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GENERAL MOTORS CORPORATION

# STRUCTURES I

# THE RESPONSE OF BEAMS AND RINGS TO HIGH-INTENSITY, SHORT-DURATION LOADING

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Hard copy (HC) 2.00

Microfiche (MF) .50

FACILITY FORM 602

| | |
|---|---|
| N65-24845 | |
| (ACCESSION NUMBER) | (THRU) |
| 44 | 1 |
| (PAGES) | (CODE) |
| CR 65039 | 32 |
| (NASA CR OR TMX OR AD NUMBER) | (CATEGORY) |

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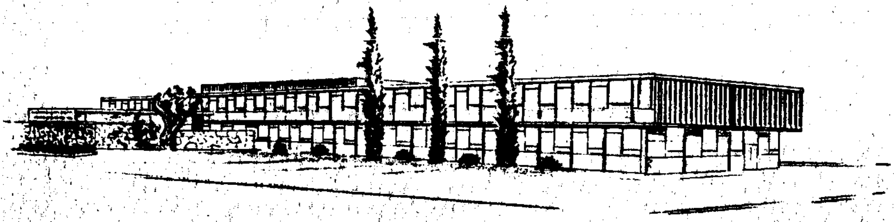

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# THE RESPONSE OF BEAMS AND RINGS TO HIGH-INTENSITY, SHORT-DURATION LOADING

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# ABSTRACT

Computer programs are given for determining the response of beams and rings to impulsive loads, with their use described in detail.

Two sample problems illustrate the input and output data formats, as well as various output options.

author

# CONTENTS

# ILLUSTRATIONS

# INTRODUCTION

In recent years, many investigators(1-4)* have attempted to determine responses of various structural elements to blast or impulsive loadings. Symonds,(5) for example, has developed a "rigid-plastic" theory of deformation in which it is assumed that no elastic deformation takes place, so that all the energy imparted to the system is channeled into plastic deformation of the structure. This type of analysis has two major disadvantages:

1) The energy input to the system must be much greater than the elastic strain-energy that can be stored by the structure.
2) Only permanent deformations are obtained; i. e., no time-history of the response can be found.

The most recent technique which is not subject to these limitations was developed by Witmer, et al,(6) at the M. I. T. Aeroelastic and Structures Research Laboratory. This technique is now described briefly.

## THEORY

The dynamic equilibrium equations for the structural element shown in Figure 1 can be written

$$\left.\begin{aligned} &\frac{\partial}{\partial s}(N\cos\theta) - \frac{\partial}{\partial s}(Q\sin\theta) + Fy - m\ddot{v} = 0 \\ &\frac{\partial}{\partial s}(N\sin\theta) + \frac{\partial}{\partial s}(Q\cos\theta) + F_z - m\ddot{w} = 0 \\ &\frac{\partial M}{\partial s} - Q = 0 \end{aligned}\right\} \qquad (1)$$

---

* Raised numbers in parentheses indicate references at the end of this report.

where $m$ = mass per unit length of structure

$\theta$ = slope of structural element

$N, Q, M$ = normal force, shear force, and bending moment at a given cross section

$\ddot{v}, \ddot{w}$ = accelerations in the horizontal and vertical directions

$F_y, F_z$ = forces per unit area in the horizontal and vertical directions

In the derivation of Eqs. (1), the effects of shear deformation and rotatory inertia have been neglected. In the case of impulsive loading, $F_y$ and $F_z$ are zero, and the beam is considered to have an initial velocity.

Equation (1) may be phrased in finite difference form and interpreted as describing a lumped-parameter model consisting of masses connected by weightless, straight links. (These equations, as well as a complete description of the model, can be found in Reference 6.)

Equations (1) and the corresponding strain-displacement equations have been programed for an IBM 7040 digital computer using Fortran IV language. The remainder of this report describes the use of this program.

## PROGRAM DESCRIPTION AND USE

Two program listings will be found in the appendix. The first, "Blast-Loaded Beams," calculates the response of a clamped-ended beam to an impulsive load. The beam may be pre-tensioned, if desired. Sample output data are also presented.

The second, "Blast-Loaded Rings," calculates the response of a circular ring to impulsive loading. The ring need not be complete.

Both the beam and the ring are of rectangular cross section, and the cross-sectional area is distributed among six "flanges," as shown in Figure 2.

Definitions of the quantities contained in the programs are given at the beginning of the listings.

## BEAM INPUT DATA

| | | |
|---|---|---|
| | CMT | classification data (up to 72 characters) |
| | DT | Time interval (sec)<br>This must be smaller than the time required for a longitudinal wave to traverse the distance between mass-points; otherwise the solution will be unstable. |
| | E | Young's modulus for the beam material (lb/sq in.) |
| | EP | strain-hardening modulus (lb/sq in.) |
| | S1G1 | yield stress of material (lb/sq in.) |
| | TI | readout time (sec) |
| | B | width of beam (in.) |
| | H | thickness of beam (in.) |
| | WIN | input displacement (in.)<br>The method for computing WIN is described in the sample problem. |
| | SM | mass of a single mass-point (lb-sec$^2$/in.) |
| | T | starting time (generally initialized at zero) |
| | TF | time of termination of solution (sec) |
| | LN | length of beam (in.) |
| | XMAX, XMIN | maximum and minimum limits of transverse displacement (in.) |
| | SIGO | pre-tension stress (lb/sq in.) |
| fixed point | NPL | total number of plots (less than or equal to 10) |
| | K1 | the number of the first mass-point that has non-zero input displacement |
| | K 2 | the number of the last mass-point that has non-zero input displacement |
| | TP(J) | plotting time (sec) |

## DETERMINATION OF INPUT DATA FOR SAMPLE BEAM PROBLEM

Consider the response of a beam 20 inches long, 1/2 inch wide, and 1/16 inch thick, made of 7075-T6 aluminum alloy pre-tensioned to 50% of the yield stress and subjected at time $T = 0$ to a uniformly distributed impulsive load over a 1-inch length at the center of the beam. The beam is shown in Figure (3).

It is desired to obtain the response of this beam for a total time of 200μ sec. Thus, $TF = 200 \times 10^{-6}$.

The yield stress for 7075-T6 aluminum is approximately 71,400 pounds per square inch. Therefore, $S1G1 = 71,400$. Since this aluminum is not a strain-hardening material, $EP = 0$.

Because the beam is pre-tensioned to 50% of the yield stress, $SIGO = 35,700$. As specified, $LN = 20$, $B = 1/2$, $H = 1/16$. It is desired to read out the required data at intervals of 20μsec; thus $TI = 20 \times 10^{-6}$.

Since there are 60 mass points representing the total mass of the beam, then

$$SM = \frac{(B)\,(H)\,(LN)\,\rho}{60}$$

where $\rho$ is the mass density of the beam material. In this example, $SM = 0.27 \times 10^{-5}$. Referring to Figure 4, we notice that mass points 30, 31, 32, and 33 will be loaded by the impulse. Thus, $K1 = 30$, and $K2 = 33$.

A time interval DT of $0.5 \times 10^{-6}$ seconds is found to satisfy the necessary criterion for a convergent solution.

We assume that the velocities at which the loaded mass-points begin to move have been computed from impulse-momentum relations. Suppose these velocities are constant and equal to 1,030 inches per second. The input displacement WIN is therefore $1,030\,(DT) = 0.515 \times 10^{-2}$ inches. That is, we assume that for the first time increment DT, the loaded masses move without restraint.

Since mass-points 30 – 33 received the initial load, the greatest strains will occur in this vicinity. Therefore, the output codes L1, L2, L3, and L4 are assigned the values 29, 31, 32, and 34. A non-zero integer must always appear for these output codes.

Plots of the beam profile are desired at 50-usec intervals from zero to 200 $\mu$sec. Thus, NP = 5 and TP(1) = 0, TP(2) = $0.5 \times 10^{-4}$, TP(3) = $0.1 \times 10^{-3}$, TP(4) = $0.15 \times 10^{-3}$, and TP(5) = $0.2 \times 10^{-3}$. Because no more than five plots are required, TP(6) through TP(10) need not be specified. The quantity IP is set equal to 1 to obtain a plot of the center displacement vs time.

## INPUT DATA FORMAT

With the exception of cards 1 and 5, all cards consist of five fields, 14 columns wide. Card 1 uses the first 72 columns for data identification, and card 5 has eight fields, two columns wide for fixed-point constants. Figure 5 shows the layout of the data fields on a data sheet. If NP = 0, cards 6 and 7 must be omitted and if NP is less than six, only card 7 must be omitted.

Possible sources of error in the input deck are the odd field widths on all cards except 1 and 5. To minimize the occurence of these errors and to facilitate the preparation of input decks, the program control feature of card-punching equipment is strongly recommended. This program control card (Fig. 6) will enable the user to prepare data without using the numeric shift key. Use of the shift key anywhere on the card will cause it to advance to the first column of the next numeric field. To avoid skipping, the ALPH shift key should be depressed whenever a minus sign is to be punched.

## BEAM PROBLEM OUTPUT

A listing of the input data appears at the beginning of the output for each set of data, followed by a set of header lines which identify the output in three basic groups: Line 1 contains the time, centerline displacement, and the transverse acceleration at the center; line 2 has the strain at flange 6 of the links specified by the output codes; line 3 contains the strains in the links at flange 1. These three output groups are printed beginning with the starting time T, and the printout interval TF.

Supplementary data can be obtained at the printout time by using the sense switch options. This information is printed on tape unit No. 4. If sense switch 3 is on, the following data is printed for mass points 1 – 31: acceleration in the horizontal direction, acceleration in the transverse direction, total transverse displacement of the mass points, and horizontal coordinates of the mass points. When sense switch 4 is on, the strain in flange J (J = 1, ... 6) of link I (I = 1, ... 32) is printed. If the sense switches are left on for an entire run, the total run time is increased by 50%.

## SAMPLE RING PROBLEM

Input Data

| | | |
|---|---|---|
| | DT | time increment (sec) |
| | E | Young's modulus (lb/sq in.) |
| | EP | strain-hardening modulus (lb/sq in.) |
| | S1G1 | yield stress (lb/sq in.) |
| | TC | readout time (sec) |
| | B | width of ring cross section (in.) |
| | H | thickness of ring (in.) |
| | ALFA | defined in Figure 8 (rad) |
| | SM | mass of a single mass-point (lb-sec$^2$/in.) |
| | T | starting time (generally initialized at zero) |
| | R | radius of the ring (in.) |
| | TP | plotting time interval (sec) |
| | TF | time of termination of solution (sec) |
| fixed point | NP | ring profile plot code (non-zero for plots) |
| | K1 | the number of the first mass-point which has non-zero input displacement |
| | K2 | the number of the last mass-point which has non-zero input displacement |

Figure (7) is a sample data sheet for the ring program.

Calculation of the input data for the ring proceeds in the same manner as that for the beam; only the calculations which differ are described here.

The angle of the clamped supports from the vertical is defined by ALFA (Fig. 8) expressed in radians. For a complete circular ring (sample problem) ALFA equals $\pi$ . Notice that for this case mass-points 2 and 62 occupy the same position, as do 1 and 61.

The quantity RIN is analogous to WIN in the beam program. A displacement toward the center of curvature is a positive input displacement.

The radius of the ring in inches is R . In the sample problem a complete ring is uniformly loaded radially over a central angle of 120 degrees by an impulsive load which imparts initial velocities of 5,460 inches per second to the loaded mass-points. Mass-points 22 (K1) to 41(K2) are loaded.

The ring material, 6061-T6 aluminum alloy, is considered to be elastic-perfectly-plastic. Thus, $E = 10.4 \times 10^6$ , EP = 0, and S1G1 = 41,400.

To complete the specification of the physical properties of the ring, R = 3 in., H = 1/8 in., and B = 1 in.

Since output is desired every 100 $\mu$sec, $TC = 0.1 \times 10^{-3}$ and $TP = 0.1 \times 10^{-3}$. This produces a plot of the ring deformation every 100 $\mu$sec. The final time TF is 300.5 $\mu$ sec to insure output data at 300 $\mu$ sec.

## RING PROGRAM OUTPUT

A listing of the input data appears at the beginning of the output for each data set. Beginning with the starting time T and continuing at printout intervals TC , the following data is presented: horizontal and vertical coordinates for mass-point I; strain in link I for flanges 1 and 6; (I = 1, . . . , 31).

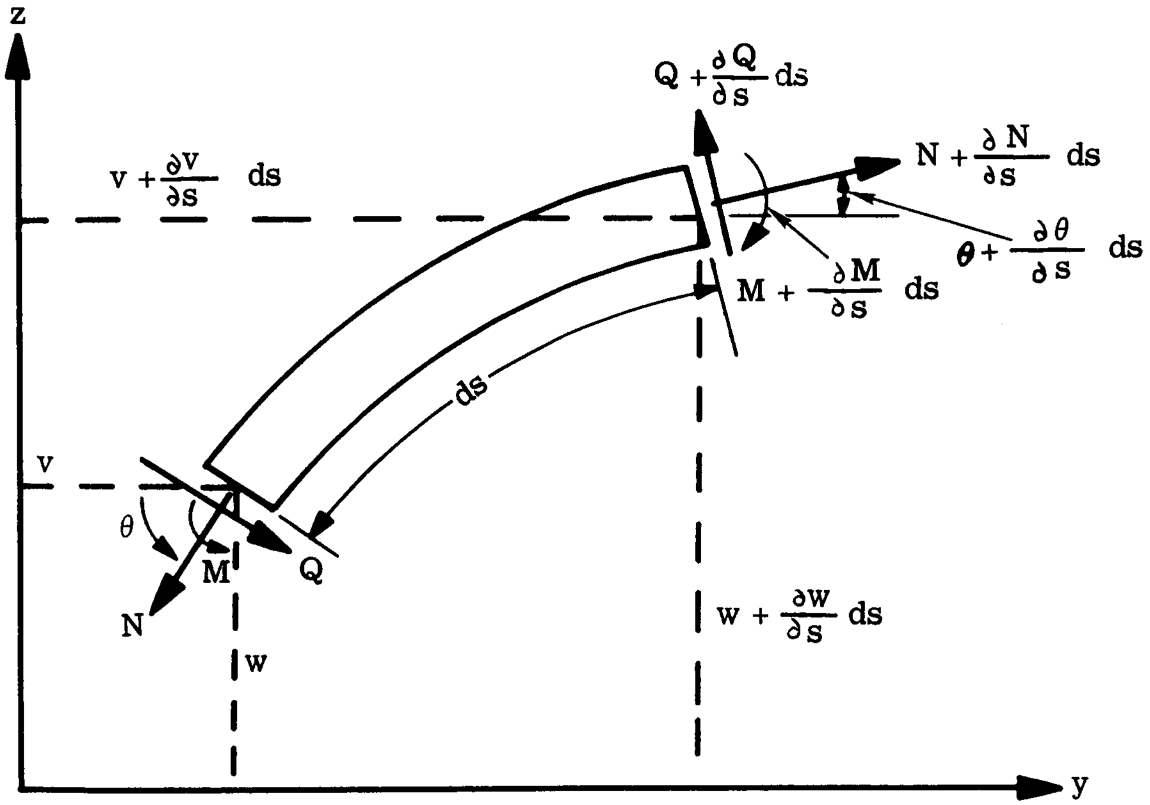


Figure 1 Coordinate System and Internal Forces

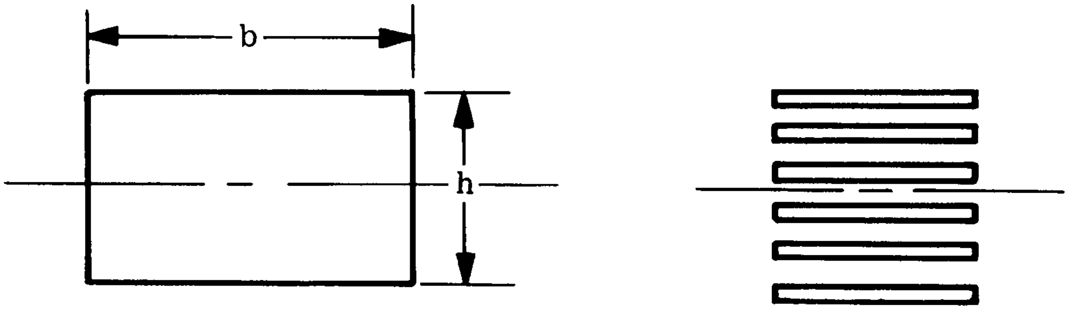


Figure 2 Idealized Thickness Model

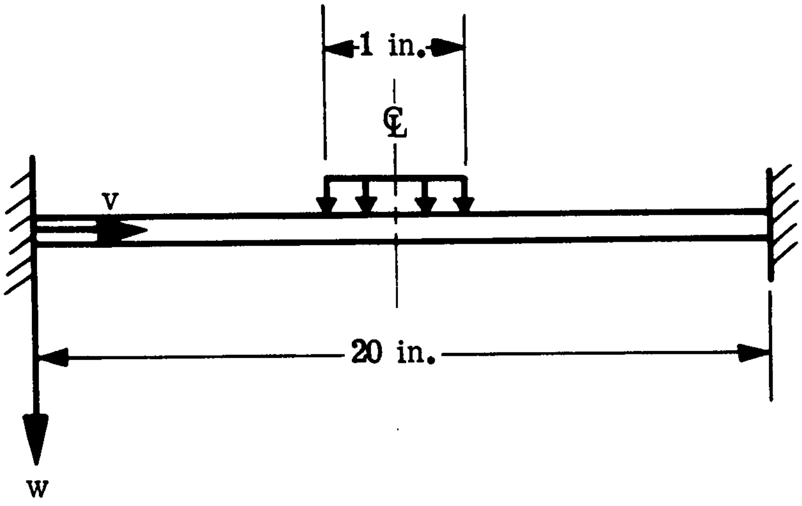


Figure 3 Beam for Sample Problem

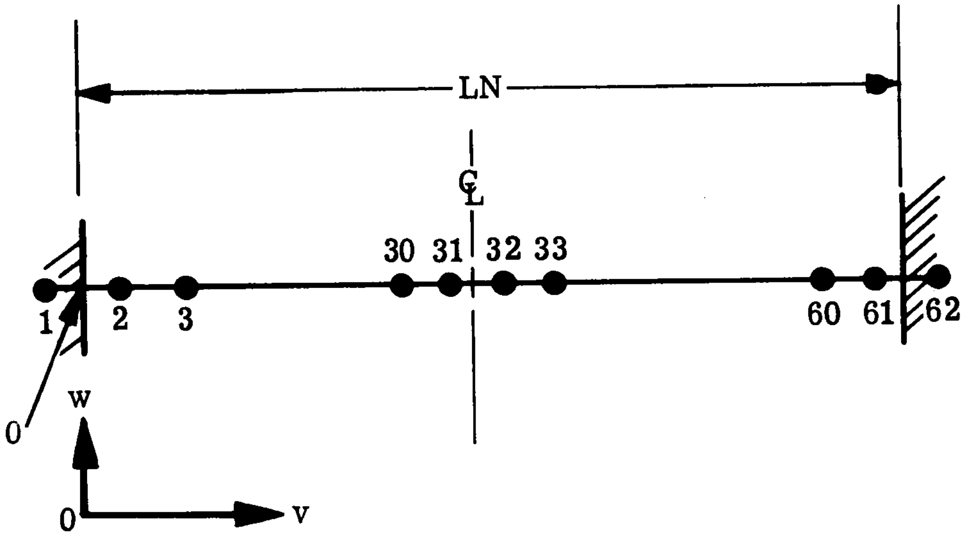


Figure 4 Lumped-Mass Beam Approximation

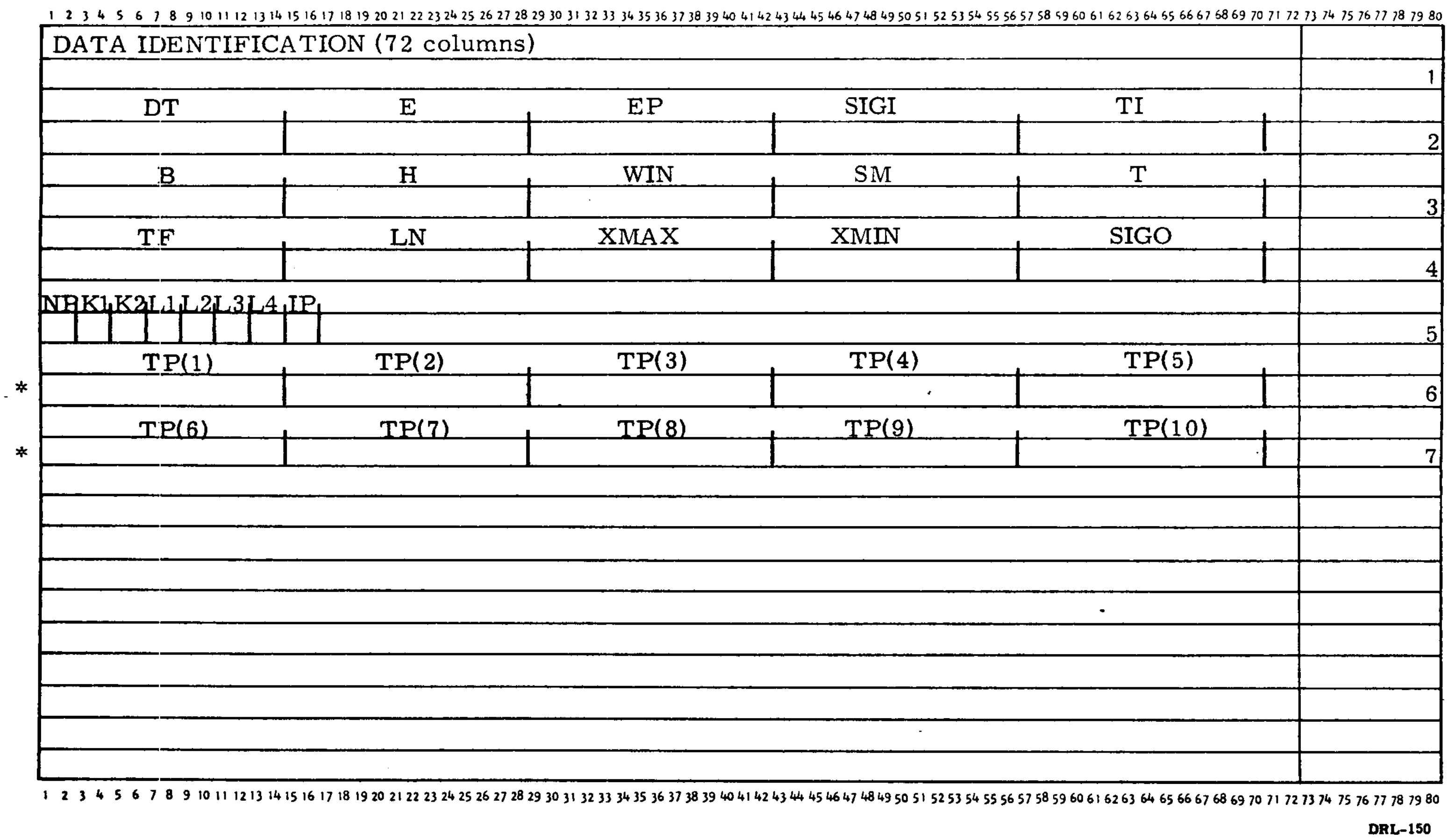


Figure 5 Sample Beam Input Format

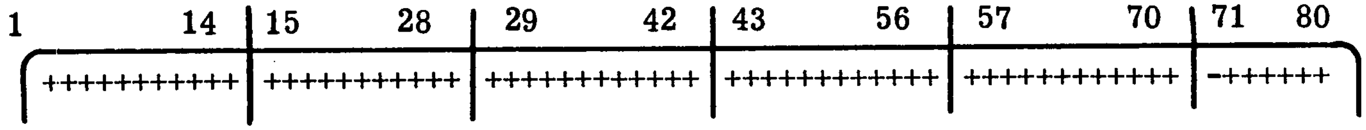


Figure 6 Suggested Program Control
(Columns 1, 15, 29, 43, and 57 are blank)

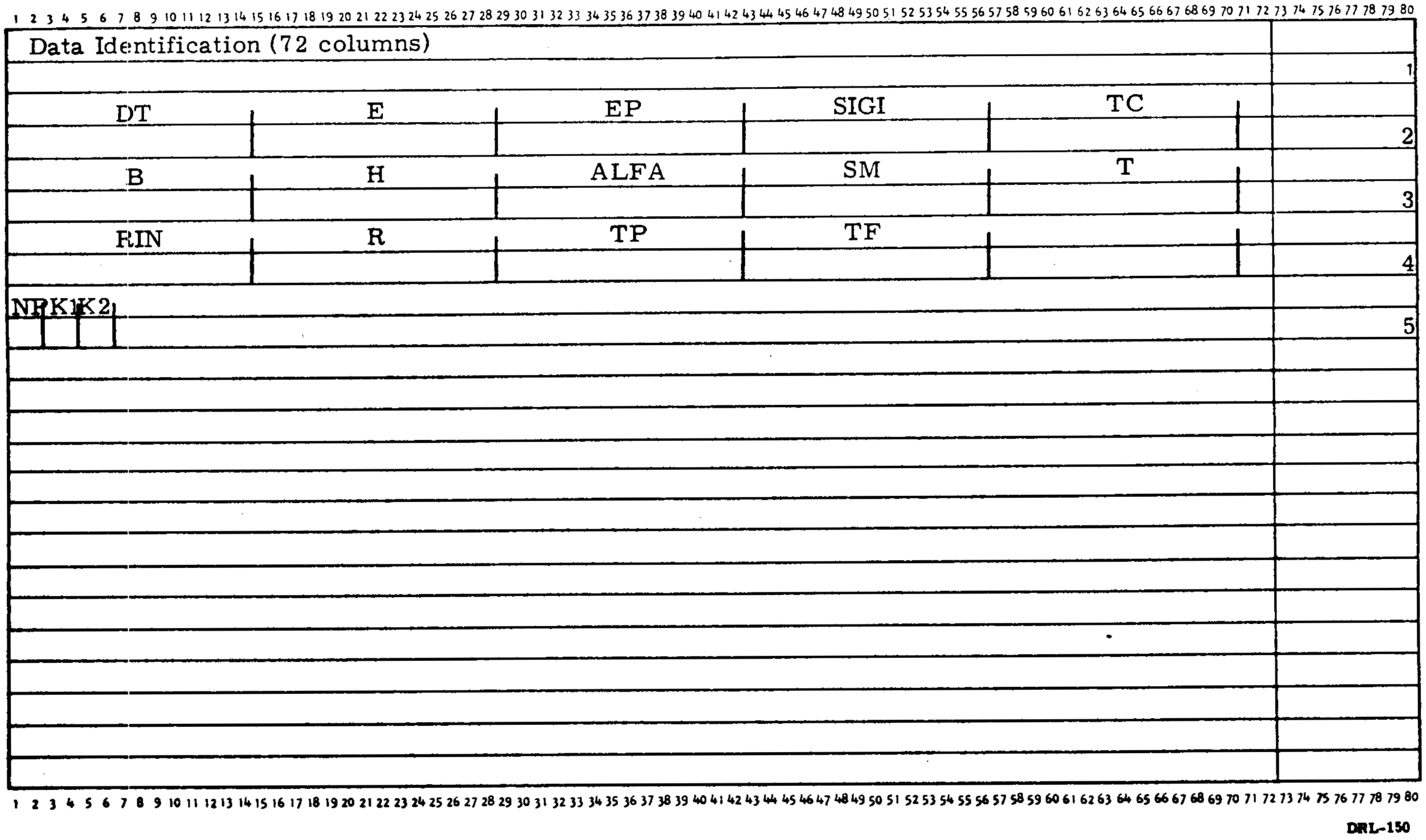


Figure 7 Sample Ring Input Format

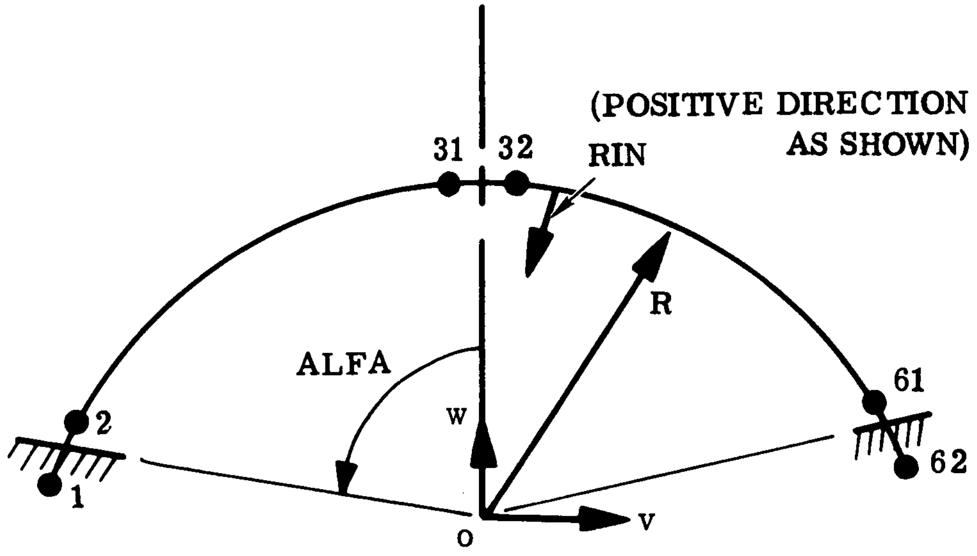


Figure 8 Ring Geometry

# REFERENCES

1. H.H. Bleich and M.G. Salvadori, "Impulsive Motion of Elasto-Plastic Beams," Transactions of the American Society of Civil Engineers, Sep 1953
2. M.M. Chen, P.T. Hsu, and T.H.H. Pian, "Impulsive Loading of Rigid-Plastic Curved Beams," Fourth U.S. National Congress of Applied Mechanics, 1962
3. M.F. Conroy, "The Plastic Deformation of Built-In Beams Due to Distributed Dynamic Loading" (paper presented at the Summer Conference of Applied Mechanics Division, American Society of Mechanical Engineers, Jun 9 – 11, 1964, Boulder, Colorado)
4. P.E. Duwez, D.S. Clark, and H.F. Bohnonblust, "The Behavior of Long Beams Under Impact Loading," J. Appl. Mech., Mar 1950
5. E.H. Lee, and P.S. Symonds, "Large Plastic Deformations of Beams Under Transverse Impact," J. Appl. Mech. Vol. 19, 1952
6. E.A. Witmer, H.A. Balmer, J.W. Leech, and T.H.H. Pian, "Large Dynamic Deformations of Beams, Circular Rings, Circular Plates, and Shells" (paper presented at the AIAA Launch and Space Vehicle Shell Structures Conference, Apr 1 – 3, 1963, Palm Springs, Calif.)

# APPENDIX

```
$IBFTC BEAM    LIST.REF
C
C                       INPUT DATA
C
C
C      B          WIDTH OF BEAM
C      CMT        DATA IDENTIFICATION
C      DT         TIME INTERVAL
C      E          YOUNG'S MODULUS
C      EP         STRAIN-HARDENING MODULUS
C      EPO        STRAIN ASSOCIATED WITH SIGO
C      EPST(I,J)  TOTAL STRAIN IN FLANGE J OF LINK I
C      H          THICKNESS OF BEAM
C      IP         DISPLACEMENT VS. TIME PLOT CODE
C      K1         THE NUMBER OF THE FIRST MASS-POINT WHICH HAS NON-ZERO
C                 INPUT DISPLACEMENT
C      K2         THE NUMBER OF THE LAST MASS-POINT WHICH HAS NON-ZERO
C                 INPUT DISPLACEMENT
C      LN         LENGTH OF BEAM
C      NPL        TOTAL NUMBER OF PLOTS
C      Q          SHEAR FORCE
C      SIG1       YIELD STRESS OF MATERIAL
C      SIGO       PRETENSION STRESS
C      SIG(I,J)   STRESS IN FLANGE J OF LINK I
C      SM         MASS OF A SINGLE MASS-POINT
C      T          STARTING TIME
C      TF         TIME OF TERMINATION OF SOLUTION
C      TI         READOUT TIME
C      TP         PLOTTING TIME
C      WDD        ACCELERATION IN TRANSVERSE DIRECTION
C      WIN        INPUT DISPLACEMENT
C      XMAX       MAXIMUM LIMIT OF TRANSVERSE DISPLACEMENT
C      XMIN       MINIMUM LIMIT OF TRANSVERSE DISPLACEMENT
C
C                       DEFINITIONS
C
C
C      BMOM     BENDING MOMENT
C      DSI      DISTANCE BETWEEN MASS POINTS
C      E1       AXIAL STRAIN
C      E2       BENDING STRAIN
C      EPO      STRAIN ASSOCIATED WITH SIGO
C      FNOR     NORMAL FORCE
C      PSI      COORDINATES OF THE FLANGES
C      SIGO     PRETENSION
C      VDD      ACCELERATION IN THE HORIZONTAL DIRECTION
C      VIT(I)   HORIZONTAL COORDINATE OF MASS I
```

```
C     VO        INITIAL LONGITUDINAL COORDINATES
C     WIT(I)    TOTAL TRANSVERSE DISPLACEMENT OF MASS I
C     WO        INITIAL TRANSVERSE COORDINATES
      REAL LN
      DIMENSION DATA(800)
      DIMENSION TIMX(500),CLDIS(500)
      DIMENSION SIGO(61,6),EPO(61,6),PSI(6),VO(62),WO(62),V1(62),W1(62),
     1    VOP(62),DSI(61),S(61),C(61),E1(61),DTI(61),E2(62),EPS(61,6),
     2    SIG(61,6),FNOR(61),BMOM(61),Q(61),VDD(61),WDD(61),VIT(62),
     3    WIT(62),EPST(61,6),DEPS(61,6),SIGT(61,6),SIGC1(61,6),
     4    SIGC2(61,6),CMT(12),X(32),Y(32),TP(10)
  500 FORMAT (5E14.8)
  501 FORMAT (12A6)
  502 FORMAT (8I2)
  510 FORMAT (49H1     DEFORMATION PROFILE OF AN IMPACT LOADED BEAM,42X,
     1    A2,1H/,A2,1H/,A2,6X5HPAGE ,I4/5X12A6)
  511 FORMAT (1H0,8X14HTIME INTERVAL=,E14.8,4X16HYOUNG-S MODULUS=,9X,
     1    E14.8,4X13HYIELD STRESS=,E14.8/9X14HINITIAL TIME= ,E14.8,4X,
     2    25HSTRAIN-HARDENING MODULUS=,E14.8,4X6HWIDTH=,7XE14.8/9X
     3    14HFINAL TIME=    ,E14.8,4X25HINITIAL DISPLACEMENT=     ,E14.8,
     4    4X13HTHICKNESS=    ,E14.8/9X14HREAD-OUT TIME=,E14.8,4X
     5    25HMASS OF A MASS-POINT=     ,E14.8,4X7HLENGTH=,6XE14.8)
  512 FORMAT (7H0LINE 1,7X4HTIME,15X7HCLDISP.,15X3HWDD/7H LINE 2,5X
     1   ,4(4HEPS(,I2,3H,6),11X)/,7H LINE 3,5X,4(4HEPS(,I2,3H,1),11X))
  513 FORMAT (6H0 LINE/5H     1,4XE15.8,8X9H---------,11X9H---------/
     1    5H     2,4X4(E15.8,5X)/5H     3,4X4(E15.8,5X))
  514 FORMAT (5H0     1,4X3(E15.8,5X)/5H     2,4X4(E15.8,5X)/5H     3,
     1    4X4(E15.8,5X))
  515 FORMAT (6H0TIME=,E12.5/11X3HVDD,14X3HWDD,14X3HWIT,14X3HVIT/)
  516 FORMAT (10X,4E17.8)
  517 FORMAT (6H0TIME=,E12.5/9X1HI,6(4X6HEPS(I,,I1,1H),5X))
  518 FORMAT (8X,I2,6E17.8)
  519 FORMAT (9X,45HINITIAL DISPLACEMENT EXTENDS FROM MASS-POINT ,I2,1X,
     1    14HTO MASS-POINT ,I2)
      CALL PLOTS  (DATA,800)
      CALL PLOT (0.0,0.0,-3)
      CALL FPT (.TRUE.,0)
      CALL DATE (ID1,ID2,ID3)
      NPGN=1
      NPGA=1
      INP=0
    1 READ (5,501) (CMT)
      WRITE (6,510) ID1,ID2,ID3,NPGN,CMT
      READ (5,500) DT,E,EP,SIG1,TI,B,H,WIN,SM,T,TF,LN,XMAX,XMIN,SIGO
      READ (5,502) NPL,K1,K2,L1,L2,L3,L4,IP
      WRITE (6,511) DT,E,SIG1,T,EP,B,TF,WIN,H,TI,SM,LN
      WRITE (6,519) K1,K2
```

```
      WRITE (6,512) L1,L2,L3,L4,L1,L2,L3,L4
      NPGN=NPGN+1
      LC=12
      TC=TI
      IF (NPL.LE.0) GO TO 2
      READ (5,500) (TP(J),J=1,NPL)
      JP=1
      IPLOT=1
      GO TO 4
    2 IPLOT=2
    4 AF= B*H/6.
      D= H/6.
      F=LN/60.
      G=0.
      VO(1)=0.
      DO 3 I=1,61
   80 VO(I+1)=VO(I)+F
      DO 3 J=1,6
      SIGO(I,J)=SIGO
    3 EPO(I,J)=SIGO(I,J)/E
      DO 20 J=1,6
      FJ =J
   20 PSI(J)=D*(FJ-((6.+1.)/2.))
      DO 86 I=1,62
   81 WO(I)=0.
   82 V1(I)=VO(I)
      W1(I)=0.
      IF (I.GE.K1.AND.I.LE.K2) W1(I)=WIN
   86 VOP(I)=VO(I)
      V1(1)=0.
      V1(62)=LN+LN/60.
      DO 24 I=1,61
   21 DSI(I)=SQRT((ABS(V1(I+1)-V1(I)))**2.+(ABS(W1(I+1)-W1(I)))**2.)
   22 S(I)=(W1(I+1)-W1(I))/DSI(I)
   23 C(I) =(V1(I+1)-V1(I))/DSI(I)
   24 E1(I)=(DSI(I)-F)/F
      DTI(1)=0.
      E2(1)=0.
      E2(62)=0.
      DO 27 I=1,60
   25 DTI(I+1)=S(I+1)*C(I)-C(I+1)*S(I)
   26 E2(I+1)=(DTI(I+1)-G)/F
      DO 27 J=1,6
   27 EPS(I,J)=E1(I)-PSI(J)*E2(I+1)+EPO(I,J)
      DO 271 J=1,6
  271 EPS(61,J)=EPS(60,J)
      WRITE (6,513) T,EPS(L1,6),EPS(L2,6),EPS(L3,6),EPS(L4,6),EPS(L1,1),
```

```
     1     EPS(L2,1),EPS(L3,1),EPS(L4,1)
      LC=LC+5
      DO 29 I=1,61
      DO 29 J=1,6
   28 S1G(I,J)=E*EPS(I,J)
      IF(EPS(I,J)) 32,31,30
   29 CONTINUE
   68 DO 38 I=1,61
      FNOR(I)=0.
      BMOM(I)=0.
      DO 38 J=1,6
   37 FNOR(I)=AF*S1G(I,J)+FNOR(I)
   38 BMOM(I) =AF*S1G(I,J)*PSI(J)+BMOM(I)
      DO 39 I=1,60
   39 Q(I+1)=(BMOM(I+1)-BMOM(I))/DSI(I+1)
      Q(1)=Q(2)
      Q(61)=Q(60)
      DO 45 I=1,60
   40 VDD(I+1)=(FNOR(I+1)*C(I+1)-FNOR(I)*C(I)-Q(I+1)*S(I+1)+Q(I)*S(I))/S
     1M
   41 WDD(I+1)=(FNOR(I+1)*S(I+1)-FNOR(I)*S(I)+Q(I+1)*C(I+1)-Q(I)*C(I))/S
     1M
   42 VIT(I+1)=VDD(I+1)*DT**2.+2.*V1(I+1)-VO(I+1)
   45 WIT(I+1)=WDD(I+1)*DT**2.+2.*W1(I+1)-WO(I+1)
      VIT(1)=0.
      VIT(62)=VO(62)
      WIT(1)=0.
      WIT(2)=0.
      WIT(61)=0.
      WIT(62)=0.
      DO 47 I=1,62
   43 VO(I)=V1(I)
   44 V1(I)=VIT(I)
   46 WO(I)=W1(I)
   47 W1(I)=WIT(I)
      DO 51 I=1,61
   48 DSI(I)=SQRT((ABS(VIT(I+1)-VIT(I)))**2.+(ABS(WIT(I+1)-WIT(I)))**2.)
   49 S(I)=(WIT(I+1)-WIT(I))/DSI(I)
   50 C(I)=(VIT(I+1)-VIT(I))/DSI(I)
   51 E1(I)=(DSI(I)-F)/F
      DTI(1)=0.
      E2(1)=0.
      E2(62)=0.
      DO 54 I=1,60
   52 DTI(I+1)=S(I+1)*C(I)-C(I+1)*S(I)
   53 E2(I+1)=(DTI(I+1)-G)/F
      DO 54 J=1,6
```

```
 54 EPST(I,J)=E1(I)-PSI(J)*E2(I+1)+EPO(I,J)
    DO 541 J=1,6
541 EPST(61,J)=EPST(60,J)
    DO 58 I=1,61
    DO 58 J=1,6
 55 DEPS(I,J)=EPST(I,J)-EPS(I,J)
 56 EPS(I,J)=EPST(I,J)
    S1GT(I,J)=S1G(I,J)+E*DEPS(I,J)
 57 S1G(I,J)=S1GT(I,J)
    IF(DEPS(I,J)) 61,60,59
 58 CONTINUE
    T=T+DT
    GO TO (150,151),IPLOT
150 IF (T.GE.TP(JP).AND.JP.LE.NPL) GO TO 66
151 IF(T.GE.TC)GO TO 72
 70 IF(TF.GT.T)GO TO 68
    IF  (IP.NE.0) CALL GRH1 (TIMX,CLDIS,INP)
 69 GO TO 1
 72 IF (LC.GE.52) GO TO 87
 88 WRITE (6,514) T,WIT(31),WDD(31),EPS(L1,6),EPS(L2,6),EPS(L3,6),
   1    EPS(L4,6),EPS(L1,1),EPS(L2,1),EPS(L3,1),EPS(L4,1)
    LC=LC+4
    CALL SSWTCH (3,JSS)
    CALL SSWTCH (4,ISS)
    IF (JSS.EQ.2) GO TO 90
    WRITE (4,510) ID1,ID2,ID3,NPGA,CMT
    NPGA=NPGA+1
    WRITE (4,515) T
    WRITE (4,516) (VDD(I),WDD(I),WIT(I),VIT(I),I=1,31)
 90 IF (ISS.EQ.2) GO TO 89
    WRITE (4,510) ID1,ID2,ID3,NPGA,CMT
    NPGA=NPGA+1
    WRITE (4,517) T,(J,J=1,6)
    WRITE (4,518) (I,(EPS(I,J),J=1,6),I=1,32)
 89 INP=INP+1
    TIMX(INP)=T
    CLDIS(INP)=WIT(31)
    TC=TC+TI
    GO TO 70
 30 S1GC1(I,J)=S1G1+EP*EPS(I,J)
    IF(S1G(I,J)-S1GC1(I,J))33,33,34
 33 S1G(I,J)=S1G(I,J)
    GO TO 29
 34 S1G(I,J) =S1GC1(I,J)
    GO TO 29
 31 S1G(I,J)=S1G(I,J)
    GO TO 29
```

```
 32 S1GC2(I,J)=-S1G1+EP*EPS(I,J)
    IF(S1G(I,J)-S1GC2(I,J))35,36,36
 35 S1G(I,J)=S1GC2(I,J)
    GO TO 29
 36 S1G(I,J)=S1G(I,J)
    GO TO 29
 59 S1GC1(I,J)=S1G1+EP*EPS(I,J)
    IF(S1G(I,J)-S1GC1(I,J))62,62,63
 62 S1G(I,J)=S1G(I,J)
    GO TO 58
 63 S1G(I,J)=S1GC1(I,J)
    GO TO 58
 60 S1G(I,J)=S1G(I,J)
    GO TO 58
 61 S1GC2(I,J)=-S1G1+EP*EPS(I,J)
    IF(S1G(I,J)-S1GC2(I,J))64,65,65
 64 S1G(I,J)=S1GC2(I,J)
    GO TO 58
 65 S1G(I,J)=S1G(I,J)
    GO TO 58
 87 WRITE (6,510) ID1,ID2,ID3,NPGN,CMT
    WRITE (6,512) L1,L2,L3,L4,L1,L2,L3,L4
    NPGN=NPGN+1
    LC=6
    GO TO 88
 66 JP=JP+1
    Y(1)=0.0
    Y(2)=F/2.
    Y(32)=10.0
    DX=(XMAX-XMIN)/7.0
    X(1)=(WIT(1)-XMIN)/DX
    X(2)=(WIT(2)-XMIN)/DX
    X(32)=(WIT(32)-XMIN)/DX
    DO 67 I=3,31
    Y(I)=Y(I-1)+F
 67 X(I)=(WIT(I)-XMIN)/DX
    CALL AXIS (0.0,0.0,28HPOSITION COORDINATE (INCHES),+28,10.0,90.0,
   1    0.0,1.0)
    CALL SYMBOL (0.2,10.05,0.14,23HBEAM PROFILE AT TIME = ,0.0,23)
    TIME=T*10.**6
    CALL NUMBER (2.96,10.05,0.14,TIME,0.0,1)
    CALL PMU (3.80,10.05,0.14)
    CALL SYMBOL (3.92,10.05,0.14,4HSEC.,0.0,4)
    CALL LINE (X,Y,32,1)
    CALL AXIS (0.0,0.0,21HDISPLACEMENT (INCHES),-21,7.0,0.0,XMIN,DX)
    CALL PLOT (8.5,0.0,-3)
    GO TO 151
```

```
      END
$IBFTC GRH1     LIST,REF
      SUBROUTINE GRH1 (T,D,N)
      DIMENSION T(1),D(1)
      CALL SCALE (T,N,6.0,XMIN,DX,1)
      CALL SCALE (D,N,8.0,YMIN,DY,1)
      CALL PLOT (1.0,1.0,-3)
      CALL AXIS (0.0,0.0,4HTIME,-4,6.0,0.0,XMIN,DX)
      CALL AXIS (0.0,0.0,12HDISPLACEMENT,12,8.0,90.,YMIN,DY)
      CALL LINE (T,D,N,1)
      CALL PLOT (7.5,-1.,-3)
      RETURN
      END
```

```
DEFORMATION PROFILE OF AN IMPACT LOADED BEAM
BEAM DOCUMENTATION RUN NUMBER 1 (PRETENSION)

    TIME INTERVAL=0.50000000E-06    YOUNG'S MODULUS=           0.10400000E 08    YIELD STRESS=0.71400000E 05
    INITIAL TIME= 0.                STRAIN-HARDENING MODULUS=0.                  WIDTH=        0.50000000E 00
    FINAL TIME=   0.20050000E-03    INITIAL DISPLACEMENT=      0.51500000E-02    THICKNESS=    0.62500000E-01
    READ-OUT TIME=0.10000000E-04    MASS OF A MASS-POINT=      0.27000000E-05    LENGTH=       0.20000000E 02

LINE 1       TIME                CLDISP.               WDD
LINE 2       EPS(29,6)           EPS(31,6)             EPS(32,6)            EPS(34,6)
LINE 3       EPS(29,1)           EPS(31,1)             EPS(32,1)            EPS(34,1)

 LINE
   1      0.
   2      0.47586810E-02      0.34324576E-02      0.46393450E-02      0.34324576E-02
   3      0.23449060E-02      0.34324576E-02      0.22255701E-02      0.34324576E-02

   1      0.10500000E-04      0.11400302E-00     -0.76078469E 07
   2      0.43780261E-01      0.77578158E-02      0.44718499E-01      0.39310349E-02
   3      0.88173969E-03      0.41972615E-02      0.19913011E-02      0.74371303E-02

   1      0.20499999E-04      0.21623332E-00     -0.77605894E 08
   2      0.62472253E-01      0.21709681E-01      0.69311598E-01      0.52314021E-02
   3      0.10506789E-01      0.57956151E-02      0.17353661E-01      0.19868556E-01

   1      0.30499997E-04      0.30964713E-00     -0.17142658E 09
   2      0.56947015E-01      0.37456945E-01      0.65939891E-01      0.26494576E-02
   3      0.23959028E-01      0.24881680E-02      0.33130652E-01      0.32185891E-01

   1      0.40499992E-04      0.38632088E-00     -0.22206971E 09
   2      0.52727893E-01      0.48464643E-01      0.61234491E-01      0.41761858E-03
   3      0.46758772E-01     -0.26836693E-02      0.55871516E-01      0.37266280E-01

   1      0.50499986E-04      0.44127355E-00     -0.24260298E 09
   2      0.53051278E-01      0.53130582E-01      0.59306710E-01      0.35942388E-02
   3      0.61206357E-01     -0.29215719E-02      0.67276502E-01      0.33945313E-01

   1      0.60499980E-04      0.47440052E-00     -0.10541067E 09
   2      0.53429920E-01      0.47576261E-01      0.61043944E-01      0.10668554E-01
   3      0.55707803E-01     -0.10714037E-02      0.61895577E-01      0.26100198E-01

   1      0.70499967E-04      0.49613916E-00     -0.46650771E 08
   2      0.61377774E-01      0.41756557E-01      0.69915278E-01      0.17133731E-01
   3      0.49506111E-01      0.57923049E-02      0.55659804E-01      0.22337682E-01

   1      0.80499952E-04      0.51387613E 00     -0.10570389E 08
   2      0.67841764E-01      0.39784020E-01      0.76258342E-01      0.18937226E-01
   3      0.48241628E-01      0.14325995E-01      0.53884676E-01      0.22837467E-01

   1      0.90499937E-04      0.53060167E 00     -0.69647442E 07
   2      0.67686344E-01      0.40627095E-01      0.76060667E-01      0.19116262E-01
   3      0.49836456E-01      0.21048581E-01      0.55455061E-01      0.24469793E-01
```

```
DEFORMATION PROFILE OF AN IMPACT LOADED BEAM
BEAM DOCUMENTATION RUN NUMBER 1 (PRETENSION)

LINE 1      TIME            CLDISP.          WDD
LINE 2      EPS(29,6)       EPS(31,6)        EPS(32,6)        EPS(34,6)
LINE 3      EPS(29,1)       EPS(31,1)        EPS(32,1)        EPS(34,1)

     1    0.10049992E-03   0.54634098E 00  -0.15855107E 08
     2    0.64233384E-01   0.39791218E-01   0.72971531E-01   0.21243039E-01
     3    0.53233023E-01   0.22479932E-01   0.59492178E-01   0.23676910E-01

     1    0.11049991E-03   0.56043693E 00  -0.24416015E 08
     2    0.61286791E-01   0.39817481E-01   0.69454273E-01   0.27838976E-01
     3    0.56218530E-01   0.23360434E-01   0.62603171E-01   0.22810096E-01

     1    0.12049989E-03   0.57210330E 00  -0.26697714E 08
     2    0.61253313E-01   0.39915150E-01   0.69005479E-01   0.36583008E-01
     3    0.57044958E-01   0.25117156E-01   0.63705686E-01   0.22465199E-01

     1    0.13049986E-03   0.58122613E 00  -0.21604185E 08
     2    0.62305239E-01   0.40223042E-01   0.70102599E-01   0.42641914E-01
     3    0.56170483E-01   0.27902029E-01   0.62969480E-01   0.22474546E-01

     1    0.14049983E-03   0.58820898E 00  -0.26679288E 08
     2    0.62539328E-01   0.41802179E-01   0.70571610E-01   0.42526639E-01
     3    0.56967502E-01   0.31247472E-01   0.63512445E-01   0.23858818E-01

     1    0.15049980E-03   0.59243707E 00  -0.37634535E 08
     2    0.61100421E-01   0.41862575E-01   0.68915951E-01   0.37905427E-01
     3    0.59219767E-01   0.32024395E-01   0.65133123E-01   0.27128845E-01

     1    0.16049976E-03   0.59334112E 00  -0.11254063E 08
     2    0.56471098E-01   0.38631101E-01   0.65371403E-01   0.34491496E-01
     3    0.57422047E-01   0.29501167E-01   0.64614302E-01   0.29600673E-01

     1    0.17049973E-03   0.59283613E 00  -0.81162471E 07
     2    0.56695994E-01   0.37690774E-01   0.65058290E-01   0.34483311E-01
     3    0.58191044E-01   0.30317263E-01   0.64507404E-01   0.27934735E-01

     1    0.18049970E-03   0.59152924E 00  -0.54582206E 07
     2    0.58019782E-01   0.37390469E-01   0.66435523E-01   0.37533132E-01
     3    0.58845608E-01   0.32440599E-01   0.64730153E-01   0.26193920E-01

     1    0.19049966E-03   0.58967689E 00  -0.25700086E 07
     2    0.57951638E-01   0.37224101E-01   0.66327078E-01   0.37700960E-01
     3    0.59268496E-01   0.34189314E-01   0.65164062E-01   0.26349590E-01

     1    0.20049963E-03   0.58757044E 00  -0.50023666E 06
     2    0.56776482E-01   0.36270502E-01   0.65161695E-01   0.34635626E-01
     3    0.60187636E-01   0.34542679E-01   0.66218626E-01   0.28581718E-01
```

# BEAM PROGRAM

Memory Required

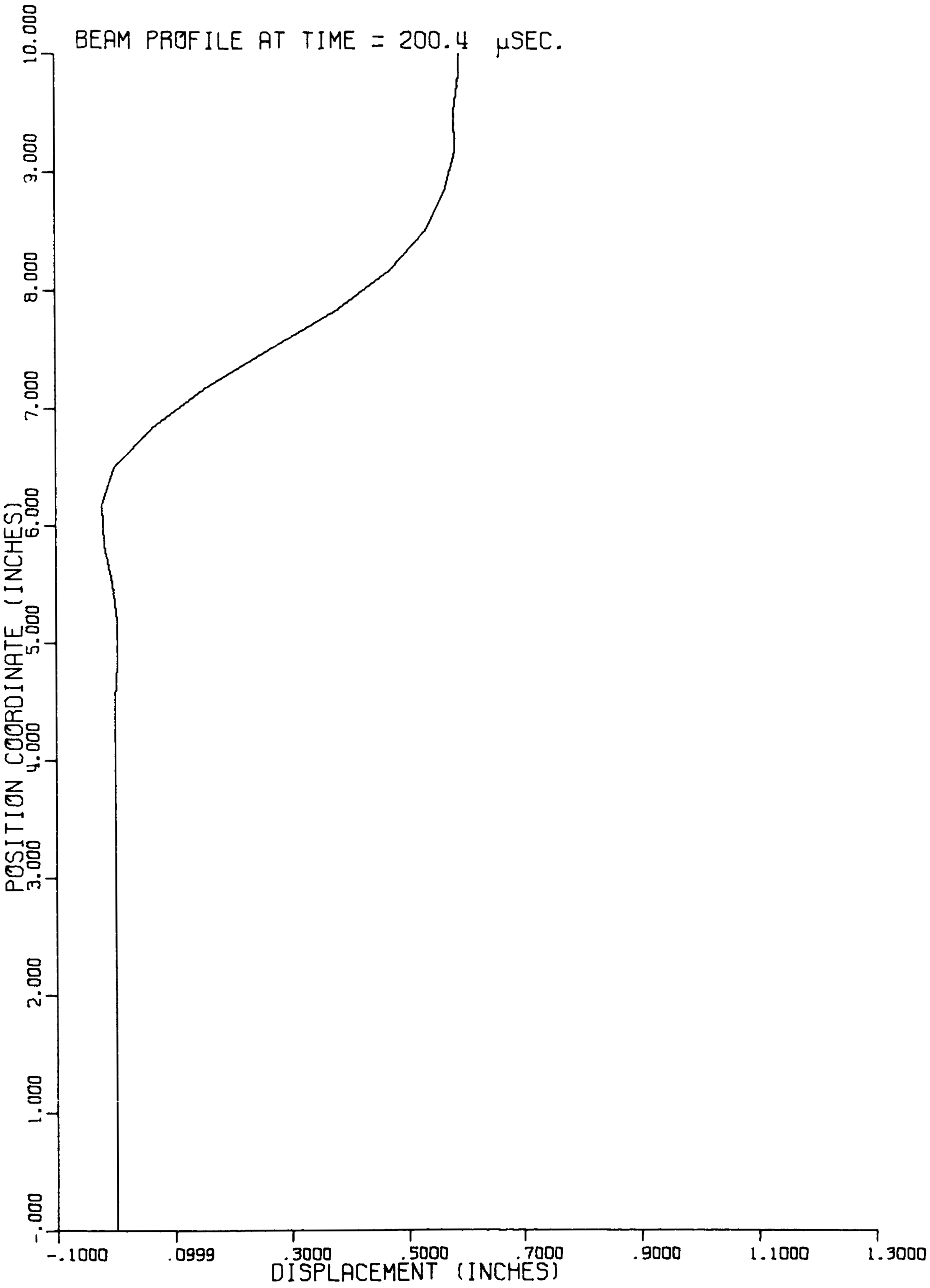
| | |
|---|---|
| Object Program | $(30552)_8$ |
| I/O Buffers | $(1530)_8$ |

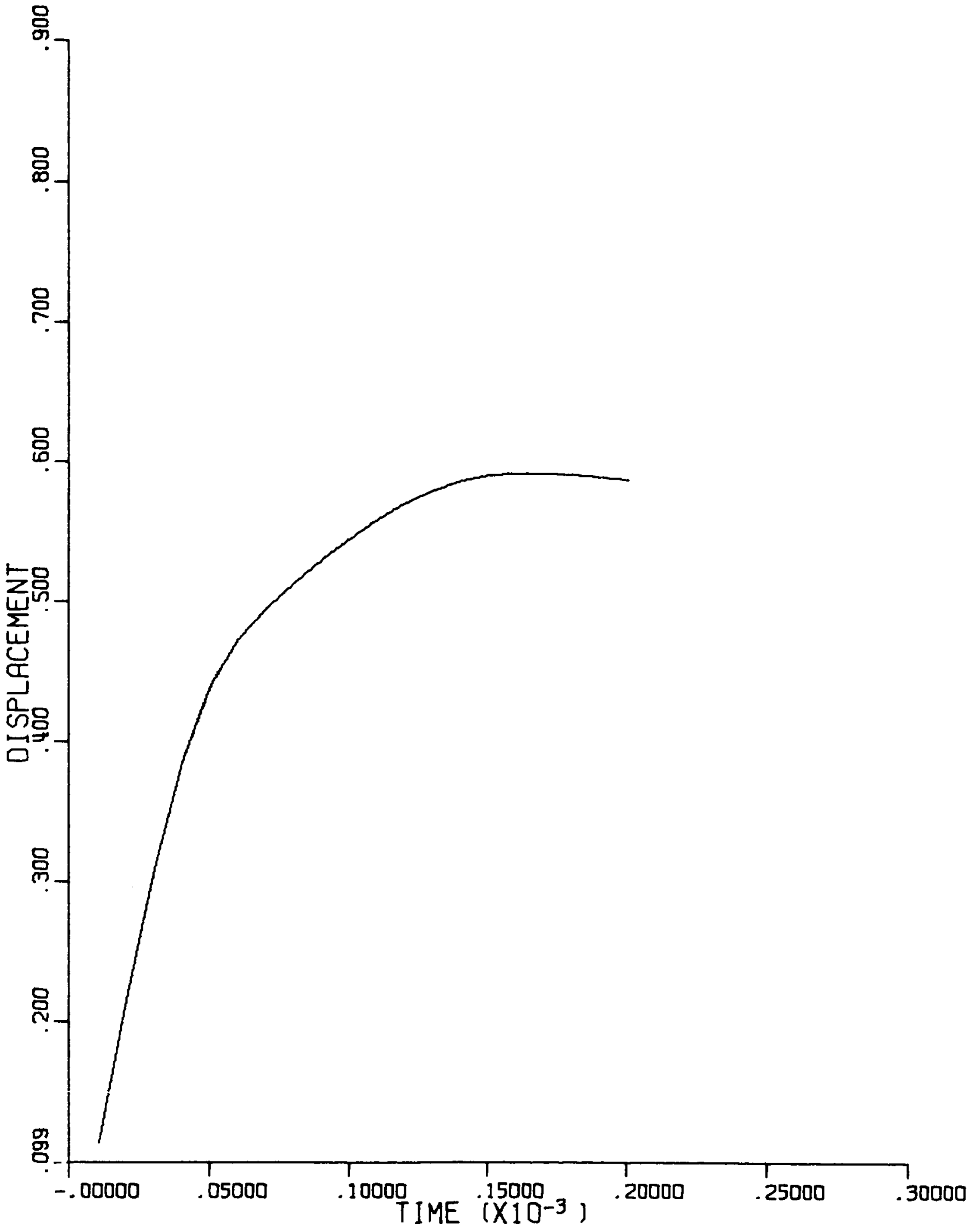
Time for Execution (sample problem)

11 min

Routines Required (those not included with IBM's IBSYS)

BEAM
GRHI
FPTMOD
PMUZ
DATE


BEAM PROFILE AT TIME = 200.4 μSEC.
POSITION COORDINATE (INCHES)
10.000
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
-.000
-.1000
.0999
.3000
.5000
.7000
.9000
1.1000
1.3000
DISPLACEMENT (INCHES)


DISPLACEMENT
.900
.800
.700
.600
.500
.400
.300
.200
.099
-.00000
.05000
.10000
.15000
.20000
.25000
.30000
TIME (X10$^{-3}$)

```
$IBFTC RING    LIST,REF
      COMMON PSI(6),VO(62),WO(62),V1(62),W1(62),BETA(31),CBETA(31),SBETA
     1      (31),RDISP(62),WRDIS(62),VRDIS(62),WOP(62),VOP(62),DSI(61),
     2      S(61),C(61),DSIU(61),SO(61),CO(61),DTIO(61),E1(61),DTI(61),
     3      E2(62),EPS(61,6),FNOR(61),BMOM(61),Q(61),VDD(61),WDD(61),
     4      VIT(62),WIT(62),EPST(61,6),DEPS(61,6),SIGT(61,6),SIGC1(61,6),
     5      SIGC2(61,6),CMT(12),TP,SIG(61,6),R,T,DP,TF,TG
      DIMENSION DATA (800)
  500 FORMAT (5E14.8)
  501 FORMAT (12A6)
  502 FORMAT (7I2)
  510 FORMAT (49H1     DEFORMATION PROFILE OF AN IMPACT LOADED RING,42X,
     1      A2,1H/,A2,1H/,A2,6X5HPAGE ,I4/5X12A6)
  511 FORMAT (1H0,8X,4HDT =,E15.8,3X,3HE =,E15.8,3X,6HSIG1 =,E15.8,3X,
     1      4HTC =,E15.8/9X4HTF =,E15.8,3X,3HH =,E15.8,3X,6HALFA =,E15.8,
     2   3X4HSM =,E15.8/9X4HT  =,E15.8,3X,3HB =,E15.8,3X,6HRIN  =,E15.8,
     3   3X4HEP =,E15.8/9X4HTP =,E15.8,3X,3HR =,E15.8)
  512 FORMAT(1H0,8X4HTIME,14X6HWIT(I),14X6HVIT(I),14X,8HEPS(I,6),12X,
     1      8HEPS(I,1), 7X,1HI)
  513 FORMAT (2H0 ,5XE12.6)
  514 FORMAT (19X,4E20.8,2XI2)
  515 FORMAT (8X11H(CONTINUED))
  516 FORMAT (9X,45HINITIAL DISPLACEMENT EXTENDS FROM MASS-POINT ,I2,1X,
     1      14HTO MASS POINT ,I2)
      CALL FPT(.TRUE.,0)
      CALL SSWTCH (3,JSS)
      CALL PLOTS (DATA,800)
      CALL PLOT (0.0,5.0,-3)
      CALL DATE (ID1,ID2,ID3)
      NPGN=1
    1 READ (5,501) CMT
    3 WRITE (6,510) ID1,ID2,ID3,NPGN,CMT
      READ (5,500) DT,E,EP,SIG1,TC,B,H,ALFA,SM,T,RIN,R,TP,TF
      READ (5,502) NPL,K1,K2,L1,L2,L3,L4
      TI=TC
      TG=TP
      WRITE (6,511) DT,E,SIG1,TC,TF,H,ALFA,SM,T,B,RIN,EP,TP,R
      WRITE (6,516) K1,K2
      WRITE (6,512)
      NPGN=NPGN+1
      LC=10
      IF (NPL.EQ.0) GO TO 6
      RC=0.
      DO 4 I=1,10
      RC=RC+5.
      IF (R.LE.RC) GO TO 5
    4 CONTINUE
```

```
    5 DP=I
    6 AF=B*H/6.
      D=H/6.
      DO 20 J=1,6
      FJ=J
   20 PSI(J)=D*(FJ-((6.+1.)/2.))
      SALFA=SIN(ALFA)
      CALFA=COS(ALFA)
      DO 600 I=1,62
      RDISP(I)=0.0
      IF (I.GE.K1.AND.I.LE.K2) RDISP(I)=RIN
  600 CONTINUE
      DO 601 I=1,31
      FI=I
      BETA(I)=ALFA*(1.05-FI/30.)
      CBETA(I)=COS(BETA(I))
      SBETA(I)=SIN(BETA(I))
      K=63-I
      WO(I)=R*(CBETA(I)-CALFA)
      WO(K)=WO(I)
      VO(I)=R*(SALFA-SBETA(I))
      VO(K)=R*(SALFA+SBETA(I))
      WRDIS(I)=-RDISP(I)*CBETA(I)
      WRDIS(K)=-RDISP(K)*CBETA(I)
      VRDIS(I)=RDISP(I)*SBETA(I)
  601 VRDIS(K)=-RDISP(K)*SBETA(I)
      DO 602 I=1,62
      V1(I)=VO(I)+VRDIS(I)
  602 W1(I)=WO(I)+WRDIS(I)
      V1(62)=VO(62)
      V1(61)=VO(61)
      V1(1)=VO(1)
      V1(2)=VO(2)
      W1(1)=WO(1)
      W1(2)=WO(2)
      W1(61)=WO(61)
      W1(62)=WO(62)
      DO 608 I=1,62
      WOP(I)=WO(I)
  608 VOP(I)=VO(I)
      DO 21 I=1,61
      DSI(I)=SQRT((ABS(V1(I+1)-V1(I)))**2+(ABS(W1(I+1)-W1(I)))**2)
      S(I)=(W1(I+1)-W1(I))/DSI(I)
      C(I)=(V1(I+1)-V1(I))/DSI(I)
      DSIU(I)=SQRT((ABS(VO(I+1)-VO(I)))**2+(ABS(WO(I+1)-WO(I)))**2)
      SO(I)=(WO(I+1)-WO(I))/DSIU(I)
      CO(I)=(VO(I+1)-VO(I))/DSIU(I)
```

```
   21 E1(1)=(DSI(I)-DSIU(1))/DSIU(I)
      DO 611 I=1,60
      DTIO(I+1)=SO(I+1)*CO(I)-CO(I+1)*SO(I)
      DTI(I+1)=S(I+1)*C(I)-C(I+1)*S(I)
      E2(I+1)=2.*(DTI(I+1)-DTIO(I+1))/(DSIU(I+1)+DSIU(I))
      DO 27 J=1,6
   27 EPS(I,J)=E1(I)-PSI(J)*E2(I+1)
  611 CONTINUE
      DO 271 J=1,6
  271 EPS(61,J)=EPS(60,J)
      DTIO(1)=0.
      DTI(1)=0.
      E2(1)=0.
      E2(62)=0.
      WRITE (6,513) T
      WRITE (6,514) (WIT(I),VIT(I),EPS(I,6),EPS(I,1),I,I=1,31)
      LC=LC+33
      DO 29 I=1,61
      DO 29 J=1,6
      SIG(I,J)=E*EPS(I,J)
      IF (EPS(I,J)) 32,31,30
   29 CONTINUE
   68 DO 38 I=1,61
      FNOR(I)=0.
      BMOM(I)=0.
      DO 38 J=1,6
      FNOR(I)=AF*SIG(I,J)+FNOR(I)
   38 BMOM(I)=AF*SIG(I,J)*PSI(J)+BMOM(I)
      DO 39 I=1,60
   39 Q(I+1)=(BMOM(I+1)-BMOM(I))/DSI(I+1)
      Q(1)=Q(2)
      Q(61)=Q(60)
      DO 42 I=2,61
      VDD(I)=(FNOR(I)*C(I)-FNOR(I-1)*C(I-1)-Q(I)*S(I)+Q(I-1)*S(I-1))/SM
      WDD(I)=(FNOR(I)*S(I)-FNOR(I-1)*S(I-1)+Q(I)*C(I)-Q(I-1)*C(I-1))/SM
      VIT(I)=VDD(I)*DT**2 +2.*V1(I)-VO(I)
   42 WIT(I)=WDD(I)*DT**2 +2.*W1(I)-WO(I)
      VIT(1)=VOP(1)
      VIT(2)=VOP(2)
      VIT(61)=VOP(61)
      VIT(62)=VOP(62)
      WIT(1)=WOP(1)
      WIT(2)=WOP(2)
      WIT(61)=WOP(61)
      WIT(62)=WOP(62)
      DO 47 I=1,62
      VO(I)=V1(I)
```

```
      V1(I)=VIT(I)
      WO(I)=W1(I)
   47 W1(I)=WIT(I)
      DO 51 I=1,61
      DSI(I)=SQRT((ABS(VIT(I+1)-VIT(I)))**2+(ABS(WIT(I+1)-WIT(I)))**2)
      S(I)=(WIT(I+1)-WIT(I))/DSI(I)
      C(I)=(VIT(I+1)-VIT(I))/DSI(I)
   51 E1(I)=(DSI(I)-DSIU(I))/DSIU(I)
      DTI(1)=0.
      E2(1)=0.
      E2(62)=0.
      DO 54 I=1,60
      DTI(I+1)=S(I+1)*C(I)-C(I+1)*S(I)
      E2(I+1)=2.*(DTI(I+1)-DTIO(I+1))/(DSIU(I+1)+DSIU(I))
      DO 53 J=1,6
   53 EPST(I,J)=E1(I)-PSI(J)*E2(I+1)
   54 CONTINUE
      DO 541 J=1,6
  541 EPST(61,J)=EPST(60,J)
      DO 56 I=1,61
      DO 58 J=1,6
      DEPS(I,J)=EPST(I,J)-EPS(I,J)
      EPS(I,J)=EPST(I,J)
      S1GT(I,J)=S1G(I,J)+E*DEPS(I,J)
      S1G(I,J) =S1GT(I,J)
       IF (DEPS(I,J)) 61,60,59
   58 CONTINUE
   56 CONTINUE
      T=T+DT
       IF (NPL.EQ.0) GO TO 151
       IF (TG.GT.T) GO TO 151
      CALL GRHR
  151 IF (T.GE.TC) GO TO 72
   70 IF (TF.GT.T) GO TO 68
   69 GO TO 1
   72 IPGE=1
      LC=LC+4
       IF (LC.GE.54) GO TO 87
      LC=LC-2
   73 WRITE (6,513) T
      IPGE=2
      DO 74 I=1,31
      LC=LC+1
       IF (LC.GE.54) GO TO 87
   89 WRITE (6,514) WIT(I),VIT(I),EPS(I,6),EPS(I,1),I
   74 CONTINUE
      TC=TC+TI
```

```
      GO TO 70
   87 WRITE (6,510) ID1,ID2,ID3,NPGN,CMT
      WRITE (6,512)
      WRITE (6,513) T
      LC=6
      NPGN=NPGN+1
      GO TO (73,88),IPGE
   88 WRITE (6,515)
      LC=LC+1
      GO TO 89
   30 S1GC1(I,J)=S1G1+EP*EPS(I,J)
      IF(S1G(I,J)-S1GC1(I,J))33,33,34
   33 S1G(I,J)=S1G(I,J)
      GO TO 29
   34 S1G(I,J) =S1GC1(I,J)
      GO TO 29
   31 S1G(I,J)=S1G(I,J)
      GO TO 29
   32 S1GC2(I,J)=-S1G1+EP*EPS(I,J)
      IF(S1G(I,J)-S1GC2(I,J))35,36,36
   35 S1G(I,J)=S1GC2(I,J)
      GO TO 29
   36 S1G(I,J)=S1G(I,J)
      GO TO 29
   59 S1GC1(I,J)=S1G1+EP*EPS(I,J)
      IF(S1G(I,J)-S1GC1(I,J))62,62,63
   62 S1G(I,J)=S1G(I,J)
      GO TO 58
   63 S1G(I,J)=S1GC1(I,J)
      GO TO 58
   60 S1G(I,J)=S1G(I,J)
      GO TO 58
   61 S1GC2(I,J)=-S1G1+EP*EPS(I,J)
      IF(S1G(I,J)-S1GC2(I,J))64,65,65
   64 S1G(I,J)=S1GC2(I,J)
      GO TO 58
   65 S1G(I,J)=S1G(I,J)
      GO TO 58
      END
$IBFTC GRHR    LIST
      SUBROUTINE GRHR
      COMMON PSI(6),VO(62),WO(62),V1(62),W1(62),BETA(31),CBETA(31),SBETA
     1   (31),RDISP(62),WRDIS(62),VRDIS(62),WOP(62),VOP(62),DSI(61),
     2   S(61),C(61),DSIU(61),SO(61),CO(61),DTIO(61),E1(61),DTI(61),
     3   E2(62),EPS(61,6),FNOR(61),BMOM(61),Q(61),VDD(61),WDD(61),
     4   VIT(62),WIT(62),EPST(61,6),DEPS(61,6),S1GT(61,6),S1GC1(61,6),
     5   S1GC2(61,6),CMT(12),TP,S1G(61,6),R,T,DP,TF,TG
```

```
      DIMENSION X(62),Y(62)
      RAD=R/DP
      XCO=RAD*2.
      CALL SYMBOL (RAD,0.0,0.14,3,0.0,-1)
      CALL SYMBOL (RAD,0.0,0.12,4,0.0,-1)
      CALL CIRCLE (XCO,0.0,0.0,360.,RAD,RAD,-.5)
      DO 2 I=1,62
      Y(I)=VIT(I)
    2 X(I)=WIT(I)
      IF (R.LE.5.0) GO TO 4
      DO 3 I=1,62
      X(I)=X(I)/DP
    3 Y(I)=Y(I)/DP
    4 DO 5 I=1,62
    5 CALL SYMBOL (X(I),Y(I),0.10,3,0.0,-1)
      CALL SYMBOL (.02,-2.54,.14,6HTIME = ,270.,6)
      TIME=T*10.**6
      CALL NUMBER (.02,-3.26,.14,TIME,270.,1)
      CALL PMUY (.02,-3.98,.14)
      CALL SYMBOL (.02,-4.10,.14,4HSEC.,270.,4)
      TG=TG+TP
      IF (TG.GT.TF) GO TO 8
      RIP=2.+2.*R/DP
    7 CALL PLOT (RIP,0.0,-3)
      RETURN
    8 RIP=1.02+2.*R/DP
      CALL SYMBOL (RIP,4.44,.21,44HDEFORMATION PROFILE OF AN IMPACT LOAD-
     1ED RING,270.,44)
      RIP=0.98+RIP
      GO TO 7
      END
```

```
DEFORMATION PROFILE OF AN IMPACT LOADED RING
RING DOCUMENTATION RUN

    DT = 0.50000000E-06   E = 0.10400000E 08   SIG1 = 0.41400000E 05   TC = 0.30000000E-03
    TF = 0.30050000E-03   H = 0.12500000E-00   ALFA = 0.31415900E 01   SM = 0.10170000E-04
    T  = 0.               B = 0.10000000E 01   RIN  = 0.27300000E-02   EP = 0.
    TP = 0.30000000E-03   R = 0.30000000E 01
    INITIAL DISPLACEMENT EXTENDS FROM MASS-POINT 22 TO MASS-POINT 41

    TIME               WIT(I)              VIT(I)              EPS(I,6)            EPS(I,1)        I

 0.
                    0.                  0.                  -0.                  0.                1
                    0.                  0.                  -0.                  0.                2
                    0.                  0.                  -0.                  0.                3
                    0.                  0.                  -0.                  0.                4
                    0.                  0.                  -0.                  0.                5
                    0.                  0.                  -0.                  0.                6
                    0.                  0.                  -0.                  0.                7
                    0.                  0.                  -0.                  0.                8
                    0.                  0.                  -0.                  0.                9
                    0.                  0.                  -0.                  0.               10
                    0.                  0.                  -0.                  0.               11
                    0.                  0.                  -0.                  0.               12
                    0.                  0.                  -0.                  0.               13
                    0.                  0.                  -0.                  0.               14
                    0.                  0.                  -0.                  0.               15
                    0.                  0.                  -0.                  0.               16
                    0.                  0.                  -0.                  0.               17
                    0.                  0.                  -0.                  0.               18
                    0.                  0.                  -0.                  0.               19
                    0.                  0.                   0.14320782E-02     -0.14320782E-02   20
                    0.                  0.                  -0.18507220E-02      0.10160371E-02   21
                    0.                  0.                  -0.91010149E-03     -0.91005206E-03   22
                    0.                  0.                  -0.90988396E-03     -0.90991362E-03   23
                    0.                  0.                  -0.91003445E-03     -0.91004805E-03   24
                    0.                  0.                  -0.90999711E-03     -0.90999093E-03   25
                    0.                  0.                  -0.90996915E-03     -0.90997038E-03   26
                    0.                  0.                  -0.91000270E-03     -0.91003237E-03   27
                    0.                  0.                  -0.91009089E-03     -0.91001550E-03   28
                    0.                  0.                  -0.90991937E-03     -0.91002040E-03   29
                    0.                  0.                  -0.91004473E-03     -0.90999035E-03   30
                    0.                  0.                  -0.91002134E-03     -0.90996634E-03   31

 0.300499E-03
                    0.41109547E-02      0.15700751E-00      -0.17510844E-02      0.17510844E-02    1
                    0.41118041E-02     -0.15700786E-00      -0.12202341E-02      0.22717823E-02    2
                    0.33636477E-01     -0.46979800E-00      -0.32411055E-02      0.39744058E-02    3
                    0.92423867E-01     -0.77837875E 00      -0.48366433E-02      0.53277878E-02    4
                    0.17654268E-00     -0.10809977E 01      -0.38542782E-02      0.50321715E-02    5
                    0.28282762E-00     -0.13766755E 01      -0.27698760E-02      0.36550516E-02    6
                    0.41175797E-00     -0.16631541E 01      -0.13988915E-02      0.17387303E-02    7
                    0.56457493E 00     -0.19375375E 01      -0.74897831E-03      0.12258124E-02    8
```

```
DEFORMATION PROFILE OF AN IMPACT LOADED RING
RING DOCUMENTATION RUN

   TIME             WIT(I)               VIT(I)              EPS(I,6)             EPS(I,1)          I

 0.300499E-03
  (CONTINUED)
                0.74279743E 00      -0.21961675E 01      -0.35142803E-03       0.91417993E-03    9
                0.94565453E 00      -0.24359805E 01      -0.54908566E-03       0.53152784E-03   10
                0.11715669E 01      -0.26540805E 01      -0.14505846E-02       0.93931945E-03   11
                0.14183440E 01      -0.28481329E 01      -0.14866236E-02       0.18224052E-02   12
                0.16829476E 01      -0.30173184E 01       0.33677281E-02      -0.35366866E-02   13
                0.19622923E 01      -0.31606908E 01       0.48175711E-02      -0.48643841E-02   14
                0.22574225E 01      -0.32679252E 01       0.71857439E-02      -0.77649624E-02   15
                0.25641596E 01      -0.33347156E 01       0.12288297E-01      -0.13122674E-01   16
                0.28773966E 01      -0.33548645E 01       0.20364607E-01      -0.23871167E-01   17
                0.31886854E 01      -0.33179926E 01       0.24888500E-01      -0.30081297E-01   18
                0.34820196E 01      -0.32082227E 01       0.54481115E-01      -0.72599020E-01   19
                0.37331381E 01      -0.30244655E 01       0.33253564E-01      -0.88497364E-01   20
                0.38603474E 01      -0.27468841E 01      -0.85092336E-01       0.27665067E-01   21
                0.38416522E 01      -0.24424587E 01      -0.11019430E-00       0.71532652E-01   22
                0.38956559E 01      -0.21392856E 01      -0.43323598E-01       0.26334954E-01   23
                0.40804791E 01      -0.18887301E 01      -0.37102421E-01       0.82057229E-02   24
                0.42894329E 01      -0.16604426E 01      -0.28675453E-01      -0.18110715E-01   25
                0.45036352E 01      -0.14409805E 01      -0.33749614E-01      -0.32864387E-01   26
                0.46993138E 01      -0.12089104E 01      -0.45459535E-01      -0.52061345E-01   27
                0.48676020E 01      -0.96212479E 00      -0.53835154E-01      -0.59561050E-01   28
                0.50027376E 01      -0.69853511E 00      -0.57009852E-01      -0.69156977E-01   29
                0.51040744E 01      -0.42233184E-00      -0.54718971E-01      -0.83741857E-01   30
                0.51650090E 01      -0.13647829E-00      -0.51959433E-01      -0.92333349E-01   31
```

## RING PROGRAM

Memory Required

| | |
|---|---|
| Object Program | $(13523)_8$ |
| Blank Common | $(10264)_8$ |
| I/O Buffers | $(1125)_8$ |

Time for Execution (sample problem)

9 min

Routines Required (those not included with IBM's IBSYS)

RING
GRHR
PMUY
CIRCLE
FPTMOD
DATE

DEFORMATION PROFILE OF AN IMPACT LOADED RING