) * EPSN(N,NSSC)
  190      CONTINUE
           IF ( AT .EQ. ZERO ) GO TO 192
                DEP = DT - CG
                PEPS = PEPSA + DEP * PPHI
                EPS = EPSA + DEP * PHI
       CALL SEARCH ( ST, EP, PEPS, EPSOT, EPS, SIG, TEORT )
                DF = AT * SIG
                T = T + DF
                BM = BM + DF * DEP
  192      IF ( AB .EQ. ZERO ) GO TO 195
                DEP = DB - CG
                PEPS = PEPSA + DEP * PPHI
                EPS = EPSA + DEP * PHI
       CALL SEARCH ( ST, EP, PEPS, EPSOB, EPS, SIG, TEORB )
                DF = AB * SIG
                T = T + DF
                BM = BM + DF * DEP
  195 CONTINUE
C
       RETURN
       END
```

```
      SUBROUTINE SEARCH ( ST, EP, PEPS, EPSO, EPS, SIG, TEPSO )
C-----SEARCH STRESS - STRAIN CURVE FOR CURRENT LEVEL
C
C
      DIMENSION ST(10), EP(10), TS(12), TE(12)
      DATA ZERO, ONE / 0.0E00, 1.0E00 /
C
C-----SET UP AUXILIARY POSITIVE CURVES
               KEY = 0
               TS(1) = ZERO
               TE(1) = ZERO
               TS(7) = ZERO
               TE(7) = ZERO
               J = 5
               K = 6
          DO 100 I = 2, 6
               TS(I) = - ST(J)
               TE(I) = - EP(J)
               TS(I+6) = ST(K)
               TE(I + 6) = EP(K)
               J = J - 1
               K = K + 1
100       CONTINUE
C-----DETERMINE PREVIOUS STRESS LEVEL
          IF ( PEPS .GE. EPSO ) GO TO 110
               ET = TS(2) / TE(2)
          GO TO 120
  110          ET = TS(8) / TE(8)
  120          PSIG = ( PEPS - EPSO ) * ET
C-----CHECK FOR POSITIVE OR NEGATIVE CURVE
          IF ( EPS - EPSO ) 320, 130, 140
  130          SIG = ZERO
               I = 8
               IT = 12
               AEPS = EPS
               C = ONE
          GO TO 250
  140     IF ( PSIG .LT. 0.0000 ) GO TO 330
          IF ( EPS .GT. PEPS ) GO TO 148
               I = 8
               IT = 12
               C = ONE
  144          SIG = ( EPS - EPSO ) * ET
               AEPS = EPS
          GO TO 250
  148          I = 8
               APEPS = PEPS
               IT = 12
               C = ONE
               AEPS = EPS
  150     IF ( PSIG - TS(I) ) 160, 170, 180
  1600         EPSS = APEPS - TE(I-1) - ( TE(I) - TE(I-1) )
     1              * ( PSIG - TS(I-1) ) / ( TS(I) - TS(I-1) )
          GO TO 190
  170          EPSS = APEPS - TE(I)
          GO TO 190
  180          I = I + 1
          GO TO 150
  190          J = I
               TSIG = PSIG
               TEPS = APEPS
  200     IF ( AEPS - ( TE(J) + EPSS ) ) 210, 220, 230
  2100         SIG = TSIG + ( TS(J) - TSIG ) * ( AEPS - TEPS )
     1              / ( TE(J) + EPSS - TEPS )
          GO TO 250
  220          SIG = TS(J)
          GO TO 250
  230     IF ( J .GE. IT ) GO TO 240
               TSIG = TS(J)
               TEPS = TE(J) + EPSS
               J = J + 1
          GO TO 200
  240          SIG = ZERO
C-----TEST OFF CURVE
  250     IF ( KEY .EQ. 1 ) GO TO 305
          IF ( AEPS - TE(I) ) 260, 270, 280
  2600         TSIG = TS(I-1) + ( TS(I) - TS(I-1) )
     1              * ( AEPS - TE(I-1) ) / ( TE(I) - TE(I-1) )
          GO TO 300
  270          TSIG = TS(I)
          GO TO 300
  280     IF ( I .GE. IT ) GO TO 290
               I = I + 1
          GO TO 250
  290          TSIG = ZERO
  300     IF ( TSIG .LT. SIG ) SIG = TSIG
  305          SIG = C * SIG
          IF ( SIG ) 306,  306, 308
  306          K = 2
          GO TO 310
  308          K = 8
  310          TEPSO = EPS - SIG * TE(K) / TS(K)
          GO TO 9999
  320     IF ( PSIG .GT.  ZERO  ) GO TO 340
          IF ( EPS .GT. PEPS ) GO TO 325
               I = 2
               IT = 6
               AEPS = - EPS
               APEPS = - PEPS
               PSIG = - PSIG
               C = -ONE
          GO TO 150
  325          C = -ONE
               SIG =  ABS ( EPS - EPSO ) * ET
               AEPS = - EPS
               I = 2
               IT = 6
          GO TO 250
C-----REVERSAL NEGATIVE TO POSITIVE
  330          EPSS = EPSO
               PSIG = ZERO
               I = 8
               J = I
               IT = 12
               APEPS = ZERO
               AEPS = EPS
               TSIG = ZERO
               TEPS = EPSO
               C = ONE
               ET = TS(8) / TE(8)
          IF ( EPSO .LT.  ZERO  ) KEY = 1
          GO TO 200
C-----REVERSAL POSITIVE TO NEGATIVE
  340          I = 2
               J = I
               IT = 6
               EPSS = - EPSO
               PSIG = ZERO
               APEPS = ZERO
               AEPS = - EPS
               TSIG = ZERO
               TEPS = - EPSO
               C = - ONE
               ET = TS(2) / TE(2)
          IF ( EPSO .GT.  ZERO  ) KEY = 1
          GO TO 200
 9999     CONTINUE
C
      RETURN
      END
```

APPENDIX D

SAMPLE INPUT AND OUTPUT DATA

PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
CODED 1-12-73 BY GMR

PROBLEM IPF1

PORTAL FRAME WITH UNIFORM LOAD ON BEAM - STATIC SOLUTION ONLY

TABLE 1. PROGRAM CONTROL DATA

NO KEEP OPTIONS EXERCISED

STATIC SOLUTION REQUIRED	YES
STATIC OUTPUT OPTION	2

TABLE 2. JOINT COORDINATES AND CROSS SECTION DESCRIPTION

A.JOINT COORDINATES AND MATERIAL

JT.NO.	X-COORD	Y-COORD	MATERIAL
24	0.	1.800E+02	1
44	1.800E+02	1.800E+02	1
64	1.800E+02	0.	1

B.CROSS SECTION AND REINFORCEMENT DESCRIPTION

STA	WIDTH SECT.	DEPTH SECT.	TOP REINF AREA	TOP REINF DEPTH	BOTTOM REINF AREA	BOTTOM REINF DEPTH	NO. SEGM.
4	8.000E+00	1.200E+01	1.000E+00	2.000E+00	1.000E+00	1.000E+01	12
64	8.000E+00	1.200E+01	1.000E+00	2.000E+00	1.000E+00	1.000E+01	12

TABLE 3. STRESS-STRAIN CURVES

CURVE NO. 1
STRESS VALUE SCALE FACTOR 1.000E+03
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES	0.000	-2.000	-4.000	-4.010	-4.000	.001	.002	.003	.004	.005
STRAIN INPUT VALUES	-10.000	-6.250	-2.500	-2.000	-1.500	2.000	4.000	6.000	8.000	10.000

CURVE NO. 2
STRESS VALUE SCALE FACTOR 1.000E+04
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES	-4.740	-4.730	-4.720	-4.710	-4.700	4.700	4.710	4.720	4.730	4.740
STRAIN INPUT VALUES	-15.700	-12.200	-8.640	-5.100	-1.570	1.570	5.100	8.640	12.200	15.700

TABLE 4. BEAM/COLUMN MASS AND ELASTIC SUPPORTS

FROM STA	TO STA	CONT CODE	MASS	HORIZONTAL SUPPORT	VERTICAL SUPPORT	SUPPORT CODE
4	4	3	-0.	1.000E+10	1.000E+10	AL
64	64	0	-0.	1.000E+10	1.000E+10	AL

TABLE 5. STATIC LOADS

FROM STA	TO STA	CONT CODE	HORIZONTAL LOAD	VERTICAL LOAD
24	44	0	-0.	-4.167E+01

TABLE 6. IMPULSE LOADING

NONE

TABLE 7. COLLAPSE PARAMETERS

NONE

PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
CODED 1-12-73 BY GMR

PROBLEM IPF2

GABLED FRAME - STATIC CONCENTRATED LOADS - NO DYNAMIC LOADS

TABLE 1. PROGRAM CONTROL DATA

NO KEEP OPTIONS EXERCISED

STATIC SOLUTION REQUIRED YES
STATIC OUTPUT OPTION 2

TABLE 2. JOINT COORDINATES AND CROSS SECTION DESCRIPTION

A. JOINT COORDINATES AND MATERIAL

JT.NO.	X-COORD	Y-COORD	MATERIAL
24	0.	1.200E+02	1
44	1.200E+02	1.800E+02	1
64	2.400E+02	1.200E+02	1
94	2.400E+02	0.	1

B. CROSS SECTION AND REINFORCEMENT DESCRIPTION

STA	WIDTH SECT.	DEPTH SECT.	TOP REINF AREA	TOP REINF DEPTH	BOTTOM REINF AREA	BOTTOM REINF DEPTH	NO. SEGM.
4	8.000E+00	1.200E+01	1.000E+00	2.000E+00	1.000E+00	1.000E+01	12
94	8.000E+00	1.200E+01	1.000E+00	2.000E+00	1.000E+00	1.000E+01	12

TABLE 3. STRESS-STRAIN CURVES

CURVE NO. 1
STRESS VALUE SCALE FACTOR 1.000E+03
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES
0.000 -2.000 -4.000 -4.010 -4.000 .001 .002 .003 .004 .005
STRAIN INPUT VALUES
-10.000 -6.250 -2.500 -2.000 -1.500 2.000 4.000 6.000 8.000 10.000

CURVE NO. 2
STRESS VALUE SCALE FACTOR 1.000E+04
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES
-4.740 -4.730 -4.720 -4.710 -4.700 4.700 4.710 4.720 4.730 4.740
STRAIN INPUT VALUES
-15.700-12.200 -8.640 -5.100 -1.570 1.570 5.100 8.640 12.200 15.700

TABLE 4. BEAM/COLUMN MASS AND ELASTIC SUPPORTS

FROM STA	TO STA	CONT CODE	MASS	HORIZONTAL SUPPORT	VERTICAL SUPPORT	SUPPORT CODE
4	4	3	-0.	1.000E+10	1.000E+10	AL
94	94	0	-0.	1.000E+10	1.000E+10	AL

TABLE 5. STATIC LOADS

FROM STA	TO STA	CONT CODE	HORIZONTAL LOAD	VERTICAL LOAD
24	24	3	1.000E+03	-0.
34	34	0	-0.	-5.000E+03

TABLE 6. IMPULSE LOADING

NONE

TABLE 7. COLLAPSE PARAMETERS

NONE

```
PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
                UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
     CODED 1-12-73 BY GMR

PROBLEM IPF3

           SIMPLE REINFORCED CONCRETE BEAM - COMBINED STATIC AND DYNAMIC LOADS


TABLE 1. PROGRAM CONTROL DATA

     NO KEEP OPTIONS EXERCISED

     STATIC SOLUTION REQUIRED        YES
     STATIC OUTPUT OPTION              2
     NUMBER OF DYNAMIC LOADINGS        1
     DYNAMIC OUTPUT OPTION             2
     OUTPUT INTERVAL                   5
     TIME LIMIT                1.000E-02
     TIME INTERVAL              INTERNAL


TABLE 2. JOINT COORDINATES AND CROSS SECTION DESCRIPTION


   A.JOINT COORDINATES AND MATERIAL

        JT.NO.        X-COORD          Y-COORD          MATERIAL

         24          1.800E+02        0.                   1

   B.CROSS SECTION AND REINFORCEMENT DESCRIPTION

        STA      WIDTH    DEPTH        TOP REINF         BOTTOM REINF      NO.
                 SECT.    SECT.      AREA    DEPTH      AREA      DEPTH   SEGM.


          4 8.000E+00 1.200E+01 0.          0.        1.000E+00 1.000E+01  12
         24 8.000E+00 1.200E+01 0.          0.        1.000E+00 1.000E+01  12


TABLE 3. STRESS-STRAIN CURVES


     CURVE NO. 1
          STRESS VALUE SCALE FACTOR    1.000E+03
          STRAIN VALUE SCALE FACTOR    1.000E-03

     STRESS INPUT VALUES
           0.000 -2.000 -4.000 -4.010 -4.000   .001   .002   .003   .004   .005
     STRAIN INPUT VALUES
          [illegible] -6.250 -2.500 -2.000 -1.500  2.000  4.000  6.000  8.000 10.000


     CURVE NO. 2
          STRESS VALUE SCALE FACTOR    1.000E+04
          STRAIN VALUE SCALE FACTOR    1.000E-03

     STRESS INPUT VALUES
           -4.740 -4.730 -4.720 -4.710 -4.700  4.700  4.710  4.720  4.730  4.740
     STRAIN INPUT VALUES
          -15.700-12.200 [illegible] -5.100 -1.570  1.570  5.100  8.640 12.200 15.700
```

```
TABLE 4. BEAM/COLUMN MASS AND ELASTIC SUPPORTS

     FROM  TO  CONT          MASS                HORIZONTAL   VERTICAL    SUPPORT
     STA   STA CODE                               SUPPORT     SUPPORT      CODE

       4    24   3       2.160E-02              -0.          -0.
       4     4   3      -0.                     -0.           1.000E+10    SL
      14    14   3      -0.                      1.000E+10   -0.           SA
      24    24   0      -0.                     -0.           1.000E+10    SL


TABLE 5. STATIC LOADS

     FROM  TO  CONT    HORIZONTAL    VERTICAL
     STA   STA CODE       LOAD         LOAD

       4    24   0     -0.          -4.167E+01


TABLE 6. IMPULSE LOADING


     IMPULSE LOADING NUMBER  1

       INITIAL              INTERMEDIATE             FINAL           LOADING
     STA   IMPULSE          STA   IMPULSE         STA   IMPULSE       CODE

       4    0.               6  -7.725E+00         8  -1.469E+01        1
       8  -1.469E+01        14  -2.500E+01        20  -1.469E+01        1
      20  -1.469E+01        22  -7.725E+00        24   0.               1


TABLE 7. COLLAPSE PARAMETERS


     DISPLACEMENT LIMITS

          MAX HORIZONTAL      MAX VERTICAL
               DEFL               DEFL
             2.000E+00          3.000E+00


     SHEAR LIMITS

                 TERM      SHEAR
                  STA      VALUE

                  24    3.000E+04


     INTERACTION DIAGRAM DATA

          MULTIPLIERS
                 TERM AXIAL FORCE          MOMENT
                  STA  MULTIPLIER        MULTIPLIER
                  24    1.000E+05         1.000E+05


          COMPRESSIVE STRAIN AT P-ULT    2.000E-03

          AXIAL FORCE INPUT VALUES
                 -0.000  1.200  2.300  3.050  4.270  2.500  1.100   .550 [illegible]
          MOMENT INPUT VALUES
                  -.490 -5.000 -6.600 -5.500 -0.000  5.300  7.700  6.500  +.350
```

PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
CODED 5-25-73 BY GMR

PROBLEM IPF4

PORTAL FRAME WITH SINUSOIDAL IMPULSE LOAD ON BEAM AND COLUMNS

TABLE 1. PROGRAM CONTROL DATA

NO KEEP OPTIONS EXERCISED

STATIC SOLUTION REQUIRED	NO
NUMBER OF DYNAMIC LOADINGS	1
DYNAMIC OUTPUT OPTION	2
OUTPUT INTERVAL	10
TIME LIMIT	1.000E-01
TIME INTERVAL	2.000E-05

TABLE 2. JOINT COORDINATES AND CROSS SECTION DESCRIPTION

A. JOINT COORDINATES AND MATERIAL

JT.NO.	X-COORD	Y-COORD	MATERIAL
24	0.	9.600E+01	1
44	9.600E+01	9.600E+01	1
64	9.600E+01	0.	1

B. CROSS SECTION AND REINFORCEMENT DESCRIPTION

STA	WIDTH SECT.	DEPTH SECT.	TOP REINF AREA	TOP REINF DEPTH	BOTTOM REINF AREA	BOTTOM REINF DEPTH	NO. SEGM.
4	4.000E+00	6.000E+00	-0.	-0.	-0.	-0.	6
64	4.000E+00	6.000E+00	-0.	-0.	-0.	-0.	6

TABLE 3. STRESS-STRAIN CURVES

CURVE NO. 1
STRESS VALUE SCALE FACTOR 1.000E+04
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES
-4.740 -4.730 -4.720 -4.710 -4.700 4.700 4.710 4.720 4.730 4.740
STRAIN INPUT VALUES
-15.700 -12.200 -8.640 -5.100 -1.570 1.570 5.100 8.640 12.200 15.700

TABLE 4. BEAM/COLUMN MASS AND ELASTIC SUPPORTS

FROM STA	TO STA	CONT CODE	MASS	HORIZONTAL SUPPORT	VERTICAL SUPPORT	SUPPORT CODE
4	64	3	1.750E-01	-0.	-0.	
4	4	3	-0.	1.000E+10	1.000E+10	AL
64	64		-0.	1.000E+10	1.000E+10	AL

TABLE 5. STATIC LOADS

FROM STA	TO STA	CONT CODE	HORIZONTAL LOAD	VERTICAL LOAD
-0	-0	-0	-0.	-0.

TABLE 6. IMPULSE LOADING

IMPULSE LOADING NUMBER 1

INITIAL STA	INITIAL IMPULSE	INTERMEDIATE STA	INTERMEDIATE IMPULSE	FINAL STA	FINAL IMPULSE	LOADING CODE
4	0.	6	-7.725E+00	8	-1.469E+01	2
8	-1.469E+01	14	-2.500E+01	20	-1.469E+01	2
20	-1.469E+01	22	-7.725E+00	24	0.	2
24	0.	26	-7.725E+00	28	-1.469E+01	1
28	-1.469E+01	34	-2.500E+01	40	-1.469E+01	1
40	-1.469E+01	42	-7.725E+00	44	0.	1
44	0.	46	-7.725E+00	48	-1.469E+01	2
48	-1.469E+01	54	-2.500E+01	60	-1.469E+01	2
60	-1.469E+01	62	-7.725E+00	64	0.	2

TABLE 7. COLLAPSE PARAMETERS

DISPLACEMENT LIMITS

MAX HORIZONTAL DEFL	MAX VERTICAL DEFL
2.000E+01	2.000E+01

SHEAR LIMITS

TERM STA	SHEAR VALUE
64	3.000E+10

INTERACTION DIAGRAM DATA

MULTIPLIERS

TERM STA	AXIAL FORCE MULTIPLIER	MOMENT MULTIPLIER
64	1.000E+15	1.000E+15

COMPRESSIVE STRAIN AT P-ULT 2.000E-03

AXIAL FORCE INPUT VALUES
-[illegible] 1.2[illegible] 2.0[illegible] 3.03[illegible] 4.27[illegible] 2.5[illegible] 1.1[illegible] .35[illegible] -[illegible]
MOMENT INPUT VALUES
-4.3[illegible] -[illegible] -6.5[illegible] -5.5[illegible] -[illegible] 5.3[illegible] 7.7[illegible] 6.5[illegible] 4.35[illegible]

PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
CODED 5-22-73 BY GMR

PROBLEM IPF6

PORTAL FRAME WITH SINUSOIDAL IMPULSE LOAD ON BEAM

TABLE 1. PROGRAM CONTROL DATA

NO KEEP OPTIONS EXERCISED

STATIC SOLUTION REQUIRED	YES
STATIC OUTPUT OPTION	2
NUMBER OF DYNAMIC LOADINGS	1
DYNAMIC OUTPUT OPTION	2
OUTPUT INTERVAL	1
TIME LIMIT	1.000E-02
TIME INTERVAL	1.000E-06

TABLE 2. JOINT COORDINATES AND CROSS SECTION DESCRIPTION

A. JOINT COORDINATES AND MATERIAL

JT.NO.	X-COORD	Y-COORD	MATERIAL
32	0.	1.680E+02	1
66	2.040E+02	1.680E+02	1
94	2.040E+02	0.	1

B. CROSS SECTION AND REINFORCEMENT DESCRIPTION

STA	WIDTH SECT.	DEPTH SECT.	TOP REINF AREA	TOP REINF DEPTH	BOTTOM REINF AREA	BOTTOM REINF DEPTH	NO. SEGM.
4	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12
32	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12
33	1.000E+01	1.400E+01	1.320E+00	2.000E+00	1.320E+00	1.200E+01	12
65	1.000E+01	1.400E+01	1.320E+00	2.000E+00	1.320E+00	1.200E+01	12
66	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12
94	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12

TABLE 3. STRESS-STRAIN CURVES

CURVE NO. 1
STRESS VALUE SCALE FACTOR 1.000E+03
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES
0.000 -2.000 -5.000 -5.000 -5.000 .001 .002 .003 .004 .005
STRAIN INPUT VALUES
-10.000 -6.250 -2.500 -2.000 -1.250 2.000 4.000 6.000 8.000 10.000

CURVE NO. 2
STRESS VALUE SCALE FACTOR 1.000E+04
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES
-6.040 -6.030 -6.020 -6.010 -6.000 6.000 6.010 6.020 6.030 6.040
STRAIN INPUT VALUES
-15.700 -12.200 -8.640 -5.100 -2.000 2.000 5.100 8.640 12.200 15.700

TABLE 4. BEAM/COLUMN MASS AND ELASTIC SUPPORTS

FROM STA	TO STA	CONT CODE	MASS	HORIZONTAL SUPPORT	VERTICAL SUPPORT	SUPPORT CODE
4	31	3	2.963E-02	-0.	-0.	
32	65	3	3.340E-02	-0.	-0.	
67	94	3	2.963E-02	-0.	-0.	
4	4	3	-0.	1.000E+10	1.000E+10	AL
5	5	3	-0.	1.000E+10	-0.	SA
93	93	3	-0.	1.000E+10	-0.	SA
94	94	3	-0.	1.000E+10	1.000E+10	AL

TABLE 5. STATIC LOADS

FROM STA	TO STA	CONT CODE	HORIZONTAL LOAD	VERTICAL LOAD
4	31	3	-0.	-1.144E+01
32	65	3	-0.	-1.290E+01
67	94	3	-0.	-1.144E+01

TABLE 6. IMPULSE LOADING

IMPULSE LOADING NUMBER 1

INITIAL STA	INITIAL IMPULSE	INTERMEDIATE STA	INTERMEDIATE IMPULSE	FINAL STA	FINAL IMPULSE	LOADING CODE
32	0.	36	-7.725E+00	40	-1.469E+01	1
40	-1.469E+01	49	-2.500E+01	58	-1.469E+01	1
58	-1.469E+01	62	-7.725E+00	66	0.	1

TABLE 7. COLLAPSE PARAMETERS

DISPLACEMENT LIMITS

MAX HORIZONTAL DEFL	MAX VERTICAL DEFL
2.000E+00	2.500E+00

SHEAR LIMITS

TERM STA	SHEAR VALUE
4	4.250E+04
31	4.250E+04
66	5.000E+04
94	4.250E+04

INTERACTION DIAGRAM DATA

MULTIPLIERS

TERM STA	AXIAL FORCE MULTIPLIER	MOMENT MULTIPLIER
94	7.000E+05	9.800E+06

COMPRESSIVE STRAIN AT P-ULT 2.000E-03

AXIAL FORCE INPUT VALUES
-3.000 .210 .320 .480 1.530 .480 .320 .210 -3.000
MOMENT INPUT VALUES
-.210 -.260 -.270 -.250 -0.000 .250 .270 .260 .210

PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
CODED 5-22-73 BY GMR

PROBLEM IPF7

PORTAL FRAME WITH SINUSOIDAL IMPULSE LOAD ON RIGHT COLUMN

TABLE 1. PROGRAM CONTROL DATA

NO KEEP OPTIONS EXERCISED

STATIC SOLUTION REQUIRED	YES
STATIC OUTPUT OPTION	2
NUMBER OF DYNAMIC LOADINGS	1
DYNAMIC OUTPUT OPTION	2
OUTPUT INTERVAL	1
TIME LIMIT	1.000E-02
TIME INTERVAL	5.000E-06

TABLE 2. JOINT COORDINATES AND CROSS SECTION DESCRIPTION

A. JOINT COORDINATES AND MATERIAL

JT.NO.	X-COORD	Y-COORD	MATERIAL
32	0.	1.680E+02	1
66	2.040E+02	1.680E+02	1
94	2.040E+02	0.	1

B. CROSS SECTION AND REINFORCEMENT DESCRIPTION

STA	WIDTH SECT.	DEPTH SECT.	TOP REINF AREA	TOP REINF DEPTH	BOTTOM REINF AREA	BOTTOM REINF DEPTH	NO. SEGM.
4	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12
32	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12
33	1.000E+01	1.400E+01	1.320E+00	2.000E+00	1.320E+00	1.200E+01	12
65	1.000E+01	1.400E+01	1.320E+00	2.000E+00	1.320E+00	1.200E+01	12
66	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12
94	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12

TABLE 3. STRESS-STRAIN CURVES

CURVE NO. 1
STRESS VALUE SCALE FACTOR 1.000E+03
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES
0.000 -2.000 -5.000 -5.000 -5.000 .001 .002 .003 .004 .005
STRAIN INPUT VALUES
-10.000 -6.250 -2.500 -2.000 -1.250 2.000 4.000 6.000 8.000 10.000

CURVE NO. 2
STRESS VALUE SCALE FACTOR 1.000E+04
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES
-6.040 -6.030 -6.020 -6.010 -6.000 6.000 6.010 6.020 6.030 6.040
STRAIN INPUT VALUES
-15.700 -12.200 -8.640 -5.100 -2.000 2.000 5.100 8.640 12.200 15.700

TABLE 4. BEAM/COLUMN MASS AND ELASTIC SUPPORTS

FROM STA	TO STA	CONT CODE	MASS	HORIZONTAL SUPPORT	VERTICAL SUPPORT	SUPPORT CODE
4	31	3	2.963E-02	-0.	-0.	
32	66	3	3.340E-02	-0.	-0.	
67	94	3	2.963E-02	-0.	-0.	
4	4	3	-0.	1.000E+10	1.000E+10	AL
5	5	3	-0.	1.000E+10	-0.	SA
93	93	3	-0.	1.000E+10	-0.	SA
94	94	0	-0.	1.000E+10	1.000E+10	AL

TABLE 5. STATIC LOADS

FROM STA	TO STA	CONT CODE	HORIZONTAL LOAD	VERTICAL LOAD
4	31	3	-0.	-1.144E+01
32	65	3	-0.	-1.290E+01
67	94	0	-0.	-1.144E+01

TABLE 6. IMPULSE LOADING

IMPULSE LOADING NUMBER 1

INITIAL STA	INITIAL IMPULSE	INTERMEDIATE STA	INTERMEDIATE IMPULSE	FINAL STA	FINAL IMPULSE	LOADING CODE
66	0.	69	7.725E+00	72	1.469E+01	2
72	1.469E+01	80	2.500E+01	88	1.469E+01	2
88	7.345E+00	91	3.863E+00	94	0.	2

TABLE 7. COLLAPSE PARAMETERS

DISPLACEMENT LIMITS

MAX HORIZONTAL DEFL	MAX VERTICAL DEFL
2.000E+00	2.500E+00

SHEAR LIMITS

TERM STA	SHEAR VALUE
4	4.250E+04
31	4.250E+04
66	5.000E+04
94	4.250E+04

INTERACTION DIAGRAM DATA

MULTIPLIERS

TERM STA	AXIAL FORCE MULTIPLIER	MOMENT MULTIPLIER
94	7.000E+05	9.800E+06

COMPRESSIVE STRAIN AT P-ULT 2.000E-03

AXIAL FORCE INPUT VALUES
-0.000 .210 .320 .480 1.530 .480 .320 .210 -0.000
MOMENT INPUT VALUES
-.210 -.260 -.270 -.250 -0.000 .250 .270 .260 .210

PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
CODED 5-22-73 BY GMR

PROBLEM IPF8

PORTAL FRAME WITH SINUSOIDAL IMPULSE LOAD ON BEAM AND RIGHT COLUMN

TABLE 1. PROGRAM CONTROL DATA

NO KEEP OPTIONS EXERCISED

STATIC SOLUTION REQUIRED	YES
STATIC OUTPUT OPTION	2
NUMBER OF DYNAMIC LOADINGS	1
DYNAMIC OUTPUT OPTION	2
OUTPUT INTERVAL	1
TIME LIMIT	1.000E-02
TIME INTERVAL	5.000E-06

TABLE 2. JOINT COORDINATES AND CROSS SECTION DESCRIPTION

A.JOINT COORDINATES AND MATERIAL

JT.NO.	X-COORD	Y-COORD	MATERIAL
32	0.	1.680E+02	1
65	2.040E+02	1.680E+02	1
94	2.040E+02	0.	1

B.CROSS SECTION AND REINFORCEMENT DESCRIPTION

STA	WIDTH SECT.	DEPTH SECT.	TOP REINF AREA	TOP REINF DEPTH	BOTTOM REINF AREA	BOTTOM REINF DEPTH	NO. SEGM.
4	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12
32	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12
33	1.000E+01	1.400E+01	1.320E+00	2.000E+00	1.320E+00	1.200E+01	12
65	1.000E+01	1.400E+01	1.320E+00	2.000E+00	1.320E+00	1.200E+01	12
66	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12
94	1.000E+01	1.200E+01	1.800E+00	2.000E+00	1.800E+00	1.000E+01	12

TABLE 3. STRESS-STRAIN CURVES

CURVE NO. 1
STRESS VALUE SCALE FACTOR 1.000E+03
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES
0.000 -2.000 -5.000 -5.000 -5.000 .001 .002 .003 .004 .005
STRAIN INPUT VALUES
-10.000 -6.250 -2.500 -2.000 -1.250 2.000 4.000 6.000 8.000 10.000

CURVE NO. 2
STRESS VALUE SCALE FACTOR 1.000E+04
STRAIN VALUE SCALE FACTOR 1.000E-03

STRESS INPUT VALUES
-6.040 -6.030 -6.020 -6.010 -6.000 6.000 6.010 6.020 6.030 6.040
STRAIN INPUT VALUES
-15.700 -12.230 -8.640 -5.100 -2.000 2.000 5.100 8.640 12.230 15.700

TABLE 4. BEAM/COLUMN MASS AND ELASTIC SUPPORTS

FROM STA	TO STA	CONT CODE	MASS	HORIZONTAL SUPPORT	VERTICAL SUPPORT	SUPPORT CODE
4	31	3	2.963E-02	-0.	-0.	
32	66	3	3.340E-02	-0.	-0.	
67	94	3	2.963E-02	-0.	-0.	
4	4	3	-0.	1.000E+10	1.000E+10	AL
5	5	3	-0.	1.000E+10	-0.	SA
93	93	3	-0.	1.000E+10	-0.	SA
94	94	[illegible]	-0.	1.000E+10	1.000E+10	AL

TABLE 5. STATIC LOADS

FROM STA	TO STA	CONT CODE	HORIZONTAL LOAD	VERTICAL LOAD
4	31	3	-0.	-1.144E+01
32	66	3	-0.	-1.290E+01
67	94	0	-0.	-1.144E+01

TABLE 6. IMPULSE LOADING

IMPULSE LOADING NUMBER 1

INITIAL STA	INITIAL IMPULSE	INTERMEDIATE STA	INTERMEDIATE IMPULSE	FINAL STA	FINAL IMPULSE	LOADING CODE
32	0.	36	-3.863E-01	40	-7.345E-01	1
40	-7.345E-01	49	-1.250E+00	58	-2.127E+00	1
58	-2.127E+00	62	-4.045E+00	66	0.	1
66	0.	69	4.045E+00	72	2.127E+00	2
72	4.045E+00	80	1.250E+00	88	7.345E-01	2
88	7.345E-01	91	3.863E-01	94	0.	2

TABLE 7. COLLAPSE PARAMETERS

DISPLACEMENT LIMITS

MAX HORIZONTAL DEFL	MAX VERTICAL DEFL
2.000E+00	2.500E+00

SHEAR LIMITS

TERM STA	SHEAR VALUE
4	4.250E+04
31	4.250E+04
66	5.000E+04
94	4.250E+04

INTERACTION DIAGRAM DATA

MULTIPLIERS

TERM STA	AXIAL FORCE MULTIPLIER	MOMENT MULTIPLIER
94	[illegible]E+05	9.8[illegible]E+06

COMPRESSIVE STRAIN AT P-[illegible] 2.000E-03

AXIAL FORCE INPUT VALUES
[illegible] .210 .320 .480 1.530 .480 .320 .210 -0.000
MOMENT INPUT VALUES
-.210 -.250 -.270 -.250 -0.000 .250 .270 .250 .210

PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
CODED 1-12-73 BY GMR

PROBLEM IPF1

PORTAL FRAME WITH UNIFORM LOAD ON BEAM - STATIC SOLUTION ONLY

COMPLETE RESPONSE, TIME = 0.

STA	X COORD	Y COORD	THRUST	MOMENT	SHEAR
0	0.	0.		2.4645E-09	
			-3.7503E+03		-3.7382E+02
1	0.	9.0000E+00		-3.3644E+03	
			-3.7503E+03		-3.7382E+02
2	0.	1.8000E+01		-6.7288E+03	
			-3.7503E+03		-3.7382E+02
3	0.	2.7000E+01		-1.0093E+04	
			-3.7503E+03		-3.7382E+02
4	0.	3.6000E+01		-1.3458E+04	
			-3.7503E+03		-3.7382E+02
5	0.	4.5000E+01		-1.6822E+04	
			-3.7503E+03		-3.7382E+02
6	0.	5.4000E+01		-2.0186E+04	
			-3.7503E+03		-3.7382E+02
7	0.	6.3000E+01		-2.3551E+04	
			-3.7503E+03		-3.7382E+02
8	0.	7.2000E+01		-2.6915E+04	
			-3.7503E+03		-3.7382E+02
9	0.	8.1000E+01		-3.0279E+04	
			-3.7503E+03		-3.7382E+02
10	0.	9.0000E+01		-3.3644E+04	
			-3.7503E+03		-3.7382E+02
11	0.	9.9000E+01		-3.7008E+04	
			-3.7503E+03		-3.7382E+02
12	0.	1.0800E+02		-4.0373E+04	
			-3.7503E+03		-3.7382E+02
13	0.	1.1700E+02		-4.3737E+04	
			-3.7503E+03		-3.7382E+02
14	0.	1.2600E+02		-4.7101E+04	
			-3.7503E+03		-3.7382E+02
15	0.	1.3500E+02		-5.0466E+04	
			-3.7503E+03		-3.7382E+02
16	0.	1.4400E+02		-5.3830E+04	
			-3.7503E+03		-3.7382E+02
17	0.	1.5300E+02		-5.7194E+04	
			-3.7503E+03		-3.7382E+02
18	0.	1.6200E+02		-6.0559E+04	
			-3.7503E+03		-3.7382E+02
19	0.	1.7100E+02		-6.3923E+04	
			-3.7503E+03		-3.7382E+02
20	0.	1.8000E+02		-6.7288E+04	
			-3.7382E+02		3.5628E+03
21	9.0000E+00	1.8000E+02		-3.5222E+04	
			-3.7382E+02		3.1878E+03
22	1.8000E+01	1.8000E+02		-6.5326E+03	
			-3.7382E+02		2.8127E+03
23	2.7000E+01	1.8000E+02		1.8782E+04	
			-3.7382E+02		2.4377E+03
24	3.6000E+01	1.8000E+02		4.0721E+04	
			-3.7382E+02		2.0627E+03
25	4.5000E+01	1.8000E+02		5.9285E+04	
			-3.7382E+02		1.6876E+03
26	5.4000E+01	1.8000E+02		7.4474E+04	
			-3.7382E+02		1.3126E+03
27	6.3000E+01	1.8000E+02		8.6287E+04	
			-3.7382E+02		9.3757E+02
28	7.2000E+01	1.8000E+02		9.4725E+04	
			-3.7382E+02		5.6254E+02
29	8.1000E+01	1.8000E+02		9.9788E+04	
			-3.7382E+02		1.8751E+02
30	9.0000E+01	1.8000E+02		1.0148E+05	
			-3.7382E+02		-1.8751E+02
31	9.9000E+01	1.8000E+02		9.9788E+04	
			-3.7382E+02		-5.6254E+02
32	1.0800E+02	1.8000E+02		9.4725E+04	
			-3.7382E+02		-9.3757E+02
33	1.1700E+02	1.8000E+02		8.6287E+04	
			-3.7382E+02		-1.3126E+03
34	1.2600E+02	1.8000E+02		7.4474E+04	
			-3.7382E+02		-1.6876E+03
35	1.3500E+02	1.8000E+02		5.9285E+04	
			-3.7382E+02		-2.0627E+03
36	1.4400E+02	1.8000E+02		4.0721E+04	
			-3.7382E+02		-2.4377E+03
37	1.5300E+02	1.8000E+02		1.8782E+04	
			-3.7382E+02		-2.8127E+03
38	1.6200E+02	1.8000E+02		-6.5326E+03	
			-3.7382E+02		-3.1878E+03
39	1.7100E+02	1.8000E+02		-3.5222E+04	
			-3.7382E+02		-3.5628E+03
40	1.8000E+02	1.8000E+02		-6.7288E+04	
			-3.7503E+03		3.7382E+02
41	1.8000E+02	1.7100E+02		-6.3923E+04	
			-3.7503E+03		3.7382E+02
42	1.8000E+02	1.6200E+02		-6.0559E+04	
			-3.7503E+03		3.7382E+02
43	1.8000E+02	1.5300E+02		-5.7194E+04	
			-3.7503E+03		3.7382E+02
44	1.8000E+02	1.4400E+02		-5.3830E+04	
			-3.7503E+03		3.7382E+02
45	1.8000E+02	1.3500E+02		-5.0466E+04	
			-3.7503E+03		3.7382E+02
46	1.8000E+02	1.2600E+02		-4.7101E+04	
			-3.7503E+03		3.7382E+02
47	1.8000E+02	1.1700E+02		-4.3737E+04	
			-3.7503E+03		3.7382E+02
48	1.8000E+02	1.0800E+02		-4.0373E+04	
			-3.7503E+03		3.7382E+02
49	1.8000E+02	9.9000E+01		-3.7008E+04	
			-3.7503E+03		3.7382E+02
50	1.8000E+02	9.0000E+01		-3.3644E+04	
			-3.7503E+03		3.7382E+02
51	1.8000E+02	8.1000E+01		-3.0279E+04	
			-3.7503E+03		3.7382E+02
52	1.8000E+02	7.2000E+01		-2.6915E+04	
			-3.7503E+03		3.7382E+02
53	1.8000E+02	6.3000E+01		-2.3551E+04	
			-3.7503E+03		3.7382E+02
54	1.8000E+02	5.4000E+01		-2.0186E+04	
			-3.7503E+03		3.7382E+02
55	1.8000E+02	4.5000E+01		-1.6822E+04	
			-3.7503E+03		3.7382E+02
56	1.8000E+02	3.6000E+01		-1.3458E+04	
			-3.7503E+03		3.7382E+02
57	1.8000E+02	2.7000E+01		-1.0093E+04	
			-3.7503E+03		3.7382E+02
58	1.8000E+02	1.8000E+01		-6.7288E+03	
			-3.7503E+03		3.7382E+02
59	1.8000E+02	9.0000E+00		-3.3644E+03	
			-3.7503E+03		3.7382E+02
60	1.8000E+02	0.		0.	

STA	X DISP	Y DISP
0	-3.7382E-08	-3.7503E-07
1	-1.1325E-02	-2.6279E-04
2	-2.2480E-02	-5.2520E-04
3	-3.3294E-02	-7.8762E-04
4	-4.3597E-02	-1.0500E-03
5	-5.3217E-02	-1.3124E-03
6	-6.1985E-02	-1.5749E-03
7	-6.9730E-02	-1.8373E-03
8	-7.6281E-02	-2.0997E-03
9	-8.1468E-02	-2.3621E-03
10	-8.5121E-02	-2.6245E-03
11	-8.7069E-02	-2.8869E-03
12	-8.7141E-02	-3.1493E-03
13	-8.5167E-02	-3.4118E-03
14	-8.0977E-02	-3.6742E-03
15	-7.4399E-02	-3.9366E-03
16	-6.5264E-02	-4.1990E-03
17	-5.3401E-02	-4.4614E-03
18	-3.8639E-02	-4.7238E-03
19	-2.0809E-02	-4.9862E-03
20	2.6157E-04	-5.2487E-03
21	2.3541E-04	-2.9729E-02
22	2.0925E-04	-5.5994E-02
23	1.8310E-04	-8.2591E-02
24	1.5694E-04	-1.0824E-01
25	1.3078E-04	-1.3182E-01
26	1.0463E-04	-1.5239E-01
27	7.8470E-05	-1.6920E-01
28	5.2313E-05	-1.8162E-01
29	2.6157E-05	-1.8925E-01
30	6.5083E-12	-1.9182E-01
31	-2.6157E-05	-1.8925E-01
32	-5.2313E-05	-1.8162E-01
33	-7.8470E-05	-1.6920E-01
34	-1.0463E-04	-1.5239E-01
35	-1.3078E-04	-1.3182E-01
36	-1.5694E-04	-1.0824E-01
37	-1.8310E-04	-8.2591E-02
38	-2.0925E-04	-5.5994E-02
39	-2.3541E-04	-2.9729E-02
40	-2.6157E-04	-5.2487E-03
41	2.0809E-02	-4.9862E-03
42	3.8639E-02	-4.7238E-03
43	5.3401E-02	-4.4614E-03
44	6.5264E-02	-4.1990E-03
45	7.4399E-02	-3.9366E-03
46	8.0977E-02	-3.6742E-03
47	8.5167E-02	-3.4118E-03
48	8.7141E-02	-3.1493E-03
49	8.7069E-02	-2.8869E-03
50	8.5121E-02	-2.6245E-03
51	8.1468E-02	-2.3621E-03
52	7.6281E-02	-2.0997E-03
53	6.9730E-02	-1.8373E-03
54	6.1985E-02	-1.5749E-03
55	5.3217E-02	-1.3124E-03
56	4.3597E-02	-1.0500E-03
57	3.3294E-02	-7.8762E-04
58	2.2480E-02	-5.2520E-04
59	1.1325E-02	-2.6279E-04
60	3.7382E-08	-3.7503E-07

PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
CODED 1-12-73 BY GMR

PROBLEM IPF3

SIMPLE REINFORCED CONCRETE BEAM - COMBINED STATIC AND DYNAMIC LOADS

COMPLETE RESPONSE, TIME = 0.

STA	X COORD	Y COORD	THRUST	MOMENT	SHEAR
0	0.	0.		-1.7795E-08	
			0.		3.5628E+03
1	9.0000E+00	0.		3.2065E+04	
			0.		3.1878E+03
2	1.8000E+01	0.		6.0755E+04	
			0.		2.8127E+03
3	2.7000E+01	0.		8.6069E+04	
			0.		2.4377E+03
4	3.6000E+01	0.		1.0801E+05	
			0.		2.0627E+03
5	4.5000E+01	0.		1.2657E+05	
			0.		1.6876E+03
6	5.4000E+01	0.		1.4176E+05	
			0.		1.3126E+03
7	6.3000E+01	0.		1.5357E+05	
			0.		9.3757E+02
8	7.2000E+01	0.		1.6201E+05	
			0.		5.6254E+02
9	8.1000E+01	0.		1.6708E+05	
			0.		1.8752E+02
10	9.0000E+01	0.		1.6876E+05	
			0.		-1.8751E+02
11	9.9000E+01	0.		1.6708E+05	
			0.		-5.6254E+02
12	1.0800E+02	0.		1.6201E+05	
			0.		-9.3757E+02
13	1.1700E+02	0.		1.5357E+05	
			0.		-1.3126E+03
14	1.2600E+02	0.		1.4176E+05	
			0.		-1.6876E+03
15	1.3500E+02	0.		1.2657E+05	
			0.		-2.0627E+03
16	1.4400E+02	0.		1.0801E+05	
			0.		-2.4377E+03
17	1.[illegible]+02	0.		8.6069E+04	
			0.		-2.8127E+03
18	1.6200E+02	0.		6.0755E+04	
			0.		-3.1878E+03
19	1.7[illegible]E+02	0.		3.2065E+04	
			0.		-3.5628E+03
20	1.8000E+02	0.		4.4488E-09	

STA	X DISP	Y DISP
0	0.	-3.7503E-07
1	0.	-6.3017E-02
2	0.	-1.2423E-01
3	0.	-1.8204E-01
4	0.	-2.3501E-01
5	0.	-2.8192E-01
6	0.	-3.2172E-01
7	0.	-3.5356E-01
8	0.	-3.7677E-01
9	0.	-3.9089E-01
10	0.	-3.9563E-01
11	0.	-3.9089E-01
12	0.	-3.7677E-01
13	0.	-3.5356E-01
14	0.	-3.2172E-01
15	0.	-2.8192E-01
16	0.	-2.3501E-01
17	0.	-1.8204E-01
18	0.	-1.2423E-01
19	0.	-6.3017E-02
20	0.	-3.7503E-07

FAILURE DUE TO THRUST-MOMENT INTERACTION AT X = 7.2000E+01 Y = 0.

FAILURE DUE TO THRUST-MOMENT INTERACTION AT X = 1.0800E+02 Y = 0.

FAILURE AT TIME = 1.1324E-03

PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
CODED 1-12-73 BY GMR

PROBLEM IPF3

SIMPLE REINFORCED CONCRETE BEAM - COMBINED STATIC AND DYNAMIC LOADS

COMPLETE RESPONSE, TIME = 1.1324E-03

STA	X COORD	Y COORD	THRUST	MOMENT	SHEAR
0	0.	0.		0.	
			4.3236E+03		1.3587E+04
1	9.0000E+00	0.		1.2228E+05	
			5.0270E+03		1.4555E+04
2	1.8000E+01	0.		2.5328E+05	
			-2.5067E+02		1.1719E+04
3	2.7000E+01	0.		3.5875E+05	
			-2.2530E+03		5.3516E+03
4	3.6000E+01	0.		4.0692E+05	
			-3.1048E+03		2.1659E+03
5	4.5000E+01	0.		4.2641E+05	
			-6.7713E+03		9.9044E+02
6	5.4000E+01	0.		4.3532E+05	
			-6.9602E+03		9.2697E+02
7	6.3000E+01	0.		4.4367E+05	
			-9.5632E+03		8.2609E+02
8	7.2000E+01	0.		4.5110E+05	
			-1.3086E+04		1.5561E+02
9	8.1000E+01	0.		4.5250E+05	
			-1.4547E+04		4.9900E+01
10	9.0000E+01	0.		4.5295E+05	
			-1.4547E+04		-4.9900E+01
11	9.9000E+01	0.		4.5250E+05	
			-1.3086E+04		-1.5561E+02
12	1.0800E+02	0.		4.5110E+05	
			-9.5632E+03		-8.2609E+02
13	1.1700E+02	0.		4.4367E+05	
			-6.9602E+03		-9.2697E+02
14	1.2600E+02	0.		4.3532E+05	
			-6.7713E+03		-9.9044E+02
15	1.3500E+02	0.		4.2641E+05	
			-3.1048E+03		-2.1659E+03
16	1.4400E+02	0.		4.0692E+05	
			-2.2530E+03		-5.3516E+03
17	1.5300E+02	0.		3.5875E+05	
			-2.5067E+02		-1.1719E+04
18	1.6200E+02	0.		2.5328E+05	
			5.0270E+03		-1.4555E+04
19	1.7100E+02	0.		1.2228E+05	
			4.3236E+03		-1.3587E+04
20	1.8000E+02	0.		0.	

STA	X DISP	Y DISP
0	1.2329E-02	0.
1	8.6294E-03	-2.6728E-01
2	4.9405E-03	-5.2813E-01
3	1.0277E-03	-7.7554E-01
4	-2.6807E-03	-1.0039E+00
5	-5.0114E-03	-1.2094E+00
6	-5.8378E-03	-1.3849E+00
7	-4.8964E-03	-1.5250E+00
8	-3.0679E-03	-1.6253E+00
9	-1.3823E-03	-1.6845E+00
10	0.	-1.7040E+00
11	1.3823E-03	-1.6845E+00
12	3.0679E-03	-1.6253E+00
13	4.8964E-03	-1.5250E+00
14	5.8378E-03	-1.3849E+00
15	5.0114E-03	-1.2094E+00
16	2.6807E-03	-1.0039E+00
17	-1.0277E-03	-7.7554E-01
18	-4.9405E-03	-5.2813E-01
19	-8.6294E-03	-2.6728E-01
20	-1.2329E-02	0.

PROGRAM IMPFM - FOR ANALYSIS OR PREDICTION OF COLLAPSE OF PLANE FRAMES
UNDER STATIC OR IMPULSE LOADS

IMPFM TEST PROBLEMS - EXAMPLE PROBLEMS FOR DISSERTATION
CODED 9-25-73 BY GMR

PROBLEM IPF4

PORTAL FRAME WITH SINUSOIDAL IMPULSE LOAD ON BEAM AND COLUMNS

COMPLETE RESPONSE, TIME = 2.0000E-04

STA	X COORD	Y COORD	THRUST	MOMENT	SHEAR
0	0.	0.		0.	
			3.0195E+02		-2.9847E+03
1	0.	4.8000E+00		-1.4327E+04	
			2.8669E+02		-1.0192E+03
2	0.	9.6000E+00		-1.9219E+04	
			2.6107E+02		-4.2591E+02
3	0.	1.4400E+01		-2.1263E+04	
			2.2819E+02		-2.5434E+03
4	0.	1.9200E+01		-3.3471E+04	
			1.8589E+02		-3.4507E+03
5	0.	2.4000E+01		-5.0035E+04	
			1.3763E+02		-2.0643E+03
6	0.	2.8800E+01		-5.9943E+04	
			8.9117E+01		-1.0581E+02
7	0.	3.3600E+01		-6.0451E+04	
			4.9714E+01		1.7222E+02
8	0.	3.8400E+01		-5.9625E+04	
			2.3047E+01		2.3737E+01
9	0.	4.3200E+01		-5.9511E+04	
			9.6868E+00		-4.0364E+00
10	0.	4.8000E+01		-5.9530E+04	
			9.6867E+00		4.0295E+00
11	0.	5.2800E+01		-5.9511E+04	
			2.3043E+01		-2.3947E+01
12	0.	5.7600E+01		-5.9626E+04	
			4.9604E+01		-1.7168E+02
13	0.	6.2400E+01		-6.0450E+04	
			8.6865E+01		1.1751E+02
14	0.	6.7200E+01		-5.9886E+04	
			1.0094E+02		2.0455E+03
15	0.	7.2000E+01		-5.0067E+04	
			-2.5660E+02		3.1117E+03
16	0.	7.6800E+01		-3.5131E+04	
			-3.3147E+03		2.8797E+03
17	0.	8.1600E+01		-2.1309E+04	
			-1.5336E+04		3.6265E+03
18	0.	8.6400E+01		-3.9013E+03	
			-2.4244E+04		-2.0821E+03
19	0.	9.1200E+01		-1.3896E+04	
			3.8100E+03		2.9210E+03
20	0.	9.6000E+01		1.2521E+02	
			-3.4254E+03		2.8600E+03
21	4.8000E+00	9.6000E+01		1.3853E+04	
			2.4729E+04		-2.0850E+03
22	9.6000E+00	9.6000E+01		3.8456E+03	
			1.5840E+04		3.6325E+03
23	1.4400E+01	9.6000E+01		2.1282E+04	
			3.7704E+03		2.8847E+03
24	1.9200E+01	9.6000E+01		3.5129E+04	
			6.2842E+02		3.1122E+03
25	2.4000E+01	9.6000E+01		5.0067E+04	
			1.7430E+02		2.0455E+03
26	2.8800E+01	9.6000E+01		5.9886E+04	
			9.1367E+01		1.1751E+02
27	3.3600E+01	9.6000E+01		6.0456E+04	
			4.9824E+01		-1.7168E+02
28	3.8400E+01	9.6000E+01		5.9626E+04	
			2.3052E+01		-2.3947E+01
29	4.3200E+01	9.6000E+01		5.9511E+04	
			9.6870E+00		4.0269E+00
30	4.8000E+01	9.6000E+01		5.9530E+04	
			9.6870E+00		-4.0269E+00
31	5.2800E+01	9.6000E+01		5.9511E+04	
			2.3052E+01		2.3947E+01
32	5.7600E+01	9.6000E+01		5.9626E+04	
			4.9824E+01		1.7168E+02
33	6.2400E+01	9.6000E+01		6.0456E+04	
			9.1367E+01		-1.1751E+02
34	6.7200E+01	9.6000E+01		5.9886E+04	
			1.7430E+02		-2.0455E+03
35	7.2000E+01	9.6000E+01		5.0067E+04	
			6.2842E+02		-3.1122E+03
36	7.6800E+01	9.6000E+01		3.5129E+04	
			3.7704E+03		-2.8847E+03
37	8.1600E+01	9.6000E+01		2.1282E+04	
			1.5840E+04		-3.6326E+03
38	8.6400E+01	9.6000E+01		3.8456E+03	
			2.4729E+04		2.0850E+03
39	9.1200E+01	9.6000E+01		1.3853E+04	
			-3.4254E+03		-2.8600E+03
40	9.6000E+01	9.6000E+01		1.2521E+02	
			3.8100E+03		-2.9210E+03
41	9.6000E+01	9.1200E+01		-1.3896E+04	
			-2.4244E+04		2.0821E+03
42	9.6000E+01	8.6400E+01		-3.9013E+03	
			-1.5336E+04		-3.6265E+03
43	9.6000E+01	8.1600E+01		-2.1309E+04	
			-3.3147E+03		-2.8797E+03
44	9.6000E+01	7.6800E+01		-3.5131E+04	
			-2.5660E+02		-3.1117E+03
45	9.6000E+01	7.2000E+01		-5.0067E+04	
			1.0094E+02		-2.0455E+03
46	9.6000E+01	6.7200E+01		-5.9886E+04	
			8.6865E+01		-1.1751E+02
47	9.6000E+01	6.2400E+01		-6.0450E+04	
			4.9504E+01		1.7168E+02
48	9.6000E+01	5.7600E+01		-5.9626E+04	
			2.3043E+01		2.3947E+01
49	9.6000E+01	5.2800E+01		-5.9511E+04	
			9.6867E+00		-4.0295E+00
50	9.6000E+01	4.8000E+01		-5.9530E+04	
			9.6869E+00		4.0364E+00
51	9.6000E+01	4.3200E+01		-5.9511E+04	
			2.3047E+01		-2.3737E+01
52	9.6000E+01	3.8400E+01		-5.9625E+04	
			4.9714E+01		-1.7222E+02
53	9.6000E+01	3.3600E+01		-6.0451E+04	
			8.9117E+01		1.0581E+02
54	9.6000E+01	2.8800E+01		-5.9943E+04	
			1.3763E+02		2.0643E+03
55	9.6000E+01	2.4000E+01		-5.0035E+04	
			1.8589E+02		3.4507E+03
56	9.6000E+01	1.9200E+01		-3.3471E+04	
			2.2819E+02		2.5434E+03
57	9.6000E+01	1.4400E+01		-2.1263E+04	
			2.6107E+02		4.2591E+02
58	9.6000E+01	9.6000E+00		-1.9219E+04	
			2.8669E+02		1.0192E+03
59	9.6000E+01	4.8000E+00		-1.4327E+04	
			3.0195E+02		2.9847E+03
60	9.6000E+01	-2.7569E-12		0.	

STA	X DISP	Y DISP
0	0.	0.
1	-4.4816E-03	-7.4846E-08
2	-8.8056E-03	-1.0716E-07
3	-1.2918E-02	-1.2496E-07
4	-1.6797E-02	-1.6776E-07
5	-2.0308E-02	-2.0988E-07
6	-2.3269E-02	-2.0361E-07
7	-2.5571E-02	-1.6012E-07
8	-2.7208E-02	-1.0718E-07
9	-2.8190E-02	-5.3560E-08
10	-2.8517E-02	-3.3604E-14
11	-2.8190E-02	5.3559E-08
12	-2.7208E-02	1.0714E-07
13	-2.5571E-02	1.5935E-07
14	-2.3259E-02	1.8779E-07
15	-2.0309E-02	-5.0615E-08
16	-1.6798E-02	-3.0487E-06
17	-1.2901E-02	-2.6776E-05
18	-8.7703E-03	-1.3101E-04
19	-4.5965E-03	-2.9480E-04
20	-2.6960E-04	-2.7130E-04
21	-2.9444E-04	-4.5968E-03
22	-1.3104E-04	-8.7702E-03
23	-2.6993E-05	-1.2901E-02
24	-3.3856E-06	-1.6798E-02
25	-4.7108E-07	-2.0309E-02
26	-2.1940E-07	-2.3269E-02
27	-1.6088E-07	-2.5571E-02
28	-1.0721E-07	-2.7208E-02
29	-5.3561E-08	-2.8190E-02
30	8.1032E-15	-2.8517E-02
31	5.3561E-08	-2.8190E-02
32	1.0721E-07	-2.7208E-02
33	1.6088E-07	-2.5571E-02
34	2.1940E-07	-2.3269E-02
35	4.7108E-07	-2.0309E-02
36	3.3856E-06	-1.6798E-02
37	2.6993E-05	-1.2901E-02
38	1.3104E-04	-8.7702E-03
39	2.9444E-04	-4.5968E-03
40	2.6960E-04	-2.7130E-04
41	4.5965E-03	-2.9480E-04
42	8.7703E-03	-1.3101E-04
43	1.2901E-02	-2.6776E-05
44	1.6798E-02	-3.0487E-06
45	2.0309E-02	-5.0615E-08
46	2.3269E-02	1.8779E-07
47	2.5571E-02	1.5935E-07
48	2.7208E-02	1.0714E-07
49	2.8190E-02	5.3559E-08
50	2.8517E-02	-3.8061E-14
51	2.8190E-02	-5.3560E-08
52	2.7208E-02	-1.0718E-07
53	2.5571E-02	-1.6012E-07
54	2.3269E-02	-2.0361E-07
55	2.0308E-02	-2.0988E-07
56	1.6797E-02	-1.6776E-07
57	1.2918E-02	-1.2496E-07
58	8.8056E-03	-1.0716E-07
59	4.4816E-03	-7.4846E-08
60	0.	0.

VITA

George Mack Riddle

Candidate for the Degree of

Doctor of Philosophy

Thesis: NONLINEAR AND LARGE DISPLACEMENT BEHAVIOR OF PORTAL FRAMES SUBJECTED TO IMPULSE LOADING

Major Field: Civil Engineering

Biographical:

Personal Data: Born in Gastonia, North Carolina, June 15, 1936, the son of Mr. and Mrs. William W. Riddle.

Education: Graduated from Clover High School, Clover, South Carolina, in May, 1954; graduated with a Bachelor of Science in Civil Engineering degree from The Citadel, Charleston, South Carolina, in May, 1958; attended Oklahoma State University on a Continental Oil Company Fellowship and received a Master of Science degree in August, 1959; completed requirements for the Degree of Doctor of Philosophy from Oklahoma State University in July, 1975.

Professional Experience: Engineer with Defense Projects Division of Western Electric Company during the summer of 1958; entered the Air Force in 1959 and have had various engineering assignments; worked as Construction Engineer in Base Civil Engineers Office at Glasgow Air Force Base, Montana, from September, 1959 to May, 1961; upon completion of a five-month missile school, worked as a Maintenance Engineer with the 550th Strategic Missile Squadron, Schilling Air Force Base, Kansas, until November, 1964; served as Base Civil Engineer at Don Muang Air Base, Thailand, during 1965; prior to returning to Oklahoma State University in August, 1969, worked as an Engineer for the Aerospace Test Wing, Cape Kennedy Air Force Station, Florida; worked as a Structural Engineer from August, 1972 to August, 1973 at the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico; completed the Armed Forces Staff College at Norfolk, Virginia, in January, 1974; served as Chief of Engineering and Construction Branch at Osan Air Base, Korea, from March, 1974 to March, 1975; presently Project Engineer with Norton Directorate of Civil Engineering, Norton Air Force Base, California.

Professional Societies: Member of Phi Kappa Phi; member of Chi Epsilon.