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USERS' MANUAL TO THE "ACTION" COMPUTER CODE

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FOREWORD

The computer program ACTION was developed to support NASA Langley Research Center's program to improve crashworthiness of general aviation aircraft. The development of the ACTION program was supported by NASA Langley under grants NGR 47-004-114, NSG 1546 and other task orders.

This project, during its first phase, was under the cognizance of Dr. Edwin Kruszewski, then Branch Chief, Dynamics Branch. For the follow-on phases, the development work was under the cognizance of Dr. Robert Thomson, Head, Loads Control Section, Dynamics Branch. The technical monitor, Dr. Robert Hayduk, of this branch was the responsible government officer and assisted in some of the work. For the first two phases the co-principal investigators at VPI & SU were Dr. Robert Melosh and Dr. George Swift. Dr. Manohar Kamat, Mr. Ben Brenneman and the late Mr. Jon Dana provided technical support. For the third phase the co-principal investigators were Dr. Manohar Kamat and Dr. George Swift. Mr. Douglas Killian provided technical support on the second and third phases of the project. Dr. Manohar Kamat was the principal investigator for the final phases. Mr. Norman Knight, Jr., and Mr. Linh T. Duong provided technical support.

The computer code CRASH previously developed by the Department of Transportation was the basis of the ACTION computer code which finally came to fruition only as a result of the efforts and dedication of several people, especially those of the graduate students. The author of this document is indebted to all of them for their contributions. The directions

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and the continued encouragement of grant monitors Dr. Robert Thomson and Dr. Robert Hayduk of NASA Langley during the development of this program were as always invaluable. The hitherto taken-for-granted assistance of Ms. Barbara Durling of NASA Langley on several occasions during the development of the ACTION program certainly merits a great deal of appreciation. Finally, a word of gratitude is in order to Marlene Taylor, Fran Carter, B. J. Vickers and Jane Harrison for typing many versions of this document.

ABSTRACT

This document is a user's guide to the ACTION computer program. It defines the form and interpretation of input and output data. ACTION performs nonlinear transient response analysis of structures subjected to time varying loads, allowing for nonlinear, time independent material properties and large geometry changes.

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SCOPE OF THE ACTION PROGRAM

"ACTION" is an acronym for Analysis of Crash Transients in Inelastic and geOmetrically Nonlinear structures. The ACTION computer program uses the finite element method to determine the relationships between loads and deflections.

Structures are modeled using a three-dimensional assemblage of line and sheet element types. Line elements include the rod, frame, and rigid types. Rod elements can only be loaded axially; frame elements can handle axial, bending, torsion and shear loads; rigid elements provide an infinitely stiff connection between two or more joints. The sheet element is a constant strain triangular membrane element capable of resisting both in-plane and out-of-plane loads through large changes in geometry.

The program accepts both displacement and force boundary conditions. Concentrated forces may be applied at joints either as static loads or as time varying loads. Concentrated masses may also be located at joints. Displacement, velocity, acceleration and jerk (first derivative of acceleration) initial conditions are permitted. Any consistent system of units may be used for input data. The ACTION code includes a model of an impenetrable plane to simulate a flat, rigid ground plane, such as a concrete runway. Resistance to forward motion along this runway is provided by Coulomb friction. Any node of the model may become constrained to lie on the ground plane. Furthermore, any number of nodes may be attached to the ground plane at any one time.

ACTION predicts the response of a structure to static and/or dynamic loading conditions. The user selects an initial time step for transient problems, but the program determines subsequent time steps to satisfy error control criteria. The deformation model allows large changes to the initial geometry of the structure. The material model represents elastic-plastic response with strain hardening. It reflects cyclic loading including Bauschinger effects. The program also represents fracture of elements.

Two algorithms are available for establishing equilibrium configurations: BFGS (Broden-Fletcher-Goldfarb-shanno) Variable Metric algorithm [1] and Powell's Conjugate Gradient algorithm [2].

The BFGS algorithm permits static and dynamic analysis by minimizing the energy function. In the process it constructs data on the inverse hessian of the function and uses these data to accelerate the search process. Powell's conjugate gradient algorithm provides an alternate energy minimization algorithm which, unlike BFGS, does not require storage for the upper triangular portion of the inverse hessian. Powell's conjugate method as implemented in ACTION has stricter convergence criteria than those of BFGS. Hence, difficulties in complete convergence may be experienced while using this algorithm.

Output data consists of joint displacements, velocities, accelerations and jerks at the end of each time step. Stresses and strain rates are displayed at up to 16 locations throughout a cross-section. Elastic and dissipative energies are printed for each element. In addition, the total system energy, total elastic energy and total energy dissipation rate are printed.

Data management features include capabilities to batch together static problems having identical geometry but different external loads, store data on tape for subsequent restarts, restart from data stored on tape. Data may be stored on a restart tape by specifying a data dump for the end of a successful run. In addition, if calculation time approaches a user specified limit or if solution errors terminate a problem, data dumps are executed automatically.

Figure 1 presents a general flow for the ACTION program. ACTION is mapped to handle 100 joints, 210 elements, five different types of material and 300 degrees of freedom. These limits may change, however, and the BLOCK DATA subroutine (not shown in Figure 1) should be consulted for a current specification of program limitations. In BLOCK DATA the variables NNODES, NELEM, NMATT and NDOF refer to the number of joints, elements, materials and the number of degrees of freedom for which the BFGS equation solver will be invoked is represented by NSOLVE in BLOCK DATA.

This document cites the form and interpretation of input data required by ACTION and discusses the output data. The technical document [3] presents the mathematical basis of the code.

This document is organized into three main sections. The next section describes the input data deck form and card entries. The second section illustrates the output and discusses its interpretation. The third section outlines a sample problem using some of the features of the code.

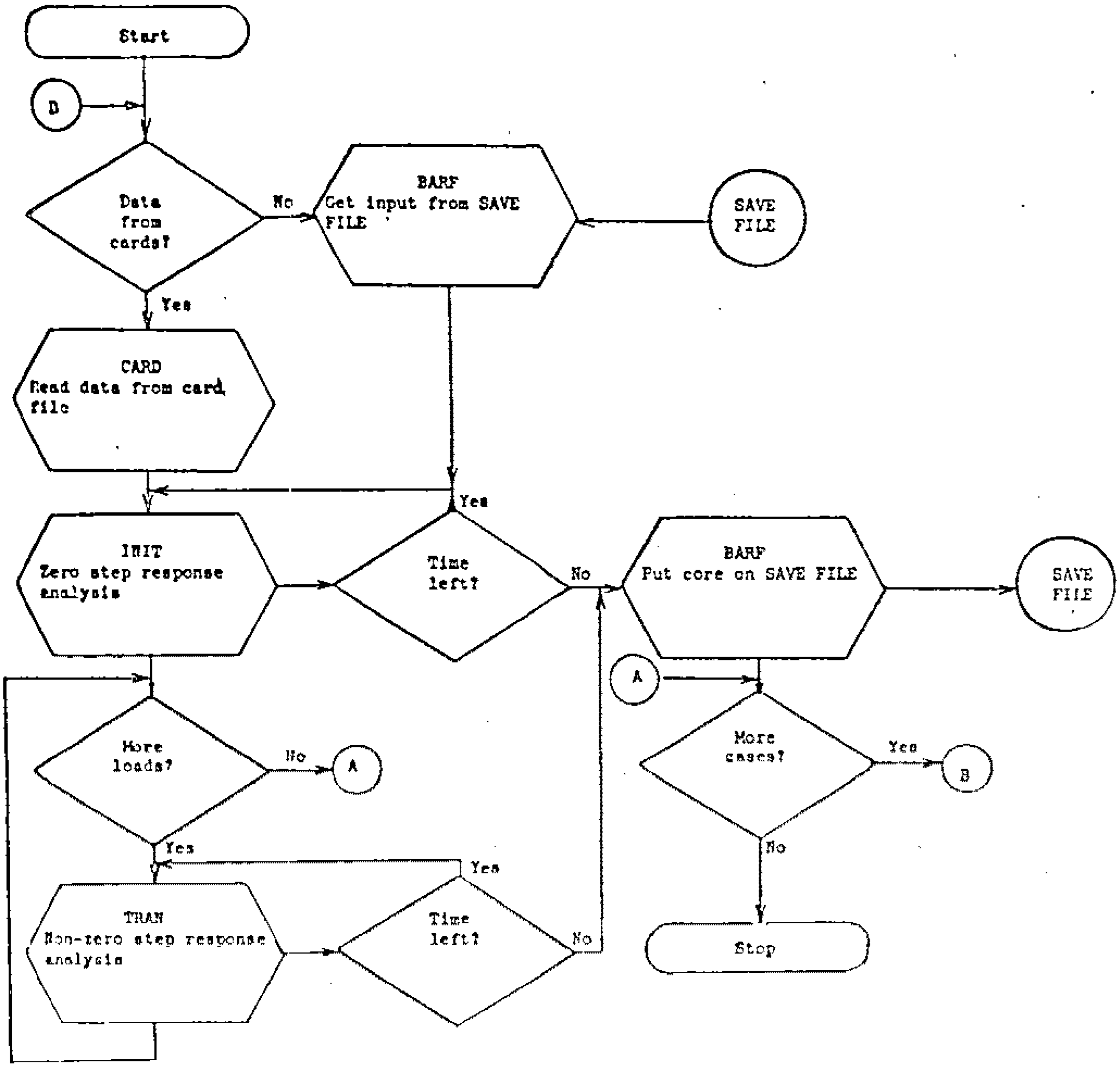

Figure 1. General Flow Chart

INPUT DATA

The input data consists of a set of Data Blocks for each problem. The number of Data Blocks included in any particular problem is dependent upon the data required for that problem. The maximum number of Data Blocks that can be input per problem is ten. This section provides detailed instructions for preparing input.

Input Data Deck

Figure 2 shows how the Problem Data Decks form the Input Data Deck. Any number of problems can be batched together in one computer run.

Two cards terminate the Input Data Deck. The next to the last card may be blank or contain any message the user desires. (It is convenient to use a message that indicates end of data for this computer run.) The last card is termed a Zero Card. This card may contain only zeros or blanks. (For ease of identification it is convenient to put a zero in all columns.)

Problem Data Deck

Figure 3 shows the format for each Problem Data Deck. The Problem Data Deck requires a Problem Title Card, three Control Parameter Cards, and at most ten Data Blocks. The Joint Coordinate and Material Data Blocks are required. The remaining Data Blocks are optional so long as they provide a sufficient definition of the problem. The Data Blocks included in the Problem Data Deck must appear in the order shown in Figure 3.

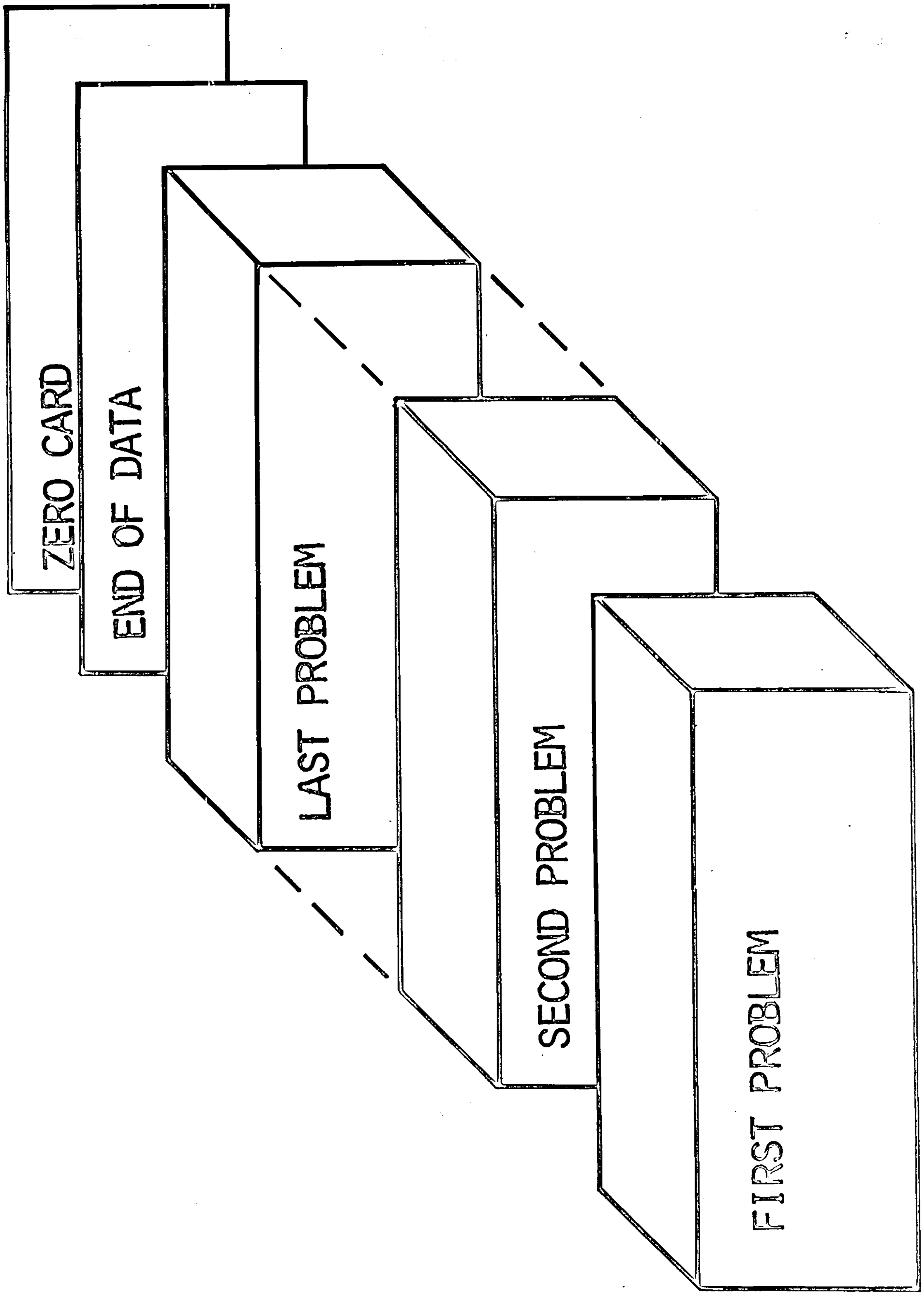

Figure 2. Input Data Deck

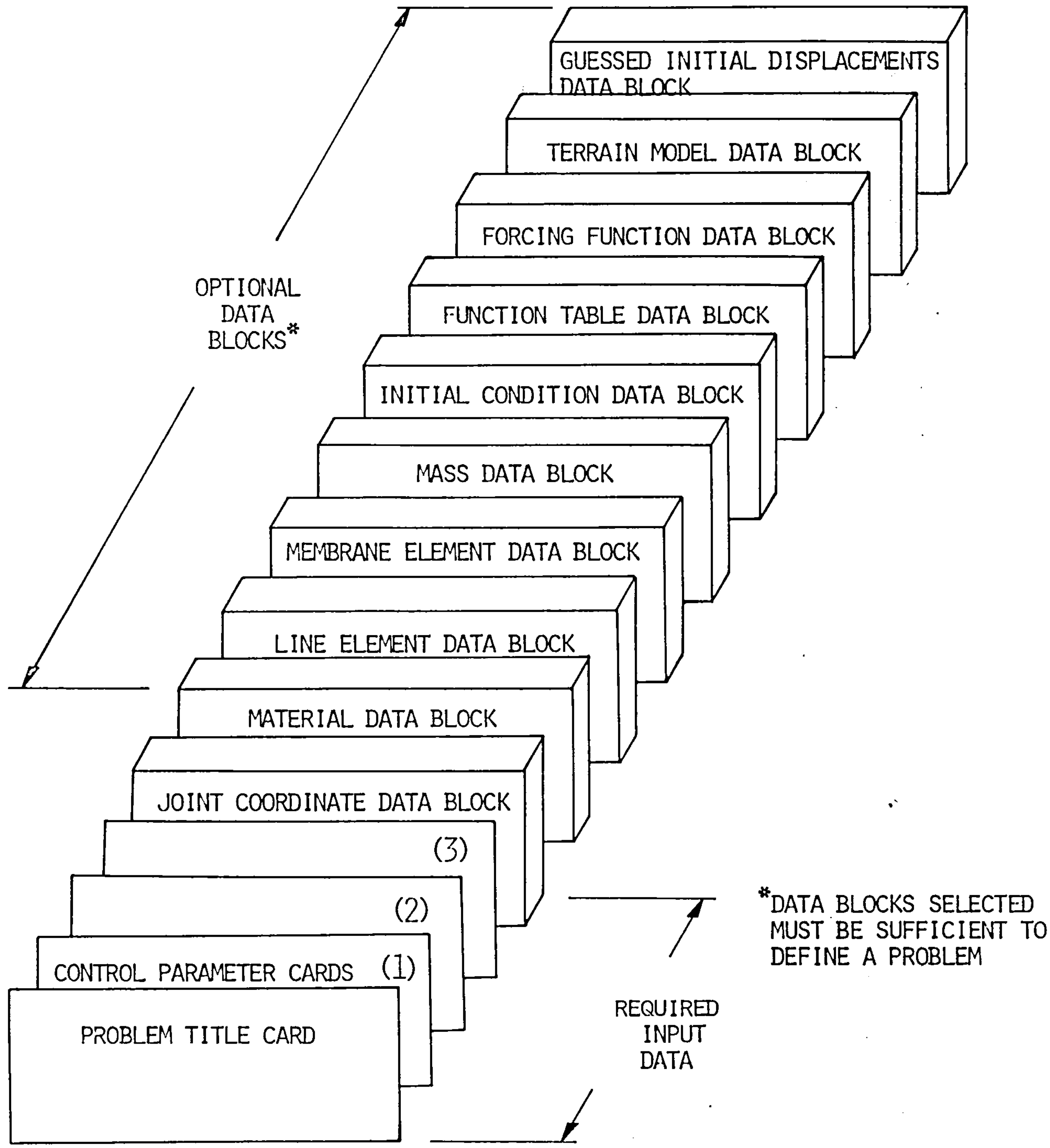

Figure 3. Problem Data Deck

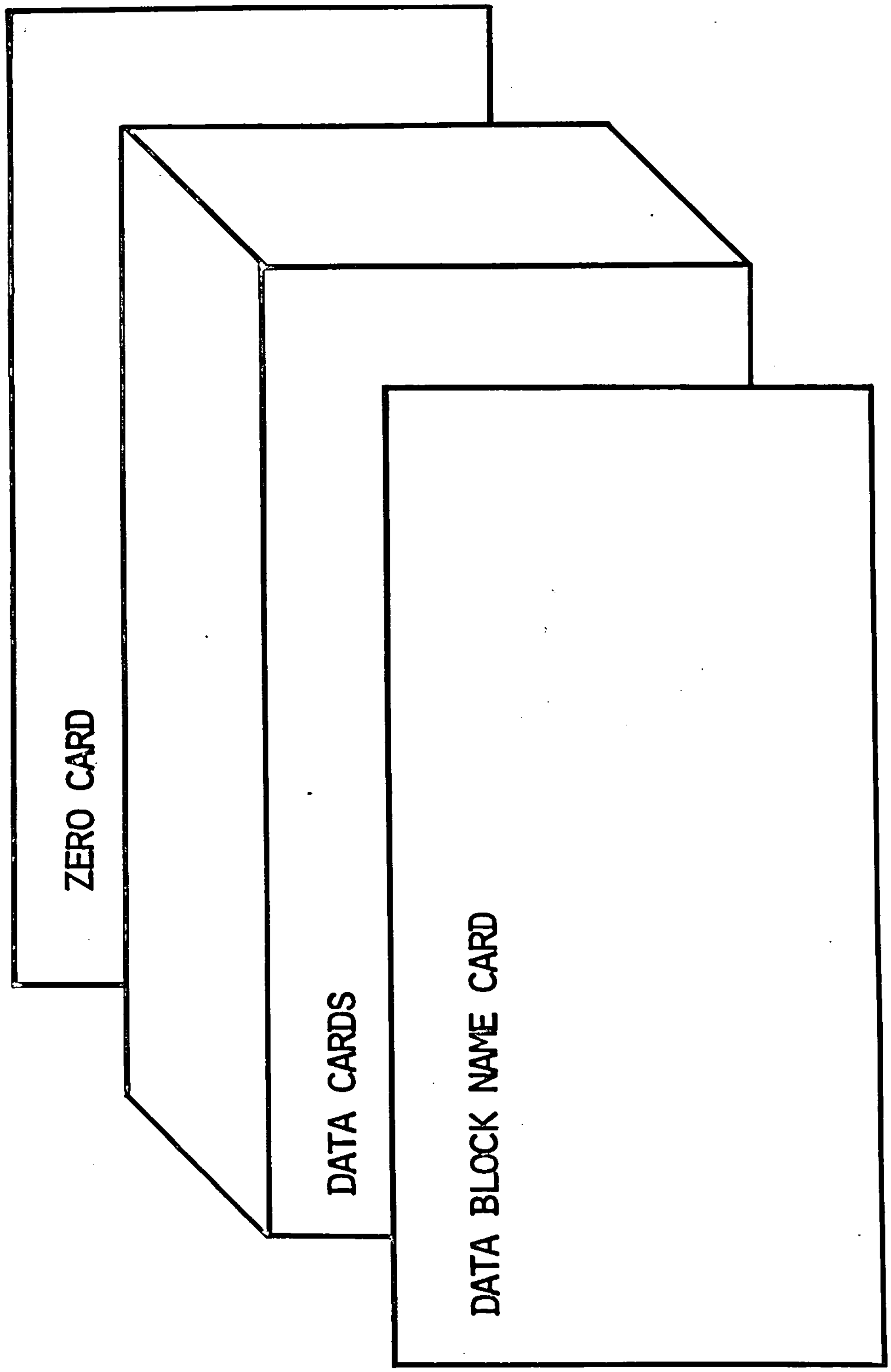

Figure 4. Data Block Organization

1. Problem Title Card: One card for each problem. The card contains any alphameric message desired by the user. The format is given in Table 1.

2. Control Parameter Cards: Three cards for each problem. The first card contains information used in selecting program options. The second card contains information used to control the step-by-step numerical integration in time. The third card contains information about the β and γ parameters of the Newmark-Beta method as well as solution and function accuracy limits. The formats are detailed in Table 2.

3. Data Blocks: Each Data Block contains information for describing a particular feature of the problem at hand. Figure 4 indicates the anatomy of each Data Block. Each Data Block begins with a Name Card and ends with a Zero Card. The first four columns of a Name Card must duplicate exactly the first four letters of the Data Block name as it appears in Figure 3. The remaining columns may contain any message desired by the user. The Zero Card may contain only zeros or blanks. (For ease of identification it is convenient to put a zero in all columns.) Data Cards peculiar to each Data Block are placed between the Name Card and Zero Card. If all values for an entire Data Block are zero, the entire Data Block including the Name Card and the Zero Card can be omitted from the Problem Data Deck.

Tables 3 through 12 define and interpret the input data required for the various Data Blocks. These tables have been made self-contained through the use of footnotes and figures. In these tables "b" is used to indicate a blank (unpunched) card field. Card formats are listed using FORTRAN notation.

Table 1

PROBLEM TITLE CARD

Card	Cols	Format	Item
1	1		"b"
	2-80	A	Problem Title[1]

[1]An alphameric problem title prescribed by the user. This title is used as the heading of the problem printout.

Table 2

CONTROL PARAMETER CARDS

Card	Cols	Format	Item
1	1-5	I5	IRUN, source of input data 1, read input from cards -2, pertains to tape 10 [1]
	6-10	I5	IINK, print level for minimization progress 0, minimum 1, standard 2, detailed
	11-15	I5	ISINK, stress print flag 0, no stresses 1, stresses 2, stresses, including detailed printout for membrane elements
	16-20	I5	ITAPE, receptacle for storing restart data 0, no restart data need be saved -1, pertains to tape 10 [2]
	21-25		Not used
	26-30	I5	ILIN, analysis sophistication 0, infinitesimal deformations (linearity) 1, infinitesimal joint motions and finite element distortions (small strains) 2, finite joint motions and element distortions (small strains) 3, finite joint motions and element distortions (moderately large strains) [3]
	31-35	I5	ICONT, batching of static problems with identical geometry but different external loads [4] 0, batching feature not desired 1, batching desired
	36-40	I5	MLIN, maximum number of linear minimizations (Defaults to three times the number of degrees of freedom if entered as zero)
	41-45		Not used

Table 2 (Continued)

CONTROL PARAMETER CARDS

Card	Cols	Format	Item
	46-50	I5	IORDER (Defaults to 2) 1, first order method (to be used when ISOLVE = 5) 2, second order method (to be used when ISOLVE = 7)
	51-55	I5	ISOLVE, equation solver option (Defaults to 7) 7, BFGS method used unless dynamic memory allocation overflows available storage - then Powell's method automatically invoked[2] 5, Powell's conjugate gradient method used entirely
	56-60		Not used
	61-65	I5	IPRT, Interval of time steps printouts (Defaults to 1 - every time step is printed. With IPRT-99999 only the results for the first and the last time are printed.)
	66-75		Not used
	76-80	I5	ISPEC 0, No non-zero prescribed displ. 1, Some non-zero prescribed displ.

[1]Restart data was written onto tape 10 during a previous run and is to be used as input for the current run. For problems restarted from tape, the Problem Data Deck consists of only the Problem Title Card and the three Control Parameter Cards.

[2]In order to store data on tape 10, a scratch work space, tape 12, is required. Tape 12 is also required as a scratch work space to handle increased dimension of the inverse hessian approximation when frame elements yield. This is due to an additional axial degree of freedom used for the definition of the deformation characteristics of a frame element that has yielded.

[3]This option should be invoked only rarely at the discretion of the user, since it does not account for large strains in a consistent manner. The only thing that is achieved by invoking this option is the use of nonlinear strain displacement relations in the corotational co-ordinate system. No distinction is made between pseudo and Cauchy stresses nor are changes in density accounted for [3].

Table 2 (Continued)

CONTROL PARAMETER CARDS

Card	Cols	Format	Item
2	1-10	E10.0	TBEGIN, time to start integration
	11-20	E10.0	HALT, time to stop integration
	21-30	E10.0	TSTEP, starting time step size
	31-40	I10	NTIMES, maximum number of time steps or load steps to take[5]
	41-50	E10.0	BTERR, biggest tolerable error (a larger error causes a decrease in time step)[6]
	51-60	E10.0	STERR, smallest tolerable error (a smaller error causes an increase in time step)[6]
	61-70	E10.0	TMIN, minimum time step permitted
	71-80	E10.0	ELAPS, maximum running time per job as measured by CPU clock, minutes (Defaults to 100 CPU minutes)

[4]A "batched" problem is entered as a "pseudo-transient" problem with zero displacement initial conditions. The only distinction in execution is that displacements are set equal to zero after each load step. Loading conditions are obtained from Function Tables. See footnote 5 for an explanation of "pseudo-transient" problems.

[5]A transient problem for which no dynamic response is desired is called a "pseudo-transient" problem. This may be used for the "static analysis" of a structure subjected to incremental changes in load. Loads are input using Function Tables, but force initial conditions must duplicate forces from Function Tables for the TBEGIN time. Pseudo-transient problems require that:

a) NTIMES be equal to the number of loads in addition to the initial load for which a static analysis is required.
b) No masses be input.
c) Function Table time steps must be constant and equal to TSTEP.
d) BTERR must be equal to zero to make integration time steps consistent with Function Table time steps.

[6]The selection of suitable error bounds requires judgment on the part of the user. Too large a time step results in truncation error (displacement response is assumed to be a third order function of time); too small a time step reduces the accuracy of the computer representation of the difference in displacements over the length of the time step.

Table 2 (Continued)

CONTROL PARAMETER CARDS

Card	Cols	Format	Item
3	1-10	E10.0	BETA, Newmark-Beta Integration Parameter (Defaults to 0.276 [4])
	11-20	E10.0	GAMMA, Newmark-Beta Integration Parameter (Defaults to 0.55 [4])
	21-30	E10.0	DISACC, Desired Solution Accuracy (Defaults to 1.E-08)
	31-40	E10.0	FUNACC, Estimated Function Accuracy (Defaults to 1.E-13)
	41-50	E10.0	TSTEP1, Restart with a step size which is required to be different from the automatic step size determined by the analysis[7]

[7]This feature can be used only when restarting from a successfully completed analysis at the end of a time step.

Table 3

JOINT COORDINATE DATA BLOCK[1]
(required)

Card	Cols	Format	Item
1	1-80	A	"JOIN . . . "
One card for each joint	1-5	I5	Joint number
	6-10		Not read
	11-40	3E10.	The X, Y, and Z coordinates of the joint
	41-44		Not read
	45	I1	X-displacement (Restraint codes: 0 = unrestrained, 1 = restrained)
	46	I1	Y-displacement (Restraint codes: 0 = unrestrained, 1 = restrained)
	47	I1	Z-displacement (Restraint codes: 0 = unrestrained, 1 = restrained)
	48	I1	X-rotation (Restraint codes: 0 = unrestrained, 1 = restrained)
	49	I1	Y-rotation (Restraint codes: 0 = unrestrained, 1 = restrained)
	50	I1	Z-rotation (Restraint codes: 0 = unrestrained, 1 = restrained)
	51-80		Not read
Last	1-80		"00000 . . . " or "bbbbb . . . "

[1]The joint coordinate data block consists of a data block name card, one card for each joint and a zero card to indicate the end of the data block. The joints must be numbered sequentially beginning at one; no number may be skipped or omitted; the total number of joints equals the largest joint number. Joint data cards must be in sequential order.

Table 4

MATERIAL DATA BLOCK[1]

Card	Cols	Format	Item	
1	1-80	A	"MATE . . ."	
1	1-5	I5	Material number	
	6-10		Not read	
	11-80	A	Material name (User's Option)	
2	1-80	8E10.0	$\sigma_1, \varepsilon_1, \sigma_2, \varepsilon_3, \sigma_3, \varepsilon_3, \sigma_4, \varepsilon_4$	stress-strain curve coordinates[2]
	1-80	8E10.0	$\sigma_5, \varepsilon_5, \sigma_6, \varepsilon_6, \sigma_7, \varepsilon_7, \sigma_8, \varepsilon_8$	
4	1-20	2E10.0	σ_9, ε_9.	
	21-30	E10.0	Elastic shear modulus	
	31-40		Not read	
	41-50	E10.0	Mass Density[3]	
	51-80		Not read	
Last	1-80		"00000 . . . " or "bbbbb . . . "	

[1]The materials data block consists of a data block name card, then four cards for each type of material to be specified, and a zero card to indicate the end of the data block.

[2]For each material, the uniaxial stress-strain curve is modeled by eight straight-line segments, as shown in Figure 5a. Four segments must be used for the tensile side and four for the compressive side; fewer than eight segments are not allowed.

For $\varepsilon_6 \leq \varepsilon \leq \varepsilon_2$, the material is treated as elastic. Yielding occurs at ε_2 in tension and ε_6 in compression. The elastic modulus in tension may not be different from the elastic modulus in compression. (The elastic moduli are the slopes of the elastic segments of the stress-strain curve.) The stress-strain curve must be single-valued in strain. This requires that the strain continuously increase with distance from left to right along the curve. However, it is permissible to specify an elastic perfectly plastic material. The specification of a rigid work-hardening material is not possible since the slope of the elastic segments of the curve cannot exceed the largest number than can be accommodated by the computer in question. The slope of the first plastic segment of the curve in tension and compression must be less than the corresponding elastic tension or compression slope. Otherwise, there is no restriction on the slopes of the stress-strain curve, except the stress must be uniquely defined for any given strain.

For unloading from the plastic segments of the stress-strain curve, the material response is elastic as described by the elastic segments of the curve. This is shown by the dotted lines. Note that the segments describing initial elastic response are translated to the plastic unloading point and used to describe the elastic unloading. Thus, strain hardening and Bauschinger effects can be represented.

It is noted that the point (σ_1, ε_1) of the material stress-strain curve may be displaced from the origin to simulate special conditions of initial stress or strain that may not be simulated by the initial conditions data. For inadmissible, indeterminate stress-strain conditions, see Figures 5b and 5c. In these figures points on certain portions of the curves are not uniquely defined.

[3]Nonzero density provides an automatic calculation of the lumped masses at nodes. If the user chooses to specify his own lumped mass distribution, the mass density should be set to zero. Lumped masses in addition to those automatically calculated by the program as a result of the nonzero density specification, may also be specified by using the MASS DATA BLOCK feature to be described later.

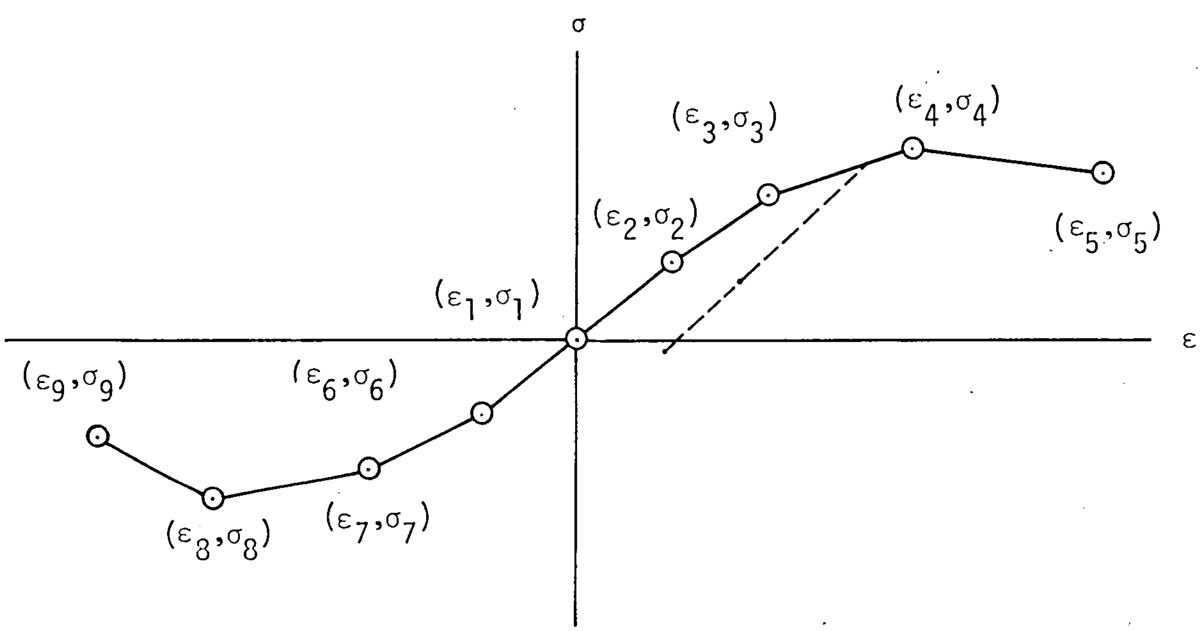

Figure 5a. Stress-strain Curve Representation

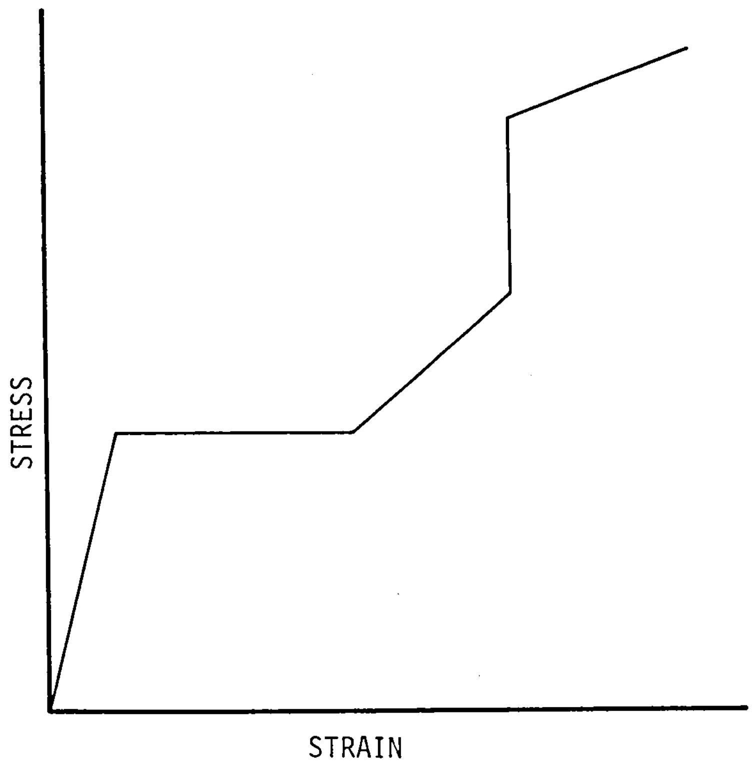

Figure 5b. Indeterminate Stress-Strain Conditions

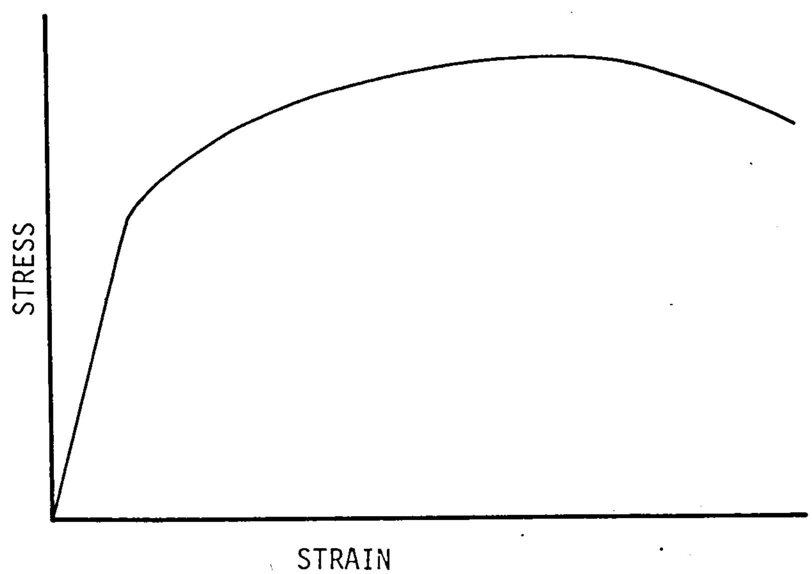

Figure 5c. Indeterminate Stress-Strain Condition

Table 5

LINE ELEMENT DATA BLOCK[1]
(may be omitted)

Card	Cols	Format	Item
1	1-80	A	"LINE . . . "
For Each Member[2] 1			Line Element Parameter Card[3]
2			Cross Section Data[4]
3			Cross Section Data[4]
Last	1-80		"00000 . . . " or "bbbbb . . . "

[1]The line element data block consists of a data block name card, three data cards for each member, and a zero card to indicate the end of the data block.

[2]Element data can be put in any order, but cards for each element must be in order.

[3]Refer to Table 5.1.

[4]The information on the two cross section data cards depends on the type of member.

Rod Member - Refer to Table 5.2.
Frame Member - General Cross Section - Refer to Table 5.3.
Frame Member - IE Section - Refer to Table 5.4.
Frame Member - Box Section - Refer to Table 5.5.
Frame Member - Circular Tube Section - Refer to Table 5.6.
Frame Member - Elliptical Section - Refer to Table 5.7.
Frame Member - Solid Rectangular Cross Section - Refer to Table 5.8.
Rigid Member - Refer to Table 5.9.

Table 5.1

LINE ELEMENT PARAMETER CARD

Cols	Format	Item
1-5	I5	Member number.
6-10	I5	The joint number for one end of the member, henceforth the P-end[1], or primary node for a STIF member.
11-15	I5	The joint number for the other end of the member, henceforth the Q-end (or total number of secondary nodes for a STIF member).
16-20	A4,1X	Type of member. Alphameric Code[2] — Description ROD — Rod Member GLOB — Frame Member of General Cross Section IE — Frame Member, IE Section[3] BOX — Frame Member, Box Section[4] TUBE — Frame Member, Circular Tube Section[5] ELIP — Frame Member, Elliptical Section[6] SORE — Frame Member, Solid Rectangular Section[7] STIF — Rigid Member[8]
21-25	I5	Member status for rod and frame members. 1 - Unimodular materials in elastic range 2 - Initially unimodular and elastic, but may change to plastic 3 - Requiring numerical integration over the cross section If the element is assumed to lie along a plane of symmetry the member status is specified with a negative sign, i.e., -1, -2 or -3 as required.
26-30	I5	Material number. Not required for rigid members.
31-35	I5	Code parameter for rod and frame members. Negative, Compression only (gap or snubber) 0, Normal Member Positive, Tension only (guy wire)[9]
36-40	I5	Not used
41-45	I5	Shear deflection for frame members[10] 0, Shear deflection of frame member neglected 1, Shear deflection of frame member permitted

Table 5.1 (Continued)

LINE ELEMENT PARAMETER CARD[11]

Cols	Format	Item
46-50		Not read
51-60	E10.0	Angle ϕ_x (in degrees) which describes the roll orientation of frame members. See Figure 6.
61-80		Not read

[1]Refer to Figure 6.

[2]Alphameric codes can be punched anywhere in the field but embedded blanks are not allowed.

[3]Refer to Figure 7.

[4]Refer to Figure 8.

[5]Refer to Figure 9.

[6]Refer to Figure 10.

[7]Refer to Figure 11.

[8]A rigid member is an infinitely stiff member. It can be used to represent rigid links in the model.

[9]Tension only is not presently an option, but it can be obtained in rod members by using a zero compressive load.

[10]Shear deflection for nonlinear members should be requested only when needed, since shear calculations may increase computer run time significantly.

[11]Any data not required of a particular member type should be entered as zero or left blank.

NOTE: ORDER OF ROTATIONS: ϕ_z, ϕ_y, ϕ_x

Assume element axes, A, B, and C, are aligned with global axes X, Y, and Z.

ϕ_z is rotation angle to bring element into the plane normal to the global X-Y plane in which it lies.

ϕ_y is rotation angle about B axis to rotate element so the A axis assumes its actual position.

ϕ_x is rotation angle about A to place cross section in proper orientation.

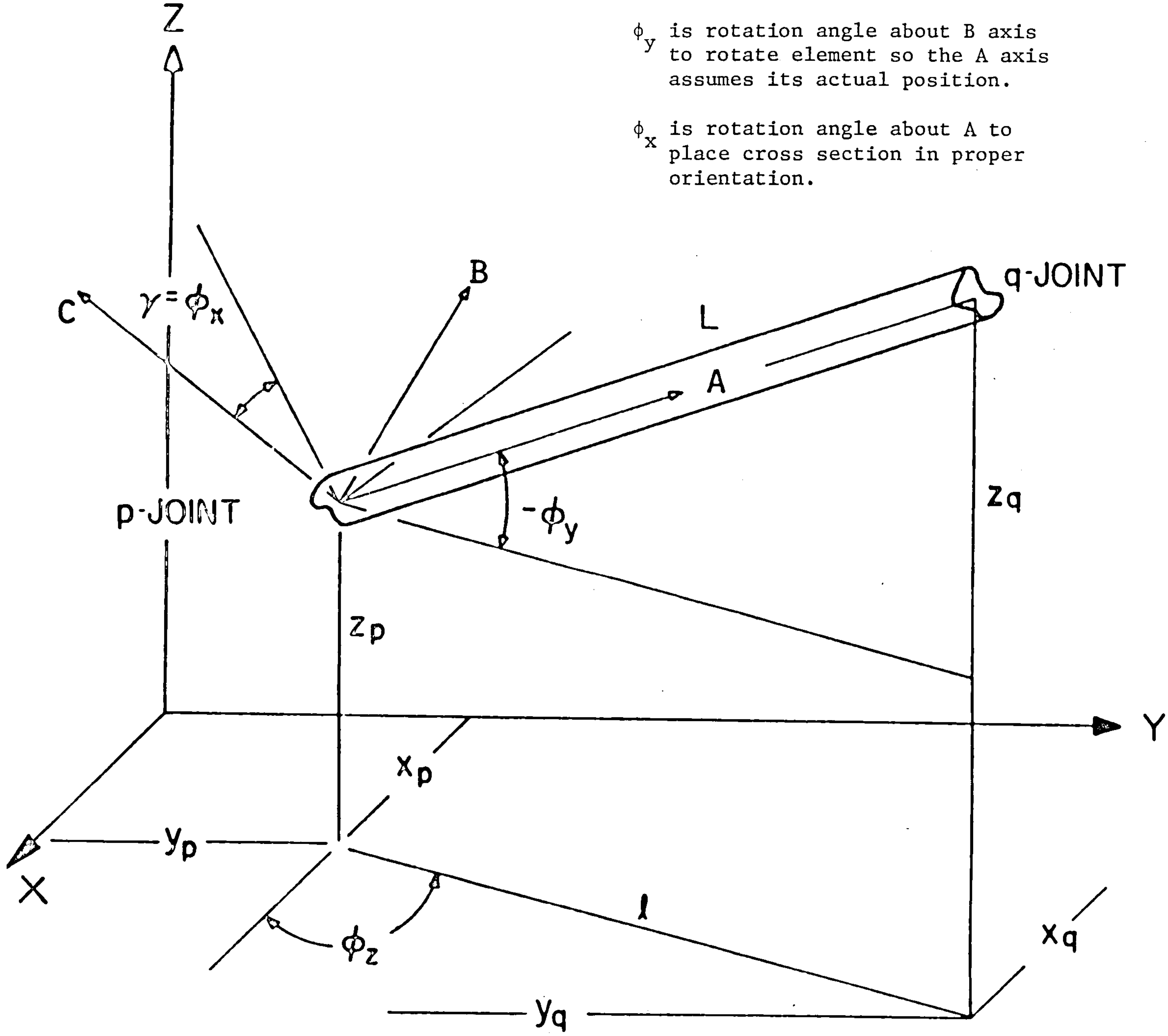

Figure 6. Initial Geometry of Frame Member

Table 5.2

ROD MEMBER

Card	Cols	Format	Item
2	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-20	E10.0	Cross section area.
	21-30	E10.0	Cross section moment of inertia for buckling (usually the minimum transverse inertia).
	31-80	5E10.0	Not used.
3	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-80	7E10.0	Not used, but this card must be present.

Table 5.3

FRAME MEMBER OF GENERAL CROSS SECTION[1]

Card	Cols	Format	Item
2	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-80	7E10.0	Area, I_B, I_C, I_{BC}, TJ, S_B, S_C.[1]
3	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-30	2E10.0	K_B, K_C[1]
	31-80	5E10.0	Not used.

[1]Cross section parameters are described with respect to axes B and C which are situated in the plane of the cross section with their origin at the centroid. These axes need not be principal axes of the cross section.

AREA = Cross section area

I_B = Area moment of inertia about B axis

I_C = Area moment of inertia about C axis

I_{BC} = Area cross product of inertia

TJ = Cross section geometrical torsion constant

S_B = Distance to shear center along B axis

S_C = Distance to shear center along C axis

K_B = Shear deflection constant, B direction

K_C = Shear deflection constant, C direction

Table 5.4

FRAME MEMBER-IE SECTION[1]

Card	Cols	Format	Item
2	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-80	7E10.0	d_1, t_1, d_2, t_2, d_3, t_3, d_4[2]
3	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-80	7E10.0	t_4, d_5, t_5, d_6, t_6, d_7, t_7[2]

[1]Refer to Figure 7.

[2]For the IE-Section any or all of the five flange pieces may be omitted. The two web pieces -- d_3, t_3, and d_5, t_5 -- must be non-zero.

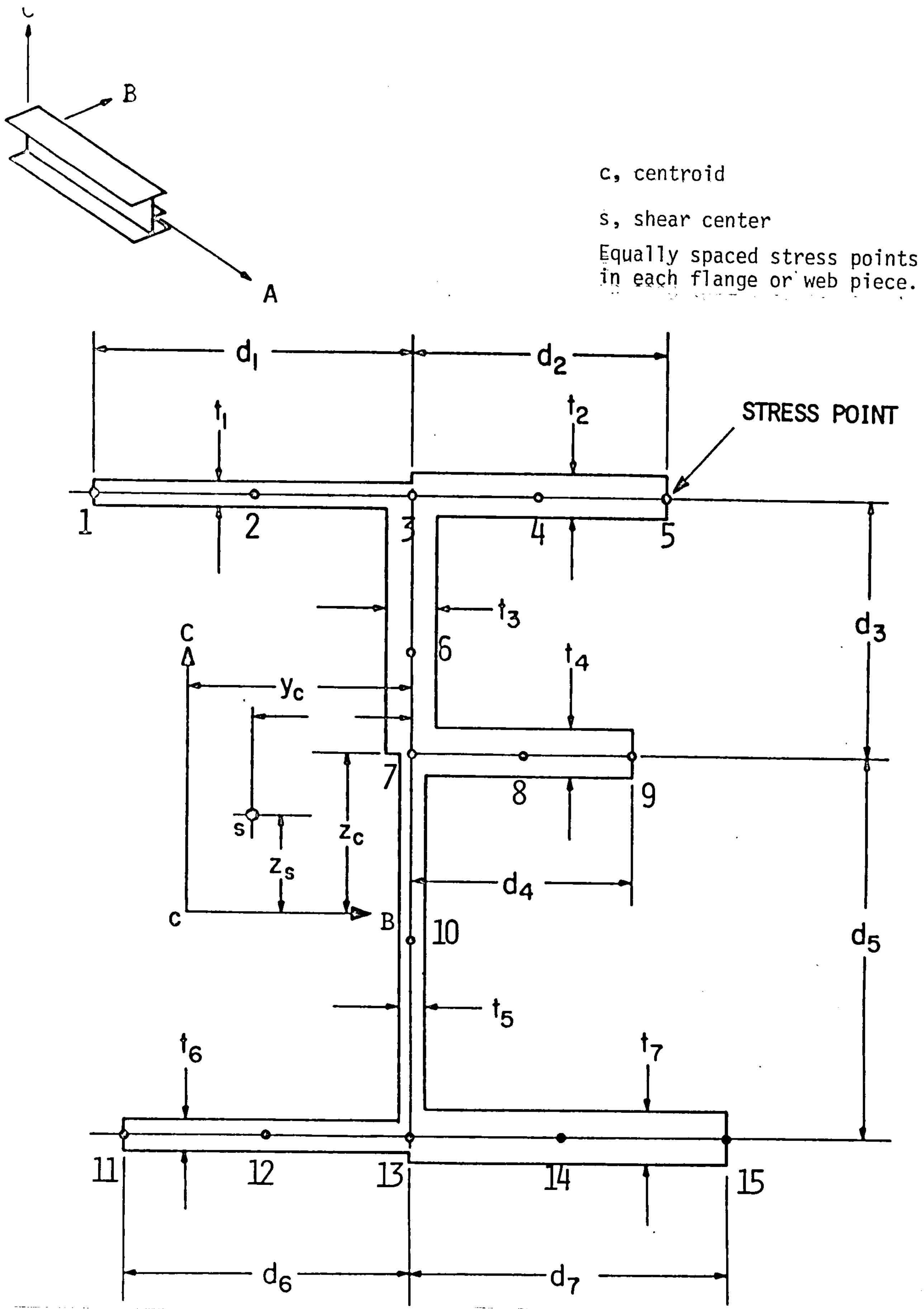

Figure 7. Geometry of IE Section

Table 5.5

FRAME MEMBER-BOX SECTION[1]

Card	Cols	Format	Item
2	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-50	4E10.0	d_1, t_1, d_2, t_2
	51-80	3E10.0	Not used.
3	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-80	7E10.0	Not used, but this card must be present.

[1]Refer to Figure 8.

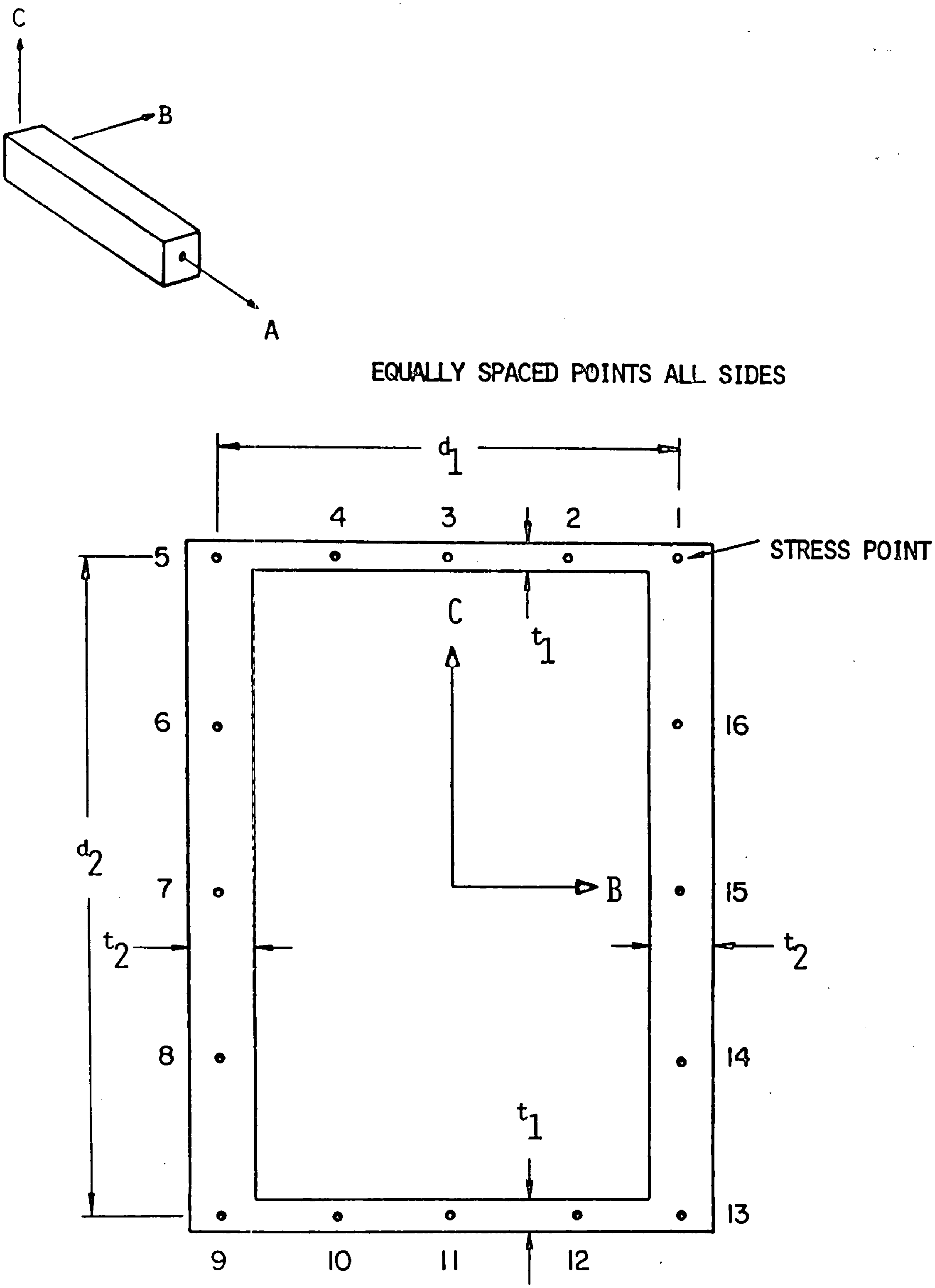

Figure 8. Geometry of Box Section

Table 5.6

FRAME MEMBER-CIRCULAR TUBE SECTION[1]

Card	Cols	Format	Item
2	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-30	2E10.0	d, t
	31-80	5E10.0	Not used.
3	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-80	7E10.0	Not used, but this card must be present.

[1]Refer to Figure 9.

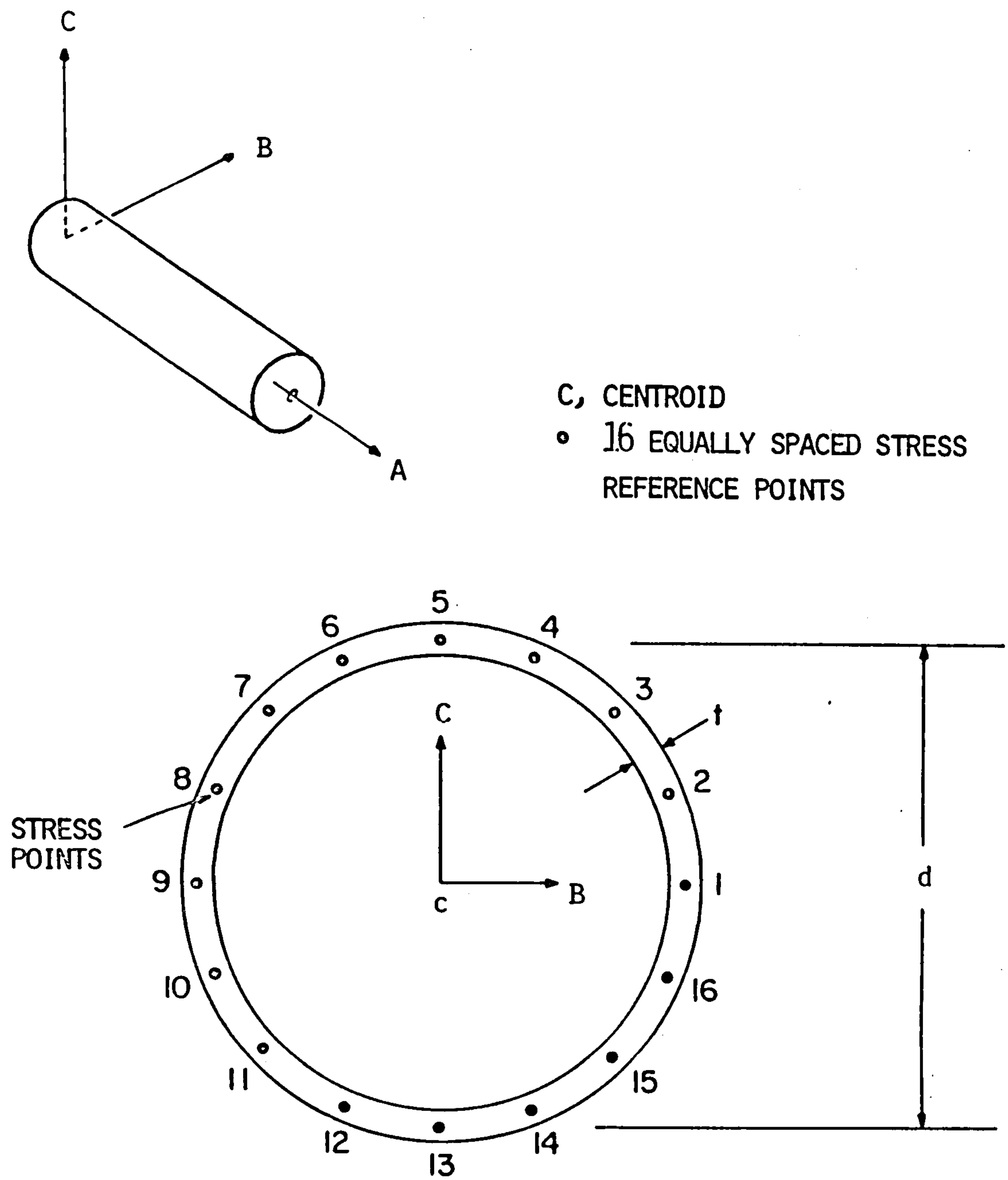

Figure 9. Geometry of Circular Tube Section

Table 5.7

FRAME MEMBER-ELLIPTICAL SECTION[1]

Card	Cols	Format	Item
2	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-50	3E10.0	d_1, t, d_2[2]
	51-80	4E10.0	Not used.
3	1-10		Not read, it is convenient to place the member type in Cols. 1-10.
	11-80	7E10.0	Not used, but this card must be present.

[1]Refer to Figure 10.

[2]If d_1 and d_2 are very nearly equal the section should be approximated by a tube of average diameter.

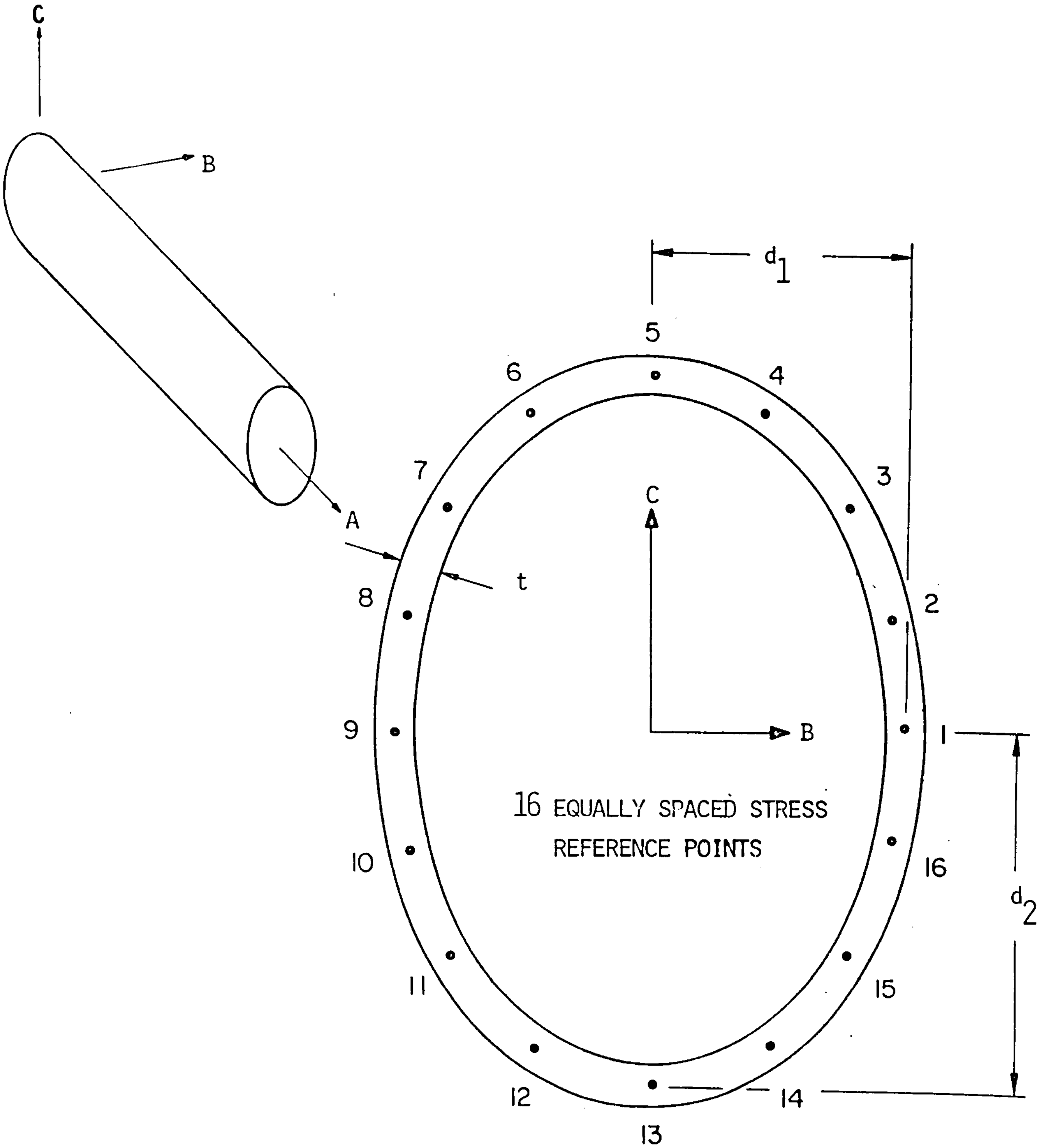

Figure 10. Geometry of Elliptical Section

Table 5.8

FRAME MEMBER-SOLID RECTANGULAR SECTION[1]

Card	Cols	Format	Item
2	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-50	2E10.0	d_1, t_1
	51-80	4E10.0	Not used.
3	1-10		Not read, it is convenient to place the member type in Cols. 1-10.
	11-80	7E10.0	Not used, but this card must be present.

[1]Refer to Figure 11.

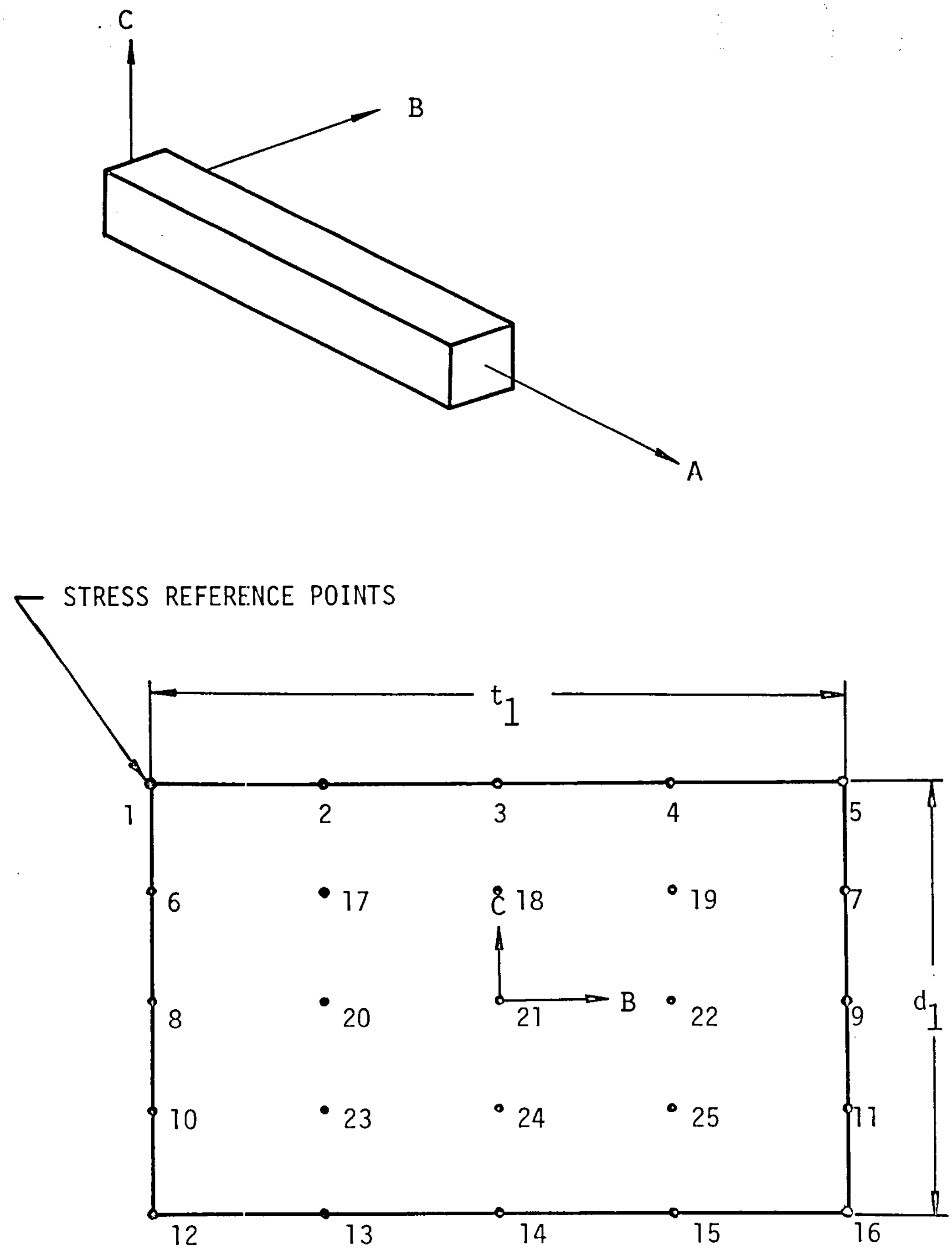

Figure 11. Geometry of Solid Rectangular Cross Section

Table 5.9

RIGID MEMBER

Card	Cols	Format	Item
2	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-80	7E10.0	Secondary node numbers[1]
3	1-10		Not read, it is convenient to place the member type in Cols 1-10.
	11-80	7E10.0	Not used, but this card must be present.

[1]The only data required for the rigid members are the numbers of the nodes connected together by the rigid member. Card 1 contains the number of the primary node as indicated previously and card 2 contains the numbers of the secondary nodes. The primary node is the only one to which degrees of freedom for rigid body motion are assigned. The choice as to which of the nodes is the primary one is arbitrary.

Table 6

MEMBRANE ELEMENT DATA BLOCK[1]

Card	Cols	Format	Item
1	1-80	A	"MEMB . . . "
One card for each member	1-5	I5	Member number
	6-10	I5	P-joint number } P, Q, R specified in a counterclockwise manner[2]
	11-15	I5	Q-joint number }
	16-20	I5	R-joint number }
	21-25	A4,1X	Alphameric member code - MBRN
	26-30	I5	Member status 1, Elastic only 2, Initially elastic, but may go inealstic 3, Inelastic
	31-35	I5	Material number
	36-40	I5	Not read
	41-50	F10.0	Thickness of the membrane element
	51-80		Not read
Last	1-80		"00000 . . . " or "bbbbb . . . "

[1]The membrane element data block consists of a data block name card, one card for each member and a zero card to indicate the end of the data block.

[2]The three stress and strain components are calculated at the centroid of the element with reference to the local element coordinate system described in Ref. [3].

Table 7

MASS DATA BLOCK[1]
(may be omitted)

Card	Cols	Format	Item
1	1-80	A	"MASS . . . "
One card for each joint with mass	1-5	I5	Joint number
	6-10		Not read
	11-70	6E10.0	M_X[2], Mass parameter for motion in the X-direction
			M_Y, Mass parameter for motion in the Y-direction
			M_Z, Mass parameter for motion in the Z-direction
			I_X, Mass moment of inertia for rotation about X-axis
			I_Y, Mass moment of inertia for rotation about Y-axis
			I_Z, Mass moment of inertia for rotation about Z-axis
	71-80		Not read
Last	1-80		"00000 . . . " or "bbbbb . . . "

[1]The mass data block consists of a data block name card, one card for each joint with non-zero lumped masses or inertias, and a zero card to indicate the end of the data block. The program does not treat products of inertia.

[2]If M_X is negative, M_X, M_Y and M_Z are set equal to $|M_X|$. In this case M_Y and M_Z are ignored, regardless of their values.

Table 8

INITIAL CONDITION DATA BLOCK[1]
(may be omitted)

Card	Cols	Format	Item
1	1-80	A	"INIT . . . "
As required for joints	1-5	I5	Joint number
	6-10	I5	Type of initial condition[2] 1. Displacement 2. Velocity 3. Acceleration 4. "Jerk" 5. Force
	11-40	3E10.	Translation component, X, Y, Z-direction
	41-70	3E10.	Rotation component, X, Y, Z-axes
	71-80		Not read
Last	1-80		"00000 . . . " or "bbbbb . . . "

[1]The initial condition data block consists of a data block name card, one card for each joint with non-zero initial conditions, and a zero card to indicate the end of the data block.

[2]Multiple initial conditions may be treated by using multiple cards with the same joint number. The program will superimpose all conditions given. However, care must be exercised to avoid inconsistent conditions. That is, an initial force implies an initial displacement and, if the force is suddenly removed, an initial acceleration. Thus, if an initial force is specified, the program calculates the associated displacements and accelerations. Normally other displacement or acceleration values should not be specified by the user. If initial displacements are non-zero, the program calculates the associated initial stresses.

The initial forces introduced here may be regarded as the forces required to produce initial displacements. The option of specifying the forces, rather than the displacements, relieves the user of the task of calculating these displacements. These are static forces applied prior to the start of the integration to produce static, initial displacements. When the integration starts, these forces are removed. If the problem requires that the force be maintained after the start of integration, the forcing function feature should be used to maintain the desired force after time integration begins.

The numerical integration procedure is such that initial accelerations and "jerks" (first derivative of acceleration) should be specified if applicable. This is contrary to the familiar analytical integration of equations of motion where only initial displacements and velocities are required.

Table 9

FUNCTION TABLE DATA BLOCK[1]
(may be omitted)

Card	Cols	Format	Item
1	1-80	A	"FUNC . . . "
1	1-5	I5	Function number
	5-10	I5	Number of time points
	11-80	A	Function name (user's option)
As required	1-10		Not read[2]
	11-70	6E10.0	t_1, F_1, t_2, F_2, . . .
	71-80		Not read
	1-10		Not read[2]
	11-70	6E10.0	. . ., t_n, F_n
	71-80		Not read
Last	1-80		"00000 . . . " or "bbbbb . . . "

[1]The function table data block consists of a data block name card, data cards for each function to be defined, and a zero card to indicate the end of the data block.

The function tables are used to define reference time-functions for describing time-varying joint forcing functions.

Each time function is defined by straight-line segments connecting prescribed time points, as sketched to the right. There is no explicit limit on the number of time points. There must be at least one time point.

There is an implicit limit on the number of time points. The function tables data is stored dynamically in a data array along with other program data. When the array size is exceeded an error message is printed.

The function must define a continuous increase in time; "backward" slopes are not permitted. Vertical slopes are acceptable. For vertical slopes the average value of the two end points is used.

The functions must be numbered sequentially beginning at one end; no number may be skipped or omitted; the total number of functions equals the largest function number. The function data cards must be ordered sequentially by function number.

[2]It is convenient to place the function number in Cols 1-5.

Table 10

FORCING FUNCTION DATA BLOCK[1]
(may be omitted)

Card	Cols	Format	Item
1	1-80	A	"FORC . . . "
One card for each forcing function	1-5	I5	Joint number
	6-10	I5	Degree-of-freedom parameter 1, Force, X-direction 2, Force, Y-direction 3, Force, Z-direction 4, Moment, X-direction 5, Moment, Y-direction 6, Moment, Z-direction
	11-15	I5	Reference function parameter Positive, Function table number -1, Constant function of magnitude A3 -2, Sinusoidal function -3, Cosinusoidal function
	16-20		Not read
	21-60	4E10.0	A1, A2, A3, A4 A1, Scaling parameter (multiplication) A2, Time shift parameter A3, Magnitude shift parameter (addition) A4, Time period for sinusoidal or cosinusoidal functions, not used otherwise.
	61-80		Not read
Last	1-80		"00000 . . . " or "bbbbb . . . "

[1]The forcing function data block consists of a data block name card, one card for each forcing function to be prescribed, and a zero card to indicate the end of the data block. This data block defines time-varying forcing functions applied at the joints. The time variation is described by a reference function. The reference function may be obtained from the function tables, may be constant, or may be sinusoidal or cosinusoidal. The reference function may be scaled by a multiplication factor (A1), shifted in time by a time factor (A2) or shifted in magnitude by an addition factor (A3). Refer to the Fig. 12 on the next page. Multiple forcing functions may be superimposed at a single degree-of-freedom.

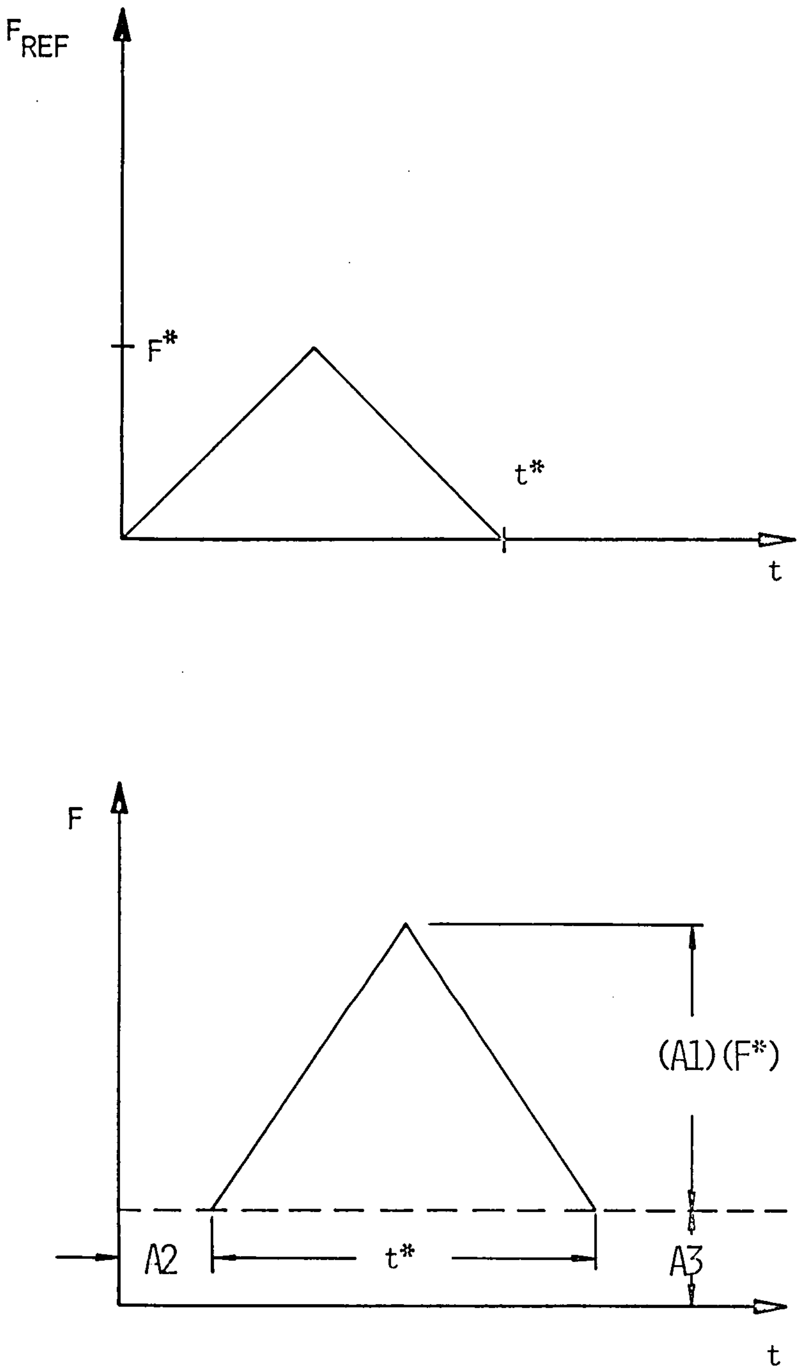

Figure 12. Forcing Function Parameters

Table 11

TERRAIN MODEL DATA BLOCK[1]
(may be omitted)

Card	Cols	Format	Item
1	1-80	A	"TERR . . . "
2	1-10	E10.0	"Y" coordinate of ground plane
	11-20	E10.0	Coefficient of friction of ground plane
	21-80		Not read
As required	1-5	I5	Number of the joint initially constrained to lie on the ground plane
			Not read
Last	1-80		"00000 . . . " or "bbbb . . . "

[1]The terrain model data block consists of a data block name card, a card describing the ground plane, a card for each joint initially on the ground plane, and a zero card.

This data block is used to establish a plane which the structure is not allowed to penetrate. The structure may slide along the plane. The plane is assumed to be the X-Z plane of the global reference system located by the Y coordinate as input.

Table 12

GUESSED INITIAL DISPLACEMENTS DATA BLOCK[1]
(may be omitted)

Card	Cols	Format	Item
1	1-80	A	"GUES . . . "
As required[2]	1-80	4E20.0	Initial guess for displacement vector. Must be read in order of degrees of freedom and must include all degrees of freedom.[3]
Last	1-80		"00000 . . . " or "bbbbb . . . "

[1]The guessed initial displacements data block consists of a data block name card, a set of data cards specifying an initial guess for displacements and a zero card to indicate the end of the data block. This data block is used to provide the minimization process with an estimate of the displacement solution vector. Minimization begins from this initial guess.

[2]The number of data cards required is equal to the number of degrees of freedom divided by four.

[3]This feature can be used only if initial conditions are specified, that is if an Initial Condition Data block is present in the input.

OUTPUT DATA

Output data includes both printed data and data stored on peripheral storage units. Printed output includes an interpretation of problem input, a record of the time response of the structure, and error messages. Data stored on peripheral storage units may be used to restart the analysis or plot the structural response. This section presents a description and interpretation of the output data.

Printed Output

Printed output consists of a definition of the problem as obtained from input data, a description of equilibrium positions for each time or load step, including a record of minimization progress, and diagnostic messages printed when anomalies arise during execution.

The amount of printed output is controlled by the IINK and ISINK parameters on the first Control Parameter Card in Table 2. IINK selects the minimization print level and ISINK controls stress printout. Some printout, however, cannot be controlled by the user. Joint displacements, velocities, accelerations and jerks, energy summaries and error measures are always printed at the end of first and last time or load step and at specified intervals.

The following pages present figures illustrating typical printed output. These figures do not represent a sample problem, but include output from several problems in order to illustrate as many features of the output as possible. The computer page representations in these figures are reduced reproductions of the actual computer printout. There are a maximum of 120 characters per line of printout. Typewritten notes do not appear on the computer printout but have been added to provide a self-contained interpretation of output data.

Actual ACTION printouts may differ from these figures because of modifications to the program. The version used to generate these figures operated under the CDC 6000 computing system, used the BCD character set and printed from single-precision floating point data.

Problem Definition Printout

Figures 13 through 21 present illustrations of typical printout for the problem description. This description is the program's interpretation of the input data. Figure 13 illustrates how the program title and control parameters are displayed. Figures 14 through 20 present printouts of input entered via data blocks. Included in the problem definition printout is a summary of descriptive parameters and storage locations. Figure 21 illustrates this printout which concludes the problem definition output. This summary terminates ACTION printed output whenever errors are detected in input data.

Printout of Response Data (Equilibrium Positions)

ACTION provides a time history of the response of a structure subjected to various loads and initial conditions. This history is in the form of printed records of equilibrium configurations. It includes a description of solution progress and accuracy, joint motions, element and system energies, and, as an option, stresses. Printouts of configurations are provided at each load step or each time step needed for numerical integration of the equations of motion, provided IPRT equals zero or one.

A record of progress made in minimizing the energy function for each time increment precedes any printout of joint and element information.

IMPULSIVELY LOADED CLAMPED BEAM/NEWMARK BETA/ACTION

```
PROBLEM CONTROL PARAMETERS   IRUN=  1, IINK= 0, ISINK= 1, ITAPE=  0, ILIN= 2, ICONT= 0, MLIN=  250
                             IORDER= 2, ISOLVE= 7, IPRT=    1, IDRV=    0

EXPLANATION OF CONTROL PARAMETERS

IRUN   - INPUT IS READ FROM CARDS
IINK   - MINIMUM PRINTOUT OF MINIMIZATION PROGRESS IS PROVIDED
ISINK  - STRESSES WILL BE PRINTED
ITAPE  - DATA WILL NOT BE SAVED FOR A SUBSEQUENT RESTART OR RECOVERY
ILIN   - ANALYSIS BASED ON LARGE JOINT DEFLECTIONS AND FIRST-ORDER MEMBER DEFORMATION
ICONT  - STATIC PROBLEMS WILL NOT BE BATCHED
MLIN   - THE MAXIMUM NUMBER OF LINEAR MINIMIZATIONS IS  250
IORDER - SECOND ORDER MINIMIZATION METHOD
ISOLVE - THE FLETCHER EQUATION SOLVER HAS BEEN SELECTED BUT THE POWELL CONJUGATE GRADIENT EQUATION SOLVER
         WILL BE AUTOMATICALLY IVOLKED IF THE NUMBER OF DEGREE OF FREEDOM EXCEEDS 200
IPRT   - FREQUENCY OF TRANSIENT ANALYSIS PRINTOUTS IS EVERY    1 TIME STEPS
IDRV - ANALYTIC GRADIENTS ARE USED
```

Figure 13. Printout of Problem Title and Control Parameters

	JOINT COORDINATES			JOINT DEGREES OF FREEDOM					
JOINT	X-AXIS	Y-AXIS	Z-AXIS	DX	DY	DZ	RX	RY	RZ
1	0.00000	0.00000	0.00000	0	1	0	0	0	0
2	.01275	0.00000	0.00000	2	3	0	0	0	4
3	.02550	0.00000	0.00000	5	6	0	0	0	7
4	.04138	0.00000	0.00000	8	9	0	0	0	10
5	.05725	0.00000	0.00000	11	12	0	0	0	13
6	.07313	0.00000	0.00000	14	15	0	0	0	16
7	.08900	0.00000	0.00000	17	18	0	0	0	19
8	.10488	0.00000	0.00000	20	21	0	0	0	22
9	.12075	0.00000	0.00000	23	24	0	0	0	25
10	.13663	0.00000	0.00000	26	27	0	0	0	28
11	.15250	0.00000	0.00000	0	0	0	0	0	0

Figure 14. Printout of Joint Coordinate Data

MATERIALS TABLE

1 BEAM ELEMENTS

UNIAXIAL STRS-STRAIN DATA-,	STRESS	STRAIN
	0.	0.
	.5585E+09	.2852E-02
	.1000E+10	.1180E+01
	.2000E+10	.3846E+01
	.4000E+10	.9178E+01
	-.5585E+09	-.2852E-02
	-.1000E+10	-.1180E+01
	-.2000E+10	-.3846E+01
	-.4000E+10	-.9178E+01

ELASTIC MODULI .1958E+12 TENSION .7531E+11 SHEAR .1958E+12 COMPRESSION .7531E+11 SHEAR.
POISSON RATIOS- .3000 ELASTIC TENSION .3000 ELASTIC COMPRESSION 0.5000 PLASTIC. .7870E+04MATERIA DENSITY

Figure 15. Printout of Material Data

MEMBER PARAMETERS

MEMBER	JOINTS	TYPE	STATUS	MATERIAL	CODE	SHEAR DEFLECTION	ANGLE
1	1- 2	IE	2	1	0	0	90.000
2	2- 3	IE	2	1	0	0	90.000
3	3- 4	IE	2	1	0	0	90.000
4	4- 5	IE	2	1	0	0	90.000
5	5- 6	IE	2	1	0	0	90.000
6	6- 7	IE	2	1	0	0	90.000
7	7- 8	IE	2	1	0	0	90.000
8	8- 9	IE	2	1	0	0	90.000
9	9- 10	IE	2	1	0	0	90.000
10	10- 11	IE	2	1	0	0	90.000

SECTION GEOMETRY OF FRAME MEMBERS

MEMBER/TYPE	D1	T1	D2	T2	D3	T3	D4	T4	D5	T5
1/ IE	0.000	0.0000	0.000	0.0000	.002	.0254	0.000	0.0000	.002	.0254
2/ IE	0.000	0.0000	0.000	0.0000	.002	.0254	0.000	0.0000	.002	.0254
3/ IE	0.000	0.0000	0.000	0.0000	.002	.0254	0.000	0.0000	.002	.0254
4/ IE	0.000	0.0000	0.000	0.0000	.002	.0254	0.000	0.0000	.002	.0254
5/ IE	0.000	0.0000	0.000	0.0000	.002	.0254	0.000	0.0000	.002	.0254
6/ IE	0.000	0.0000	0.000	0.0000	.002	.0254	0.000	0.0000	.002	.0254
7/ IE	0.000	0.0000	0.000	0.0000	.002	.0254	0.000	0.0000	.002	.0254
8/ IE	0.000	0.0000	0.000	0.0000	.002	.0254	0.000	0.0000	.002	.0254
9/ IE	0.000	0.0000	0.000	0.0000	.002	.0254	0.000	0.0000	.002	.0254
10/ IE	0.000	0.0000	0.000	0.0000	.002	.0254	0.000	0.0000	.002	.0254

MEMBER/TYPE	D6	T6	D7	T7
1/ IE	0.000	0.0000	0.000	0.0000
2/ IE	0.000	0.0000	0.000	0.0000
3/ IE	0.000	0.0000	0.000	0.0000
4/ IE	0.000	0.0000	0.000	0.0000
5/ IE	0.000	0.0000	0.000	0.0000
6/ IE	0.000	0.0000	0.000	0.0000
7/ IE	0.000	0.0000	0.000	0.0000
8/ IE	0.000	0.0000	0.000	0.0000
9/ IE	0.000	0.0000	0.000	0.0000
10/ IE	0.000	0.0000	0.000	0.0000

Figure 16. Printout of Line Element Data

LUMPED MASS PARAMETERS

JOINT	MX	MY	MZ	IX	IY	IZ
1	.4052E-02	.4052E-02	.4052E-02	0.	0.	0.
2	.8105E-02	.8105E-02	.8105E-02	0.	0.	0.
3	.9098E-02	.9098E-02	.9098E-02	0.	0.	0.
4	.1009E-01	.1009E-01	.1009E-01	0.	0.	0.
5	.1009E-01	.1009E-01	.1009E-01	0.	0.	0.
6	.1009E-01	.1009E-01	.1009E-01	0.	0.	0.
7	.1009E-01	.1009E-01	.1009E-01	0.	0.	0.
8	.1009E-01	.1009E-01	.1009E-01	0.	0.	0.
9	.1009E-01	.1009E-01	.1009E-01	0.	0.	0.
10	.1009E-01	.1009E-01	.1009E-01	0.	0.	0.
11	.5046E-02	.5046E-02	.5046E-02	0.	0.	0.

Figure 17. Printout of Mass Data

INITIAL CONDITIONS AS READ FROM CARDS

JOINT	DIRECTION	DISPLACEMENT	VELOCITY	ACCELERATION	BETA	STATIC FORCE
1	DY	0.	-.55180E+02	0.	0.	0.
2	DY	0.	-.55180E+02	0.	0.	0.
3	DY	0.	-.55180E+02	0.	0.	0.

Figure 18. Printout of Initial Conditions

FUNCTION TABLES

TABLE 1	3 POINTS	LOADS AT NODES 15 AND 16			
TIME	FORCE	TIME	FORCE	TIME	FORCE
0.	0.	.400E+02	.600E+04	.120E+03	-.600E+04

Figure 19. Printout of Function Tables

EXTERNAL FORCING FUNCTIONS APPLIED AT JOINTS

JOINT	DIRECTION	TABLE	MULTIPLICATION FACTOR	TIME SHIFT	ADDITION CONSTANT	TIME PERIOD
15	DY	1	-.1000E+01	0.	0.	0.
16	DY	1	-.1000E+01	0.	0.	0.

NEGATIVE JOINT NUMBERS INDICATE DISPLACEMENT CONSTRAINTS

Figure 20. Printout of Forcing Funtions

```
DATA PARAMETERS>
   NUMBER OF JOINTS                                   11
             MATERIAL TYPES                            1
             MEMBERS                                  10
             LUMPED MASSES                            11
             INITIAL CONDITIONS                        3
             FUNCTION TABLES                           0
             JOINT FORCING FUNCTIONS                   0
             DEGREES OF FREEDOM                       28


STORAGE LOCATION INDEXES IN DATA ARRAY>
   MINIMIZATION DATA                                   0
   FUNCTION TABLES                                   741
   FORCING FUNCTIONS                                 741
   STRAIN DATA                                       741
   PLASTIC STRESS DATA                              1201
   END OF ARRAY                                     1211
   SPACES AVAILABLE                                35000

INTEGRATION PARAMETERS>
   TIME AT START                                      0.
   TIME AT END                                        .100E+00
   INITIAL TIME INTERVAL                              .100E-05
   MAXIMUM NUMBER OF TIME
                        STEPS ALLOWED                 2
   UPPER BOUND ERROR CRITERIA
          FOR DECREASING INTERVAL                     .100E-04
   LOWER BOUND ERROR CRITERIA
          FOR INCREASING INTERVAL                     .100E-05
   MINIMUM TIME INTERVAL ALLOWED                      .100E-05
   MAXIMUM RUN TIME IN CPU MIN.                       .100E+03

MINIMIZATION PARAMETERS>
   MAXIMUM NUMBER OF LINEAR
          MINIMIZATION ITERATIONS                   250
   DESIRED SOLUTION ACCURACY                          .100E-07
   ESTIMATED FUNCTION ACCURACY                        .100E-12
   ESTIMATED LOWER BOUND FOR
                 FUNCTION MINIMUM                    -.100E+01
```

Figure 21. Printout of Summary of Parameters and Storage Location

This record provides data indicating the path taken in arriving at the solution of the equations of motion of the system. The IINK parameter of the first Control Parameter Card controls the amount of minimization data provided. Figures 22 through 24 illustrate printout for IINK values of 0, 1, 2, and 3, respectively.

Information regarding solution accuracy, the state of joints, and stored and dissipated energies is always printed at the end of each time step. Figure 25 and 26 exhibit examples of this printout.

A measure of solution accuracy is provided by the zero, half, and full time error data of Figure 25. This data refers to a normalized equilibrium imbalance obtained for each degree of freedom at the beginning, middle and end of the time step, respectively. The equilibrium imbalance is taken to be the variation of the energy function with respect to a small change in the displacement component, multiplied by the displacement component and divided by the current value of the energy function. The error measures displayed at the top of Figure 25 are the maximum absolute values of the individual degree of freedom errors. From these a single measure of error is computed as the difference between the half time error and the average of the zero and full time errors. (If this value is larger than an upperbound specified on the second Control Parameter Card the time step is reduced by 0.5 and the integration for the time step is repeated. If the error is smaller than a specified lower-bound the time step is increased by 1.50 for the next integration cycle. In addition the time step is not permitted to be less than a specified minimum and the time step will also be reduced if the full time error is greater than the upper-bound requirement.)

```
SOLUTION FOR TIME    .1000CE-05, WITH TIME INTERVAL OF    .1000OE-05


MINIMIZATION PERFORMANCE


CONVERGENCE OF MINIMIZATION TO SPECIFIED ACCURACY
NORMAL COMPLETION OF MINIMIZATION
  FUNCTION VALUE          VARIABLES
   -.62920008150250E-03     -.55163956470035E-04   .11530686007149E-10 -.55212383370090E-04 -.48647914406266E-03   .21235103243010E-08
                            -.55132120635688E-04   .19534060785300E-02 -.28981585518270E-08 -.37969787727710E-07   .22684691502230E-02
                             .87589055123498E-09   .18201053427020E-07 -.60589559642530E-03   .90354984750840E-10 -.48532240297550E-08
                             .16142282295290E-03   .70953086165100E-11   .12930056417500E-08 -.42980677296880E-04   .50951057536970E-12
                            -.34423820519740E-09   .11445829129760E-04   .68391016664100E-14   .92030311420940E-10 -.30454046338210E-05
                            -.66908657848035E-13 -.26168249758100E-10   .76981144933450E-06
 FUNCTION SUBROUTINE CALLS=       85
 GRADIENT SUBROUTINE CALLS=       85
 LINEAR MINIMIZATIONS=            71
 MINIMIZATION ACCURACY    =      .3228813851E-08


THERE ARE NO NEWLY YIELDED MEMBERS
```

Figure 22. Printout of Minimization Progress (IINK = 0)

```
SOLUTION FOR TIME   .10000E-05, WITH TIME INTERVAL OF   .10000E-05


MINIMIZATION PERFORMANCE


INITIAL POINT
 GRADIENTS
                       .477004056E-15  0.                  .954008112E-15  0.                 0.
                      -.139474475E-03  -.725953208E-04   0.                  .139474475E-03  -.725953208E-04
                      0.               0.                0.                0.                 0.
                      0.               0.                0.                0.                 0.
                      0.               0.                0.                0.                 0.
                      0.               0.                0.


LINEAR MINIMIZATION    0
  FUNCTION VALUE       VARIABLES
   -.6200464459671E-03    -.5518000000000E-04 0.                  -.5518000000000E-04 0.                 0.
                          -.5518000000000E-04 0.                  0.                  0.                 0.
                          0.                  0.                  0.                  0.                 0.
                          0.                  0.                  0.                  0.                 0.
                          0.                  0.                  0.                  0.                 0.
                          0.                  0.                  0.


LINEAR MINIMIZATION    1
  FUNCTION VALUE       VARIABLES
   -.6200473788999E-03    -.5518000000000E-04 0.                  -.5518000000000E-04 0.                   0.
                          -.5509973797506E-04  .2739391875006E-05 0.                  -.8026202493620E-07   .2739391875006E-05
                          0.                  0.                  0.                  0.                   0.
                          0.                  0.                  0.                  0.                   0.
                          0.                  0.                  0.                  0.                   0.
                          0.                  0.                  0.


LINEAR MINIMIZATION    2
  FUNCTION VALUE       VARIABLES
   -.6200608479139E-03    -.5518000000001E-04 0.                  -.5517289349062E-04  .2128611909859E-06  .2112956890106E-09
                          -.5488116480595E-04  .1430548457267E-03 -.2110708721343E-09  .1210999043272E-06  .1429807399147E-03
                          -.2248168762342E-12 -.3430736219384E-08  .1315961183089E-06 0.                   0.
                          0.                  0.                  0.                  0.                   0.
                          0.                  0.                  0.                  0.                   0.
                          0.                  0.                  0.


LINEAR MINIMIZATION    3
  FUNCTION VALUE       VARIABLES
```

Figure 23. Printout of Minimization Progress (IINK = 1)

```
SOLUTION FOR TIME   .10000E-05, WITH TIME INTERVAL OF   .10000E-05


MINIMIZATION PERFORMANCE


INITIAL POINT
 GRADIENTS                   .477004056E-15   0.               .954008112E-15   0.               0.
                            -.139474475E-03  -.725953208E-04   0.               .139474475E-03  -.725953208E-04
                             0.               0.               0.               0.               0.
                             0.               0.               0.               0.               0.
                             0.               0.               0.               0.               0.
                             0.               0.               0.


LINEAR MINIMIZATION    0
  FUNCTION VALUE          VARIABLES
   -.62004644596715E-03     -.55180000000000E-04 0.                  -.55180000000000E-04 0.                  0.
                            -.55180000000000E-04 0.                  0.                   0.                  0.
                             0.                  0.                  0.                   0.                  0.
                             0.                  0.                  0.                   0.                  0.
                             0.                  0.                  0.                   0.                  0.
                             0.                  0.                  0.
 GRADIENTS                  -.213206246E-14   0.              -.328414173E-05  -.150014033E-05  -.945169991E-07
                             .166253453E-02  -.709636617E-04   .934033610E-07  -.185659976E-02  -.704413770E-04
                             .111363809E-08   .158545125E-05  -.927424314E-06   0.               0.
                             0.               0.               0.               0.               0.
                             0.               0.               0.               0.               0.
                             0.               0.               0.
 GRADIENTS                   .478036612E-15   0.              -.306388370E-06  -.139953020E-06  -.910975250E-08
                             .286408661E-04  -.724430958E-04   .910005980E-08  -.467458489E-04  -.723943723E-04
                             .969270178E-11   .147911952E-06  -.865224611E-07   0.               0.
                             0.               0.               0.               0.               0.
                             0.               0.               0.               0.               0.
                             0.               0.               0.


LINEAR MINIMIZATION    1
  FUNCTION VALUE          VARIABLES
   -.62004737889990E-03     -.55180000000000E-04 0.                  -.55180000000000E-04 0.                  0.
                            -.55099737975060E-04  .27393918750060E-05 0.                  -.80262024936200E-07  .27393918750060E-05
                             0.                  0.                  0.                   0.                  0.
                             0.                  0.                  0.                   0.                  0.
                             0.                  0.                  0.                   0.                  0.
                             0.                  0.                  0.
 GRADIENTS                  -.255013199E-08  -.110671538E-08   .119929303E-05  -.692388699E-07  -.747399027E-08
                             .702693941E-04  -.719924306E-04   .350703468E-08  -.463787711E-05  -.719239051E-04
```

Figure 24. Printout of Minimization Progress (IINK = 2)

SOLUTION FOR TIME .10000E-05, WITH TIME INTERVAL OF .10000E-05

TOTAL ERROR MEASURES	ZERO-TIME ERROR =	0.	TOTAL INPUT ENERGY	=	.3236553E+02
	HALF-TIME ERROR =	.6868E-06	CURRENT SYSTEM ENERGY	=	.3236553E+02
	FULL-TIME ERROR =	.1674E-08	CURRENT ELASTIC ENERGY	=	.5961504E-02
			CURRENT DISSIPATION RATE	=	0.

******* SPECIFIED MAXIMUM CPU TIME = 600000 ***** ELAPSED CPU TIME = 939 IN 100THS OF SECONDS

DEFORMATION RESULTS

JOINT	DIRECTION	DISPLACEMENT	VELOCITY	ACCELERATION	BETA	FORCING FUNCTION	ZERO-TIME ERROR	HALF-TIME ERROR	FULL-TIME ERROR
1	DX	0.	0.	0.	0.	0.	0.	0.	0.
	DY	-.55164E-04	-.55148E+02	.58129E+05	.96261E+11	0.	0.	-.25841E-06	-.14649E-10
	DZ	0.	0.	0.	0.	0.	0.	0.	0.
	RX	0.	0.	0.	0.	0.	0.	0.	0.
	RY	0.	0.	0.	0.	0.	0.	0.	0.
	RZ	0.	0.	0.	0.	0.	0.	0.	0.
2	DX	.11531E-10	.22978E-04	.41778E+02	.69184E+08	0.	0.	-.38739E-14	-.82922E-16
	DY	-.55212E-04	-.55245E+02	-.11733E+06	-.19430E+12	0.	0.	.68682E-06	-.12000E-10
	DZ	0.	0.	0.	0.	0.	0.	0.	0.
	RX	0.	0.	0.	0.	0.	0.	0.	0.
	RY	0.	0.	0.	0.	0.	0.	0.	0.
	RZ	-.48646E-03	0.	0.	0.	0.	0.	.95454E-08	.56573E-11
3	DX	.21235E-08	.42316E-02	.76939E+04	.12741E+11	0.	0.	-.29321E-10	.28882E-13
	DY	-.55132E-04	-.55085E+02	.17348E+06	.28728E+12	0.	0.	-.65620E-06	.46019E-12
	DZ	0.	0.	0.	0.	0.	0.	0.	0.
	RX	0.	0.	0.	0.	0.	0.	0.	0.
	RY	0.	0.	0.	0.	0.	0.	0.	0.
	RZ	.19534E-02	0.	0.	0.	0.	0.	-.25513E-07	.14415E-08
4	DX	-.28982E-08	-.57753E-02	-.10501E+05	-.17389E+11	0.	0.	-.61370E-10	.42176E-13
	DY	-.3797[illegible]E-07	-.75664E-01	-.13757E+06	-.22782E+12	0.	0.	.64995E-10	.52305E-15
	DZ	0.	0.	0.	0.	0.	0.	0.	0.
	RX	0.	0.	0.	0.	0.	0.	0.	0.
	RY	0.	0.	0.	0.	0.	0.	0.	0.
	RZ	.2268[illegible]E-02	0.	0.	0.	0.	0.	.30043E-07	-.16741E-08
5	DX	.87589E-09	.17454E-02	.31735E+04	.52533E+10	0.	0.	-.54288E-11	.10426E-13
	DY	.18231E-07	.36270E-01	.65946E+05	.10921E+12	0.	0.	.17594E-10	-.19659E-14

Figure 25. Printout of State of Joints

Figure 25 also displays printout describing the state of joints for the time indicated at the top of the page. The current displacement, velocity, acceleration, jerk and applied forcing function is defined for each joint degree of freedom. DX, DY, and DZ refer to displacement degrees of freedom along the global, X, Y, and Z axes, respectively; RX, RY, and RZ refer to rotational degrees of freedom about the global X, Y, and Z axes, respectively.

The total response of the structural system is summarized by the system energy evaluations printed at the top of Figure 25. The total input energy of the system is the total amount of work done on the system since the integration began. This total energy is then broken down first into the current system energy which is the sum of the current elastic strain energy and kinetic energy, and then into simply the current elastic strain energy. Finally, the current dissipation rate is printed. This is the rate at which strain energy was lost due to yielding during the current time step.

Figure 26 shows the output defining how the strain energy stored as elastic energy and lost due to yielding during the current time step is attributed to individual elements. By examining the percentage of the total system strain energy contributed by each element, the contribution of each element to the total structural stiffness becomes readily apparent. Plus and minus errors on this printout provide measures of the accuracy of numerical integration over the element cross section. Errors are reported in percent.

Stress and strain-rate printout is provided when the ISINK parameter of the first Control Parameter Card is set equal to 1. When ISINK = 0,

ELEMENT STRAIN ENERGY STATUS AT TIME .1000E-05

ELEMENT	ENERGY STORED	ENERGY LOST	TOTAL ENERGY	PERCENT
1 - 2	.4833E-03	0.	.4833E-03	2.038
2 - 3	.6428E-02	0.	.6428E-02	27.102
3 - 4	.9355E-02	0.	.9355E-02	39.445
4 - 5	.6920E-02	0.	.6920E-02	29.179
5 - 6	.4927E-03	0.	.4927E-03	2.077
6 - 7	.3497E-04	0.	.3497E-04	.147
7 - 8	.2479E-05	0.	.2479E-05	.010
8 - 9	.1759E-06	0.	.1759E-06	.001
9 - 10	.1255E-07	0.	.1255E-07	.000
10 - 11	.9886E-09	0.	.9886E-09	.000

Figure 26. Printout of Element Energy Status

this printout is suppressed. When ISINK = 2, membrane element generalized force printout is produced as well as all printout available at the ISINK = 1 level. Figure 27 presents a typical printout. Stress and strain-rate values are provided for up to 16 locations throughout a cross-section. These locations are referred to as stress points and are illustrated in Figures 7 through 11.

Pages providing stress output also include failure checks for fracture, buckling, deformation, dissipated energy and shear yield. ACTION simulates fracture at individual quadrature points if the axial stress at a point would exceed the ultimate stress of the material. Fracture is indicated by "1.0" in the "FAILURE" columns of the printout. The buckling check flags compression forces exceeding eight-tenths of the axial buckling force as calculated from element input data. The buckling force is included in the printout of member section properties. The deformation check flags **relative** rotations within elements exceeding 0.3 radians. The dissipated energy check warns of the existence of an energy distribution not properly accounted for in the formulation of the energy function. The deformation model neglects shear deformations in the plastic region. The check on shear yield warns the user when this approximation may lead to significant errors. These latter four checks are printed following the printout for individual stress points. If ISINK > 0, the actual values used in the checks are printed. Failure will then be indicated by "1" in the appropriate failure column. If ISINK = 0, the checks are printed only when the analysis determines failure. These checks are not fatal but merely serve as a warning to the user.

STRESS RESULTS FOR FRAME MEMBERS

MEMBER	JOINTS P-Q	STRESS POINT	NORMAL STRESS P-END	NORMAL STRESS Q-END	SHEAR STRESS	FAILURE P-END	FAILURE Q-END	STRAIN RATE P-END	STRAIN RATE Q-END
1	1- 2	1	0.	0.	0.	0.0	0.0	0.	0.
		2	0.	0.	0.	0.0	0.0	0.	0.
		3	2.32009E+07	-4.69576E+07	0.	0.0	0.0	1.18493E+02	-2.39824E+02
		4	0.	0.	0.	0.0	0.0	0.	0.
		5	0.	0.	0.	0.0	0.0	0.	0.
		6	1.16005E+07	-2.34787E+07	-3.28094E+06	0.0	0.0	5.92467E+01	-1.19912E+02
		7	1.77075E+02	1.77075E+02	-4.37459E+06	0.0	0.0	9.04368E-04	9.04368E-04
		8	0.	0.	0.	0.0	0.0	0.	0.
		9	0.	0.	0.	0.0	0.0	0.	0.
		10	-1.16002E+07	2.34791E+07	-4.37459E+06	0.0	0.0	-5.92449E+01	1.19914E+02
		11	0.	0.	-3.28094E+06	0.0	0.0	0.	0.
		12	0.	0.	0.	0.0	0.0	0.	0.
		13	-2.32005E+07	4.69580E+07	0.	0.0	0.0	-1.18491E+02	2.39826E+02
		14	0.	0.	0.	0.0	0.0	0.	0.
		15	0.	0.	0.	0.0	0.0	0.	0.
		16			0.				

STATUS 2, ANALYSIS CHECKS DATA (.143E-01 .486E-03 0. 0.)
(BUCKLING, DEFORMATION, DISSIPATED ENGY, SHEAR YIELD)

MEMBER	JOINTS P-Q	STRESS POINT	NORMAL STRESS P-END	NORMAL STRESS Q-END	SHEAR STRESS	FAILURE P-END	FAILURE Q-END	STRAIN RATE P-END	STRAIN RATE Q-END
2	2- 3	1	0.	0.	0.	0.0	0.0	0.	0.
		2	0.	0.	0.	0.0	0.0	0.	0.
		3	-4.69491E+07	1.66118E+08	0.	0.0	0.0	-2.39781E+02	8.48405E+02
		4	0.	0.	0.	0.0	0.0	0.	0.
		5	0.	0.	0.	0.0	0.0	0.	0.
		6	-2.34702E+07	8.30632E+07	9.96401E+06	0.0	0.0	-1.19868E+02	4.24225E+02
		7	8.66455E+03	8.66455E+03	1.32853E+07	0.0	0.0	4.42520E-02	4.42520E-02
		8	0.	0.	0.	0.0	0.0	0.	0.
		9	0.	0.	0.	0.0	0.0	0.	0.
		10	2.34875E+07	-8.30459E+07	1.32853E+07	0.0	0.0	1.19957E+02	-4.24136E+02
		11	0.	0.	9.96401E+06	0.0	0.0	0.	0.
		12	0.	0.	0.	0.0	0.0	0.	0.
		13	4.69664E+07	-1.66100E+08	0.	0.0	0.0	2.39869E+02	-8.48317E+02
		14	0.	0.	0.	0.0	0.0	0.	0.
		15	0.	0.	0.	0.0	0.0	0.	0.
		16			0.				

STATUS 2, ANALYSIS CHECKS DATA (.700E+00 .244E-02 0. 0.)
(BUCKLING, DEFORMATION, DISSIPATED ENGY, SHEAR YIELD)

Figure 27. Printout of Stress Results

Error Messages

Diagnostic error messages describing input errors and solution errors are printed as errors are encountered during execution of the program. These error messages are self-explanatory.

LIST OF REFERENCES

[1] Harwell Subroutine Library, compiled by M. J. Hopper, Theoretical Physics Division, U.K.A.E.A. Research Group, Atomic Energy Research Establishment, Harwell, Vol. 2, 1973.

[2] M. J. Powell, "Restart Procedures for the Conjugate Gradient Method," C.S.S. 24, Computer Science and Systems Division, Nov. 1975.

[3] M. P. Kamat, "Nonlinear Transient Analysis by Energy Minimization - A Theoretical Basis for the ACTION Computer Code, NASA CR-3287, 1980.

[4] G. L. Goudreau and R. L. Taylor, "Evaluation of Numerical Integration Methods in Elastodynamics," Computer Meth. in Appl. Mech. and Engrg., 2, 1972.

[5] M. P. Kamat, "Nonlinear Transient Analysis of Aircraft-Like Structures - Theory and Validation," VPI & SU Rep. VPI-E-79-10, 1979.

[6] M. P. Kamat and R. J. Hayduk, "Energy Minimization Versus Pseudo Force Technique for Nonlinear Structural Analysis," Journal of Computers and Structures, (To be published).

[7] R. D. Krieg, T. A. Duffey and S. W. Key, "The Large Deflection Elastic-Plastic Response of Impulsively Loaded Beams: A Comparison Between Computations and Experiment," Sandia Lab. Rep. SC-RR-68-226, 1968.

SAMPLE PROBLEM

This section provides additional information on the use of scratch files, restart tapes, etc. in attempting to run a sample problem using a CDC procedure file and/or an IBM JCL file. The objective in providing such sample input and selected output, as in Figures 25 through 27, is to provide the users with some means to validate their version. The selection of the sample problem was motivated by the availability of an independent solution for correlation purposes. Figure 28 provides the input files for the sample problem.

A discussion of this and a few other problems that demonstrate the overall capability of the ACTION program may be found in refs. [5] and [6].

1. Instructions for Input:

1.1 CDC Machine:

The following is a procedure file that may be used to excute a data deck read from cards on a CDC machine.

```
JOB CARD
USER CARD
CHARGE CARD
COPYCR(DATA)
REWIND(DATA)
GET(BACT/NA)
GET(TAPE10)
REWIND(BACT,TAPE10)
GET(NMACFTN/UN=LIBRARY)
LDSET(PRESETA=NGINF,LIB=NMACFTN)
BACT(DATA)
REPLACE(TAPE10)
GOTO,1.
1,RETURN(BACT)
RETURN(TAPE10)
REWIND(DATA)
COPYSBFDATA,OUTPUT)
/EOR
          .
          .
          .
      DATA DECK (see next page)
          .
          .
          .
/EOF
```

Note that BACT is a binary file of the ACTION source which is presumably residing on user's permanent disk space. The cards involving TAPE10 are required only for modifying a restart tape.

```
    IMPULSIVELY LOADED CLAMPED BEAM/NEWMARK BETA/ACTION
  1     0     0    -1         2          250           1     5           1
0.0         0.10       .000001                  51.0000E-051.0000E-061.0000E-060.0

JOINT COORDS AND RESTRAINTS
    1          0.000E+00 0.000E+00 0.000E+00     101111
    2          1.275E-02 0.000E+00 0.000E+00     001110
    3          2.550E-02 0.000E+00 0.000E+00     001110
    4         4.1375E-02 0.000E+00 0.000E+00     001110
    5         5.7250E-02 0.000E+00 0.000E+00     001110
    6         7.3125E-02 0.000E+00 0.000E+00     001110
    7         8.9000E-02 0.000E+00 0.000E+00     001110
    8        1.04875E-1 0.000E+00 0.000E+00     001110
    9        1.20750E-1 0.000E+00 0.000E+00     001110
   10        1.36625E-1 0.000E+00 0.000E+00     001110
   11        1.52500E-1 0.000E+00 0.000E+00     111111
0000000000
MATERIAL
    1       BEAM ELEMENTS
 0.000E+00 0.000E+005.565000+82.852400-31.000000+91.179872072.000000+93.84582828
4.000000+99.1777401-5.58500+8-2.85240-3-1.00000+9-1.1798721-2.00000+9-3.8458283
-4.00000+9-9.17774077.53077+107.53077+107870.0
0000000000
LINE ELEMENTS - IE SECTION REDUCED TO RECT X-SECTION
    1     1    21E        2     1     0      0     0          90.0
          0.0           0.0           0.0           0.0          0.00159    0.0254     0.0
          0.0           0.00159      0.0254
    2     2    31E        2     1     0      0     0          90.0
          0.0           0.0           0.0           0.0          0.00159    0.0254     0.0
          0.0           0.00159      0.0254
    3     3    41E        2     1     0      0     0          90.0
          0.0           0.0           0.0           0.0          0.00159    0.0254     0.0
          0.0           0.00159      0.0254
    4     4    51E        2     1     0      0     0          90.0
          0.0           0.0           0.0           0.0          0.00159    0.0254     0.0
          0.0           0.00159      0.0254
    5     5    61E        2     1     0      0     0          90.0
          0.0           0.0           0.0           0.0          0.00159    0.0254     0.0
          0.0           0.00159      0.0254
    6     6    71E        2     1     0      0     0          90.0
          0.0           0.0           0.0           0.0          0.00159    0.0254     0.0
          0.0           0.00159      0.0254
    7     7    81E        2     1     0      0     0          90.0
          0.0           0.0           0.0           0.0          0.00159    0.0254     0.0
          0.0           0.00159      0.0254
    8     8    91E        2     1     0      0     0          90.0
          0.0           0.0           0.0           0.0          0.00159    0.0254     0.0
          0.0           0.00159      0.0254
    9     9   101E        2     1     0      0     0          90.0
          0.0           0.0           0.0           0.0          0.00159    0.0254     0.0
          0.0           0.00159      0.0254
   10    10   111E        2     1     0      0     0          90.0
          0.0           0.0           0.0           0.0          0.00159    0.0254     0.0
          0.0           0.00159      0.0254

INIT
    1     2             -55.16
    2     2             -55.16
    3     2             -55.16

END OF PROBLEM
END OF ALL PROBLEMS
```

Figure 28. Input Data for an Impulsively Loaded Clamped Beam

1.2 IBM Machine:

The following is a Job Control Language file that may be used to execute a data deck read from cards on an IBM machine.

```
JOB CARD
PRIORITY CARD
/*JOBPARM LINES=XX
//STEP1 EXEC PGM=LMACT,TIME=XX,REGION=1000K
//STEPLIB DD DSN=AXXXXX.ACTION,DISP=SHR
//GO.FT12F001 DD DSN=&TEMP,UNIT=SYSDA,
//   SPACE=(TRK,(30,10)),DCB=(RECFM=VSB,LRECL=8000,BLKSIZE=8004)
//GO.FT10F001 DD DSN=AXXXXX.ACT10,UNIT=SYSDA,
//   SPACE=(TRK,(60,60)),VOL=SER=XXXXX,DISP=(OLD,KEEP),
//   DCB=(RECFM=VSB,LRECL=8000,BLKSIZE=8004)
//FT06F001 DD SYSOUT=A
//FT05F001 DD *
                 .
                 .
                 .
       DATA DECK (see previous page)
                 .
                 .
                 .
/*
//
```

Note that LMACT is the load module member name in the data set AXXXXX.ACTION previously created. The GO.FT10F001 card is required only in the event that a restart tape is being written.

2. Sample Problem Details:

Problem Title: Impulsively Loaded Clamped Beam

Comments: This problem uses the LINE Element IE to model a beam with a solid rectangular cross-section. Since the beam undergoes bending about only one of its principal axis this element is preferred over the other LINE element SORE which should be used for the more general case of bending about both prinicpal axes.

Figure 29 compares the predicted response using two versions of the Newmark-Beta method with that known for experiments [7]. Results indicate sensitivity of the response to assumed values of the β and γ parameters of the Newmark-Beta Method.

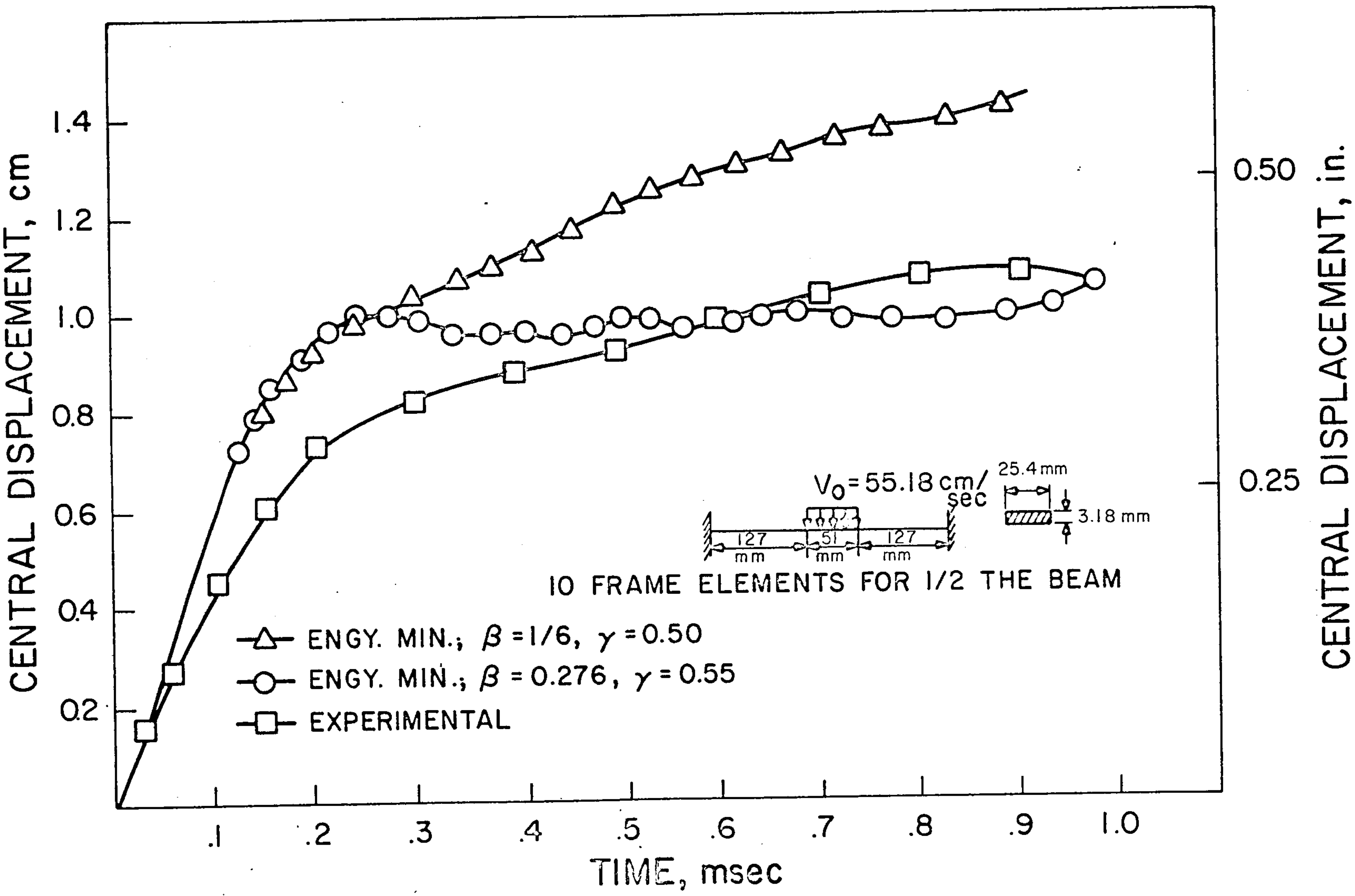

Figure 29. Displacement Response of the Impulsively Loaded Clamped Beam

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15. Supplementary Notes

Contract Monitor: Robert J. Hayduk, NASA Langley Research Center

16. Abstract

This document is a user's guide to the ACTION computer program. It defines the form and interpretation of input and output data. ACTION performs nonlinear transient response analysis of structures subjected to time varying loads, allowing for nonlinear, time independent material properties and large geometry changes.

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