COMPUTER ANALYSIS

OF

FRAMED STRUCTURES

by

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Thesis

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Since the advent of the engineering diciplines, there has been a constant effort to develop numerical techniques in engineering analysis. It is only recently that efforts have been made by the engineering professions to use digital computers as an analysis tool. In the field of structural analysis these efforts have led to the development of methods which use matrix algebra techniques. Computers and matrix algebra have permitted structural engineers to return to basic principles, rather than spend the majority of their efforts in developing techniques to reduce the amount of computation in the analysis procedure.

For the use of computers in the engineering field, the eventual, ultimate need is for large software systems capable of handling entire projects, possibly involving several branches of civil engineering. Before entire projects can be completely handled, every phase of the operation must be fully developed. Thus, the short-term needs are to make each phase or engineering field as complete as possible. This requires special purpose programs to be developed for the respective fields. Such programs would be able to analyze arches, rigid frames, semi-rigidly connected frames, shear wall frames, shells, domes, etc., and design structural components such as beams, columns, plates, etc.

Once these programs are developed, the needs of the small engineering organizations can be accomodated. This can be accomplished by having consoles at engineering offices tied into a time-sharing computer facility where the programs are stored.

1.2 OBJECT AND SCOPE

The object of this thesis is two fold:

(a) To establish a structural analysis and design program system which incorporates a framework into which any number of special purpose programs can be inserted and called into the computer by a single calling program.

(b) To generate and insert into the system two of the most useful analysis programs: a space frame analysis program and a plane frame analysis program.

1.3 RELATIONSHIP TO EXISTING SOFTWARE SYSTEMS

Two approaches to the development of engineering analysis and design systems are possible. The first employs the concept of the multi purpose program; a single program with a variety of capabilities to accomodate a large spectrum of analysis and/or design problems. Two examples of civil engineering software systems of this type are STRESS(11)* (Structural Engineering System Solver) and ICES(10,12) (Integrated Civil Engineering Systems). The latter example involves a system of complex translation and data management programs which permit communication among a series of sub systems which deal with various branches of civil engineering.

The second approach employs the concept of the special purpose program; a program designed to solve effeciently a specific engineering

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* Numbers in parenthesis refer to entries in list of references.

problem. A series of such programs, all accessible from a single calling program, is resident on disc in much the same way as is a subroutine library. To solve a specific problem, the appropriate program only is called into the computer. An example of a system employing this approach is the Universal Programs[10] system, which involves a series of civil engineering analysis and design programs.

There are many questions that could be asked in order that one may rate the merits of one system relative to the other. Some of the more obvious questions are: "What organization in industry covers the entire field of engineering in its services such that these vast systems could fully be made use of?"; "What is the immediate need of the engineering profession in solving problems quickly and accurately?"; and "Are these present systems capable of efficiently serving the engineer in a specialized technical area?". The field of civil engineering consists of a highly skilled type of professional service with individuals, private firms, and even public agencies dedicated to specialized functions. A system which accomodates this type of service is the Universal Programs system.

The Universal Programs system does not have the capacity as does I.C.E.S. of going from one branch of civil engineering to another, but the loss of interaction flexibility is balanced by total capability in each respective field. The basic specifications for Universal Programs were established by isolating one complete branch of engineering and assembling every conceivable area that was conducive to solution by computer. In addition, the capability of every program had to be such that it could handle any problem of any size. The capabilities of its subsystems are vastly superior to the published versions of the comparable I.C.E.S. subsystems.

The multi-purpose program approach may be most suitable for large scale computer users such as building authorities for very large cities, or certain transportation authorities, and ultimately, it may best satisfy the needs of most civil engineering organizations. It is felt however, that at the present state of the art, the needs of most civil engineering organizations, and particularly the smaller organizations, are best satisfied by the special purpose program approach.

Programs that can produce direct results for the day-to-day regular operation of an engineering firm are much more desirable than a very sophisticated system that tends to place a premium on computer ability. It is this idea which prompted this thesis to follow the concept embodied in the Universal Programs system.

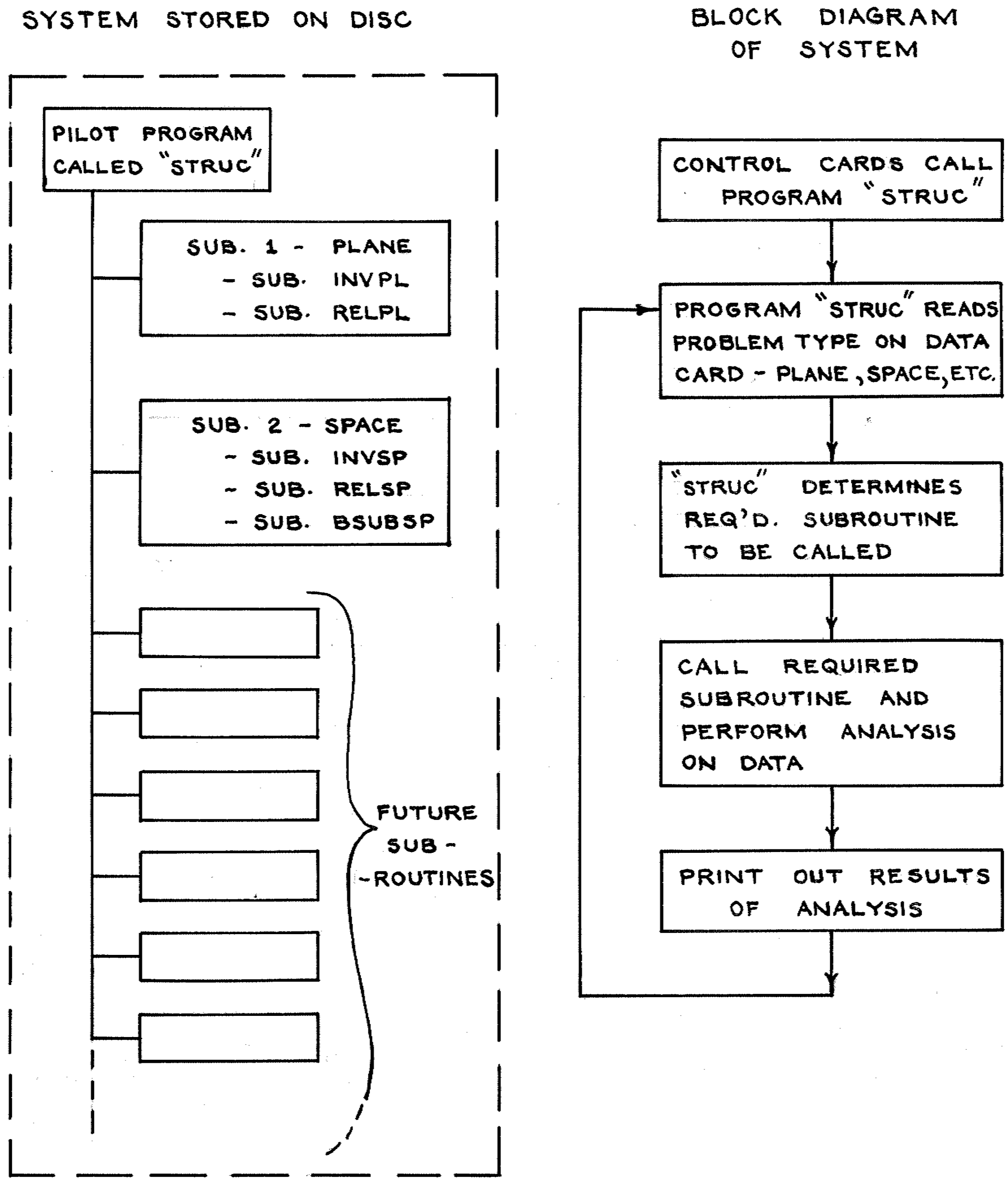
CHAPTER 2

THE SYSTEM

2.1 DESCRIPTION

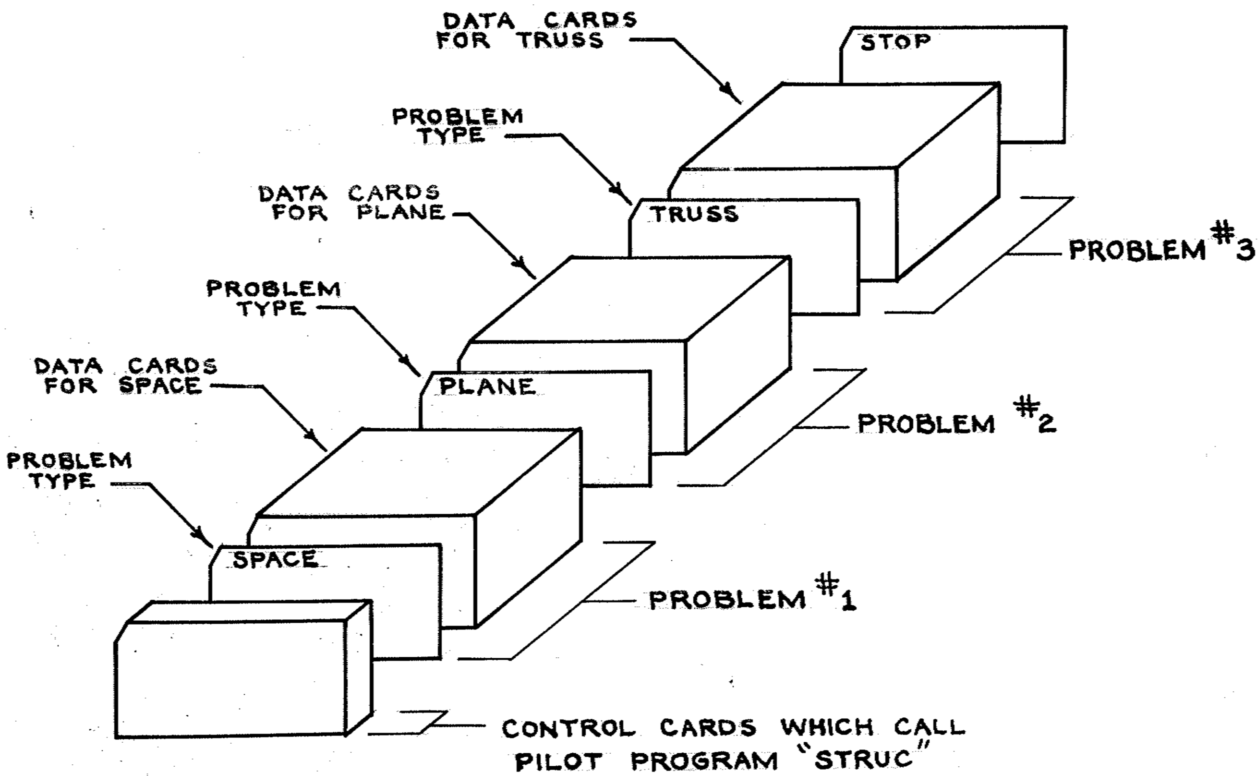
The structural analysis and design system is stored on disc and consists of a series of special purpose programs, all accessible from a single calling program. At present, the system consists of a calling program "STRUC" and two subroutines, "PLANE" and "SPACE". Each of the subroutines is self-contained. The block diagram of the system is shown in Fig. 2.1. The listing of the required control cards and the deck arrangement for storing these two subroutines on disc for a one month period are shown on pages 8 and 9. Note that "PLANE" has its own subroutines "INVPL" and "RELPL", while "SPACE" contains subroutines "INVSP", "RELSP" and "BSUBSP". The subroutines are called into the core of the computer by the pilot program "STRUC" which determines what type of problem is to be solved. To reduce the amount of working store occupied by the system, only the pilot program and one library subroutine occupy core at any one time.

The data cards for each problem type must be arranged according to the format outlined in the user's manuals in Appendices (B) and (C). Each set of data cards is preceeded by a single card which indicates the subroutine (PLANE, SPACE, etc.) which is required for the analysis. This enables the user to solve a variety of problem types and an unlimited number of problems in any one computer run. Fig. 2.2 illustrates the input deck arrangement for a typical series of problems.



BLOCK DIAGRAM OF SYSTEM

FIG. 2.1



INPUT DECK ARRANGEMENT

FIG. 2.2

LISTING OF CONTROL CARDS & DECK ARRANGEMENT FOR STORING PROGRAMS "PLANE" & "SPACE" ON DISC FOR ONE MONTH

```
//STRUC    JØB (2720,19,01,20,08),"BØYANIWSKY",MSGLEVEL=1,CLASS=C
//STEP1 EXEC FØRTGCL,REGIØN.FØRT=200K,PARM.LKED="MAP,LIST,LET,ØVLY"
//FØRT.SYSIN DD *
      REAL *8 NAMES(2) /"PLANE   ","SPACE   "/,NAME
  100 READ(5,2) NAME
      DØ 1 NI=1,2
      IF( NAMES(NI).EQ.NAME ) GØ TØ 12
    1 CØNTINUE
      WRITE(6,3)
    3 FØRMAT(18H ILLEGAL NAME USED)
      GØ TØ 90
   12 GØ TØ ( 10,20 ), NI
   10 CALL PLANE
      GØ TØ 100
   20 CALL SPACE
      GØ TØ 100
   90 CALL EXIT
    2 FØRMAT(A8)
      END
      SUBRØUTINE PLANE
      SUBRØUTINE INVPL
      SUBRØUTINE RELPL
```

PILOT PROGRAM

COMPLETE DECK OF CARDS TO BE INCLUDED FOR EACH SUBROUTINE

LISTING OF CONTROL CARDS & DECK ARRANGEMENT FOR STORING PROGRAMS "PLANE" & "SPACE" ON DISC FOR ONE MONTH

```
      SUBRØUTINE SPACE       }
      SUBRØUTINE INVSP       }  COMPLETE DECK OF CARDS TO BE INCLUDED
      SUBRØUTINE RELSP       }          FOR EACH SUBROUTINE
      SUBRØUTINE BSUBSP      }
/*
//LKED.SYSLMØD DD DSNAME=WILLY.X02319(STRUC),VØLUME=REF=ØNE.MØNTH,          X
//              UNIT=DISK,DISP=(NEW,KEEP),                                   X
//              DCB=(RECFM=U,BLKSIZE=7294),SPACE=(TRK,(40,5,8),RLSE)
//LKED.SYSIN DD *
      INSERT MAIN
      ØVERLAY ØNE
      INSERT PLANE
      INSERT INVPL
      INSERT RELPL
      ØVERLAY ØNE
      INSERT SPACE
      INSERT INVSP
      INSERT RELSP
      INSERT BSUBSP
      ENTRY MAIN
/*
```

2.2 SIZE CONSIDERATIONS

The size considerations discussed in this section pertain to the computer installation at the University of Manitoba. The number of special programs which can be added to the system is unlimited. At present, the amount of core space requested on the control cards for the system is 200K. This amount of space is needed in order to compile the programs.

Initially, the complete system is compiled and stored on disc. Once this is done, there is no need to compile the system for every problem. It is then, only necessary to submit the control cards which call up the pilot program "STRUC", followed by the data cards. A listing of these control cards is shown on page 12.

It should be noted that the larger the core capacity requested, the greater the usuage cost. The system, as described thus far, is only a prototype and future revisions and additions will increase the capacity and effeciency of the programs.

2.3 OVERLAYING

Because of the relatively small core capacity permitted each program, the size of problem that can be handled is often limited. To increase the capacity, the user can request more computer space. But memory space costs money. There is a technique which can increase the size of the problem that can be solved, and yet not increase the core capacity required. The technique used is that of "overlaying".

Overlaying involves loading a segment of a program into the computer and during or after its execution, calling in one or more other segments. Those segments may or may not use the same memory space used by the previous segments. Still later, other segments may overlay other segments. The history of a specific segment during the running of a program may be such that it is brought into memory several times to overlay other segments, and to be overlayed in turn. Overlaying doesn't necessarily mean that the results obtained from the first segment are destroyed by a second segment which overlays the first. Those results can be stored in the blank COMMON storage area of the computer memory. By the use of this technique, the size of engineering problems that can be handled can often be substantially increased.

2.4 INSERTION OF NEW SUBROUTINE INTO SYSTEM

Let us consider that a program for analyzing trusses has been developed; and it is desired to insert this program, which is designated as subroutine "TRUSS", into the system. The control cards and the deck arrangement required to insert the existing system and the subroutine "TRUSS" on disc for a one month period is listed on pages 13 to 15.

The modifications to be made to the control cards of the existing system involve the insertion of two computer cards which request that subroutine "TRUSS" and its own subroutine "INVTR" be inserted. The pilot program must also be modified so control can be transferred to the proper subroutine. This involves that two statements be adjusted and that two new ones be added. These modifications to the existing system are all that is required to insert a new subroutine into the system.

LISTING OF CONTROL CARDS & DECK ARRANGEMENT FOR RETRIEVING PROGRAMS "PLANE" & "SPACE" FROM DISC IN ORDER TO OPERATE ON DATA

STATEMENT NUMBER | Cont. | FORTRAN STATEMENT

```
//STRUC    JØB (2720,19,01,05),"BØYANIWSKY",CLASS=C
//JØBLIB   DD DSNAME=WILLY.X02319,VØLUME=REF=ØNE.MØNTH,UNIT=DISK,               X
//              DISP=ØLD
//STEP2 EXEC PGM=STRUC,REGIØN=150K
//FT06F001 DD SYSØUT=A
//FT07F001 DD UNIT=PUNCH
//FT05F001 DD *
PLANE    <---- DATA CARD WHICH INDICATES PROBLEM TYPE
            }
            } DATA CARDS FOR PLANE
            }
SPACE
            }
            } DATA CARDS FOR SPACE
            }
/*
```

LISTING OF CONTROL CARDS & DECK ARRANGEMENT FOR STORING PROGRAMS "PLANE", "SPACE" & "TRUSS" ON DISC FOR ONE MONTH

```
//STRUC     JØB (2720,19,01,20,08),"BØYANIWSKY",MSGLEVEL=1,CLASS=C
//STEP1 EXEC FØRTGCL,REGIØN.FØRT=200K,PARM.LKED="MAP,LIST,LET,ØVLY"
//FØRT.SYSIN DD *
      REAL*8 NAMES(3) /"PLANE   ","SPACE   ","TRUSS   "/,NAME
  100 READ(5,2) NAME
      DØ 1 NI=1,3
      IF( NAMES(NI).EQ.NAME ) GØ TØ 12
    1 CØNTINUE
      WRITE(6,3)
    3 FØRMAT(18H ILLEGAL NAME USED)
      GØ TØ 90
   12 GØ TØ ( 10,20,30 ), NI
   10 CALL PLANE
      GØ TØ 100
   20 CALL SPACE
      GØ TØ 100
   30 CALL TRUSS
      GØ TØ 100
   90 CALL EXIT
    2 FØRMAT(A8)
      END
      SUBRØUTINE PLANE
```

PILOT PROGRAM

COMPLETE DECK OF CARDS TO BE INCLUDED FOR THIS SUBRØUTINE

LISTING OF CONTROL CARDS & DECK ARRANGEMENT FOR STORING PROGRAMS "PLANE", "SPACE" & "TRUSS" ON DISC FOR ONE MONTH

```
      SUBRØUTINE INVPL
      SUBRØUTINE RELPL
      SUBRØUTINE SPACE
      SUBRØUTINE INVSP     COMPLETE DECK OF CARDS TO BE INCLUDED
      SUBRØUTINE RELSP          FOR EACH SUBROUTINE
      SUBRØUTINE BSUBSP
      SUBRØUTINE TRUSS
      SUBRØUTINE INVTR
/*
//LKED.SYSLMØD DD DSNAME=WILLY.X02319(STRUC),VØLUME=REF=ØNE.MØNTH,          X
//             UNIT=DISK,DISP=(NEW,KEEP),                                   X
//             DCB=(RECFM=U,BLKSIZE=7294),SPACE=(TRK,(40,5,8),RLSE)
//LKED.SYSIN DD *
      INSERT MAIN
      ØVERLAY ØNE
      INSERT PLANE
      INSERT INVPL
      INSERT RELPL
      ØVERLAY ØNE
      INSERT SPACE
      INSERT INVSP
```

LISTING OF CONTROL CARDS & DECK ARRANGEMENT FOR STORING PROGRAMS "PLANE", "SPACE" & "TRUSS" ON DISC FOR ONE MONTH

```
      INSERT BSUBSP
      INSERT TRUSS
      INSERT INVTR
      ENTRY MAIN
/*
```

CHAPTER 3

THE STIFFNESS-METHOD APPROACH

In this chapter the two basic methods of analyzing structures are compared; these are the flexibility and the stiffness methods. The stiffness analysis method, which is employed in the PLANE and SPACE programs, is briefly described along with the necessary matrix transformations used in the analysis programs.

3.1 STIFFNESS METHOD VERSUS FLEXIBILITY METHOD

The two distinct methods of structural analysis are the flexibility[1,2] (force or action), and stiffness[1,2] (displacement) methods. Both are based on the same equilibrium and compatibility relationships and the principle of superposition. However, the steps followed toward the solution of structural problems and performed in a different order for the two methods. To compare them, it is necessary to discuss the steps required to analyze a structure.

The analysis of a structure consists of the determination of the forces acting on the ends of all members and the displacements of all joints. Three sets of conditions which these loads and displacements must satisfy are the following:

(1) The forces acting on the ends of each member are related to the displacements of those ends by equations derived from the stress-strain relationship of the material of the member.

(2) The displacements of the ends of each member must be compatible with the displacements of the joints to which the member is attached. These are termed the conditions of compatibility.

(3) The forces acting on the ends of each member must keep the member in equilibrium. Also, the sum of the forces acting on the ends of the members meeting at any joint must equal the external load applied at the joint. These are termed the conditions of equilibrium.

In analyzing determinate structures, all internal forces and moments can be directly obtained using the third set of conditions. If the displacements of the structure are required, conditions (1) and (2) may be applied afterwards. In analyzing indeterminate structures, it is necessary to use all three conditions in order to obtain stresses and displacements.

Methods in which the compatibility conditions are used first give rise to equations of joint equilibrium, and are called equilibrium (displacement or stiffness) methods. Methods in which the equilibrium conditions are satisfied first lead to equations of dipslacement compatibility and are called compatibility (force or flexibility) methods. The flexibility method requires the use of judgement in the selection of redundants, and by careful selection, the amount of calculation can be considerably reduced. Thus, the stiffness method generally requires more calculation than the flexibility method, but the former method is more systematic and thus is more suitable to programming for digital computers. As a result, the stiffness method is used exclusively in this thesis.

3.2 ASSUMPTIONS

All the structures considered will be assumed to have the following properties:

1. The material obeys Hooke's Law,

2. The effects of the displacements on the geometry and the forces are negligible,

3. Possible buckling of individual members or portions of structure is ignored.

For the PLANE and SPACE programs developed, the limitations are as follows:

1. Only framed structures can be analyzed.

2. All members must be prismatic and straight.

3. Only static loading in the form of concentrated or uniformly distributed loads can be applied.

4. The maximum size of a plane frame structure is limited to:

   70 --- joints

   30 --- support joints

   15 --- support joints with releases (not fully fixed)

   100 --- members

   20 --- members with releases

   7 --- members can be connected to any one joint

   3 --- loading systems can be handled simultaneously

5. The maximum size of a space frame structure is limited to:

   15 --- joints

   10 --- support joints

   5 --- support joints with releases (not fully fixed)

25 --- members

10 --- members with releases

10 --- members can be connected to any one joint

6 --- loading systems can be handled simultaneously

6. Member releases can be located anywhere along the member as long as that member only has concentrated loads applied to it. If the member has a distributed load acting on it, member releases will only be allowed at the ends of the member.

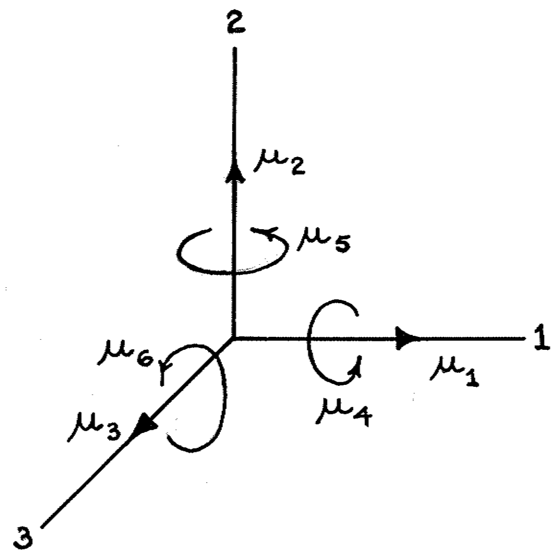
7. The direct shearing deformations are not considered in the analysis.

8. Structure is assumed to be linearly elastic.

3.3. COORDINATE SYSTEMS

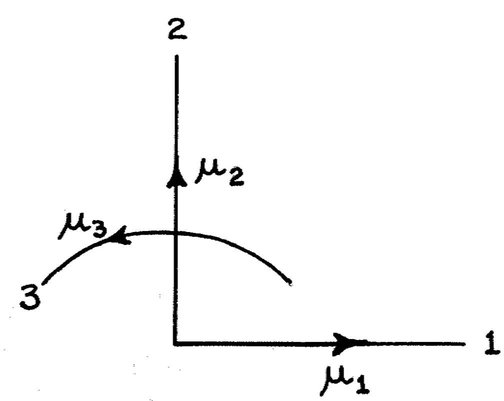
All components of force and displacement are described in right-handed, orthogonal coordinate systems. Such a coordinate system for a three dimensional structure is shown in Fig. 3.1(a) where 1, 2 and 3 denote coordinate directions and U_1 through U_6 denote the six components of a force or displacement. Labels U_1, U_2 and U_3 represent linear displacements in three perpendicular directions, and labels U_4, U_5 and U_6 represent the rotation about axes 1, 2 and 3 respectively. For a planar structure, each joint has three possible displacement components and corresponding force components which correspond to directions 1, 2 and 3 as shown in Fig. 3.1(b).

The two types of coordinate systems used for planar structures are illustrated in Fig. 3.2 and are described as follows:



3 - DIMENSIONAL
COMPONENT DIRECTIONS

(a)

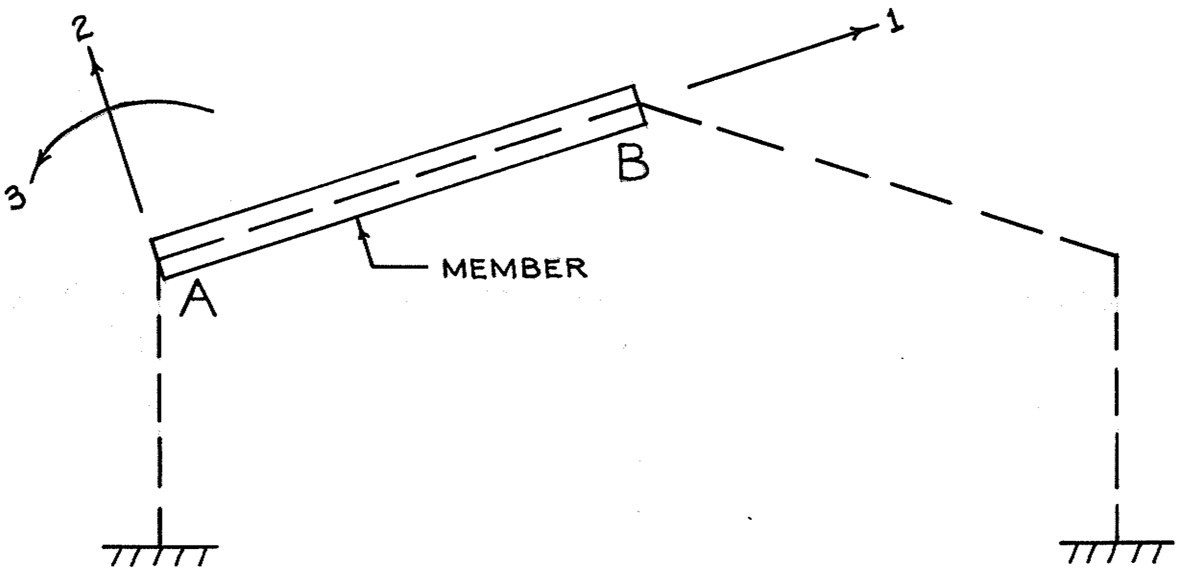


2 - DIMENSIONAL
COMPONENT DIRECTIONS

(b)

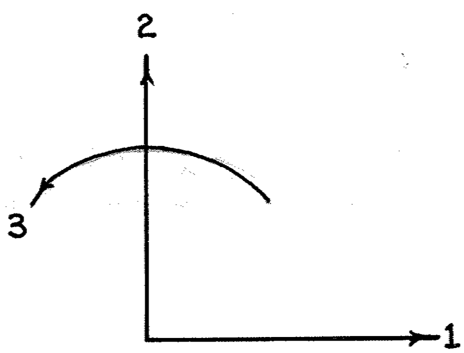
FORCE AND DISPLACEMENT COMPONENTS

FIG. 3.1



LOCAL COORDINATE SYSTEM

(b)



GLOBAL COORDINATE SYSTEM

(a)

COORDINATE SYSTEMS USED

FIG. 3.2

(1) Global System - a single, right-hand, coordinate system for the whole structure which is usually chosen so that the directions of the axes coincide with the major dimensions of the structure. The 1 and 2 axes are horizontal and vertical respectively, and the 3 direction corresponds to rotation about a third axis perpendicular to the plane of the structure. The postive global directions are those indicated in Fig. 3.2. Joint coordinates, loads, displacements and all support reactions are expressed in the global system.

(2) Local System - All member data are specified in terms of a local coordinate system whose 1 axis coincides with the axis of the member, and is directed from the A end of the member to its B end as shown in Fig. 3.2. In the same figure are shown the positive 2 and 3 directions, which coincide with the principal axes of the member.

3.4 ROTATION AND TRANSLATION TRANSFORMATIONS

3.4.1 ROTATION

When writing the joint equilibrium equations, it is necessary to express the member forces in the global system rather than in the various member systems. This can be done by premultiplying each member force vector by a rotation transformation matrix as follows:

$$P = RP' \tag{3.1}$$

where P = force vector in member system

P' = force vector in global system

R = member rotation matrix which transforms any vector from the member coordinate system to the global system.

It can be shown that the inverse transformation is

$$P' = R^T P \tag{3.2}$$

since R is an orthogonal matrix and $R^{-1} = R^T$. Similarly for displacement vectors,

$$\left.\begin{aligned} D &= RD' \\ \text{and} \qquad D' &= R^T D \end{aligned}\right\} \tag{3.3}$$

where D = displacement vector in member system

D' = displacement vector in global system

For a given member orientation, the 1 axis for the member coordinate system is fixed. However, there are an infinite number of possible positions for axes 2 and 3 which are perpendicular to 1. Since most structures are loaded vertically by gravity loads, one of the principal axes for each member usually lies in a vertical plane parallel to the 2' global axis.

Consequently the member coordinate system is usually oriented as shown in Fig. 3.3(a), with axis 3 in the 1' - 3' plane and axes 1 and 2 lying in a vertical plane. The basic R matrix for this coordinate system contains four submatrices:

$$R = \begin{vmatrix} \bar{R} & 0 \\ 0 & \bar{R} \end{vmatrix} \tag{3.4}$$

The elements of $\bar{R}$ are the direction cosines of one system with respect to the other. To derive these elements, assume unit vectors X_1,

X_2 and X_3 to act along directions 1, 2 and 3 as shown in Fig. 3.3(b). Let the direction cosines for X_1 relative to the global axes 1', 2' and 3' be ℓ, m and n respectively. The basic $\bar{R}$ matrix is thus:

$$\bar{R} = \begin{vmatrix} \ell & \dfrac{-\ell m}{\sqrt{\ell^2 + n^2}} & \dfrac{-n}{\sqrt{\ell^2 + n^2}} \\ m & \sqrt{\ell^2 + n^2} & 0 \\ n & \dfrac{-mn}{\sqrt{\ell^2 + n^2}} & \dfrac{\ell}{\sqrt{\ell^2 + n^2}} \end{vmatrix} \qquad (3.5)$$

The size of the R matrix depends upon the type of structure considered. In general, the R matrix has x rows and y columns where:

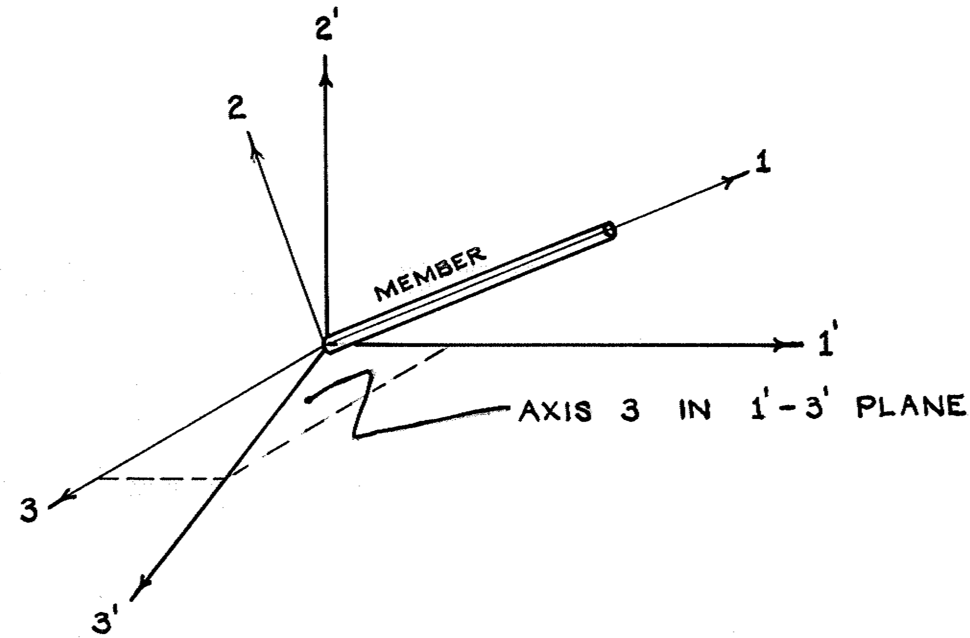
x = number of possible force components considered at any joint - expressed in global system.

y = number of possible non-zero force components that can act on any member cross-section - expressed in the local system.

For a space frame, x = y = 6; for a plane frame with rigid connections, x = y = 3; for a plane truss, x = 2 and y = 1, since a truss is pin-jointed.

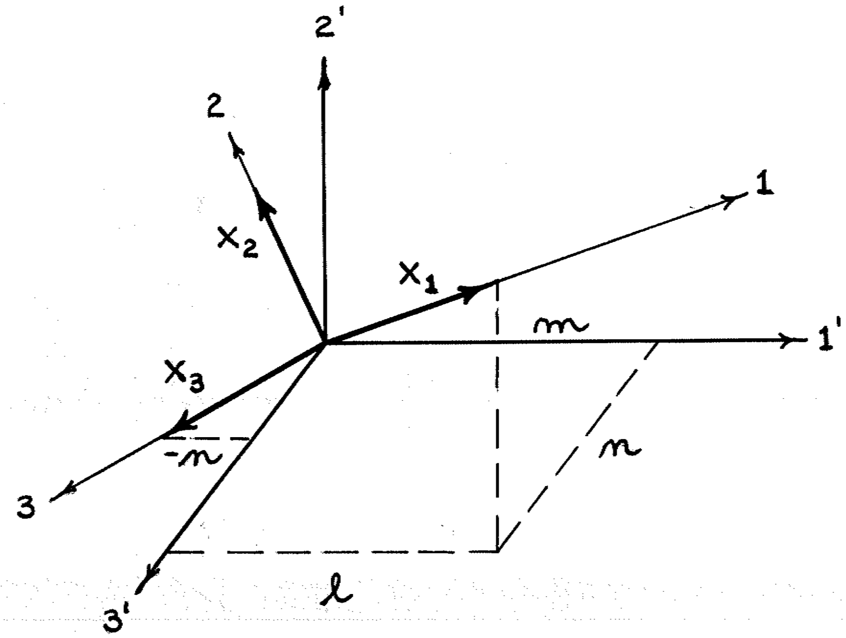
3.4.2 TRANSLATION

In the analysis procedure, it is required to translate the effect of either a force or a displacement from one point to another. These



USUAL MEMBER ORIENTATION

(a)



DIRECTIONAL COSINES FOR MEMBER

(b)

ROTATION TRANSFORMATION FOR A SPECIAL MEMBER COORDINATE SYSTEM

FIG. 3.3

transformations are accomplished by means of member translation matrices which are designated as H^{AB}.

The force translation matrix H^{AB} relates the effect of a load P at one point on a member to another point on the same member. This is useful in finding the loads transmitted to a joint by a member which carries a load at its far end. Consider that a force vector P_B acts at end B of a member as shown in Fig. 3.4, and it is desired to calculate the force transmitted to the joint at end A, i.e. P_A.

From the above explanation of the translation matrix and the diagram in Fig. 3.4:

$$P_A = H^{AB} P_B \tag{3.6}$$

where

$$H^{AB} = \begin{vmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & -L & 0 & 1 & 0 \\ 0 & L & 0 & 0 & 0 & 1 \end{vmatrix} \tag{3.7}$$

$$P_A = \begin{vmatrix} P_{A1} \\ P_{A2} \\ P_{A3} \\ M_{A4} \\ M_{A5} \\ M_{A6} \end{vmatrix} \tag{3.8}$$

where P_{A1}, P_{A2} and P_{A3} are the A end member forces in directions 1,2 and 3 respectively; and M_{A4}, M_{A5} and M_{A6} are the A end member moments about axes 1, 2 and 3 respectively.

$$P_B = \begin{vmatrix} P_{B1} \\ P_{B2} \\ P_{B3} \\ M_{B4} \\ M_{B5} \\ M_{B6} \end{vmatrix} \tag{3.9}$$

where P_{B1}, P_{B2}, P_{B3}, M_{B4}, M_{B5} and M_{B6} are the B end member forces and moments as shown in Fig. 3.4.

Similarly, if a load P_A acts at end A, then the load transmitted to the joint at end B is :

$$P_B = (H^{AB})^{-1} P_A \tag{3.10}$$

The displacement translation matrix relates the effect of a displacement D at one point on a member to another point on the same member during a rigid-body displacement (displacement of the whole member but with no deformation of the member). Consider that a member AB as shown in Fig. 3.4 is given a rigid-body displacement such that the displacement vector at B is D_B (expressed in the local coordinate system). The corresponding displacement vector at end A is:

$$D_A = [(H^{AB})^{-1}]^T D_B \tag{3.11}$$

where

$$[(H^{AB})^{-1}]^T = \begin{vmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & -L \\ 0 & 0 & 1 & 0 & L & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{vmatrix} \tag{3.12}$$

$$D_A = \begin{vmatrix} \delta_{A1} \\ \delta_{A2} \\ \delta_{A3} \\ \theta_{A4} \\ \theta_{A5} \\ \theta_{A6} \end{vmatrix} \tag{3.13}$$

where δ_{A1}, δ_{A2} and δ_{A3} are the A end member displacements in directions 1, 2 3 respectively; and θ_{B4}, θ_{B5} and θ_{B6} are the A end member rotations about axes 1, 2 and 3 respectively.

$$D_B = \begin{vmatrix} \delta_{B1} \\ \delta_{B2} \\ \delta_{B3} \\ \theta_{B4} \\ \theta_{B5} \\ \theta_{B6} \end{vmatrix} \tag{3.14}$$

where δ_{B1}, δ_{B2} and δ_{B3} are the B end member displacements and rotations.

Similarly, if a displacement vector D_A acts at end A, the corresponding displacement vector at end B is:

$$D_B = (H^{AB})^T D_A \tag{3.15}$$

3.5 STIFFNESS ANALYSIS METHOD

The stiffness method involves the generation and solution of a set of linear simultaneous equations relating the external joint loads on a structure to the resulting displacements of all joints. While only concentrated joint loads (any point in the structure can be assumed to be a joint) are treated in the analysis of the whole structure, it is necessary to equate all types of external loads acting on the structure into equivalent joint loads. Distributed loadings can be handled by employing a procedure which is discussed in the next section.

In the stiffness method, the displacements at the joints in the structure are assumed to be the unknowns. The member forces are expressed in terms of the displacements of the appropriate ends of the members (which are the same as the joint displacements). A set of joint equilibrium equations is then written. Since the negatives of the member forces act on the joints, the unknowns in the equilibrium equations are the joint displacements, which are then calculated. Once the joint displacements are known, the member forces can be solved.

To generate the equations which relate the joint loads and displacements, a joint stiffness matrix for the entire structure is required. This requires the generation of a stiffness matrix for each member. These stiffness matrices relate the member end forces and member end displacements. The structure stiffness matrix can be assembled by adding, for each joint, the stiffness matrices of all the members incident upon that joint. In matrix form, the equations are:

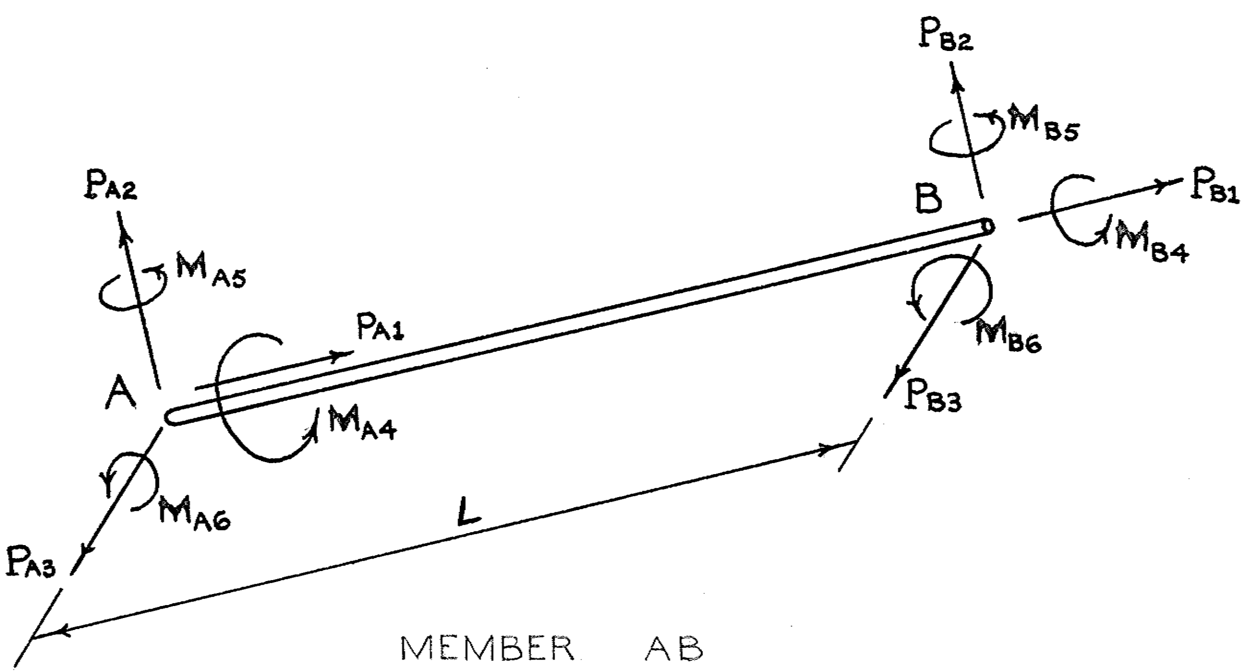
$$P' = K_s D' \qquad (3.16)$$

where P' = vector of all applied loads in global system

D' = vector of all resulting joint displacements in global system

K_s = structure stiffness matrix which relates loads and deflections at all joints.

To explain the generation of the structure stiffness matrix consider a directed member AB as shown in Fig. 3.4; local coordinate systems are used at A and B.



MEMBER AB

FIG. 3.4

The end forces and displacements for member AB are related by the equation:

$$P = K^{AB} D \qquad (3.17)$$

or in partitioned form:

$$\begin{vmatrix} P_A \\ \\ P_B \end{vmatrix} = \begin{vmatrix} K_{AA} & K_{AB} \\ \\ K_{BA} & K_{BB} \end{vmatrix} \begin{vmatrix} D_A \\ \\ D_B \end{vmatrix} \tag{3.18}$$

where P_A = vector of end forces at A in local system

D_B = vector of end displacements at B in local system

K_{AB} = matrix that when postmultiplied by D_B gives corresponding forces at A (end A fixed).

The stiffness matrix of member AB is denoted as K^{AB}. The size of this matrix depends upon the type of structure considered; and, in general, K^{AB} consists of four submatrices as stated in equation (3.18). The elements in submatrices K_{AA} and K_{AB} are the force resultants at A and B arising from unit displacements successively applied in each coordinate direction at A with B held fixed. During each application of a unit displacement, all other displacements are restrained. Similarly, submatrices K_{BA} and K_{BB} are the force resultants at B and A arising from unit displacements successively applied in each coordinate direction at B with A held fixed.

It is extremely advantageous in structural analysis programs to represent submatrices K_{AA}, K_{AB} and K_{BA} in terms of K_{BB}. Once K_{BB} is known, the other three submatrices can be obtained by an appropriate multiplication with a force translation matrix H^{AB} from end B to end A.

If K_{BB} is known in the local system,

$$\left.\begin{aligned} K_{AA} &= H^{AB}\ K_{BB}\ (H^{AB})^T \\ K_{AB} &= -H^{AB}\ K_{BB} \\ K_{BA} &= -K_{BB}\ (H^{AB})^T \end{aligned}\right\} \qquad (3.19)$$

All member stiffness matrices are expressed in the local systems. In order to assemble the structure stiffness matrix, all member stiffness matrices must be transformed to the global system.

In the local system the relationships between forces and displacements at A and B are:

$$\begin{vmatrix} P_A \\ \\ P_B \end{vmatrix} = \begin{vmatrix} H^{AB}\ K_{BB}(H^{AB})^T & -H^{AB}K_{BB} \\ \\ -K_{BB}(H^{AB})^T & K_{BB} \end{vmatrix} \begin{vmatrix} D_A \\ \\ D_B \end{vmatrix} \qquad (3.20)$$

But any force vector can be transformed from the local to the global by equation (3.2); and displacements can be transformed from the local to the global by equation (3.3). Combining equations (3.2), (3.3) and (3.20):

$$\begin{vmatrix} P'_A \\ \\ P'_B \end{vmatrix} = \begin{vmatrix} RK_{AA}R^T & RK_{AB}R^T \\ \\ RK_{BA}R^T & RK_{BB}R^T \end{vmatrix} \begin{vmatrix} D'_A \\ \\ D'_B \end{vmatrix} \qquad (3.21)$$

In the gneration of the structure stiffness matrix, each member is considered in turn and its contributions are inserted into the structure stiffness matrix. Since the member stiffness matrices in equation (3.21) are expressed in global coordinates, they can be added directly. For each member with its A end incident upon joint J, K'_{AA} is added to submatrix K'_{JJ}, in row J and column J of the structure stiffness matrix. Similarly, all members with their B ends incident upon joint J add K'_{BB} to submatrix K'_{JJ}. A member which connects joints J and K will have its cross stiffness matrices K'_{AB} and K'_{BA} added to submatrices K'_{JK} and K'_{KJ} respectively.

The column vector P of known unbalanced joint forces is found by adding the member fixed-end forces to the joint loads. Once this has been accomplished, the unknown joint displacements D are found by solving equations (3.16). Once the joint displacements are known, the induced member distortions and end forces can be found from equation (3.17). These induced quantities are added to the applied distortion and fixed-end forces computed with the joints locked, to produce the final solution.

3.6 TREATMENT OF MEMBER LOADS

To handle distributed loads or a series of concentrated loads on a member, it is most convenient to use the principle of superposition as described below. Assume any loading such as that shown on member AB in Fig. 3.5(a) to be equivalent to the superposition of the loadings shown in (b) and (c).

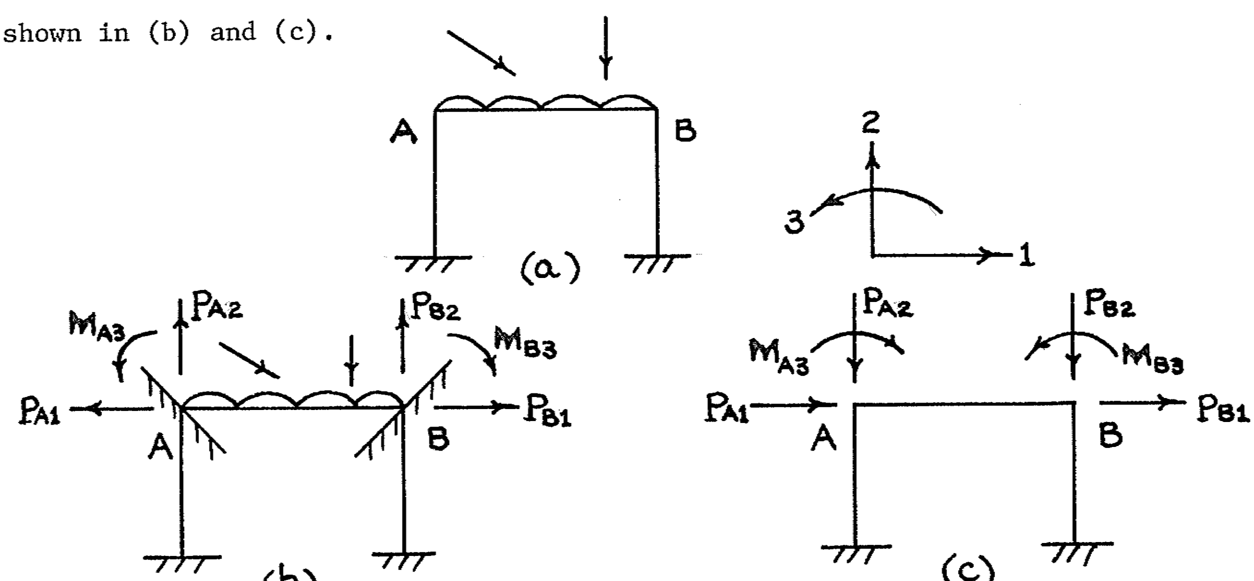


FIG. 3.5

The forces at A and B in (b) are the fixed end forces required to prevent displacements of joints A and B. These forces are obtained by considering only member AB as a fixed-ended member. The forces shown in (c) are the negatives of the forces in (b).

Once the analysis for the joint forces in (c) is performed, the joint displacements and member end forces for these joint forces only are obtained. The results of the analysis for the loading in (a) are found by summing those for loadings (b) and (c).

3.7 SUPPORT RELEASES

If one or more force components at a support joint are constrained to have zero value due to the presence of pins, rollers, etc., the joint is said to be released. Since members framing into the joint undergo end displacements in the released directions, the joint must be included as a free joint in the equilibrium equations.

At each released support, compatibility requires that the displacements of the joint in the non-released directions equal zero. Thus, for each non-released joint force component, a compatibility equation of the form:

$$0 = 1 \times \delta_{J(REL)} \tag{3.22}$$

should be inserted among the equilibrium equations where $\delta_{J(REL)}$ corresponds to a non-released direction at joint J.

In a plane frame structure the equilibrium equations required for the solution should include three equations for each free joint, no equations for completely fixed supports and one equation for each released component at the released supports. It is convenient to treat all supports as free supports. In order to omit the equations which involve non-released components the simplest method is to insert the number 1 on the main diagonal of the non released rows of the structure stiffness matrix as shown in Fig. 3.6. The remainder of the row and the load vectors in that row are made equal to zero.

$$
\left|\begin{array}{ccccccc} \ddots & & & K_S & & & \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ & & & & \ddots & & \end{array}\right|
\quad
\left|\begin{array}{cccc} P'_1 & P'_2 & - & - \\ 0 & 0 & - & - \\ 0 & 0 & - & - \\ & & & \end{array}\right|
\begin{array}{l} \\ \leftarrow \text{non-released} \\ \text{rows} \\ \\ \end{array}
$$

Fig 3.6

SUPPORT RELEASES

This is equivalent to applying equation (3.22) for the non-released components. This has the same effect as deleting the equations corresponding to non-released, support, force components.

Even this procedure requires considerable computation to modify the non-released rows. The simplest possible procedure is to perform the modification by inserting a very large number, such as 1×10^8, on the main diagonal of the non-released rows, and zero in the load vectors. This latter procedure is used in the structural analysis programs described in this thesis.

3.8 MEMBER RELEASES

If a member force component is constrained to have zero value at any cross-section, the member is said to have a member release at that cross-section. Provision for incorporating member releases is accomplished by suitably modifying the force-displacement equations for any released members. This involves a modification of the member stiffness matrix and the member fixed end forces.

To illustrate, consider a continuous elastic member AB as shown in Fig. 3.7.

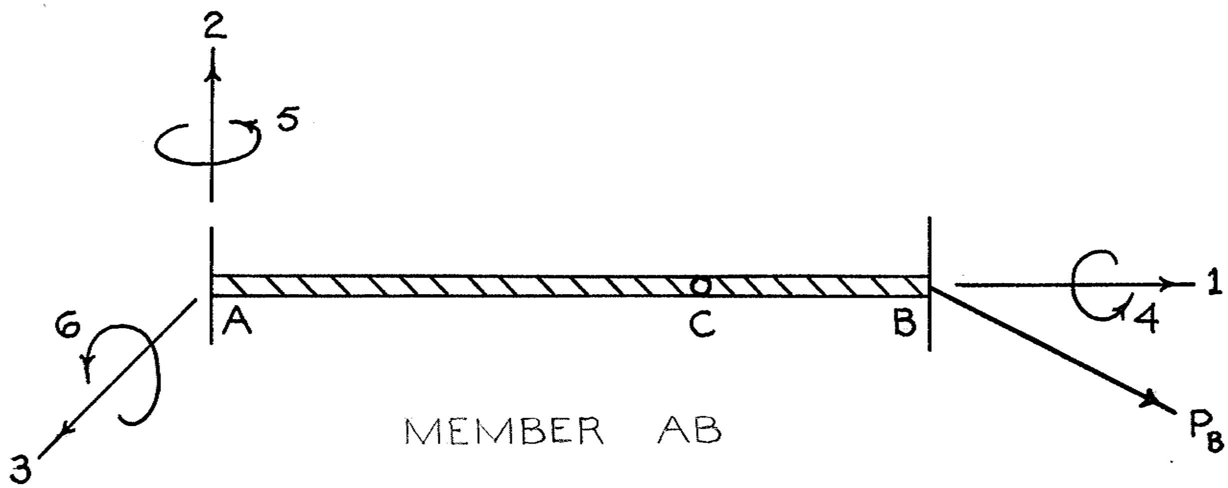


FIG. 3.7

The force vector P_B at B due to the end displacements and member loads is:

$$P_B = P_B^{\circ} + P_B^F = K_{BB} E_B^E - K_{BB} D_B^C \tag{3.23}$$

where P_B° = force vector corresponding to joint displacement at end of member

P_B^F = fixed end force vector

E_B^E = elastic distortion for a continuous member

D_B^C = cantilever deflection at B due to loads on member

K_{BB} = stiffness matrix for a continuous, elastic member

Next consider a member AB with force releases at "r" cross-sections C. The member distortion vector is:

$$E_B = E_B^E + E_B^R \tag{3.24}$$

where E_B^E = elastic member distortion for a continuous member

E_B^R = member distortion corresponding to relative displacements that occur at releases.

Thus, substituting equation (3.24) into equation (3.23), the member force vector at B is:

$$P_B = K_{BB}E_B - K_{BB}E_B^R - K_{BB}D_B^C \tag{3.25}$$

At each cross-section of a member, it is possible to have more than one force component constrained to have zero value. For a 3-dimensional structural frame each member cross-section contains six force components corresponding to the component directions shown in Fig. 3.1(a). Corresponding to each released component, it is convenient to define a vector N_c of the form:

$$N_C = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{vmatrix} \tag{3.26}$$

where the only non-zero element equals 1, and occurs in the position corresponding to the released force component. The vector N_C as stated in equation (3.26) indicates that the force component in direction 6 is released.

For each released component, it is convenient to express the relative displacement in the direction of the released component as a vector V, which gives the discontinuity occurring at the release. Vector V has only one non-zero element, which corresponds to the released component. If more than one release occurs at a cross-section, more than one vector V is required.

Consider that member AB as shown in Fig. (3.8) has a hinge located at point C.

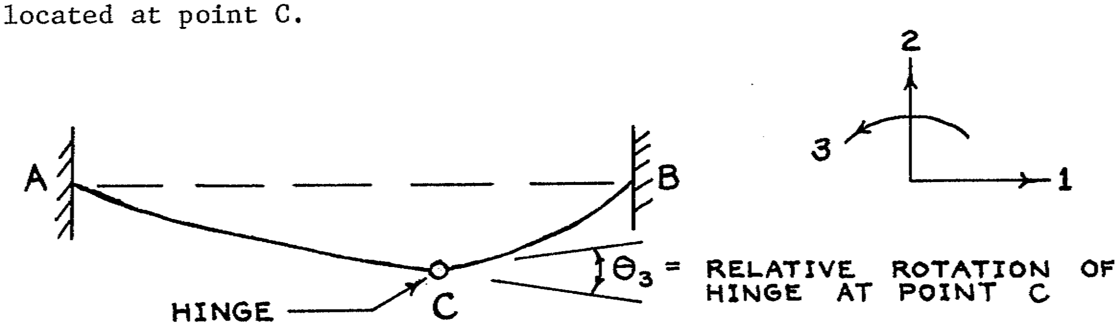


FIG. 3.8

The vector V for the released component at point C is:

$$V_C = \begin{vmatrix} 0 \\ 0 \\ \theta_3 \end{vmatrix} \tag{3.27}$$

The zero elements of vector V_C indicate that there are no relative displacements in directions 1 and 2 at point C.

The vector V corresponding to release C can also be written as:

$$V_C = N_C \mu_C \tag{3.28}$$

where μ_C is a scalar factor which gives the magnitude of the relative displacement at the release. For the member shown in Fig. 3.8, the scalar μ_C equals θ_3.

The effect of all such relative displacements at end B is:

$$E_B^R = \sum_{C=1}^{r} H_{CB}^T V_C \tag{3.29}$$

Substituting equation (3.28) into equation (3.29):

$$E_B^R = \sum_{C=1}^{r} H_{CB}^T N_C \mu_C \tag{3.30}$$

Equations (3.30) can be written as:

$$E_B^R = GM \tag{3.31}$$

where G is a matrix with r columns; one column for each released force component. The C^{th} column of matrix G is:

$$G_{\cdot C} = H_{CB}^T N_C \tag{3.32}$$

Note that the number of rows in G is equal to the number of degrees of freedom for the member; and that M is a column vector of the scalars μ_C.

For a member with three released force components, equation (3.31) is written as:

$$\left|E_B^R\right| = \left|H_1^T N_1, \qquad H_2^T N_2, \qquad H_3^T N_3\right| \begin{vmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \end{vmatrix} \tag{3.33}$$

Substituting equation (3.31) into equation (3.25) gives:

$$P_B = K_{BB}E_B - K_{BB}GM - K_{BB}D_B^C \tag{3.34}$$

The force vector at any release cross-section C can be calculated from statics as:

$$P_C = H_{CB}P_B + P_C^C \tag{3.35}$$

where P_C^C is the force at C due to loads on portion CB of the member. Substituting equation (3.34) into equation (3.35) gives:

$$P_C = H_{CB}K_{BB}E_B - H_{CB}K_{BB}GM - H_{CB}K_{BB}D_B^C + P_C^C \tag{3.36}$$

The fact that the released force component at C is zero can be expressed by:

$$N_C^T P_C = 0 \qquad (C = 1,2,3,---r) \tag{3.37}$$

Substituting equation (3.36) into equation (3.37) and rearranging the terms, the following equation is obtained:

$$N_C^T H_{CB}K_{BB}GM = N_C^T H_{CB}K_{BB}E_B - N_C^T H_{CB}K_{BB}D_B^C + N_C^T P_K^C \tag{3.38}$$

Note that $N_C^T P_C^C$ is a scalar term which represents the force component in the released direction due to the loads on a cantilever to the right of the release position C.

For convenience, a vector Q is defined by the assembling of scalars $N_C^T P_C^C$ as such:

$$Q = \begin{vmatrix} N_1^T P_1^C \\ N_2^T P_2^C \\ \cdot \\ \cdot \\ \cdot \\ N_r^T P_r^C \end{vmatrix} \tag{3.39}$$

By making use of the fact that

$$G^T_{\cdot C} = N_C^T H_{CB} \tag{3.40}$$

the r scalar equations (3.38) can be assembled into a single matrix equation:

$$(G^T K_{BB} G)M = G^T K_{BB} E_B - G^T K_{BB} D_B^C + Q \tag{3.41}$$

Setting $F = (GK_{BB}G)^{-1}$, equation (3.41) can be written as:

$$M = FG^T K_{BB} E_B - FG^T K_{BB} D_B^C + FQ \tag{3.42}$$

Substituting equation (3.42) into equation (3.34) results in:

$$P_B = K_{BB} E_B - K_{BB} GFG^T K_{BB} E_B + K_{BB} GFG^T K_{BB} D_B^C - K_{BB} GFQ - K_{BB} D_B^C \tag{3.43}$$

Equation (3.43) gives the force-deformation equations for a member with any number of releases at any cross-sections. By comparing equation (3.43) with equation (3.23), it can be seen that:

(a) The modified stiffness matrix for a released member is:

$$K^M_{BB} = K_{BB}(I - GFG^T K_{BB}) \tag{3.44}$$

(b) The fixed end force vector at B is:

$$P^F_B = - K^M_{BB} D^C_B - K_{BB} GFQ \tag{3.45}$$

3.9 SUMMARY OF ANALYSIS PROGRAM

The main features of the analysis program are illustrated by means of block diagrams which are shown on pages 46 to 48. More detailed block diagrams of the generation and elimination of the joint equilibrium equations, and of the back substitution and release subroutines are given in Appendix (A). Details of the required input and program output, along with illustrative examples are given in the user's manuals in Appendices (B) and (C).

The main steps for a general frame analysis program are as follows:

1. Definition of structure.

The material properties of the structure are defined by the modulus of elasticity and the modulus of rigidity. The size of the structure is defined by the total number of joints, members and supports. It is also necessary to state the number of members and supports which have releases.

The user must label all joints and members for easy reference.

The joints are located with respect to an origin, which can be any point in space; but the distance from the origin to every joint must be measured in the global co-ordinate directions. Members are located in space by giving the joint number at the start and end of each member.

To define the properties of each member, a local co-ordinate system for each member is required as shown in Fig. 3.2(b). Thus, with the member axes defined, the properties of the members, such as the area, moments of inertia and torsional constant, can be described.

If releases occur at a support or along a member, these releases must be indicated by the appropriate release indicators as described in the User's Manuals in Appendices (B) and (C).

2. Evaluation of stiffness matrices.

For each member, it is necessary to evaluate the member stiffness matrix. If the member has releases, the modified stiffness matrix is calculated by subroutine RELPL (2-dimensional) or RELSP (3-dimensional).

3. Inputting the loads.

Loads on joints are defined in terms of concentrated forces or moments at the joint. The directions of these loads are referred to the global co-ordinate system.

Member loads are defined in terms of concentrated loads, uniformly distributed loads and moments. The directions and locations of these loads are referred to the member or local co-ordinate systems.

4. Calculation of joint forces for which structure is to be analyzed.

The fixed-end-forces at the ends of each member AB are calculated. These forces are obtained by considering only member AB as a fixed-ended member. At this stage, the external joint loadings for each joint have been read and stored, At each joint, the external joint loadings are added to the negative fixed-end-forces of the appropriate members which have their A and B ends connected to the joint.

5. Generation of joint equilibrium equations.

The joint equilibrium equations relate the joint loads to the joint displacements. This relation is accomplished by generating a joint stiffness matrix for the entire structure, which is known as the structure stiffness matrix. This matrix can be assembled by adding, for each joint, the stiffness matrices of all members incident upon that joint, as was explained in detail in section 3.5. A block diagram for the generation of the joint equilibrium equations is shown in Appendix (A).

6. Reduction of joint equilibrium equations.

These equations, which contain rows of the coefficient matrix and constant vectors, are combined in such a way that the coefficient matrix becomes an upper triangle matrix. This reduction routine uses the Gauss elimination procedure. The block diagram of the reduction of the joint equilibrium equations is shown in Appendix (A).

7. Back substitution routine.

After the Gauss elimination routine has been performed, the last equation will involve only one unknown, and it can be solved for directly. That value can then be substituted into the second last equation (which involves only two unknowns) to solve for the second last unknown. This back substitution is continued until all unknowns are solved. These unknowns constitute the joint displacements.

8. Calculation of member end forces.

The end forces and displacements for a member are related by its member stiffness matrix. Once the joint displacements are known, the induced member distortions and end forces can be found. These induced quantities are added to the applied distortion and fixed-end forces computed with the joints locked, to produce the final member end forces.

9. Output.

The output for each loading case includes:

(a) The joint displacements.

(b) The member end forces.

(c) The joint reactions.

BLOCK DIAGRAM
FOR A
GENERAL FRAME ANALYSIS
PROGRAM

START

READ: NAME OF JOB
MODULUS OF ELASTICITY - E
MODULUS OF RIGIDITY - G (IF REQ'D)
NO. OF LOAD CASES - NL
NO. OF JOINTS - NJ
NO. OF MEMBERS - NMEM
NO. OF JOINT SUPPORTS - NJS
NO. OF JOINT SUPPORTS WITH RELEASES - NJSR
NO. OF MEMBERS WITH RELEASES - NMR

COMPUTE NO. OF JOINT EQUILIBRIUM EQUATIONS TO BE SOLVED: NE = NJ - NJS + NJSR

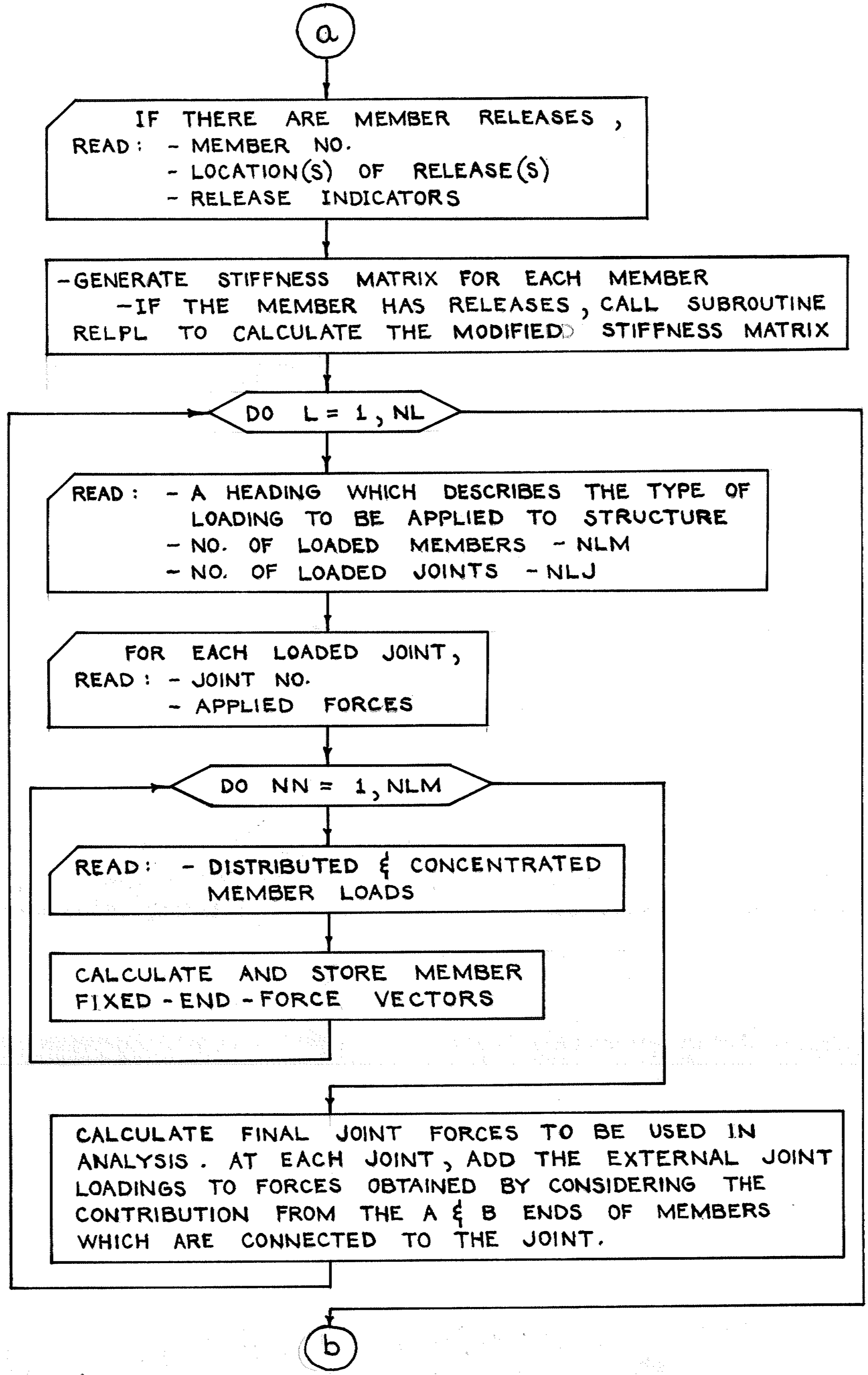
READ: - COORDINATES FOR EACH JOINT
- STRUCTURAL TOPOLOGY BY MEANS OF A MEMBER INCIDENCE TABLE WHICH LISTS THE TWO JOINTS CONNECTED BY EACH MEMBER

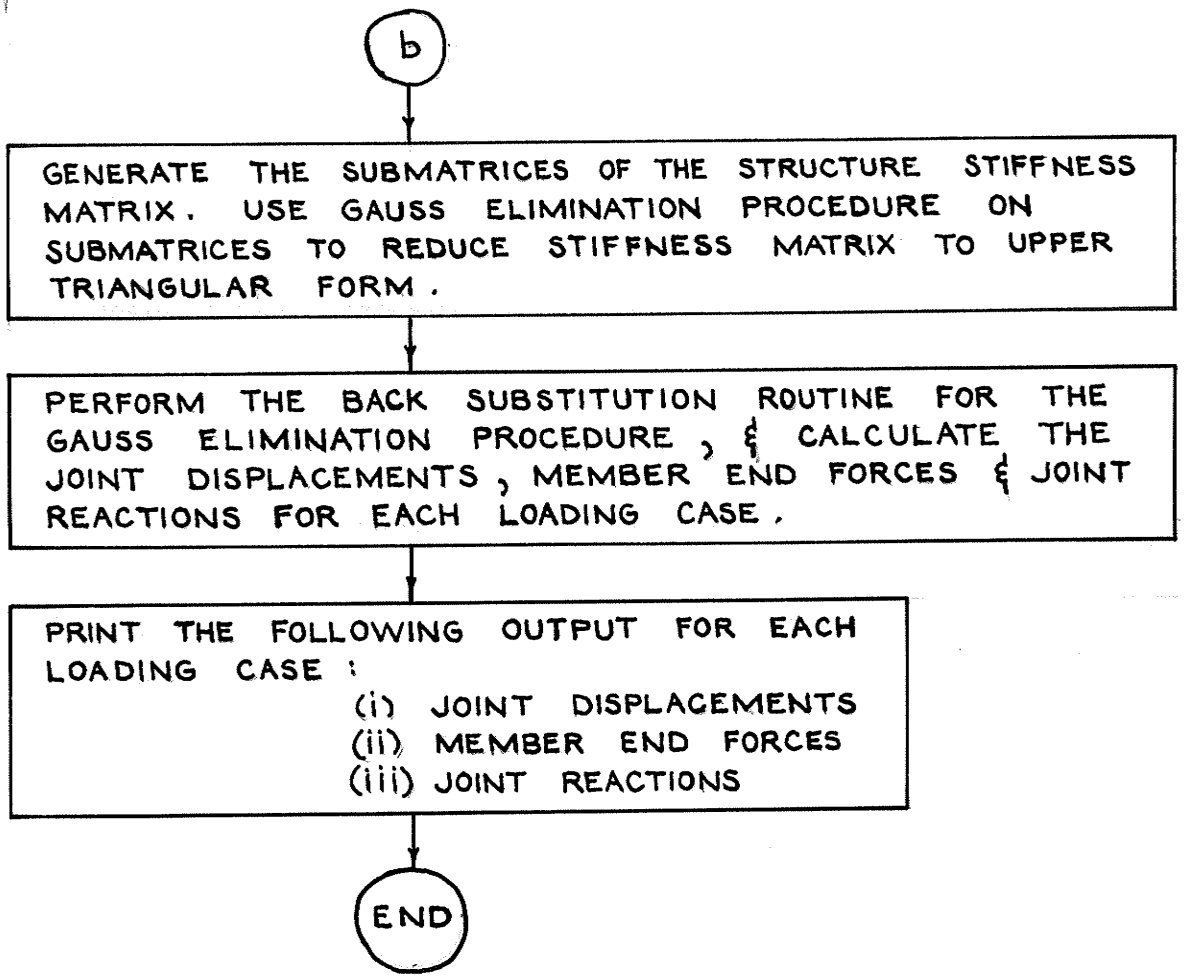
- CALCULATE THE MEMBER LENGTHS
- SET UP A JOINT INCIDENCE TABLE WHICH LISTS THE MEMBERS INCIDENT ON EACH JOINT
- GENERATE THE ROTATION MATRIX FOR EACH MEMBER

READ: MEMBER PROPERTIES
- X-SECTIONAL AREA, MOMENTS OF INERTIA AND TORSIONAL CONSTANT OF EACH MEMBER

IF THERE ARE SUPPORT RELEASES,
READ: - JOINT NO.
- RELEASE INDICATORS

a


a
IF THERE ARE MEMBER RELEASES,
READ: - MEMBER NO.
- LOCATION(S) OF RELEASE(S)
- RELEASE INDICATORS
-GENERATE STIFFNESS MATRIX FOR EACH MEMBER
-IF THE MEMBER HAS RELEASES, CALL SUBROUTINE RELPL TO CALCULATE THE MODIFIED STIFFNESS MATRIX
DO L = 1, NL
READ: - A HEADING WHICH DESCRIBES THE TYPE OF LOADING TO BE APPLIED TO STRUCTURE
- NO. OF LOADED MEMBERS - NLM
- NO. OF LOADED JOINTS - NLJ
FOR EACH LOADED JOINT,
READ: - JOINT NO.
- APPLIED FORCES
DO NN = 1, NLM
READ: - DISTRIBUTED & CONCENTRATED MEMBER LOADS
CALCULATE AND STORE MEMBER FIXED-END-FORCE VECTORS
CALCULATE FINAL JOINT FORCES TO BE USED IN ANALYSIS. AT EACH JOINT, ADD THE EXTERNAL JOINT LOADINGS TO FORCES OBTAINED BY CONSIDERING THE CONTRIBUTION FROM THE A & B ENDS OF MEMBERS WHICH ARE CONNECTED TO THE JOINT.
b


b
GENERATE THE SUBMATRICES OF THE STRUCTURE STIFFNESS MATRIX. USE GAUSS ELIMINATION PROCEDURE ON SUBMATRICES TO REDUCE STIFFNESS MATRIX TO UPPER TRIANGULAR FORM.
PERFORM THE BACK SUBSTITUTION ROUTINE FOR THE GAUSS ELIMINATION PROCEDURE, & CALCULATE THE JOINT DISPLACEMENTS, MEMBER END FORCES & JOINT REACTIONS FOR EACH LOADING CASE.
PRINT THE FOLLOWING OUTPUT FOR EACH LOADING CASE:
(i) JOINT DISPLACEMENTS
(ii) MEMBER END FORCES
(iii) JOINT REACTIONS
END

CHAPTER 4

NUMERICAL EXAMPLES

This chapter describes the representation of a structure in order to assist a person using the User's Manuals as described in Appendices (B) and (C). Also, the required input information and the resulting output for plane and space frame structures are illustrated by numerical examples.

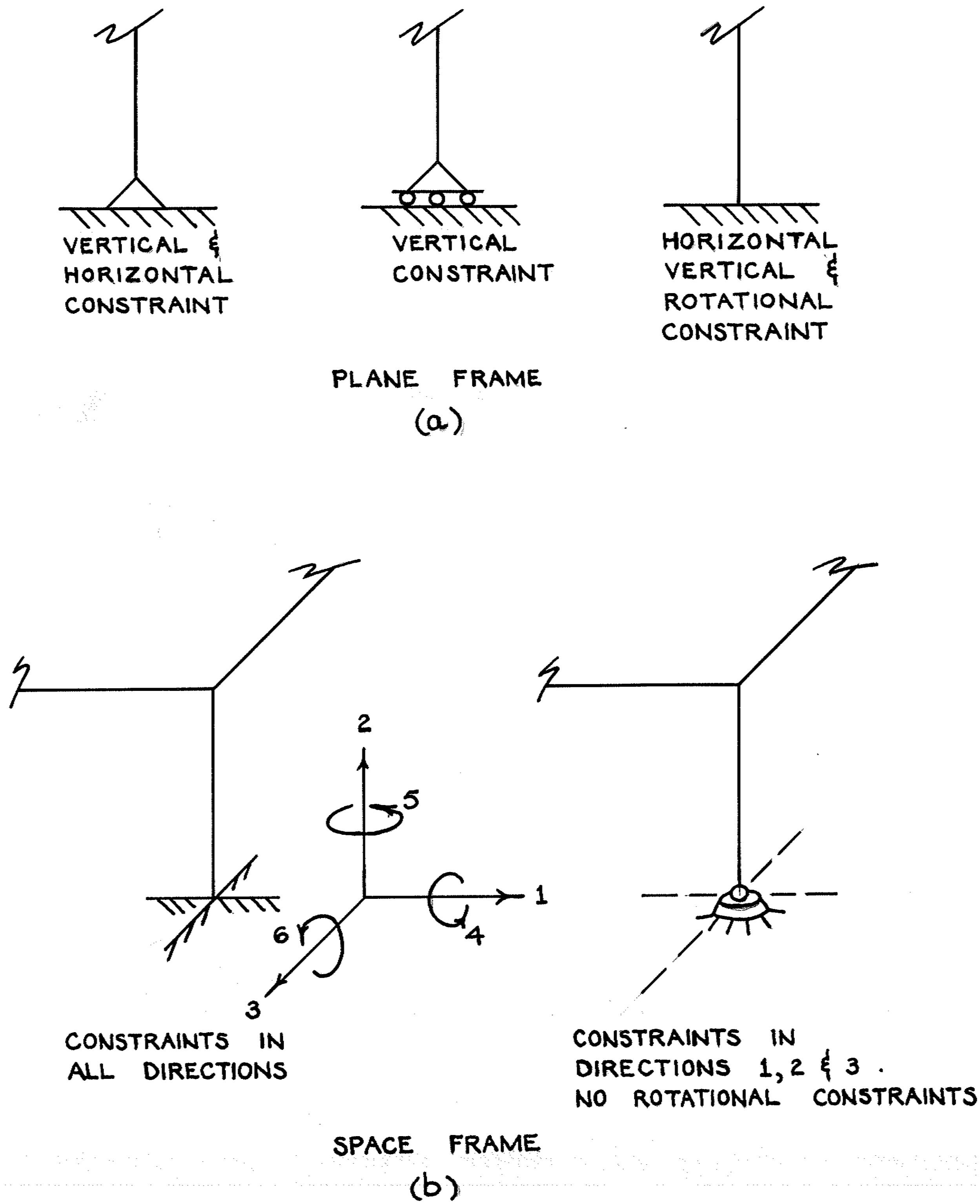
4.1 REPRESENTATION OF A FRAMED STRUCTURE

In order to make up a set of data cards to represent a structure it is convenient to consider the structure as being composed of joints and members. In general, joints are free to translate and rotate but constraints may be imposed to prevent some motions. A convenient way of describing support constraints is by using the pictoral conventions shown in Fig. 4.1.

Members may be fixed or pinned to a joint. When fixed, the joint and member end have the same translation and rotation. When pinned, the member end and joint have the same translation but may have different rotations. The pictoral conventions as shown in Fig. 4.2 are convenient for describing member connections.

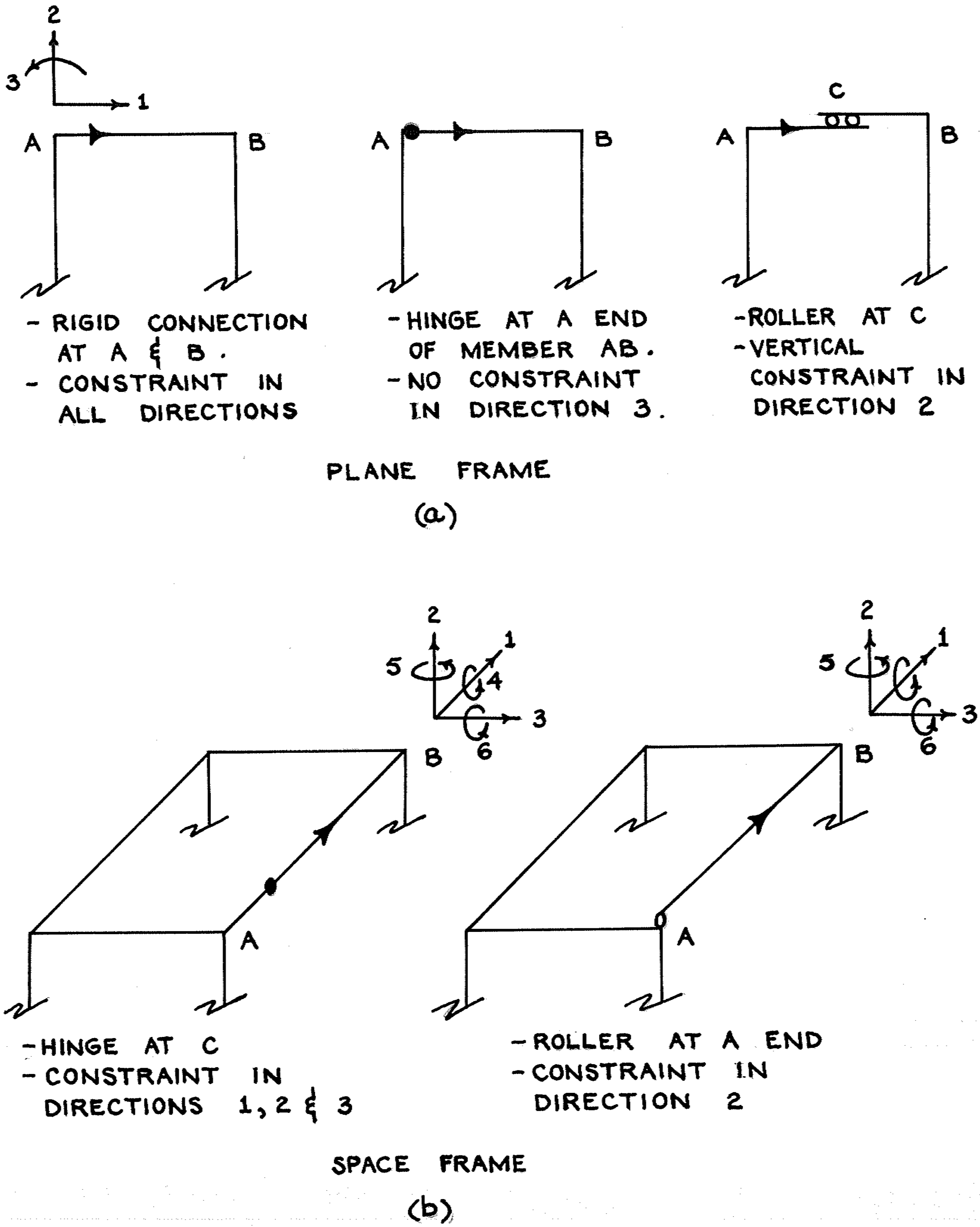
4.2 INPUT INFORMATION

It is necessary to input the geometry, topology and properties of all the members, and the type, position and magnitude of all the applied loads. The geometry is specified in terms of joint coordinates with respect to a chosen origin. The topology of a structure denotes the inter-connection of members and joints by a list giving the starting and ending joint of



PICTORAL CONVENTIONS
FOR
TYPICAL SUPPORT CONSTRAINTS

FIG. 4.1



PICTORAL CONVENTIONS
FOR
TYPICAL MEMBER CONSTRAINTS

FIG. 4.2

each member. The load-deflection properties of each member must also be specified. If a joint or member has releases, then the position and orientation of the released force components must be stated. The "User's Manuals" in Appendices (B) and (C) give a detailed description of the required data cards.

4.3 OUTPUT

All information described on the data sheets is printed out for checking purposes. Once the analysis portion of each loading case is completed, the deflections of all joints, the forces at the ends of all members and the support reactions are output.

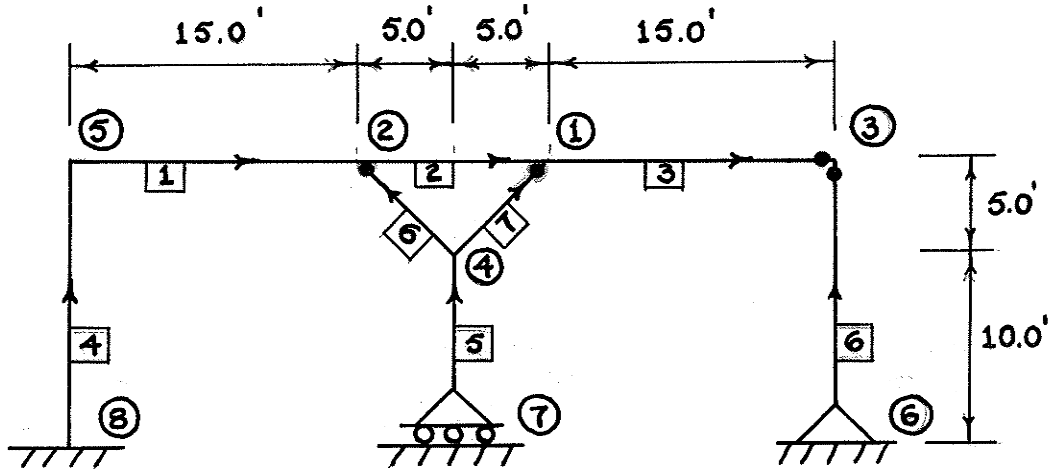
4.4 SAMPLE PROBLEMS

(i) Plane Frame Structure

The framed structure shown in Fig. 4.3(a) is to be analyzed for the applied loads given in Fig. 4.3(b). The members and non-support joints may be numbered in arbitrary fashion, but computation time depends to some extent on the numbering sequence used for the joints. A procedure for determining the optimum numbering sequence is discussed in Appendix (B). Once the required data are input properly, the final results are output as shown on pages 54 to 56.

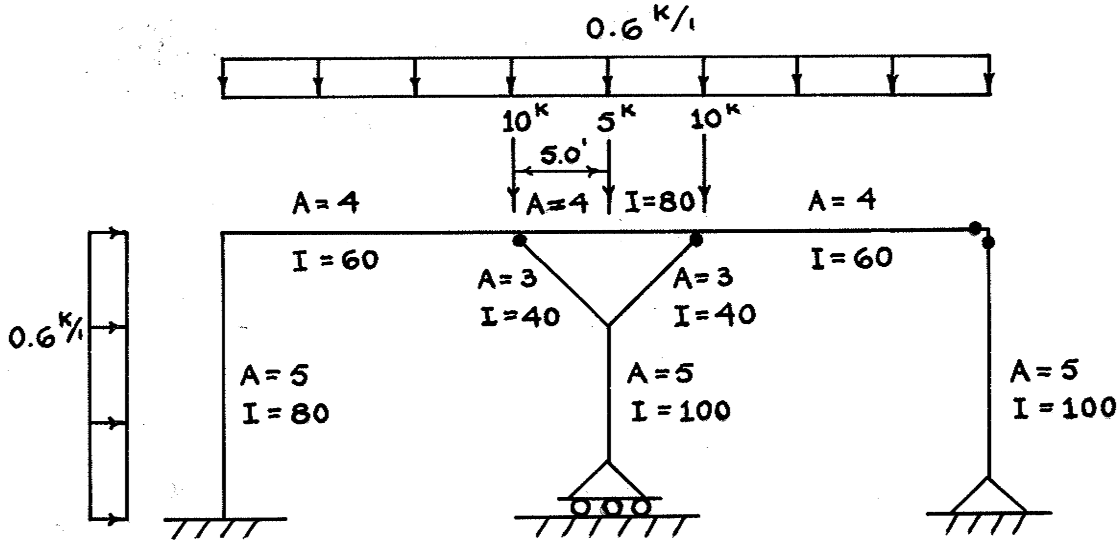
(ii) Space Frame Structure

The framed structure shown in Fig. 4.4(a) is to be analyzed for the applied loads given in Figures 4.4(c) and (d). The format of the arrangement of the data cards is described in Appendix (C). The entire output is given on pages 58 to 62.



NUMBERING OF MEMBERS & JOINTS

(a)



A = X-SECTIONAL AREA ($IN.^2$)
I = MOMENT OF INERTIA ($IN.^4$)
E = 30000. K.S.I.

APPLIED LOADING

(b)

PLANE FRAME STRUCTURE

FIG. 4.3

PLANE FRAME ANALYSIS

NUMERICAL EXAMPLE

8 JOINTS 8 MEMBERS 3 SUPPORTS
2 SUPPORT RELEASE(S) 5 MEMBER RELEASE(S)
ODULUS OF ELASTICITY (KSI.)=30000.00 1 LOAD CASE(S)

JOINT COORDINATES (FT) (GLOBAL SYSTEM)

OINT	COORD. 1	COORD. 2
1	25.00	15.00
2	15.00	15.00
3	40.00	15.00
4	20.00	10.00
5	0.0	15.00
6	40.00	0.0
7	20.00	0.0
8	0.0	0.0

MEMBER INCIDENCE TABLE

EMBER	A END	B END
1	5	2
2	2	1
3	1	3
4	8	5
5	7	4
6	4	2
7	4	1
8	6	3

MEMBER PROPERTIES

EMBER	X-SECT. AREA(IN.2)	MOMENT OF INERTIA(IN.4)
1	4.000	60.000
2	4.000	80.000
3	4.000	60.000
4	5.000	80.000
5	5.000	100.000
6	3.000	40.000
7	3.000	40.000
8	5.000	80.000

SUPPORT RELEASE INDICATORS

OINT	DIRECTION		
	1	2	3
6	0	0	1
7	1	0	1

MEMBER RELEASE INDICATORS

EMBER	NO. OF REL. POSITIONS	DIST. FROM A END(FT.)	DIRECTIONS		
			1	2	3
6	1	7.07	0.	0.	1.
7	1	7.07	0.	0.	1.
5	1	0.0	0.	1.	1.
3	1	15.00	0.	0.	1.
[illegible]	[illegible]	0.0	0.	0.	1.

LOADING CASE 1

NON ZERO JOINT LOADS

OINT	DIRECTION 1 (KIPS)	2 (KIPS)	3 (FT-K)
2	0.0	-10.00	0.0
1	0.0	-10.00	0.0

NON ZERO MEMBER LOADS

EMBER	DISTRIB. LOADS 1	2	DIST. FROM A END(FT.)	CONCENT. LOADS 1	2	3
4	0.60	0.0				
1	0.0	-0.60				
2	0.0	-0.60				
			5.00	0.0	-5.00	0.0
3	0.0	-0.60				

LOADING CASE 1

APPLIED LOADING - DISTRIB.,CONC.,AND JOINT LOADS

JOINT DISPLACEMENTS (GLOBAL SYSTEM)

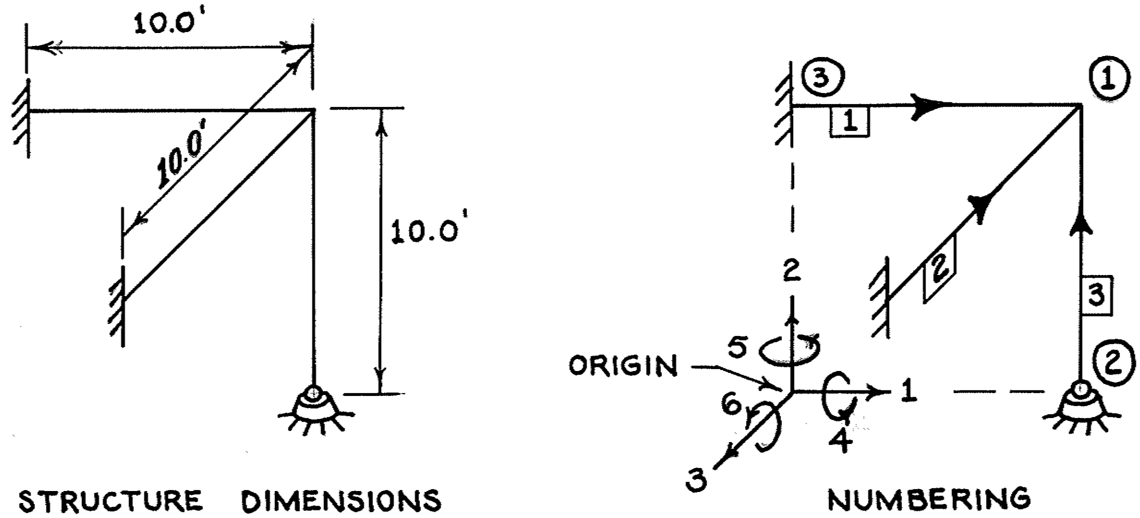
NO.	HORIZ.(IN)	VERT.(IN)	ROTATION(RAD.)
1	1.793651	0.001087	0.000010
2	1.772590	-0.170835	0.002562
3	1.793653	-0.004042	-0.020655
4	1.869082	-0.034282	0.001433
5	1.772605	-0.003334	-0.009588
6	0.000000	-0.000000	-0.032034
7	2.041008	-0.000000	0.001429
8	0.0	0.0	0.0

MEMBER END FORCES(K & IN.-K) (LOCAL SYSTEM)

	A END			B END		
NO.	AXIAL	SHEAR	MOMENT	AXIAL	SHEAR	MOMENT
1	0.010	2.778	-141.451	-0.010	6.222	-168.443
2	-21.061	5.207	168.447	21.061	5.793	-203.652
3	-0.001	5.631	203.648	0.001	3.369	-0.002
4	2.778	8.992	667.138	-2.778	0.008	141.451
5	42.852	0.0	-0.000	-42.852	0.0	0.000
6	30.045	-0.255	-21.609	-30.045	0.255	-0.003
7	30.047	0.255	21.607	-30.047	-0.255	0.003
8	3.369	0.000	0.000	-3.369	-0.000	0.002

JOINT REACTIONS(K & IN.-K) (GLOBAL SYSTEM)

NO.	HORIZONTAL	VERTICAL	MOMENT
6	-0.000	3.369	0.000
7	-0.0	42.852	-0.000
8	-8.992	2.778	667.138



STRUCTURE DIMENSIONS

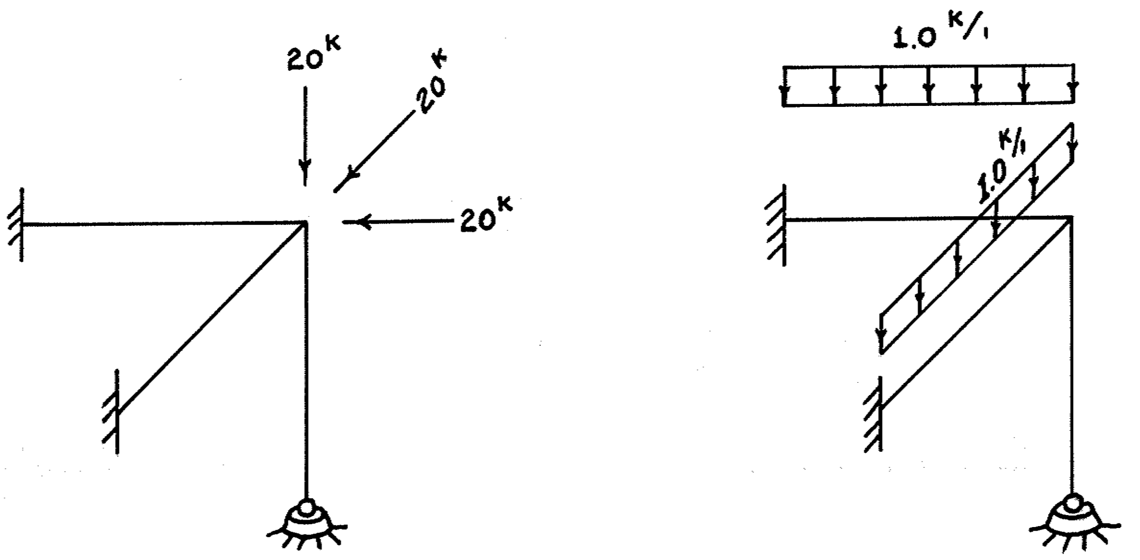
(a)

NUMBERING

(b)

- ALL MEMBERS HAVE SAME PROPERTIES
- PROPERTIES AS GIVEN IN THE LOCAL SYSTEM ARE :

$A = 4.98$ IN.^{2} $\quad I_1 = J = 88.72$ IN.^{4} $\quad I_2 = I_3 = 44.36$ IN.^{4}



LOADING CASE 1
JOINT LOADS

(c)

LOADING CASE 2
DISTRIBUTED LOADING

(d)

SPACE FRAME STRUCTURE

FIG. 4.4

SPACE FRAME ANALYSIS

NUMERICAL EXAMPLE OF SPACE FRAME

4 JOINTS 3 .MEMBERS 3 SUPPORTS
1 SUPPORT RELEASE(S) 1 MEMBER RELEASE(S)
ODULUS OF ELASTICITY (KSI.)=30000.00 2 LOAD CASE(S)

JOINT COORDINATES (FT) (GLOBAL SYSTEM)

OINT	COORD. 1	COORD. 2	COORD. 3
1	10.00	10.00	0.0
2	10.00	0.0	0.0
3	0.0	10.00	0.0
4	10.00	10.00	10.00

MEMBER INCIDENCE TABLE

IEMBER	A END	B END
1	3	1
2	4	1
3	2	1

MEMBER PROPERTIES

IEMBER NO.	X-SECT. AREA(IN.2)	MOMENT OF INERTIA(IN.4) AXIS 1	AXIS 2	AXIS 3	SHEAR MODULUS (KSI.)
1	4.98	88.72	44.36	44.36	12000.00
2	4.98	88.72	44.36	44.36	12000.00
3	4.98	88.72	44.36	44.36	12000.00

SUPPORT RELEASE INDICATORS

JOINT	DIRECTION 1	2	3	4	5	6
2	0	0	0	1	1	1

MEMBER RELEASE INDICATORS

IEMBER	NO. OF REL. POSITIONS	DIST. FROM A END(FT.)	DIRECTIONS 1	2	3	4	5	6
3	1	0.0	0.	0.	0.	1.	1.	1.

LOADING CASE 1

NON ZERO JOINT LOADS (KIPS & FT-K)

JOINT	DIRECTION 1	2	3	4	5	6
1	-20.00	-20.00	20.00	0.0	0.0	0.0

LOADING CASE 2

NON ZERO MEMBER LOADS

EMBER	DISTRIB. LOADS(K/FT.) 1	2	3	4	DIST. FROM A END(FT.)	CONCENT. LOADS(K&FT-K) 1	2	3	4	5	6
1	0.0	-1.00	0.0	0.0							
2	0.0	-1.00	0.0	0.0							

LOADING CASE 1

JOINT LOADS

JOINT DISPLACEMENTS(GLOBAL SYSTEM - IN. & RAD.)

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	-0.015899	-0.015870	0.015899	-0.000046	-0.000004	-0.000
2	-0.000000	-0.000000	0.000000	0.000275	-0.000122	0.000
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0

MEMBER FORCES(LOCAL SYSTEM - K & IN.-K)

A END OF MEMBER

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	19.794	0.120	-0.144	0.404	8.718	7.740
2	19.795	0.121	0.149	-0.424	-8.914	7.790
3	19.758	-0.056	-0.061	-0.391	0.908	-0.518

B END OF MEMBER

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	-19.794	-0.120	0.144	-0.404	8.621	6.680
2	-19.795	-0.121	-0.149	0.424	-9.011	6.781
3	-19.758	0.056	0.061	0.391	6.377	-6.256

JOINT REACTIONS(GLOBAL SYSTEM - K & IN.-K)

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
2	0.056	19.758	-0.061	-0.908	-0.391	-0.518
3	19.794	0.120	-0.144	0.404	8.718	7.740
4	0.149	0.121	-19.795	7.790	-8.914	0.424

LOADING CASE 2

DISTRIBUTED LOADS

JOINT DISPLACEMENTS(GLOBAL SYSTEM - IN. & RAD.)

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	-0.000227	-0.006927	0.000225	0.001123	0.000010	0.001[illegible]
2	0.000000	-0.000000	-0.000000	-0.000732	0.000244	-0.000[illegible]
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0

MEMBER FORCES(LOCAL SYSTEM - K & IN.-K)

A END OF MEMBER

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	0.282	5.689	-0.008	-9.961	0.348	128.858
2	0.281	5.687	-0.003	10.007	0.098	128.743
3	8.624	0.279	0.288	0.893	1.795	-2.687

B END OF MEMBER

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	-0.282	4.311	0.008	9.961	0.572	-46.125
2	-0.281	4.313	0.003	-10.007	0.321	-46.355
3	-8.624	-0.279	-0.288	-0.893	-36.394	36.119

JOINT REACTIONS(GLOBAL SYSTEM - K & IN.-K)

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
2	-0.279	8.624	0.288	-1.795	0.893	-2.687
3	0.282	5.689	-0.008	-9.961	0.348	128.858
4	-0.003	5.687	-0.281	128.743	0.098	-10.007

CHAPTER 5

SUMMARY AND SUGGESTIONS FOR FURTHER STUDY

5.1 SUMMARY

There is a need for vast computer systems capable of handling entire projects or entire branches of civil engineering. However, since the field of civil engineering consists of a highly skilled type of professional service with individuals, private firms and even public agencies dedicated to specialized functions, the present need of relatively small engineering organizations is for libraries of specialized programs capable of performing specific engineering design and analysis tasks. These specific programs involve a minimum of sophisticated data management, complex translation and communication with various branches of engineering.

This thesis has described a special-program system for analyzing structural problems. As of now, two programs have been developed for such structural types as plane frames and space frames. To facilitate the use of either of these programs, user's manuals are included in Appendices (B) and (C). The prime aim of these manuals is to make the engineer's job in communicating with a computer as easy as possible. This is accomplished by requiring all input data to be filled out on standard data sheets as described in the manuals.

Thus far, the two basic programs PLANE and SPACE are capable of analyzing structures which are rigidly or pin connected, and which incorporate member and joint releases. The loading system may consist of concentrated and distributed loads, and several loading cases can be analyzed simultaneously. The results include the displacements of all joints, the forces at the ends of all members, and the support reactions.

5.2 SUGGESTIONS FOR FURTHER STUDY

The objectives of further investigation should be to extend the capabilities of the two analysis programs already developed, and to incorporate new programs into the structural analysis and design system.

The following suggestions regarding the two programs PLANE and SPACE could be incorporated:

1. In order to investigate the effect of changing the loading on one or two members in a structure while keeping the loading on the rest of the structure constant, the user is required to input a complete loading case for each change. A provision which would permit modification of only a few loads from the original loading case without having to input another complete loading case should be incorporated.

2. For trial designs, it is necessary to modify member properties, and at present, the programs require the user to re-input the complete description of the structure for each member change. A provision should be made which automatically assigns new member properties so that an analysis of the new trial design can be calculated without having to input the entire description of the structure again.

3. The programs do not incorporate the forces which result when one or more members change in length due to a temperature change or are manufactured of the wrong length. A provision which considers the effect of temperature change and improperly dimensioned members should be incorporated.

4. The analysis of beams on elastic foundations should be included. This would require springs to be introduced at the joints. The elastic foundation would be replaced by a series of springs at a

sequence of points. Since the spring constants can be different at each point a variable foundation modulus can be approximated.

5. The effects due to earthquake and dynamic loadings could be incorporated.

6. Provisions should be made to include the formation of plastic hinges in the structure (partial failure); and as a result, could be used to obtain the load factor to cause a structure to collapse.

7. The technique of "overlaying" as discussed in section 2.3 should be incorporated into the individual programs. This would increase the size of the structure to be analyzed, and yet, not increase the core capacity required.

The following suggestions regarding the system could be incorporated:

1. An inspection should be made to see what segments of all special-purpose programs are common to one another. If there are common areas, then these should be separated out as special subroutines. This allows all programs which require these special subroutines to call them into core only when required. Since these special subroutines can serve all the special-purpose programs, there results in a saving of storage space.

2. A comparison should be made of equation solution routines in connection with different types and sizes of structures. There are a number of iterative and direct methods of solving simultaneous equations. These methods should be compared regarding storage requirements and computational time required for solution. It is hoped that the system will have available more than one solution routine.

LIST OF REFERENCES

1. Livesley, R.K., Matrix Methods of Structural Analysis, Pergamon Press, New York, 1964.

2. Hall, A.S., and R.W. Woodhead, Frame Analysis, John Wiley & Sons, Inc., New York, 1961.

3. Farina, M.V., Fortran IV Self-Taught, Prentice-Hall, Inc., New Jersey, 1966.

4. McCracken, D.D., A Guide to Fortran IV Programming, John Wiley & Sons, Inc., New York, 1965.

5. Clough, R.W., E. L. Wilson and I.P. King, "Large Capacity Multistory Frame Analysis Programs", Journal of the Structural Division, ASCE, Vol. 89, No. ST4, August 1963.

6. Tezcan, S., "Large Capacity Multistory Frame Analysis Programs", Discussion, Journal of the Structural Division, ASCE, Vol. 90, April 1964.

7. Tezcan, S., "Computer Analysis of Plane and Space Structures", Journal of the Structural Division, Proceedings of the ASCE, April 1966.

8. Tezcan, S., "Direct Stiffness Analysis of Large Frames By Computers", Transactions of the Engineering Institute of Canada Bridge and Structural Division, Vol. 8, December 1965.

9. Brooks, D.E., "Computer Systems for Analysis of Large Frameworks", Journal of the Structural Division, Proceedings of the ASCE, Dec. 1967.

10. Tung, C. and D. Carson, "Universal Programs-third generation systems for third generation computers", Journal of the Structural Division, Proceedings of the ASCE, February 1968.

11. Fenves, S.J., R. D. Logcher and S.P. Mauch, "Stress: A Reference Manual", The Dept. of Civil Engineering, Massachusetts Institute of Technology; The M.I.T. Press, 1965.

12. Roos, D., "ICES System Design", The Dept. of Civil Engineering, Massachusetts Institute of Technology; The M.I.T. Press, 1966.

13. Morris, G.A., "Analysis of Elastic and Inelastic Behaviour of Frameworks", Thesis for Ph.D. at Univ. of Illinois, 1967.

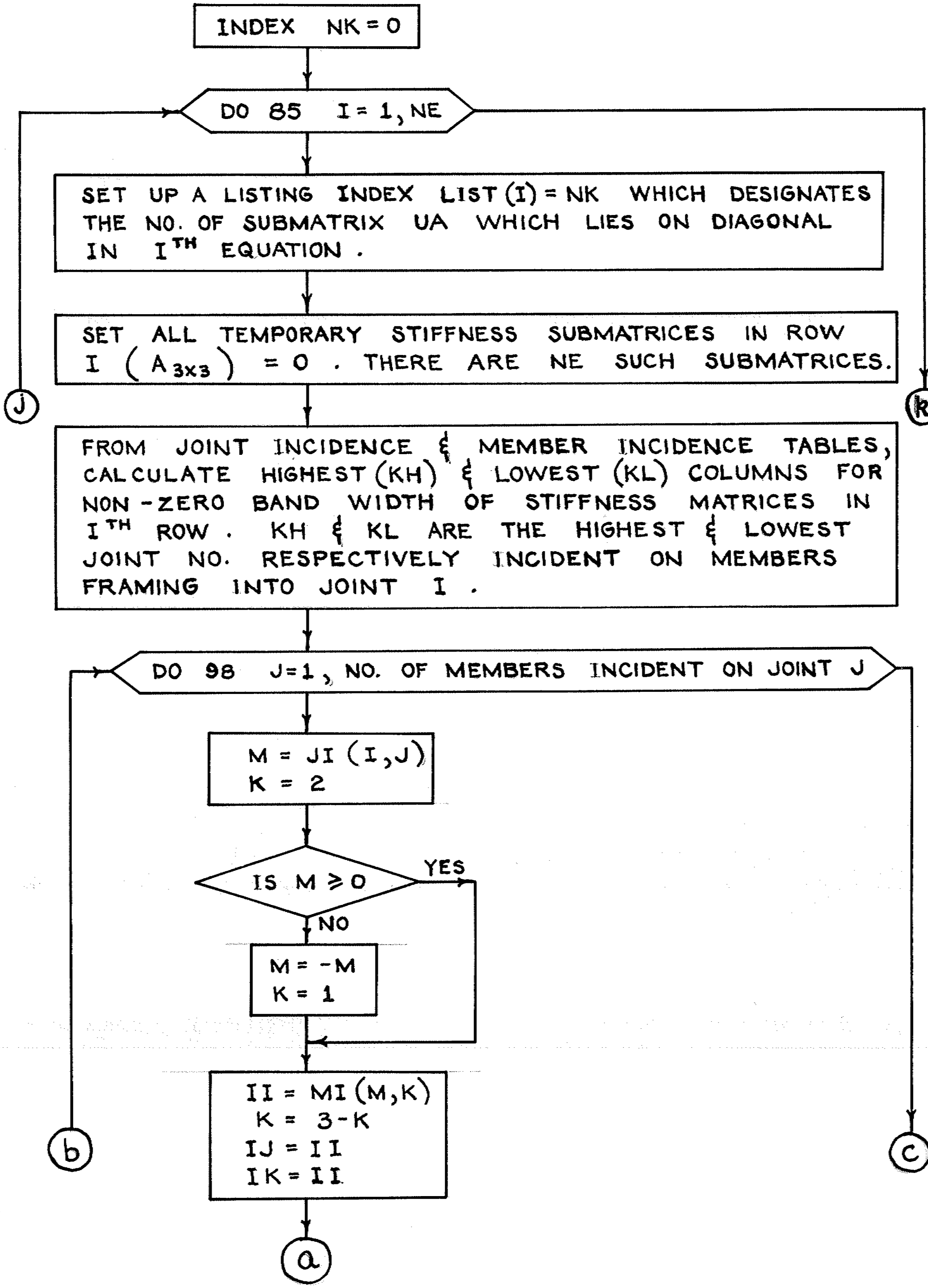
APPENDIX A:

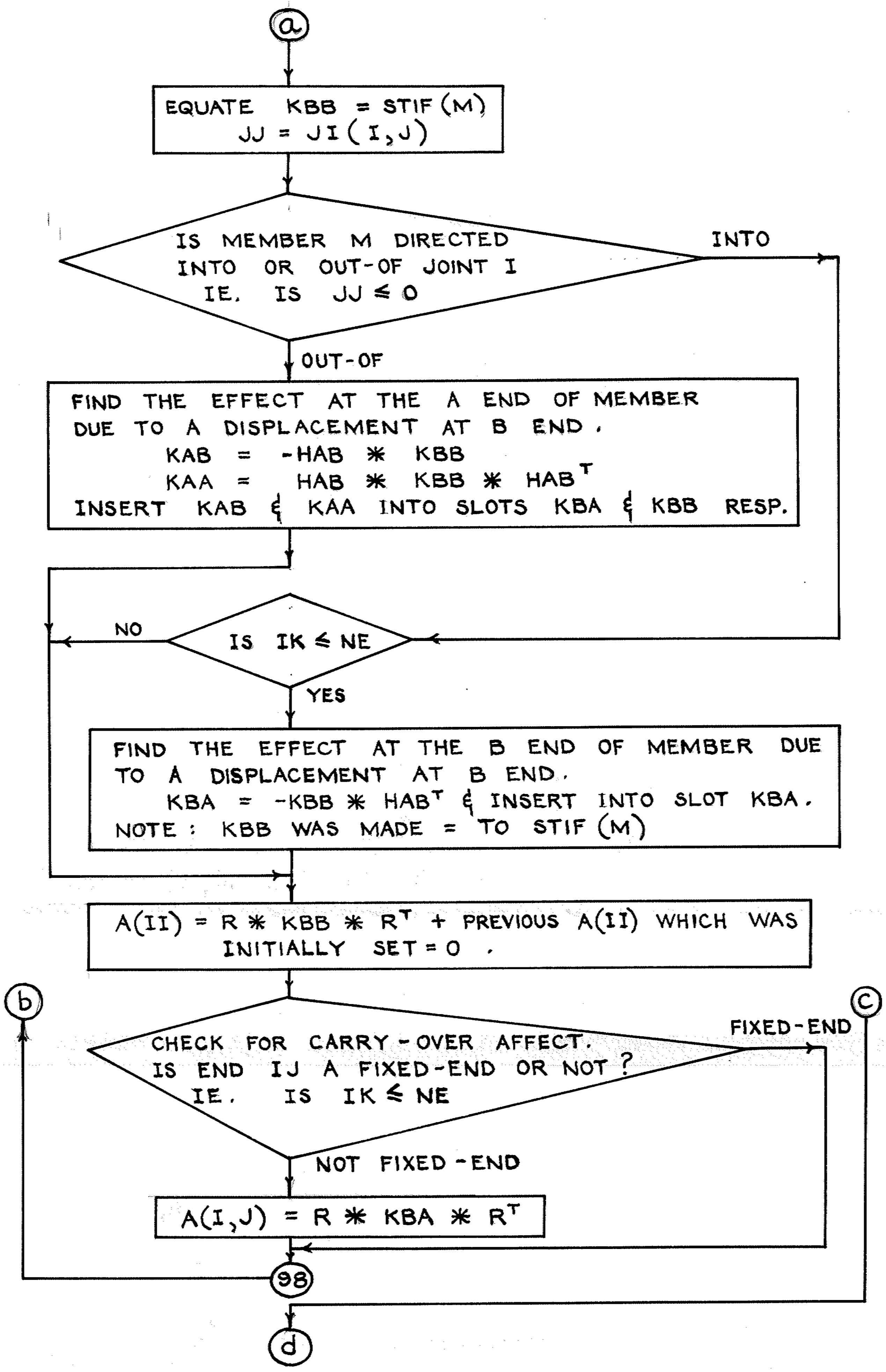
BLOCK DIAGRAMS

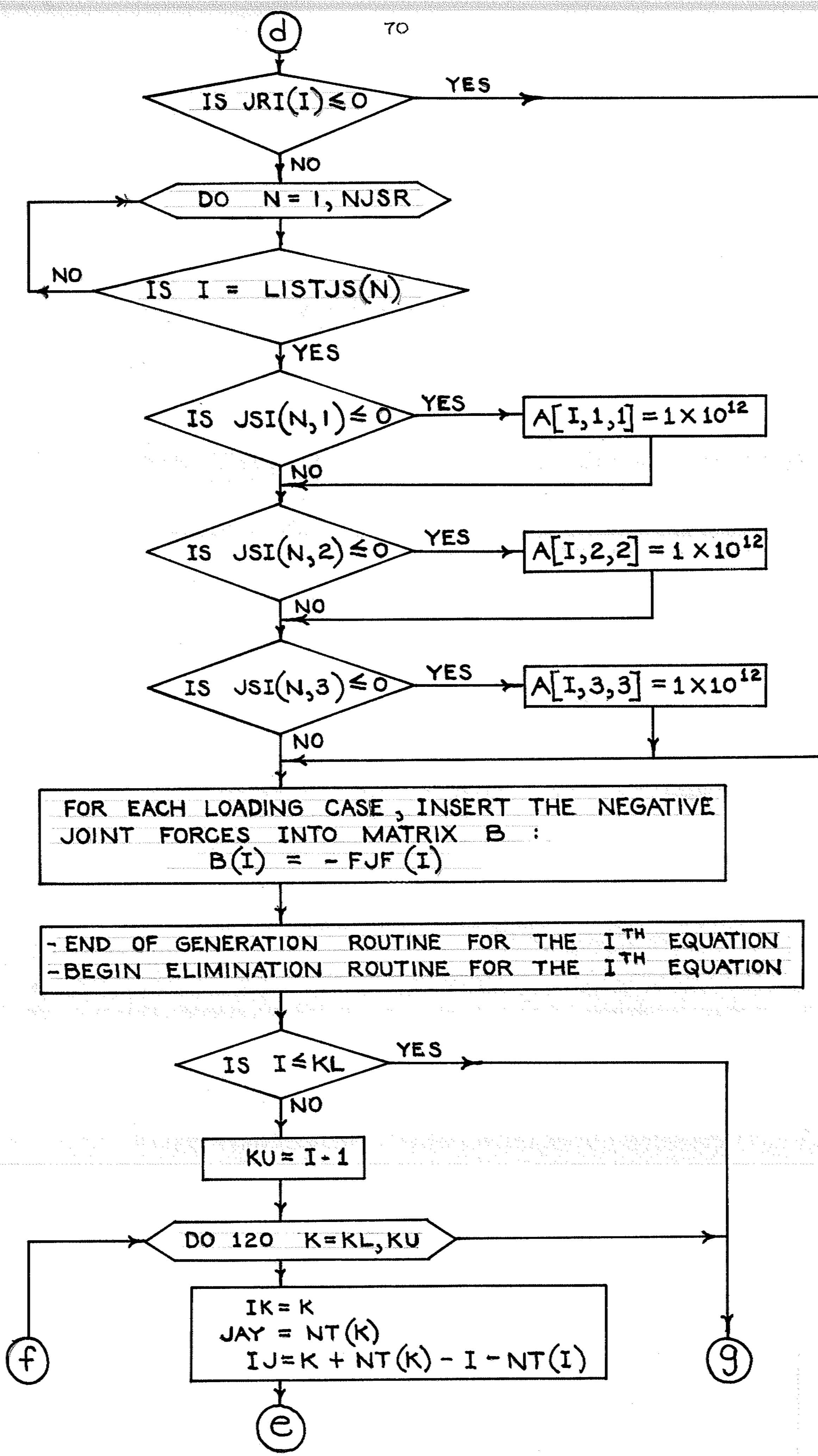
FOR

PROGRAM SUBROUTINES

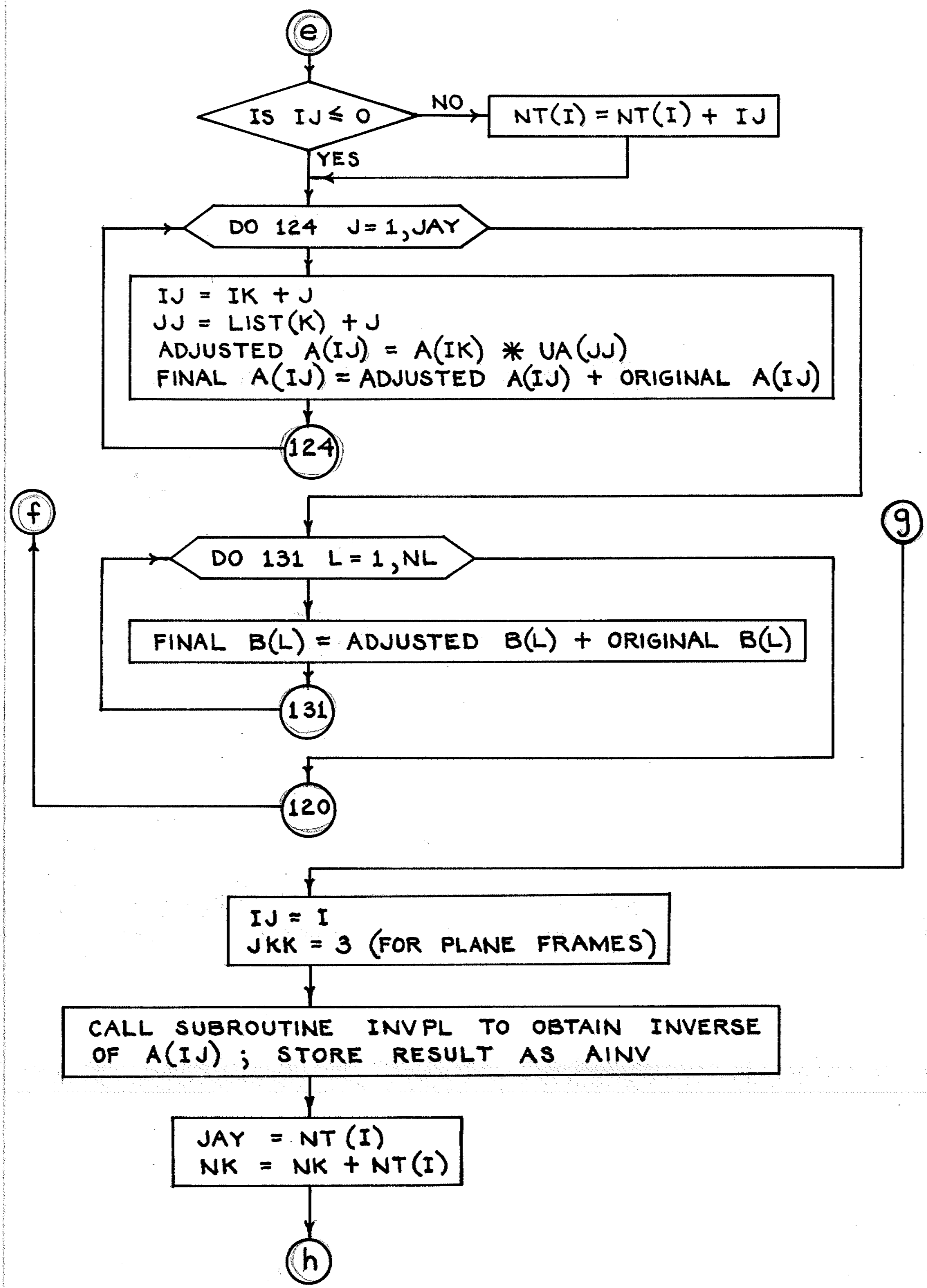
GENERATION OF JOINT EQUILIBRIUM EQUATIONS (PLANE FRAMES)



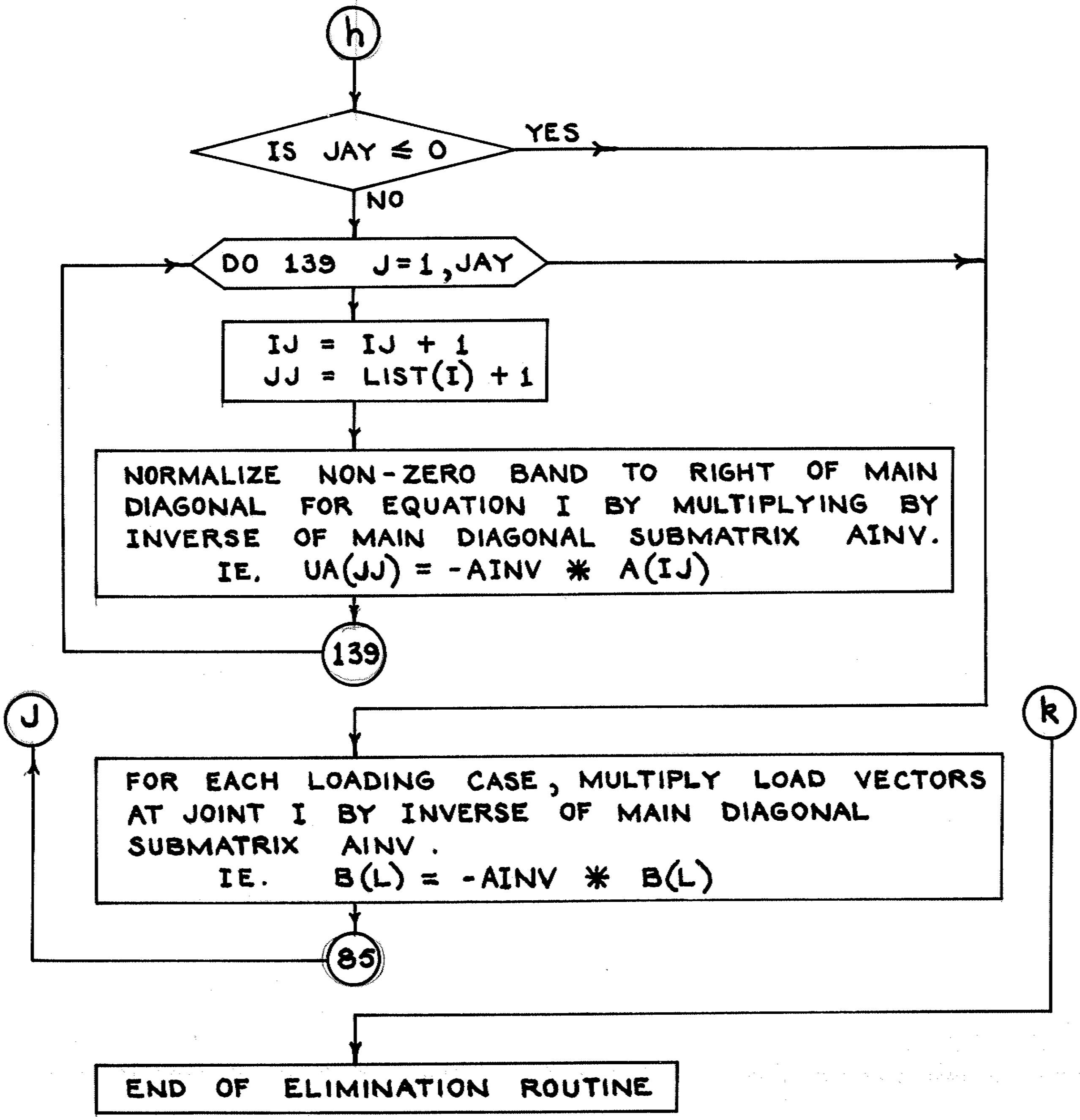

a
EQUATE KBB = STIF (M)
JJ = JI (I,J)
IS MEMBER M DIRECTED INTO OR OUT-OF JOINT I IE. IS JJ ≤ 0
INTO
OUT-OF
FIND THE EFFECT AT THE A END OF MEMBER DUE TO A DISPLACEMENT AT B END.
KAB = -HAB * KBB
KAA = HAB * KBB * HAB^T
INSERT KAB & KAA INTO SLOTS KBA & KBB RESP.
NO
IS IK ≤ NE
YES
FIND THE EFFECT AT THE B END OF MEMBER DUE TO A DISPLACEMENT AT B END.
KBA = -KBB * HAB^T & INSERT INTO SLOT KBA.
NOTE : KBB WAS MADE = TO STIF (M)
A(II) = R * KBB * R^T + PREVIOUS A(II) WHICH WAS INITIALLY SET = 0 .
b
c
CHECK FOR CARRY-OVER AFFECT. IS END IJ A FIXED-END OR NOT ? IE. IS IK ≤ NE
FIXED-END
NOT FIXED-END
A(I,J) = R * KBA * R^T
98
d



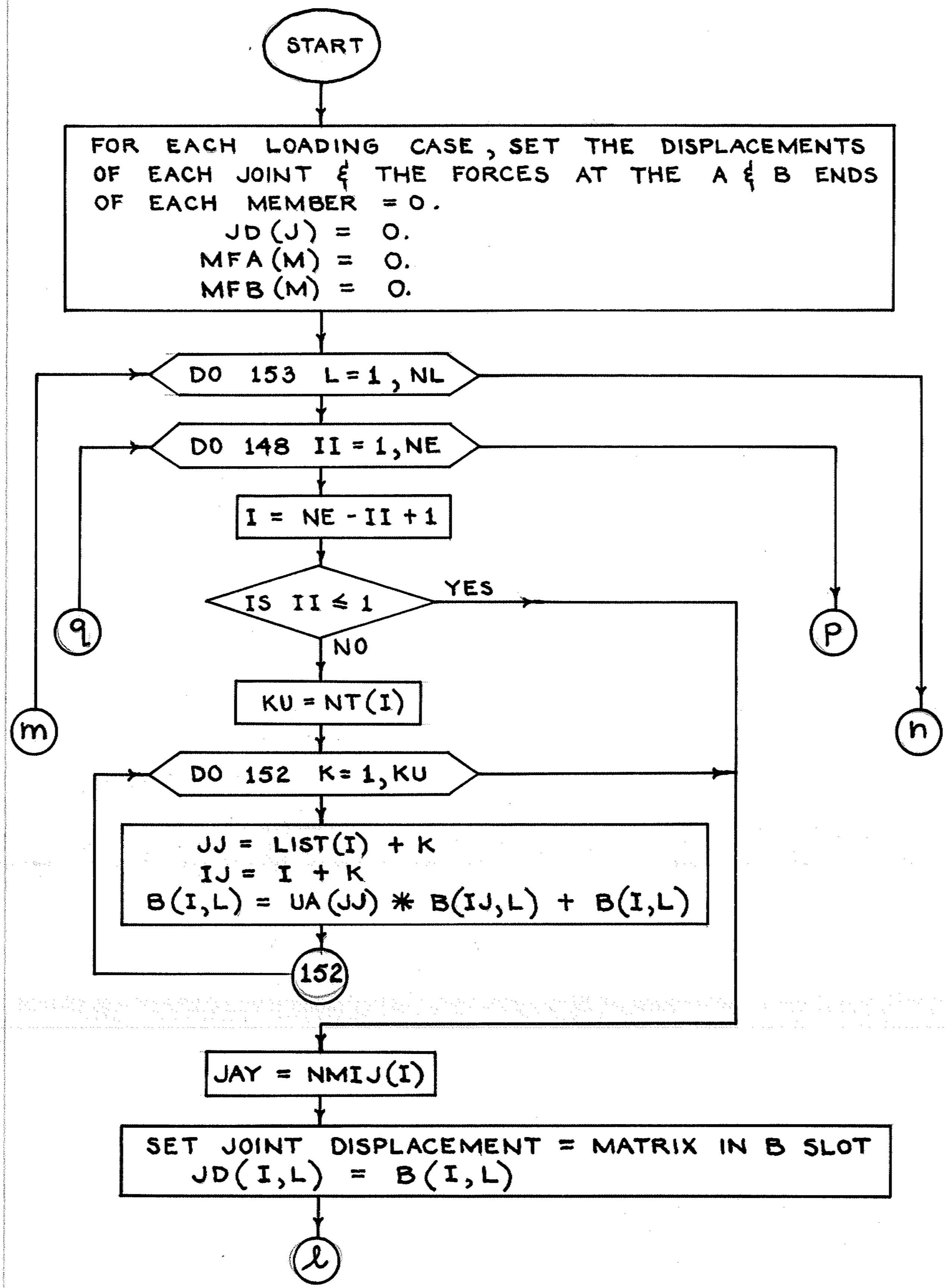
d
IS JRI(I) ≤ 0
YES
NO
DO N = 1, NJSR
NO
IS I = LISTJS(N)
YES
IS JSI(N,1) ≤ 0
YES
A[I,1,1] = 1 × 10^12
NO
IS JSI(N,2) ≤ 0
YES
A[I,2,2] = 1 × 10^12
NO
IS JSI(N,3) ≤ 0
YES
A[I,3,3] = 1 × 10^12
NO
FOR EACH LOADING CASE, INSERT THE NEGATIVE JOINT FORCES INTO MATRIX B :
B(I) = - FJF (I)
- END OF GENERATION ROUTINE FOR THE I TH EQUATION
- BEGIN ELIMINATION ROUTINE FOR THE I TH EQUATION
IS I ≤ KL
YES
NO
KU = I - 1
DO 120 K = KL, KU
IK = K
JAY = NT (K)
IJ = K + NT (K) - I - NT (I)
f
g
e

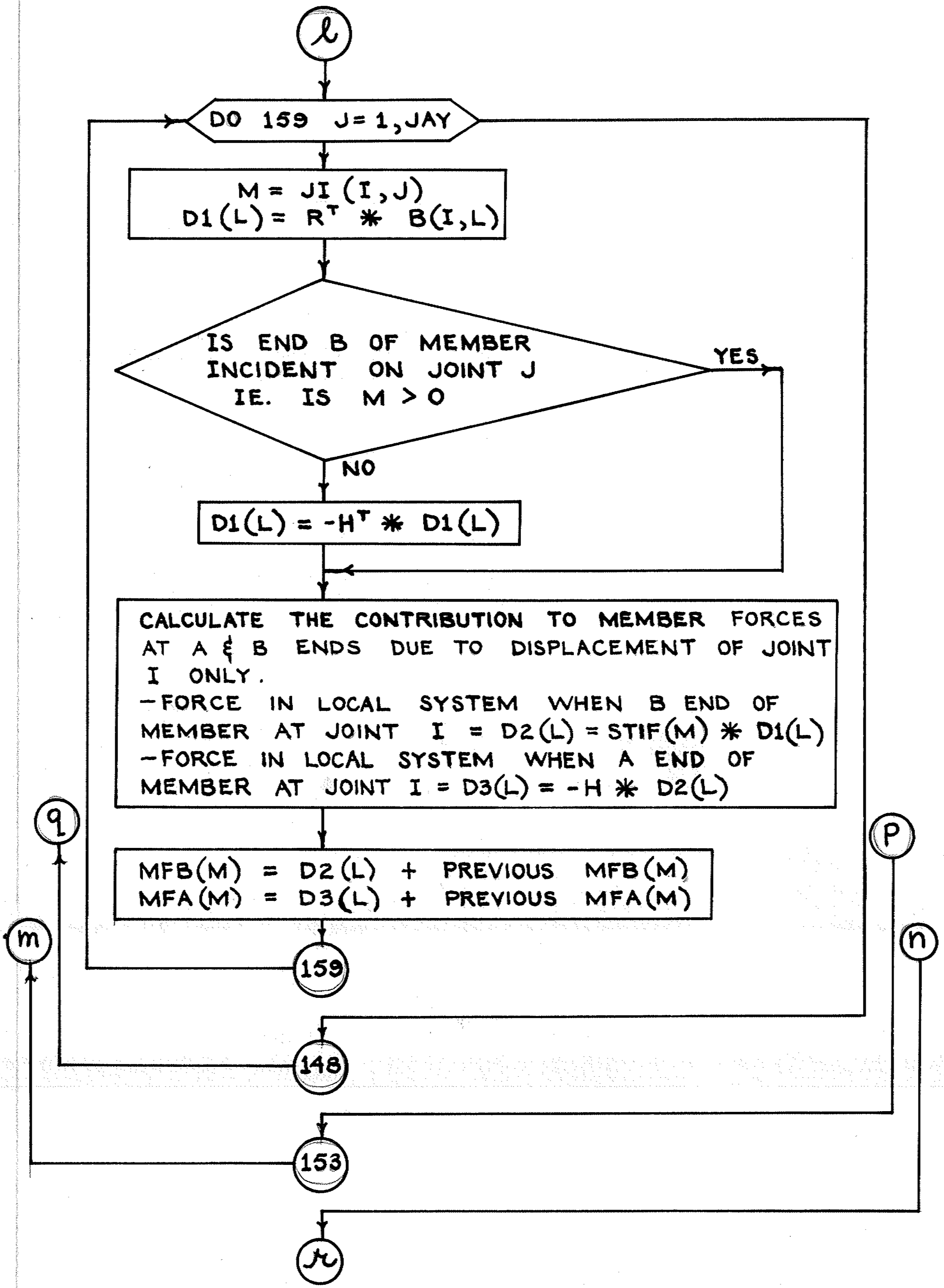


e
IS IJ ≤ 0
NO
NT(I) = NT(I) + IJ
YES
DO 124 J = 1, JAY
IJ = IK + J
JJ = LIST(K) + J
ADJUSTED A(IJ) = A(IK) * UA(JJ)
FINAL A(IJ) = ADJUSTED A(IJ) + ORIGINAL A(IJ)
124
f
g
DO 131 L = 1, NL
FINAL B(L) = ADJUSTED B(L) + ORIGINAL B(L)
131
120
IJ = I
JKK = 3 (FOR PLANE FRAMES)
CALL SUBROUTINE INVPL TO OBTAIN INVERSE OF A(IJ) ; STORE RESULT AS AINV
JAY = NT(I)
NK = NK + NT(I)
h

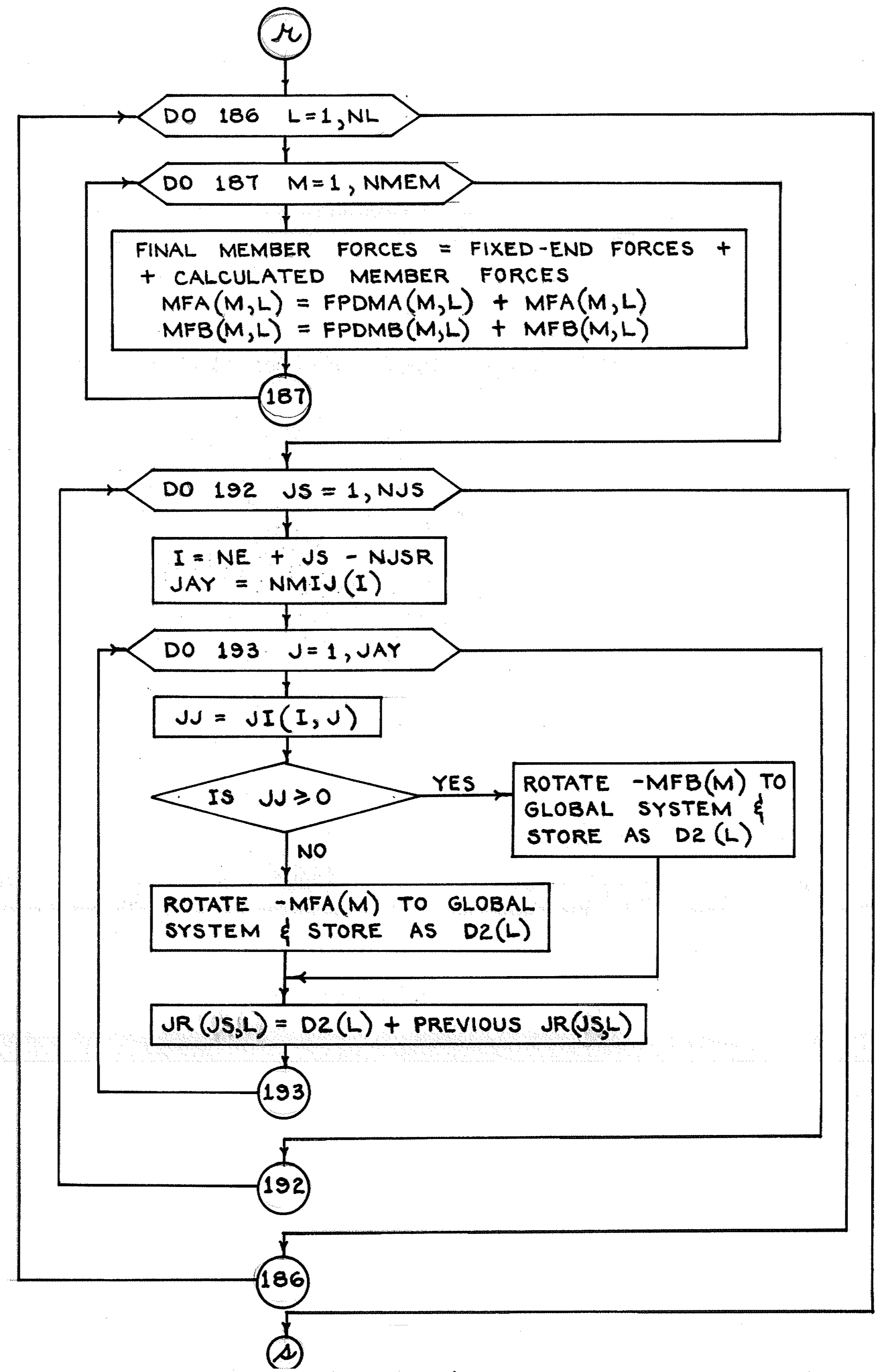

h
IS JAY ≤ 0
YES
NO
DO 139 J=1,JAY
IJ = IJ + 1
JJ = LIST(I) + 1
NORMALIZE NON-ZERO BAND TO RIGHT OF MAIN DIAGONAL FOR EQUATION I BY MULTIPLYING BY INVERSE OF MAIN DIAGONAL SUBMATRIX AINV.
IE. UA(JJ) = -AINV * A(IJ)
139
J
k
FOR EACH LOADING CASE, MULTIPLY LOAD VECTORS AT JOINT I BY INVERSE OF MAIN DIAGONAL SUBMATRIX AINV .
IE. B(L) = -AINV * B(L)
85
END OF ELIMINATION ROUTINE

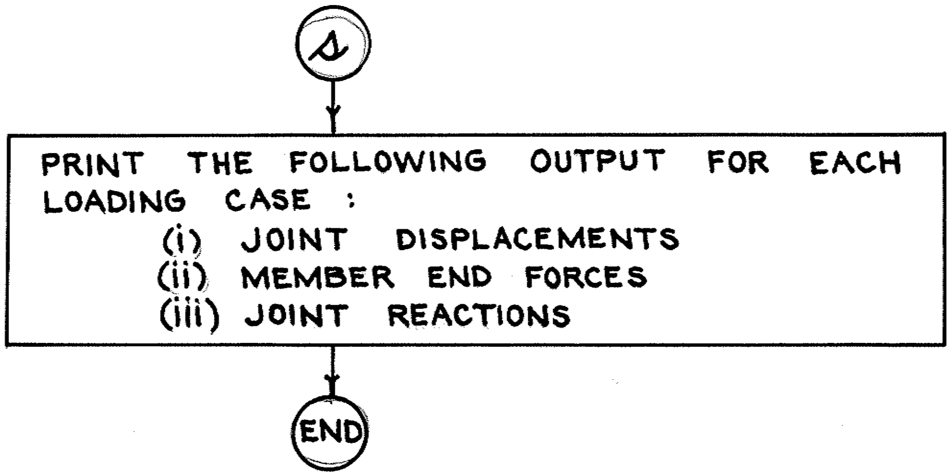
BACK SUBSTITUTION ROUTINE





l
DO 159 J = 1, JAY
M = JI (I, J)
D1 (L) = R^T * B(I, L)
IS END B OF MEMBER INCIDENT ON JOINT J IE. IS M > 0
YES
NO
D1 (L) = -H^T * D1 (L)
CALCULATE THE CONTRIBUTION TO MEMBER FORCES AT A & B ENDS DUE TO DISPLACEMENT OF JOINT I ONLY.
-FORCE IN LOCAL SYSTEM WHEN B END OF MEMBER AT JOINT I = D2(L) = STIF(M) * D1(L)
-FORCE IN LOCAL SYSTEM WHEN A END OF MEMBER AT JOINT I = D3(L) = -H * D2(L)
MFB(M) = D2 (L) + PREVIOUS MFB(M)
MFA(M) = D3(L) + PREVIOUS MFA(M)
q
p
m
n
159
148
153
r

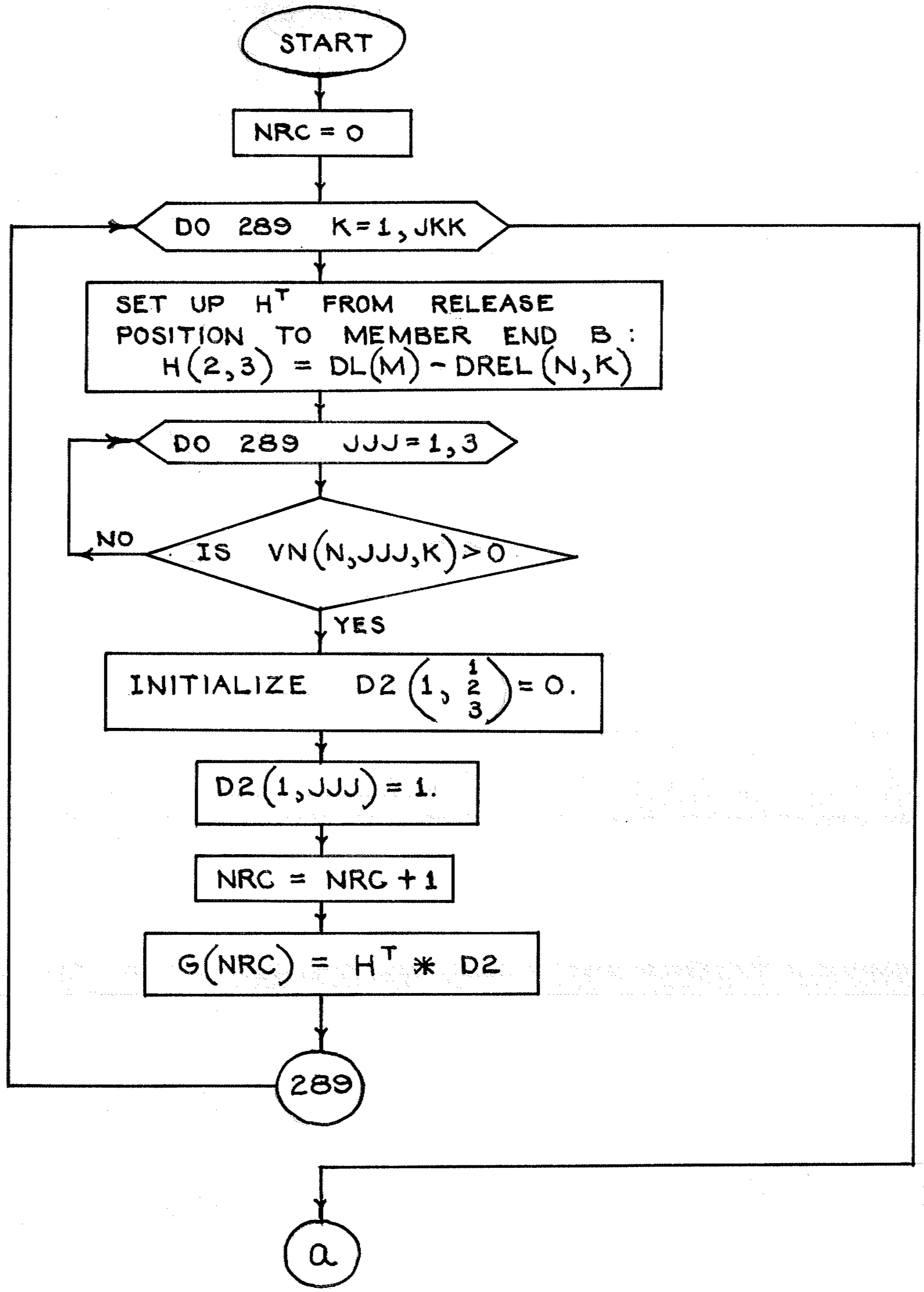

DO 186 L=1,NL
DO 187 M=1,NMEM
FINAL MEMBER FORCES = FIXED-END FORCES + + CALCULATED MEMBER FORCES
MFA(M,L) = FPDMA(M,L) + MFA(M,L)
MFB(M,L) = FPDMB(M,L) + MFB(M,L)
187
DO 192 JS = 1, NJS
I = NE + JS - NJSR
JAY = NMIJ(I)
DO 193 J = 1, JAY
JJ = JI(I,J)
IS JJ ≥ 0
YES
ROTATE -MFB(M) TO GLOBAL SYSTEM & STORE AS D2(L)
NO
ROTATE -MFA(M) TO GLOBAL SYSTEM & STORE AS D2(L)
JR(JS,L) = D2(L) + PREVIOUS JR(JS,L)
193
192
186

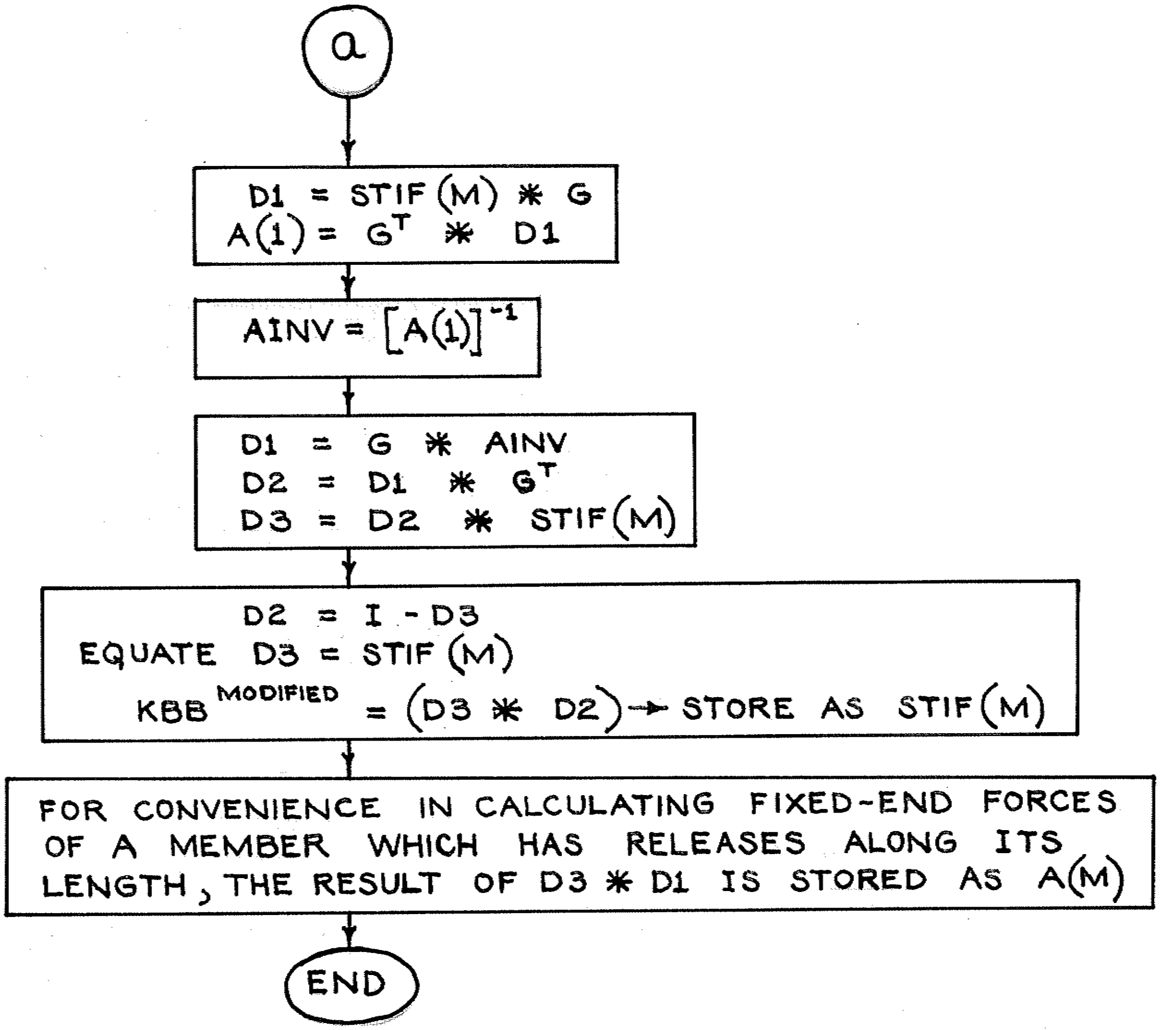


S
PRINT THE FOLLOWING OUTPUT FOR EACH LOADING CASE :
(i) JOINT DISPLACEMENTS
(ii) MEMBER END FORCES
(iii) JOINT REACTIONS
END

SUBROUTINE RELPL

- CALCULATES MODIFIED STIFFNESS MATRIX
- STIF(M) IS THE STIFFNESS MATRIX OF A CONTINUOUS(NO RELEASES) MEMBER M.
- NO. OF POSITIONS WHERE RELEASES OCCUR = JKK
- NO. OF RELEASED COMPONENTS = NRC




a
D1 = STIF(M) * G
A(1) = G^T * D1
AINV = [A(1)]^-1
D1 = G * AINV
D2 = D1 * G^T
D3 = D2 * STIF(M)
D2 = I - D3
EQUATE D3 = STIF(M)
KBB^MODIFIED = (D3 * D2) → STORE AS STIF(M)
FOR CONVENIENCE IN CALCULATING FIXED-END FORCES OF A MEMBER WHICH HAS RELEASES ALONG ITS LENGTH, THE RESULT OF D3 * D1 IS STORED AS A(M)
END

APPENDIX B:

USER'S MANUAL

FOR

A PLANE FRAME

STRUCTURAL ANALYSIS PROGRAM

PLANE FRAME STRUCTURAL ANALYSIS PROGRAM

SCOPE

This manual describes the necessary input data and the results obtained from a plane frame structural analysis program. The program performs a linear analysis of any planar structure loaded in its plane. While the program is primarily intended for rigid connected structures, support releases (support reactions contrained to have zero values - eg. pins, rollers), and member releases (eg. pins in members) can be accomodated. The user is required to input the structural geometry, the topology (description of what members are connected to what joints), the properties of all the members, and the type, position and magnitude of all applied loads. Up to three separate load systems can be analyzed simultaneously. The results include the support reactions, the forces at the ends of all members, and the deflections of all joints.

ASSUMPTIONS

The program incorporates the following assumptions and limitations:

1. The structural material obeys Hooke's Law,

2. Small deflections are assumed; ie. the effects of the displacements on the structural geometry and forces are negligible,

3. Possible buckling of individual members or portions of the structure is ignored.

MAXIMUM SIZE OF STRUCTURE

The following maximum size limitations exist:

70 --- joints

30 --- support joints

15 --- support joints with releases (not fully fixed)

100 --- members

20 --- members with releases

7 --- members can be connected to any one joint

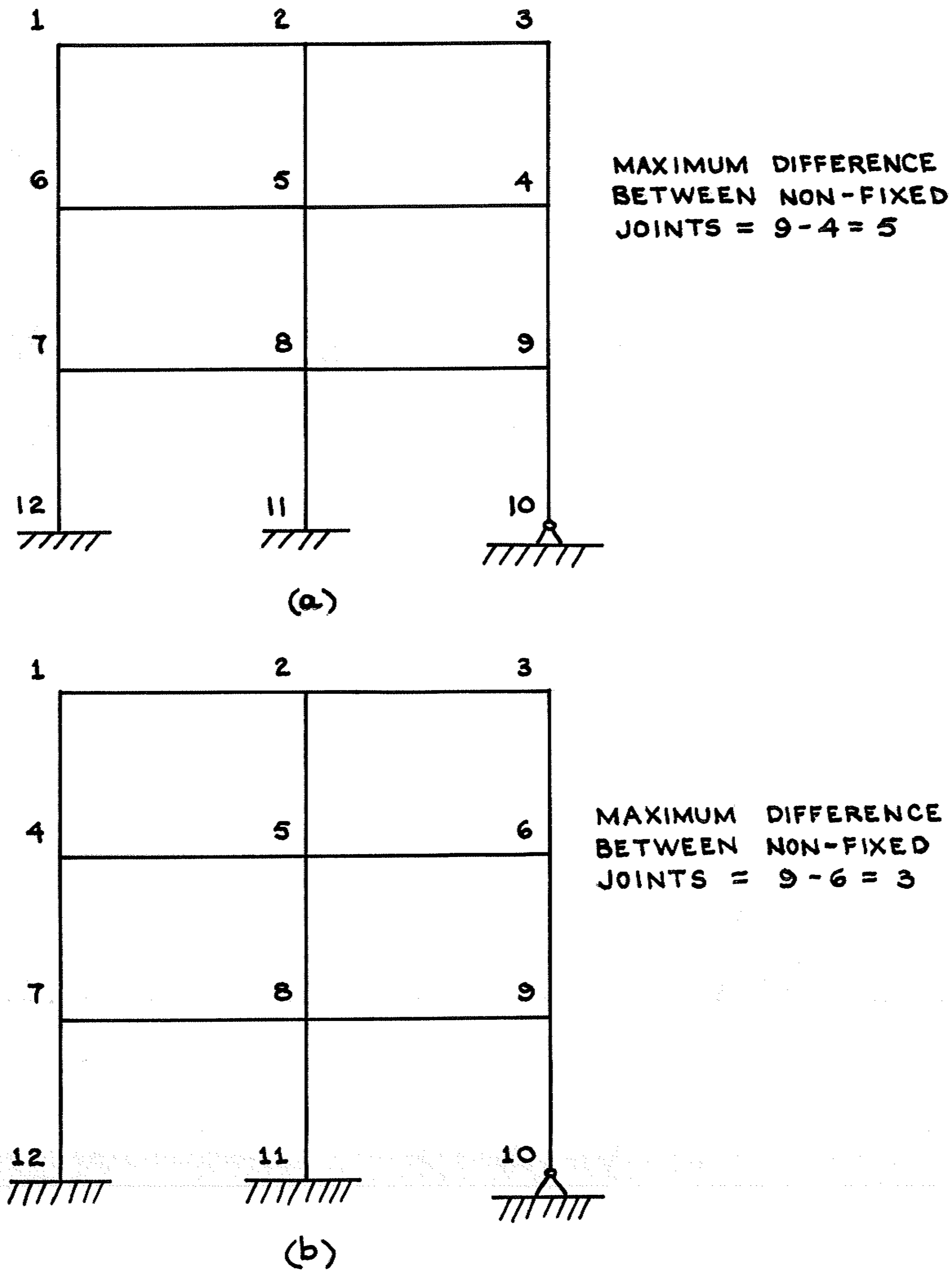
3 --- loading systems can be handled simultaneously

IDENTIFICATION OF MEMBERS AND JOINTS

For identification purposes, all members and all joints in the structure must be numbered. The joint numbering sequence must be as follows: all free (non-support) joints, all released (not fully fixed) supports, and finally the fully fixed supports. In addition, for best effeciency it is well to number the joints such that the difference between the numbers of any two, non-fixed joints connected by a member is as small as possible. For example, the numbering system in Fig. 1(b) is preferable to that in Fig. 1(a) since the maximum difference between any two connected joint numbers is smaller in the former case. The structural topology is specified by means of a member incidence table which lists the two joints connected by each member.

COORDINATE SYSTEMS

For a plane frame structure, the displacement vector at any point has three components as shown in Fig. 2. Labels U_1 and U_2 represent linear displacements in two perpendicular directions, and label U_3 represents the rotation about an axis 3 which is perpendicular to axes 1



JOINT NUMBERING SYSTEMS

FIG. 1

and 2. Any concentrated load vector, or the vector of forces acting on any member cross-section has three corresponding components, ie. two direct forces and a moment.

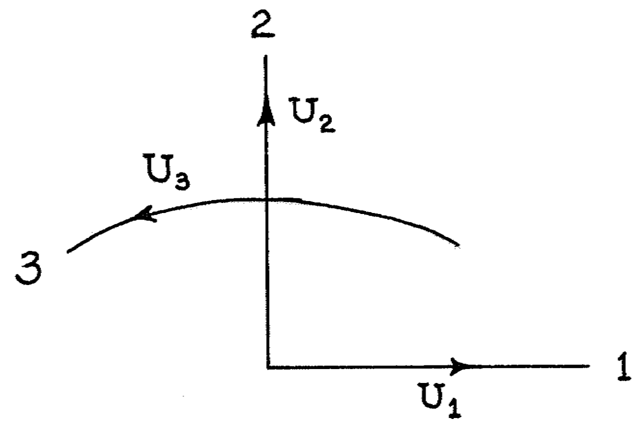
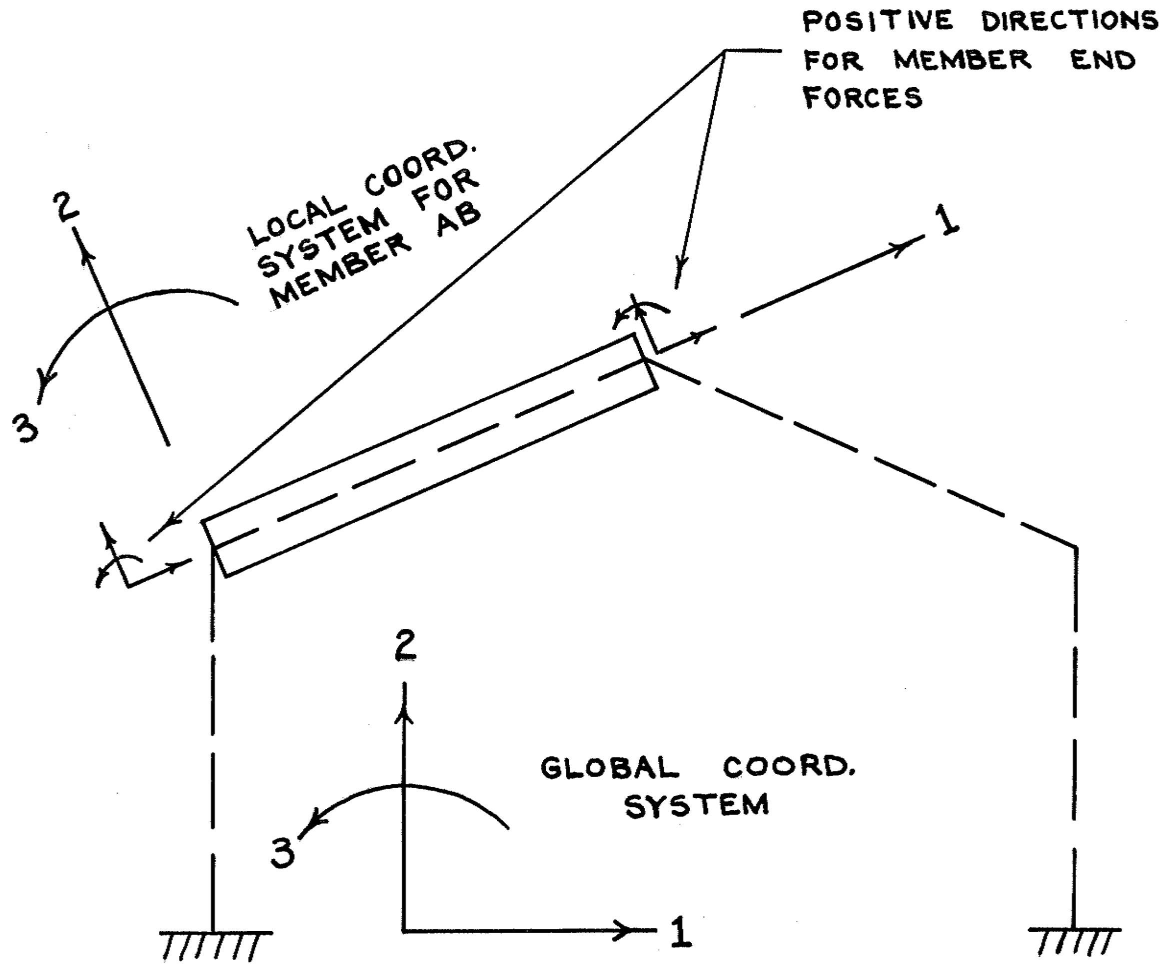


FIG. 2

The two types of coordinate systems used in the analysis program are illustrated in Fig. 3 and described as follows:

1. Global System

The global system is a single coordinate system for the whole structure and is usually chosen so that the direction of the axes coincides with the major dimensions of the structure. The 1 and 2 axes are horizontal and vertical respectively, and the 3 direction corresponds to rotation about a third axis perpendicular to the plane of the structure. The positive global directions are those indicated in Fig. 3. Joint coordinates, loads, displacements and all support reactions are expressed in the global system.



COORDINATE SYSTEMS USED

FIG. 3

The origin of the structure can be any point in space, but the distance from the origin to every joint must be measured in the global directions. For plane structures, the origin is usually located at the lowest left-most joint. Joint number 12 in Fig. 1 would be a convenient origin.

2. Local System

The end forces for each member are expressed in a local coordinate system whose 1 axis coincides with the axis of the member and is directed from its A end to its B end as shown in Fig. 3. Positive directions for the axial and shearing forces and moments at the ends of the member are as illustrated in the figure.

LOADING CONVENTIONS

The permissible loading types consist of concentrated loads, concentrated moments and distributed loads. All direct loads are expressed in kips and all moments in foot-kips.

1. Joint Loads

Each joint load may consist of a concentrated horizontal force (direction 1), a concentrated vertical force (direction 2), and a concentrated moment (direction 3), all given in the global coordinate system.

2. Member Concentrated Loads

Each concentrated member load may consist of componenets in the 1, 2 and 3 directions for the global coordinate system, as illustrated in Fig. 4. The point of application of the load is defined by its distance "a" (in feet) from the A end of the member.

3. Member Distributed Loads

Each distributed load is specified by means of the load intensities W1 and W2 (kips/foot) in the 1 and 2 global directions, as illustrated in Fig. 5. In addition, distances "a" and "b" (feet) define the distances from ends A and B respectively to the extremities of the loaded portion.

USE OF RELEASES

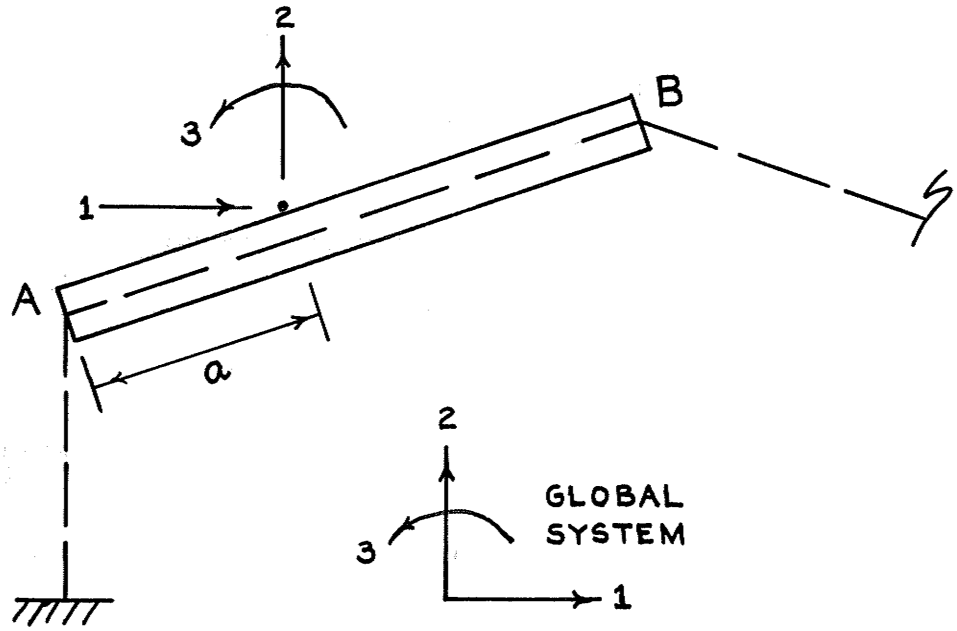
In many structures the introduction of hinges, rollers, etc., sets certain force components equal to zero. In order to avoid ambiguities in designations such as hinges and rollers, the term release is used to designate any force component that is constrained to have zero value. The two types of releases are support releases and member releases.

1. Support Releases

Releases at a given support are specified by means of three support release indicators corresponding to the three possible reaction components (horizontal, vertical and moment). A released component is specified by an indicator 1, while a fixed component is designated by a 0. For example, a hinged support would have the support release indicators [0 0 1] while a horizontal roller would be designated by [1 0 1].

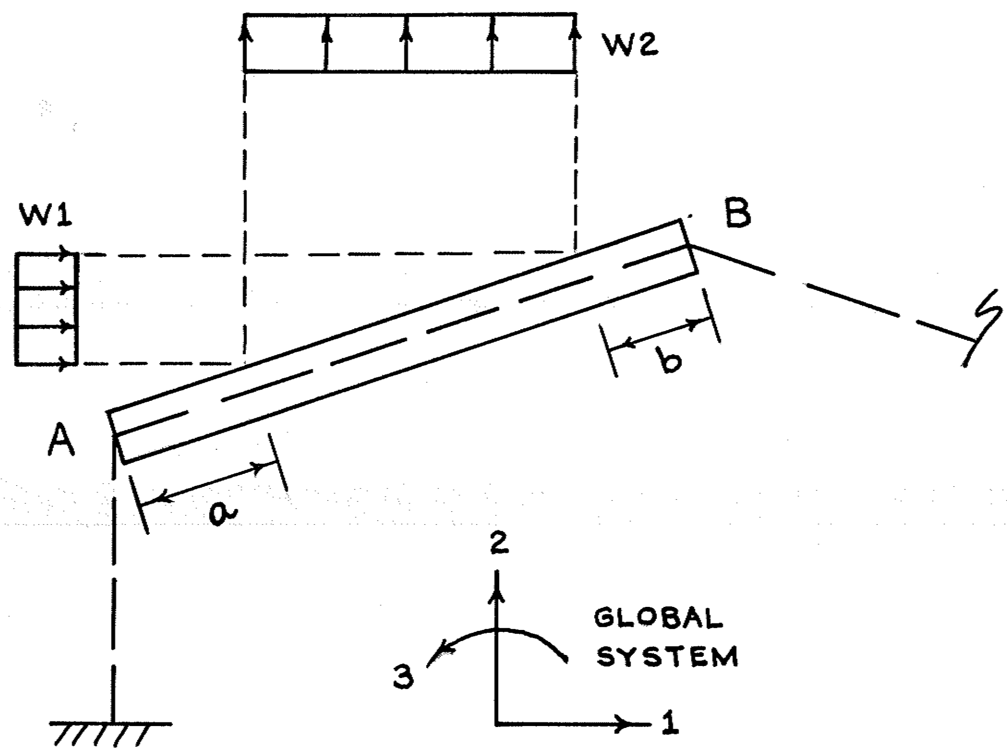
2. Member Releases

The position of a member release is specified by giving its distance "d" from the A end of the member as shown below in Fig. 6; and the member release indicators are designated similarly as the support release indicators.



MEMBER CONCENTRATED LOADS

FIG. 4



MEMBER DISTRIBUTED LOADS

FIG. 5

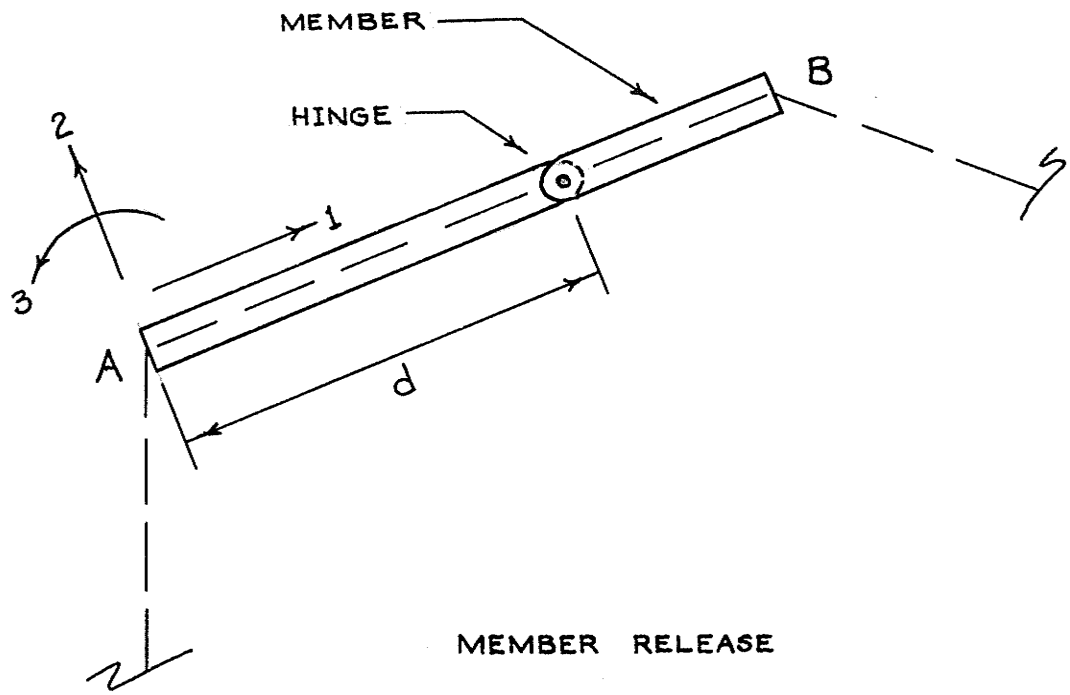


FIG. 6

For example, a pin connection located as shown in Fig. 6 would have member release indicators [0 0 1].

A maximum of two release positions and three released force components is allowed for each member. When distributed loads are acting on the member, the releases may be located only at the member ends. When concentrated loads only are present, releases may be located anywhere along the member.

INPUT INFORMATION

Eight standard data sheets as shown on pages 107 to 114 are used to specify the necessary input information. The first six sheets are self explanatory and are used to specify the structural geometry and topology, the member properties, and the support and member release information.

Data sheets 7 and 8 are used to specify the structural loadings (loading systems are specified sequentially).

DATA SHEET 7 - includes a heading for describing the loading type; and for identification purposes, this heading is printed above the corresponding output results. The number of loaded members and the number of loaded joints are indicated next. For each loaded joint, the joint number and load components are to be read.

DATA SHEET 8 - is filled out only if there are loaded members; and a complete sheet is required for each loaded member. The member number, an indication of whether or not the member carries distributed loads, and the number of point load positions on the member are read.

If distributed loads are present, the magnitudes of the loads in directions 1 and 2 are entered; and for partial distributed loads, the distances to the extremities of the loaded portion are specified. If there are no distributed loads, this portion is omitted.

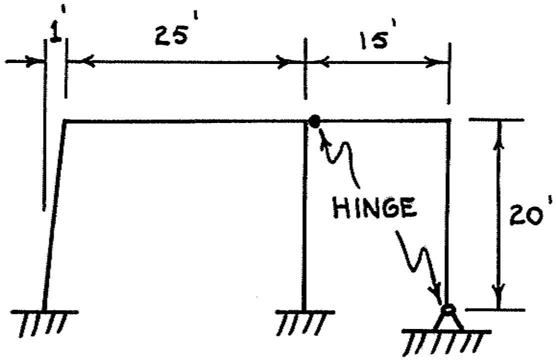
For each point load, the distance from the A end of the member and the magnitudes of the load components must be entered. If there are no point loads acting, this information is omitted.

Except where decimal points are included on the input sheets, all numbers are to be inserted at the extreme right of the blank fields.

NUMERICAL EXAMPLE

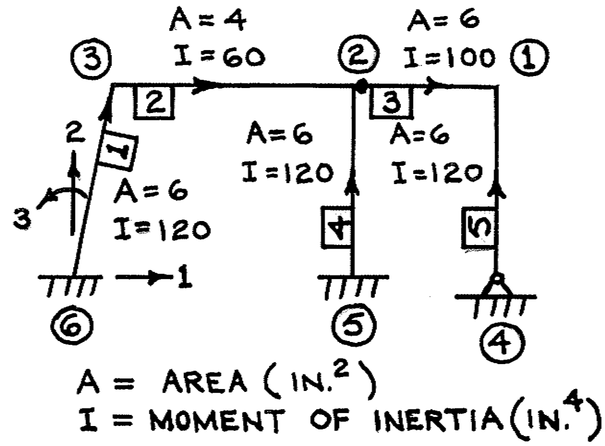
The structure shown in Fig. 7 is to be analyzed for the two loading cases shown. The required data sheets are shown on pages 92 to 101 and the output information on pages 102 to 106.

The computer output consists of all input information (for checking purposes), and the results of the analysis for each loading case. The rotation and deflections of each joint and the joint support reactions are expressed in the global coordinate system, while the forces (axial, shear and bending moment) at both ends of all members are expressed in the local coordinate system.



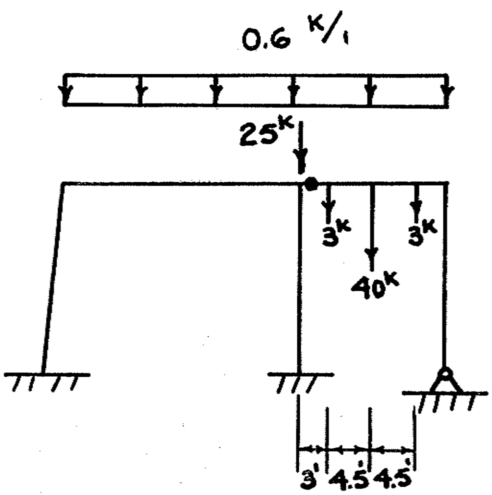
STRUCTURE
DIMENSIONS

(a)



NUMBERING &
PROPERTIES

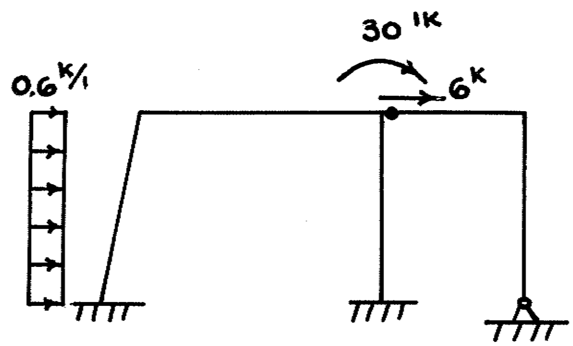
(b)



LOADING CASE 1

VERTICAL LOADS

(c)



LOADING CASE 2

WIND LOADS

(d)

NUMERICAL EXAMPLE

FIG. 7

PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #1

	BY	DATE

JOB DESCRIPTION (EG. BUILDING FRAME, TOWER, ETC.)

NUMERICAL EXAMPLE - TWO BAY FRAME

MODULUS OF ELASTICITY (KSI.)	NO. OF LDG. CASES	NO. OF JOINTS	NO. OF MEMBERS	NO. OF SUPPORTS	NO. OF SUPPORTS WITH RELEASES	NO. OF MEMBERS WITH RELEASES
30000.	2	6	5	3	1	2

JOINT COORDINATE TABLE (GLOBAL SYSTEM - FT.)

JOINT	DIR. 1 COORD.	DIR. 2 COORD.
1	41.	20.
2	26.	20.
3	1.	20.
4	41.	0.
5	26.	0.
6	0.	0.
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PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #3.

MEMBER INCIDENCE TABLE

BY

DATE

MEMBER NO.	GOES FROM JOINT NO.	TO JOINT NO.
1	6	3
2	3	2
3	2	1
4	5	2
5	4	1

PLANE FRAME ANALYSIS PROGRAM — DATA SHEET #4

MEMBER PROPERTIES

BY	DATE

MEMBER NO.	X-SECT. AREA ($IN.^2$)	MOMENT OF INERTIA ($IN.^4$)
1	6.	120.
2	4.	60.
3	6.	100.
4	6.	120.
5	6.	120.

PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #5

SUPPORT RELEASES

- APPLY ONLY FOR THOSE SUPPORTS WITH RELEASES
- INDICATORS FOR DIRECTIONS 1, 2, & 3 (GLOBAL SYSTEM) ARE: 1 = RELEASE ; 0 = FIXED

DATE

JOINT NO.	RELEASE INDICATORS DIR. 1	DIR. 2	DIR. 3
4	0	0	1

PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #6

MEMBER RELEASES

- APPLY ONLY FOR THOSE MEMBERS WITH RELEASES
- INDICATORS FOR DIRECTIONS 1, 2, & 3 (LOCAL SYSTEM) ARE: 1 = RELEASED ; 0 = FIXED

DATE

MEMBER NO.	NO. OF RELEASE POSITIONS	DIST. TO 1ST RELEASE (FT.)	INDICATORS 1	2	3	DIST. TO 2ND RELEASE (FT.)	INDICATORS 1	2	3
3	1	0.	0	0	1	.			
5	1	0.	0	0	1	.			

PLANE FRAME ANALYSIS PROGRAM — DATA SHEET #7

LOADING DESCRIPTION	BY	DATE

HEADING TO DESCRIBE TYPE OF LOADING (E.G. WIND, GRAVITY)

VERTICAL LØADS

NO. OF LOADED MEMBERS = 2

NO. OF LOADED JOINTS = 1 (IF = 0, OMIT REMAINDER OF SHEET)

JOINT NO.	JOINT LOADS DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (FT.-KIPS)
2	0.	-25.	0.
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PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #8

LOADING FOR ONE MEMBER ONLY
- APPLY ONLY FOR THOSE MEMBERS WHICH ARE LOADED

BY

DATE

MEMBER NO. 2

DISTRIB. LOAD INDICATOR (1 = DISTRIB. LOAD, 0 = NO DISTRIB. LOAD) 1

NO. OF CONC. LOAD POSITIONS = 0

DESCRIPTION OF DISTRIBUTED LOADS (GLOBAL SYSTEM) IF ANY; OTHERWISE OMIT

DIR. 1 (K/')	DIR. 2 (K/')	DIST. FROM A END TO BEGIN. OF LDG (FT.)	DIST. FROM B END TO END OF LDG. (FT.)
0.	-.6	0.	0.

DESCRIPTION OF CONCENTRATED LOADS (GLOBAL SYSTEM) IF ANY; OTHERWISE OMIT

DIST. FROM A END (FT.)	DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (FT.-KIPS)
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PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #8

LOADING FOR ONE MEMBER ONLY
- APPLY ONLY FOR THOSE MEMBERS WHICH ARE LOADED

BY

DATE

MEMBER NO. 3

DISTRIB. LOAD INDICATOR (1 = DISTRIB. LOAD, 0 = NO DISTRIB. LOAD): 1

NO. OF CONC. LOAD POSITIONS = 3

DESCRIPTION OF DISTRIBUTED LOADS (GLOBAL SYSTEM) IF ANY; OTHERWISE OMIT

DIR. 1 (K/')	DIR. 2 (K/')	DIST. FROM A END TO BEGIN. OF LDG (FT.)	DIST. FROM B END TO END OF LDG. (FT.)
0.	-.6	0.	0.

DESCRIPTION OF CONCENTRATED LOADS (GLOBAL SYSTEM) IF ANY; OTHERWISE OMIT

DIST. FROM A END (FT.)	DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (FT.-KIPS)
3.	0.	-3.	0.
7.5	0.	-40.	0.
12.	0.	-3.	0.
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PLANE FRAME ANALYSIS PROGRAM — DATA SHEET #7

LOADING DESCRIPTION	BY	DATE

HEADING TO DESCRIBE TYPE OF LOADING (E.G. WIND, GRAVITY)

WIND LØADS

NO. OF LOADED MEMBERS = 1

NO. OF LOADED JOINTS = 1 (IF = 0, OMIT REMAINDER OF SHEET)

JOINT NO.	JOINT LOADS DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (FT.-KIPS)
2	6.	0.	-30.
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PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #8

LOADING FOR ONE MEMBER ONLY - APPLY ONLY FOR THOSE MEMBERS WHICH ARE LOADED	BY	DATE

MEMBER NO. 1

DISTRIB. LOAD INDICATOR (1 = DISTRIB. LOAD; 0 = NO DISTRIB. LOAD) 1

NO. OF CONC. LOAD POSITIONS = 0

DESCRIPTION OF DISTRIBUTED LOADS (GLOBAL SYSTEM) IF ANY; OTHERWISE OMIT

DIR. 1 (K/')	DIR. 2 (K/')	DIST. FROM A END TO BEGIN. OF LDG (FT.)	DIST. FROM B END TO END OF LDG. (FT.)
.6	0.	0.	0.

DESCRIPTION OF CONCENTRATED LOADS (GLOBAL SYSTEM) IF ANY; OTHERWISE OMIT

DIST. FROM A END (FT.)	DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (FT.-KIPS)
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PLANE FRAME ANALYSIS

NUMERICAL EXAMPLE - TWO BAY FRAME

6 JOINTS 5 MEMBERS 3 SUPPORTS
1 SUPPORT RELEASE(S) 2 MEMBER RELEASE(S)
MODULUS OF ELASTICITY (KSI.)=30000.00 2 LOAD CASES

JOINT COORDINATES (FT) (GLOBAL SYSTEM)

JOINT	COORD. 1	COORD. 2
1	41.00	20.00
2	26.00	20.00
3	1.00	20.00
4	41.00	0.0
5	26.00	0.0
6	0.0	0.0

MEMBER INCIDENCE TABLE

MEMBER	A END	B END
1	6	3
2	3	2
3	2	1
4	5	2
5	4	1

MEMBER PROPERTIES

MEMBER	X-SECT. AREA(IN.2)	MOMENT OF INERTIA(IN.4)
1	6.000	120.000
2	4.000	60.000
3	6.000	100.000
4	6.000	120.000
5	6.000	120.000

SUPPORT RELEASE INDICATORS

JOINT	DIRECTION		
	1	2	3
4	0	0	1

MEMBER RELEASE INDICATORS

MEMBER	NO. OF REL. POSITIONS	DIST. FROM A END(FT.)	DIRECTIONS		
			1	2	3
3	1	0.0	0.	0.	1.
5	1	0.0	0.	0.	1.

LOADING CASE 1

NON ZERO JOINT LOADS

JOINT	DIRECTION 1 (KIPS)	2 (KIPS)	3 (FT-K)
2	0.0	-25.00	0.0

NON ZERO MEMBER LOADS

MEMBER	DISTRIB. LOADS 1	2	DIST. FROM A END(FT.)	CONCENT. LOADS 1	2	3
2	0.0	-0.60				
3	0.0	-0.60				
3			3.00	0.0	-3.00	0.0
3			7.50	0.0	-40.00	0.0
3			12.00	0.0	-3.00	0.0

LOADING CASE 2

NON ZERO JOINT LOADS

OINT	DIRECTION 1 (KIPS)	2 (KIPS)	3 (FT-K)
2	6.00	0.0	-30.00

NON ZERO MEMBER LOADS

EMBER	DISTRIB. LOADS 1	2	DIST. FROM A END(FT.)	CONCENT. LOADS 1	2	3
1	0.60	0.0				

LOADING CASE 1

VERTICAL LOADS

JOINT DISPLACEMENTS (GLOBAL SYSTEM)

NO.	HORIZ.(IN)	VERT.(IN)	ROTATION(RAD.)
1	-0.766029	-0.042040	0.019311
2	-0.763007	-0.073614	0.008071
3	-0.753846	0.026420	-0.002404
4	0.000000	-0.000000	0.019311
5	0.0	0.0	0.0
6	0.0	0.0	0.0

MEMBER END FORCES(K & IN.-K) (LOCAL SYSTEM)

	A END			B END		
NO.	AXIAL	SHEAR	MOMENT	AXIAL	SHEAR	MOMENT
1	8.433	-3.247	-354.149	-8.433	3.247	-426.169
2	3.664	8.260	426.168	-3.664	6.740	-198.135
3	3.022	23.470	-0.000	-3.022	31.530	-725.345
4	55.210	0.642	-43.996	-55.210	-0.642	198.135
5	31.530	3.022	0.000	-31.530	-3.022	725.344

JOINT REACTIONS(K & IN.-K) (GLOBAL SYSTEM)

NO.	HORIZONTAL	VERTICAL	MOMENT
4	-3.022	31.530	0.000
5	-0.642	55.210	-43.996
6	3.664	8.260	-354.149

LOADING CASE 2

WIND LOADS

JOINT DISPLACEMENTS (GLOBAL SYSTEM)

NO.	HORIZ.(IN)	VERT.(IN)	ROTATION(RAD.)
1	3.259506	-0.002382	-0.006434
2	3.260848	-0.001995	-0.017337
3	3.258423	-0.158073	-0.008978
4	0.000000	-0.000000	-0.006434
5	0.0	0.0	0.0
6	0.0	0.0	0.0

MEMBER END FORCES(K & IN.-K) (LOCAL SYSTEM)

	A END			B END		
NO.	AXIAL	SHEAR	MOMENT	AXIAL	SHEAR	MOMENT
1	-3.926	12.790	1191.275	3.327	-0.805	442.260
2	-0.970	-3.283	-442.260	0.970	3.283	-542.569
3	1.342	-1.787	0.001	-1.342	1.787	-321.609
4	1.496	3.689	702.692	-1.496	-3.689	182.567
5	1.787	1.340	-0.000	-1.787	-1.340	321.610

JOINT REACTIONS(K & IN.-K) (GLOBAL SYSTEM)

NO.	HORIZONTAL	VERTICAL	MOMENT
4	-1.340	1.787	-0.000
5	-3.689	1.496	702.692
6	-12.971	-3.283	1191.275

PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #1

	BY	DATE

1 10 20 30 40 50 60 70 80

JOB DESCRIPTION (EG. BUILDING FRAME, TOWER, ETC.)

MODULUS OF ELASTICITY (KSI.)	NO. OF LDG. CASES	NO. OF JOINTS	NO. OF MEMBERS	NO. OF SUPPORTS	NO. OF SUPPORTS WITH RELEASES	NO. OF MEMBERS WITH RELEASES

JOINT COORDINATE TABLE (GLOBAL SYSTEM - FT.)

JOINT	DIR.1 COORD.	DIR. 2 COORD.
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PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #2

CONTINUATION OF JOINT COORDINATE TABLE (IF REQ'D.)	BY	DATE

1 10	20	30	40	50	60	70	80
JOINT		DIR. 1 COORD.		DIR. 2 COORD.			
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PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #3

MEMBER INCIDENCE TABLE	BY	DATE

1 — 10	20	30	40	50	60	70	80
MEMBER NO.	GOES FROM	JOINT NO.	TO JOINT NO.				

G-963 UNIVERSITY OF MANITOBA, COMPUTER SCIENCE

PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #4

MEMBER PROPERTIES

BY

DATE

1 … 10	20	30	40	50	60	70	80
MEMBER NO.		X-SECT. AREA (IN.^{2})		MOMENT OF INERTIA (IN.^{4})			

PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #5

SUPPORT RELEASES

DATE

- APPLY ONLY FOR THOSE SUPPORTS WITH RELEASES
- INDICATORS FOR DIRECTIONS 1, 2, & 3 (GLOBAL SYSTEM) ARE : 1 = RELEASE ; 0 = FIXED

1 10 20 30 40 50 60 70 80

JOINT NO.	RELEASE INDICATORS DIR. 1	DIR. 2	DIR. 3

G-963 UNIVERSITY OF MANITOBA, COMPUTER SCIENCE

PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #6

MEMBER RELEASES

- APPLY ONLY FOR THOSE MEMBERS WITH RELEASES
- INDICATORS FOR DIRECTIONS 1, 2, & 3 (LOCAL SYSTEM) ARE. 1 = RELEASED ; 0 = FIXED

DATE

1 10 20 30 40 50 60 70 80

MEMBER NO.	NO. OF RELEASE POSITIONS	DIST. TO 1ST RELEASE (FT.)	INDICATORS 1	2	3	DIST. TO 2ND RELEASE (FT.)	INDICATORS 1	2	3
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PLANE FRAME ANALYSIS PROGRAM — DATA SHEET #7

LOADING DESCRIPTION	BY	DATE

1 10 20 30 40 50 60 70 80

HEADING TO DESCRIBE TYPE OF LOADING (E.G. WIND, GRAVITY)

NO. OF LOADED MEMBERS =

NO. OF LOADED JOINTS = (IF = 0, OMIT REMAINDER OF SHEET)

JOINT NO.	JOINT LOADS DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (FT.-KIPS)
	.	.	.
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PLANE FRAME ANALYSIS PROGRAM - DATA SHEET #8

LOADING FOR ONE MEMBER ONLY - APPLY ONLY FOR THOSE MEMBERS WHICH ARE LOADED	BY	DATE

1 10 20 30 40 50 60 70 80

MEMBER NO. [ ]

DISTRIB. LOAD INDICATOR [ ]
1 = DISTRIB. LOAD
0 = NO DISTRIB. LOAD

NO. OF CONC. LOAD POSITIONS = [ ]

DESCRIPTION OF DISTRIBUTED LOADS (GLOBAL SYSTEM) IF ANY ; OTHERWISE OMIT

DIR. 1 (K/')	DIR. 2 (K/')	DIST. FROM A END TO BEGIN. OF LDG (FT.)	DIST. FROM B END TO END OF LDG. (FT.)
.	.	.	.

DESCRIPTION OF CONCENTRATED LOADS (GLOBAL SYSTEM) IF ANY ; OTHERWISE OMIT

DIST. FROM A END (FT.)	DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (FT.-KIPS)
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APPENDIX C:

USER'S MANUAL

FOR

A SPACE FRAME

STRUCTURAL ANALYSIS PROGRAM

SPACE FRAME STRUCTURAL ANALYSIS PROGRAM

SCOPE

This manual describes the necessary input data and the results obtained from a space frame structural analysis program. The program performs a linear analysis of any spacial structure loaded in the three directions of space. While the program is primarily intended for rigid connected structures, support releases (support reactions constrained to have zero values - eg. pins, rollers), and member releases (eg. pins in members) can be accomodated. The user is required to input the structural geometry, the topology (description of what members are connected to what joints), the properties of all the members, and the type, position and magnitude of all applied loads. Up to six separate load systems can be analyzed simultaneously. The results include the support reactions, the forces at the ends of all members, and the deflections of all joints.

ASSUMPTIONS

The program incorporates the following assumptions and limitations:

1. The structural material obeys Hooke's Law,

2. Small deflections are assumed; ie. the effects of the displacements on the structural geometry and forces are negligible,

3. Possible buckling of individual members or portions of the structure is ignored.

MAXIMUM SIZE OF STRUCTURE

The following maximum size limitations exist:

15 --- joints

10 --- support joints

5 --- support joints with releases (not fully fixed)

25 --- members

10 --- members with releases

10 --- members can be connected to any one joint

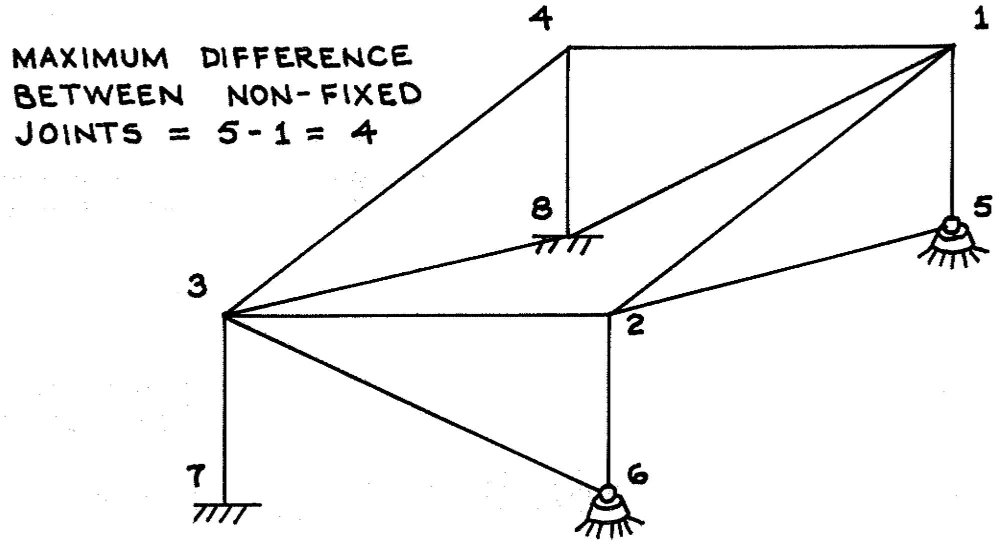
6 --- loading systems can be handled simultaneously

IDENTIFICATION OF MEMBERS AND JOINTS

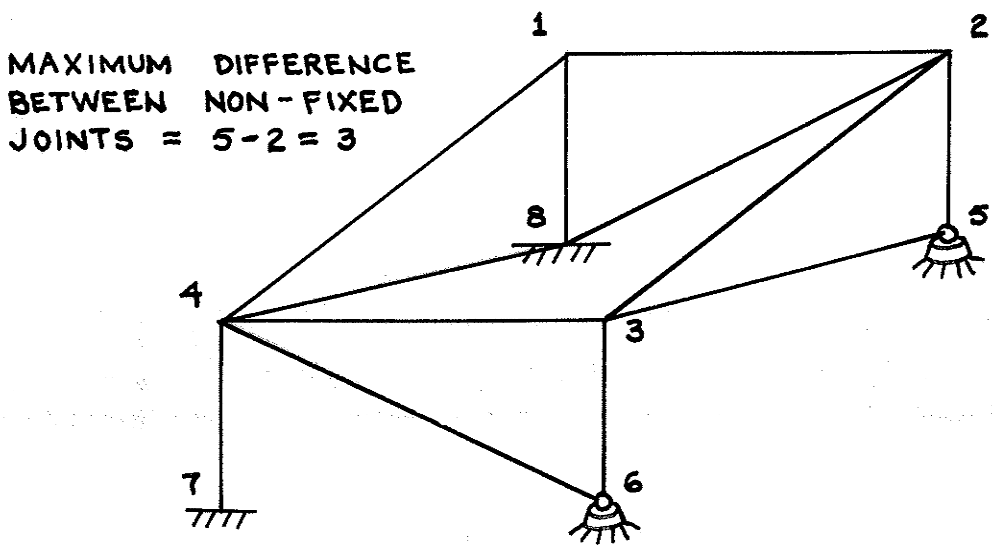
For identification purposes, all members and all joints in the structure must be numbered. The joint numbering sequence must be as follows: all free (non-support) joints, all released (not fully fixed) supports, and finally the fully fixed supports. In addition, for best effeciency it is well to number the joints such that the difference between the numbers of any two, non-fixed joints connected by a member is as small as possible. For example, the numbering system in Fig. 1(b) is preferable to that in Fig. 1(a) since the maximum difference between any two connected joint numbers is smaller in the former case. The structural topology is specified by means of a member incidence table which lists the two joints connected by each member.

COORDINATE SYSTEMS

For a space frame structure, the displacement vector at any point has six components as shown in Fig. 2. Labels U_1, U_2 and U_3 represent linear displacements in three perpendicular directions, and labels U_4, U_5 and U_6 represent the rotation about axes 1, 2 and 3



(a)



(b)

JOINT NUMBERING SYSTEMS

FIG. 1

respectively. Any concentrated load vector, or the vector of forces acting on any member cross-section has six corresponding components, ie. three direct forces and three moments.

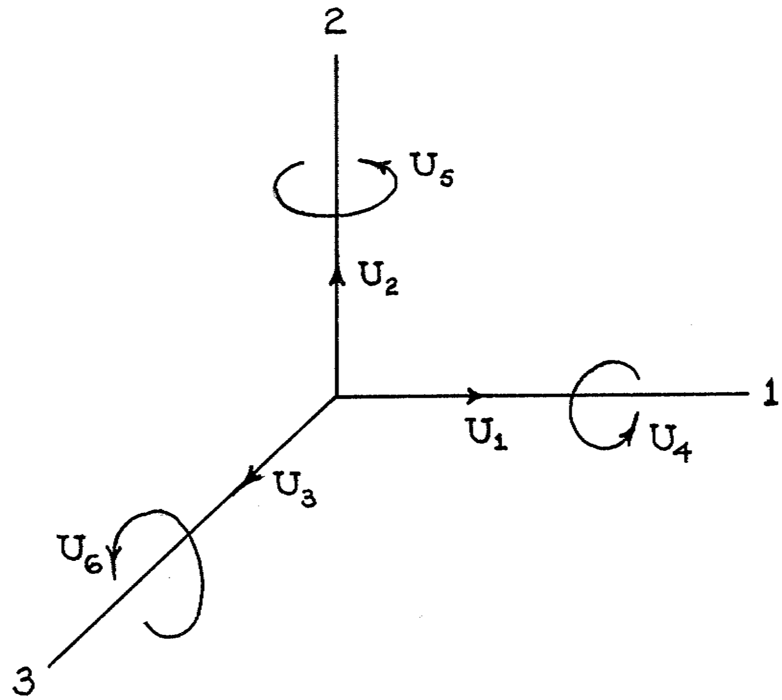
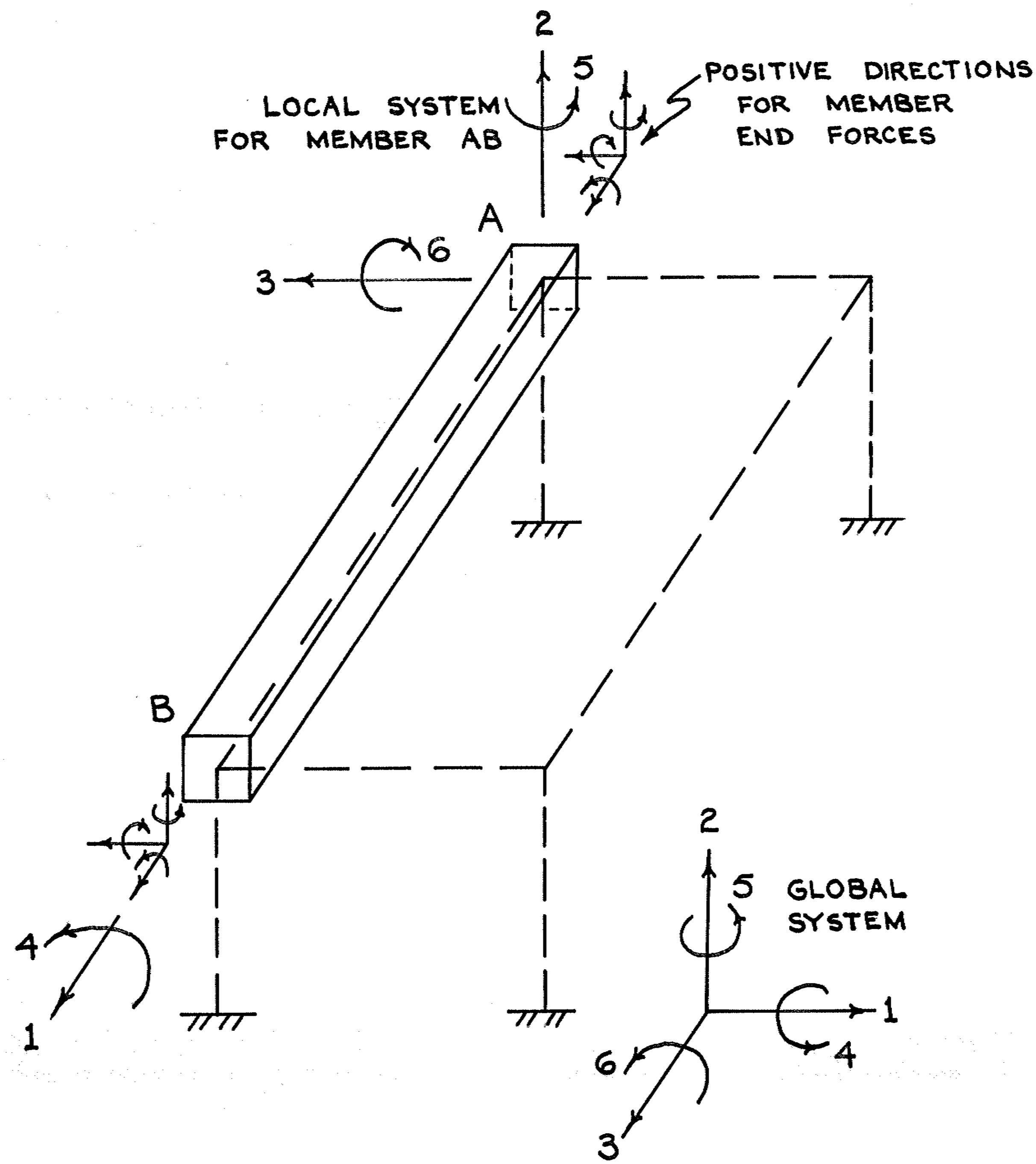


FIG. 2

The two types of coordinate systems used in the analysis program are illustrated in Fig. 3 and are described as follows:

1. Global System

The global system is a single coordinate system for the whole structure and is usually chosen so that the direction of the axes coincides with the major dimensions of the structure. The 1 and 2 axes are horizontal and vertical respectively, and axis 3 is perpendicular to axes 1 and 2. The positive global directions are those indicated in Fig. 3. Joint coordinates, loads, displacements and all support reactions are expressed in the global system.



COORDINATE SYSTEMS USED

FIG. 3

The origin of a structure can be any point in space, but the distance from the origin to every joint must be global directions. For a space frame structure such as that shown in Fig. 1, a convenient origin location would be joint number 8.

2. Local System

The end forces for each member are expressed in a local coordinate system whose 1 axis coincides with the axis of the member and is directed from its A end to its B end as shown in Fig. 3. Positive directions for the axial and shearing forces and moments at the ends of the member are as illustrated in the figure.

LOADING CONVENTIONS

The permissible loading types consist of concentrated loads, concentrated moments, and distributed loads. All direct loads are expressed in kips and all moments in foot-kips.

1. Joint Loads

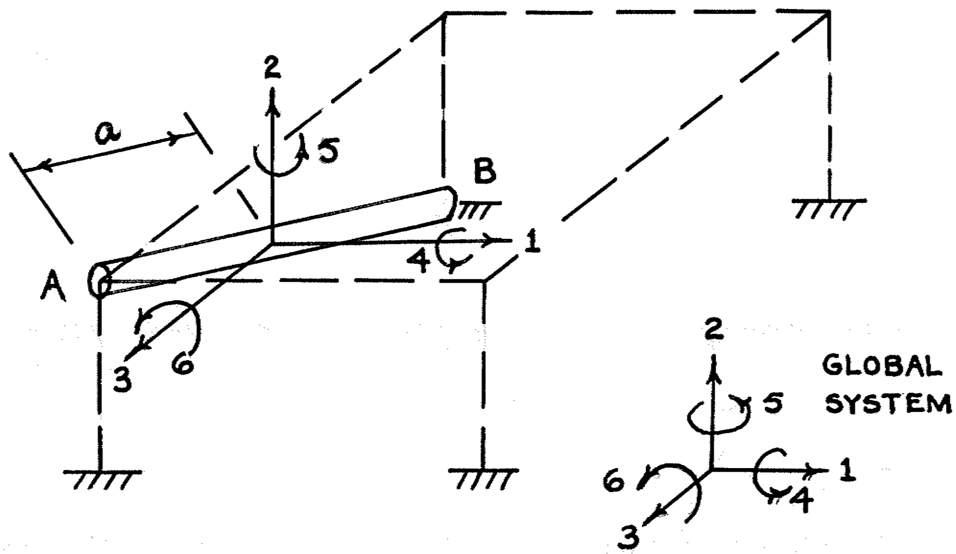
Each joint load may consist of a concentrated load in directions 1, 2 and 3, and a concentrated moment in directions 4, 5 and 6.

2. Member Concentrated loads

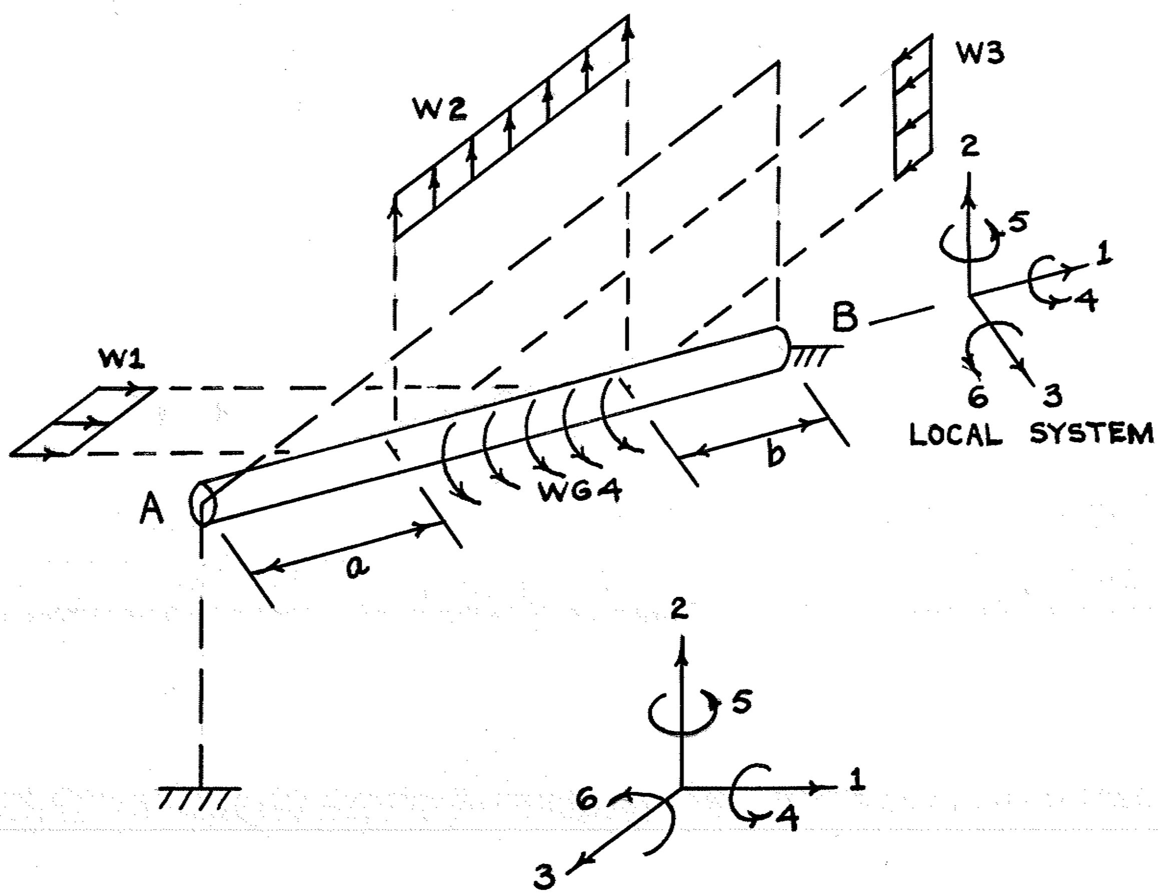
Each concentrated member load may consist of components in all six directions for the global coordinate system, as illustrated in Fig. 4. The point of application of the load is defined by its distance "a" (in feet) from the A end of the member.

3. Member Distributed Loads

As illustrated in Fig. 5, each distributed load is specified by means of the load intensities W1, W2 and W3 (kips per foot) which



MEMBER CONCENTRATED LOADS
FIG. 4



DISTRIBUTED MEMBER LOADS

FIG. 5

correspond to the global directions 1, 2 and 3 respectively. Also considered is the distributed moment intensity WG4 (ft.-kips per ft.) which acts about the member axis and is specified in the local system. In addition, distances a and b (in feet) define the distances from ends A and B respectively to the extremities of the loaded portion.

USE OF RELEASES

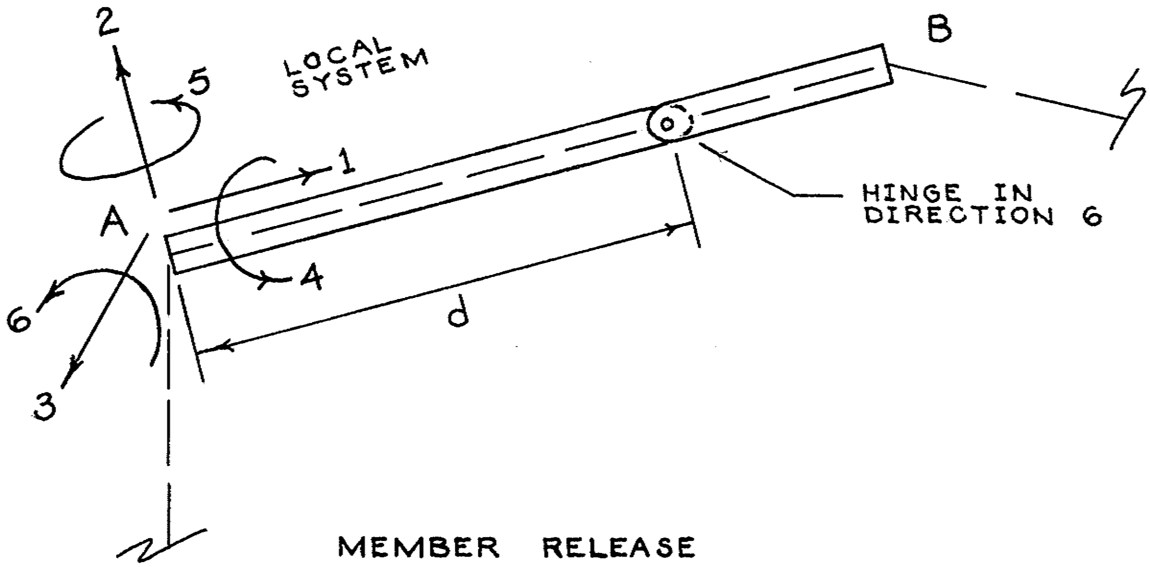
In many structures the introduction of hinges, rollers, etc., sets certain force components equal to zero. In order to avoid ambiguities in designations such as hinges and rollers, the term release is used to designate any force component that is constrained to have zero value. The two types of releases are support releases and member releases.

1. Support Releases

Releases at a given support are specified by means of three support release indicators corresponding to the six possible reaction components. A released component is specified by an indicator 1, while a fixed component is designated by a 0. For example, a ball-and-socket support would have the support release indicators [0 0 0 1 1 1].

2. Member Releases

The position of a member release is specified by giving its distance d from the A end of the member as shown below in Fig. 6; and the member release indicators are designated similarly as the support release indicators.



MEMBER RELEASE

FIG. 6

For example, a hinge connection located as shown in Fig. 6 would have member release indicators [0 0 0 0 0 1].

A maximum of two release positions and six released force components is allowed for each member. When distributed loads are acting on the member, the releases may be located only at the member ends. When concentrated loads only are present, releases may be located anywhere along the member.

INPUT INFORMATION

Eight standard data sheets as shown on pages 143 to 150 are used to specify the necessary input information. The first six sheets are self explanatory and are used to specify the structural geometry and topology, the member properties, and the support and member release information.

Data sheets 7 and 8 are used to specify the structural loadings (loading systems are specified sequentially).

DATA SHEET 7 - includes a heading for describing the loading type. For identification purposes, this heading is printed above the corresponding output results. The number of loaded members and the number of loaded joints are indicated next. For each loaded joint only, the joint number and load components are to be read.

DATA SHEET 8 - is filled out only if there are loaded members; and a complete sheet is required for each loaded member. The member number, an indication of whether or not the member carries distributed loads, and the number of point load positions on the member are read.

If distributed loads are present, the magnitudes of the loads in directions 1, 2, 3 and 4 are entered; and for partial distributed loads, the distances to the extremities of the loaded portion are specified. If there are no distributed loads, this portion is omitted.

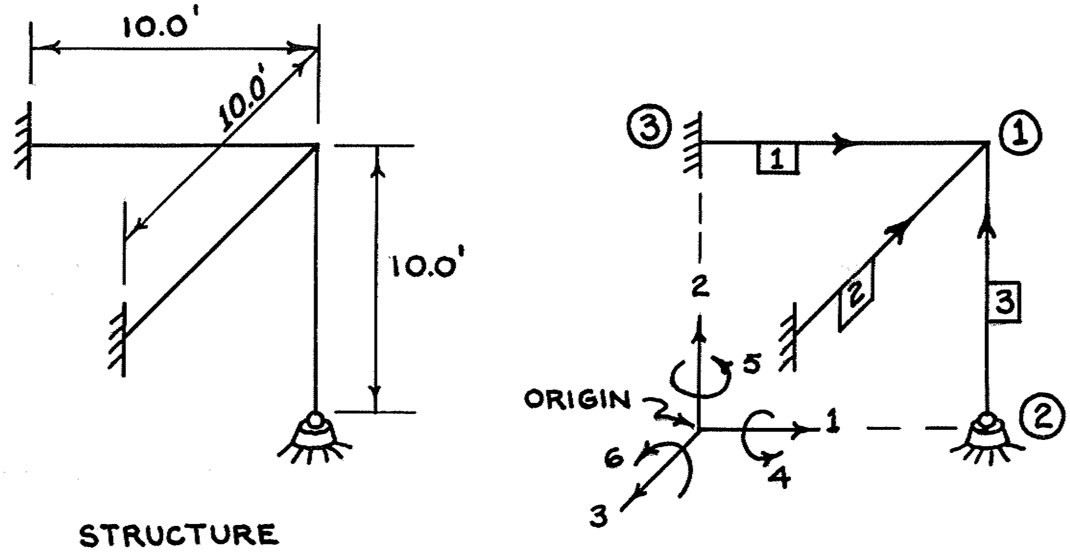
For each point load, the distance from the A end of the member and the magnitudes of the load components must be entered. If there are no point loads acting, this information is omitted.

Except where decimal points are included on the input sheets, all members are to be inserted at the extreme right of the blank fields.

NUMERICAL EXAMPLE

The structure in Fig. 7 is to be analyzed for the two loading cases shown. The required data sheets are shown on pages 128 to 137, and the output information on pages 138 to 142.

The computer output consists of all input information (for checking purposes), and the results of the analysis for each loading case. The rotation and deflections of each joint and the support reactions are expressed in the global coordinate system, while the forces at both ends of all members are expressed in the local coordinate system.



STRUCTURE DIMENSIONS

(a)

NUMBERING

(b)

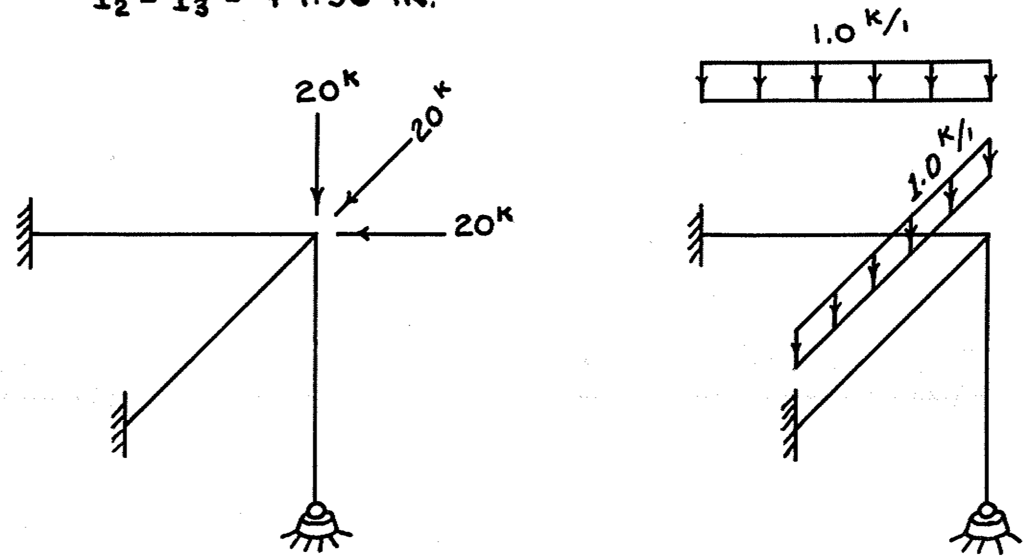
— ALL MEMBERS HAVE THE SAME PROPERTIES

— PROPERTIES AS GIVEN IN THE LOCAL SYSTEM ARE :

$A = 4.98$ IN.^{2}

$I_1 = J = 88.72$ IN.^{4}

$I_2 = I_3 = 44.36$ IN.^{4}



LOADING CASE 1
JOINT LOADS

(c)

LOADING CASE 2
DISTRIBUTED LOADS

(d)

NUMERICAL EXAMPLE

FIG. 7

SPACE FRAME ANALYSIS PROGRAM — DATA SHEET #1

	BY	DATE

JOB DESCRIPTION (EG. BUILDING FRAME, TOWER, ETC.)

NUMERICAL EXAMPLE ØF SPACE FRAME

MODULUS OF ELASTICITY (KSI.)	MODULUS OF RIGIDITY (KSI.)	NO. OF LDG. CASES	NO. OF JOINTS	NO. OF MEMBERS	NO. OF SUPPORTS	NO. OF SUPPORTS WITH RELEASES	NO. OF MEMBERS WITH RELEASE
30000.	12000.	2	4	3	3	1	1

JOINT COORDINATE TABLE (GLOBAL SYSTEM) (FT.)

JOINT	DIR. 1 COORD.	DIR. 2 COORD.	DIR. 3 COORD.
1	10.	10.	0.
2	10.	0.	0.
3	0.	10.	0.
4	10.	10.	10.
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SPACE FRAME ANALYSIS PROGRAM - DATA SHEET #3

MEMBER INCIDENCE TABLE

BY

DATE

MEMBER NO.	GOES FROM JOINT NO.	TO JOINT NO.
1	3	1
2	4	1
3	2	1

SPACE FRAME ANALYSIS PROGRAM — DATA SHEET #4.

MEMBER PROPERTIES

BY

DATE

MEMBER NO.	X-SECT. AREA (IN. 2)	MOMENT OF INERTIA (IN.4) (LOCAL SYSTEM) AXIS 1	AXIS 2	AXIS 3
1	4.98	88.72	44.36	44.36
2	4.98	88.72	44.36	44.36
3	4.98	88.72	44.36	44.36

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SPACE FRAME ANALYSIS PROGRAM - DATA SHEET #5

SUPPORT RELEASES

- APPLY ONLY FOR THOSE SUPPORTS WITH RELEASES
- INDICATORS FOR DIRECTIONS 1, 2 & 3 (GLOBAL SYSTEM) ARE : 1 = RELEASED ; 0 = FIXED

DATE

JOINT NO.	RELEASE INDICATORS DIR. 1	DIR. 2	DIR. 3	DIR. 4	DIR. 5	DIR. 6
2	0	0	0	1	1	1

SPACE FRAME ANALYSIS PROGRAM — DATA SHEET #6

MEMBER RELEASES

- APPLY ONLY FOR THOSE MEMBERS WITH RELEASES
- INDICATORS FOR DIRECTIONS 1 TO 6 (LOCAL SYSTEM) ARE: 1=RELEASED ; 0 = FIXED

DATE

MEMBER NO. (1–10)	NO. OF RELEASE POSITIONS (11–20)	DIST. TO 1ST RELEASE (FT.) (21–40)	INDICATORS 123456 (41–50)	DIST. TO 2ND RELEASE (FT.) (51–60)	INDICATORS 123456 (61–70)	(71–80)
3	1	0.	000111	.		

SPACE FRAME ANALYSIS PROGRAM - DATA SHEET #7

LOADING DESCRIPTION	BY	DATE

HEADING TO DESCRIBE TYPE OF LOADING (E.G. WIND, GRAVITY)

JØINT LØADS

NO. OF LOADED MEMBERS = 0

NO. OF LOADED JOINTS = 1 (IF = 0, OMIT REMAINDER OF SHEET)

JOINT NO.	JOINT LOADS DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (KIPS)	DIR. 4 (FT.-K)	DIR. 5 (FT.-K)	DIR. 6 (FT.-K)
1	-20.	-20.	20.	0.	0.	0.
	.	.	.	.	.	.
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Leaf 134 omitted in page numbering.

SPACE FRAME ANALYSIS PROGRAM - DATA SHEET #7

LOADING DESCRIPTION	BY	DATE

HEADING TO DESCRIBE TYPE OF LOADING (E.G. WIND, GRAVITY)

DISTRIBUTED LØADS

NO. OF LOADED MEMBERS = 2

NO. OF LOADED JOINTS = 0 (IF = 0, OMIT REMAINDER OF SHEET)

JOINT NO.	JOINT LOADS DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (KIPS)	DIR. 4 (FT.-K)	DIR. 5 (FT.-K)	DIR. 6 (FT.-K)
	.	.	.	.	.	.
	.	.	.	.	.	.
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SPACE FRAME ANALYSIS PROGRAM — DATA SHEET #8

LOADING FOR ONE MEMBER ONLY - APPLY ONLY FOR THOSE MEMBERS WHICH ARE LOADED	BY	DATE

MEMBER NO. 1

DISTRIB. LOAD INDICATOR (1 = DIST. LOAD, 0 = NO DIST. LOAD) 1

NO. OF CONC. LOAD POSITIONS = 0

DESCRIPTION OF DISTRIBUTED LOADS (GLOBAL SYSTEM) IF ANY ; OTHERWISE OMIT

DIR. 1 (K/')	DIR. 2 (K/')	DIR. 3 (K/')	DIR. 4 ('K/' ; LOCAL)	DIST. FROM A END TO BEGIN. OF LDG. (FT.)	DIST. FROM B END TO END OF LDG. (FT.)
0.	-1.	0.	0.	0.	0.

DESCRIPTION OF CONCENTRATED LOADS (GLOBAL SYSTEM) IF ANY ; OTHERWISE OMIT

DIST. FROM A END (FT.)	DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (KIPS)	DIR. 4 (FT.-K)	DIR. 5 (FT.-K)	DIR. 6 (FT.-K)
.	.	.	.	.	.	.
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SPACE FRAME ANALYSIS PROGRAM — DATA SHEET #8

LOADING FOR ONE MEMBER ONLY - APPLY ONLY FOR THOSE MEMBERS WHICH ARE LOADED	BY	DATE

MEMBER NO. 2

DISTRIB. LOAD INDICATOR (1 = DIST. LOAD, 0 = NO DIST. LOAD) 1

NO. OF CONC. LOAD POSITIONS = 0

DESCRIPTION OF DISTRIBUTED LOADS (GLOBAL SYSTEM) IF ANY ; OTHERWISE OMIT

DIR. 1 (K/')	DIR. 2 (K/')	DIR. 3 (K/')	DIR. 4 ('K/' ; LOCAL)	DIST. FROM A END TO BEGIN. OF LDG. (FT.)	DIST. FROM B END TO END OF LDG. (FT.)
0.	-1.	0.	0.	0.	0.

DESCRIPTION OF CONCENTRATED LOADS (GLOBAL SYSTEM) IF ANY ; OTHERWISE OMIT

DIST. FROM A END (FT.)	DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (KIPS)	DIR. 4 (FT.-K)	DIR. 5 (FT.-K)	DIR. 6 (FT.-K)
.	.	.	.	.	.	.
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SPACE FRAME ANALYSIS

NUMERICAL EXAMPLE OF SPACE FRAME

4 JOINTS 3 MEMBERS 3 SUPPORTS
1 SUPPORT RELEASE(S) 1 MEMBER RELEASE(S)
ODULUS OF ELASTICITY (KSI.)=30000.00 2 LOAD CASE(S)

JOINT COORDINATES (FT) (GLOBAL SYSTEM)

OINT	COORD. 1	COORD. 2	COORD. 3
1	10.00	10.00	0.0
2	10.00	0.0	0.0
3	0.0	10.00	0.0
4	10.00	10.00	10.00

MEMBER INCIDENCE TABLE

EMBER	A END	B END
1	3	1
2	4	1
3	2	1

MEMBER PROPERTIES

EMBER NO.	X-SECT. AREA(IN.2)	MOMENT OF INERTIA(IN.4) AXIS 1	AXIS 2	AXIS 3	SHEAR MODULUS (KSI.)
1	4.98	88.72	44.36	44.36	12000.00
2	4.98	88.72	44.36	44.36	12000.00
3	4.98	88.72	44.36	44.36	12000.00

SUPPORT RELEASE INDICATORS

OINT	DIRECTION 1	2	3	4	5	6
2	0	0	0	1	1	1

MEMBER RELEASE INDICATORS

EMBER	NO. OF REL. POSITIONS	DIST. FROM A END(FT.)	DIRECTIONS 1	2	3	4	5	6
3	1	0.0	0.	0.	0.	1.	1.	1.

LOADING CASE 1

NON ZERO JOINT LOADS (KIPS & FT-K)

OINT	DIRECTION 1	2	3	4	5	6
1	-20.00	-20.00	20.00	0.0	0.0	0.0

LOADING CASE 2

NON ZERO MEMBER LOADS

EMBER	DISTRIB. LOADS(K/FT.)					CONCENT. LOADS(K&FT-K)					
	1	2	3	4	DIST. FROM A END(FT.)	1	2	3	4	5	6
1	0.0	-1.00	0.0	0.0							
2	0.0	-1.00	0.0	0.0							

LOADING CASE 1

JOINT LOADS

JOINT DISPLACEMENTS(GLOBAL SYSTEM - IN. & RAD.)

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	-0.015899	-0.015870	0.015899	-0.000046	-0.000004	-0.000(
2	-0.000000	-0.000000	0.000000	0.000275	-0.000122	0.000
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0

MEMBER FORCES(LOCAL SYSTEM - K & IN.-K)

A END OF MEMBER

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	19.794	0.120	-0.144	0.404	8.718	7.740
2	19.795	0.121	0.149	-0.424	-8.914	7.790
3	19.758	-0.056	-0.061	-0.391	0.908	-0.518

B END OF MEMBER

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	-19.794	-0.120	0.144	-0.404	8.621	6.680
2	-19.795	-0.121	-0.149	0.424	-9.011	6.781
3	-19.758	0.056	0.061	0.391	6.377	-6.256

JOINT REACTIONS(GLOBAL SYSTEM - K & IN.-K)

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
2	0.056	19.758	-0.061	-0.908	-0.391	-0.518
3	19.794	0.120	-0.144	0.404	8.718	7.740
4	0.149	0.121	-19.795	7.790	-8.914	0.424

LOADING CASE 2

DISTRIBUTED LOADS

JOINT DISPLACEMENTS(GLOBAL SYSTEM - IN. & RAD.)

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	-0.000227	-0.006927	0.000225	0.001123	0.000010	0.0011
2	0.000000	-0.000000	-0.000000	-0.000732	0.000244	-0.0004
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0

MEMBER FORCES(LOCAL SYSTEM - K & IN.-K)

A END OF MEMBER

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	0.282	5.689	-0.008	-9.961	0.348	128.858
2	0.281	5.687	-0.003	10.007	0.098	128.743
3	8.624	0.279	0.288	0.893	1.795	-2.687

B END OF MEMBER

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
1	-0.282	4.311	0.008	9.961	0.572	-46.125
2	-0.281	4.313	0.003	-10.007	0.321	-46.355
3	-8.624	-0.279	-0.288	-0.893	-36.394	36.119

JOINT REACTIONS(GLOBAL SYSTEM - K & IN.-K)

NO.	DIR.1	DIR.2	DIR.3	DIR.4	DIR.5	DIR.6
2	-0.279	8.624	0.288	-1.795	0.893	-2.687
3	0.282	5.689	-0.008	-9.961	0.348	128.858
4	-0.003	5.687	-0.281	128.743	0.098	-10.007

SPACE FRAME ANALYSIS PROGRAM — DATA SHEET #1

	BY	DATE

1 10 20 30 40 50 60 70 80

JOB DESCRIPTION (EG. BUILDING FRAME, TOWER, ETC.)

MODULUS OF ELASTICITY (KSI.)	MODULUS OF RIGIDITY (KSI.)	NO. OF LDG. CASES	NO. OF JOINTS	NO. OF MEMBERS	NO. OF SUPPORTS	NO. OF SUPPORTS WITH RELEASES	NO. OF MEMBERS WITH RELEASES
.	.						

JOINT COORDINATE TABLE (GLOBAL SYSTEM) (FT.)

JOINT	DIR. 1 COORD.	DIR. 2 COORD.	DIR. 3 COORD.
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SPACE FRAME ANALYSIS PROBLEM – DATA SHEET #2

CONTINUATION OF JOINT COORDINATE TABLE (IF REQ'D.)	BY	DATE

1 10 20 30 40 50 60 70 80

JOINT	DIR. 1 COORD.	DIR. 2 COORD.	DIR. 3 COORD.
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SPACE FRAME ANALYSIS PROGRAM - DATA SHEET #3

MEMBER INCIDENCE TABLE	BY	DATE

MEMBER NO.	GOES FROM JOINT NO.	TO JOINT NO.

SPACE FRAME ANALYSIS PROGRAM — DATA SHEET #4

MEMBER PROPERTIES

BY

DATE

MEMBER NO.	X-SECT. AREA (IN. 2)	MOMENT OF INERTIA (IN. 4) (LOCAL SYSTEM) AXIS 1	AXIS 2	AXIS 3
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SPACE FRAME ANALYSIS PROGRAM - DATA SHEET #5

SUPPORT RELEASES

- APPLY ONLY FOR THOSE SUPPORTS WITH RELEASES
- INDICATORS FOR DIRECTIONS 1, 2 & 3 (GLOBAL SYSTEM) ARE : 1 = RELEASED ; 0 = FIXED

DATE

JOINT	RELEASE INDICATORS					
NO.	DIR. 1	DIR. 2	DIR. 3	DIR. 4	DIR. 5	DIR. 6

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SPACE FRAME ANALYSIS PROGRAM - DATA SHEET #6

MEMBER RELEASES

- APPLY ONLY FOR THOSE MEMBERS WITH RELEASES
- INDICATORS FOR DIRECTIONS 1 TO 6 (LOCAL SYSTEM) ARE: 1 = RELEASED ; 0 = FIXED

DATE

MEMBER NO.	NO. OF RELEASE POSITIONS	DIST. TO 1ST RELEASE (FT.)	INDICATORS 123456	DIST. TO 2ND RELEASE (FT.)	INDICATORS 123456
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SPACE FRAME ANALYSIS PROGRAM - DATA SHEET #7

LOADING DESCRIPTION	BY	DATE

1 10 20 30 40 50 60 70 80

HEADING TO DESCRIBE TYPE OF LOADING (E.G. WIND, GRAVITY)

NO. OF LOADED MEMBERS =

NO. OF LOADED JOINTS = (IF = 0, OMIT REMAINDER OF SHEET)

JOINT NO.	JOINT LOADS DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (KIPS)	DIR. 4 (FT.-K)	DIR. 5 (FT.-K)	DIR. 6 (FT.-K)
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SPACE FRAME ANALYSIS PROGRAM — DATA SHEET #8

LOADING FOR ONE MEMBER ONLY
- APPLY ONLY FOR THOSE MEMBERS WHICH ARE LOADED

BY

DATE

1 10 20 30 40 50 60 70 80

MEMBER NO.

DISTRIB. LOAD INDICATOR
1 = DIST. LOAD
0 = NO DIST. LOAD

NO. OF CONC. LOAD POSITIONS =

DESCRIPTION OF DISTRIBUTED LOADS (GLOBAL SYSTEM) IF ANY ; OTHERWISE OMIT

DIR. 1 (K/')	DIR. 2 (K/')	DIR. 3 (K/')	DIR. 4 ('K/' ; LOCAL)	DIST. FROM A END TO BEGIN. OF LDG.(FT.)	DIST. FROM B END TO END OF LDG. (FT.)
.	.	.	.	.	.

DESCRIPTION OF CONCENTRATED LOADS (GLOBAL SYSTEM) IF ANY ; OTHERWISE OMIT

DIST. FROM A END (FT.)	DIR. 1 (KIPS)	DIR. 2 (KIPS)	DIR. 3 (KIPS)	DIR. 4 (FT.-K)	DIR. 5 (FT.-K)	DIR. 6 (FT.-K)
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APPENDIX D

PROGRAM LISTING

FOR

SYSTEM

```
      REAL *8  NAMES(2) /'PLANE   ','SPACE   '/,NAME
  100 READ(5,2) NAME
    2 FORMAT(A8)
      DO 1  NI=1,2
      IF( NAMES(NI).EQ.NAME ) GO TO 12
    1 CONTINUE
      WRITE(6,3)
    3 FORMAT(18H ILLEGAL NAME USED)
      GO TO 90
   12 GO TO ( 10,20 ), NI
   10 CALL PLANE
      GO TO 100
   20 CALL SPACE
      GO TO 100
   90 CALL EXIT
      END
```

```
      SUBROUTINE PLANE
      REAL  KBA,KBB,MFA,MFB,JD,JR,JL,JFA,JFB
      COMMON H(3,3),STIF(100,3,3),KBA(3,3),KBB(3,3),A(100,3,3),AINV(3,3)
     1 , JRI(70),JSI(15,3),LISTJS(15),LISTMR(40),MI(100,2),JI(100,7),JWT
     2 ,NMIJ(70),DX(100),DY(100),DL(100),R(100,3,3),X(70),Y(70),XA(100),
     3 XI(100),FLBB(3,3),FPLMA(3),FPLMB(3),FDLMA(3),FDLMB(3),G(3,3),JRD,
     4 D1(3,3),D2(3,3),D3(3,15),D4(3,3),RT(3,3),DPL(15),
     5 PLME(3,15),FPDMA(100,3,3),FPDMB(100,3,3),GT(3,3),JL(70,3),NT(100)
     6 ,JFA(70,3),JFB(70,3),FJF(70,3,3),LIST(70),B(70,3,3),JR(30,3,3),L,
     7 UA(210,3,3),JD(70,3,3),MFA(100,3,3),MFB(100,3,3),HDG(3,20),    IJ,
     8 E,DLI,NPLPOS,KK(40),DREL(40,2),VN(40,3,3),JKK,MRI(100),M,N
      INTEGER PL
      JRD = 5
      JWT = 6
      READ(JRD,936) ( HDG(1,I),I=1,20 )
      READ(JRD,3) E, NL, NJ, NMEM, NJS, NJSR, NMR
    3 FORMAT(F10.0,6(7X,I3))
      NE = NJ -NJS + NJSR
      WRITE(JWT,11)
   11 FORMAT(1H1)
      WRITE(JWT,4)
    4 FORMAT(49H                                    PLANE FRAME ANALYSIS)
      WRITE(JWT,406)
      WRITE(JWT,936) (HDG(1,I),I=1,20)
      WRITE(JWT,406)
      WRITE(JWT,381) NJ, NMEM, NJS
  381 FORMAT(I3,1X,7H JOINTS,5X,I3,1X,8H MEMBERS,5X,I3,1X,9H SUPPORTS)
      WRITE(JWT,12) NJSR, NMR
   12 FORMAT(I3,1X,19H SUPPORT RELEASE(S),I8,1X,18H MEMBER RELEASE(S))
      WRITE(JWT,5) E,NL
    5 FORMAT(30H MODULUS OF ELASTICITY (KSI.)=,F8.2,I8,13H LOAD CASE(S))
C     INPUT JOINT COODINATES, LET LOWEST LEFT JOINT BE THE ORIGIN
      WRITE(JWT,406)
      WRITE(JWT,627)
  627 FORMAT(54H                    JOINT COORDINATES (FT) (GLOBAL SYSTEM))
      WRITE(JWT,628)
  628 FORMAT(42H JOINT              COORD. 1              COORD. 2)
      DO 1003  NN = 1,NJ
      READ(JRD,21) J,X(J),Y(J)
   21 FORMAT( I10,2(10X,F10.0) )
   23 FORMAT(1X,I3,2(10X,F8.2))
      WRITE(JWT,23)    J,X(J),Y(J)
      X(J) = X(J) * 12.
      Y(J) = Y(J) *12.
 1003 CONTINUE
C     GENERATE JI TABLE
      DO 1033  NN=1,NMEM
   10 FORMAT(I10,10X,2I10)
 1033 READ(JRD,10) I,MI(I,1),MI(I,2)
      WRITE(JWT,406)
      WRITE(JWT,13)
   13 FORMAT(15X,23H MEMBER INCIDENCE TABLE)
C     CALCULATE LENGTHS OF MEMBERS
      DO 24  I=1,NMEM
      JA = MI(I,1)
      JB = MI(I,2)
      DX(I) = X(JB) - X(JA)
      DY(I) = Y(JB) - Y(JA)
```

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      DL(I) =  SQRT ( DX(I)*DX(I)  +  DY(I)*DY(I) )
   24 CONTINUE
      WRITE(JWT,629)
  629 FORMAT(37H MEMBER             A END           B END)
C     SET JOINT INCIDENCE TABLE = 0
      DO 16  J=1,NJ
      NMIJ(J) = 0
      DO 16  I=1,7
      JI(J,I) = 0
   16 CONTINUE
      DO 17  I=1,NMEM
      J = MI(I,1)
      NMIJ(J) = NMIJ(J) + 1
      JI( J,NMIJ(J) ) = -I
      J = MI(I,2)
      NMIJ(J) = NMIJ(J)+1
      JI( J,NMIJ(J) ) = I
      WRITE(JWT,15) I,MI(I,1),MI(I,2)
   15 FORMAT(1X,I3,13X,I3,12X,I3)
   17 CONTINUE
C     SET UP UNIT TRANSLATION MATRIX
      DO 83  I=1,3
      H(I,I) = 1.
      DO 83  J=1,3
      IF(I-J) 84,83,84
   84 H(I,J) = 0.
   83 CONTINUE
C     GENERATE ROTATION MATRIX, FIRST SET ROTATION MATRIX = 0.
      DO 26  M=1,NMEM
      DO 27  I=1,3
      DO 27  J=1,3
   27 R(M,I,J) = 0.
      XL     = DX(M)/DL(M)
      XM     = DY(M)/DL(M)
      R(M,1,1) = XL
      R(M,1,2) = -XM
      R(M,2,1) = XM
      R(M,2,2) = XL
      R(M,3,3) = 1.
   26 CONTINUE
C     X-SECT. AREA,      XI= MOMENT OF INTERTIA
      DO 1043  NN=1,NMEM
 1043 READ(JRD,21) M,XA(M),XI(M)
      WRITE(JWT,406)
      WRITE(JWT,30)
   30 FORMAT(15X,18H MEMBER PROPERTIES)
      WRITE(JWT,630)
  630 FORMAT(55H MEMBER   X-SECT. AREA(IN.2)     MOMENT OF INERTIA(IN.4))
      WRITE(JWT,33)(M,XA(M),XI(M),M=1,NMEM)
   33 FORMAT(1X,I3,10X,F10.3,13X,F10.3)
C     SET UP JOINT SUPPORT RELEASE INDICATORS  IE. JSRI
      DO 230  N=1,NJ
      JRI(N) = 0
  230 CONTINUE
C     CHECK IF ANY SUPPORT RELEASES
      IF(NJSR) 228,228,229
  229 WRITE(JWT,406)
      WRITE(JWT,631)
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  631 FORMAT(15X,27H SUPPORT RELEASE INDICATORS)
      WRITE(JWT,632)
  632 FORMAT(35H JOINT                      DIRECTION)
      WRITE(JWT,633)
  633 FORMAT(41H                    1         2         3)
      DO 231  N=1,NJSR
      READ(JRD,232) JS, ( JSI(N,III),III=1,3 )
  232 FORMAT(7X,I3,3(9X,I1))
      JRI(JS) = 1
      LISTJS(N) = JS
      WRITE(JWT,634) JS, ( JSI(N,III),III=1,3 )
  634 FORMAT(1X,I3,16X,I1,9X,I1,9X,I1)
  231 CONTINUE
  228 IF(NMR) 643,643,642
  642 WRITE(JWT,406)
      WRITE(JWT,635)
  635 FORMAT(15X,26H MEMBER RELEASE INDICATORS)
      WRITE(JWT,636)
  636 FORMAT(55H MEMBER    NO. OF REL.   DIST. FROM            DIRECTIONS)
      WRITE(JWT,637)
  637 FORMAT(55H             POSITIONS     A END(FT.)         1    2    3)
C     SET UP MEMBER RELEASE INDICATORS  IE  MRI(M)
      DO 640  M=1,NMEM
  640 MRI(M) = 0
      DO 643  N=1,NMR
      READ(JRD,644) M, KK(N), DREL(N,1), VN(N,1,1), VN(N,2,1), VN(N,3,1)
     1,DREL(N,2), VN(N,1,2), VN(N,2,2), VN(N,3,2)
  644 FORMAT(2I10,10X,F10.0,3(1X,F1.0),4X,F10.0,3(1X,F1.0) )
      MRI(M) = 1
      LISTMR(N) = M
      WRITE(JWT,645) M, KK(N), DREL(N,1),VN(N,1,1), VN(N,2,1), VN(N,3,1)
  645 FORMAT(I4,I12,7X,F10.2,11X,F2.0,3X,F2.0,3X,F2.0)
      DREL(N,1) = DREL(N,1) * 12.
      IF( KK(N) - 1 ) 643,643,646
  646 WRITE(JWT,647)  DREL(N,2), VN(N,1,2), VN(N,2,2), VN(N,3,2)
  647 FORMAT(23X,F10.2,11X,F2.0,3X,F2.0,3X,F2.0)
      DREL(N,2) = DREL(N,2) * 12.
  643 CONTINUE
C     GENERATE STIFFNESS MATRIX FOR EACH MEMBER
C     SET STIFFNESS MATRIX = 0.
      DO 34  M=1,NMEM
      DO 35  I=1,3
      DO 35  J=1,3
      STIF(M,I,J) = 0.
   35 CONTINUE
      STIF(M,1,1) = E*XA(M)/DL(M)
      STIF(M,2,2) = 12. *E*XI(M)/DL(M)**3
      STIF(M,3,3) = 4. *E*XI(M)/DL(M)
      STIF(M,2,3) = -6. *E*XI(M)/DL(M)**2
      STIF(M,3,2) = STIF(M,2,3)
   34 CONTINUE
      DO 1620  N=1,NMR
      M = LISTMR(N)
      JKK = KK(N)
      CALL RELPL
 1620 CONTINUE
C     INITIALLY SET JOINT REACTIONS = 0.
      DO 54  L=1,NL
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      DO 54  J=1,NJS
      DO 54  III=1,3
   54 JR(J,L,III) = 0.
      DO 1000  L=1,NL
      DO 1001  M=1,NMEM
      DO 1001  III=1,3
      FPDMA(M,L,III) = 0.
 1001 FPDMB(M,L,III) = 0.
 1000 CONTINUE
      DO 1002  L=1,NL
      READ(JRD,936) (HDG(L,I),I=1,20)
  936 FORMAT(20A4)
      WRITE(JWT,11)
      WRITE(JWT,370) L
  370 FORMAT(25X,13H LOADING CASE,I2)
      READ(JRD,676) NLM
      READ(JRD,676) NLJ
  676 FORMAT(27X,I3)
      DO 65  J=1,NJ
      DO 66  III=1,3
   66 JL(J,III) = 0.
   65 CONTINUE
      IF( NLJ) 69,69,70
   70 WRITE(JWT,406)
      WRITE(JWT,376)
  376 FORMAT(20X,21H NON ZERO JOINT LOADS)
      WRITE(JWT,674)
  674 FORMAT(30H JOINT                    DIRECTION)
      WRITE(JWT,675)
  675 FORMAT(43H            1 (KIPS)     2 (KIPS)     3 (FT-K))
      DO 71  K=1,NLJ
      READ(JRD,72) J, JL(J,1), JL(J,2), JL(J,3)
   72 FORMAT( 7X,I3,3( 9X,F10.0) )
      WRITE(JWT,377) J, ( JL(J,III),III=1,3 )
  377 FORMAT(I4,6X,F8.2,2(5X,F8.2))
      JL(J,3) = JL(J,3) * 12.
   71 CONTINUE
   69 DO 55  JS=1,NJS
      J= NE + JS - NJSR
      DO 56  KKK=1,3
   56 JR(JS,L,KKK) = JL(J,KKK)
   55 CONTINUE
      DO 75  J=1,NJ
      DO 73  III=1,3
      JFA(J,III) = 0.
   73 JFB(J,III) = 0.
   75 CONTINUE
      IF( NLM ) 80,80,1004
 1004 WRITE(JWT,406)
      WRITE(JWT,9)
    9 FORMAT(20X,22H NON ZERO MEMBER LOADS)
      WRITE(JWT,671)
  671 FORMAT(61H MEMBER     DISTRIB. LOADS                          CONCENT.
     1LOADS)
      WRITE(JWT,672)
  672 FORMAT(67H            1          2          DIST. FROM          1
     1 2         3)
      WRITE(JWT,673)
```

```
  673 FORMAT(40H                                       A END(FT.))
      DO 1005  NN=1,NLM
      READ(JRD,1006) M, DLI, NPLPOS
 1006 FORMAT(I10,19X,F1.0,I20)
      IF(DLI) 284,284,282
C     READ IN DISTRIBUTED LOADS IN THE GLOBAL SYSTEM
C     MEASURE S AND T ALONG MEMBER LENGTH
  282 READ(JRD,283) WG1, WG2,S,T
  283 FORMAT(F10.0,3(10X,F10.0) )
      WRITE(JWT,375) M, WG1, WG2
  375 FORMAT(I4,5X,F6.2,3X,F6.2)
      S = S * 12.
      T = T * 12.
      IF(DX(M)) 923,924,923
  923 WG2 = WG2 * ( ABS(DX(M)) /DL(M))
      IF(DY(M)) 925,924,925
  925 WG1 = WG1 * ( ABS(DY(M)) / DL(M) )
  924 CONTINUE
C     ROTATE DISTRIBUTED LOAD TO MEMBER SYSTEM
      ACOS = DY(M) / DL(M)
      ASIN = DX(M) / DL(M)
      W1 = ((WG2*ACOS) + (WG1*ASIN)) / 12.
      IF( DX(M) ) 926,927,927
  926 W2 = ( (WG1*ACOS) - (WG2*ASIN) ) / 12.
      GO TO 928
  927 W2 = ( (-WG1*ACOS) + (WG2*ASIN) ) /12.
  928 CONTINUE
C     W1 AND W2 ARE DIST. LOADS IN MEMBER SYSTEM
      IF( MRI(M) ) 1007,1007,1008
 1008 DO 1630  N=1,NMR
      IF( M - LISTMR(N)) 1630,1631,1630
 1630 CONTINUE
 1631 JKK=KK(N)
      NRC = 0
      DO 333  K=1,JKK
      IF( DREL(N,K) ) 334,334,335
C     RELEASE K MUST BE AT POSITION A
C     GENERATE CANTILEVER FORCE COMPONENT AT RELEASE
  334 AA = DL(M) - S - T
      D4(1,1) =  W1 * AA
      D4(2,1) =  W2 * AA
      D4(3,1) =  W2 * AA * ( S+ AA/2.  )
      GO TO 1633
  335 DO 1636  III=1,3
 1636 D4(III,1) = 0.
 1633 DO 1632  JJJ=1,3
      IF( VN(N,JJJ,K) - 0. ) 1634,1632,1634
 1634 DO 1635  III=1,3
 1635 D1(1,III) = 0.
      D1(1,JJJ) = 1.
      NRC = NRC + 1
      D2(NRC,1) = 0.
      DO 338  KKK=1,3
  338 D2(NRC,1) = D1(1,KKK) * D4(KKK,1) + D2(NRC,1)
 1632 CONTINUE
  333 CONTINUE
C     CALCULATE  A(M) * D2          -STORE IN D3
      DO 339  III=1,3
```

```
      D3(III,1) = 0.
      DO 339  KKK=1,NRC
  339 D3(III,1) = A(M,III,KKK) * D2(KKK,1) + D3(III,1)
C     SET UP D4 TO REPRESENT CANTILEVER DEFLECTION AT B END
      AA = DL(M)-T
      BB =  AA * AA
      CC =  BB * AA
      DD =  CC * AA
      EE =  W2/6./E / XI(M)
      D4(1,1) =  (W1/2./ XA(M)/ E) * (BB - S**2)
      D4(2,1) = 0.75*EE *(DD-S**4) + EE*( T*CC - (S**3)*(DL(M)-S) )
      D4(3,1) =  EE*( CC- S**3)
 1735 FORMAT( 3(1H0,I4,I4,F20.6) )
C     CALCULATE  -STIF * D4        -STORE IN D1
      DO 340  III=1,3
      D1(III,1) = 0.
      DO 340  KKK=1,3
  340 D1(III,1) =  -STIF(M,III,KKK) * D4(KKK,1) + D1(III,1)
C     END FORCES AT B END ARE(D1 - D3)
      DO 341  III=1,3
  341 FDLMB(III) =    D1(III,1) - D3(III,1)
C     CALCULATE FPLMA FROM STATICS
      DD = DL(M) - S - T
      FDLMA(1) =  -W1*DD -FDLMB(1)
      FDLMA(2) =  -W2*DD -FDLMB(2)
      FDLMA(3) =  -FDLMB(3) -FDLMB(2)*DL(M) -W2*DD*(S+.5*DD)
      GO TO 1023
 1007 FDLMB(1)    = -((W1)*( DL(M)-T )**2 /2./DL(M)) + (W1*S**2/2./DL(M))
      CC = (S**3)*((S/2.)-DL(M)) +(((DL(M)-T)**3)*((DL(M)/2.) + (T/2.)))
      FDLMB(2)    =   -(W2/ DL(M)**3) * CC
      DD = ( -DL(M)/12.) - (T/4.)
      CC = (S**2) * ((3.*S/4.)-1. + (S*DL(M)/3.)) +(((DL(M)-T)**3) * DD)
      FDLMB(3)    =   (-W2/(DL(M))**2) * CC
C     CALCULATE END FORCES AT A END FROM STATICS
      DD = DL(M)-S-T
      FDLMA(1)    = (-W1*DD) - FDLMB(1)
      FDLMA(2)    = (-W2*DD) - FDLMB(2)
      FDLMA(3) =  -FDLMB(3)  -FDLMB(2)*DL(M)  -W2*DD*(S+.5*DD)
      GO TO 1023
  284 DO 280  JJJ=1,3
      FDLMA(JJJ) = 0.
      FDLMB(JJJ) = 0.
  280 CONTINUE
 1023 IF(NPLPOS) 249,249,250
  250 IF( MRI(M) ) 1013,1013,1014
C     SET UP D4 TO REPRESENT FORCE VECTOR AT RELEASE K FROM LOADS ON KB
C     GENERATE  R TRANSPOSE        -STORE IN RT
 1014 DO 402  III=1,3
      DO 402  KKK=1,3
  402 RT(KKK,III) = R(M,III,KKK)
      NRC=0
C     READ IN POINT LOADS IN GLOBAL SYSTEM
C     DIST. TO POINT LOADS MEASURED ALONG MEMBER LENGTH FROM A END
      DO 306  PL=1,NPLPOS
      READ(JRD,307)  DPL(PL), D3(1,PL), D3(2,PL), D3(3,PL)
  307 FORMAT(F10.0,10X,3(F10.0))
      WRITE(JWT,373)  M,DPL(PL), ( D3(III,PL),III=1,3 )
  373 FORMAT(I4,26X,F8.2,6X,F7.2,2X,F7.2,2X,F7.2)
```

```
      DPL(PL) = DPL(PL) * 12.
      D3(3,PL) = D3(3,PL) * 12.
C     ROTATE GLOBAL FORCE VECTOR TO MEMBER FORCE VECTOR
      DO 403  III=1,3
      PLME(III,PL)= 0.
      DO 403  KKK=1,3
  403 PLME(III,PL)= RT(III,KKK) * D3(KKK,PL)+ PLME(III,PL)
  306 CONTINUE
      DO 305  K=1,JKK
C     SET UP D4 TO REPRESENT FORCE VECTOR AT RELEASE K FROM LOADS ON KB
      DO 304 III=1,3
  304 D4(III,1) =0.
      DO 1645  PL=1,NPLPOS
      DIFF = DPL(PL) - DREL(N,K)
      IF(DIFF ) 1645,308,308
C     GENERATE  H MTX. BETWEEN RELEASE POINT AND POSITION OF LOAD
C     INSURE UNIT MATRIX
  308 H(2,3) = 0.
      H(3,2) = DIFF
C     CALCULATE  H * PLME     -STORE IN D1
      DO 309  III=1,3
      D1(III,1) = 0.
      DO 309  KKK=1,3
  309 D1(III,1) =    H(III,KKK) * PLME(KKK,PL)+ D1(III,1)
      DO 310  III=1,3
  310 D4(III,1) = D4(III,1) + D1(III,1)
 1645 CONTINUE
      DO 1637  JJJ=1,3
      IF( VN(N,JJJ,K) - 0. ) 1638,1637,1638
 1638 DO 1639  III=1,3
 1639 D1(1,III) = 0.
      D1(1,JJJ) = 1.
      NRC = NRC + 1
      D2(NRC,1) = 0.
      DO 1640  KKK=1,3
 1640 D2(NRC,1) = D1(1,KKK) * D4(KKK,1) + D2(NRC,1)
 1637 CONTINUE
  305 CONTINUE
C     CALCULATE KBB * G * AINV * D2    -STORE IN D3
C     NOTE THAT KBB * G * AINV IS STORED IN A(M)
      DO 312  III=1,3
      D3(III,1) = 0.
      DO 312  KKK=1,NRC
  312 D3(III,1) = A(M,III,KKK) * D2(KKK,1) + D3(III,1)
C     SET UP D4 TO REPRESENT CANTILEVER DEFLECTION AT B END
      DO 313  III=1,3
  313 D4(III,1) = 0.
      DO 314 PL=1,NPLPOS
C     GENERATE FLEXIBILITY MATRIX AT EACH POINT
      DO 315  III=1,3
      DO 315  JJJ=1,3
  315 FLBB(III,JJJ) = 0.
      FLBB(1,1) = DPL(PL)/ E / XA(M)
      FLBB(2,2) = (DPL(PL))**3/ 3. / E / XI(M)
      FLBB(2,3) = 1.5 / DPL(PL) * FLBB(2,2)
      FLBB(3,2) = FLBB(2,3)
      FLBB(3,3) = 2.0 * FLBB(2,3) / DPL(PL)
C     CALCULATE FLBB * PLME AT THAT POSITION      -STORE IN D2
```

```
      DO 316  III=1,3
      D2(III,1) = 0.
      DO 316  KKK=1,3
  316 D2(III,1) = FLBB(III,KKK) * PLME(KKK,PL)+ D2(III,1)
C     GENERATE (H TRANSPOSE) BETWEEN POINT LOAD AND END B OF MEMBER
      H(3,2) = 0.
      H(2,3) = DL(M) - DPL(PL)
C     CALCULATE (H TRANSPOSE) * D2      -STORE IN D1
      DO 317  III=1,3
      D1(III,1) = 0.
      DO 317  KKK=1,3
  317 D1(III,1) =   H(III,KKK) * D2(KKK,1) + D1(III,1)
      DO 318  III=1,3
  318 D4(III,1) = D4(III,1) + D1(III,1)
  314 CONTINUE
C     CALCULATE  (-KBB MODIFIED) * D4       -STORE IN D1
      DO 319  III=1,3
      D1(III,1) = 0.
      DO 319  KKK=1,3
  319 D1(III,1) = -STIF(M,III,KKK) * D4(KKK,1) + D1(III,1)
C     CALCULATE (D1-D3) TO GIVE B END FORCES DUE TO POINT LOADS
      DO 320  III=1,3
  320 FPLMB(III) =   D1(III,1) - D3(III,1)
C     CALCULATE FPLMA FROM STATICS
C     GENERATE HAB
      H(2,3) = 0.
      H(3,2) = DL(M)
C     CALCULATE -HAB * FPLMB AND STORE IN SLOT D1
      DO 322  III=1,3
      D1(III,1) = 0.
      DO 322  KKK=1,3
  322 D1(III,1) =   -H(III,KKK) * FPLMB(KKK)   + D1(III,1)
C     INITIALIZE MATRIX D2
      DO 323  III=1,3
  323 D2(III,1) = 0.
      DO 506 PL=1,NPLPOS
      H(3,2)   = DPL(PL)
C     CALCULATE  -H * POINT LOAD        -STORE IN D3
      DO 324  III=1,3
      D3(III,1) = 0.
      DO 324  KKK=1,3
  324 D3(III,1) =   -H(III,KKK) * PLME(KKK,PL)+ D3(III,1)
      DO 325  III=1,3
  325 D2(III,1) = D2(III,1) + D3(III,1)
  506 CONTINUE
      DO 326  III=1,3
  326 FPLMA(III) =   D2(III,1) + D1(III,1)
      GO TO 1012
C     CALCULATE CANTILEVER DEFLECTION AT POINT B
C     INITIALIZE DUMMY MATRIX D4 AND FLEXIBILITY MATRIX FLBB
 1013 DO 251  III=1,3
  251 D4(III,1) = 0.
      DO 252  III=1,3
      DO 252  JJJ=1,3
  252 FLBB(III,JJJ) = 0.
C     GENERATE R TRANSPOSE          -STORE IN RT
      DO 400  III=1,3
      DO 400  KKK=1,3
```

```
  400 RT(KKK,III) = R(M,III,KKK)
      DO 253 PL=1,NPLPOS
C     READ IN POINT LOADS IN GLOBAL SYSTEM
C     DISTANCE TO POINT LOADS MEASURED ALONG LENGTH OF MEMBER FROM A END
      READ(JRD,307) DPL(PL),D3(1,PL),D3(2,PL),D3(3,PL)
      WRITE(JWT,373)  M,DPL(PL),( D3(III,PL),III=1,3 )
      DPL(PL)= DPL(PL)* 12.
      D3(3,PL)= D3(3,PL)* 12.
C     ROTATE GLOBAL FORCE VECTOR TO MEMBER FORCE VECTOR
      DO 401  III=1,3
      PLME(III,PL)= 0.
      DO 401  KKK=1,3
  401 PLME(III,PL)= RT(III,KKK) * D3(KKK,PL)+ PLME(III,PL)
      FLBB(1,1) = DPL(PL)/ E / XA(M)
      FLBB(2,2) = (DPL(PL))**3/ 3. / E / XI(M)
      FLBB(2,3) = 1.5 / DPL(PL) * FLBB(2,2)
      FLBB(3,2) = FLBB(2,3)
      FLBB(3,3) = 2.0 * FLBB(2,3) / DPL(PL)
C     CALCULATE FLBB * PLME AND STORE IN D2
      DO 270  III=1,3
      D2(III,1) = 0.
      DO 270  KKK=1,3
  270 D2(III,1) = FLBB(III,KKK) * PLME(KKK,PL)+ D2(III,1)
C     GENERATE H TRANSPOSE BETWEEN POINT LOAD AND END B OF MEMBER
C     INSURE UNIT MATRIX
      H(3,2) = 0.
      H(2,3) = DL(M) - DPL(PL)
C     CALCULATE H TRANSPOSE * SLOT D2
      DO 271  III=1,3
      D1(III,1) = 0.
      DO 271  KKK=1,3
  271 D1(III,1) =    H(III,KKK) * D2(KKK,1) + D1(III,1)
      DO 272  III=1,3
  272 D4(III,1) = D4(III,1) + D1(III,1)
  253 CONTINUE
C     CALCULATE   -(STIF) * D4   TO GET   FPLMB
      DO 273 III=1,3
      FPLMB(III) = 0.
      DO 273 KKK=1,3
  273 FPLMB(III) =  -STIF(M,III,KKK) * D4(KKK,1)  + FPLMB(III)
C     CALCULATE FPLMA FROM STATICS
C     GENERATE HAB
      H(2,3) = 0.
      H(3,2) = DL(M)
C     CALCULATE -HAB * FPLMB AND STORE IN SLOT D1
      DO 274  III=1,3
      D1(III,1) = 0.
      DO 274  KKK=1,3
  274 D1(III,1) =  -H(III,KKK) * FPLMB(KKK)  + D1(III,1)
C     INITIALIZE MATRIX D2
      DO 275 III=1,3
  275 D2(III,1) = 0.
      DO 276 PL=1, NPLPOS
      H(3,2) = DPL(PL)
C     CALCULATE -H * POINT LOAD AND STORE AS D3
      DO 277  III=1,3
      D3(III,1) = 0.
      DO 277  KKK=1,3
```

```
  277 D3(III,1) =    -H(III,KKK) * PLME(KKK,PL)+ D3(III,1)
      DO 278  III=1,3
  278 D2(III,1) = D2(III,1) + D3(III,1)
  276 CONTINUE
      DO 279  III=1,3
  279 FPLMA(III) = D2(III,1) + D1(III,1)
      GO TO 1012
  249 DO 248  J=1,3
      FPLMA(J) = 0.
      FPLMB(J) = 0.
  248 CONTINUE
C     CALCULATE FINAL MEMBER FORCES DUE TO DIST. AND POINT LOADS
 1012 DO 285  III=1,3
      FPDMA(M,L,III) = FPLMA(III) + FDLMA(III)
      FPDMB(M,L,III) = FPLMB(III) + FDLMB(III)
  285 CONTINUE
 1005 CONTINUE
C     MATRICES FPLMA,FPLMB,FDLMA,FDLMB CAN NOW BE USED AS DUMMY MATRICES
C     CALCULATION OF JOINT FORCES TO BE USED IN ANALYSIS
C     JFA MEANS JOINT FORCES DUE TO A END OF MEMBER
      DO 76  I=1,NMEM
      M = I
C     ROTATE F.E.F. AT A END INTO GLOBAL SYSTEM - STORE IN FPLMA
      DO 60  III=1,3
      FPLMA(III) = 0.
      DO 60  KKK=1,3
   60 FPLMA(III) = R(M,III,KKK) * FPDMA(M,L,KKK) + FPLMA(III)
      J = MI(I,1)
      DO 63  III=1,3
   63 JFA(J,III) = JFA(J,III) - FPLMA(III)
   76 CONTINUE
      DO 78  I=1,NMEM
      M = I
C     ROTATE F.E.F. AT B END INTO GLOBAL SYSTEM - STORE IN FPLMB
      DO 59  III=1,3
      FPLMB(III) = 0.
      DO 59  KKK=1,3
   59 FPLMB(III) = R(M,III,KKK) * FPDMB(M,L,KKK) + FPLMB(III)
      J = MI(I,2)
      DO 62  III=1,3
   62 JFB(J,III) = JFB(J,III) - FPLMB(III)
   78 CONTINUE
   80 DO 61  J=1,NJ
      DO 61  III=1,3
      FJF(J,L,III) = JFA(J,III) + JFB(J,III) + JL(J,III)
   61 CONTINUE
 1002 CONTINUE
      NK = 0
      DO 85  I=1,NE
      LIST(I) = NK
C     ZERO THE MATRICES IN THE I,TH ROW
      DO 86  K=1,NE
      DO 86  L=1,3
      DO 86  M=1,3
      A(K,L,M) = 0.
   86 CONTINUE
C     FIND KLOW AND KHIGH AT JOINT I
      KL = I
```

```
      KH = I
      JAY = NMIJ(I)
      DO 88  J=1,JAY
      JJ = JI(I,J)
      IF(JJ) 89,90,90
   89 M = -JJ
      K = 2
      GO TO 91
   90 M = JJ
      K = 1
   91 JJ = MI(M,K)
      IF(JJ-NE) 92,92,88
   92 IF(JJ-KH) 93,93,94
   94 KH = JJ
   93 IF(JJ-KL) 96,88,88
   96 KL = JJ
   88 CONTINUE
C     START GENERATION OF I, TH EQUATION
      DO 98  J=1,JAY
      M = JI(I,J)
      K = 2
      IF(M) 99,100,100
   99 M = -M
      K = 1
  100 II = MI(M,K)
      K = 3-K
      IJ = MI(M,K)
      IK=IJ
      DO 102  KKK=1,3
      DO 102  JJJ=1,3
  102 KBB(KKK,JJJ) = STIF(M,KKK,JJJ)
      JJ = JI(I,J)
      IF(JJ) 103,103,104
C     INSURE THAT UNIT MATRIX IS INITIALIZED
  103 H(2,3) = 0.
C     INSERT MEMBER LENGTH TO RESULT IN H MATRIX
      H(3,2) = DL(M)
      DO 208  KKK=1,3
      DO 208  JJJ=1,3
      KBA(KKK,JJJ) = 0.
      DO 208  III=1,3
  208 KBA(KKK,JJJ) = -( H(KKK,III)*STIF(M,III,JJJ) ) + KBA(KKK,JJJ)
C     ACTUALLY ABOVE IS KAB BUT IS INSERTED IN SLOT KBA
C     KAA = HAB * KBB * HABT    OR = -KBA*HABT
C     INSURE UNIT MATRIX IS INITIALIZED
      H(3,2) = 0.
C     INSERT MEMBER LENGTH TO RESULT IN H TRANSPOSE
      H(2,3) = DL(M)
      DO 209  KKK=1,3
      DO 209  JJJ=1,3
      KBB(KKK,JJJ) = 0.
      DO 209  III=1,3
  209 KBB(KKK,JJJ) = -(KBA(KKK,III)*H(III,JJJ)) + KBB(KKK,JJJ)
      GO TO 105
  104 IF(IK-NE) 106,106,105
C     INSURE THAT UNIT MATRIX IS INITIALIZED
  106 H(3,2) = 0.
C     INSERT MEMBER LENGTH TO RESULT IN H TRANSPOSE
```

```
      H(2,3) = DL(M)
C     GOING TO CALCULATE   -KBB*(HABT)
      DO 210  KKK=1,3
      DO 210  JJJ=1,3
      KBA(KKK,JJJ) = 0.
      DO 210  III=1,3
  210 KBA(KKK,JJJ) = -( STIF(M,KKK,III)*H(III,JJJ) ) + KBA(KKK,JJJ)
  105 CONTINUE
C     FIRST CALCULATE  R * KBB
      DO 107  III=1,3
      DO 107 JJJ=1,3
      D1(III,JJJ) = 0.
      DO 107  KKK=1,3
  107 D1(III,JJJ) = R(M,III,KKK) * KBB(KKK,JJJ) + D1(III,JJJ)
C     GENERATE  R TRANSPOSE  IE. RT(KKK,III)
      DO 109 III=1,3
      DO 109 KKK=1,3
  109 RT(KKK,III) = R(M,III,KKK)
C     NOW CALCULATE  R*KBB*RT AND STORE IN D2
      DO 110  III=1,3
      DO 110  KKK=1,3
      D2(III,KKK) = 0.
      DO 110  JJJ=1,3
  110 D2(III,KKK) = D1(III,JJJ) * RT(JJJ,KKK) + D2(III,KKK)
C     FOR FINAL SUBMATRIX A ADD PREVIOUS VALUE OF MATRIX A
      DO 111  III=1,3
      DO 111  KKK=1,3
  111 A(II,III,KKK) = D2(III,KKK) + A(II,III,KKK)
      IF(IK-NE) 112,112,98
C     FIRST CALCULATE  R*KAB  NOTE THAT KAB IS IN SLOT KBA
  112 DO 113  III=1,3
      DO 113  JJJ=1,3
      D1(III,JJJ) = 0.
      DO 113  KKK=1,3
  113 D1(III,JJJ) = R(M,III,KKK) * KBA(KKK,JJJ) + D1(III,JJJ)
C     NOW CALCULATE  R*KAB*RT
      DO 114  III=1,3
      DO 114  KKK=1,3
      A(IJ,III,KKK) = 0.
      DO 114  JJJ=1,3
  114 A(IJ,III,KKK) = D1(III,JJJ) * RT(JJJ,KKK) + A(IJ,III,KKK)
   98 CONTINUE
C     CHECK FOR SUPPORT RELEASES
      MM = JRI(I)
      IF(MM) 233,233,234
  234 DO 1622  N=1,NJSR
      IF( I - LISTJS(N) ) 1622,1623,1622
 1622 CONTINUE
 1623 IF( JSI(N,1) ) 236,236,237
  236 A(I,1,1) = 1000000000000.
  237 IF( JSI(N,2) ) 238,238,239
  238 A(I,2,2) = 1000000000000.
  239 IF( JSI(N,3) ) 242,242,233
  242 A(I,3,3) = 1000000000000.
  233 CONTINUE
C     INSERT JOINT FORCES INTO B MATRIX
C     REQUIRE  -,IVE SIGN SINCE  AX + B = 0.
      DO 115  L=1,NL
```

```
      DO 116  III=1,3
  116 B(I,L,III) = -FJF(I,L,III)
  115 CONTINUE
C     ELIMINATION ROUTINE
C     NT IS LENGTH OF NON-ZERO BAND TO RIGHT OF MAIN DIAGONAL
      NT(I) = KH-I
      IF(I-KL) 118,118,119
  119 KU = I-1
      DO 120  K=KL,KU
      IK = K
      JAY = NT(K)
      DO 121  M=1,3
      DO 121  N=1,3
  121 D1(M,N) = A(IK,M,N)
      IJ = K + NT(K) - I - NT(I)
      IF(IJ) 122,122,123
  123 NT(I) = NT(I) + IJ
  122 DO 124  J=1,JAY
      IJ = IK+J
      JJ = LIST(K) + J
      DO 126  N=1,3
      DO 126  M=1,3
  126 D3(N,M) = UA(JJ,N,M)
      DO 127  III=1,3
      DO 127  JJJ=1,3
  127 D2(III,JJJ) = A(IJ,III,JJJ)
      DO 128  III=1,3
      DO 128  JJJ=1,3
      A(IJ,III,JJJ) = 0.
      DO 128  KKK=1,3
  128 A(IJ,III,JJJ) = D1(III,KKK) * D3(KKK,JJJ) + A(IJ,III,JJJ)
      DO 130  III=1,3
      DO 130  JJJ=1,3
  130 A(IJ,III,JJJ) = A(IJ,III,JJJ) + D2(III,JJJ)
  124 CONTINUE
      DO 131  L=1,NL
      DO 132  III=1,3
  132 D2(L,III) = B(I,L,III)
      DO 133  III=1,3
  133 B(I,L,III) = 0.
      DO 134  III=1,3
      DO 134  KKK=1,3
  134 B(I,L,III) = D1(III,KKK) * B(K,L,KKK) + B(I,L,III)
      DO 135  III=1,3
  135 B(I,L,III) = B(I,L,III) + D2(L,III)
  131 CONTINUE
  120 CONTINUE
  118 IJ = I
      JKK = 3
      CALL INVPL
      JAY = NT(I)
      NK = NK + NT(I)
      IF(JAY) 137,137,138
  138 DO 139  J=1,JAY
      IJ = IJ+1
      JJ = LIST(I) + J
      DO 140  III=1,3
      DO 140  KKK=1,3
```

```
      UA(JJ,III,KKK) = 0.
      DO 140  JJJ=1,3
  140 UA(JJ,III,KKK) = -AINV(III,JJJ) * A(IJ,JJJ,KKK) + UA(JJ,III,KKK)
  139 CONTINUE
  137 DO 141  L=1,NL
      DO 142  K=1,3
  142 D2(L,K) = B(I,L,K)
      DO 143  K=1,3
  143 B(I,L,K) = 0.
      DO 144  III=1,3
      DO 144  K=1,3
  144 B(I,L,III) = -AINV(III,K) * D2(L,K) + B(I,L,III)
  141 CONTINUE
   85 CONTINUE
C     BACK SUBSTITUTION ROUTINE
C     ALSO SET JOINT DISPLACEMENTS = 0.
      DO 145  L=1,NL
      DO 146  J=1,NJ
      DO 146  K=1,3
      JD(J,L,K) = 0.
  146 CONTINUE
      DO 147  M=1,NMEM
      DO 147  K=1,3
      MFA(M,L,K) = 0.
      MFB(M,L,K) = 0.
  147 CONTINUE
  145 CONTINUE
      DO 153  L=1,NL
      DO 148  II=1,NE
      I = NE-II+1
      IF(II-1) 150,150,151
  151 KU = NT(I)
      DO 152  K=1,KU
      JJ = LIST(I) + K
      IJ = I+K
      DO 154  KKK=1,3
  154 D2(L,KKK) = B(I,L,KKK)
      DO 155  KKK=1,3
  155 B(I,L,KKK) = 0.
      DO 156  III=1,3
      DO 156  KKK=1,3
  156 B(I,L,III) = B(I,L,III) + UA(JJ,III,KKK) * B(IJ,L,KKK)
      DO 157  III=1,3
  157 B(I,L,III) = D2(L,III) + B(I,L,III)
  152 CONTINUE
  150 JAY = NMIJ(I)
C     SET JOINT DISPLACEMENT = MATRIX IN B SLOT
      DO 158  K=1,3
      JD(I,L,K) = B(I,L,K)
  158 CONTINUE
      DO 159  J=1,JAY
      M = JI(I,J)
      MABS = IABS(M)
C     RECALL KBB AND R FOR THE J,TH MEMBER INCIDENT ON JOINT I
      DO 160  III=1,3
      DO 160  K=1,3
  160 RT(K,III) = R(MABS,III,K)
C     CALCULATE   R TRANSPOSE * B MATRIX     -STORE IN D1
```

```
      DO 162  K=1,3
      D1(L,K) = 0.
      DO 162  JJJ=1,3
  162 D1(L,K) = RT(K,JJJ) * B(I,L,JJJ) + D1(L,K)
      IF(M) 164,165,165
  164 M = -M
C     EQUATE D2 = D1
      DO 166  K=1,3
  166 D2(L,K) = D1(L,K)
C     GENERATE H TRANSPOSE FOR MEMBER M
C     INSURE THAT UNIT MTX. IS INITIALIZED
      H(3,2) = 0.
C     INSERT MEMBER LENGTH TO RESULT IN H TRANSPOSE
      H(2,3) = DL(M)
C     CALCULATE  -(H TRANSPOSE) * D2 = NEW D1
      DO 167  K=1,3
      D1(L,K) = 0.
      DO 167  JJJ=1,3
  167 D1(L,K) = -( H(K,JJJ)*D2(L,JJJ) ) + D1(L,K)
C     CALCULATE  KBB * D1 = D2
  165 DO 168  K=1,3
      D2(L,K) = 0.
      DO 168  JJJ=1,3
  168 D2(L,K) = STIF(M,K,JJJ) * D1(L,JJJ) + D2(L,K)
C     CALCULATE  -H * D2 = D3
C     INSURE UNIT TRANSLATION MATRIX IS INITIALIZED
      H(2,3) = 0.
C     INSERT MEMBER LENGTH TO RESULT IN H MATRIX
      H(3,2) = DL(M)
      DO 171  K=1,3
      D3(L,K) = 0.
      DO 171  JJJ=1,3
  171 D3(L,K) = -H(K,JJJ) * D2(L,JJJ) + D3(L,K)
C     CALCULATE MEMBER FORCE AT B END  IE. MFB
      DO 175  K=1,3
  175 MFB(M,L,K) = D2(L,K) + MFB(M,L,K)
C     CALCULATE MEMBER FORCE AT A END  IE. MFA
      DO 177  K=1,3
  177 MFA(M,L,K) = D3(L,K) + MFA(M,L,K)
  159 CONTINUE
  148 CONTINUE
  153 CONTINUE
C     FINAL MEMBER FORCES = FIXED-END FORCES + CALCULATED MEMBER FORCES
      DO 186  L=1,NL
      DO 187  M=1,NMEM
      DO 187  K=1,3
      MFA(M,L,K) = FPDMA(M,L,K) + MFA(M,L,K)
      MFB(M,L,K) = FPDMB(M,L,K) + MFB(M,L,K)
  187 CONTINUE
C     CALCULATION OF JOINT SUPPORT REACTIONS
      DO 192  JS=1,NJS
      I = NE + JS - NJSR
      JAY = NMIJ(I)
      DO 193  J=1,JAY
      JJ = JI(I,J)
      IF(JJ) 194,195,195
  194 M = -JJ
C     ROTATE MFA TO GLOBAL SYSTEM BY R * MFA
```

```
C     STORE THE  -,IVE RESULT IN D2
      DO 196  JJJ=1,3
      D2(L,JJJ) = 0.
      DO 196  K=1,3
  196 D2(L,JJJ) = -R(M,JJJ,K) * MFA(M,L,K) + D2(L,JJJ)
      GO TO 197
  195 M = JJ
C     ROTATE MFB TO GLOBAL SYSTEM BY R * MFB
      DO 198  JJJ=1,3
      D2(L,JJJ) = 0.
      DO 198  K=1,3
  198 D2(L,JJJ) = -R(M,JJJ,K) * MFB(M,L,K) + D2(L,JJJ)
  197 DO 199  K=1,3
  199 JR(JS,L,K) = JR(JS,L,K) + D2(L,K)
  193 CONTINUE
  192 CONTINUE
  186 CONTINUE
      DO 503  L=1,NL
      WRITE(JWT,11)
      WRITE(JWT,370) L
      WRITE(JWT,406)
      WRITE(JWT,936) (HDG(L,I),I=1,20)
      WRITE(JWT,406)
      WRITE(JWT,504)
  504 FORMAT(43H          JOINT DISPLACEMENTS (GLOBAL SYSTEM))
      WRITE(JWT,505)
  505 FORMAT(54H      NO.    HORIZ.(IN)      VERT.(IN)      ROTATION(RAD.))
      DO 404  J=1,NJ
  404 WRITE(JWT,405) J,JD(J,L,1),JD(J,L,2),JD(J,L,3)
  405 FORMAT(4X,I2,4X,F10.6,6X,F10.6,5X,F10.6)
      WRITE(JWT,406)
  406 FORMAT(1H0)
      WRITE(JWT,407)
  407 FORMAT(51H          MEMBER END FORCES(K & IN.-K) (LOCAL SYSTEM))
      WRITE(JWT,408)
  408 FORMAT(65H                            A END
     1     B END)
      WRITE(JWT,409)
  409 FORMAT(78H      NO.      AXIAL       SHEAR       MOMENT          AXIAL
     1     SHEAR       MOMENT)
      DO 410  M=1,NMEM
      WRITE(JWT,411) M,(MFA(M,L,K),K=1,3),(MFB(M,L,J),J=1,3)
  411 FORMAT(4X,I2,2X,F10.3,5(2X,F10.3))
  410 CONTINUE
      WRITE(JWT,406)
      WRITE(JWT,412)
  412 FORMAT(50H          JOINT REACTIONS(K & IN.-K) (GLOBAL SYSTEM))
      WRITE(JWT,413)
  413 FORMAT(62H      NO.          HORIZONTAL             VERTICAL
     1MOMENT)
      DO 414  JS=1,NJS
      I = NE + JS - NJSR
      DO 511  K=1,3
  511 JR(JS,L,K) = -1. * JR(JS,L,K)
      WRITE(JWT,415) I, (JR(JS,L,K),K=1,3)
  415 FORMAT(4X,I2,7X,F12.3,7X,F12.3,7X,F12.3)
  414 CONTINUE
  503 CONTINUE
```

```
      RETURN
      END
```

```
      SUBROUTINE INVPL
      REAL  KBA,KBB,MFA,MFB,JD,JR,JL,JFA,JFB
      COMMON H(3,3),STIF(100,3,3),KBA(3,3),KBB(3,3),A(100,3,3),AINV(3,3)
     1 , JRI(70),JSI(15,3),LISTJS(15),LISTMR(40),MI(100,2),JI(100,7),JWT
     2 ,NMIJ(70),DX(100),DY(100),DL(100),R(100,3,3),X(70),Y(70),XA(100),
     3 XI(100),FLBB(3,3),FPLMA(3),FPLMB(3),FDLMA(3),FDLMB(3),G(3,3),JRD,
     4 D1(3,3),D2(3,3),D3(3,15),D4(3,3),RT(3,3),DPL(15),
     5 PLME(3,15),FPDMA(100,3,3),FPDMB(100,3,3),GT(3,3),JL(70,3),NT(100)
     6 ,JFA(70,3),JFB(70,3),FJF(70,3,3),LIST(70),B(70,3,3),JR(30,3,3),L,
     7 UA(210,3,3),JD(70,3,3),MFA(100,3,3),MFB(100,3,3),HDG(3,20),    IJ,
     8 E,DLI,NPLPOS,KK(40),DREL(40,2),VN(40,3,3),JKK,MRI(100),M,N
      INTEGER PL
C     SET UP UNIT MATRIX D2
      DO 211  K=1,JKK
      D2(K,K) = 1.
      DO 211  J=1,JKK
      IF(K-J) 212,211,212
  212 D2(K,J) = 0.
  211 CONTINUE
      JK =JKK-1
      DO 213  K=1,JK
      KP1 = K+1
C     CHECK TO SEE WHICH ROW HAS LARGEST ELEMENT
      LL = K
      DO 214  IL=KP1,JKK
      IF( ABS( A(IJ,IL,K) ) - ABS( A(IJ,LL,K) ) ) 214,214,215
  215 LL = IL
  214 CONTINUE
C     CHECK IF ROW HAS TO BE INTERCHANGED
      IF(LL-K) 216,216,217
C     INTERCHANGE ROW
  217 DO 218  J=K,JKK
      TEMPO = A(IJ,K,J)
      A(IJ,K,J) = A(IJ,LL,J)
  218 A(IJ,LL,J) = TEMPO
      DO 219  J=1,JKK
      TEMPO = D2(K,J)
      D2(K,J) = D2(LL,J)
  219 D2(LL,J) = TEMPO
C     ELIMINATION
  216 DO 213  IL=KP1,JKK
      FACTO = A(IJ,IL,K) / A(IJ,K,K)
      A(IJ,IL,K) = 0.
      DO 221  J=KP1,JKK
  221 A(IJ,IL,J) = A(IJ,IL,J) - FACTO * A(IJ,K,J)
      DO 213  J=1,JKK
  213 D2(IL,J) = D2(IL,J) - FACTO * D2(K,J)
C     BACK SUBSTITUTION
      DO 224  K=1,JKK
      AINV(JKK,K) = D2(JKK,K) / A(IJ,JKK,JKK)
      IL =JKK-1
  225 IP1 = IL+1
      SUM = 0.
      DO 226  J=IP1,JKK
  226 SUM = SUM + A(IJ,IL,J) * AINV(J,K)
      AINV(IL,K) = ( D2(IL,K)-SUM) / A(IJ,IL,IL)
      IL = IL-1
      IF(IL) 224,224,225
```

```
      SUBROUTINE RELPL
      REAL  KBA,KBB,MFA,MFB,JD,JR,JL,JFA,JFB
      COMMON H(3,3),STIF(100,3,3),KBA(3,3),KBB(3,3),A(100,3,3),AINV(3,3)
     1 , JRI(70),JSI(15,3),LISTJS(15),LISTMR(40),MI(100,2),JI(100,7),JWT
     2 ,NMIJ(70),DX(100),DY(100),DL(100),R(100,3,3),X(70),Y(70),XA(100),
     3 XI(100),FLBB(3,3),FPLMA(3),FPLMB(3),FDLMA(3),FDLMB(3),G(3,3),JRD,
     4 D1(3,3),D2(3,3),D3(3,15),D4(3,3),RT(3,3),DPL(15),
     5 PLME(3,15),FPDMA(100,3,3),FPDMB(100,3,3),GT(3,3),JL(70,3),NT(100)
     6 ,JFA(70,3),JFB(70,3),FJF(70,3,3),LIST(70),B(70,3,3),JR(30,3,3),L,
     7 UA(210,3,3),JD(70,3,3),MFA(100,3,3),MFB(100,3,3),HDG(3,20),    IJ,
     8 E,DLI,NPLPOS,KK(40),DREL(40,2),VN(40,3,3),JKK,MRI(100),M,N
      INTEGER PL
C     INSURE UNIT MATRIX IS INITIALIZED FOR H TRANSPOSE MTX.
      H(3,2) = 0.
      NRC = 0
C     CALCULATE NO. OF RELEASE COMPONENTS AT RELEASE POSITION K  IE. NRC
      DO 289  K=1,JKK
      H(2,3) = DL(M) - DREL(N,K)
      IF( ABS(H(2,3)).LT. 0.001 ) H(2,3)=0.
      DO 289  JJJ=1,3
      IF ( VN(N,JJJ,K) - 0. ) 289,289,1602
 1602 DO  1603  III=1,3
 1603 D2(1,III) = 0.
      D2(1,JJJ) = 1.
      NRC = NRC + 1
C     CALCULATE  HT * D2  & STORE IN G
      DO 291  KKK=1,3
      G(KKK,NRC) = 0.
      DO 291  III=1,3
  291 G(KKK,NRC) = H(KKK,III) * D2(1,III) + G(KKK,NRC)
  289 CONTINUE
C     CALCULATE  KBB * G  -STORE IN D1
      DO 290  III=1,3
      DO 290  JJJ=1,NRC
      D1(III,JJJ) = 0.
      DO 290  KKK=1,3
  290 D1(III,JJJ) = STIF(M,III,KKK) * G(KKK,JJJ) + D1(III,JJJ)
C     TRANSPOSE MTX. G AND STORE IN GT
      DO 491  III=1,3
      DO 491  KKK=1,NRC
  491 GT(KKK,III) = G(III,KKK)
C     CALCULATE  GT * D1  -STORE IN A(1) FOR INVERSION PURPOSE
      DO 292  III=1,NRC
      DO 292  JJJ=1,NRC
      A(1,III,JJJ) = 0.
      DO 292  KKK=1,3
  292 A(1,III,JJJ) = GT(III,KKK) * D1(KKK,JJJ) + A(1,III,JJJ)
C     OBTAIN INVERSE OF A(1)    -STORE IN AINV
      IF( NRC - 1 ) 801,801,802
  801 AINV(1,1) = 1.0 / A(1,1,1)
      GO TO 803
  802 IJ=1
      JKK = NRC
      CALL INVPL
C     CALCULATE G * AINV     -STORE IN D1
  803 DO 293  III=1,3
      DO 293  JJJ=1,NRC
      D1(III,JJJ) = 0.
```

```
      DO 293  KKK=1,NRC
  293 D1(III,JJJ) = G(III,KKK)*AINV(KKK,JJJ) +   D1(III,JJJ)
C     CALCULATE  D1 * GT   -STORE IN D2
      DO 294  III=1,3
      DO 294  JJJ=1,3
      D2(III,JJJ) = 0.
      DO 294  KKK=1,NRC
  294 D2(III,JJJ) = D1(III,KKK) * GT(KKK,JJJ) + D2(III,JJJ)
C     CALCULATE  D2 * STIF   -STORE IN D3
      DO 295  III=1,3
      DO 295  JJJ=1,3
      D3(III,JJJ) =0.
      DO 295  KKK=1,3
  295 D3(III,JJJ) = D2(III,KKK) * STIF(M,KKK,JJJ) + D3(III,JJJ)
      XX =  D3(3,3)- 1.0
      IF ( ABS(XX).LT.  0.001 ) D3(3,3)=1.0
      YY = D3(3,3) + .5
      IF ( ABS(YY).LT.  0.001 ) D3(3,3)=-.5
C     OBTAIN UNIT MATRIX FROM  H
      H(2,3) = 0.
      H(3,2) = 0.
C     CALCULATE  H - D3      -STORE IN D2
      DO 296  III=1,3
      DO 296  JJJ=1,3
  296 D2(III,JJJ) =   H(III,JJJ) - D3(III,JJJ)
C     CALCULATE STIF * D2      -STORE IN STIF(M)
C     FIRST EQUATE  STIF TO D3
      DO 297  III=1,3
      DO 297  JJJ=1,3
  297 D3(III,JJJ) = STIF(M,III,JJJ)
      WRITE(JWT,1701) ((( III,JJJ,D3(III,JJJ)),JJJ=1,3  ),III=1,3)
      DO 298  III=1,3
      DO 298  JJJ=1,3
      STIF(M,III,JJJ) = 0.
      DO 298  KKK=1,3
  298 STIF(M,III,JJJ) = D3(III,KKK) * D2(KKK,JJJ) + STIF(M,III,JJJ)
      IF( ABS(STIF(M,3,2)).LT.  0.01 ) STIF(M,3,2)=0.
C     STORE  KBB * G * AINV IN SLOT A(M)
C     NOTE (G * AINV) IN D1 ; KBB IN D3
      DO 300  III=1,3
      DO 300  JJJ=1,NRC
      A(M,III,JJJ) = 0.
      DO 300  KKK=1,3
  300 A(M,III,JJJ) = D3(III,KKK) * D1(KKK,JJJ) + A(M,III,JJJ)
      RETURN
      END
```

```
      SUBROUTINE SPACE
      REAL KBA,KBB,MFA,MFB,JD,JR,JL,JFA,JFB
      COMMON H(6,6),STIF(25,6,6),KBA(6,6),KBB(6,6),A(25,6,6),AINV(6,6),
     1   JRI(25),JSI( 5,6),LISTJS( 5),LISTMR(10),
     2MI(25,2),JI(25,10),NMIJ(15),DX(25),DY(25),DZ(25),DL(25),D5(6,6),
     3R(25,6,6),X(15),Y(15),Z(15),XA(15),XI1(25),XI2(25),D6(6,6),NL,NJ,
     4XI3(25),XG     ,FLBB(6,6),FPLMA(6),FPLMB(6),FDLMA(6),FDLMB(6),NE,
     5HDG(3,20)   ,G(6,6),D1(6,6),D2(6,6),D3(6,15),D4(6,6),RT(6,6),NMEM,
     6DPL(15),PLME(6,15),FPDMA(25,6,6),FPDMB(25,6,6),GT(6,6),JL(15,6),L,
     7JFA(15,6),JFB(15,6),FJF(15,6,6),LIST(15),B(15,6,6),NT(25),JWT,IJ,
     8JR(10,6,6),UA( 50,6,6),JD(15,6,6),MFA(25,6,6),MFB(25,6,6),JRD,M,
     9 E,DLI,NPLPOS,KK(10)   ,DREL(10,2),VN(10,6,6),JKK,MRI(25),N
      INTEGER  PL
      JRD = 5
      JWT = 6
      READ(JRD,936) ( HDG(1,I),I=1,20 )
      READ(JRD,3) E,XG,NL,NJ,NMEM,NJS,NJSR,NMR
    3 FORMAT(2F10.0,6(7X,I3))
      NE = NJ-NJS+NJSR
      WRITE(JWT,11)
   11 FORMAT(1H1)
      WRITE(JWT,4)
    4 FORMAT(49H                                 SPACE FRAME ANALYSIS)
      WRITE(JWT,406)
      WRITE(JWT,936) (HDG(1,I),I=1,20)
      WRITE(JWT,406)
      WRITE(JWT,5) E,NL
    5 FORMAT(30H MODULUS OF ELASTICITY (KSI.)=,F8.2,I8,13H LOAD CASE(S))
      WRITE(JWT,703) XG
  703 FORMAT(28H MODULUS OF RIGIDITY (KSI.)=,F8.2)
      WRITE(JWT,381) NJ, NMEM, NJS
  381 FORMAT(I3,1X,7H JOINTS,5X,I3,1X,8H MEMBERS,5X,I3,1X,9H SUPPORTS)
      WRITE(JWT,12) NJSR, NMR
   12 FORMAT(I3,1X,19H SUPPORT RELEASE(S),I8,1X,18H MEMBER RELEASE(S))
C     INPUT JOINT COODINATES, LET LOWEST LEFT JOINT BE THE ORIGIN
      WRITE(JWT,406)
      WRITE(JWT,627)
  627 FORMAT(54H                    JOINT COORDINATES (FT) (GLOBAL SYSTEM))
      WRITE(JWT,628)
  628 FORMAT(60H JOINT          COORD. 1              COORD. 2           COOR
     1D. 3)
      DO 1003  NN = 1,NJ
      READ(JRD,21) J,X(J),Y(J),Z(J)
   21 FORMAT( I10,3(10X,F10.0) )
   23 FORMAT( I4,3(10X,F8.2) )
      WRITE(JWT,23) J,X(J),Y(J),Z(J)
      X(J) = X(J) * 12.
      Y(J) = Y(J) *12.
      Z(J) = Z(J) * 12.
 1003 CONTINUE
C     GENERATE JI TABLE
      DO 1033  NN=1,NMEM
   10 FORMAT(I10,10X,2I10)
 1033 READ(JRD,10) I,MI(I,1),MI(I,2)
      WRITE(JWT,406)
      WRITE(JWT,13)
   13 FORMAT(15X,23H MEMBER INCIDENCE TABLE)
C     CALCULATE LENGTHS OF MEMBERS
```

```
      DO 24  I=1,NMEM
      JA = MI(I,1)
      JB = MI(I,2)
      DX(I) = X(JB) - X(JA)
      DY(I) = Y(JB) - Y(JA)
      DZ(I) = Z(JB) - Z(JA)
      DL(I) =  SQRT ( DX(I)*DX(I)  +  DY(I)*DY(I)  + DZ(I)*DZ(I)  )
   24 CONTINUE
      WRITE(JWT,629)
  629 FORMAT(37H MEMBER            A END           B END)
C     SET JOINT INCIDENCE TABLE = 0
      DO 16  J=1,NJ
      NMIJ(J) = 0
      DO 16  I=1,7
      JI(J,I) = 0
   16 CONTINUE
      DO 17  I=1,NMEM
      J = MI(I,1)
      NMIJ(J) = NMIJ(J) + 1
      JI( J,NMIJ(J) ) = -I
      J = MI(I,2)
      NMIJ(J) = NMIJ(J)+1
      JI( J,NMIJ(J) ) = I
      WRITE(JWT,15) I,MI(I,1),MI(I,2)
   15 FORMAT(1X,I3,13X,I3,12X,I3)
   17 CONTINUE
C     SET UP UNIT TRANSLATION MATRIX
      DO 83  I=1,6
      H(I,I) = 1.
      DO 83  J=1,6
      IF(I-J) 84,83,84
   84 H(I,J) = 0.
   83 CONTINUE
C     GENERATE ROTATION MATRIX, FIRST SET ROTATION MATRIX = 0.
      DO 26  M=1,NMEM
      XL = DX(M) / DL(M)
      XM = DY(M) / DL(M)
      XN = DZ(M) / DL(M)
      R(M,1,1) = XL
      R(M,2,1) = XM
      R(M,3,1) = XN
      DEN =  XL**2 + XN**2
      IF(DEN) 477,478,477
C     IF DEN IS 0 THEN MEMBER IS VERTICALLY ORIENTED
  478 R(M,1,2) = -1.
      R(M,2,2) = 0.
      R(M,3,2) = 0.
      R(M,1,3) = 0.
      R(M,2,3) = 0.
      R(M,3,3) = 1.
      GO TO 479
C     IF DEN IS + THEN MEMBER IS NOT VERTICALLY ORIENTED
  477 DEN = DEN**.5
      R(M,1,2) = -XL *XM / DEN
      R(M,2,2) = DEN
      R(M,3,2) = -XM*XN / DEN
      R(M,1,3) = -XN / DEN
      R(M,2,3) = 0.
```

```
      R(M,3,3) = XL / DEN
  479 DO 6  I=4,6
      DO 6  J=4,6
      JK = I-3
      JN = J-3
    6 R(M,I,J) = R(M,JK,JN)
      DO 7  I=1,3
      DO 7  J=4,6
    7 R(M,I,J) = 0.
      DO 8  I=4,6
      DO 8  J=1,3
    8 R(M,I,J) = 0.
   26 CONTINUE
C     XA = X-SECT. AREA
C     XI1 = MOMENT OF INERTIA ABOUT AXIS ALONG DIRECTION 1
C     XI2 AND XI3 ABOUT DIRECTIONS  2 AND 3 RESP.
C     XG = SHEAR MODULUS
      DO 1043  NN=1,NMEM
 1043 READ(JRD,821) M, XA(M), XI1(M), XI2(M), XI3(M)
  821 FORMAT(I5,5X,4F10.0)
      WRITE(JWT,406)
      WRITE(JWT,30)
   30 FORMAT(15X,18H MEMBER PROPERTIES)
      WRITE(JWT,630)
  630 FORMAT(47H MEMBER     X-SECT.       MOMENT OF INERTIA(IN.4))
      WRITE(JWT,1630)
 1630 FORMAT(49H   NO.     AREA(IN.2)    AXIS 1     AXIS 2     AXIS 3)
      WRITE(JWT,33) ( M,XA(M),XI1(M),XI2(M),XI3(M),M=1,NMEM )
   33 FORMAT( I4,4X,F8.2,4X,F8.2,2X,F8.2,2X,F8.2 )
C     SET UP JOINT SUPPORT RELEASE INDICATORS  IE. JSRI
      DO 230  N=1,NJ
      JRI(N)=0
  230 CONTINUE
      IF(NJSR) 228,228,229
  229 WRITE(JWT,406)
      WRITE(JWT,631)
  631 FORMAT(15X,27H SUPPORT RELEASE INDICATORS)
      WRITE(JWT,632)
  632 FORMAT(35H JOINT                         DIRECTION)
      WRITE(JWT,633)
  633 FORMAT(46H                         1    2    3    4    5    6)
      DO 231  N=1,NJSR
      READ(JRD,232) JS, (JSI(N,III),III=1,6)
  232 FORMAT (7I10)
      JRI(JS) = 1
      LISTJS(N) = JS
      WRITE(JWT,382) JS, (JSI(N,III),III=1,6)
  382 FORMAT( I4,12X,6(4X,I1) )
  231 CONTINUE
  228 CONTINUE
C     SET UP MEMBER RELEASE INDICATORS  IE  MRI(M)
      DO 640  M=1,NMEM
  640 MRI(M) = 0
      IF(NMR) 643,643,642
  642 WRITE(JWT,406)
      WRITE(JWT,635)
  635 FORMAT(15X,26H MEMBER RELEASE INDICATORS)
      WRITE(JWT,636)
```

```
  636 FORMAT(55H MEMBER     NO. OF REL.    DIST. FROM              DIRECTIONS)
      WRITE(JWT,637)
  637 FORMAT(70H                POSITIONS      A END(FT.)           1     2     3
     1    4     5     6)
      DO 643  N=1,NMR
      READ(JRD,644) M, KK(N), DREL(N,1),( VN(N,III,1),III=1,6 ), DREL(N,
     12), ( VN(N,JJJ,2),JJJ=1,6 )
  644 FORMAT (2I10,10X,F10.0,1X,6F1.0,3X,F10.0,1X,6F1.0 )
      MRI(M) = 1
      LISTMR(N) = M
      WRITE(JWT,645) M, KK(N), DREL(N,1), ( VN(N,III,1),III=1,6 )
  645 FORMAT( I4,I12,7X,F10.2,8X,6(3X,F2.0))
      DREL(N,1) = DREL(N,1) * 12.
      IF( KK(N) - 1 ) 643,643,646
  646 WRITE(JWT,647) DREL(N,2), ( VN(N,III,2),III=1,6 )
  647 FORMAT( 23X,F10.2,4X,6(2X,F2.0) )
      DREL(N,2) = DREL(N,2) * 12.
  643 CONTINUE
C     GENERATE STIFFNESS MATRIX  IE. KBB
      DO 34 M=1,NMEM
      DO 35  I=1,6
      DO 35  J=1,6
   35 STIF(M,I,J) = 0.
      DEN =  XI2(M) / XI3(M)
      STIF(M,1,1) =  E * XA(M) / DL(M)
      STIF(M,2,2) =  12. * E * XI3(M) / DL(M) **3
      STIF(M,3,3) =  DEN * STIF(M,2,2)
      STIF(M,4,4) = XG * XI1(M) / DL(M)
      STIF(M,6,6) =  4.* E * XI3(M) / DL(M)
      STIF(M,5,5) =  DEN * STIF(M,6,6)
      STIF(M,2,6) =  -6. * E * XI3(M) /   DL(M) **2
      STIF(M,6,2) =  STIF(M,2,6)
      STIF(M,3,5) =  6. * E * XI2(M) /  DL(M) **2
      STIF(M,5,3) =  STIF(M,3,5)
   34 CONTINUE
      DO 1620  N=1,NMR
      M = LISTMR(N)
      JKK = KK(N)
      CALL RELSP
 1620 CONTINUE
C     INITIALLY SET JOINT REACTIONS = 0.
      DO 54  L=1,NL
      DO 54  J=1,NJ
      DO 54  I=1,6
   54 JR(J,L,I) = 0.
      DO 1000  L=1,NL
      DO 1001  M=1,NMEM
      DO 1001  III=1,6
      FPDMA(M,L,III) = 0.
 1001 FPDMB(M,L,III) = 0.
 1000 CONTINUE
      DO 1002  L=1,NL
      READ(JRD,936) (HDG(L,I),I=1,20)
  936 FORMAT(20A4)
      WRITE(JWT,11)
      WRITE(JWT,370) L
  370 FORMAT(25X,13H LOADING CASE,I2)
      DO 65  J=1,NJ
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```
      DO 66  III=1,6
   66 JL(J,III) = 0.
   65 CONTINUE
      READ(JRD,676) NLM
      READ(JRD,676) NLJ
  676 FORMAT(27X,I3)
      IF( NLJ) 69,69,70
   70 WRITE(JWT,406)
      WRITE(JWT,376)
  376 FORMAT(10X,35H NON ZERO JOINT LOADS (KIPS & FT-K))
      WRITE(JWT,674)
  674 FORMAT(38H JOINT                              DIRECTION)
      WRITE(JWT,675)
  675 FORMAT(53H                  1       2       3       4       5       6)
      DO 71  K=1,NLJ
      READ(JRD,72) J, ( JL(J,III),III=1,6 )
   72 FORMAT( I5,5X,6F10.0 )
      WRITE(JWT,377) J, ( JL(J,III),III=1,6 )
  377 FORMAT(I5,2X,6(F8.2))
      JL(J,4) = JL(J,4) * 12.
      JL(J,5) = JL(J,5) * 12.
      JL(J,6) = JL(J,6) * 12.
   71 CONTINUE
   69 DO 55  JS=1,NJS
      J = NE + JS - NJSR
      DO 56  KKK=1,6
   56 JR(JS,L,KKK)= JL(J,KKK)
   55 CONTINUE
      DO 75  J=1,NJ
      DO 73  I=1,6
      JFA(J,I) = 0.
   73 JFB(J,I) = 0.
   75 CONTINUE
      IF( NLM ) 80,80,1004
 1004 WRITE(JWT,406)
      WRITE(JWT,9)
    9 FORMAT(20X,22H NON ZERO MEMBER LOADS)
      WRITE(JWT,671)
  671 FORMAT(79H MEMBER     DISTRIB. LOADS(K/FT.)
     1 CONCENT. LOADS(K&FT-K))
      WRITE(JWT,672)
  672 FORMAT(79H                 1    2    3    4   DIST. FROM      1     2
     1    3     4     5     6)
      WRITE(JWT,673)
  673 FORMAT(42H                                    A END(FT.))
      DO 1005  NN=1,NLM
      READ(JRD,1006) M, DLI, NPLPOS
 1006 FORMAT(I10,19X,F1.0,I20)
      IF(DLI) 284,284,282
C     READ IN DISTRIBUTED LOADS IN THE GLOBAL SYSTEM
C     MEASURE S AND T ALONG MEMBER LENGTH
  282 READ(JRD,283) D2(1,1), D2(2,1), D2(3,1), WM4, S, T
  283 FORMAT( 4F10.0,10X,2F10.0 )
      WRITE(JWT,375) M, D2(1,1), D2(2,1), D2(3,1), WM4
  375 FORMAT(I5,6X,4F5.2)
      IF( DX(M) ) 923,823,923
  923 D2(2,1) = D2(2,1) *   ( DX(M)**2 + DZ(M)**2 ) **0.5 / DL(M)
  823 IF( DY(M) ) 924,824,924
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```
  924 D2(1,1) = D2(1,1) *    ( DY(M)**2 + DZ(M)**2 )**0.5 / DL(M)
  824 IF( DZ(M) ) 925,825,925
  925 D2(3,1) = D2(3,1) *    ( DX(M)**2 + DY(M)**2 )**0.5 / DL(M)
  825 CONTINUE
C       DIST. LOAD CHANGED TO ACT ALONG LENGTH OF MEMBER IN GLOBAL SYSTEM
C       LOADING WM4 ORIGINALLY READ IN ALONG LENGTH OF MEMBER IN LOCAL
C       ROTATE LOADINGS  D2 INTO MEMBER SYSTEM
C       GENERATE A PORTION OF R TRANSPOSE
        DO 828  I=1,3
        DO 828  K=1,3
  828 RT(K,I) = R(M,I,K)
C       CALCULATE  R TRANSPOSE(PARTIAL) * D2   -INSERT IN SLOT D1
        DO 829  I=1,3
        D1(I,1) = 0.
        DO 829  K=1,3
  829 D1(I,1) = RT(I,K) * D2(K,1) + D1(I,1)
C       NOW HAVE ALL DIST. LOADS IN MEMBER SYSTEM IN KIPS PER INCH
        W1 = D1(1,1) / 12.
        W2 = D1(2,1) / 12.
        W3 = D1(3,1) / 12.
        S = S * 12.
        T = T * 12.
        IF ( MRI(M) ) 1007,1007,1008
 1008 DO 1830  N=1,NMR
        IF( M - LISTMR(N)) 1830,1631,1830
 1830 CONTINUE
 1631 JKK=KK(N)
        WRITE(JWT,1811) M,N
 1811 FORMAT(15H VALUES OF M&N=,2I3)
        NRC = 0
        DO 333  K=1,JKK
        IF( DREL(N,K) ) 334,334,335
C       RELEASE K MUST BE AT POSITION A
C       GENERATE CANTILEVER FORCE COMPONENTS AT RELEASE
  334 AA = DL(M) - S - T
        D4(1,1) =  W1 * AA
        D4(2,1) =  W2 * AA
        D4(3,1) =  W3 * AA
        D4(4,1) =  WM4 * AA
        D4(5,1) = -W3 * AA * ( S +  AA/2.)
        D4(6,1) = -W2 * AA * ( S +  AA/2.)
        GO TO 1633
  335 DO 1636  III=1,6
 1636 D4(III,1) = 0.
 1633 DO 1632  JJJ=1,6
        IF( VN(N,JJJ,K) - 0. ) 1634,1632,1634
 1634 DO 1635  III=1,6
 1635 D1(1,III) = 0.
        D1(1,JJJ) = 1.
        NRC = NRC + 1
        D2(NRC,1) = 0.
        DO 338  KKK=1,6
  338 D2(NRC,1) = D1(1,KKK) * D4(KKK,1) + D2(NRC,1)
 1632 CONTINUE
  333 CONTINUE
C       CALCULATE  A(M) * D2          -STORE IN D3
        DO 339  III=1,6
        D3(III,1) = 0.
```

```
      DO 339  KKK=1,NRC
  339 D3(III,1) = A(M,III,KKK) * D2(KKK,1) + D3(III,1)
C     SET UP D4 TO REPRESENT CANTILEVER DEFLECTION AT B END
      AA = DL(M) -T
      BB = AA**2
      CC = AA**3
      DD = AA**4
      EE = W2 / 6. / E / XI3(M)
      FF = W3 / 6. / E / XI2(M)
      GG = DD - S**4
      HH = T * CC - (S**3)*(DL(M)-S)
      D4(1,1) = W1/2./XA(M)/E * ( BB - S**2)
      D4(2,1) = 0.75*EE*(DD - S**4) + EE*( T*CC -(S**3)*( DL(M)-S ) )
      D4(3,1) = 0.75*FF*GG  +  FF*HH
      D4(4,1) = WM4 /2./ XG / XI1(M) *( BB - S**2)
      D4(5,1) =  FF *( S**3 - CC )
      D4(6,1) =  EE *( S**3 + CC )
C     CALCULATE  -STIF * D4      -STORE IN D1
      DO 340  III=1,6
      D1(III,1) = 0.
      DO 340  KKK=1,6
  340 D1(III,1) =  -STIF(M,III,KKK) * D4(KKK,1) + D1(III,1)
C     END FORCES AT B END ARE(D1 - D3)
      DO 341  III=1,6
  341 FDLMB(III)  =  D1(III,1) - D3(III,1)
C     CALCULATE FPLMA FROM STATICS
      DD = DL(M) - S - T
      FDLMA(1) =  -FDLMB(1) - W1*DD
      FDLMA(2) =  -FDLMB(2) - W2*DD
      FDLMA(3) =  -FDLMB(3) - W3*DD
      FDLMA(4) =  -FDLMB(4) - WM4*DD
      FDLMA(5) =  FDLMB(3)*DL(M) - FDLMB(5) + W3*DD*(S + .5*DD)
      FDLMA(6) =  -FDLMB(2)*DL(M) - FDLMB(6) - W2*DD*(S + .5*DD)
      GO TO 1023
 1007 AA = ( DL(M)-T )**2
      BB = AA**1.5
      CC = AA**2
      DD = S**3
      EE = S**4
      FF = CC - EE
      GG = T*BB - DL(M)*DD + EE
      DEN = (DD - BB) * DL(M)
      FDLMB(1)   = -0.5 * W1 / DL(M) * ( AA - S**2 )
      FDLMB(2)   =  W2/DL(M)**3 *(-1.5*FF -2.*GG - DEN)
      FDLMB(3)   =  W3/DL(M)**3 *(-1.5*FF -2.*GG - DEN )
      FDLMB(4)   =  -.5 * WM4 / DL(M) * ( AA - S**2 )
      FDLMB(5)   =  W3/DL(M)**2 *(-0.75*FF -GG -    2.*DEN/3.)
      FDLMB(6)   =  W2/DL(M)**2 *( 0.75*FF +GG + 2.*DEN/3.)
C     CALCULATE END FORCES AT A END FROM STATICS
      DD =  DL(M)-S-T
      FDLMA(1) = -FDLMB(1) - W1*DD
      FDLMA(2) = -FDLMB(2) - W2*DD
      FDLMA(3) = -FDLMB(3) - W3*DD
      FDLMA(4) = -FDLMB(4) - WM4*DD
      FDLMA(5) =  DL(M)*FDLMB(3) - FDLMB(5) + W3*DD*(S + .5*DD)
      FDLMA(6) =  -DL(M)*FDLMB(2) - FDLMB(6) - W2*DD*(S + .5*DD)
      GO TO 1023
  284 DO 280  J=1,6
```

```
      FDLMA(J) = 0.
      FDLMB(J) = 0.
  280 CONTINUE
 1023 IF ( NPLPOS ) 249,249,250
  250 IF ( MRI(M) ) 1013,1013,1014
C     SET UP D4 TO REPRESENT FORCE VECTOR AT RELEASE K FROM LOADS ON KB
C     GENERATE  R TRANSPOSE       -STORE IN RT
 1014 DO 402  III=1,6
      DO 402  KKK=1,6
  402 RT(KKK,III) = R(M,III,KKK)
      NRC = 0
C     READ IN POINT LOADS IN GLOBAL SYSTEM
C     DIST. TO POINT LOADS MEASURED ALONG MEMBER LENGTH FROM A END
      DO 306  PL=1,NPLPOS
      READ(JRD,307) DPL(N), (D3(III,PL),III=1,6)
  307 FORMAT (F10.0,10X,6F10.0 )
      WRITE(JWT,373)M,DPL(N),(D3(III,PL),III=1,6)
  373 FORMAT(I5,26X,F7.2,5X,3F7.2,3F6.2)
      DPL(PL) = DPL(PL) * 12.
      D3(4,PL) = D3(4,PL) * 12.
      D3(5,PL) = D3(5,PL) * 12.
      D3(6,PL) = D3(6,PL) * 12.
C     ROTATE GLOBAL FORCE VECTOR TO MEMBER FORCE VECTOR
      DO 403  III=1,6
      PLME(III,PL)= 0.
      DO 403  KKK=1,6
  403 PLME(III,PL)= RT(III,KKK) * D3(KKK,PL)+ PLME(III,PL)
  306 CONTINUE
      DO 305  K=1,JKK
C     SET UP D4 TO REPRESENT FORCE VECTOR AT RELEASE K FROM LOADS ON KB
      DO 304 III=1,6
  304 D4(III,1) =0.
      DO 1645  PL=1,NPLPOS
      DIFF = DPL(PL) - DREL(N,K)
      IF(DIFF ) 1645,308,308
C     GENERATE  H MTX. BETWEEN RELEASE POINT AND POSITION OF LOAD
  308 H(3,5) = 0.
      H(2,6) = 0.
      H(5,3) = -DIFF
      H(6,2) =  DIFF
C     CALCULATE  H * PLME     -STORE IN D1
      DO 309  III=1,6
      D1(III,1) = 0.
      DO 309  KKK=1,6
  309 D1(III,1) =    H(III,KKK) * PLME(KKK,PL)+ D1(III,1)
      DO 310  III=1,6
  310 D4(III,1) = D4(III,1) + D1(III,1)
 1645 CONTINUE
      DO 1637  JJJ=1,6
      IF( VN(N,JJJ,K) - 0. ) 1638,1637,1638
 1638 DO 1639  III=1,6
 1639 D1(1,III) = 0.
      D1(1,JJJ) = 1.
      NRC = NRC + 1
      D2(NRC,1) = 0.
      DO 1640  KKK=1,6
 1640 D2(NRC,1) = D1(1,KKK) * D4(KKK,1) + D2(NRC,1)
 1637 CONTINUE
```

```
  305 CONTINUE
C     CALCULATE KBB * G * AINV * D2     -STORE IN D3
C     NOTE THAT KBB * G * AINV IS STORED IN A(M)
      DO 312  III=1,6
      D3(III,1) = 0.
      DO 312  KKK=1,NRC
  312 D3(III,1) = A(M,III,KKK) * D2(KKK,1) + D3(III,1)
C     SET UP D4 TO REPRESENT CANTILEVER DEFLECTION AT B END
      DO 313  III=1,6
  313 D4(III,1) = 0.
      DO 314 PL=1,NPLPOS
C     GENERATE FLEXIBILITY MATRIX AT EACH POINT
      DO 315  III=1,6
      DO 315  JJJ=1,6
  315 FLBB(III,JJJ) = 0.
      FLBB(1,1) = DPL(PL)/ E / XA(M)
      FLBB(2,2) = DPL(PL)**3/3./E/XI3(M)
      FLBB(3,3) = XI3(M) * FLBB(2,2) / XI2(M)
      FLBB(4,4) = DPL(PL)/ XG / XI1(M)
      FLBB(5,5) = DPL(PL)/ E / XI2(M)
      FLBB(6,6) = DPL(PL)/ E / XI3(M)
      FLBB(2,6) = 1.5 * FLBB(2,2) / DPL(PL)
      FLBB(6,2) = FLBB(2,6)
      FLBB(5,3) =  1.5 * FLBB(3,3) / DPL(PL)
      FLBB(3,5) = -FLBB(5,3)
C     CALCULATE FLBB * PLME AT THAT POSITION       -STORE IN D2
      DO 316  III=1,6
      D2(III,1) = 0.
      DO 316  KKK=1,6
  316 D2(III,1) = FLBB(III,KKK) * PLME(KKK,PL)+ D2(III,1)
C     GENERATE (H TRANSPOSE) BETWEEN POINT LOAD AND END B OF MEMBER
      H(2,6) = DL(M) - DPL(PL)
      H(3,5) = -H(2,6)
      H(5,3) = 0.
      H(6,2) = 0.
C     CALCULATE (H TRANSPOSE) * D2      -STORE IN D1
      DO 317  III=1,6
      D1(III,1) = 0.
      DO 317  KKK=1,6
  317 D1(III,1) =   H(III,KKK) * D2(KKK,1) + D1(III,1)
      DO 318  III=1,6
  318 D4(III,1) = D4(III,1) + D1(III,1)
  314 CONTINUE
C     CALCULATE  (-KBB MODIFIED) * D4         -STORE IN D1
      DO 319  III=1,6
      D1(III,1) = 0.
      DO 319  KKK=1,6
  319 D1(III,1) = -STIF(M,III,KKK) * D4(KKK,1) + D1(III,1)
C     CALCULATE (D1-D3) TO GIVE B END FORCES DUE TO POINT LOADS
      DO 320  III=1,6
  320 FPLMB(III)   = D1(III,1) - D3(III,1)
C     CALCULATE FPLMA FROM STATICS
C     GENERATE HAB
      H(5,3) = -DL(M)
      H(6,2) =  DL(M)
      H(3,5) = 0.
      H(2,6) = 0.
C     CALCULATE -HAB * FPLMB AND STORE IN SLOT D1
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```
      DO 322  III=1,6
      D1(III,1) = 0.
      DO 322  KKK=1,6
  322 D1(III,1) =  -H(III,KKK) * FPLMB(KKK)  + D1(III,1)
C     INITIALIZE MATRIX D2
      DO 323  III=1,6
  323 D2(III,1) = 0.
      DO 506 PL=1,NPLPOS
      H(5,3) = -DPL(PL)
      H(6,2) = DPL(PL)
      H(3,5) = 0.
      H(2,6) = 0.
C     CALCULATE  -H * POINT LOAD       -STORE IN D3
      DO 324  III=1,6
      D3(III,1) = 0.
      DO 324  KKK=1,6
  324 D3(III,1) =   -H(III,KKK) * PLME(KKK,PL)+ D3(III,1)
      DO 325  III=1,6
  325 D2(III,1) = D2(III,1) + D3(III,1)
  506 CONTINUE
      DO 326  III=1,6
  326 FPLMA(III)    = D2(III,1) + D1(III,1)
  302 CONTINUE
      GO TO 1012
C     CALCULATE CANTILEVER DEFLECTION AT POINT B
C     INITIALIZE DUMMY MATRIX D4 AND FLEXIBILITY MATRIX FLBB
 1013 DO 251  I=1,6
  251 D4(I,1) = 0.
      DO 252  I=1,6
      DO 252  J=1,6
  252 FLBB(I,J) = 0.
      DO 253 PL=1,NPLPOS
C     READ IN POINT LOADS IN GLOBAL SYSTEM
C     DISTANCE TO POINT LOADS MEASURED ALONG LENGTH OF MEMBER FROM A END
      READ(JRD,307) DPL(PL),(D3(III,PL),III=1,6)
      WRITE(JWT,373)M,DPL(PL),(D3(III,PL),III=1,6)
      DPL(PL)= DPL(PL)* 12.
      D3(4,PL)= D3(4,PL)* 12.
      D3(5,PL)= D3(5,PL)* 12.
      D3(6,PL)= D3(6,PL)* 12.
C     ROTATE GLOBAL FORCE VECTOR TO MEMBER FORCE VECTOR
C     GENERATE R TRANSPOSE           -STORE IN RT
      DO 400  I=1,6
      DO 400  K=1,6
  400 RT(K,I) = R(M,I,K)
      DO 401  I=1,6
      PLME(I,PL)=0.
      DO 401  K=1,6
  401 PLME(I,PL)= RT(I,K) * D3(K,1) + PLME(I,PL)
C     GENERATE FLEXIBILITY MATRIX
      FLBB(1,1) = DPL(PL)/ E / XA(M)
      FLBB(2,2) =  DPL(PL)**3 / 3. / E / XI3(M)
      FLBB(3,3) =  XI3(M) * FLBB(2,2) / XI2(M)
      FLBB(4,4) = DPL(PL)/ XG / XI1(M)
      FLBB(5,5) =  DPL(PL)/ E / XI2(M)
      FLBB(6,6) =  DPL(PL)/ E / XI3(M)
      FLBB(2,6) =  1.5 * FLBB(2,2) / DPL(PL)
      FLBB(6,2) = FLBB(2,6)
```

```
      FLBB(3,5) =  -1.5 * FLBB(3,3) / DPL(PL)
      FLBB(5,3) =  FLBB(3,5)
C     CALCULATE FLBB * PLME AND STORE IN D2
      DO 270  I=1,6
      D2(I,1) = 0.
      DO 270  K=1,6
  270 D2(I,1) = FLBB(I,K) * PLME(K,PL)+ D2(I,1)
C     GENERATE H TRANSPOSE BETWEEN POINT LOAD AND END B OF MEMBER
      H(2,6) = DL(M) - DPL(PL)
      H(3,5) = -H(2,6)
      H(6,2) = 0.
      H(5,3) = 0.
C     CALCULATE H TRANSPOSE * SLOT D2
      DO 271  I=1,6
      D1(I,1) = 0.
      DO 271  K=1,6
  271 D1(I,1) = H(I,K) * D2(K,1) + D1(I,1)
      DO 272  I=1,6
  272 D4(I,1) = D4(I,1) + D1(I,1)
  253 CONTINUE
C     CALCULATE   -(STIF) * D4  TO GET  FPLMB
      DO 273  I=1,6
      FPLMB(I) = 0.
      DO 273  K=1,6
  273 FPLMB(I) =  -STIF(M,I,K) * D4(K,1) + FPLMB(I)
C     CALCULATE FPLMA FROM STATICS
C     GENERATE HAB
      H(2,6) = 0.
      H(3,5) = 0.
      H(6,2) = DL(M)
      H(5,3) = -DL(M)
C     CALCULATE -HAB * FPLMB AND STORE IN SLOT D1
      DO 274  I=1,6
      D1(I,1) = 0.
      DO 274  K=1,6
  274 D1(I,1) =  -H(I,K) * FPLMB(K) + D1(I,1)
C     INITIALIZE MATRIX D2
      DO 275  I=1,6
  275 D2(I,1) = 0.
      DO 276 PL=1, NPLPOS
      H(5,3) = -DPL(PL)
      H(6,2) =  DPL(PL)
      H(2,6) = 0.
      H(3,5) = 0.
C     CALCULATE -H * POINT LOAD AND STORE AS D3
      DO 277  I=1,6
      D3(I,1) = 0.
      DO 277  K=1,6
  277 D3(I,1) =  -H(I,K) * PLME(K,PL)+ D3(I,1)
      DO 278  I=1,6
  278 D2(I,1) =D2(I,1) + D3(I,1)
  276 CONTINUE
      DO 279  I=1,6
  279 FPLMA(I) = D2(I,1) + D1(I,1)
      GO TO 1012
  249 DO 248  J=1,6
      FPLMA(J) = 0.
      FPLMB(J) = 0.
```

```
  248 CONTINUE
C     CALCULATE FINAL MEMBER FORCES DUE TO DIST. & CONC. LOADS
 1012 DO 285  I=1,6
      FPDMA(M,L,I) = FPLMA(I) + FDLMA(I)
      FPDMB(M,L,I) = FPLMB(I) + FDLMB(I)
  285 CONTINUE
 1005 CONTINUE
C     MATRICES FPLMA,FPLMB,FDLMA,FDLMB CAN NOW BE USED AS DUMMY MATRICES
C     CALCULATION OF JOINT FORCES TO BE USED IN ANALYSIS
C     JFA MEANS JOINT FORCES DUE TO A END OF MEMBER
      DO 76  I=1,NMEM
      M = I
C     ROTATE F.E.F. AT A END INTO GLOBAL SYSTEM - STORE AS FPLMA
      DO 60  III=1,6
      FPLMA(III) = 0.
      DO 60  KKK=1,6
   60 FPLMA(III) = R(M,III,KKK) * FPDMA(M,L,KKK) + FPLMA(III)
      J = MI(I,1)
      DO 63  III=1,6
   63 JFA(J,III) = JFA(J,III) - FPLMA(III)
   76 CONTINUE
      DO 78  I=1,NMEM
      M = I
C     ROTATE F.E.F. AT B END INTO GLOBAL SYSTEM - STORE AS FPLMB
      DO 59  III=1,6
      FPLMB(III) = 0.
      DO 59  KKK=1,6
   59 FPLMB(III) = R(M,III,KKK) * FPDMB(M,L,KKK) + FPLMB(III)
      J = MI(I,2)
      DO 62 III=1,6
   62 JFB(J,III) = JFB(J,III) - FPLMB(III)
   78 CONTINUE
   80 DO 61  J=1,NJ
      DO 61  III=1,6
   61 FJF(J,L,III) = JFA(J,III) + JFB(J,III) + JL(J,III)
 1002 CONTINUE
      NK = 0
      DO 85  I=1,NE
      LIST(I) = NK
C     ZERO THE MATRICES IN THE I,TH ROW
      DO 86  K=1,NE
      DO 86  L=1,6
      DO 86  M=1,6
      A(K,L,M) = 0.
   86 CONTINUE
C     FIND KLOW AND KHIGH AT JOINT I
      KL = I
      KH = I
      JAY = NMIJ(I)
      DO 88  J=1,JAY
      JJ = JI(I,J)
      IF(JJ) 89,90,90
   89 M = -JJ
      K = 2
      GO TO 91
   90 M = JJ
      K = 1
   91 JJ = MI(M,K)
```

```
      IF(JJ-NE) 92,92,88
   92 IF(JJ-KH) 93,93,94
   94 KH = JJ
   93 IF(JJ-KL) 96,88,88
   96 KL = JJ
   88 CONTINUE
C     START GENERATION OF I, TH EQUATION
      DO 98  J=1,JAY
      M = JI(I,J)
      K = 2
      IF(M) 99,100,100
   99 M = -M
      K = 1
  100 II = MI(M,K)
      K = 3-K
      IJ = MI(M,K)
      IK=IJ
      DO 102  KKK=1,6
      DO 102  JJJ=1,6
  102 KBB(KKK,JJJ) = STIF(M,KKK,JJJ)
      JJ = JI(I,J)
      IF(JJ) 103,103,104
C     INSURE THAT UNIT MATRIX IS INITIALIZED
C     KAB =  -HAB * KBB
  103 H(3,5) = 0.
      H(2,6) = 0.
      H(5,3) =  -DL(M)
      H(6,2) =   DL(M)
      DO 208  KKK=1,6
      DO 208  JJJ=1,6
      KBA(KKK,JJJ) = 0.
      DO 208  III=1,6
  208 KBA(KKK,JJJ) = -( H(KKK,III)*STIF(M,III,JJJ) ) + KBA(KKK,JJJ)
C     ACTUALLY ABOVE IS KAB BUT IS INSERTED IN SLOT KBA
C     KAA = HAB * KBB * HABT   OR = -KBA*HABT
C     GENERATE H TRANSPOSE
      H(5,3) = 0.
      H(6,2) = 0.
      H(3,5) =  -DL(M)
      H(2,6) =  DL(M)
      DO 209  KKK=1,6
      DO 209  JJJ=1,6
      KBB(KKK,JJJ) = 0.
      DO 209  III=1,6
  209 KBB(KKK,JJJ) = -(KBA(KKK,III)*H(III,JJJ)) + KBB(KKK,JJJ)
      GO TO 105
  104 IF(IK-NE) 106,106,105
C     INSURE THAT UNIT MATRIX IS INITIALIZED
C     GENERATE H TRANSPOSE
  106 H(5,3) = 0.
      H(6,2) = 0.
      H(3,5) =  -DL(M)
      H(2,6) =  DL(M)
C     GOING TO CALCULATE   -KBB*(HABT)
      DO 210  KKK=1,6
      DO 210  JJJ=1,6
      KBA(KKK,JJJ) = 0.
      DO 210  III=1,6
```

```
  210 KBA(KKK,JJJ) = -( STIF(M,KKK,III)*H(III,JJJ) ) + KBA(KKK,JJJ)
  105 CONTINUE
C     FIRST CALCULATE  R * KBB
      DO 107  III=1,6
      DO 107  JJJ=1,6
      D1(III,JJJ) = 0.
      DO 107  KKK=1,6
  107 D1(III,JJJ) = R(M,III,KKK) * KBB(KKK,JJJ) + D1(III,JJJ)
C     GENERATE  R TRANSPOSE  IE. RT(KKK,III)
      DO 109  III=1,6
      DO 109  KKK=1,6
  109 RT(KKK,III) = R(M,III,KKK)
C     NOW CALCULATE  R*KBB*RT AND STORE IN D2
      DO 110  III=1,6
      DO 110  KKK=1,6
      D2(III,KKK) = 0.
      DO 110  JJJ=1,6
  110 D2(III,KKK) = D1(III,JJJ) * RT(JJJ,KKK) + D2(III,KKK)
C     FOR FINAL SUBMATRIX A ADD PREVIOUS VALUE OF MATRIX A
      DO 111  III=1,6
      DO 111  KKK=1,6
  111 A(II,III,KKK) = D2(III,KKK) + A(II,III,KKK)
      IF(IK-NE) 112,112,98
C     FIRST CALCULATE  R*KAB  NOTE THAT KAB IS IN SLOT KBA
  112 DO 113  III=1,6
      DO 113  JJJ=1,6
      D1(III,JJJ) = 0.
      DO 113  KKK=1,6
  113 D1(III,JJJ) = R(M,III,KKK) * KBA(KKK,JJJ) + D1(III,JJJ)
C     NOW CALCULATE  R*KAB*RT
      DO 114  III=1,6
      DO 114  KKK=1,6
      A(IJ,III,KKK) = 0.
      DO 114  JJJ=1,6
  114 A(IJ,III,KKK) = D1(III,JJJ) * RT(JJJ,KKK) + A(IJ,III,KKK)
   98 CONTINUE
C     CHECK FOR SUPPORT RELEASES
      MM = JRI(I)
      IF(MM) 833,833,834
  834 DO 1622  N=1,NJSR
      IF( I - LISTJS(N) ) 1622,1623,1622
 1622 CONTINUE
 1623 IF( JSI(N,1)) 836,836,837
  836 A(I,1,1) = 1000000000000.
  837 IF( JSI(N,2)) 838,838,839
  838 A(I,2,2) = 1000000000000.
  839 IF( JSI(N,3)) 840,840,841
  840 A(I,3,3) = 1000000000000.
  841 IF( JSI(N,4)) 842,842,843
  842 A(I,4,4) = 1000000000000.
  843 IF( JSI(N,5)) 844,844,845
  844 A(I,5,5) = 1000000000000.
  845 IF( JSI(N,6)) 846,846,833
  846 A(I,6,6) = 1000000000000.
  833 CONTINUE
C     INSERT JOINT FORCES INTO B MATRIX
C     REQUIRE  -,IVE SIGN SINCE  AX + B = 0.
      DO 115  L=1,NL
```

```
      DO 116  III=1,6
  116 B(I,L,III) = -FJF(I,L,III)
  115 CONTINUE
C     ELIMINATION ROUTINE
C     NT IS LENGTH OF NON-ZERO BAND TO RIGHT OF MAIN DIAGONAL
      NT(I) = KH-I
      IF(I-KL) 118,118,119
  119 KU = I-1
      DO 120  K=KL,KU
      IK = K
      JAY = NT(K)
      DO 121  M=1,6
      DO 121  N=1,6
  121 D1(M,N) = A(IK,M,N)
      IJ = K + NT(K) - I - NT(I)
      IF(IJ) 122,122,123
  123 NT(I) = NT(I) + IJ
  122 DO 124  J=1,JAY
      IJ = IK+J
      JJ = LIST(K) + J
      DO 126  N=1,6
      DO 126  M=1,6
  126 D3(N,M) = UA(JJ,N,M)
      DO 127  III=1,6
      DO 127  JJJ=1,6
  127 D2(III,JJJ) = A(IJ,III,JJJ)
      DO 128  III=1,6
      DO 128  JJJ=1,6
      A(IJ,III,JJJ) = 0.
      DO 128  KKK=1,6
  128 A(IJ,III,JJJ) = D1(III,KKK) * D3(KKK,JJJ) + A(IJ,III,JJJ)
      DO 130  III=1,6
      DO 130  JJJ=1,6
  130 A(IJ,III,JJJ) = A(IJ,III,JJJ) + D2(III,JJJ)
  124 CONTINUE
      DO 131  L=1,NL
      DO 132  III=1,6
  132 D2(L,III) = B(I,L,III)
      DO 133  III=1,6
  133 B(I,L,III) = 0.
      DO 134  III=1,6
      DO 134  KKK=1,6
  134 B(I,L,III) = D1(III,KKK) * B(K,L,KKK) + B(I,L,III)
      DO 135  III=1,6
  135 B(I,L,III) = B(I,L,III) + D2(L,III)
  131 CONTINUE
  120 CONTINUE
  118 IJ = I
      JKK=6
      CALL INVSP
      JAY = NT(I)
      NK = NK + NT(I)
      IF(JAY) 137,137,138
  138 DO 139  J=1,JAY
      IJ = IJ+1
      JJ = LIST(I) + J
      DO 140  III=1,6
      DO 140  KKK=1,6
```

```
      UA(JJ,III,KKK) = 0.
      DO 140  JJJ=1,6
  140 UA(JJ,III,KKK) = -AINV(III,JJJ) * A(IJ,JJJ,KKK) + UA(JJ,III,KKK)
  139 CONTINUE
  137 DO 141  L=1,NL
      DO 142  K=1,6
  142 D2(L,K) = B(I,L,K)
      DO 143  K=1,6
  143 B(I,L,K) = 0.
      DO 144  III=1,6
      DO 144  K=1,6
  144 B(I,L,III) = -AINV(III,K) * D2(L,K) + B(I,L,III)
  141 CONTINUE
   85 CONTINUE
      CALL BSUBSP
C     FINAL MEMBER FORCES = FIXED-END FORCES + CALCULATED MEMBER FORCES
      DO 186  L=1,NL
      DO 187  M=1,NMEM
      DO 187  K=1,6
      MFA(M,L,K) = FPDMA(M,L,K) + MFA(M,L,K)
      MFB(M,L,K) = FPDMB(M,L,K) + MFB(M,L,K)
  187 CONTINUE
C     CALCULATION OF JOINT SUPPORT REACTIONS
      DO 192  JS=1,NJS
      I = NE + JS - NJSR
      JAY = NMIJ(I)
      DO 193  J=1,JAY
      JJ = JI(I,J)
      IF(JJ) 194,195,195
  194 M = -JJ
C     ROTATE MFA TO GLOBAL SYSTEM BY R * MFA
C     STORE THE  -,IVE RESULT IN D2
      DO 196  JJJ=1,6
      D2(L,JJJ) = 0.
      DO 196  K=1,6
  196 D2(L,JJJ) = -R(M,JJJ,K) * MFA(M,L,K) + D2(L,JJJ)
      GO TO 197
  195 M = JJ
C     ROTATE MFB TO GLOBAL SYSTEM BY R * MFB
      DO 198  JJJ=1,6
      D2(L,JJJ) = 0.
      DO 198  K=1,6
  198 D2(L,JJJ) = -R(M,JJJ,K) * MFB(M,L,K) + D2(L,JJJ)
  197 DO 199  K=1,6
  199 JR(JS,L,K)=JR(JS,L,K) + D2(L,K)
  193 CONTINUE
  192 CONTINUE
  186 CONTINUE
      DO 503  L=1,NL
      WRITE(JWT,11)
      WRITE(JWT,370) L
      WRITE(JWT,406)
      WRITE(JWT,936) (HDG(L,I),I=1,20)
      WRITE(JWT,406)
      WRITE(JWT,504)
  504 FORMAT(31X,48H JOINT DISPLACEMENTS(GLOBAL SYSTEM - IN. & RAD.))
      WRITE(JWT,505)
  505 FORMAT(79H  NO.     DIR.1            DIR.2            DIR.3            DIR.4
```

```
     1       DIR.5          DIR.6)
      DO 404  J=1,NJ
  404 WRITE(JWT,405) J, (JD(J,L,III),III=1,6)
  405 FORMAT(I4,4X,F10.6,5(3X,F10.6))
      WRITE(JWT,406)
  406 FORMAT(1H0)
      WRITE(JWT,407)
  407 FORMAT(31X,40H MEMBER FORCES(LOCAL SYSTEM - K & IN.-K))
      WRITE(JWT,408)
  408 FORMAT(51H                                         A END OF MEMBER)
      WRITE(JWT,505)
      DO 410  M=1,NMEM
      WRITE(JWT,411) M, (MFA(M,L,K),K=1,6)
  411 FORMAT(1X,I3,1X,F10.3,5(3X,F10.3) )
  410 CONTINUE
      WRITE(JWT,406)
      WRITE(JWT,753)
  753 FORMAT(51H                                         B END OF MEMBER)
      WRITE(JWT,505)
      DO 754  M=1,NMEM
      WRITE(JWT,411) M, (MFB(M,L,K),K=1,6)
  754 CONTINUE
      WRITE(JWT,406)
      WRITE(JWT,412)
  412 FORMAT(31X,43H JOINT REACTIONS(GLOBAL SYSTEM - K & IN.-K))
      WRITE(JWT,505)
      DO 414  JS=1,NJS
      I = NE + JS - NJSR
      DO 511  K=1,6
  511 JR(JS,L,K)= -1.0 * JR(JS,L,K)
      WRITE(JWT,411) I, (JR(JS,L,K),K=1,6)
  414 CONTINUE
  503 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INVSP
      REAL KBA,KBB,MFA,MFB,JD,JR,JL,JFA,JFB
      COMMON H(6,6),STIF(25,6,6),KBA(6,6),KBB(6,6),A(25,6,6),AINV(6,6),
     1   JRI(25),JSI( 5,6),LISTJS( 5),LISTMR(10),
     2MI(25,2),JI(25,10),NMIJ(15),DX(25),DY(25),DZ(25),DL(25),D5(6,6),
     3R(25,6,6),X(15),Y(15),Z(15),XA(15),XI1(25),XI2(25),D6(6,6),NL,NJ,
     4XI3(25),XG     ,FLBB(6,6),FPLMA(6),FPLMB(6),FDLMA(6),FDLMB(6),NE,
     5HDG(3,20)   ,G(6,6),D1(6,6),D2(6,6),D3(6,15),D4(6,6),RT(6,6),NMEM,
     6DPL(15),PLME(6,15),FPDMA(25,6,6),FPDMB(25,6,6),GT(6,6),JL(15,6),L,
     7JFA(15,6),JFB(15,6),FJF(15,6,6),LIST(15),B(15,6,6),NT(25),JWT,IJ,
     8JR(10,6,6),UA( 50,6,6),JD(15,6,6),MFA(25,6,6),MFB(25,6,6),JRD,M,
     9 E,DLI,NPLPOS,KK(10)    ,DREL(10,2),VN(10,6,6),JKK,MRI(25),N
      INTEGER  PL
C     SET UP UNIT MATRIX D2
      DO 211  K=1,JKK
      D2(K,K) = 1.
      DO 211  J=1,JKK
      IF(K-J) 212,211,212
  212 D2(K,J) = 0.
  211 CONTINUE
      JK =JKK-1
      DO 213  K=1,JK
      KP1 = K+1
C     CHECK TO SEE WHICH ROW HAS LARGEST ELEMENT
      LL = K
      DO 214  IL=KP1,JKK
      IF( ABS( A(IJ,IL,K) ) - ABS( A(IJ,LL,K) ) ) 214,214,215
  215 LL = IL
  214 CONTINUE
C     LL INDICATES WHICH ROW HAS LARGEST ELEMENT
C     CHECK IF ROW HAS TO BE INTERCHANGED
      IF(LL-K) 216,216,217
C     INTERCHANGE ROW
  217 DO 218  J=K,JKK
      TEMPO = A(IJ,K,J)
      A(IJ,K,J) = A(IJ,LL,J)
  218 A(IJ,LL,J) = TEMPO
      DO 219  J=1,JKK
      TEMPO = D2(K,J)
      D2(K,J) = D2(LL,J)
  219 D2(LL,J) = TEMPO
C     ELIMINATION
  216 DO 213  IL=KP1,JKK
      FACTO = A(IJ,IL,K) / A(IJ,K,K)
      A(IJ,IL,K) = 0.
      DO 221  J=KP1,JKK
  221 A(IJ,IL,J) = A(IJ,IL,J) - FACTO * A(IJ,K,J)
      DO 213  J=1,JKK
  213 D2(IL,J) = D2(IL,J) - FACTO * D2(K,J)
C     BACK SUBSTITUTION
      DO 224  K=1,JKK
      AINV(JKK,K) = D2(JKK,K) / A(IJ,JKK,JKK)
      IL =JKK-1
  225 IP1 = IL+1
      SUM = 0.
      DO 226  J=IP1,JKK
  226 SUM = SUM + A(IJ,IL,J) * AINV(J,K)
      AINV(IL,K) = ( D2(IL,K)-SUM) / A(IJ,IL,IL)
```

```
      SUBROUTINE RELSP
      REAL KBA,KBB,MFA,MFB,JD,JR,JL,JFA,JFB
      COMMON H(6,6),STIF(25,6,6),KBA(6,6),KBB(6,6),A(25,6,6),AINV(6,6),
     1   JRI(25),JSI( 5,6),LISTJS( 5),LISTMR(10),
     2MI(25,2),JI(25,10),NMIJ(15),DX(25),DY(25),DZ(25),DL(25),D5(6,6),
     3R(25,6,6),X(15),Y(15),Z(15),XA(15),XI1(25),XI2(25),D6(6,6),NL,NJ,
     4XI3(25),XG     ,FLBB(6,6),FPLMA(6),FPLMB(6),FDLMA(6),FDLMB(6),NE,
     5HDG(3,20)   ,G(6,6),D1(6,6),D2(6,6),D3(6,15),D4(6,6),RT(6,6),NMEM,
     6DPL(15),PLME(6,15),FPDMA(25,6,6),FPDMB(25,6,6),GT(6,6),JL(15,6),L,
     7JFA(15,6),JFB(15,6),FJF(15,6,6),LIST(15),B(15,6,6),NT(25),JWT,IJ,
     8JR(10,6,6),UA( 50,6,6),JD(15,6,6),MFA(25,6,6),MFB(25,6,6),JRD,M,
     9 E,DLI,NPLPOS,KK(10)   ,DREL(10,2),VN(10,6,6),JKK,MRI(25),N
      INTEGER  PL
C     GENERATE  HAB TRANSPOSE
      H(6,2) = 0.
      H(5,3) = 0.
C     CALCULATE NO. OF RELEASE COMPONENTS AT RELEASE POSITION K  IE. NRC
      NRC = 0
      DO 289  K=1,JKK
C     SET UP H TRANSPOSE MTX. FROM RELEASE POSITION TO END POINT B
      H(2,6) = DL(M) - DREL(N,K)
      IF( ABS(H(2,6)).LT. 0.001 ) H(2,6)=0.
      H(3,5) = -H(2,6)
      DO 289  JJJ=1,6
      IF ( VN(N,JJJ,K) - 0. ) 289,289,1602
 1602 DO  1603  III=1,6
 1603 D2(1,III) = 0.
      D2(1,JJJ) = 1.
      NRC = NRC + 1
C     CALCULATE  HT * D2  & STORE IN G
      DO 291  KKK=1,6
      G(KKK,NRC) = 0.
      DO 291  JJJ=1,6
  291 G(KKK,NRC) = H(KKK,JJJ) * D2(1,JJJ) + G(KKK,NRC)
  289 CONTINUE
C     CALCULATE  KBB * G  -STORE IN D1
      DO 290  III=1,6
      DO 290  JJJ=1,NRC
      D1(III,JJJ) = 0.
      DO 290  KKK=1,6
  290 D1(III,JJJ) = STIF(M,III,KKK) * G(KKK,JJJ) + D1(III,JJJ)
C     TRANSPOSE MTX. G AND STORE IN GT
      DO 491  III=1,6
      DO 491  KKK=1,NRC
  491 GT(KKK,III) = G(III,KKK)
C     CALCULATE  GT * D1  -STORE IN A(1) FOR INVERSION PURPOSE
      DO 292  III=1,NRC
      DO 292  JJJ=1,NRC
      A(1,III,JJJ) = 0.
      DO 292  KKK=1,6
  292 A(1,III,JJJ) = GT(III,KKK) * D1(KKK,JJJ) + A(1,III,JJJ)
C     OBTAIN INVERSE OF A(1)    -STORE IN AINV
      IF( NRC - 1 ) 801,801,802
  801 AINV(1,1) = 1.0 / A(1,1,1)
      GO TO 803
  802 IJ=1
      JKK = NRC
      CALL INVSP
```

```
C     CALCULATE G * AINV    -STORE IN D1
  803 DO 293  III=1,6
      DO 293  JJJ=1,NRC
      D1(III,JJJ) = 0.
      DO 293  KKK=1,NRC
  293 D1(III,JJJ) = G(III,KKK)*AINV(KKK,JJJ) +   D1(III,JJJ)
C     CALCULATE  D1 * GT   -STORE IN D2
      DO 294  III=1,6
      DO 294  JJJ=1,6
      D2(III,JJJ) = 0.
      DO 294  KKK=1,NRC
  294 D2(III,JJJ) = D1(III,KKK) * GT(KKK,JJJ) + D2(III,JJJ)
C     CALCULATE  D2 * STIF   -STORE IN D3
      DO 295  III=1,6
      DO 295  JJJ=1,6
      D3(III,JJJ) =0.
      DO 295  KKK=1,6
  295 D3(III,JJJ) = D2(III,KKK) * STIF(M,KKK,JJJ) + D3(III,JJJ)
C     OBTAIN UNIT MATRIX FROM  H
      H(3,5) = 0.
      H(2,6) = 0.
      H(5,3) = 0.
      H(6,2) = 0.
C     CALCULATE  H - D3     -STORE IN D2
      DO 296  III=1,6
      DO 296  JJJ=1,6
  296 D2(III,JJJ) =   H(III,JJJ) - D3(III,JJJ)
C     CALCULATE STIF * D2     -STORE IN STIF(M)
C     FIRST EQUATE  STIF TO D3
      DO 297  III=1,6
      DO 297  JJJ=1,6
  297 D3(III,JJJ) = STIF(M,III,JJJ)
      DO 298  III=1,6
      DO 298  JJJ=1,6
      STIF(M,III,JJJ) = 0.
      DO 298  KKK=1,6
  298 STIF(M,III,JJJ) = D3(III,KKK) * D2(KKK,JJJ) + STIF(M,III,JJJ)
C     STORE  KBB * G * AINV IN SLOT A(M)
C     NOTE (G * AINV) IN D1 ; KBB IN D3
      DO 300  III=1,6
      DO 300  JJJ=1,NRC
      A(M,III,JJJ) = 0.
      DO 300  KKK=1,6
  300 A(M,III,JJJ) = D3(III,KKK) * D1(KKK,JJJ) + A(M,III,JJJ)
      RETURN
      END
```

```
      SUBROUTINE BSUBSP
      REAL KBA,KBB,MFA,MFB,JD,JR,JL,JFA,JFB
      COMMON H(6,6),STIF(25,6,6),KBA(6,6),KBB(6,6),A(25,6,6),AINV(6,6),
     1   JRI(25),JSI( 5,6),LISTJS( 5),LISTMR(10),
     2MI(25,2),JI(25,10),NMIJ(15),DX(25),DY(25),DZ(25),DL(25),D5(6,6),
     3R(25,6,6),X(15),Y(15),Z(15),XA(15),XI1(25),XI2(25),D6(6,6),NL,NJ,
     4XI3(25),XG    ,FLBB(6,6),FPLMA(6),FPLMB(6),FDLMA(6),FDLMB(6),NE,
     5HDG(3,20)  ,G(6,6),D1(6,6),D2(6,6),D3(6,15),D4(6,6),RT(6,6),NMEM,
     6DPL(15),PLME(6,15),FPDMA(25,6,6),FPDMB(25,6,6),GT(6,6),JL(15,6),L,
     7JFA(15,6),JFB(15,6),FJF(15,6,6),LIST(15),B(15,6,6),NT(25),JWT,IJ,
     8JR(10,6,6),UA( 50,6,6),JD(15,6,6),MFA(25,6,6),MFB(25,6,6),JRD,M,
     9 E,DLI,NPLPOS,KK(10)  ,DREL(10,2),VN(10,6,6),JKK,MRI(25),N
      INTEGER  PL
C     BACK SUBSTITUTION ROUTINE
C     SET JOINT REACTIONS = INITIAL JOINT LOADING
C     ALSO SET JOINT DISPLACEMENTS = 0.
      DO 145  L=1,NL
      DO 146  J=1,NJ
      DO 146  K=1,6
      JD(J,L,K) = 0.
  146 CONTINUE
      DO 147  M=1,NMEM
      DO 147  K=1,6
      MFA(M,L,K) = 0.
      MFB(M,L,K) = 0.
  147 CONTINUE
  145 CONTINUE
      DO 153  L=1,NL
      DO 148  II=1,NE
      I = NE-II+1
      IF(II-1) 150,150,151
  151 KU = NT(I)
      DO 152  K=1,KU
      JJ = LIST(I) + K
      IJ = I+K
      DO 154  KKK=1,6
  154 D2(L,KKK) = B(I,L,KKK)
      DO 155  KKK=1,6
  155 B(I,L,KKK) = 0.
      DO 156  III=1,6
      DO 156  KKK=1,6
  156 B(I,L,III) = B(I,L,III) + UA(JJ,III,KKK) * B(IJ,L,KKK)
      DO 157  III=1,6
  157 B(I,L,III) = D2(L,III) + B(I,L,III)
  152 CONTINUE
  150 JAY = NMIJ(I)
C     SET JOINT DISPLACEMENT = MATRIX IN B SLOT
      DO 158  K=1,6
      JD(I,L,K) = B(I,L,K)
  158 CONTINUE
      DO 159  J=1,JAY
      M = JI(I,J)
      MABS = IABS(M)
C     RECALL KBB AND R FOR THE J,TH MEMBER INCIDENT ON JOINT I
      DO 160  III=1,6
      DO 160  K=1,6
  160 RT(K,III) = R(MABS,III,K)
C     CALCULATE   R TRANSPOSE * B MATRIX    -STORE IN D1
```

```
      DO 162  K=1,6
      D1(L,K) = 0.
      DO 162  JJJ=1,6
  162 D1(L,K) = RT(K,JJJ) * B(I,L,JJJ) + D1(L,K)
      IF(M) 164,165,165
  164 M = -M
C     EQUATE D2 = D1
      DO 166  K=1,6
  166 D2(L,K) = D1(L,K)
C     GENERATE H TRANSPOSE FOR MEMBER M
      H(5,3) = 0.
      H(6,2) = 0.
      H(3,5) = -DL(M)
      H(2,6) =  DL(M)
C     CALCULATE  -(H TRANSPOSE) * D2 = NEW D1
      DO 167  K=1,6
      D1(L,K) = 0.
      DO 167  JJJ=1,6
  167 D1(L,K) = -( H(K,JJJ)*D2(L,JJJ) ) + D1(L,K)
C     CALCULATE  KBB * D1 = D2
  165 DO 168  K=1,6
      D2(L,K) = 0.
      DO 168  JJJ=1,6
  168 D2(L,K) = STIF(M,K,JJJ) * D1(L,JJJ) + D2(L,K)
C     CALCULATE  -H * D2 = D3
      H(3,5) = 0.
      H(2,6) = 0.
      H(5,3) = -DL(M)
      H(6,2) =  DL(M)
      DO 171  K=1,6
      D3(L,K) = 0.
      DO 171  JJJ=1,6
  171 D3(L,K) = -H(K,JJJ) * D2(L,JJJ) + D3(L,K)
C     CALCULATE MEMBER FORCE AT B END  IE. MFB
      DO 175  K=1,6
  175 MFB(M,L,K) = D2(L,K) + MFB(M,L,K)
C     CALCULATE MEMBER FORCE AT A END  IE. MFA
      DO 177  K=1,6
  177 MFA(M,L,K) = D3(L,K) + MFA(M,L,K)
  159 CONTINUE
  148 CONTINUE
  153 CONTINUE
      RETURN
      END
```