COMPUTER AIDED DESIGN OF STRUCTURES

IN THE ELASTIC AND PLASTIC REGIONS

USING THE FINITE ELEMENT METHOD

by

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ABSTRACT

COMPUTER AIDED DESIGN USING
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The objective of this thesis is to increase student awareness in regard to the Finite Element method and its application in the design of structures comprised of two force members. To achieve this goal, a set of computer programs wsa'developed to work in conjunction with each other to solve various design problems. In addition, classroom presentations, discussions and computer-room demonstrations were held in the last two years for two class offerings of the ME 807 Design of Mechanical Systems course.

After using the programs, the students offered a number of comments and suggestions which were the main considerations during the modification of the programs to meet the students' needs. A large number of "menus" and messages have been incorporated to make the programs as user-friendly as possible. Most intermediate calculations are performed during the time that the operator needs to input data. This reduces run-time significantly and maximizes the system's efficiency. In addition, all significant

data are permanently stored in data files to protect the operator from data loss during power or system failures.

The finite element theory principles and their applications in the design of structures utilizing two-force elements are explained in Chapter I. Chapter II presents the type of computer and support devices used, along with the manufacturer's utility software. Two structures are studied in Chapter III as a demonstration of the proper use of these programs under conditions of elastic and plastic behavior. The first is a two member statically indeterminant structure studied under two environmental conditions: first, at uniform temperature, second, with one of the members at an elevated temperature. The second is the study of a statically determinant C-frame having the advantages of structural symmetry. Conclusions on the effectiveness of the programs and recommendations for further expansion are presented in Chapter IV.

ACKNOWLEDGEMENTS

I dedicate this thesis to my parents Michael and Kalliopi for their constant support and encouragement.

I extend a most sencere thank you to my thesis advisor and department chairman Dr. Frank A. D'Isa whose patient guidance and inspiring enthousiasm were instrumental in the completion of this thesis. I also extend my gratitude to professors Frank A. D'Isa, Frank J. Tarantine and Daniel H. Suchora for their time and effort in serving as my defense committee.

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CHAPTER I

THE FINITE ELEMENT METHOD

Introduction

The Finite Element method of analysis of complex problems is based on the principle that the complex system (or structure, or circuit, etc.) can be divided in very small and yet finite'elements" whose collective behavior closely simulates the behavior of the total structure.

The complexity of this method arises from the fact that behavior characteristics of only the individual elements are known instead of the behavior of the total structure, Based on common variables, a system of equations which may describe the behavior of the whole structure can be written using the characteristics of each element, In the study of structures, one common variable is the dis placement of each node (connecting point between elements).' Figure 1 illustrates the effect of a force on the position of a node (node B). The displacement of the node from its original position is related to the strains induced in the members by the external force. Figure 2 shows a complete structure and the "finite elements" it is comprised of. This is known as analysis of trusses by the method of joints.[1]

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[1] F. P. Beer and R. E. Johnston, Vector Mechanics For Engineers (New York: McGraw-Hill,1977), pp.216, 217.

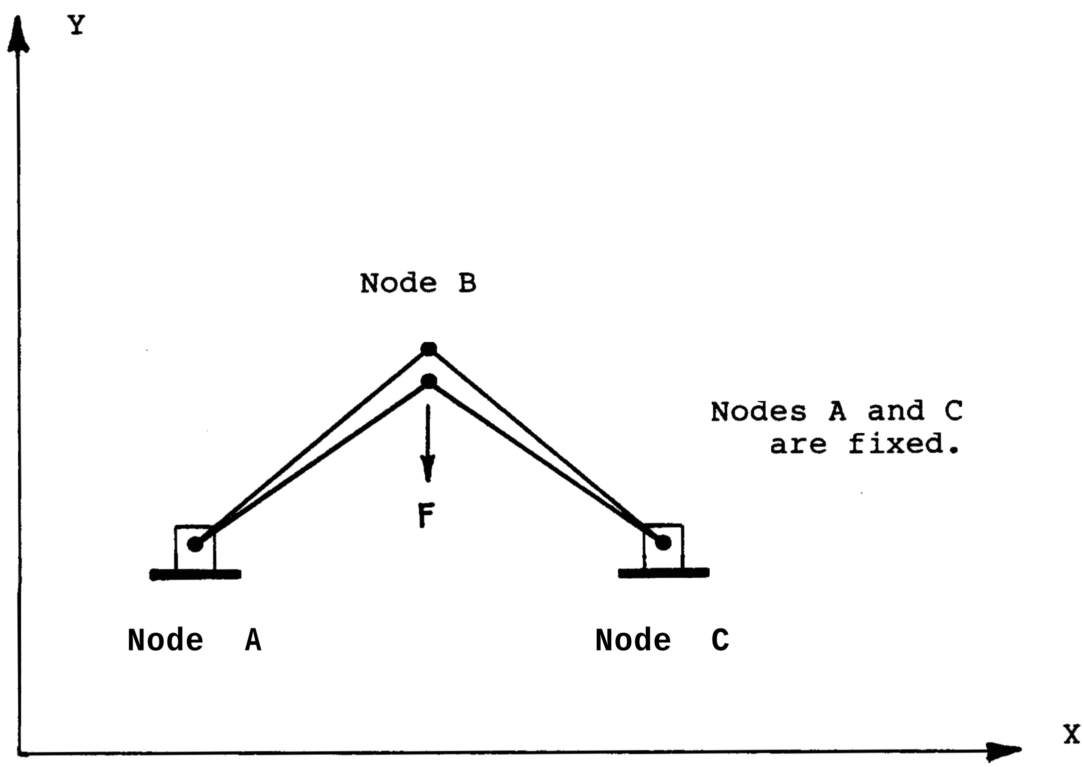

Fig. 1. Displacement of node B due to force F.

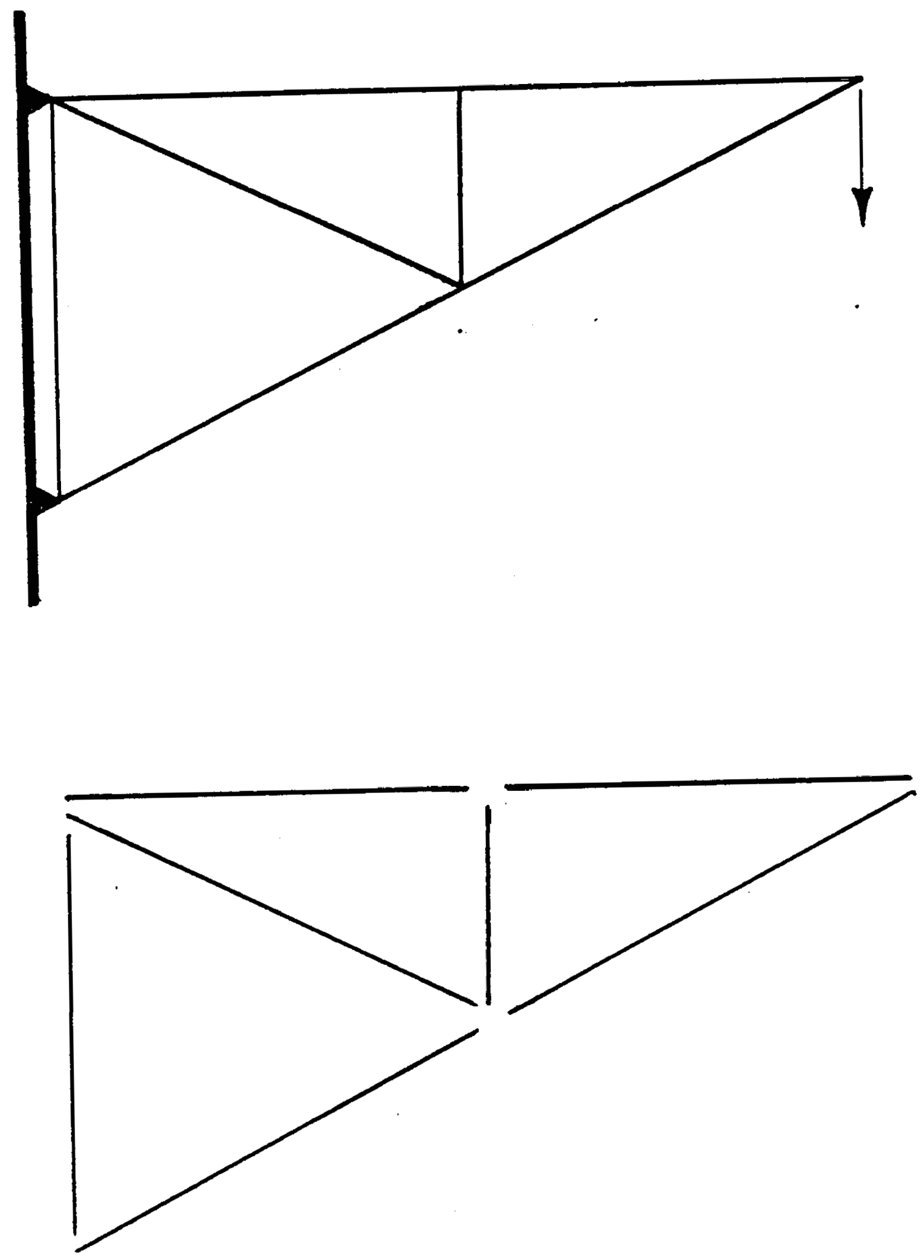

Fig. 2. Structure and its Finite Elements.

The development of the equations relating the displacements of the nodes to the external and internal forces is based on the principle of virtual displacements.[2] This principle states that the following equality must be satisfied for all virtual displacement increments:

$$dW\,[I] = dW\,[Internal] = dW\,[External] = dW\,[E]\,, \qquad (1)$$

where dW is the change in Work done. The terms of the above equation relate to the virtual displacements and external forces as follows:

dW = Force * displacement

dW [I] = Internal force * change in member length

dW [E] = (External force applied to node A * magnitude of vector displacement of node A) + (External force applied to node B * magnitude of vector displacement of node B)

considering the member of figure 3. The externally applied forces are known. The internal forces are the product of (A(i)*E(i) / L(i)) * (change in member length).[3] The magnitude of the vector displacements of the nodes, as well as the changes in the members' length are the common variables necessary to set up a system of equations, and represent the only set of unknowns.

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[2] J. N. Cernica, <u>Strength Of Materials</u> (New York: Holt, Rinehart and Winston, 1977), pp. 361, 362.

[3] Cernica, <u>Strength Of Materials</u>, pp. 33, eq. 1-7.

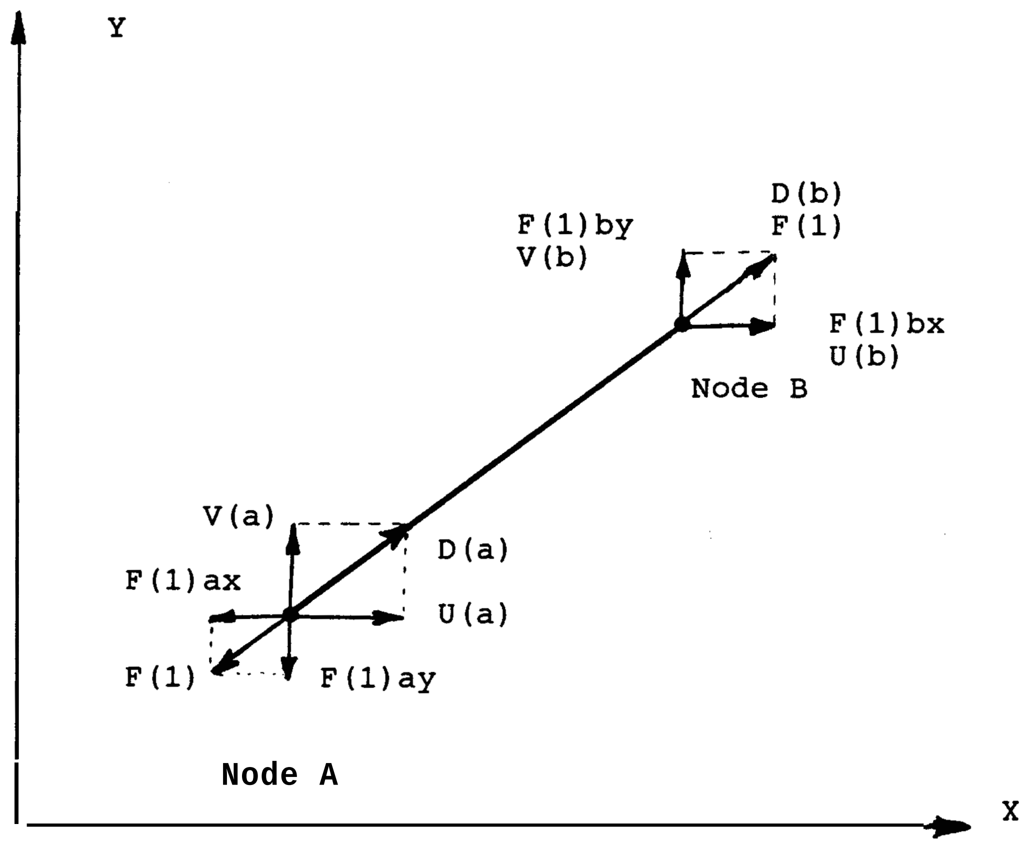

Fig. 3. Two-force member (AB).

Based on figure 3 and the convention that follows, a number of equations can be written for the member of this figure which represents the general case.

U(a) = Absolute displacement of node A in the x-dir'n.

V(a) = Absolute displacement of node A in the y-dir'n.

U(b) = Absolute displacement of node B in the x-dir'n.

V(b) = Absolute displacement of node B in the y-dir'n.

Th(1)= Angle between member 1 (AB) and x-axis.

D(a) = Magnitude of displacement vector of node A along the direction of the member.

D(b) = Magnitude of displacement vector of node B along the direction of the member.

F(1) = Force in member 1 (AB) due to the relative displacement of nodes A and B. A positive value indicates that the member is in tension.

F(1)ax = x-direction component of F(1) at node A.

F(1)ay = y-direction component of F(1) at node A.

F(1)bx and F(1)by apply to node B.

L(1) = Length of member 1 (AB)

= SQR [(Xb-Xa)^2 + (Yb-Ya)^2] [4] (2)

A(1) = Cross-sectional Area of member 1 (AB).

E(1) = Modulus of elasticity of member 1 (AB).

Also, sin(Th(1)) = [(Yb-Ya) / L(1)] (3)

and cos(Th(1)) = [(Xb-Xa) / L(1)] (4)

---

[4] Due to increasing popularity and convenience of presentation, all equations are presented in computer entry form.

EQUATIONS

D(a) = U(a) * cos(Th(1)) + V(a) * sin(Th(1)) (5)

D(b) = U(b) * cos(Th(1)) + V(b) * sin(Th(1)) (6)

F(1) = (A(1) * E(1) / L(1)) * (D(b) - D(a)) (7)

For node A : F(1)ax = -F(1) * cos (Th(1)) (8)

F(1)ay = -F(1) * sin (Th(1)) (9)

For node B : F(1)bx = F(1) * cos (Th(1)) (10)

F(1)by = F(1) * sin (Th(1)) (11)

By letting 1 = (A * E(1) / L(1)) , the "element equations" (8, 9, 10, 11) for member 1 become :

F(1)ax = K(1) * [(U(a)-U(b)) * cos^2(Th(1))
+ (V(a)-V(b)) * cos (Th(1)) * sin (Th(1))]

F(1)ay = K(1) * [(U(a)-U(b)) * cos (Th(1)) * sin (Th(1))
+ (V(a)-V(b)) * sin^2(Th(1))]

F(1)bx = K(1) * [(U(b)-U(a)) * cos^2(Th(1))
+ (V(b)-V(a)) * cos (Th(1)) * sin (Th(1))]

F(1)by = K(1) * [(U(b)-U(a)) * cos (Th(1)) * sin (Th(1))
+ (V(b)-V(a)) * sin^2(Th(1))]

All systems of equations similar to the one seen above can be written and solved as matrices.[5] The following is the matrix representation of the example and its solution using matrix techniques.

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[5] R. G. Budynas, Advanced Strength and Applied Stress Analysis (New York: McGraw-Hill, 1977), pp. 418, 419.

$$\begin{vmatrix} F(1)ax \\ F(1)ay \\ F(1)bx \\ F(1)by \end{vmatrix} = \underline{C} * \begin{vmatrix} U(a) \\ V(a) \\ U(b) \\ V(b) \end{vmatrix} \qquad (12)$$

$$\underline{C} = K(1) * \begin{vmatrix} \cos\hat{}2 & \cos * \sin & -\cos\hat{}2 & -\cos * \sin \\ \cos * \sin & \sin\hat{}2 & -\cos * \sin & -\sin\hat{}2 \\ -\cos\hat{}2 & -\cos * \sin & \cos\hat{}2 & \cos * \sin \\ -\cos * \sin & -\sin\hat{}2 & \cos * \sin & \sin\hat{}2 \end{vmatrix}$$

The above terms are related to each member's angle. All the external forces applied on a structure under study are always known. Also, the coefficient matrix is known. The only unknowns are the displacements of the nodes. As with any equation of the form $Y = C * X$, the solution for X is $X = (1/C) * Y$.[6] Since this is a system of equations represented in matrix form, the solution for the displacement matrix would be similar to $X = INV(C) * Y$ where INV(C) is the Inverse Matrix C. Applying this to the example, the solution is the matrix product of the inverse coefficient matrix and the external force matrix.

It is obvious that some nodes will be restricted (fixed) in one or both directions (x and y). Also, the coefficient matrix will be different if more than one member

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[6] Budynas, pp.429, eq. 8-34.

is considered. As an example, consider the structure shown in figure 1. This structure is comprised of two members (AB and BC) with nodes A and C fixed in both directions. The system of equations for AB contains coefficients for the displacements of nodes A and B (total of four equations). Similarly, there are four equations for member BC. When both are combined into one system of six equations with six unknowns, the coefficients of the variables which do not appear in the first set will be zero, and the coefficients of the variables which do not appear in the second set will be zero. There are, however, two forces (F(1)bx and F(2)by) common to both sets of equations. Of course, in other structures there may be more because more members may connect at the same node. The coefficients of these variables must be added because the equations are added.

Following the above method, the equations are written as a system of equations.

	U (a)		V (a)		U (b)		V (b)		U (c)		V (c)
F(1)ax	( )	+	( )	+	( )	+	( )	+	0	+	0
F(1)ay	( )	+	( )	+	( )	+	( )	+	0	+	0
F(1+2)bx	(+0)	+	(+0)	+	(+)	+	(+)	+	(0+)	+	(0+)
F(1+2)by	(+0)	+	(+0)	+	(+)	+	(+)	+	(0+)	+	(0+)
F(2)cx	0	+	0	+	( )	+	( )	+	( )	+	( )
F(2)cy	0	+	0	+	( )	+	( )	+	( )	+	( )

Note that force F(1+2)bx is the resultant external force acting at node B in the x direction. Similarly, force

F(1+2)by is the resultant external force acting at node B in the y direction. The boundary conditions must be accounted for before proceeding with the solution. Since the values of the U's and V's associated with nodes A and C are already known to be zero (fixed nodes), the coefficients of the equations involving forces present at nodes A and C must be adjusted. In this way, the coefficient matrix is adjusted according to the boundary conditions.

The proper way in matrix mathematics to make such an adjustment to a matrix without changing its size is to change the equations as shown below.

F(1)ax = 0 = U(a) + 0V(a) + 0U(b) + 0V(b) + 0U(c) + 0V(c)

F(1)ay = 0 = 0U(a) + V(a) + 0U(b) + 0V(b) + 0U(c) + 0V(c)

F(2)cx = 0 = 0U(a) + 0V(a) + 0U(b) + 0V(b) + U(c) + 0V(c)

F(2)cy = 0 = 0U(a) + 0V(a) + 0U(b) + 0V(b) + 0U(c) + V(c)

The final form of the coefficient matrix immediately before inversion is :

	U (a)		V (a)		U (b)		V (b)		U (c)		V (c)
F(1)ax	1	+	0	+	0	+	0	+	0	+	0
F(1)ay	0	+	1	+	0	+	0	+	0	+	0
F(1+2)bx	0	+	0	+	(+)	+	(+)	+	0	+	0
F(1+2)by	0	+	0	+	(+)	+	(+)	+	0	+	0
F(2)cx	0	+	0	+	0	+	0	+	1	+	0
F(2)cy	0	+	0	+	0	+	0	+	0	+	1

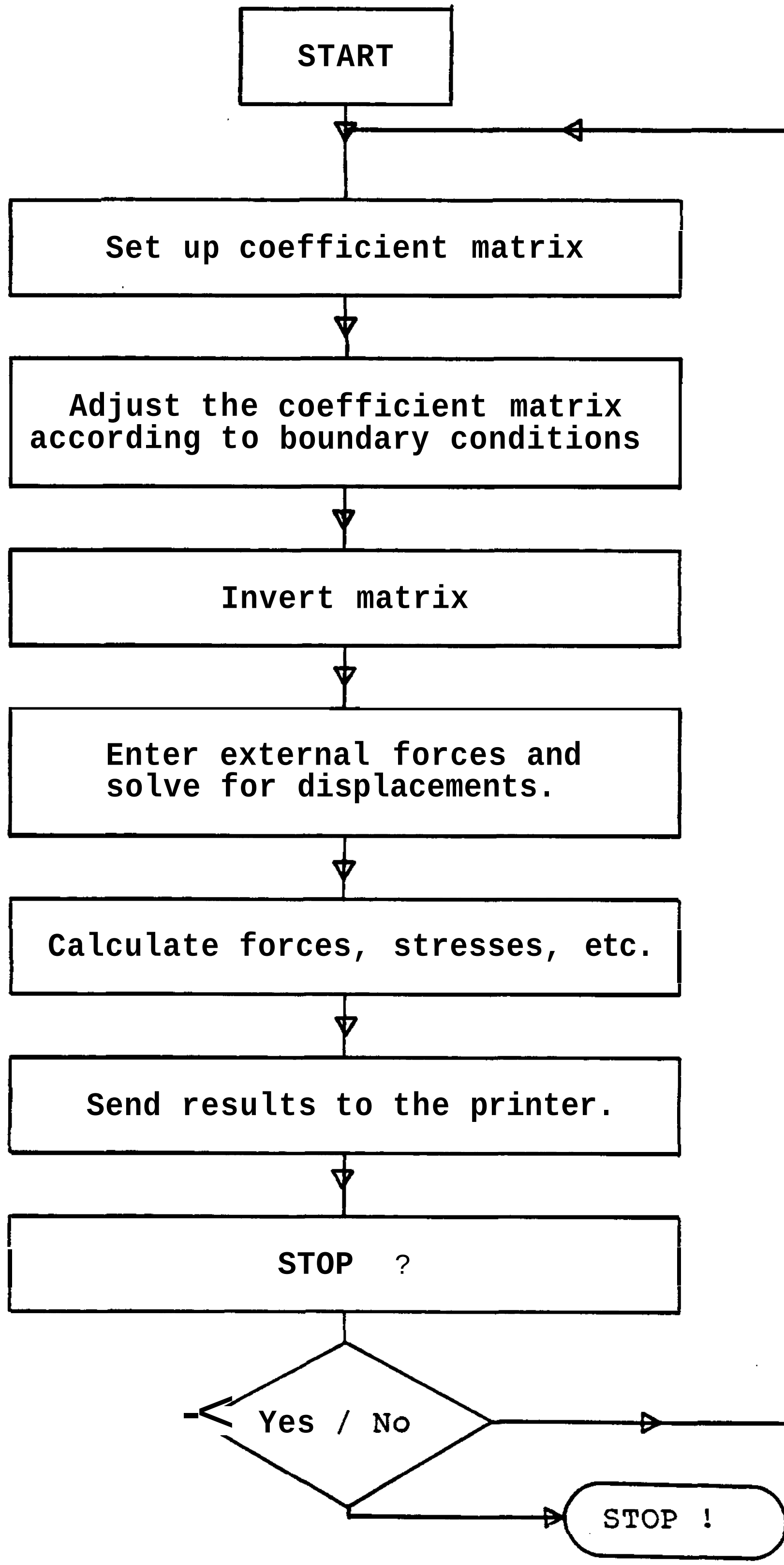

Fig. 4. Computerized solution algorithm.

After the U's and V's are calculated, the internal forces acting in the members can be calculated using the given equations. The stress in a member SS(i) = F(i)/A(i) and the strain SR(i) = SS(i)/E(i) can be calculated.

This method of solution can be computerized since it is standard and can be used repeatedly to solve systems of equations that result from the analyses of structures of the type of the example above. Figure 4 shows the algorithm of the computerized solution. The first step is the set-up of the coefficient matrix. This involves the use of the equations that calculate the 16 coefficients for each member of the structure. The second step involves the use of the boundary conditions to adjust the coefficients in the matrix. The third step is the matrix inversion. The solution to the equations follows as the result of matrix multiplication.

Plastic Region

Typically, the study of the behavior of a structure subjected to various loading conditions is complete when it extends to the point when one of the members buckles or ruptures causing the structure to collapse. This could happen in either region (elastic or plastic). A study in the plastic region involves the same structural geometry as in the elastic region (assuming small strains) but the modulus of elasticity changes for the members that have either yielded, buckled, or, ruptured.[7] In the case of pure yielding, a new value for a member's modulus of elasticity is calculated in the following way:

1) The value of the previous loading condition is used to calculate the new stress state of the yielded member.

2) The new stress value is used in the following formula to calculate the modulus of elasticity that will be used for this member during the next loading condition,

NE(i) = OE(i) * (5 * YS(i) - 3 * SS(I)) / (2 * YS(i)) (13)

where NE(i) is the new value and OE(i) is the value of the modulus of elasticity of the elastic region. If a member is unloading (the internal force is decreasing,) the value of NE(i) automatically becomes equal to OE(i) and remains as such until the stress state exceeds the point at which the member had started to unload,

All the changes in the values of the externally applied forces should be of the order of 1 % of the values which cause the highest stressed member of the structure to yield (elastic limit loads). Such small increments create small changes in the stress state of each member and promote higher accuracy in the calculation of the plastic region moduli of elasticity.

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[7] Frank A. D'Isa, Mechanics Of Metals (Reading, Massachusetts: Addison-Wesley, 1968), pp.182 and pp. 209.

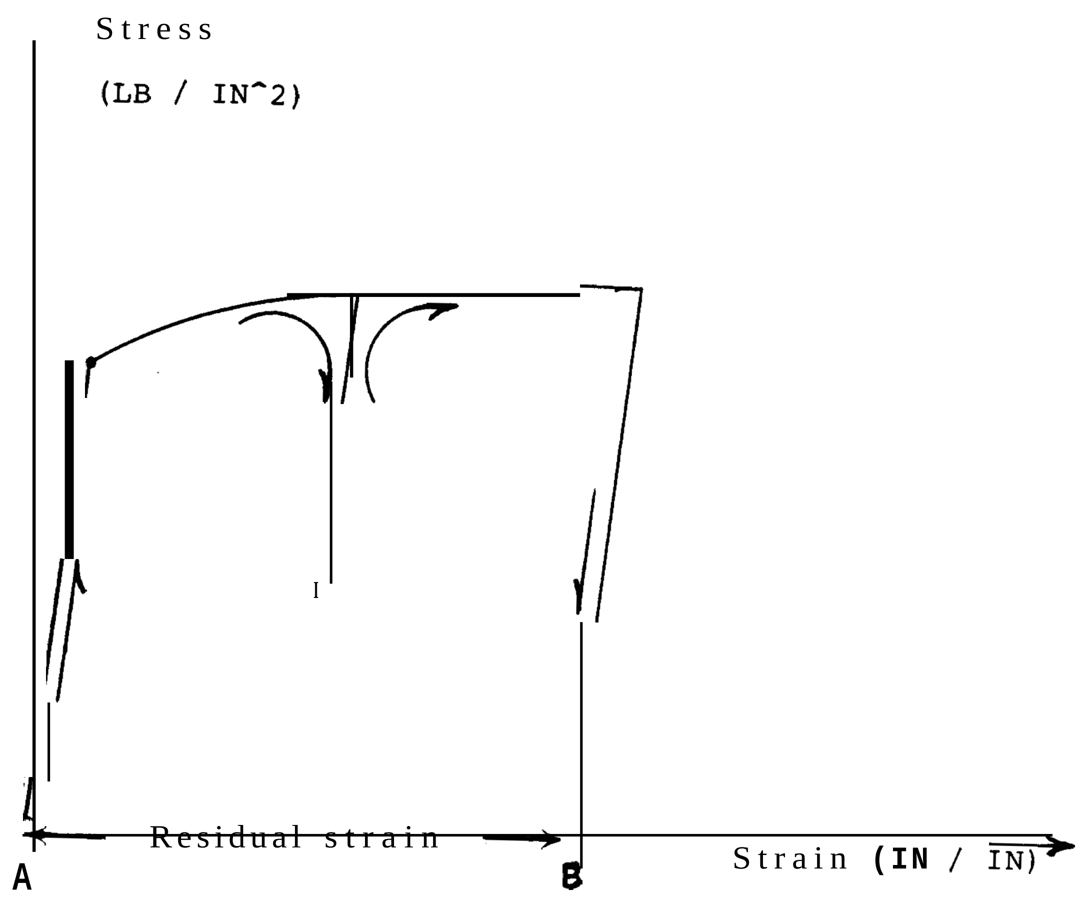

Fig. 5. Residual strain.

It is typical of loading tests to end with the unloading of the complete structure. This means that each and every externally applied force is reduced to zero. In order to do so, the new incremental forces are automatically set equal to the total negative value of each external force. Also, since all the members are unloading, all moduli of elasticity are replaced by the respective elastic moduli of elasticity. Such unloading causes the stress in every member to decrease to a residual stress which is the result of residual strain. Residual strain is the amount of strain that was not recovered during the unloading of the member because of the sudden change of its modulus of elasticity from the plastic region value to its elastic region value. Figure 5 is an example of the change of the value of the modulus of elasticity of a member due to loading past the yield point, some unloading, and complete unloading. Also, the amount of residual strain is indicated (AB).

Sometimes, a structure is loaded in such a way that one or more members exceed the rupture point. This may not cause the structure to collapse and further study may be desired. The most effective way to remove a ruptured member from a structure is to set its modulus of elasticity to zero. Loading may continue until the structure as a whole collapses or until the deflections of the nodes exceed the design specifications.

A wide variety of structures can be studied under a variety of loading conditions using the same set of programs. The behavior of two structures is studied in chapter III. The first is also an example of the way the programs operate. The second is the study of a C-frame.

Buckling

In addition to calculating the internal forces induced by the external forces and the boundary conditions, the programs calculate the buckling forces. These forces represent the maximum permissible compressive forces that the members can safely withstand. The equations used to calculate the buckling force for any simply connected member (i) are the following:

1) Elastic region equation (14) :

```
FB(i) = (-1) * [ (3.1415)^2 * OE(i) * MI(i) ] / (L(i))^2
      = (-1) * AR(i) * SS(i)
```

2) Plastic region equation (15) :

```
FB(i) = (-1) * AR(i) * (5* (3.14159)^2 * MI(i) * OE(i)
              * YS(i) ) / [ 2 * AR(i) * YS(i) * (L(i)^2)
              + 3 * (3.14159^2) * MI(i) * OE(i) ]
```

FB(i) is the buckling force, (-1) represents compression, OE(i) is the modulus of elasticity, MI(i) is the Minimum Moment of Inertia (about any axis of the plane of the cross-section) and L(i) is the length of the member. Equation (15) is the result of combining equation (14) with equation (13). When in the plastic region, the plastic modulus of elasticity must be used. Substituting NE(i) for OE(i) in equation (14) produces an equation with the term

SS(i) on both sides of the equal sign. Since SS(i) is needed to calculate FB(i), the resulting equation is solved for SS(i) to produce equation (15).

If the member force is greater than the buckling force (Fab > FB(i)), the member will buckle. The program always checks for this condition and if it is true it prompts the operator that the member should be removed from the structure if further study is desired. At this point, the value of the modulus of elasticity of the member is set to unity. This has the effect of reducing the load carried by the member to nearly zero without eliminating the member from the graphics or the printout of results. However, if the operator wishes not to proceed any further with the loading, the modulus of elasticity remains the same. This enables complete unloading of the structure for the evaluation of the residual'stresses.

Thermal Stresses

An important design factor is the effect of temperature differences among the members of a structure. Often, the assumption of constant temperature distribution in a structure is justified and can simplify a problem. However, temperature differences among members can change a design significantly. In some cases, the heat induced strains are more significant than those of externally applied forces. Also, the whole structure can be subjected to a uniform change in temperature. This is shown in chapter III in the study of a C-frame.

The programs presented here consider the effects of temperature in the following way:

1) It is assumed that all the materials' physical properties and structural geometry are specified for an average environment temperature.

2) Any temperature deviations are treated as positive or negative differences.

3) Since the systems of equations studied so far relate externally applied forces to the members' nodal displacements, the heat induced displacements are used to calculate equivalent externally applied forces.[8]

4) These equivalent forces are added to the specified forces and the system of equations is solved. The strains, stresses and forces acting in the members are found.

5) The net forces acting in the heated members are found by subtracting the equivalent forces from the calculated forces.

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[8] Frank A. D'Isa, Mechanics Of Metals (Reading, Massachusetts: Addison-Wesley, 1968), pp.112.

CHAPTER II

SOFTWARE AND HARDWARE

This chapter studies the computer programs, the system on which they were developed, and the operating system's software that are used in conjuction with them.

The main objective of the programming approach used in the computerization of the design process was to write user-friendly programs. Good user-friendly programs provide the operator with the maximum number of options available at any time during the design process. However, the development of a single program became impossible due to the large number of options and the system's limited memory capacity. So, the total design process was partitioned into seven main programs (in addition to the "housekeeping" files).

The first three programs solve design problems involving loads which do not exceed the yield strengths of the members. The next three programs are specialized versions of the previous three which solve problems that involve loads which are applied after one or more members have yielded. The seventh program is the Master Reset program. The following is a list of the programs:

1) "MATRIX1.BAS"

2) "MATRIX2.BAS"

3) "MATRIX3.BAS"

4) "M1.BAS"

5) "M2.BAS"

6) "M3.BAS"

7) "RESET.BAS"

Elastic Region

The above programs perform the following operations: "MATRIX1.BAS" inputs all the data and creates data files for permanent storage. It also sets up the coefficient matrix for the given system and adjusts it according to the specified boundary conditions. "MATRIX2.BAS" performs the inversion of the matrix. "MATRIX3.BAS" solves for the internal forces, stresses and strains in each member. If the operator wishes to extend the study of the structure into the plastic region, "MATRIX3.BAS" will recommend the values of the forces that will yield the weakest member of the structure (for the specified type of loading), Before proceeding to the plastic region, the recommended values must be used in the elastic region. This ensures that a yielding condition exists and tests for possible elastic region buckling before entering the plastic region,

Plastic Region

Since the structure's geometry remains the same in the plastic region (under the assumption of small strains).

as it was in the elastic region, "M1.BAS" automatically sets up the coefficient matrix (which is different every time due to changes in the modulus of elasticity). "M2.BAS" automatically inverts the matrix and "M3.BAS" requests the increments of the external forces and solves for forces, stresses, strains and new moduli of Elasticity.

"M3.BAS" also presents an elaborate menu similar to that of "MATRIX3.BAS". Full details of the various options can be found in the first test case of Chapter III. Listings of the programs and the program flowcharts can be found in the Appendices.

Utility Software

Since the computer uses a CP/M operating system, an amount of software (called utility software) can be accessed. SUBMIT.COM is one of the more important (and often underestimated) utilities. This software searches for a file specified by the operator and executes the commands spelled out in that file. For a specific cycle of operations, a very first "submit file" is permanently stored on disk and contains the commands necessary to initiate the design cycle. As the set of commands contained in the first file are executed, one of the basic programs creates a second submit file containing the specific options requested by the operator during the design process and also a command to return to the first file. By using submit files, the operator can simulate an endless loop and also access sofware available to the system without the need of typing a number of commands manually. For example:

First submit file name:FILE1.SUB

Second submit file name:FILE2.SUB

Basic program name:DESIGN.BAS

File FILE1.SUB contains:

```
MBASIC DESIGN.BAS
SUBMIT FILE2
```

File DESIGN.BAS contains:

```
10 REM   THIS IS A TEST PROGRAM TO DEMONSTRATE THE  USE
20 REM   OF THE SUBMIT UTILITY SOFTWARE.
30 REM
40
50
```

...

This is the part that may contain a design method and a menu of options available to the operator. For example, suppose that a graphics file was created by the name GRAPH.CMD and graphics were requested.

...

```
100 OPEN "O",#1,"FILE2.SUB"
110 PRINT #1,"CHART GRAPH.CMD"
120 PRINT #1,"SUBMIT FILE1"
130 CLOSE
140 REM
150 REM   Line 100 opens access to file "FILE2.SUB"
160 REM
170 REM   Line 110 prints a request to access the
180 REM   graphics software and graph file "GRAPH.CMD"
190 REM
200 REM   Line 120 requests access to the set of commands
210 REM   in file "FILE1.SUB" and completes the cycle:
```

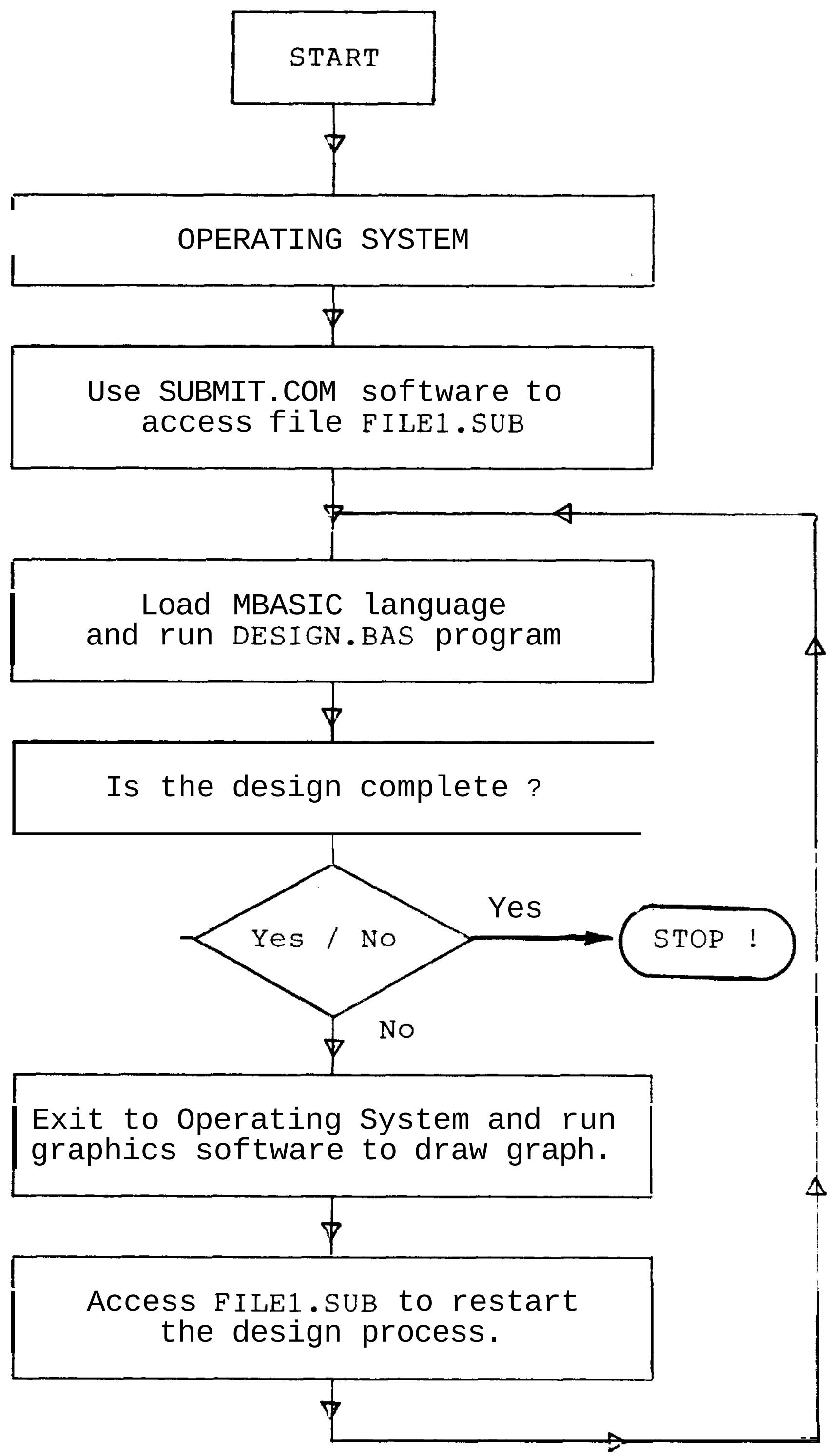


Fig. 6. Flow of operations.

```
220 REM
230 REM   Line 130 terminates access to file. (Closes the
240 REM   file.)
250 SYSTEM
260 REM   The above command turns control over to the
270 REM   system which will continue by submitting file
280 REM   "FILE2.SUB". This file contains the commands
290 REM   for the options selected in this program.
300 END
```

The flowchart of figure 6 demonstrates the flow of operations of the above example.

A list of the software available to the operating system is in Appendix E. The software used in this design are:

1) SUBMIT.COM — Automatically executes specified commands.
2) MBASIC.COM — By Microsoft. Runs programs written in BASIC language.
3) CHART.COM — Uses graphics files to create drawings.
4) PRINTER.PRL — Specifies the output port number.
5) USER.PRL — Specifies one of 15 users' program directories. USER 0 indicates that operations are at the System Level. This permits access to all software.

The first case of Chapter III is given as an example of the operation of the programs and the use of the related software.

The Hardware

The computer system shown in Figures 7 and 8 is a Z-80 based microprocessor system. It has 64,000 bytes of on-board Random Access Memory (RAM) and operates on typical CP/M software. It has the capability of using a number of units that include a printer, a plotter and a high resolution C.R.T. A list of the system's technical characteristics is given in Appendix A. Figure 7 shows (from left to right) console #2, the printer, the computing device with the dual disk drive and the printer/plotter switch. The console is a standard communications terminal. The printer is an 80 column dot-matrix EPSON model MX-80. The switch shown on top of the computer switches an output line between the printer and the plotter. The dark unit below the computer is the dual disk drive. It uses 8-inch double-sided soft sectored flexible disks. The combined storage capacity is approximately 3,000,000 bytes (3 Mega-bytes). Behind the computer there is a main power outlet with a line filter and a single ON/OFF switch. Figure 8 shows console #1, the plotter and the graphics C.R.T. The plotter is a TEKTRONIX model with a plotting area resolution of 1024 by 780 points. It uses standard 11 by 19 inch paper. The C.R.T. console is used as an "output-only" device and has the same characteristics as the plotter since they come from the same manufacturer and were designed to operate together.

Fig. 7. Computer console.

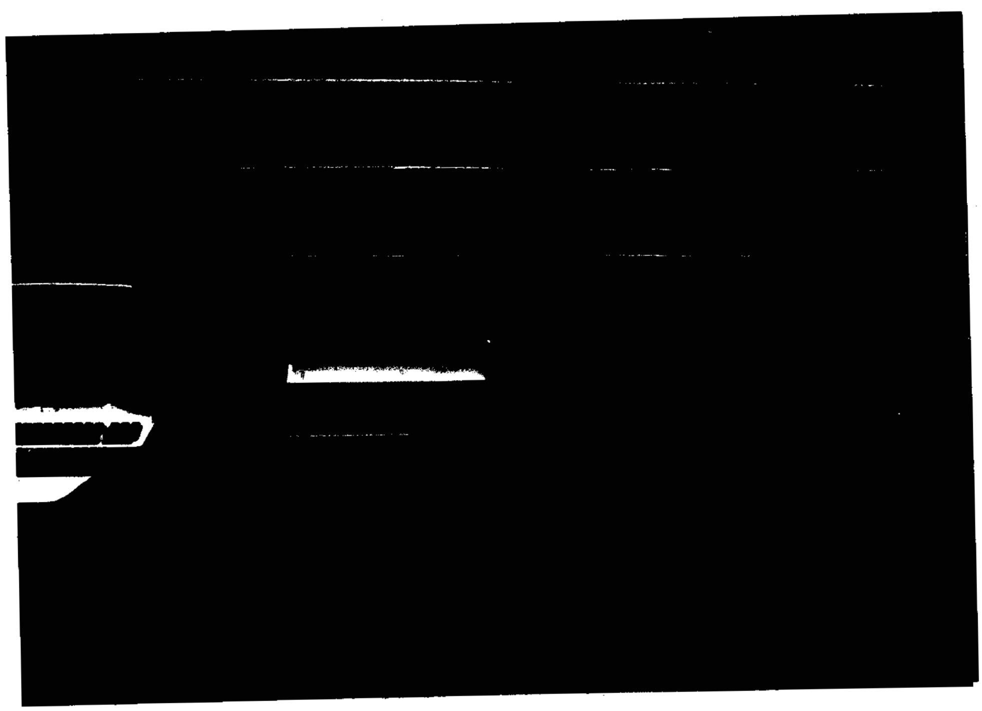


Fig. 8. Peripheral devices.

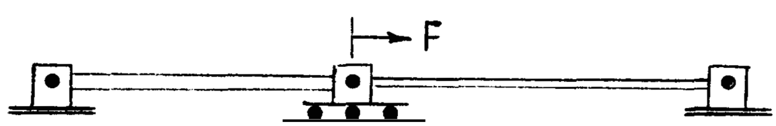
CHAPTER III

APPLICATIONS

Test Case

As an example of the operation of the computer programs, a test case is given as the first part of this chapter. It is the study of a two member structure which serves as an operator's guide on the use of the programs and the computer system hardware. The second part of the chapter involves the design of a C-frame. It is a representative example of the advantage of structural symmetry in problem size reduction.

The first structure is shown below. It is comprised of two members under axial loading. The material in use is steel. The material's properties and structural geometry data are listed below.



Node 1 Node 2 Node 3

Fig. 9. Test case

TABLE 1

NODAL POINT DATA

Node #	(x,y)	Fixed x-dir.	Fixed y-dir.
I	(0,0)	YES	YES
2	(15,0)	NO	YES
3	(35,0)	YES	YES

Member # 1

Nodes : 1,2 (Length = 15 inches)

Modulus of elasticity = 30 million LBS/IN^2

Yield strength = 40000 LBS/IN^2

Rupture strength = 67000 LBS/IN^2

Smallest moment of inertia = .1440 IN^4

Cross-sectional area = 1.440 IN^2

Specific weight = .283 LBS/IN^3

Temperature difference = 0.0 °F.

Thermal expansion coefficient = 6 millionths (IN/IN/°F)

Member # 2

Nodes : 2,3 (Length = 20 inches)

Modulus of elasticity = 30 million LBS/IN^2

Yield strength = 40000 LBS/IN^2

Rupture strength = 67000 LBS/IN^2

Smallest moment of inertia = .08333 IN^4

Cross-sectional area = 1.0 IN^2

Specific weight = .283 LBS/IN^3

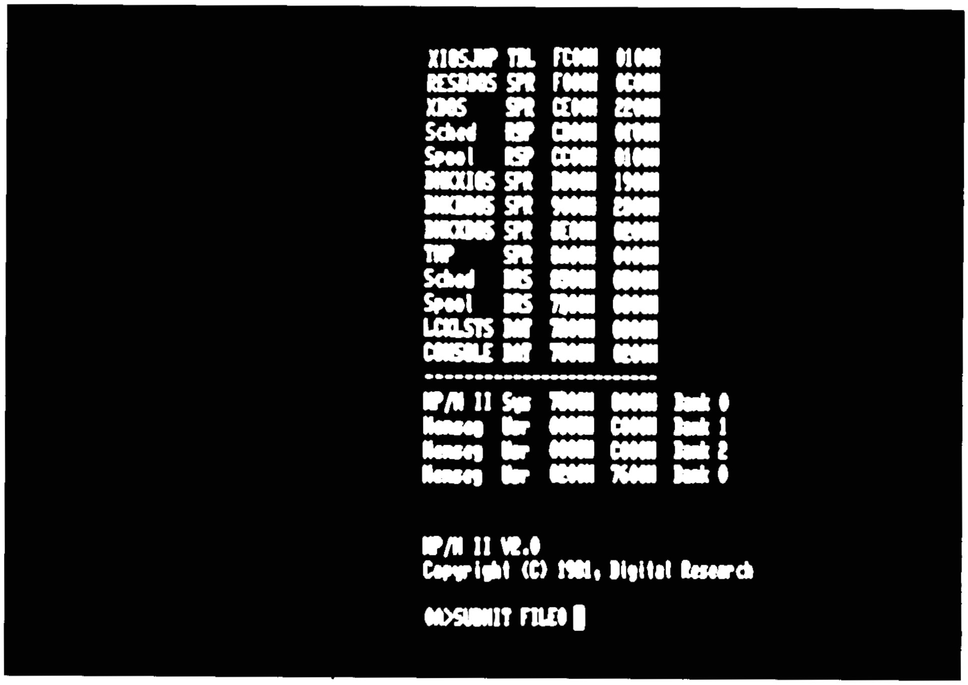


Fig. 10. System diagnostics.

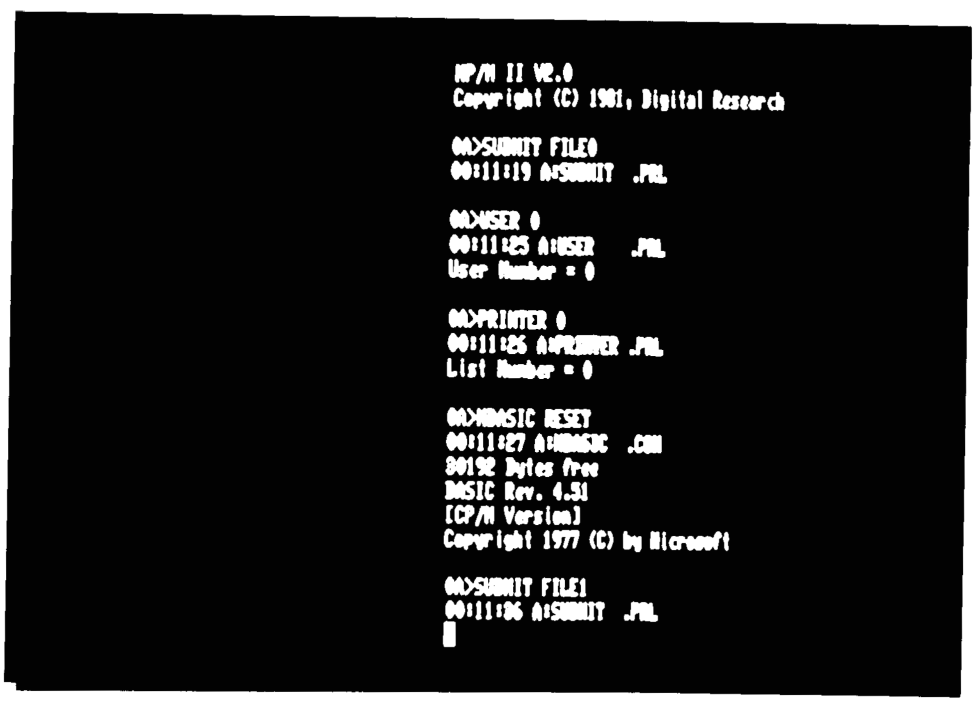


Fig. 11. Program initiation.

Temperature difference = 0.0 °F.

Thermal expansion coefficient = 6 millionths (IN/IN/°F)

In order to use the programs, all the above data must be entered and stored on disk as a data file. To initiate the process and run the programs, type the following command:

0A>SUBMIT FILEO

For the log-on procedure preceding this command, see the instructions sheet in Appendix B. The log-on procedure produces the system-diagnostics messages that appear in figure 10. Figure 11 shows the system's response to the SUBMIT FILEO command. FILEO is a master command file which resets the system and creates and runs FILE1. USER 0 permits access to system software such as the PRINTER 0 command which establishes communications with the printer. Note that printer 1 is the graphics console. The basic program 'RESET.BAS' is the one that creates 'FILE1.SUB' as part of the master-reset procedure.

The first file will submit the second and the menu of figure 12 appears on the screen. The first option is used to specify a new structure. The second considers the same structure with the same boundary conditions but runs the third program called 'MATRIX3.BAS' which requests new external loading. The third option (QUIT) is rather self-explanatory.

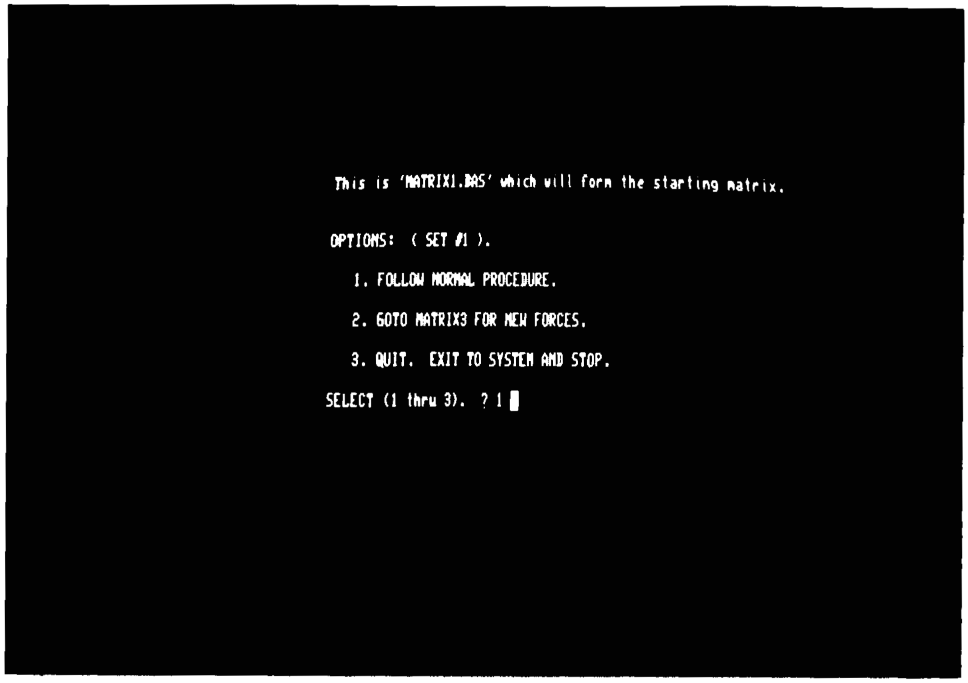


Fig. 12. Initial options.

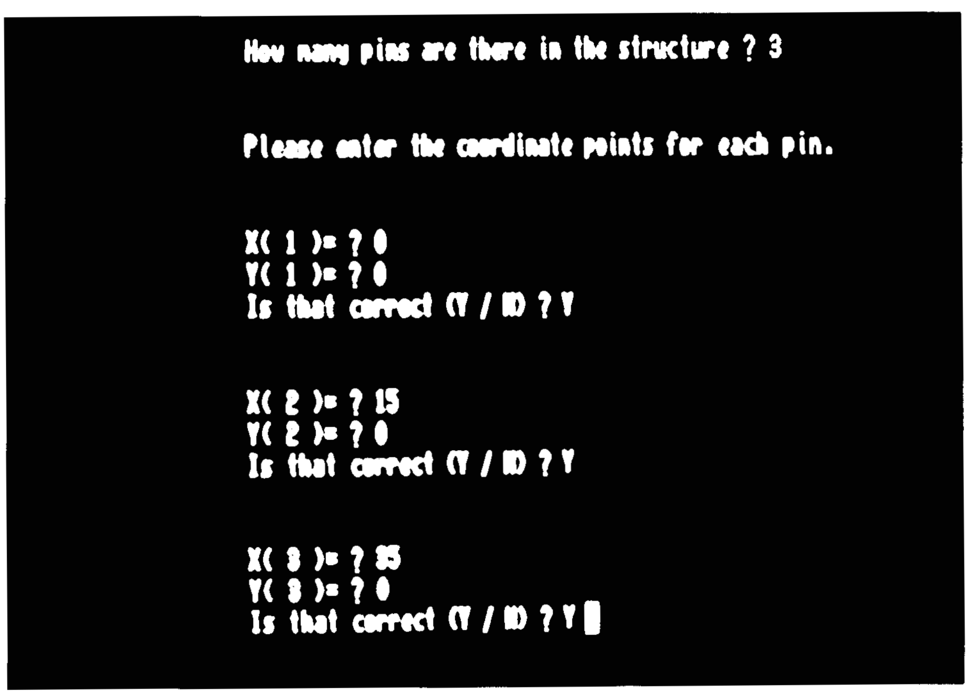


Fig. 13. Node specification.

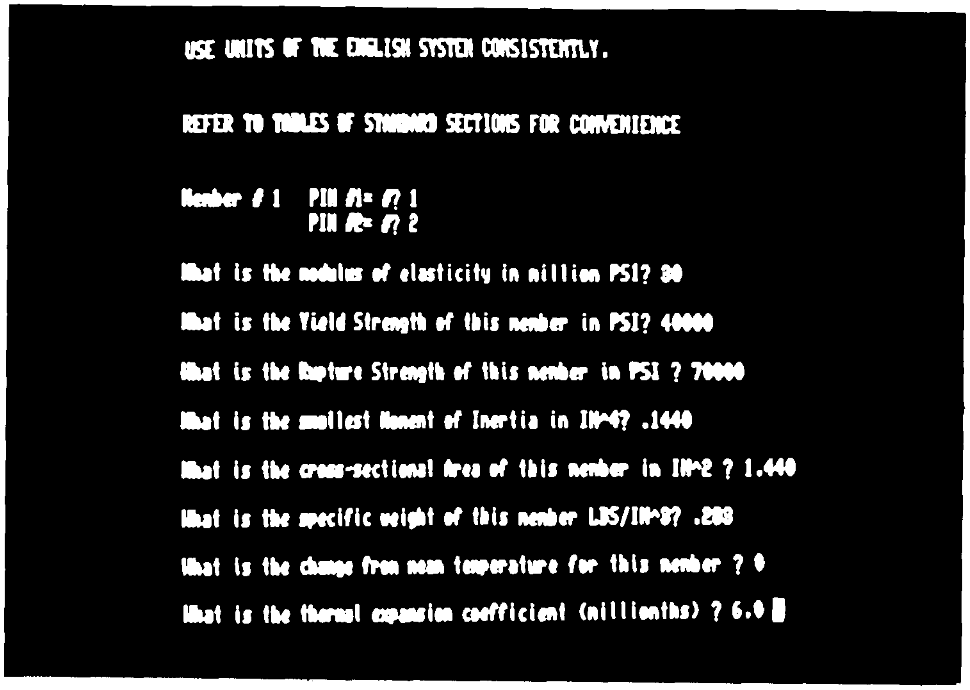


Fig. 14. Material properties.

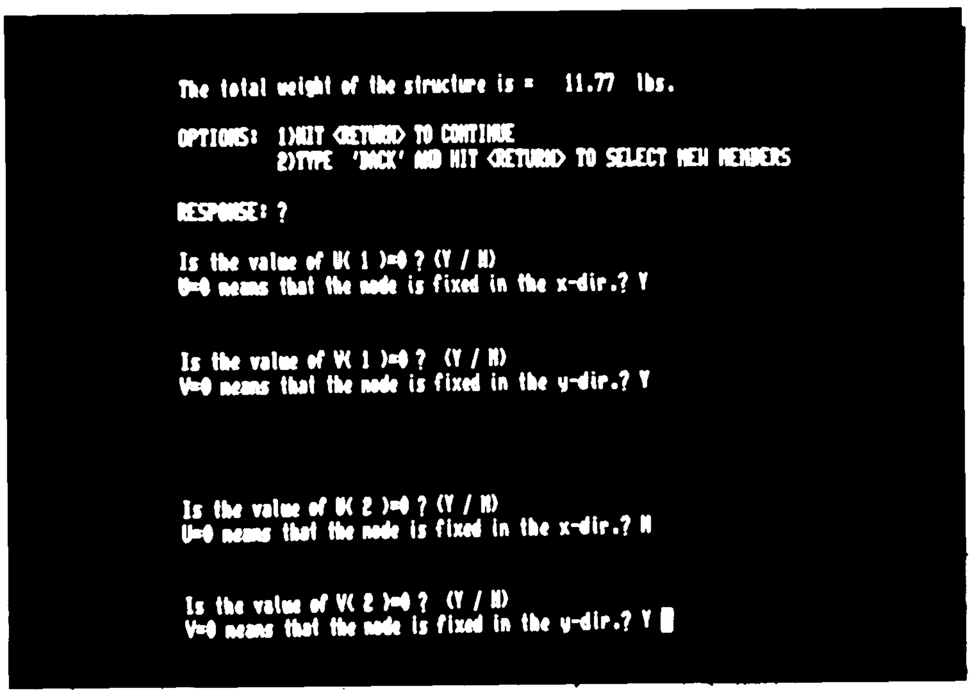


Fig. 15. Boundary conditions.

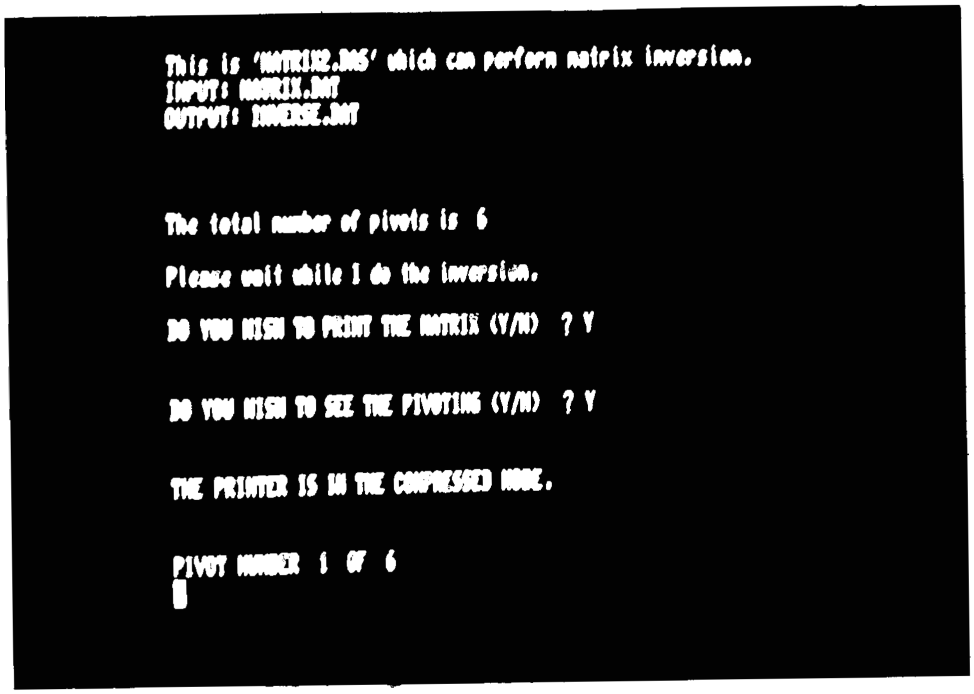


Fig. 16. Matrix inversion.

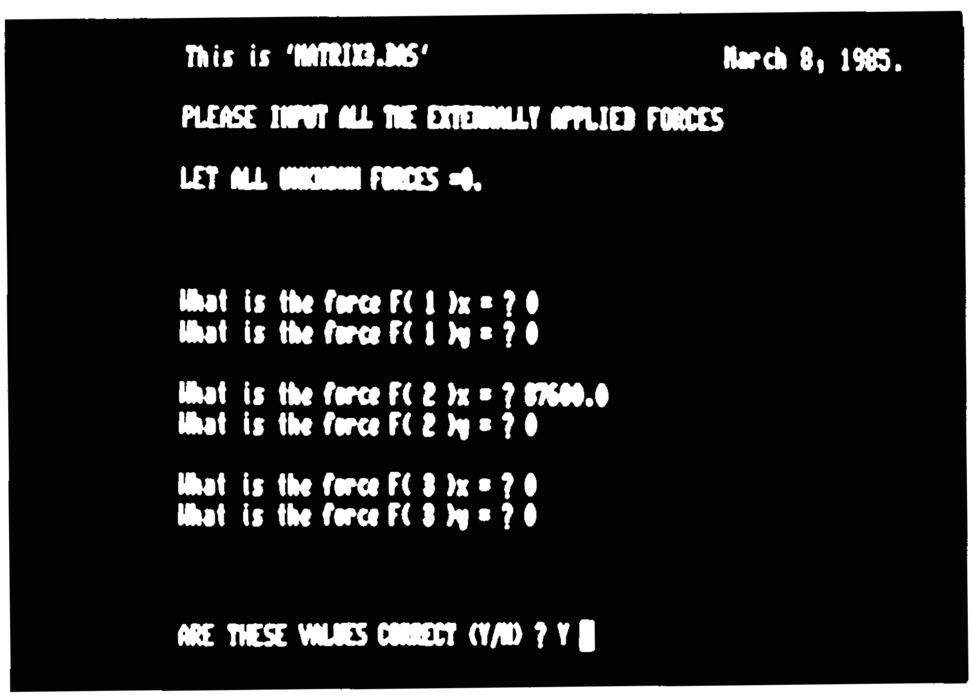


Fig. 17. External forces.

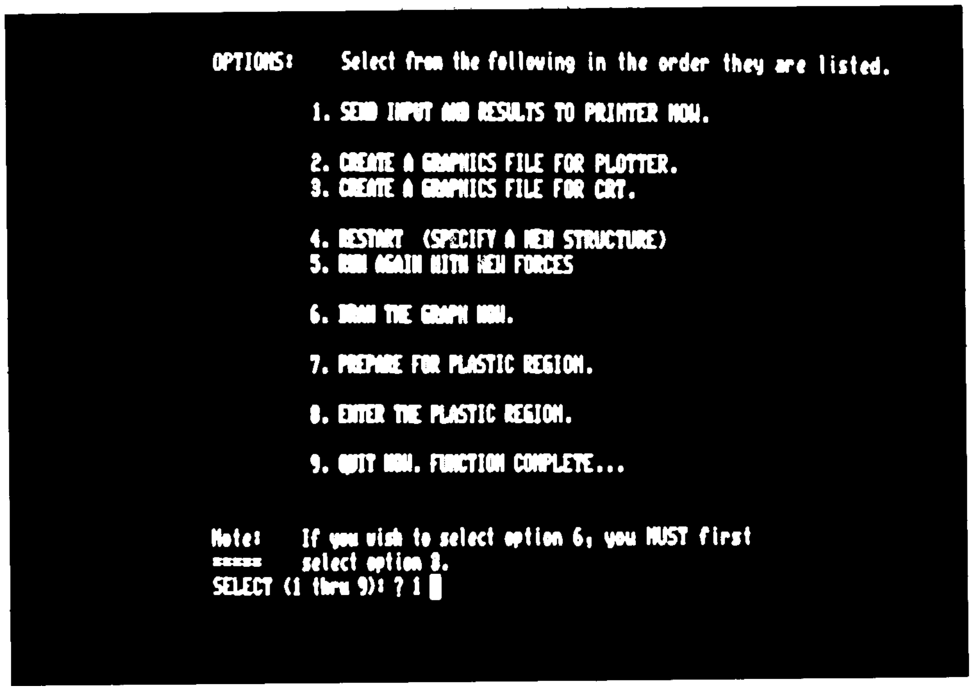


Fig. 18. Elastic region options.

Upon selection of option 1, the program requests the pivot coordinates as shown in figure 13. At the end, a review of all the nodes and their coordinates is shown and the program proceeds to ask for the number of members comprising the structure and for the material properties of each member (figure 14). The structure's total weight is calculated and displayed in figure 15. If it is not within the design specifications, a new (lighter) structure can be specified by re-running the program. If the weight is acceptable, the boundary conditions are entered. The program has now all the necessary information to set-up the coefficient matrix and adjust it according to the boundary conditions. Control is transferred over to 'MATRIX2.BAS' (figure 16) which inverts the matrix and runs 'MATRIX3.BAS'. 'MATRIX3.BAS' requests the externally applied forces (figure 17) and uses them to calculate nodal displacements, forces and stresses. This information is displayed on the screen as an initial review of the structure's behavior, and a list of options appears (figure 18).

Option 1 produced the printout on page 41. Options 2 and 3 create a graphics file for use with option 6. Option 4 restarts the design process by specifying a new structure, Option 5 is used to study the effect of new external forces on the same structure. If the operator wishes to extend the study into the plastic region, option 7 will ratio the forces to the yield strength(s) of the members and suggest values for the external forces which will cause the highest stressed member to yield. At this point, option 5 was necessary in order to obtain the effect of the suggested forces. It was followed by options 1 and 8. The second printout is shown on page 42. The response of option 9 (QUIT) is somewhat obvious.

In this example, the following options were selected in the order they are listed: 1,7,5,1,3,8. When option 2 or 3 is selected before 8, the latest graphics information is transfered to the plastic region. If option 2 or 3 were not selected immediately before option 8, the graphics data of the plastic region would not be correct. Options 2 and 3 are independent subroutines and can be selected repeatedly in any order and at any time because one erases the results of the other. The last selection will be considered as the final one.

Upon selection of option 8, control is turned over to 'M1.BAS' which is the first program of the plastic region set. At first, two options appear: continue the incremental changes or unload. The first proceeds to set up the coefficient matrix. The second sets up the coefficient matrix that is used in the elastic region since all the members are unloading with the characteristics of the elastic region. For the sake of this example, the study is extended into the plastic region by incrementing the load with 1752 LB increments. The first option of 'M1.BAS' is used and the system proceeds in a fashion similar to that of the programs of the elastic region. 'M2.BAS' and 'M3.BAS' run consecutively

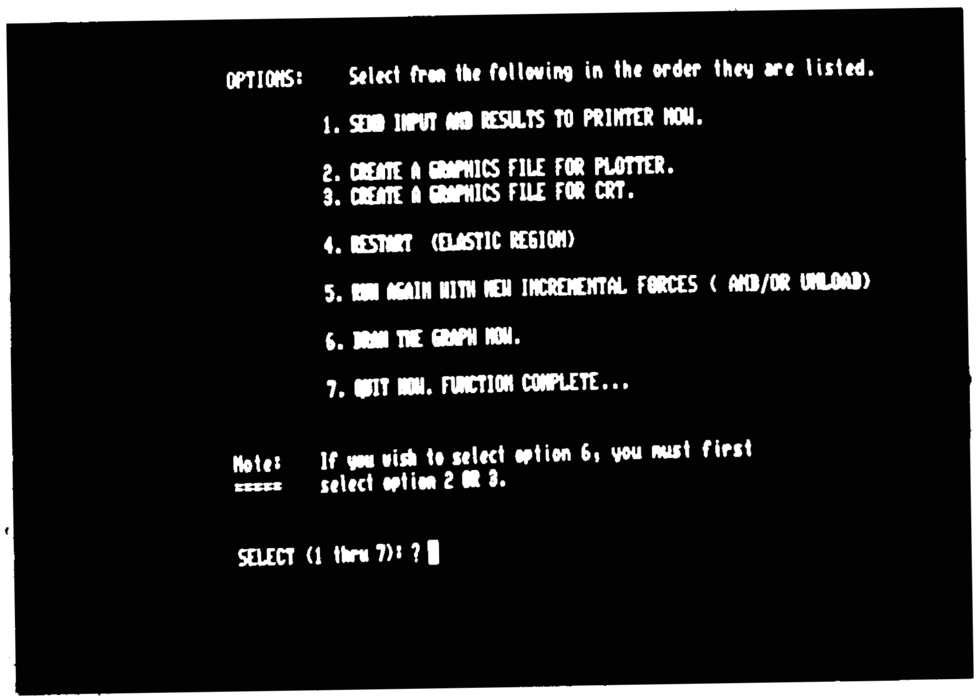


Fig. 19. Plastic region options.

and the incremental forces are entered. The plastic region list of options is shown in figure 19.

The first three options are identical to the elastic region options. The fourth restarts everything from the point of specification of a new structure. Options 5 and 6 are the same, and option 7 (QUIT) stops everything. To continue with the increments, options 1 and 5 are selected. If a drawing of each incremental deflection is required, options 1,3,6 will print the results, draw the graph and return to 'M1.BAS'. Option 5 returns to 'M1.BAS' directly.

The following pages are the printouts obtained for this example for the elastic and plastic regions. The first two pages (39, 40) show the coefficient matrix and the pivoting information. The right half of the last pivot is the inverted matrix. The next page shows the first results obtained by using an external load of 1000 LB. This is a test load used to calculate by extrapolation the elastic limit load. The elastic limit load was found to be 87600 LB and, when entered, it produced printout S. N. 244.

The next 23 pages (43 thru 66) show the results of loading increments in the plastic region. The last two printouts S. N. 267 and 268 show buckling in member 2 and the residual stresses after unloading.

STARTING MATRIX:

I	1.00	0.00	0.00	0.00	0.00	0.00	I
I	0.00	1.00	0.00	0.00	0.00	0.00	I
I	0.00	0.00	4.38	0.00	0.00	0.00	I
I	0.00	0.00	0.00	1.00	0.00	0.00	I
I	0.00	0.00	0.00	0.00	1.00	0.00	I
I	0.00	0.00	0.00	0.00	0.00	1.00	I

PIVOT NUMBER 1 OF 6

1.00	0.00	0.00	0.00	0.00	0.00	!	1.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	0.00	0.00	!	0.00	1.00	0.00	0.00	0.00	0.00
0.00	0.00	4.38	0.00	0.00	0.00	!	0.00	0.00	1.00	0.00	0.00	0.00
0.00	0.00	0.00	1.00	0.00	0.00	!	0.00	0.00	0.00	1.00	0.00	0.00
0.00	0.00	0.00	0.00	1.00	0.00	!	0.00	0.00	0.00	0.00	1.00	0.00
0.00	0.00	0.00	0.00	0.00	1.00	!	0.00	0.00	0.00	0.00	0.00	1.00

PIVOT NUMBER 2 OF 6

1.00	0.00	0.00	0.00	0.00	0.00	!	1.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	0.00	0.00	!	0.00	1.00	0.00	0.00	0.00	0.00
0.00	0.00	4.38	0.00	0.00	0.00	!	0.00	0.00	1.00	0.00	0.00	0.00
0.00	0.00	0.00	1.00	0.00	0.00	!	0.00	0.00	0.00	1.00	0.00	0.00
0.00	0.00	0.00	0.00	1.00	0.00	!	0.00	0.00	0.00	0.00	1.00	0.00
0.00	0.00	0.00	0.00	0.00	1.00	!	0.00	0.00	0.00	0.00	0.00	1.00

PIVOT NUMBER 3 OF 6

1.00	0.00	0.00	0.00	0.00	0.00	!	1.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	0.00	0.00	!	0.00	1.00	0.00	0.00	0.00	0.00
0.00	0.00	1.00	0.00	0.00	0.00	!	0.00	0.00	0.23	0.00	0.00	0.00
0.00	0.00	0.00	1.00	0.00	0.00	!	0.00	0.00	0.00	1.00	0.00	0.00
0.00	0.00	0.00	0.00	1.00	0.00	!	0.00	0.00	0.00	0.00	1.00	0.00
0.00	0.00	0.00	0.00	0.00	1.00	!	0.00	0.00	0.00	0.00	0.00	1.00

PIVOT **NUMBER** 4 OF 6

1.00	0.00	0.00	0.00	0.00	0.00 !	1.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	0.00	0.00 !	0.00	1.00	0.00	0.00	0.00	0.00
0.00	0.00	1.00	0.00	0.00	0.00 !	0.00	0.00	0.23	0.00	0.00	0.00
0.00	0.00	0.00	1.00	0.00	0.00 !	0.00	0.00	0.00	1.00	0.00	0.00
0.00	0.00	0.00	0.00	1.00	0.00 !	0.00	0.00	0.00	0.00	1.00	0.00
0.00	0.00	0.00	0.00	0.00	1.00 !	0.00	0.00	0.00	0.00	0.00	1.00

PIVOT NUMBER 5 OF 6

1.00	0.00	0.00	0.00	0.00	0.00 !	1.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	0.00	0.00 !	0.00	1.00	0.00	0.00	0.00	0.00
0.00	0.00	1.00	0.00	0.00	0.00 !	0.00	0.00	0.23	0.00	0.00	0.00
0.00	0.00	0.00	1.00	0.00	0.00 !	0.00	0.00	0.00	1.00	0.00	0.00
0.00	0.00	0.00	0.00	1.00	0.00 !	0.00	0.00	0.00	0.00	1.00	0.00
0.00	0.00	0.00	0.00	0.00	1.00 !	0.00	0.00	0.00	0.00	0.00	1.00

PIVOT **NUMBER** 6 OF 6

1.00	0.00	0.00	0.00	0.00	0.00 !	1.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	0.00	0.00 !	0.00	1.00	0.00	0.00	0.00	0.00
0.00	0.00	1.00	0.00	0.00	0.00 !	0.00	0.00	0.23	0.00	0.00	0.00
0.00	0.00	0.00	,	0.00	0.00 !	0.00	0.00	0.00	1.00	0.00	0.00
0.00	0.00	0.00	0.00	1.00	0.00 !	0.00	0.00	0.00	0.00	1.00	0.00
0.00	0.00	0.00	0.00	0.00	1.00 !	0.00	0.00	0.00	0.00	0.00	1.00

SERIAL# 243

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(fill units are LBS. IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

PIN#	(X,Y)	U (in)	V (in)
1	(0.00, 0.00)	0.0000	0.0000
2	(15.00, 0.00)	0.0002	0.0000
3	(35.00, 0.00)	0.0000	0.0000

MEMBER#	PINS: (A,B)	LENGTH (in)	AREA (in2)	E(*1E6)	SP.WT.
1	1, 2	15.00	1.44	[illegible]	.283[illegible]
[illegible]	2, 3	20.00	1.00	30.00	0.2830

MEMBER#	FORCE (lbs)	STRESS (psi)	STRAIN
1	657.5	456.6	.000015
[illegible]	-342.5	-342.5	-0.000011

TEMPERATURES:

ALL TEMPERATURES ARE EQUAL EXCEPT:

EXTERNAL FORCES:

ALL EXTERNALLY APPLIED FORCES ARE ZERO EXCEPT :

F(2 . = 1000 Lbs.

The total weight of this structure is 11.77 lbs.

SERIAL# 244

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS. IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

PIN#	(X,Y)		U (in)	V (in)
1	(0.00,	0.00)	0.0000	0.0000
2	(15.00,	0.00)	0.0200	0.0000
3	(35.00,	0.00)	0.0000	0.0000

MEMBER#	PINS: (A,B)		LENGTH (in)	AREA (in2)	E(*1E6)	SP.WT.
1	1.	2	15.00	1.44	[illegible]	0.2830
-	2.	3	20.00	1.00	30.00	0.2830

MEMBER#	FORCE (lbs)	STRESS (psi!	STRAIN
1	57600.1	40000.1	[illegible].001333
-	-30000.1	-30000.1	-0.001000

TEMPERATURES:

ALL TEMPERATURES ARE EQUAL EXCEPT:

EXTERNAL FORCES:

ALL EXTERNALLY APPLIED FORCES ARE ZERO EXCEPT :

F(2)x = 87600 Lbs.

The total weight of this structure is 11.77 lbs.

SERIAL# 245

ANALYSIS OF A STRUCTURE BY THE FINITE ELEHENT METHOD

(All units are LBS, IN.)

NUMBER OF PINS= 3 NUHBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0	0	YES	YES
?	1752	0	89352	0	NO	YES
3	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	1152	58752	40800	30.000	YES	NO	NO
2	-600	-30600	-30600	30.000	NO	NO	NO

SERIAL# 246

ANALYSIS OF A STRUCTURE BY THE FINITE ELEHENT METHOD

(All units are LBS, IN.)

NUHBE!? OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-r	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0	0	YES	YES
2	1752	0	91104	0	NO	YES
3	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDEI!	HEHBEE BUCKLED	MEMBER RUPTURED
1	1140	59892	41592	29.100	YES	NO	NO
2	-612	-31212	-31212	30.000	NO	tiO	NO

SERIAL# 247

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

!$I! units are LBS.IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
	0	[illegible]	0	[illegible]	YES	YES
	1752	0	92856	0	NO	YES
	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	1127	61019	[illegible]	[illegible]	YES	NO	NO
[illegible]	-625	-31837	-31837	30,000	NO	NO	NO

SERIAL# 248

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS.IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	!WC FORCE-x	tic FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
[illegible]	0	0	0	0	YES	
[illegible]	1752	0	94608	0	NO	YES
[illegible]	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	1115	62134	43149	27.329	YES	NO	NO
2	-637	-32474	-32474	30.000	NO	NO	NO

SERIAL# 249

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS.IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
	0	0	0	0	YES	YES
	1752	0	96360	0	NO	YES
		0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	1101	63236	43914	26.458	YES	NO	NO
2	-651	-33125	-33125	30.000	NO	NO	NO

SERIAL# 250

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS.IN.)

NUMBER OF PINS= 3   NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0	0	YES	YES
[illegible]	1752		98112	0	NO	Y[illegible]
	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	1088	64324	44669	25.597	YES	NO	NO
2	-664	-33789	-33789	30.000	NO	NO	NO

SERIAL# 251

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS.IN. !

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	IHC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	3	0	0	0	YES	YE;
-	1752	0	99864	0	NO	YES
	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
	1074	65398	45415	24.747	YES	NO	NO
	-678	-34467	-34467	30.000	NO	NO	NO

SERIAL# 252

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS.IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0	0	YES	YES
2	1752	0	101616	0	NO	YES
3	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
	1060	66457	46151	23.908	YES	NO	NO
	-692	-35159	-35159	30.000	NO	NO	NO

SERIAL# 253

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS,IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-v	NET FORCE-x	NET FORCE-v	Fixed-x	Fixed-v
1	0	0	0	0	YES	YES
2	1752	0	103368	0	NO	YES
3	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	1045	67502	46876	23.080	YES	NO	NO
2	-707	-35866	-35866	30.000	NO	NO	NO

SERIAL# 254

ANALYSIS OF A STRUCTURE by THE FINITE ELEMENT METHOD

(All units are LBS,IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

F..	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1		0	[illegible]	0	YES	YE
[illegible]	1752	0	105120	0	NO	YES
		0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	1030	68531	47591	22.264	YES	NO	NO
2	-723	-36589	-36589	30.000	NO	NO	NO

SERIAL# 255

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS.IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

IN#	~ H E FORCE-x	INC FORCE-v	NET	NET		Fixed-v
i		0	0	0	YES	YES
	1752	0	106975	0	NO	YES
	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	1014	69545	48549	21.460	YES	NO	NO
	-756	-37327	-37327	30.000	NO	NO	NO

SERIAL# 256

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

[Ail units art LBS.IN. ›

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	[illegible]	0	[illegible]	YES	YES
[illegible]	1752		108624	0	NO	YES
		0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	998	70543	48988	20.668	YES	NO	NO
2	-754	-38081	-38081	30.000	NO	NO	NO

SERIAL# 257

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD
==

(All units are LBS.IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0	0	YES	YES
[illegible]	1752	0	110376	0	NO	YES
[illegible]	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FOECE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	981	71524	49669	19.888	YES	NO	NO
2	-771	-38852	-38852	30.000	NO	NO	NO

SERIAL# 258

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS, IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0		YES	YES
2	1752	0	112128	0	NO	YES
	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	964	72488	50339	19.122	YES	NO	NO
2	-763	-39640	-39640	30.000	NO	NO	NO

SERIAL# 259

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

GI! units are LBS.IN. !

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EATERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-v	NET FORCE-x	NET FORCE-v	Fixed-x	Fixed-v
1	0	0	0	0	YES	YES
	1752	0	113880	0	NO	YES
\	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	947	73435	50997	18.369	YES	NO	NO
2	-805	-40445	-40445	30.000	YES	NO	NO

SERIAL# 260

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS,IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
	0	0	I	0	YES	YES
7	1752	0	115632	0	NO	YES
7	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	YET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	929	74364	51641	17.629	YES	NO	NO
2	-823	-41269	-41269	30.000	YES	NO	NO

SERIAL# 261

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD
==

!All units arc LBS.IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	!NC FORCE-y	NET FORCE-x	NET FORCE-v	Fixed-x	Fixed-v
1	0	0	0		YES	YES
	1752	0	117384	0	NO	YES
	0	0	0	0	YES	YE5

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	932	75295	52289	16.903	YES	NO	NO
.	-820	-42089	-42089	28.573	YES	NO	NO

CO

SERIAL# 262

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS,IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0	0	YES	YES
2	1752	0	119136	0	NO	YES
3	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	927	76222	52932	16.175	YES	NO	NO
2	-825	-42914	-42914	27.650	YES	NO	NO

SERIAL# 263

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

! All units are LBS.IN. !

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0	0	YES	YES
2	175	0	120888	0	NO	YES
	0	[illegible]	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	[illegible]	77144	53572	15.451	YES	NO	NO
	-830	-43744	-43744	26.722	YES	NO	NO

SERIAL# 264

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All ~ ~ iatesLBS.IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0	0	YES	
2	1752	0	122640	0	NO	YES
	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	916	78060	54209	14.731	YES	NO	NO
2	-836	-44580	-44580	25.788	YES	NO	NO

SERIAL# 265

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

!All units are LBS.IN. !

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
	0	0	0	0	YES	YES
-	1752	0	124392	0	NO	YES
	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	911	78971	54841	14.015	YES	NO	NO
2	-841	-45421	-45421	24.848	YES	NO	NO

SERIAL# 266

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

[illegible] units are [illegible]

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0	0	[illegible]	YES
[illegible]	1752	0	126144	0	NO	YES
	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	905	79876	55470	13.304	YES	NO	NO
2	-847	-46268	-46268	23.901	YES	NO	NO

SERIAL# 267

ANALYSIS OF A STRUCTURE BY THE FINITE ELEHEN? METHOD

(All units are LBS.IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-v	NET FORCE-x	NET FORCE-v	Fixed-x	Fixed-v
	0	0	0	0	YES	YES
[illegible]	1752	0	127896	0	NO	YES
	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	899	80775	56094	12.597	YES	NO	NO
2	-853	-47121	-47121	22.949	YES	YES	NO

SERIAL# 268

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

iki! units are LBS,IN.)

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	0	0	0	YES	YES
2	-127896	0	0	0	NO	YES
3	0	0	0	0	YES	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	-84096	[illegible]	-2306	30.000	NO	NO	NO
	43800	-3321	[illegible]	30.000	NO	YES	NO

Temperature Effects

As an example of the effect that temperature changes have on the strength of a structure, the same structure is used with member 2 at an elevated temperature of 150 F. This could be the case of a structure located next to a furnace which increases the average temperature of one member by 150 °F.

The results are shown in the first printout (S.N. 271) which shows the stresses caused by the temperature change alone. The second printout (S.N. 272) indicates that member 2 yields at the significantly lower external force level of 65000 Lbs.

It is important to note that when option 7 is selected in order to calculate the suggested elastic limit loads, any temperature changes are not considered because the temperature forces are not true external forces. The program will automatically adjust the forces in the members to reflect forces due to true external loads.

It is important to note that changes in temperature change the strains (and node deflections) significantly. However, these strains do not translate into internal forces and internal stresses unless boundary conditions restrict the members' expansion.

SERIAL# 271

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

All units are LBS, IN.

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

PIN#	(X, Y)	U (in)	V (in)
1	(0.00, 0.00)	0.0000	0.0000
2	(15.00, 0.00)	-0.0062	0.0000
3	(35.00, 0.00)	0.0000	0.0000

MEMBER#	PINS: (A,B)	LENGTH (in)	AREA (in2)	E(*1E6)	SP. WT.
1	1, 2	15.[illegible]	1.44	[illegible]	[illegible].2830
2	2, 3	20.00	1.00	30.00	0.2830

MEMBER#	FORCE (lbs)	STRESS (psi)	STRAIN
1	-17753.5	-12328.8	-0.000411
2	-17753.4	-17753.4	-0.000592

TEMPERATURES:

ALL TEMPERATURES ARE EQUAL EXCEPT:

MEMBER# 2 . TEMP.=T+ 150 F. THERMAL EXP. COEFF.= 6 (*1E-6)

EXTERNAL FORCES:

ALL EXTERNALLY APPLIED FORCES ARE ZERO EXCEPT :

The total weight of this structure is 11.77 lbs.

SERIAL# 272

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

!All units are LBS,IN. !

NUMBER OF PINS= 3 NUMBER OF MEMBERS= 2

PIN#	(X,Y)	U (in)	V (in)
1	(0.00, 0.00)	0.0000	0.0000
2	(15.00, 0.00)	0.0087	0.0000
3	(35.00, 0.00)	0.0000	0.0000

MEMBER#	PINS: (A,B)	LENGTH (in)	AREA (in2)	E(*1E6)	SP.WT.
1	1, 2	15.00	1.44	30.00	0.2830
2	2, 3	20.00	1.00	30.00	0.2830

MEMBER#	FORCE (lbs)	STRESS (psi)	STRAIN
1	24986.4	17351.6	0.000578
2	-40013.7	-40013.7	-0.001334

TEMPERATURES:

ALL TEMPERATURES ARE EQUAL EXCEPT:

MEMBER# 2 . TEMP.=T+ 150 F. THERMAL EXP. COEFF.= 6 (*1E-6)

EXTERNAL FORCES:

ALL EXTERNALLY APPLIED FORCES ARE ZERO EXCEPT :

F(2)x = 65000 Lbs.

The total weight of this structure is 11.77 lbs.

C - Frame Analysis

The second case is the analysis of a C - frame. The study of only one-half of the section is necessary due to the advantage of symmetry. The structure is shown in figures 20 and 21. The frame is divided at the horizontal axis of symmetry. Node 5 is fixed in both directions to establish a reference, and node 6 is fixed only in the y-direction because the node is assumed to remain at the same level at all times.

There are three conditions which must be satisfied in order to safely make the above assumption. The first and most obvious is geometrical symmetry. All the members must be identical in orientation and node restrictions (boundary conditions.) The second is the type of loading and the additional assumptions on the boundary conditions. As with the above mentioned C - frame, boundary conditions are applied to nodes 5 and 6 although in reality there are no restrictions. Node 6 is completely fixed to provide some reference for the deflections of the other nodes. However, node 5 is fixed only in the y-direction because normally it can move in the x-direction. The forces acting in the y-direction are equal and opposite and support the assumption that the node is fixed. The third condition is that all physical properties and other material charecteristics of each member are identical to those of their respective members.

The physical characteristics of the members used in this structure are identical for convenience. The nodal information and material characteristics follow.

TABLE 2

NODAL POINT DATA

Node #	(x,y)	Fixed x-dir.	Fixed y-dir.
1	(40,-20)	NO	NO
2	(20,-40)	NO	NO
3	(20,-20)	NO	NO
4	(0,-20)	NO	NO
5	(0,0)	YES	YES
6	(-20,0)	NO	YES

TABLE 3

MEMBER ORIENTATION

MEMBER	PIN A	PIN B
1	1	3
2	1	2
3	2	3
4	2	4
5	3	4
6	3	5
7	4	5
8	4	6
9	5	6

Properties (Standard Structural Steel).

Modulus of elasticity = 30 million LBS/IN^2

Yield strength = 36000 LBS/IN^2

Rupture strength = 60000 LBS/IN^2

Smallest moment of inertia = .037 IN^4

Cross-sectional area = .333 IN^2

Specific weight = .283 LBS/IN^3

Temperature difference = 0 °F.

Thermal expansion coefficient = 6.7 millionths (IN/IN/°F)

The structure is shown in figures 20, 21 and 22. The coefficient matrix is on page 76. The pivoting information can not be printed even in the compressed mode because the matrix is too wide. The test load of -100 LB acting on node 1 produced printout S. N. 274. The elastic limit load of -4242.5 LB produced printout S. N. 275. The next five printouts (S. N. 276 thru 280) are related to plastic region load increments of -50 LB. The last printout (S.N. 280) indicates buckling in member 8.

Since the external load(s) are directly proportional to the stresses (in the elastic region only), the maximum allowable load that can be supported is 4242 LB. If a factor of safety is to be considered, the load is reduced appropriately. For example, if a factor of safety of 2 is considered, the maximum allowable load before yielding is 4242 / 2 = 2121 LB.

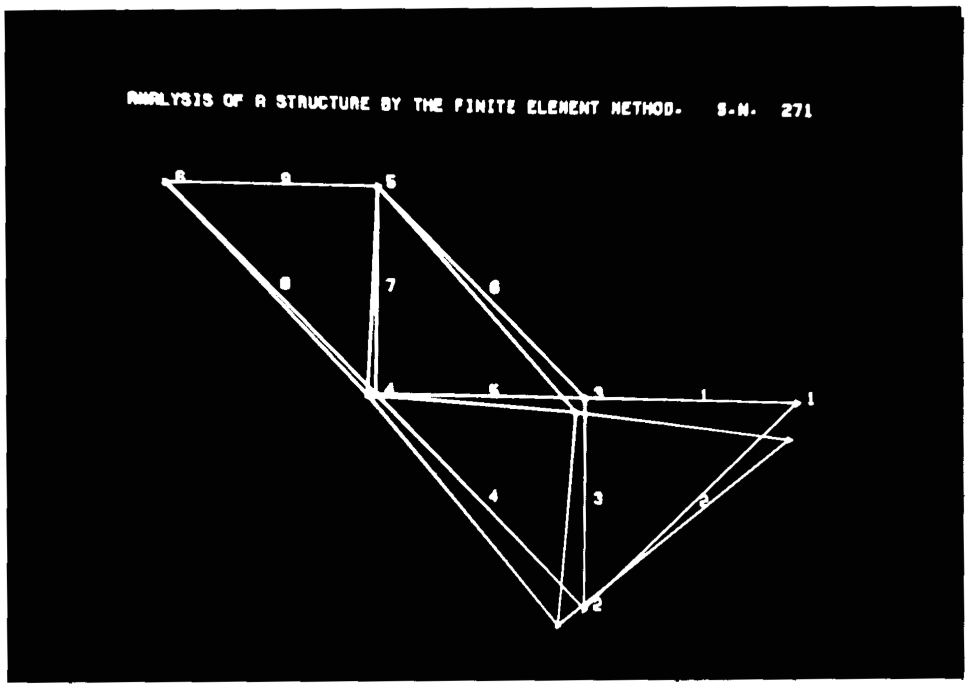


Fig. 21. C - frame before and after loading.

RNRLYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD. S.N. 256

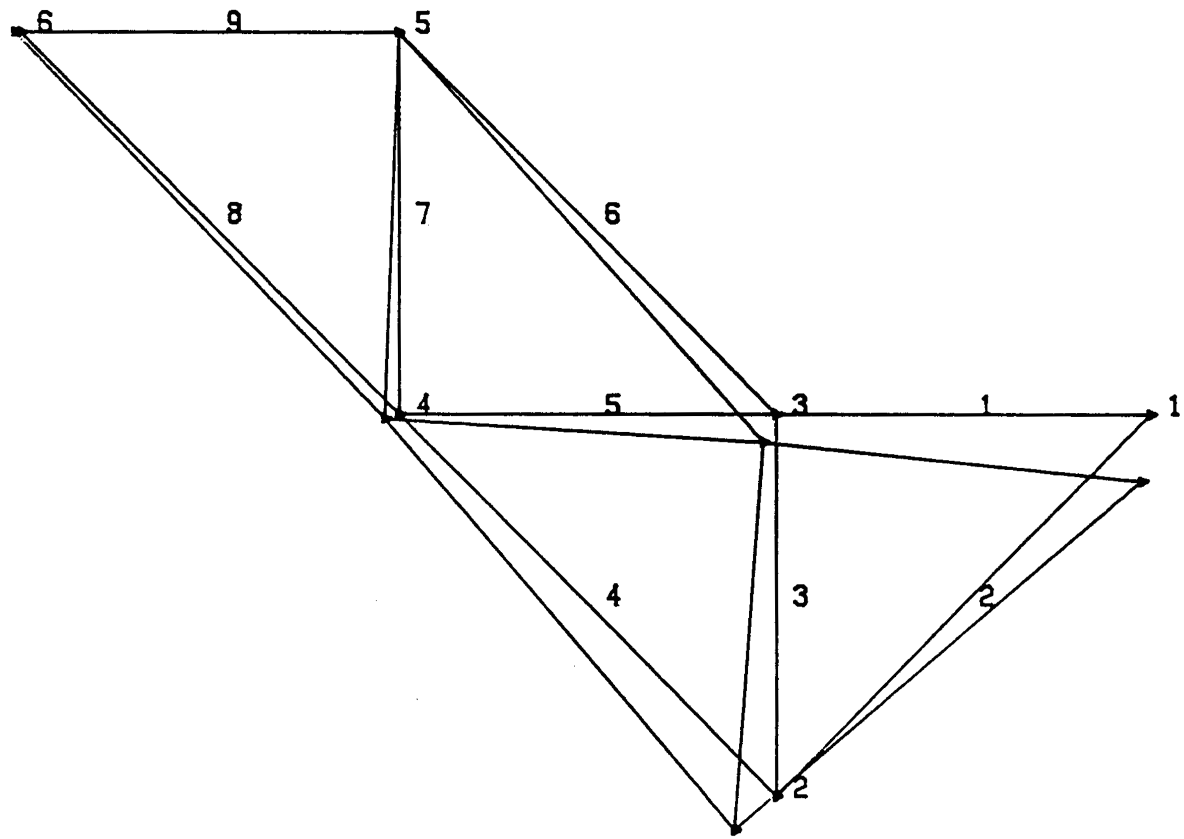


Fig. 22. Plotter Drawing.

STARTING MATRIX:

```
I   0.68   0.18  -0.18  -0.18  -0.50   0.00   0.00   0.00   0.00   0.00   0.00   0.00 I
I   0.18   0.18  -0.18  -0.18   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00 I
I  -0.18  -0.18   0.35   0.00   0.00   0.00  -0.18   0.18   0.00   0.00   0.00   0.00 I
I  -0.18  -0.18   0.00   0.85   0.00  -0.50   0.18  -0.18   0.00   0.00   0.00   0.00 I
I  -0.50   0.00   0.00   0.00   1.18  -0.18  -0.50   0.00   0.00   0.00   0.00   0.00 I
I   0.00   0.00   0.00  -0.50  -0.18   0.68   0.00   0.00   0.00   0.00   0.00   0.00 I
I   0.00   0.00  -0.18   0.18  -0.50   0.00   0.85  -0.35   0.00   0.00  -0.18   0.00 I
I   0.00   0.00   0.18  -0.18   0.00   0.00  -0.35   0.85   0.00   0.00   0.18   0.00 I
I   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.00   0.00   0.00   0.00 I
I   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.00   0.00   0.00 I
I   0.00   0.00   0.00   0.00   0.00   0.00  -0.18   0.18   0.00   0.00   0.68   0.00 I
I   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.00 I
```

SERIAL# 274

ANALYSTS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LHS. IN.)

NUMBER OF PINS= 6 NUMBER OF MEMBERS= Y

PIN#	(X,Y)	U (in)	V (in)
1	(40.00, -20.00)	-0.[illegible]17	-0.0079
2	(20.00, -40.00)	-0.0056	-0.0035
3	(20.00, -20.00)	-0.0019	-0.0031
4	(0.00, -20.00)	-0.0017	-0.0002
5	(0.00, 0.00)	0.0000	0.0000
6	(-20.00, 0.00)	-0.0004	0.0000

MEMBER#	PINS: (A,B)	LENGTH (in)	AREA (in2)	E(*1E6)	SF'. WT.
1	1, 3	20.00	0.33	30.00	0.2830
2	1, 2	28.28	0.33	30.00	0.2830
3	2, 3	20.00	0.33	30.00	0.2830
4	2, 4	28.28	0.33	30.00	0.2830
5	3, 4	20.00	0.33	30.00	0.2830
6	3, 5	28.28	0.33	30.00	0.2830
7	4, 5	20.00	0.33	30.00	0.2830
8	4, 6	28.28	0.33	30.00	0.2830
9	5, 6	20.00	0.33	30.00	0.2830

MEMBER#	FORCE (lbs)	STRESS (psi)	STRAIN
1	100.0	300.0	0.000010
2	-141.4	-424.3	-0.000014
3	200.0	600.0	0.000020
4	-141.4	-424.3	-0.000014
5	-100.0	-300.0	-0.000010
6	282.8	848.5	0.000028
7	100.0	300.0	0.000010
8	-282.9	-848.6	-0.000028
9	200.0	600.0	0.000020

TEMPERATURES:

ALL TEMPERATURES ARE EQUAL EXCEPT:

EXTERNAL FORCES:

ALL EXTERNALLY APPLIED FORCES ARE ZERO EXCEPT :

F(1)y =-100 Lbs.

The total weight of this structure is 20.11 lbs.

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS. IN.)

NUMBER OF PINS= 6 NUMBER OF MEMBERS= 9

PIN#	(X,Y)	U (in)	V (in)
1	(40.00, -20.00)	-0.0735	-0.3333
[illegible]	(20.00, -40.00)	-0.2359	-0.1467
	(20.00, -20.00)	-0.0819	-0.1299
4	(0.00, -20.00)	-0.0735	-0.0085
5	(0.00, 0.00)	0.0000	0.0000
6	(-20.00, 0.00)	-0.0170	0.0000

MEMBER#	PINS: (A,B)	LENGTH (in)	AREA (in2)	E(*1E6)	SP.WT.
1	1. 3	20.00	0.33	30.[illegible]	[illegible].2830
	1. 2	28.28	0.33	30.00	0.2830
3	2, 3	20.00	0.33	[illegible]	0.2830
4	2, 4	28.28	0.33	30.00	0.2830
5	[illegible], 4	20.00	0.33	30.00	0.2830
6	3, 5	28.28	0.33	30.00	0.2830
7	4. 5	20.00	0.33	30.00	0.2830
8	4. 6	28.28	0.33	[illegible].00	0.2830
9	5, 6	20.00	0.33	[illegible]	0.2830

MEMBER#	FORCE (lbs)	STRESS (psi)	STRAIN
1	4242.7	12728.1	0.000424
2	-5799.8	-17999.5	-0.000600
3	R484.7	25455.0	0.000849
4	-5797.8	-17999.6	-0.000600
5	-4243.1	-12727.4	-0.000424
6	11993.6	35999.1	0.001200
7	4.242.7	12728.9	0.000424
8	-12000.2	-36000.8	-0.001200
9	8485.4	25456.5	0.000849

TEMPERATURES:

HLL TEMPERATURES ARE EQUAL EXCEPT:

EXTERNAL FORCES:

ALL EXTERNALLY APPLIED FORCES ARE ZERO EXCEPT :

F(1)y =-4242.5 Lba.

The total weight of this structure **is** 20.11 **lbs.**

SER.AL# 276

ANAL'SIS OF A S TRUCTURE BY THE FINI E ELEME T METHOD

(A ll un.ts are LBS IN.)

NUMBER OF P INS= 6 NUMBER OF MEMBERS= 9

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed x	Fixed-y
1	0	-50	0	-4293	NO	NO
2	0	0	0	0	NO	NO
3	0	0	0	0	NO	NO
4	0	0	0	0	NO	NO
5	0	0	0	0	YES	YES
6	0	0	0	0	NO	YES

MEMBER#	INCRE MTL FORCE (lbs)	NET FORCE (lbs	NET STRESS (psi	ELAST. MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	50	4293	1287.	30.000	NO	NO	NO
2	-71	-6071	-18212	30.000	NO	NO	NO
3	100	8585	25755	30.000	NO	NO	NO
4	-71	-6071	-18212	30.000	NO	NO	NO
5	-50	-42.3	-1287.	30.000	NO	NO	N.
6	141	12141	36423	30.000	YES	NO	.0
7	50	4293	12879	30.000	NO	NO	NO
8	-141	-12142	-36425	30.000	YES	NO	NO
9	100	8585	25757	30.000		0	N.

SERIAL# 277

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS,IN.)

NUMBER OF PINS= 6 NUMBER OF MEMBERS= 9

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	-50	0	-4343	NO	
[illegible]	0	0	0	0	NO	NO
[illegible]	0	0	0	0	NO	NO
4	0		0	0	NO	NO
5	0	0	0	0	YES	
6	0	0	0	0	NO	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	50	4343	13028	30.000	NO	NO	NO
2	-71	-6141	-18424	30.000	NO	NO	NO
3	100	8685	26055	30.000	NO	NO	NO
4	-71	-6141	-18424	30.000	NO	NO	NO
5	-50	-4343	-13029	30.000	NO	NO	NO
6	141	12282	36848	30.000	YES	NO	NO
7	50	4343	13029	30.000	NO	NO	NO
8	-141	-12283	-36849	29.469	YES	NO	NO
9	100	8685	26057	30.000	NO	NO	NO

SERIAL# 278

ANALYSIS OF A STRUCTURE BY THE FINITE ELEHENT METHOD

(All units are LBS, IN.)

NUMBER OF PINS= 6 NUMBER OF MEMBERS= 9

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	-50	0	-4393	NO	NO
2	0	0	0	0	NO	NO
3	0	0	0	0	NO	NO
4	0	0	0	0	NO	NO
5	0	0	0	0	YES	YES
6	0	0	0	0	NO	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	50	4393	13178	30.000	NO	NO	NO
2	-71	-6212	-18636	30.000	NO	NO	NO
3	100	8785	26355	30.000	NO	NO	NO
4	-71	-6212	-18636	30.000	NO	NO	NO
5	-50	-4393	-13179	30.000	NO	NO	NO
6	141	12424	37272	28.940	YES	NO	NO
7	50	4393	13179	30.000	NO	NO	NO
8	-141	-12424	-37274	28.938	YES	NO	NO
9	100	8785	26357	30.000	NO	NO	NO

SERIAL# 279

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

(All units are LBS,IN.)

NUMBER OF PINS= 6 NUMBER OF MEMBERS= 9

EXTERNAL FORCES :

PIN#	INC FORCE-x	INC FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
1	0	-50	0	-4443	NO	NO
2	0	0	0	0	NO	NO
3	0	0	0	0	NO	NO
4	0	0	0	0	NO	NO
5	0	0	0	0	YES	YES
6	0	0	0	0	NO	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	50	4443	13328	30.000	NO	NO	NO
2	-71	-6283	-18848	30.000	NO	NO	NO
3	100	8885	26655	30.000	NO	NO	NO
4	-71	-6283	-18848	30.000	NO	NO	NO
5	-50	-4443	-13329	30.000	NO	NO	NO
6	141	12565	37696	28.410	YES	NO	NO
7	50	4443	13329	30.000	NO	NO	NO
8	-141	-12566	-37698	28.408	YES	NO	NO
9	100	8885	26656	30.000	NO	NO	NO

ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD

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NUMBER OF PINS= 6 NUMBER OF MEMBERS= 9

EXTERNAL FORCES :

PIN#	INC FORCE-x	ING FORCE-y	NET FORCE-x	NET FORCE-y	Fixed-x	Fixed-y
,	0	-50	0	-4493	NO	NO
-	0	0	0	0	NO	NO
	0	0	0	0	NO	NO
4	0	0	0	0		NO
f	0	0	0	0	YES	YES
6	0	0	0	0	NO	YES

MEMBER#	INCREM'TL FORCE (lbs)	NET FORCE (lbs)	NET STRESS (psi)	ELASTIC MODULUS(*1E-6)	MEMBER YIELDED	MEMBER BUCKLED	MEMBER RUPTURED
1	50	4493	13478	30.000	NO	NO	NO
2	-71	-6353	-19060	30.000	NO	NO	NO
3	100	8985	26955	30.000	NO	NO	NO
4	-71	-6353	-19060	30.000	NO	NO	NO
5	-50	-4493	-13479	30.000	NO	NO	NO
6	141	12707	38121	27.880	YES	NO	NO
7	50	4493	13479	30.000	NO	NO	NO
8	-141	-12707	-38122	27.878	YES	YES	NO
9	100	8985	26957	30.000	NO	NO	NO

CHAPTER IV

SUMMARY

Conclusions

The objective of this thesis is to increase student awareness in regard to the finite element method and its application in the design of structures by the use of computer programs. As a result, seven computer programs were developed and in-class presentations, discussions and computer room demonstrations were held for two class offerings of the ME 807 Design of Mechanical Systems course. Approximately 40 students have successfully used these programs during the design of their final project and were impressed with the capabilities and efficiency of the programs. Also, Dr. Frank A. D'Isa's elaborate hand calculations of the elastic and plastic behavior of the two-member test case of chapter III produced identical results to those of the programs proving their accuracy.

Part of the success of the programming is due to numerous refinements guided by student comments on their individual design needs and desired software support. Some of the many options available include a hard copy of the input and results on the dot-matrix printer, a preview of the structure's drawing on the graphics console before a final drawing is obtained on the plotter and the presentation of the suggested elastic limit load values. A major advantage of these programs over other design programs is that the operator has the option of monitoring intermediate information. For example, the equation matrix can be printed before and after the inversion routine. Also, all the pivoting information is printed. This gives the operator the opportunity to monitor the computer's operations and check the results of each step against hand-calculations.

The capability of the programs was significantly expanded by incorporating the effects of temperature changes occuring in members as part of the finite element based solution. Also, the ability to evaluate the changing characteristics of members loaded past their elastic limit (plastic region), enhances the programs' value as a tool for studies of the expected plastic region behavior. Various messages effectively notify the operator in the event of member yielding, buckling and rupture which critically determine the outcome of the design.

The use of the programs by the students has proven to be a very successful way of linking the finite element method with computer aided design methods. The students had the opportunity to test their creativity and intuition by using these programs which are simmilar to programs used in industry today. Also, it was easy to experiment by studying various combinations of structural shapes, composites and plastics. This has increased their understanding of the effects of combining different structural shapes, and introduced advanced design questions such as feasibility and the different effects of time on the materials' characteristics.

The studies of chapter III have proven that the programs are very effective in minimizing the tedious and repetitive part of the design procedure. In this way, students can conserve more time and energy for the consideration of further refinements of a specific design. It must be noted that these programs will solve both statically determinant and statically indeterminant problems. The latter are impossible to solve using the traditional methods of statics such as equations of equilibrium and force triangles. The first study of chapter III is a statically indeterminant problem (one equation with two unknowns: Sum of Fx = 0).

Recommendations

It is well known that the perfect program has not been written yet and it never will, because there is always "a little something'' to be added or changed. Since all the recommendations of the students who have used these programs have already been taken into consideration, only minor improvements can be made, especially when considering the purpose of the design course.

However, it is recommended that the programs be extended to study three dimensional structures, although elaborate programs already exist for such studies. It is also recommended that a different computer system be used, because the existing system is already being used to maximum capacity.

If a dynamic load is applied to the structure, it is recommended that these programs are used only if the change of the loading is small compared to the change in time. Fast changing loads can be studied only under the assumption that the effective inertial forces produced by the dynamic loading are minimal and can be safely ignored. The recommended approach for the solution of such dynamic problems is to divide the problem into a number of static loading problems by considering the values of the applied loads at regular incremental time intervals. This is simmilar to the study of the second structure of chapter III if it is assumed that the incremental loading represents the change in loading at regular time intervals.

APPENDIX A

Computer System's Technical Specifications.

A. BOARD DESCRIPTION

The DIGIAC single board computer is one of the most powerful Z80 processor boards available for the S100 bus. The CT-804 provides the user with all necessary support functions for the IEEE-696 (S100) bus specification. Please read the entire CPU manual before inserting this card in your system.

B. TECHNICAL SPECIFICATIONS

PROCESSOR..................Z80 CPU
CLOCK RATE.................2 or 4 MHZ
INSTRUCTION SET...... .....158-Z80 instructions including
78-8080 processor instructions

MEMORY:

RAM.. ....1K Byte Static
ROM... ....3K Bytes (SYSTEM MONITOR)

BUS COMPATIBILITY.........IEEE-696 (S100)

C. BOARD SPECIFICATIONS

POWER REQUIREMENTS:

+8V.......................750 milliamps
+16V......................150 milliamps
-16V......................150 milliamps

OPERATING ENVIRONMENT.....0-55 DEGREES CELSIUS

SIZE......................5" x 10" x 0.65"

CONNECTORS:

P0........................IEEE-696 (S100) 100 pin
P1........................804P connector 34 pin
P2........................804S connector 34 pin
P3........................ DIP header 16 pin

D. BOARD ILLUSTRATIONS

A. BOARD DESCRIPTION

The CT810 is a multiple 1/0 interrupt support card for mqlti-user operating systems (eg. M P/M). The CT810 is designed to handle four users in a multi-processing environment.

Major Components of the CT810 are:

- Four independent EIA serial ports
- Two parallel ports with full handshaking (one input/one output)
- Jump on reset to a 1K or 2K EPROM Address space
- On Board Memory Disable
- Crystal timebase for the periodic interrupt generator
- Logic to correct unacknowledged interrupts (Timekeeping)
- A software settable port that is read and executed on interrupt acknowledge in either 8080 (mode 0) or 2-80 (mode 2) interrupt modes
- An IEEE-696 (S100) extended addressing memory (A16-A19) management port to allow up to 1 megabyte of addressing
- Serial clock generators for all standard asynchronous - data' rates from 75 Baud - 19,200 Baud
- Full IEEE-696 (S100) compatibility

The versatility of the CT810 makes it suitable to be used as a general purpose I/O, EPROM and Jump on Resets for non-multi-user applications.

B. TECHNICAL SPECIFICATIONS

CLOCK RATE...... ....2 Mhz for baud generation

MEMORY:

ROM... ....1K or 2K depending on Jurnper Selection

BUS COMPATIBILITY........IEEE-696 (S100)

INTERRUPT SUPPORT........8080 OR Z80 MODE

I/O.......................4 ASYNCHRONOUS PORTS
2 PARALLEL PORTS (one input/ one output)

C. BOARD SPECIFICATIONS

POWER REQUIREMENTS.

+8V.................. milliamps
+16V................. milliamps
-16V................. milliamps

OPERATING ENVIRONMENT.0-55 DEGREES CELSIUS

SIZE....................5" X 10" X 0.65"

CONNECTORS:

P0.....................IEEE-696 (S100) 100 pin
P1.....................Serial port (Dip Header 16 pin)
P2....................Parallel Port Input (Dip Header 14 pin)
P3.....................Parallel Port Output Dip Header 14 pin)

1.1 The DIGIAC Serial Interface Board (CT804S) is used by the CT804 to provide RS232-C electrical and signal interfaces to the various peripheral devices that are to be connected to the CT804. Using the "daughter" board concept provides DIGIAC with some unique advantages that are typically not available on micro computer products. Some of these features are:

- noise isolation
- upgradability to other types of serial interfaces (RS449, WE303, V.35, 40 Ma. Current Loop, etc.)
- RS232-C "D" type connectors are provided on board: no need for the customer to make special cables to connect to a non-standard pinout.
- The CT804S connects to the CT804 via a 31 pin Ribbon Cable.

Please read this entire manual before connecting the CT804S to the CT804 or any of your peipherals.

1.2 TECHNICAL SPECIFICATIONS:

Interface...........RS232-C Drivers and Receivers
Baud Rates..........110-9600 + External
Bus Compatability....34 PIN Custom Interface

1.3 BOARD SPECIFICATIONS:

Power Requirements:
+5V................< 75 MA.
+12V...............~50 MA.
-12V...............~50 MA.

Operating Environments.0-55 Degrees Celsius

Size...................4-1//4" x 3-1/2" x 0.65"

Connectors:
P2........CT804 Connector (34 Pin)
P4........Serial Port (TTY) 25 Pin "D" Type DCE Source
P5.........Serial Port (VIDEO) 25 Pin "D" Type DCE Source
P6........Serial Port (MODEM) 25 Pin "D" Type DTE Source

Technical Specifications

Printing

Printing method	Impact dot matrix
Printing speed	80 characters per second
Line feed time	Approximately 200 msec (at 1/6"/line.
Printing direction	Bidirectional, logic seeking. May be set to unidirectional (left to right) printing via software codes.
Character set	255 ASCII characters in a 9 × 9 dot matrix
Character size	2.1 mm (W) × 3.1 mm (H) (0.083" x 0.11") MX-80 2.1 mm (W) × 3.1 mm (H) (0.08" × 0.12") MX-100
Dot graphics density MX-80	480 dots/8" line horizontal (normal mode). 960 dots/8" line horizontal (super hi res mode).
Dot graphics density MX-100	816 dots/13.6" line horizontal (normal). 1632 dots/13.6" line horizontal (super hi res mode).
Line spacing	1/6 inch normal. Programmable in increments of 1/72 inch and 1/216 inch.
Columns (MX-80)	80 columns (normal size) 40 columns (double width) 132 columns (compressed) 66 columns (compressed/double width)
Columns (MX-100)	136 columns (normal size) 68 columns (double width) 233 columns (compressed) 116 columns (compressed/double width)

Paper

Paper feed	Adjustable sprocket feed. Friction feed on MX-100 and MX-80 F/T. Roll paper holder available for MX-80 F/T.
Paper type	Fanfold. Single sheet on MX-100 and MX-80 F/T. Roll paper on MX-80 F/T with optional holder,
Paper width	101.6 mm to 254 mm (4" to 10") on MX-80 101.6 mm to 393.7 mm (4" to 15.5") on MX-100.
Paper thickness	0.3 mm (0.012") maximum.
Number of copies	One plus two carbon copies.

Printer

Ribbon	Cartridge ribbon (exclusive use), black.
MTBF	5 million lines (excluding print head life).
Print head life	100 x 10 (6) characters.
Dimensions	374 mm (W) × 305 mm (D) x 107 mm (H) (14.7" x 12.0" x 4.2") 592 mm (W) x 393 mm (D) x 133 mm (H) (23.3" x 15.5" x 5.2") on MX-100
Weight (approximate)	5.5 kg (12.1 lbs) - MX-80. 10 kg (22 lbs) - MX-100.
Power	115V plus or minus 10% 49.5–60.5 Hz.
Power requirement	100 VA max.
Temperature	Operating 5°C to 35°C (41°F to 95°F) Storage −30°C to 70°C (−22°F to 158°F).
Humidity	Operating 5% to 90% (no condensation). Storage 0% to 95% (no condensation).
Shock	Operating 1 G (less than 1 msec.). Storage 2 G (less than 1 msec.).
Vibration	Operating 0.25 G, 55 Hz (max.). Storage 0.50 G, 55 Hz (max.).
Insulation resistance	10M Ω between AC power line and chassis
Dielectric strength	Between AC power line and chassis, AC 1 KV (RMS) 50 Hz or 60 Hz during 1 minute and no abnormal condition shall be observed.

Parallel Interface

Interface	Standard Centronics parallel. Optional RS-232 and IEEE.
Data transfer rate	4,000 CPS (max.).
Synchronization	By externally supplied STROBE pulses.
Handshaking	By ACKNLG or BUSY signals.
Logic level	Input data and all interface control signals are compatible with the TTL level.

SPECIFICATIONS

The following tables list specifications and accesories and supplies available for the 4662 Interactive Digital Plotter. The specifications are listed for your information only and are not verifiable. Information on options, supplies, and accessories are subject to change.

Table D-1

PHYSICAL SPECIFICATIONS

Characteristics	Standard 4662	With Option 31
Height	8 in (203 mm)	8 in (203 mm
Width	20.375 in (517 mm)	25.75 in (654 mm)
Depth	19.5 in (495 mm)	19.5 in (495 mm)
Weight	30 lbs 4 oz (13.8 kg)	35 lbs (16 kg)
Shipping Weight	45 lbs 14 oz (20.8 kg)	46 lbs (21 kg)

Table D-2

ELECTRICAL SPECIFICATIONS

Characterirtic	Specification (Standard and Option 31 Equipped 4662)
Input Power	90W maximum, 60W typical
Line Voltage	115 or 230 volts nominal Line voltages are strappable within the ploner lo select 105. 116, 210. or 232 volts (±14%)
Line Frequency	48 to 66 Hz
Line Fuse	1 amp (slow-blow) when operating in the 115 volt range 0 5 amp (slow-blow) when operating in the 230 volt range

Table D-3

ENVIRONMENTAL SPECIFICATIONS

Characteristic	Specification (Standard and Option 31 Equipped 4662)
Temperature	−55 to +75 degree C. (non-operating) 0 to +50 degree C (operating)
Altitude	To 50,000 feet (15240 m) (non-operating) To 15,000 feet (4572 m) (operating)

SPECIFICATIONS

Table D 4
PERFORMANCE SPECIFICATIONS

Characterlatic	Specification
Plotting Area **(see Figure D-1)**	**X-Axis** — 15 in (381 **mm**) **Y-Axis — 10 in (254 mm)** Can be increased to **15.35x10.23** in **(390x260 mm).**
Scaling	The **plotter** will scale incoming data that **is** intended for full-scale plotting into any size page **within** the **plotting** area.
Plotting Accuracy	**± 0.0025 in (0.06 mm) or ± .4% of vector** length, whichever is larger.
Repeatability	**The plotter will return to any previously-plotted** point within ± 0.0025 in (0.06 mm). With Option 31. within ± 0.012 inch (0.3 **mm) after** pen exchange.
Vector Linearity	Geometry — **The** mean vector line will not deviate more than **0.0007** inch (0.02 mm). per inch of line length, from a straight line drawn between *two* points. Line **Aberrations** — Short **term non-linearities of** a vector will not deviate more than ± 0.005 in (0.127 mm) **from** the mean vector.
Plotting Rate	**Fast Speed — 16 in per second (400 mm/sec)** at axlal. 22 In per second (559 **mm/second)** maximum. Maximum rate achieved **after** about 100 **ms,** or about 13 in (33 **mm)** of pen travel. Slow Speed — approximately 0.5 of fast **speed**. Programmable Speed **(Option** 31 only) — limits the **maximum** pen velocity **from** 10 **mm/sec** to 570 **mm/sec** (0.4 inlsec to 22.4 inlsec) in 10 **mm/sec** (0.4 **in/sec)** steps **(i.e.,** there are 57 speeds).
Joystick Moves (Manual)	The pen may be **moved** by using the fmnt panel joystick at vector rates variable from 0.015 **in/second** to 4 **inches/second** (0.38 **mm/sec** to 101.6 **mm/sec).**
Point Plotting Rate	**Pen action rate (up/down) is approximately** 10 **points/second** maximum. **Plotter** points per second decreases for an increasing **distance between points.**
Data Resolution	**0.005 in (0.127 mm)**
Motor Drive Resolution	Approximately 8 times the data **resolution** (0.000625 in or 0.016 mm)

Table D 5
STANDARD ACCESSORIES AND SUPPLIES

Part	Tcktronlx Part **Number**
Power Cord	**161-0066-00**
RS-232-C Cable	012482940
4682 **Interactive** Digital **Plotter Operator's** Manual	070416540
4662 **Interactive Digital Plotter Programmer's** Reference Manual	061-2642-00
4662 Interactive Digital Plotter Programmer's **Reference** Card	070-255640
Paper, 100 sheets. 279x419 mm **(11x16.5 in)** linear grid, **10x10** lines lo the in	**006-1698-00**
Digitizing **Reticle** — Standard 4662	214-240941
Digitizing Reticle — Option 31	**119-1432-01**
Pens. **Fiber-Tip** — Standard 4662 **(Pkgs** of 3)	
Red	016-058940
Green	**016-0589-01**
Black	016458902
Blue	016458943
Pens. Fiber-Tip — **Option** 31 Two **9-pen** pkgs (one pen each of nine **colors)**	016-0687-00

See Figure D-2 lor **telephone numbers** lor **use when ordering.**

APPENDIX *B*

<u>Uer Log-On Instructions</u>

THE FINITE ELEMENT ANALYSIS PROGRAMS

USER INSTRUCTIONS FOR THE

DIGIAC CT-80 SYSTEM

Evangelos Michael Marinis

May 1985

1) Turn system ON from main outlet.

2) Turn ON the plotter and C.R.T units.

3) Hit the RESET switch (top left corner of computer.)

4) Insert disk in drive A.

5) Type the letter B and hit the RETURN key (console 1.) This step will Boot-up the system. It will load the operating system from the disk into the main memory.

6) After system boots-up it will display OA> at the bottom of the screen.

7) Use the following command to start the program:

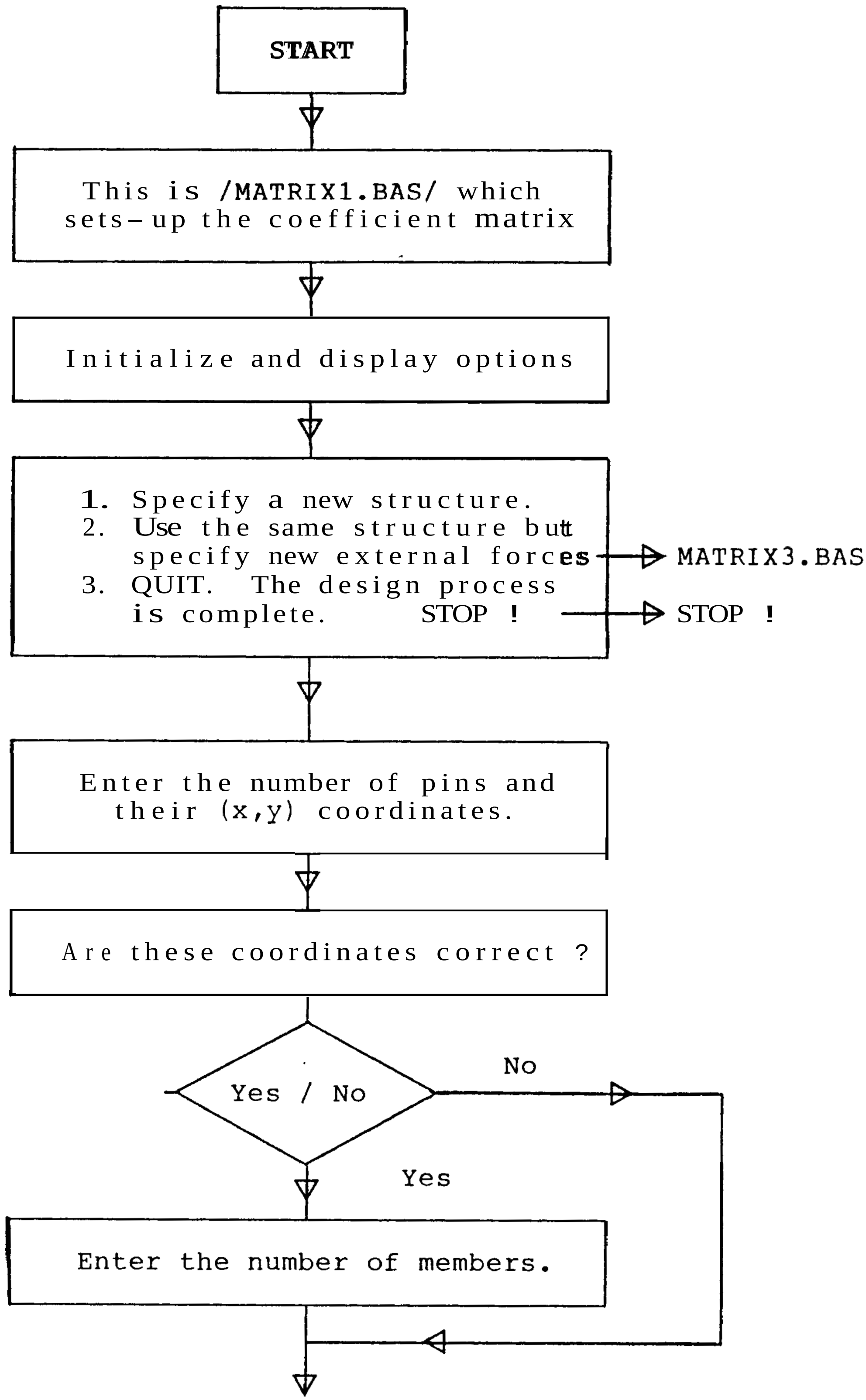
   OA>SUBMIT FILE0 (RETURN)

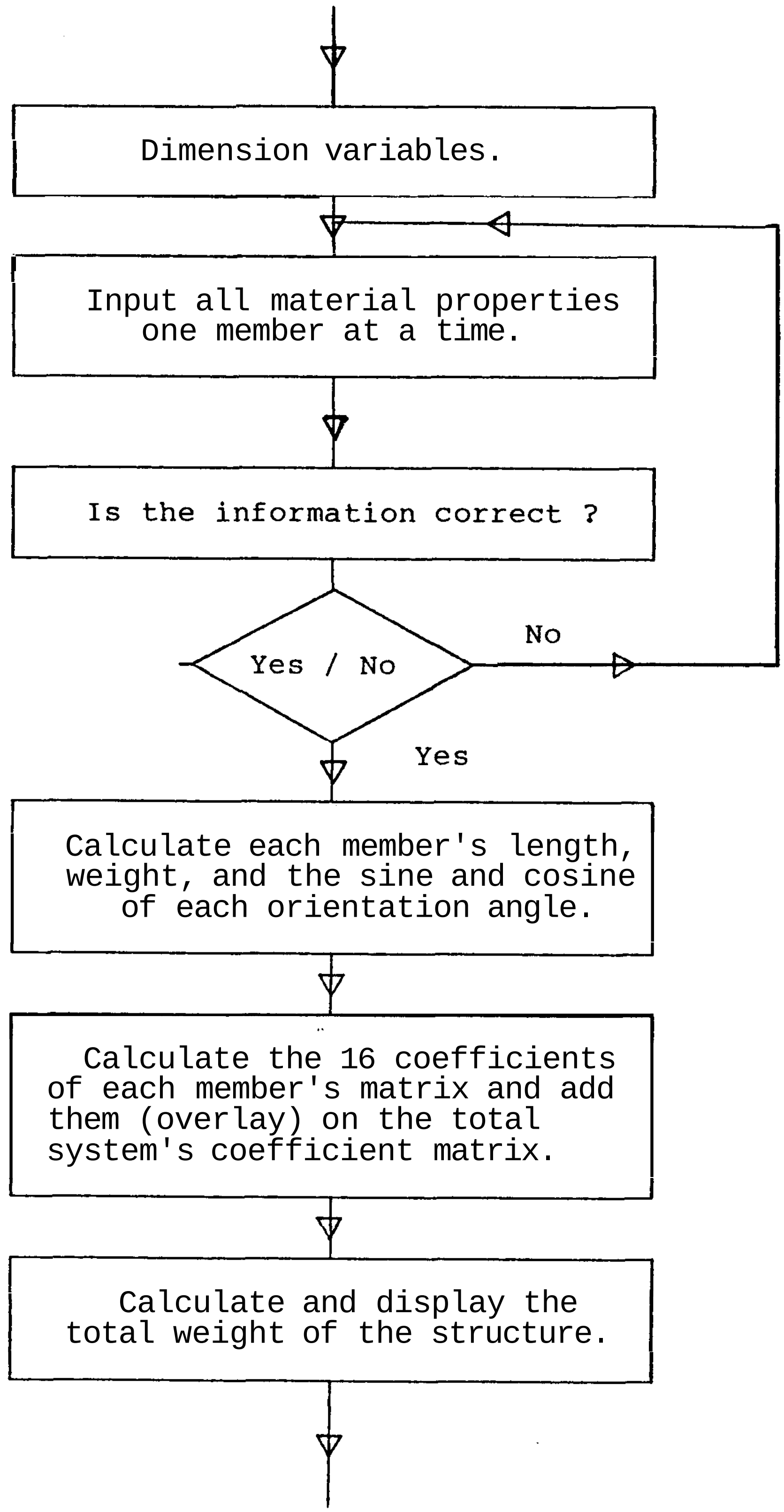
8) The programs will run automatically.

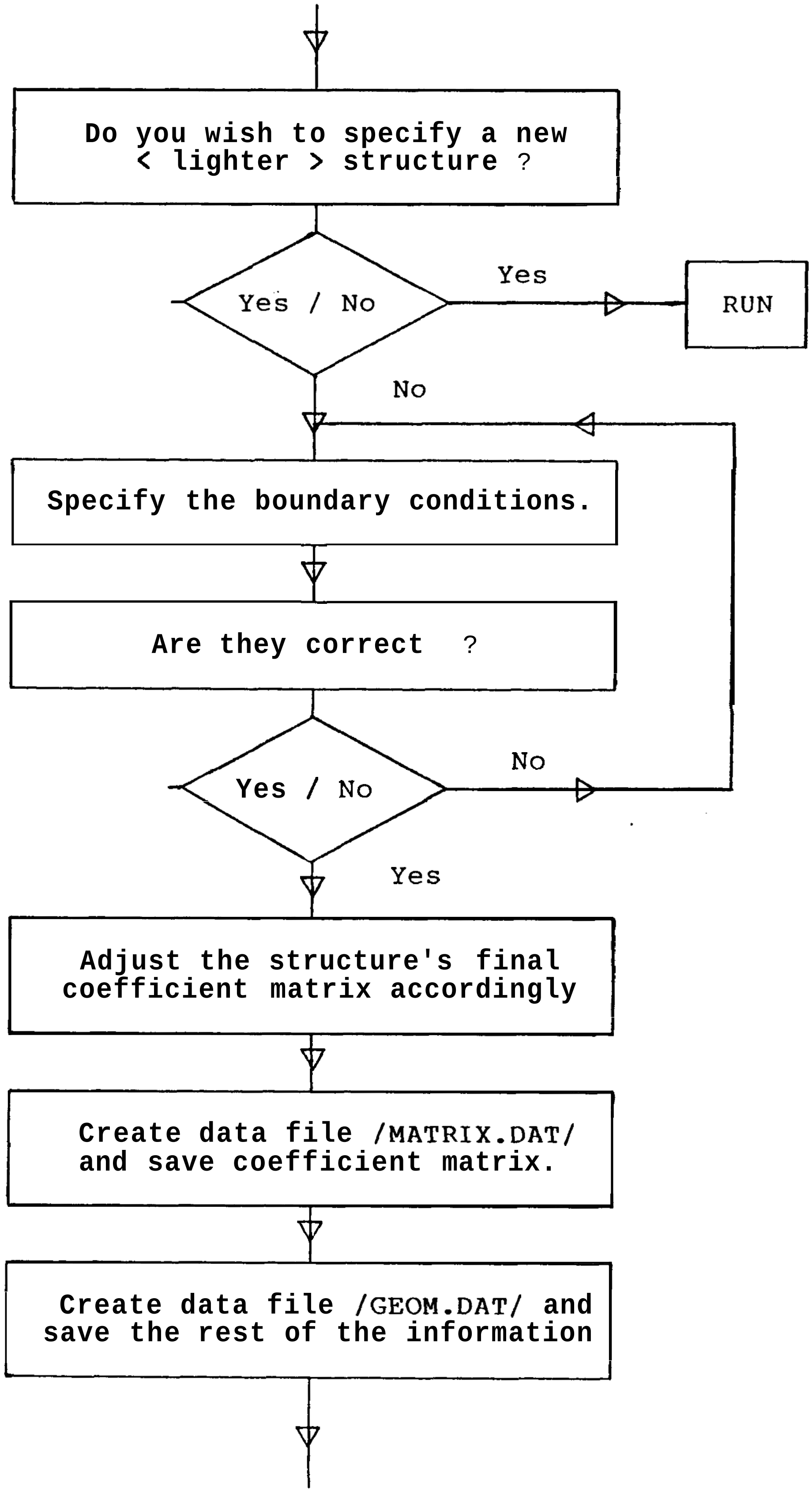
9) To STOP or QUIT, hit Control-C (more than once may be necessary.)

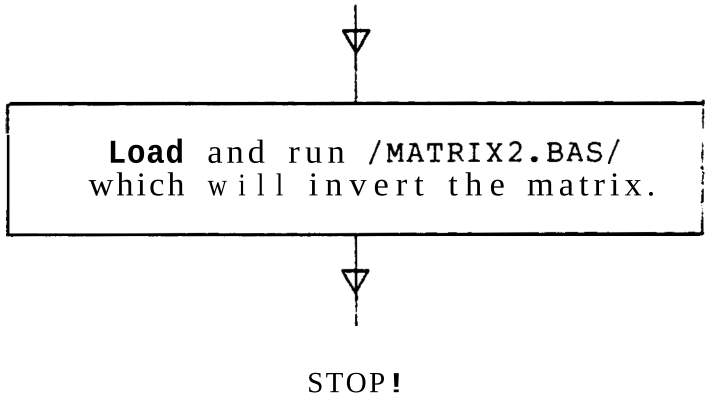
APPENDIX C

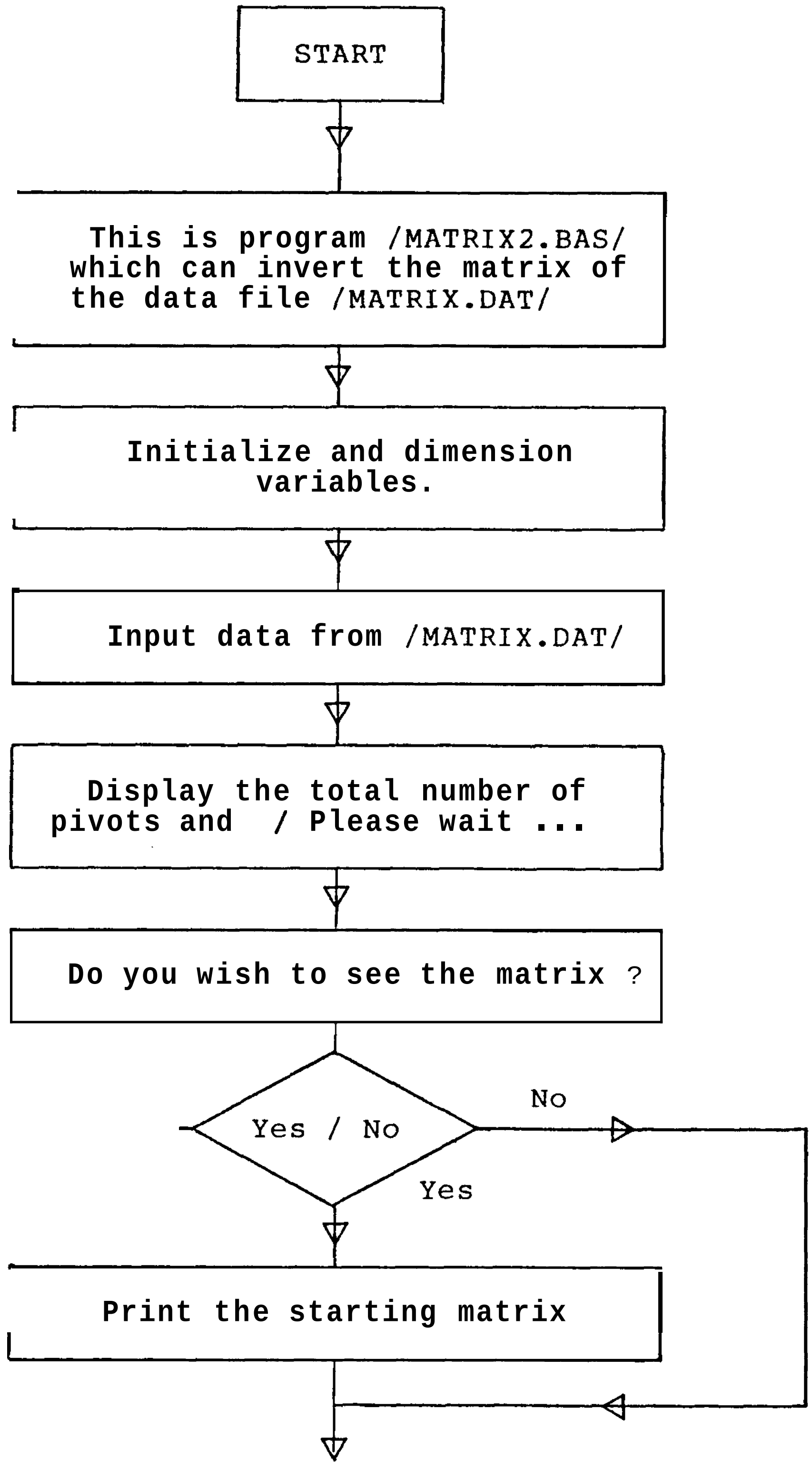
Program Flow Diagrams

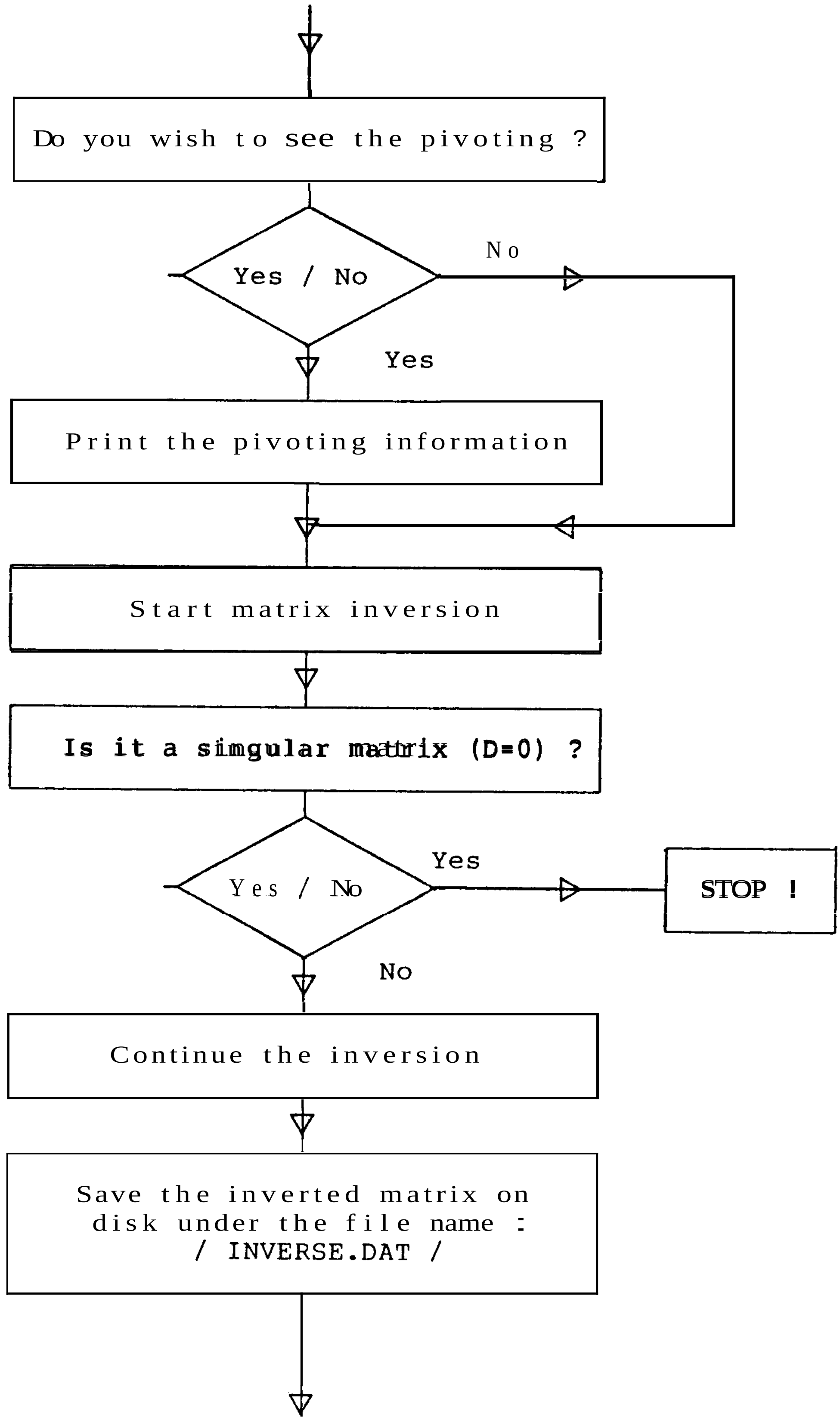

START
This is /MATRIX1.BAS/ which sets-up the coefficient matrix
Initialize and display options
1. Specify a new structure.
2. Use the same structure but specify new external forces
3. QUIT. The design process is complete. STOP !
MATRIX3.BAS
STOP !
Enter the number of pins and their (x,y) coordinates.
Are these coordinates correct ?
Yes / No
No
Yes
Enter the number of members.

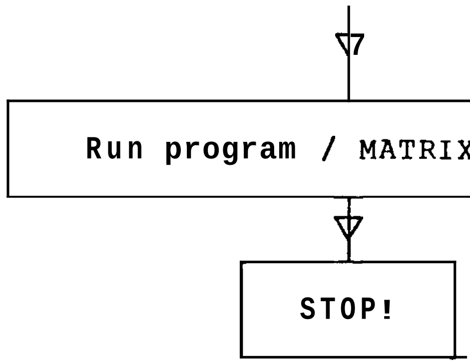

Dimension variables.
Input all material properties one member at a time.
Is the information correct ?
Yes / No
No
Yes
Calculate each member's length, weight, and the sine and cosine of each orientation angle.
Calculate the 16 coefficients of each member's matrix and add them (overlay) on the total system's coefficient matrix.
Calculate and display the total weight of the structure.

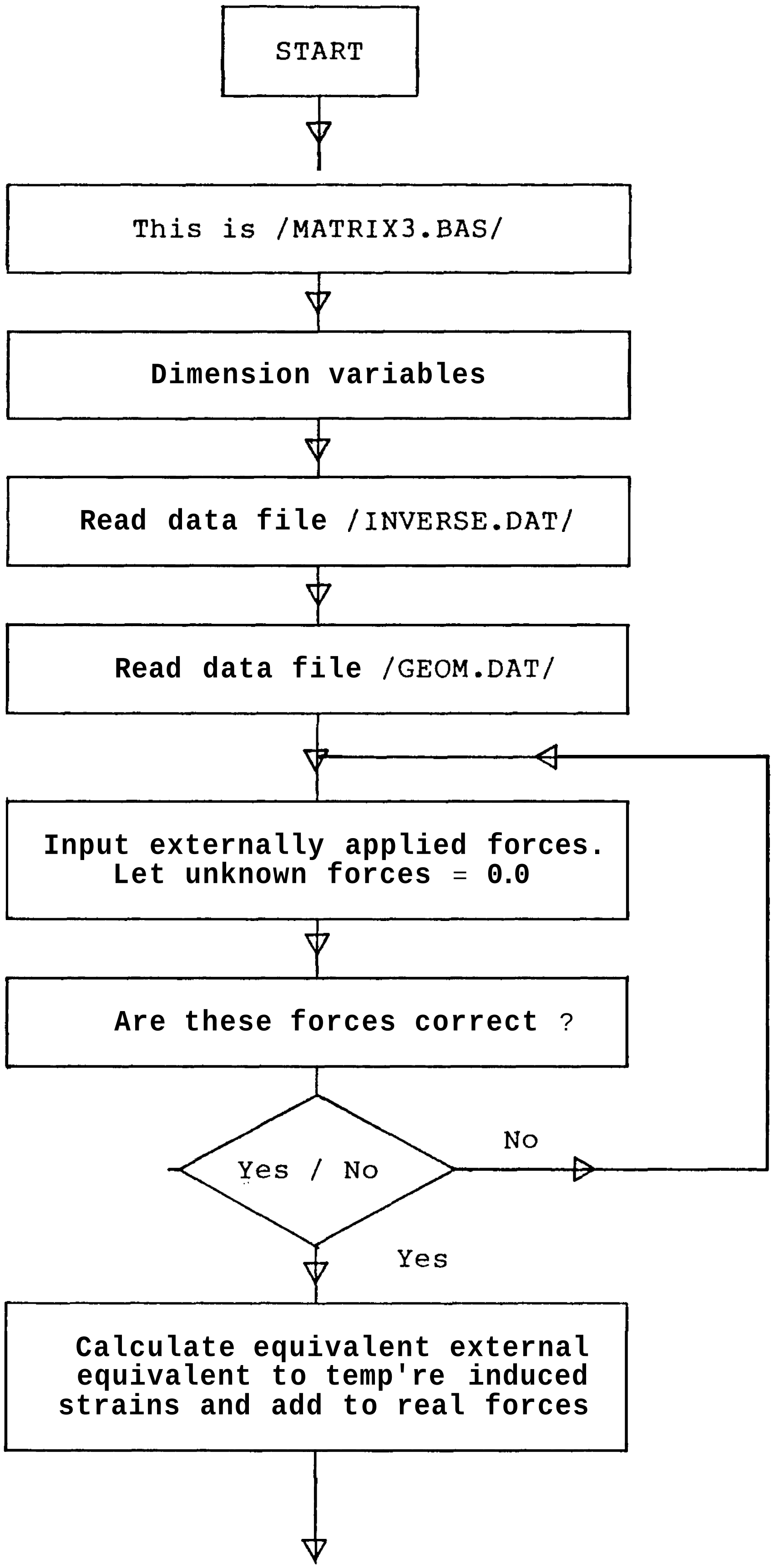

Do you wish to specify a new < lighter > structure ?
Yes / No
Yes
RUN
No
Specify the boundary conditions.
Are they correct ?
Yes / No
No
Yes
Adjust the structure's final coefficient matrix accordingly
Create data file /MATRIX.DAT/ and save coefficient matrix.
Create data file /GEOM.DAT/ and save the rest of the information

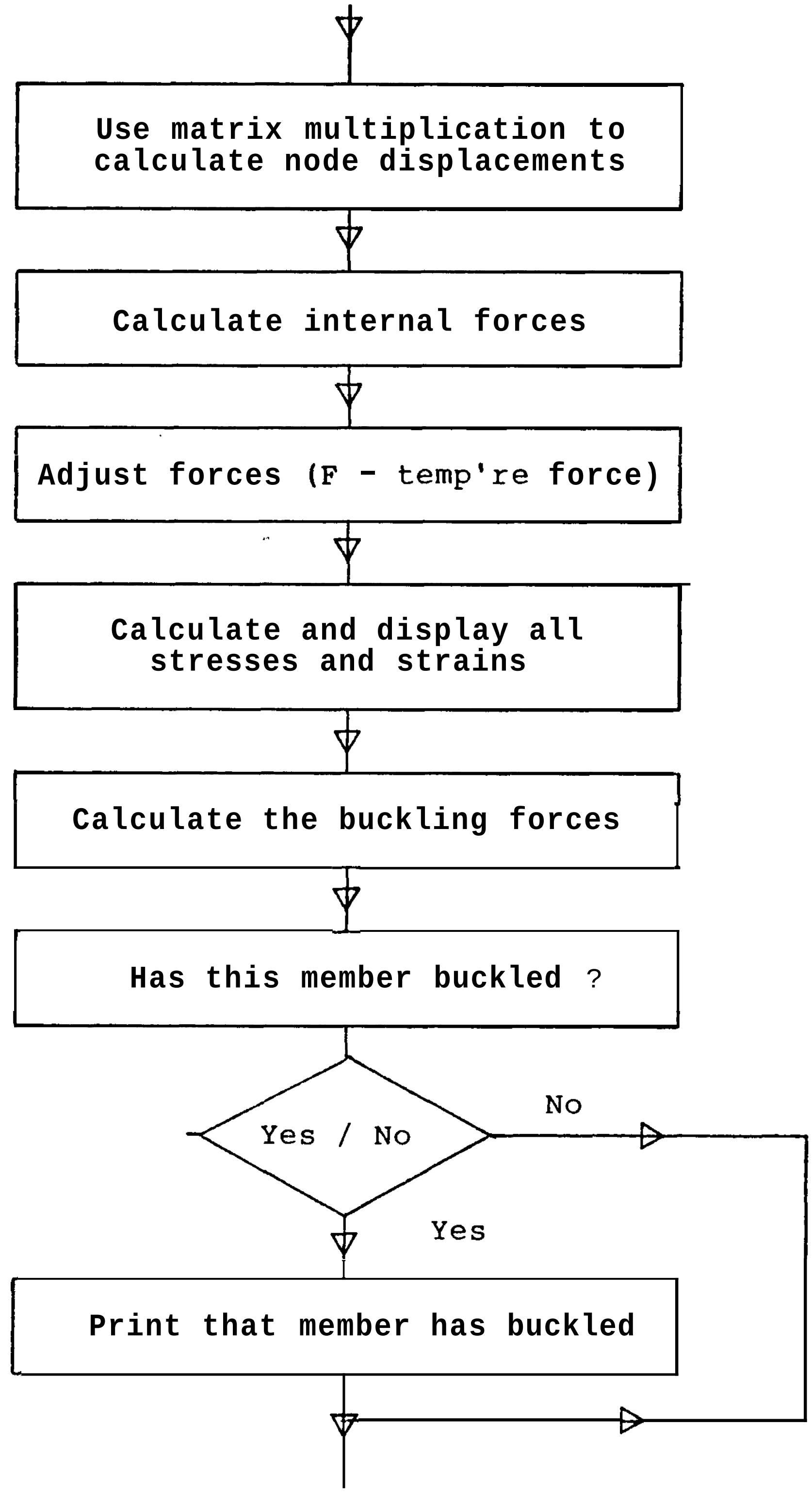

Load and run /MATRIX2.BAS/
which will invert the matrix.
STOP!

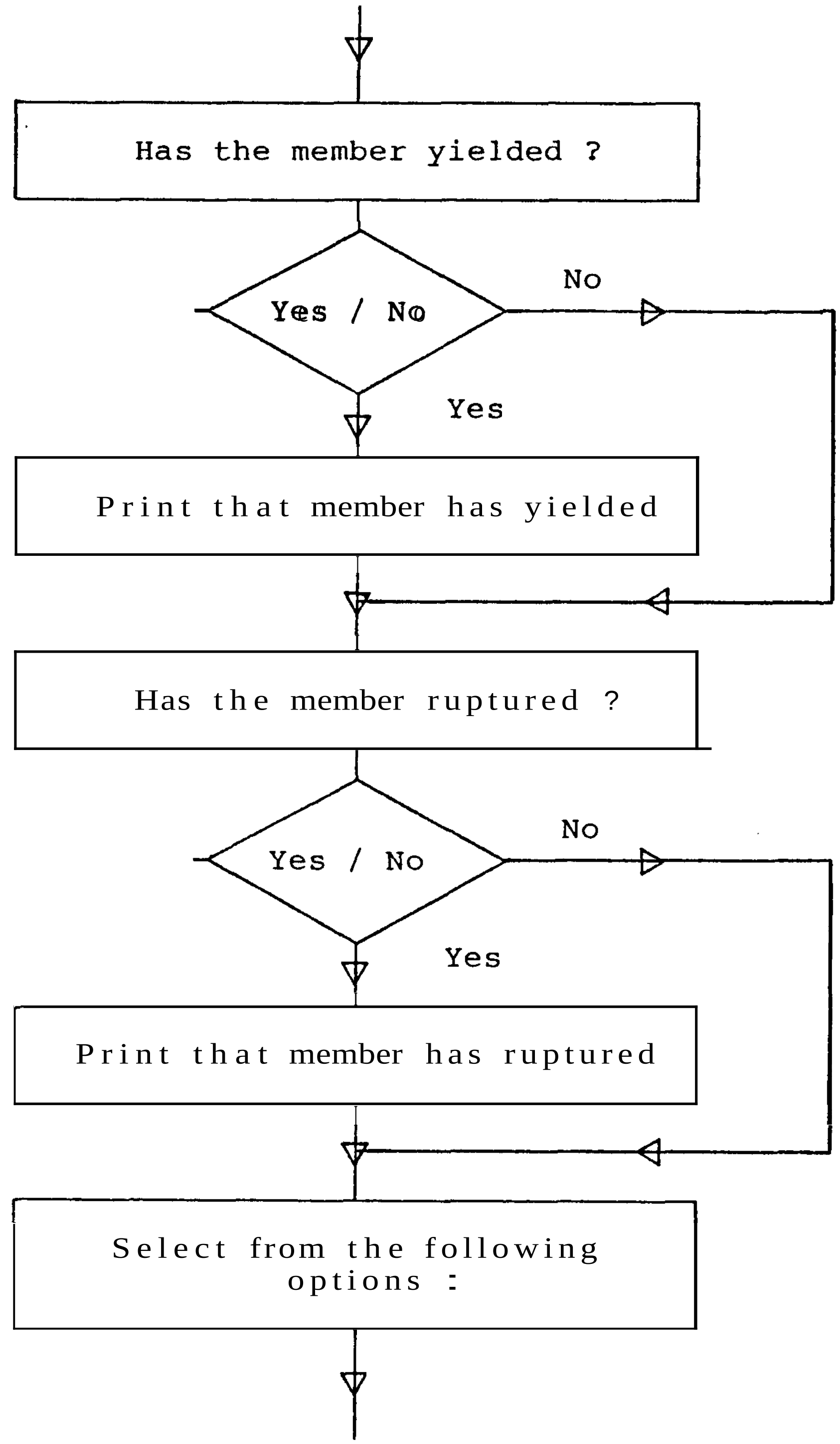

START
This is program /MATRIX2.BAS/ which can invert the matrix of the data file /MATRIX.DAT/
Initialize and dimension variables.
Input data from /MATRIX.DAT/
Display the total number of pivots and / Please wait ...
Do you wish to see the matrix ?
Yes / No
No
Yes
Print the starting matrix

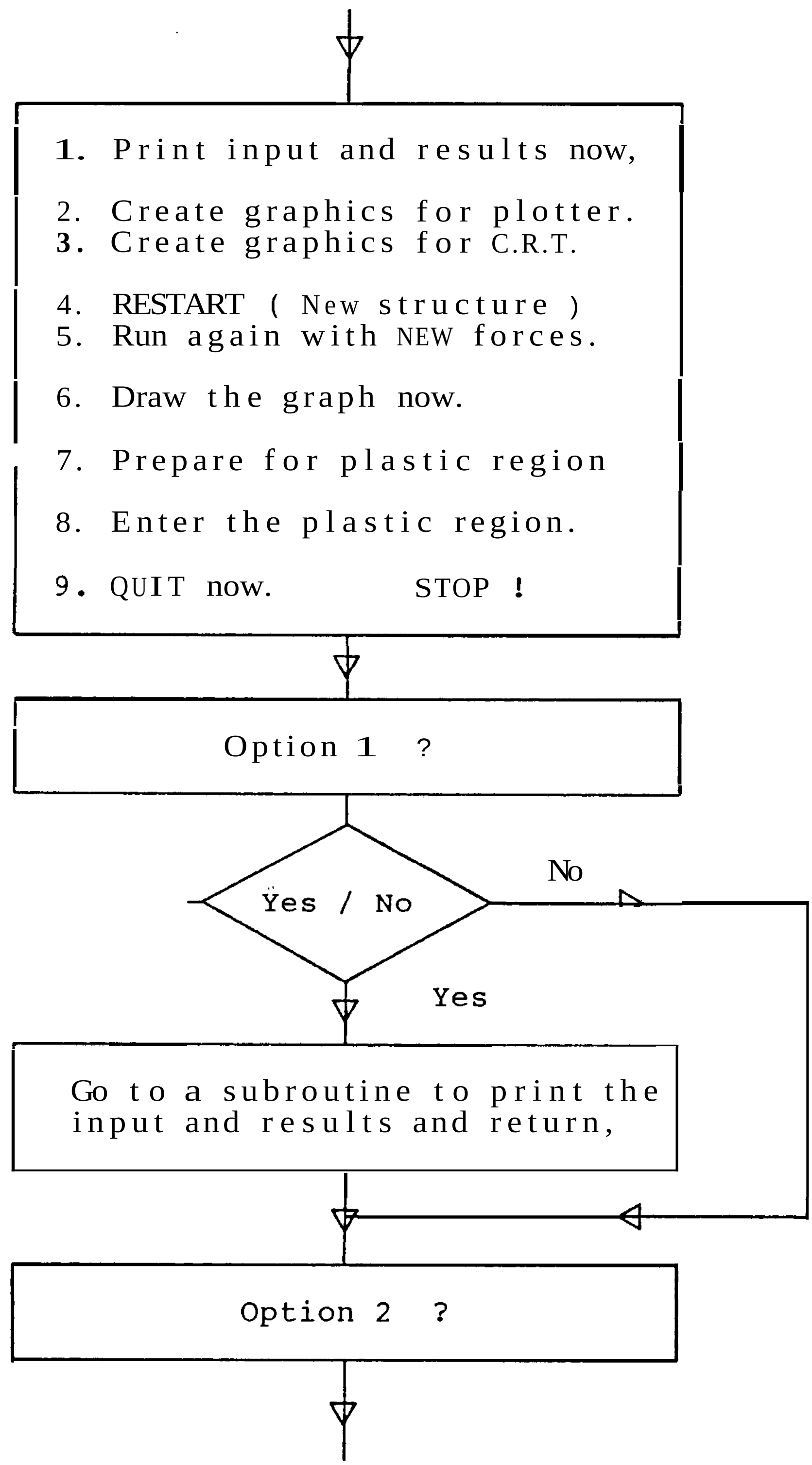

Do you wish to see the pivoting ?
Yes / No
No
Yes
Print the pivoting information
Start matrix inversion
Is it a simgular matrix (D=0) ?
Yes / No
Yes
STOP !
No
Continue the inversion
Save the inverted matrix on
disk under the file name :
/ INVERSE.DAT /


7
Run program / MATRIX3.BAS /
STOP!

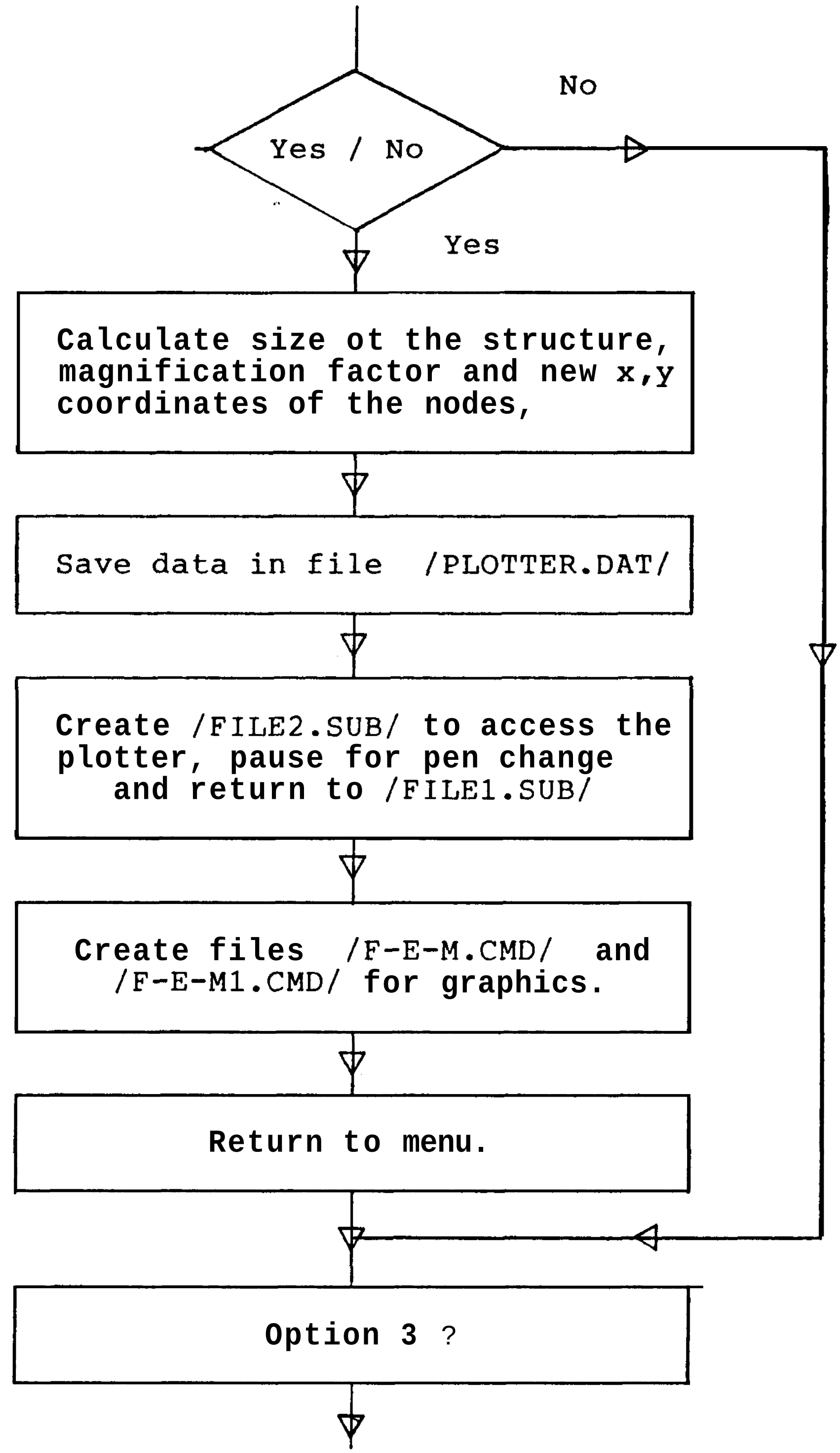

START
This is /MATRIX3.BAS/
Dimension variables
Read data file /INVERSE.DAT/
Read data file /GEOM.DAT/
Input externally applied forces.
Let unknown forces = 0.0
Are these forces correct ?
Yes / No
No
Yes
Calculate equivalent external
equivalent to temp're induced
strains and add to real forces

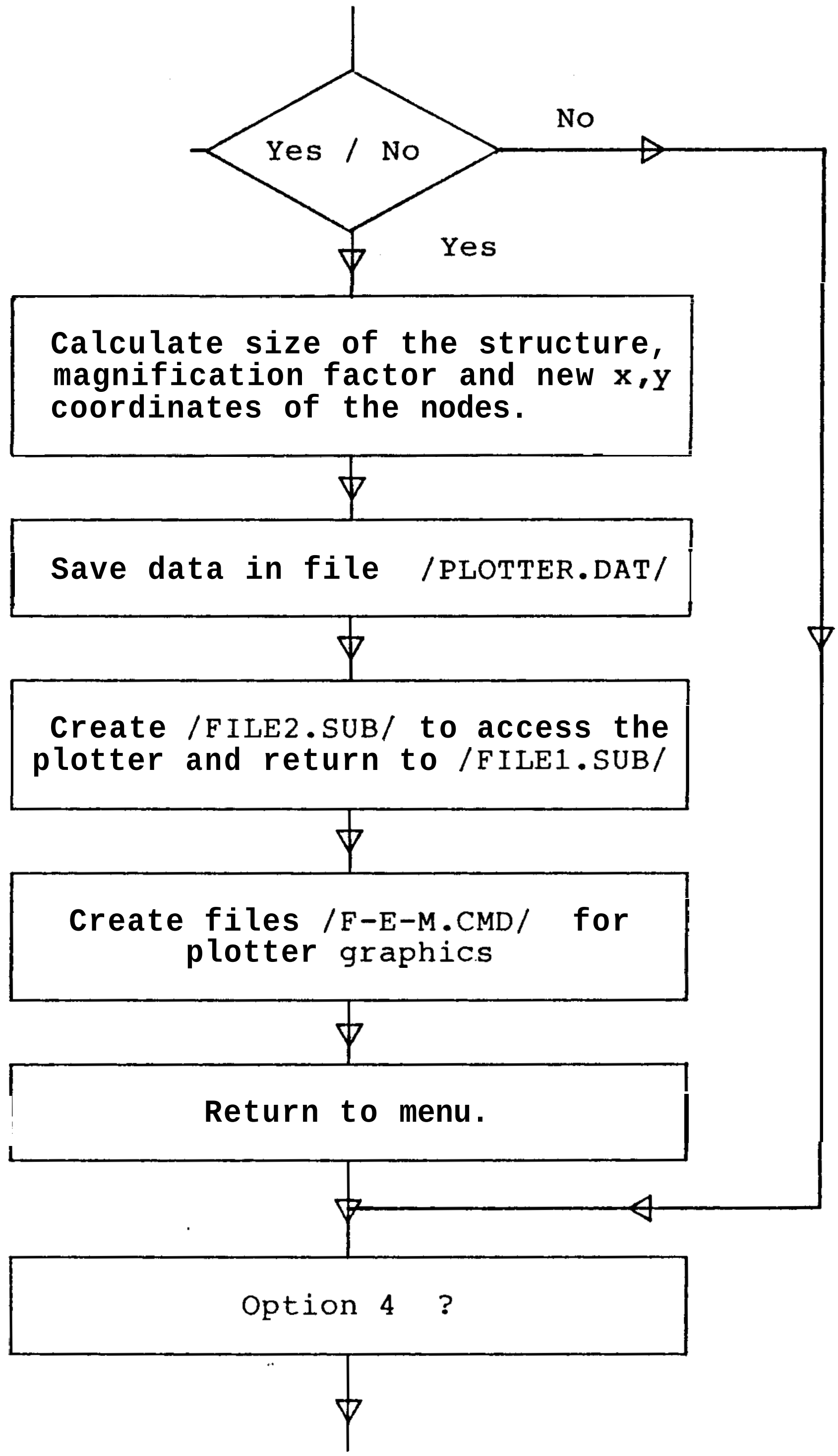

Use matrix multiplication to calculate node displacements
Calculate internal forces
Adjust forces (F - temp're force)
Calculate and display all stresses and strains
Calculate the buckling forces
Has this member buckled ?
Yes / No
No
Yes
Print that member has buckled

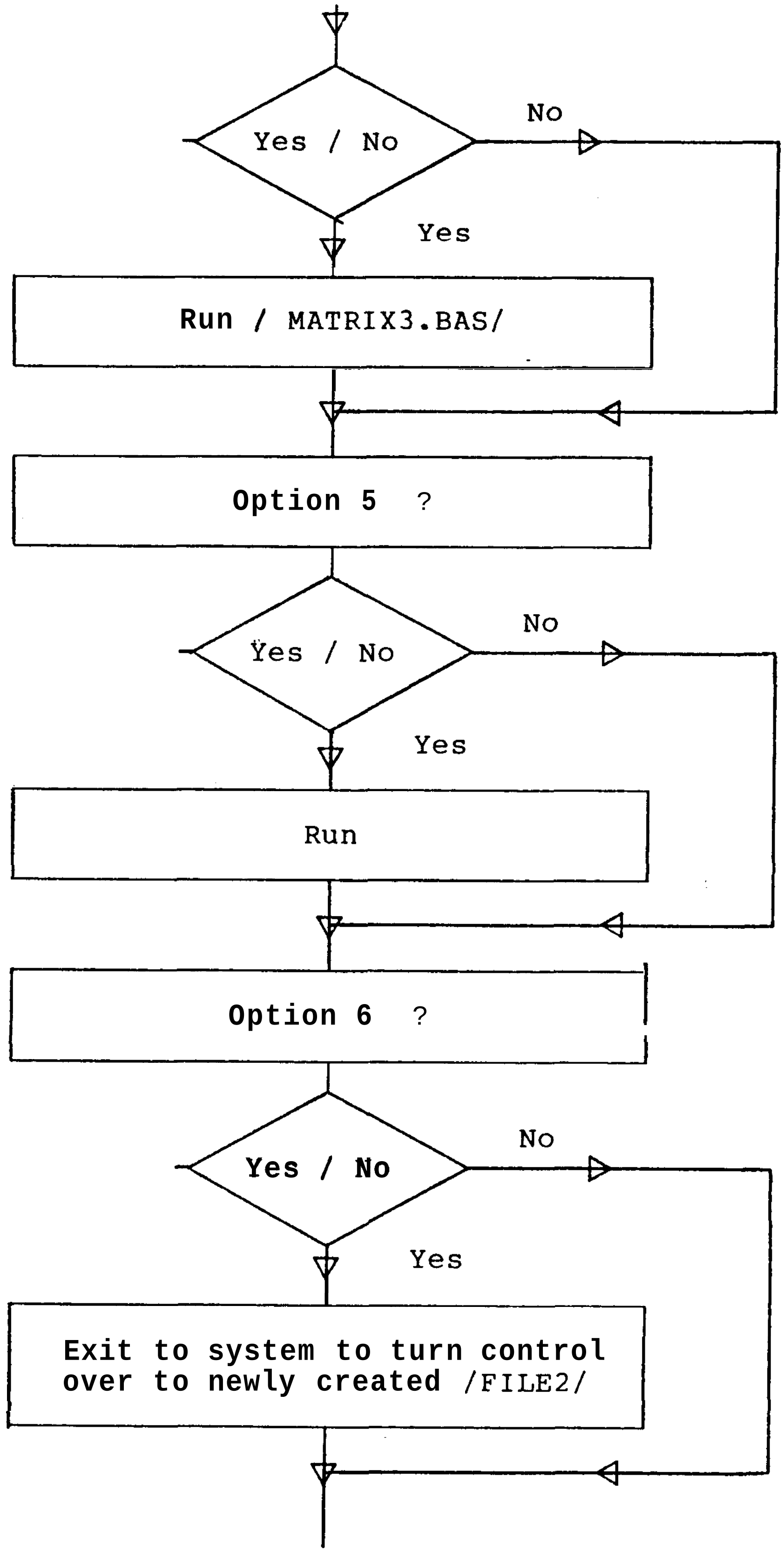

Has the member yielded ?
Yes / No
No
Yes
Print that member has yielded
Has the member ruptured ?
Yes / No
No
Yes
Print that member has ruptured
Select from the following options :

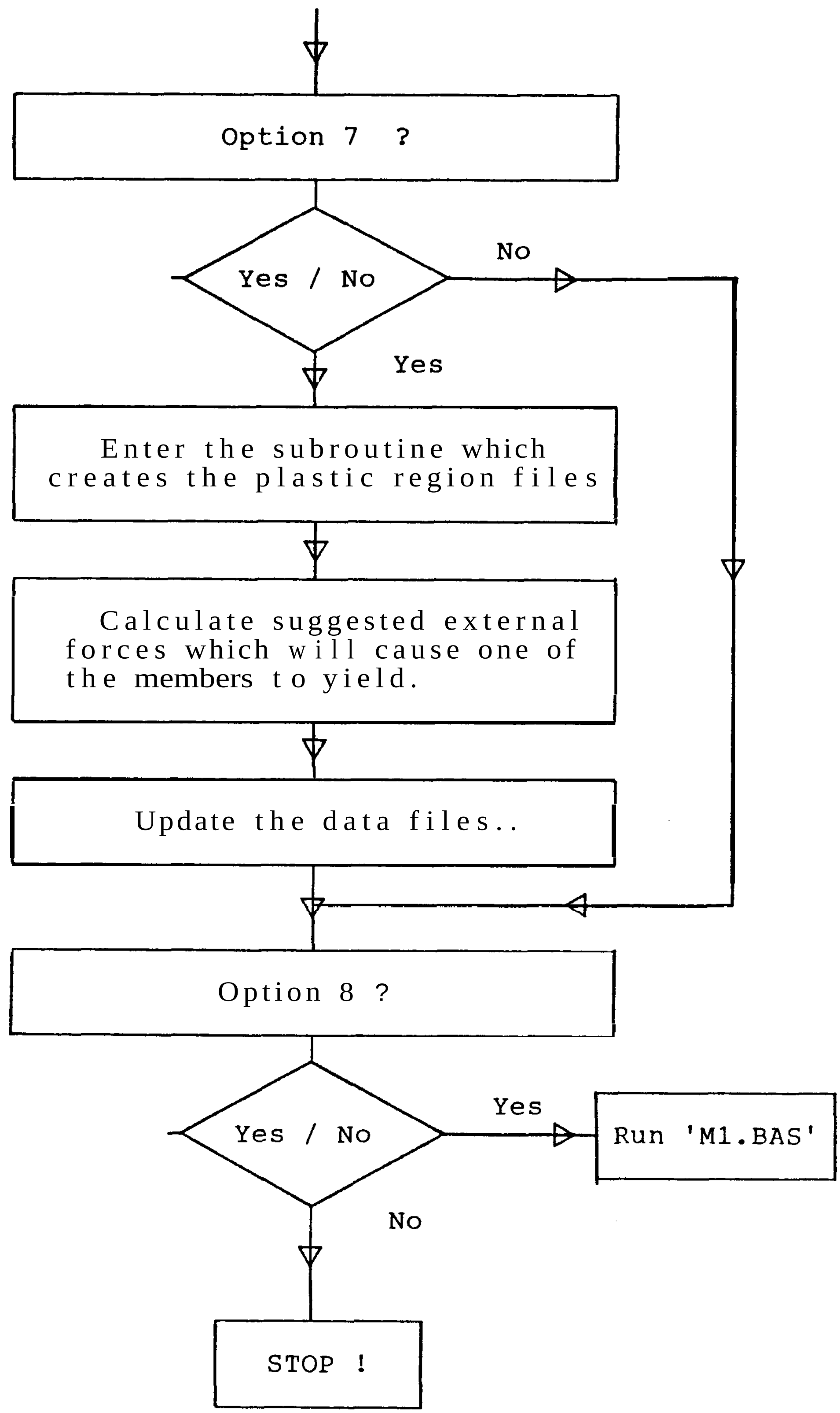


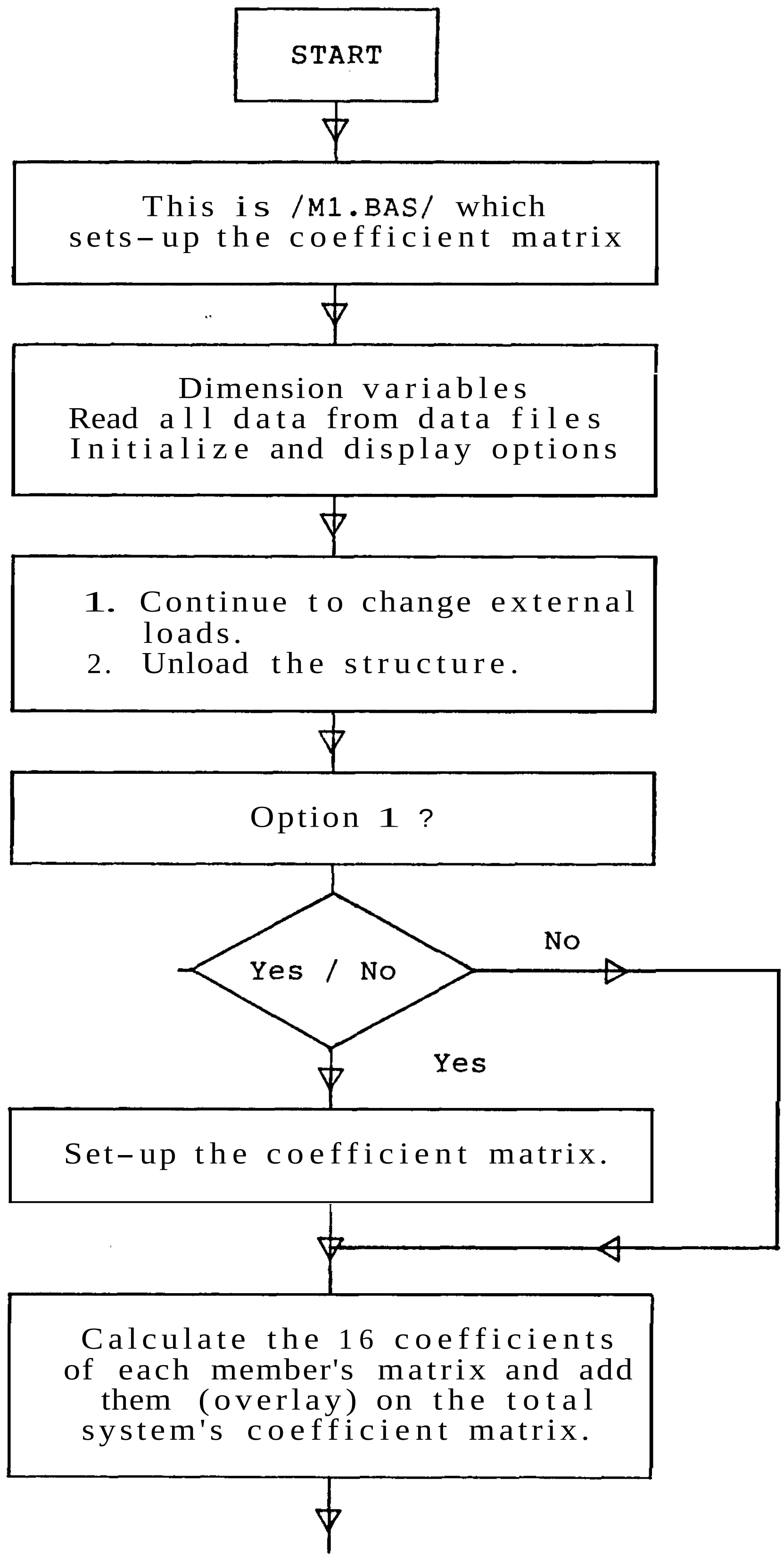
1. Print input and results now,
2. Create graphics for plotter.
3. Create graphics for C.R.T.
4. RESTART (New structure)
5. Run again with NEW forces.
6. Draw the graph now.
7. Prepare for plastic region
8. Enter the plastic region.
9. QUIT now. STOP !
Option 1 ?
Yes / No
No
Yes
Go to a subroutine to print the input and results and return,
Option 2 ?

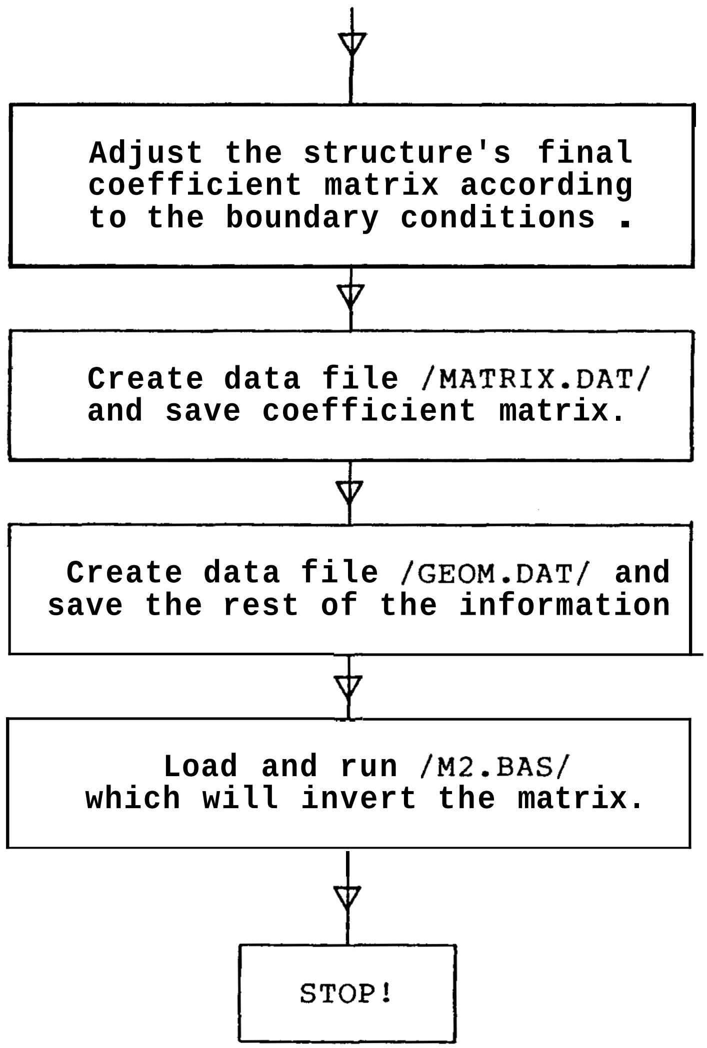

Yes / No
No
Yes
Calculate size ot the structure, magnification factor and new x,y coordinates of the nodes,
Save data in file /PLOTTER.DAT/
Create /FILE2.SUB/ to access the plotter, pause for pen change and return to /FILE1.SUB/
Create files /F-E-M.CMD/ and /F-E-M1.CMD/ for graphics.
Return to menu.
Option 3 ?

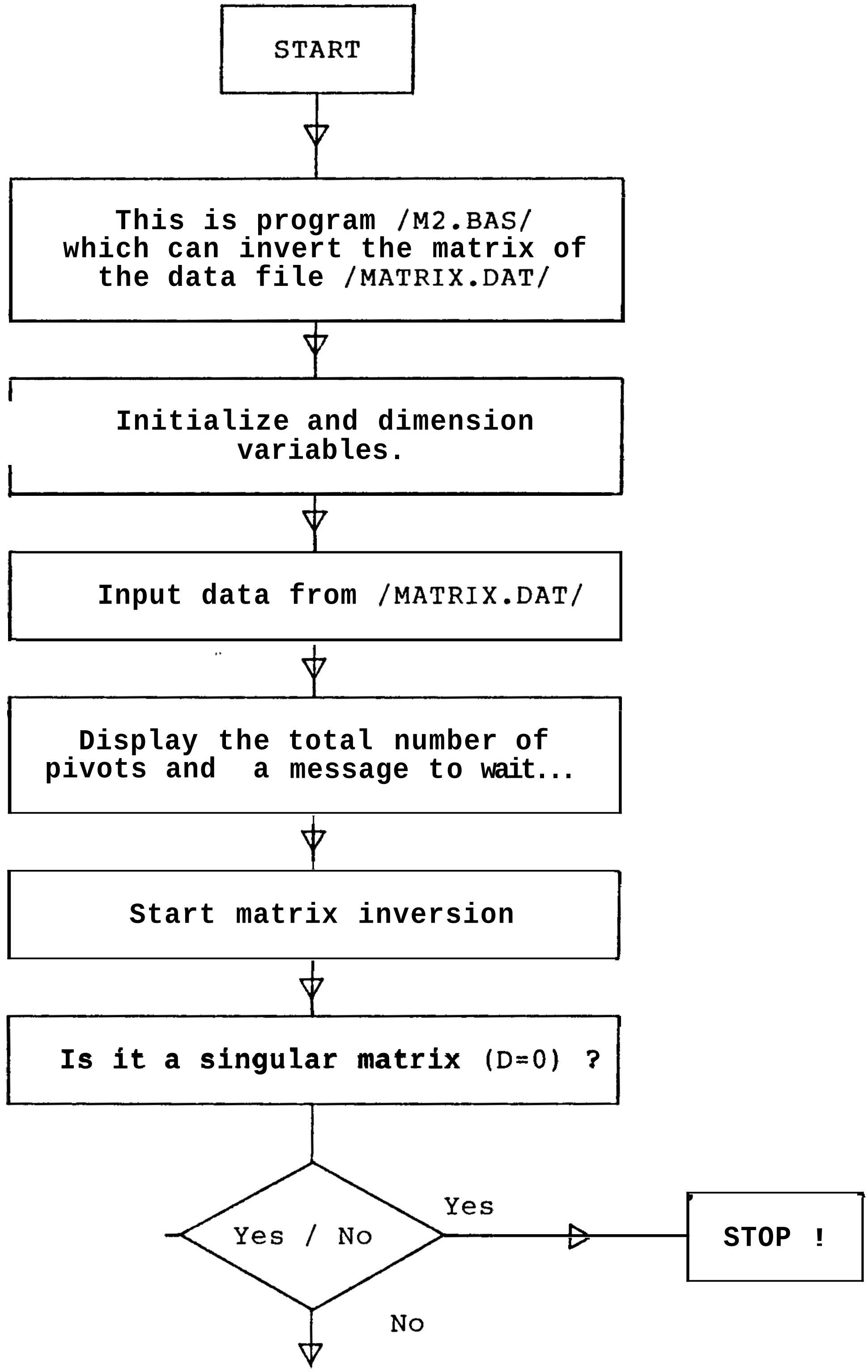

No
Yes / No
Yes
Calculate size of the structure, magnification factor and new x,y coordinates of the nodes.
Save data in file /PLOTTER.DAT/
Create /FILE2.SUB/ to access the plotter and return to /FILE1.SUB/
Create files /F-E-M.CMD/ for plotter graphics
Return to menu.
Option 4 ?


Yes / No
No
Yes
Run / MATRIX3.BAS/
Option 5 ?
Yes / No
No
Yes
Run
Option 6 ?
Yes / No
No
Yes
Exit to system to turn control over to newly created /FILE2/

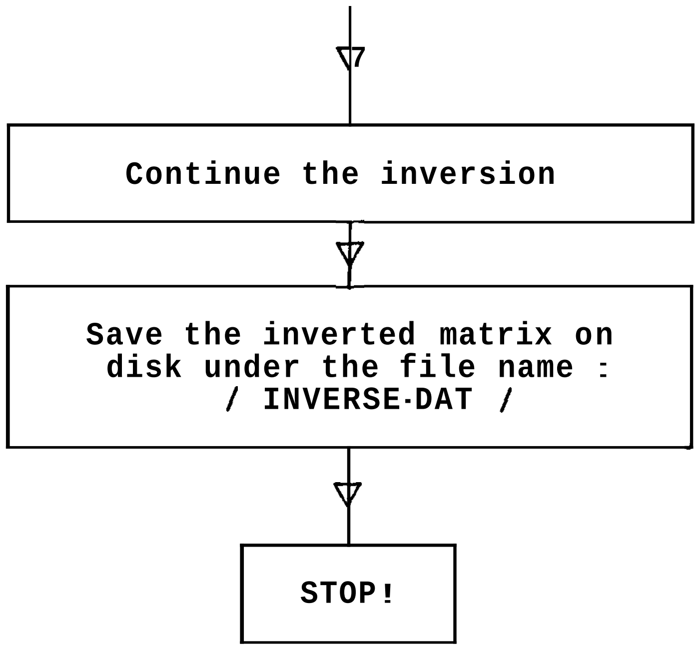

Option 7 ?
Yes / No
No
Yes
Enter the subroutine which creates the plastic region files
Calculate suggested external forces which will cause one of the members to yield.
Update the data files..
Option 8 ?
Yes / No
Yes
Run 'M1.BAS'
No
STOP !

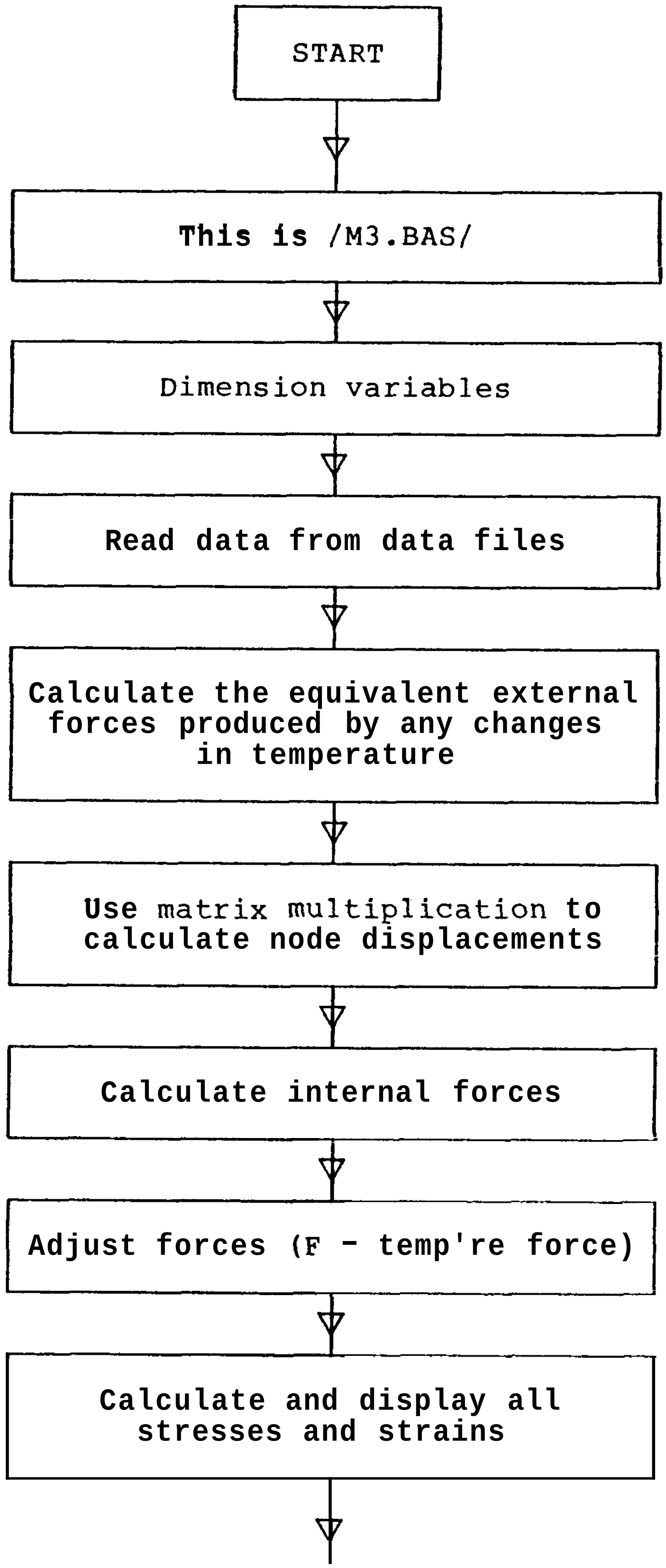

START
This is /M1.BAS/ which sets-up the coefficient matrix
Dimension variables
Read all data from data files
Initialize and display options
1. Continue to change external loads.
2. Unload the structure.
Option 1 ?
Yes / No
No
Yes
Set-up the coefficient matrix.
Calculate the 16 coefficients of each member's matrix and add them (overlay) on the total system's coefficient matrix.

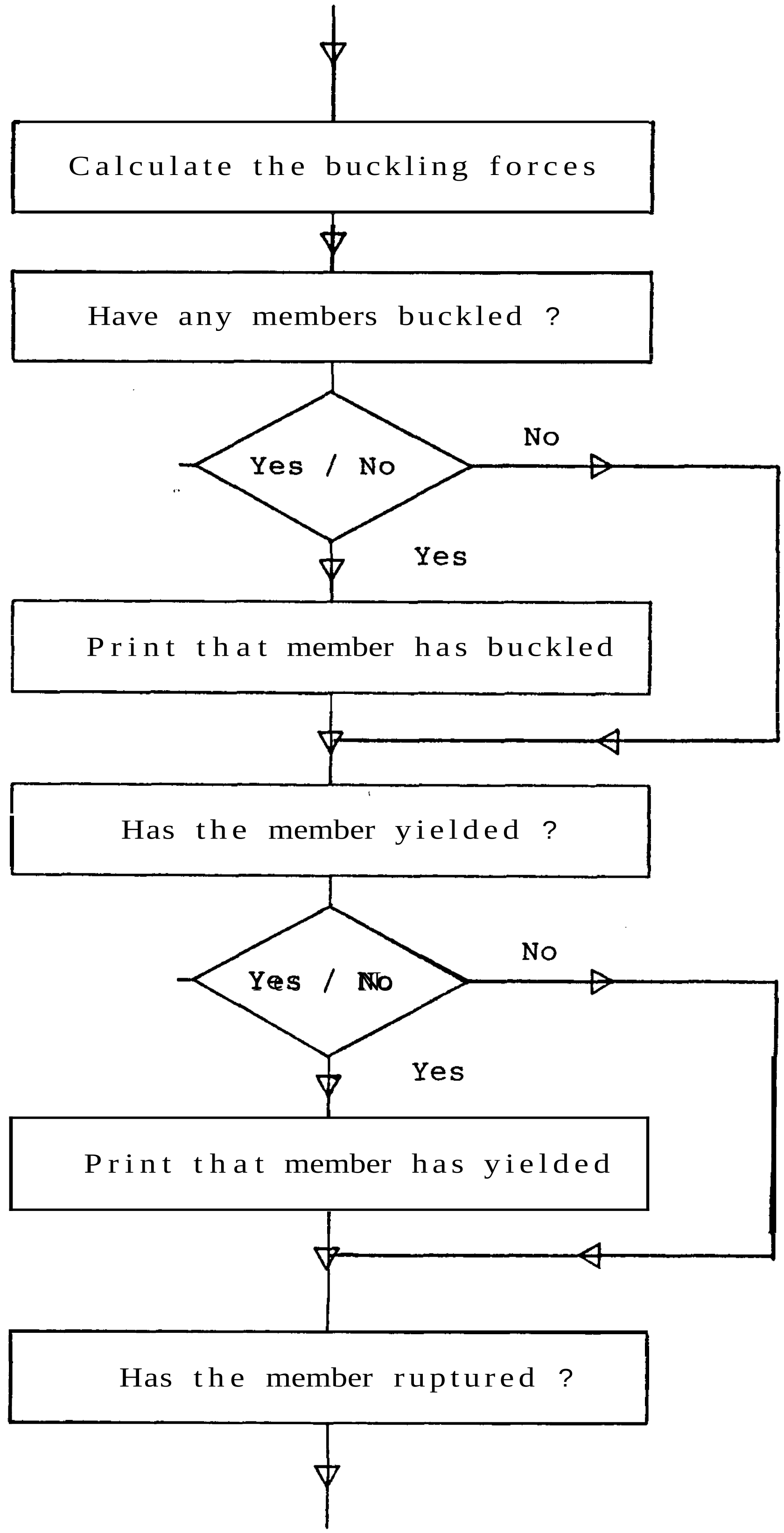

Adjust the structure's final coefficient matrix according to the boundary conditions .
Create data file /MATRIX.DAT/ and save coefficient matrix.
Create data file /GEOM.DAT/ and save the rest of the information
Load and run /M2.BAS/ which will invert the matrix.
STOP!



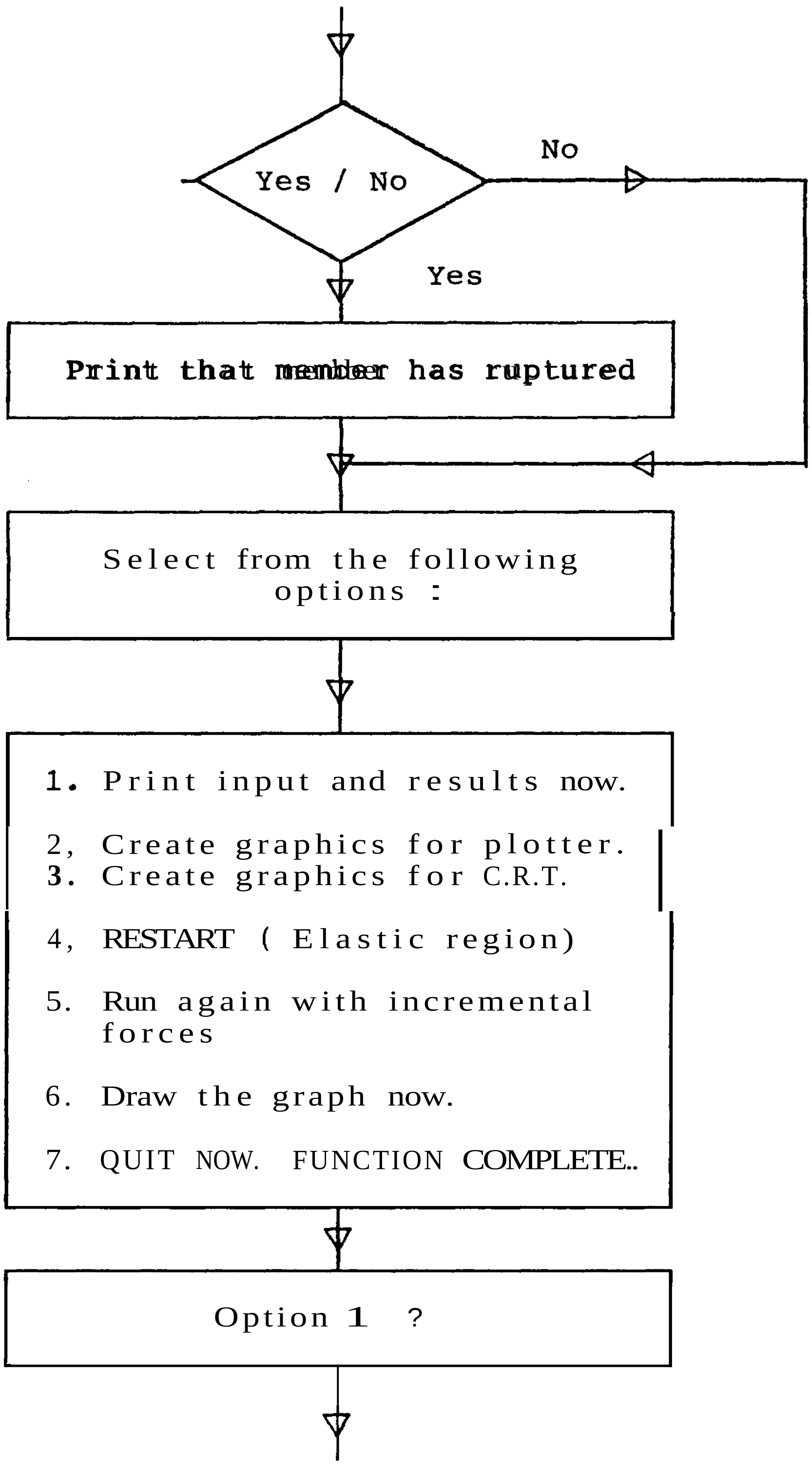
START
This is program /M2.BAS/ which can invert the matrix of the data file /MATRIX.DAT/
Initialize and dimension variables.
Input data from /MATRIX.DAT/
Display the total number of pivots and a message to wait...
Start matrix inversion
Is it a singular matrix (D=0) ?
Yes / No
Yes
STOP !
No

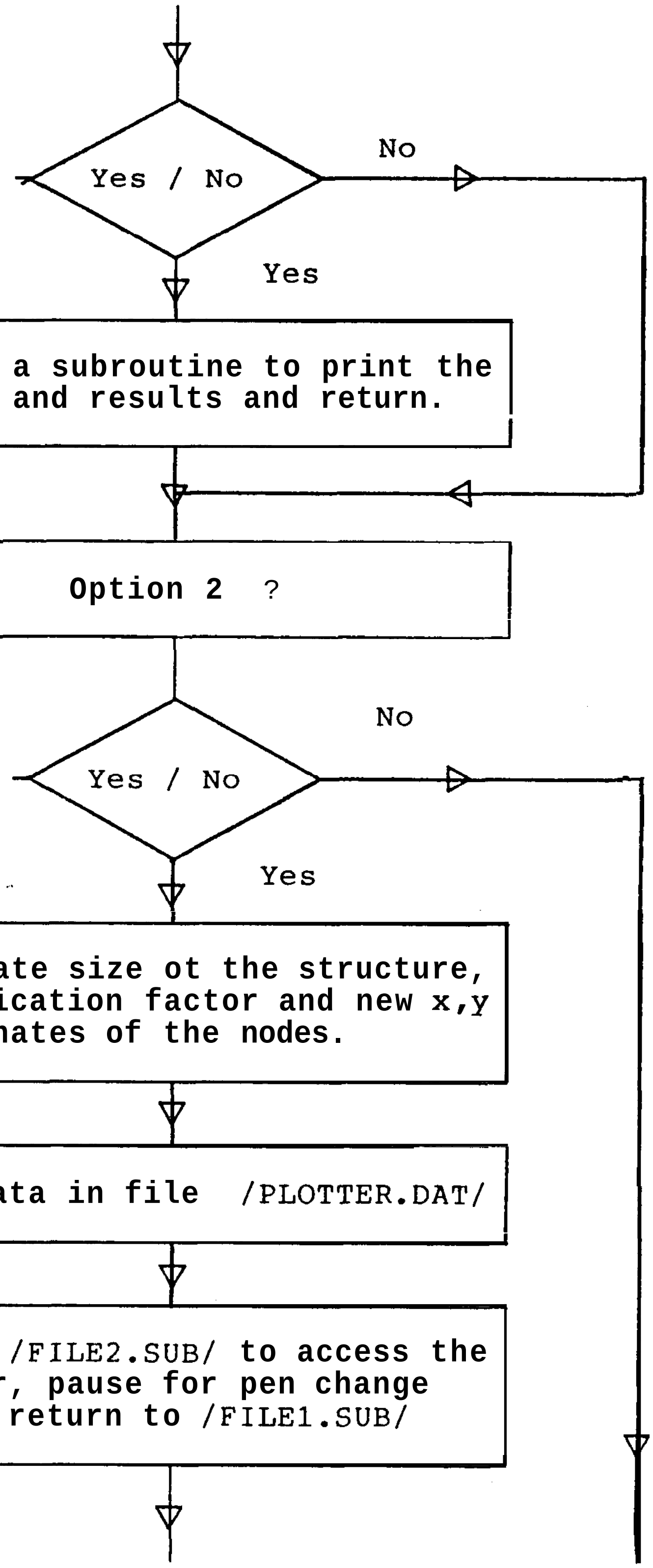

Continue the inversion
Save the inverted matrix on disk under the file name : / INVERSE.DAT /
STOP!

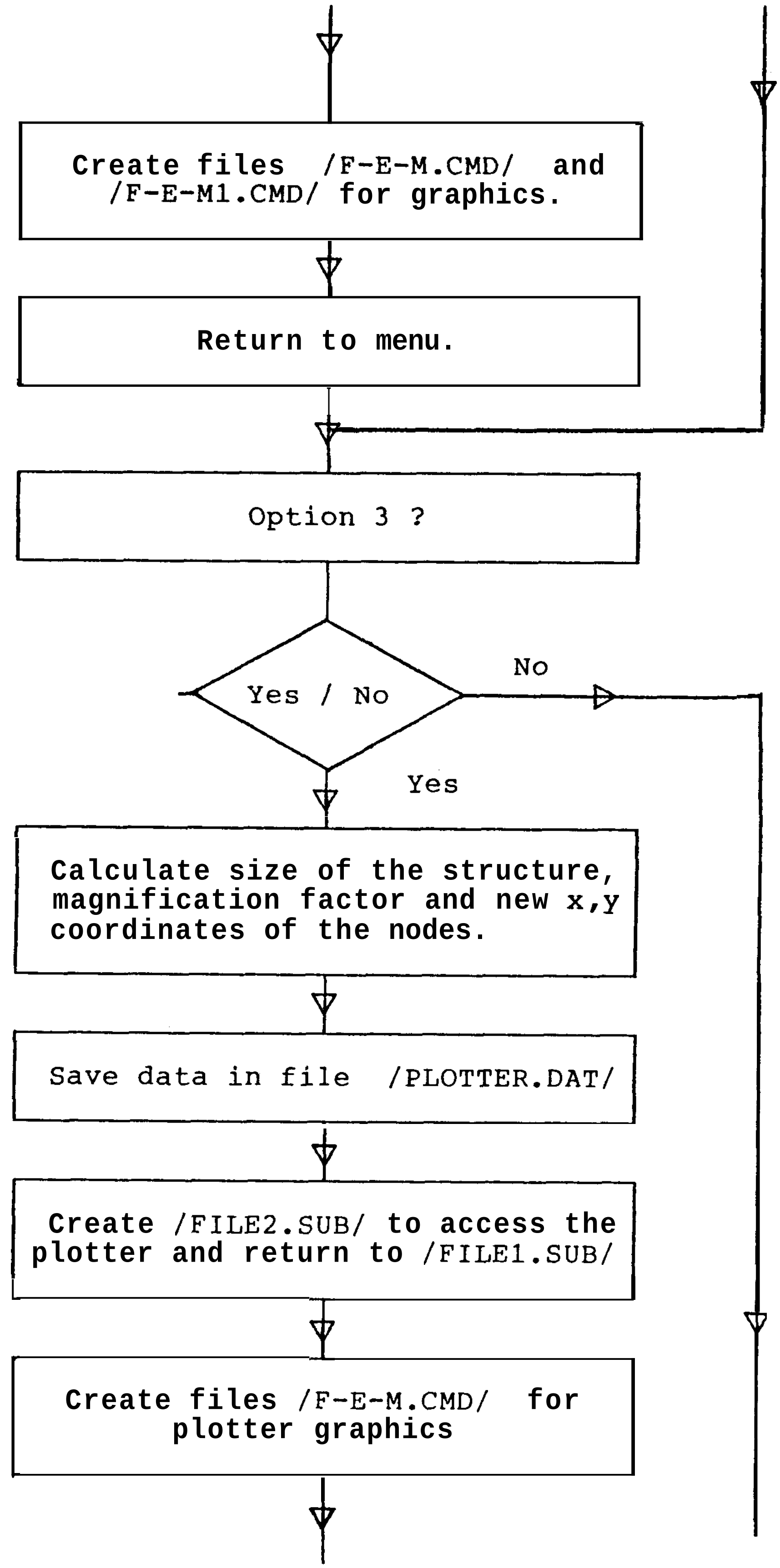

START
This is /M3.BAS/
Dimension variables
Read data from data files
Calculate the equivalent external forces produced by any changes in temperature
Use matrix multiplication to calculate node displacements
Calculate internal forces
Adjust forces (F - temp're force)
Calculate and display all stresses and strains

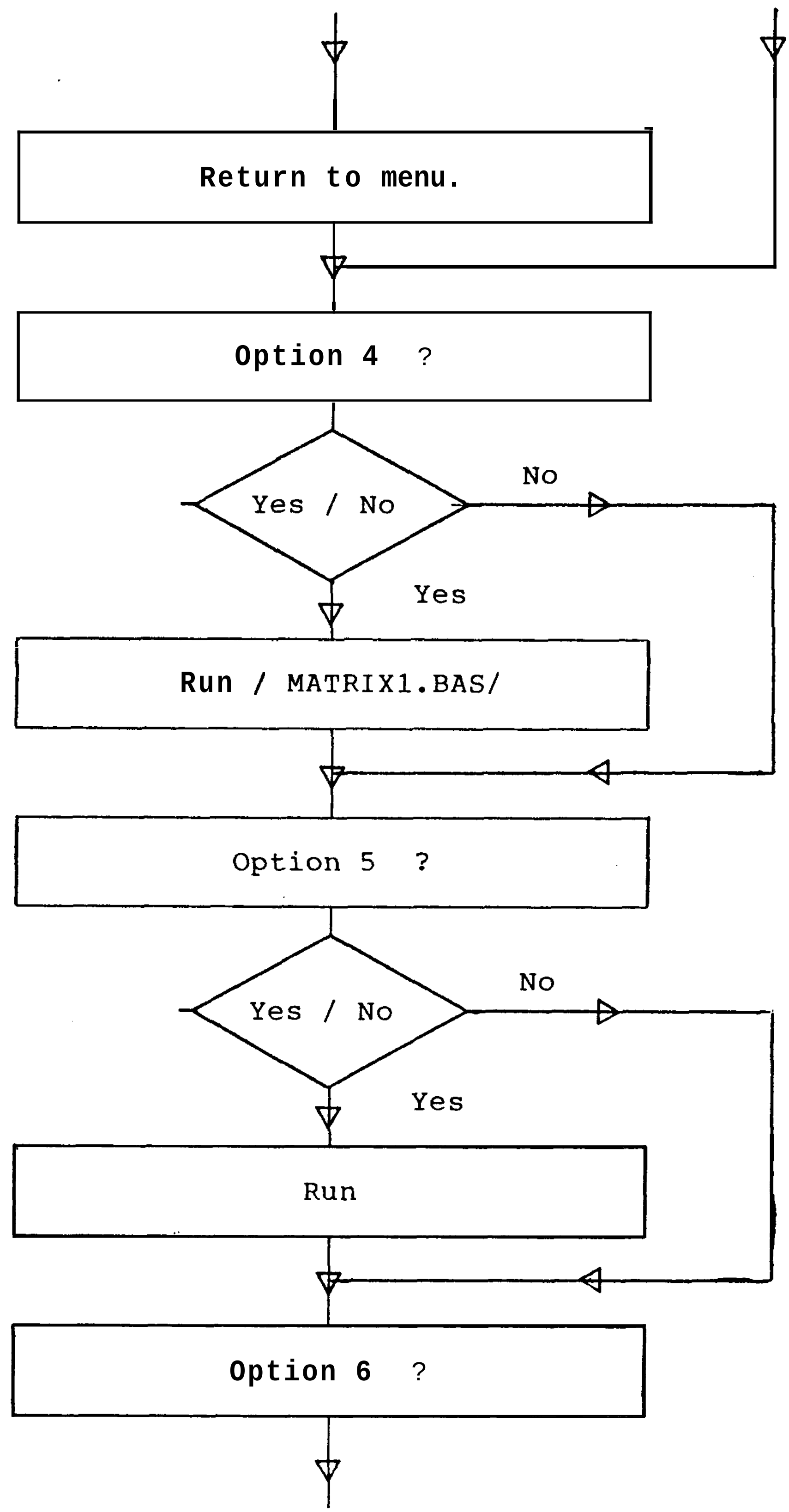


Calculate the buckling forces
Have any members buckled ?
Yes / No
No
Yes
Print that member has buckled
Has the member yielded ?
Yes / No
No
Yes
Print that member has yielded
Has the member ruptured ?

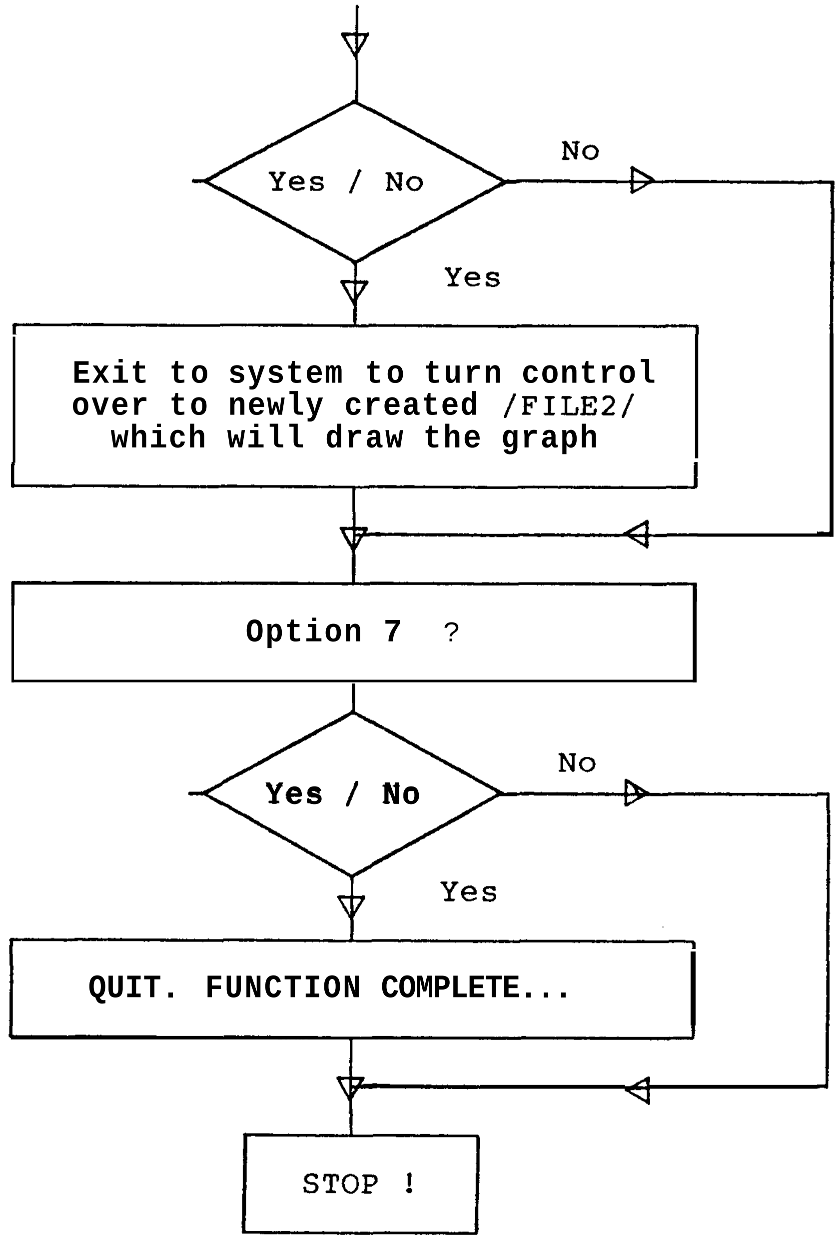

Yes / No
No
Yes
Print that member has ruptured
Select from the following options :
1. Print input and results now.
2, Create graphics for plotter.
3. Create graphics for C.R.T.
4, RESTART (Elastic region)
5. Run again with incremental forces
6. Draw the graph now.
7. QUIT NOW. FUNCTION COMPLETE..
Option 1 ?


Yes / No
No
Yes
Go to a subroutine to print the input and results and return.
Option 2 ?
Yes / No
No
Yes
Calculate size ot the structure, magnification factor and new x,y coordinates of the nodes.
Save data in file /PLOTTER.DAT/
Create /FILE2.SUB/ to access the plotter, pause for pen change and return to /FILE1.SUB/


Create files /F-E-M.CMD/ and /F-E-M1.CMD/ for graphics.
Return to menu.
Option 3 ?
Yes / No
No
Yes
Calculate size of the structure, magnification factor and new x,y coordinates of the nodes.
Save data in file /PLOTTER.DAT/
Create /FILE2.SUB/ to access the plotter and return to /FILE1.SUB/
Create files /F-E-M.CMD/ for plotter graphics



Return to menu.
Option 4 ?
Yes / No
No
Yes
Run / MATRIX1.BAS/
Option 5 ?
Yes / No
No
Yes
Run
Option 6 ?



Yes / No
No
Yes
Exit to system to turn control over to newly created /FILE2/ which will draw the graph
Option 7 ?
Yes / No
No
Yes
QUIT. FUNCTION COMPLETE...
STOP !

APPENDIX D

Computer Program Listings

```
10 REM
20 REM   This is 'MATRIX1.BAS'  by  Evangelos  Marinis
30 REM   Updated:  March 28,  1985.
40 REM   It can form a square matrix from data supplied  by
the user
50 REM   and apply the boundary conditions to it so that the
60 REM   determinant will not be zero.
70 REM
80 REM   Then,  it will save that matrix on disk under  the
name
90 REM   "MATRIX.DAT".  This file will be used as input  to
"MATRIX2.BAS"
100 REM   which will invert it.
110 OPEN"O",#1,"FILE2.SUB"
120 PRINT #1,"    "
130 CLOSE
140 REM
150 PRINT CHR$(26)
160 PRINT"This is 'MATRIX1.BAS' which will form the starting
matrix.
170 PRINT
180 REM  This is the first set of oprions.  The second is in
MATRIX3
190 PRINT: PRINT"OPTI        ( SET #1 )."
200 PRINT:PRINT"    1.  FOLLOW NORMAL PROCEDURE. "
210 PRINT:PRINT"    2.  GOTO MATRIX3 FOR NEW FORCES. "
220 PRINT:PRINT"    3.  QUIT.  EX'IT TO SYSTEM AND STOP. "
230 PRINT:PRINT"SELECT (S thru 3).  ";
240 LET SELECT=5 : INPUT SELECT
250 IF SELECT<1 OR SELECT>3 THEN GOTO 150
260 IF SELECT=2 THEN RUN"MATRIX3.BAS"
270 IF SELECT=3 THEN  CLEAR:SYSTEM:ELSE 280
280 REM FOR IF-ELSE
290 PRINT CHR$(26):PRINT:PRINT
300 REM
310 PRINT"How many pins are there in the structure ";
320 INPUT N1
330 PRINT:PRINT:PRINT"Please enter the caurdinate points for
each pin. "
340 PRINT:PRINT
350 N=2*N
360 DIM A(N*N)
[illegible] FOR I = [illegible] : LET [illegible]       : NEXT [illegible]
380   DIM X(N1) : DIM Y(N1)
390 FOR I=1 [illegible] N1
400 PRINT "X(";I;")=[illegible]:
410 INPUT X[illegible]
420 PRINT "Y(";I;")= ""
430 INPUT Y(I)
440 LET AN$="N":INPUT"Is that correct (Y , N) ";AN$
450 IF AN$<>"Y" THEN 400
460 PRINT:PRINT
470 NEXT I
480 PRINT:PRINT:PRINT
```

```
490 FOR I=1 TO N1
500 PRINT "PIN# ";I;"   X(I)=";
510 PRINT USING"#####.#######";X(I);:PRINT "  Y(I)=";
520 PRINT USING"#####.#######";Y(I)
530 NEXT I
540 PRINT:PRINT:PRINT
550 INPUT"How many members are there in the system ";M1
555 PRINT:PRINT:PRINT"USE UNITS OF THE ENGLISH SYSTEM CONSISTENTLY. "
557 PRINT:PRINT:PRINT"REFER TO TABLES OF STANDARD SECTIONS FOR CONVENIENCE"
560 DIM P1(M1) : DIM P2(M1) : DIM MI(M1)
570 DIM E(M1) : DIM AR(M1) : DIM L(M1): DIM YS(M1) : DIM RS(M1)
580 DIM CT(M1) : DIM ST(M1) : DIM AT(M1) : DIM TE(M1)
590 DIM K(M1) : DIM WT(M1) : DIM SG(M1) : DIM VL(I)
600 DIM K1(M1) : DIM K2(M1) : DIM K3(M1)
610 PRINT
620 REM
630 REM   The following statements input the data for the members.
640 FOR I=1 TO M1
650 PRINT
660 PRINT "Member #";I;:INPUT "  PIN #1= #";P1(I)
670 PRINT "                PIN #2= #";:INPUT P2(I)
680 PRINT:INPUT"What is the modulus of elasticity in million PSI";E(I)
1592 PRINT:INPUT"What is the Yield Strength of this member in PSI";YS(I)
684 PRINT:INPUT"What is the Rupture Strength of this member in PSI ";RS(I)
688 PRINT:INPUT"What is the smallest Moment of Inertia in IN^4";MI(I)
690 PRINT:INPUT"What is the cross-sectional Area of this member in IN^2 ";AR(I)
700 PRINT:INPUT"What is the specific weight of this member LBS/IN^3";SG(I)
710 PRINT:INPUT"What is the change from mean temperature for this member ";TE(I)
720 PRINT:INPUT"What is the thermal expansion coefficient (millionths) ";AT(I)
730 PRINT
740 LET AN$="N"   INPUT " Is that correct (Y / N) ";AN$
750 IF AN$<>"Y" THEN 650
760 PRINT
770 LET L(I)=( (Y(P2(I))-Y(P1(I)  .        )-Y(P1(I)    + (X(P2(I))-X(P1(I)))*(X(P2(I))-X(P1(I))  )!
780 LET L(I)=SQR(L(I))
790 WT(I)=SG(I)*AR(I)*L(I)
800 LET K(I)=AR(I)*E(I)/L(I)
810 LET CT(I)= ( X(P2(I))-X(P1(I)) ) / L(I)
820 LET ST(I)=   Y(P2(I))-Y(P1(I)) ) / L(I)
830 LET K1(I)=K(I)*CT(I)*CT(I)
840 LET K2(I)=K(I)*CT(I)*ST(I)
```

```
850 LET K3(1!=K(I)*ST(I)*ST(I)
860 REM
€370 LET AL=P1(I)
980 LET BE=P2(I)
890   A((2*AL-2)*N+(2*AL-1)  )=A((2*AL-2)*N+(2*AL-1)  )+K1(I)
900   A((2*AL-2)*N+(2*AL)    )=A((2*AL-2)*N+(2*AL)  )+K2(I)
910   A((2*AL-2)*N+(2*BE-1)  )=A((2*AL-2)*N+(2*BE-1))-K1(I)
920   A((2*AL-2)*N+(2*BE)    )=A((2*AL-2)*N+(2*BE))-K2(I)
930   A((2*AL-1)*N+(2*AL-1)  )=A((2*AL-1)*N+(2*AL-1))+K2(I)
940   A((2*AL-1)*N+(2*AL)    )=A((2*AL-1)*N+(2*AL))+K3(I)
950   A((2*AL-1)*N+(2*BE-1)  )=A((2*AL-1)*N+(2*BE-1))-K2(I)
960   A((2*AL-1)*N+(2*BE)    )=A((2*AL-1)*N+(2*BE))-K3(I)
970   A((2*BE-2)*N+(2*AL-1)  )=A((2*BE-2)*N+(2*AL-1))-K1(I)
980   A((2*BE-2)*N+(2*AL)    )=A((2*BE-2)*N+(2*AL))-K2(I)
990   A((2*BE-2)*N+(2*BE-1)  )=A((2*BE-2)*N+(2*BE-1))+K1(I)
1000   A((2*BE-2)*N+(2*BE)    )=A((2*BE-2)*N+(2*BE))+K2(I!
1010   A((2*BE-1)*N+(2*AL-1)  )=A((2*BE-1)*N+(2*AL-1))-K2(I)
1020   A((2*BE-1)*N+(2*AL)    )=A((2*BE-1)*N+(2*AL))-K3(I)
1030   A((2*BE-1)*N+(2*BE-1)  )=A((2*BE-1)*N+(2*BE-1))+K2(I)
1040   A((2*BE-1)*N+(2*BE)    )=A((2*BE-1)*N+(2*BE))+K3(I)
1050 PRINT
1060 NEXT I
1070  REM   At  this  point the volume  and  weight  of  the
structure are
1080 REM  calculated.  If the weight is not satisfactory the
1090 REM  operator may return to the begining of the program
to choose
1100 REM  new members.
1110 REM
1120 LET TW=O!
1130 FOR I=1 TO M1 : TW=TW+WT(I) : NEXT I
1140  PRINT:PRINT"The  total  weight  of  the  structure  is
=";USING"#####.##";TW;:PRINT"  lbs. "
1150  AN$="GO"
I160 PRINT:PRINT"OPTIONS:  1)HIT <RETURN> TO CONTINUE"
I  - PRINT"              2)TYPE  'BACK'  AND  HIT  <RETURN>  TO
SELECT NEW MEMBERS"
1180 PRINT:PRINT"RESPONSE: ";
1190 INPUT AN$
1200 IF AN$="BACK" THEN GOTO 630
1210 REM
1220 REM  This is the point where the B(M) array is set up.
1230  REM  This B(M) array is a dummy variable.  It will.  he
erased at
1240 REM  the end of this program.
1250 REM
1260  DIM B(N)
1270 REM
1280 REM  At this point the B.C's are entered.
1290                REM             :PI?INT:PR NT:PRINT"BOUNDARY
CONDITIONS:":PRINT"===================="
1300   FOR M=1 TO N1
1310     LET AN$="N" : LET B(2*M-1)=-99.119191#
1320     PRINT :  PRINT"Is the value of U(";(M);")=0 ?  (Y /
```

```
N)"
1325                  PRINT"U=0 means that the node is fixed  in
the x- dir.";
1330 INPUT AN4 :PRINT
1340     IF AN$="Y" THEN  B(2*M-1)=0!
1360     LET AN$="N"
1370      LET B(2*M)=99.119191#
1380     PRINT :  PRINT"Is the value of V(";M;")=0 ?   (Y  /
N! "
1385                  PRINT"V=0 means that the nude is fixed  in
the y- dir.";
1390 INPUT AN$ :PRINT:PRINT:PRINT
1400    IF AN$="Y" THEM  B(2*M)=0!
1420  NEXT M
1430 REM
1440 REM This tests for correct B.C's.
1450 PRINT:PRINT
1460 LET ANS$="NO":INPUT"ARE THE BOUNOARY CONDITIONS CORRECT
? (Y/N) ";ANS$
1470 IF ANS$="N" OR ANS$="NO" THEN GOTO 1280
1480 FOR OC=1 TO N
1490 IF B(OC)=0 THEN GTJSUB 1750
1500 NEXT OC
1510   REM This is where the program has formed the A matrix
and
1520   REM  is ready to print it on disk  along  with  other
information
1530   REM  to  be  used by  "MATRIX2.BAS"  for  the  matrix
inversian.
1540  REM
1550  OPEN "O",#1,"MATRIX. DAT"
1560     LET NN=N*N1
1570     PRINT #1,N,NN
1580  FOR I=1 TO NN : PRINT #1,A(I)  : NEXT I
1582 CLOSE
1584 OPEN "O",#1,"GEOM.DAT"
1590  'PRINT #1,N1,M1
1600  FOR I=1 TO N1 : PRINT #1,X(I),Y(I) : NEXT I
1610  FOR I=1 TO M1
1620                                                    PHINT
#1,P1(I),P2(I),E(I),MI(I),AR(I),L(I),K(I),SG(I),YS(I),RS(I)
1630  NEXT I
1640 REM
1660 REM
1670 FOR I=1 TO M1 : PRINT #1,ST(I),CT(I) : NEXT I
1680 FOR I=1 TO M1 : PRINT #1,AT(I),TE(I) : NEXT I
1690 FOR I=1 TO N  : PRINT #1,B(I) : NEXT I
1700 REM
1710 CLOSE
1720 RUN"MATRIX2.BAS"
1730 STOP
1740 REM
1750  REM  'This :is Subroutine #1.  It changes the A matrix
according
```

```
1760 REM   to the boundary conditions.
1770 HEM
1780 LET QQ
1790    FOR J=1 TO N :  LET I1=(QQ-1)*N+J : A(I1)=0! :  NEXT
J
1800 REM
1810    FOR I=1 TO N :  LET I1=(I-1)*N+QQ : A(I1)=0! :  NEXT
I
1820 REM
1830   LET A((QQ-1)*N+QQ)=0
1840   RETURN
1850 REM    ***   END OF FILE   ***
```

```
10 REM
20 REM   This is 'MATRIX2.BAS'   by Evangelos Marinis
2J REM   Updated:  March 28, 1985.
30 REM
4  REM   It can perform a matrix inversion on any size square matrix
50 REM   up to 30x30.
60 HEM
70 PRINT CHR$(26)
80 PRINT"This is 'MATRIX2.BAS' which can perform matrix inversion."
90 PRINT"INPUT:  MATRIX.DAT ":PRINT"OUTPUT: INVERSE.DAT "
92 PRINT:PRINT
100 OPEN "I",#1,"MATRIX.DAT"
110 INPUT #1,N,NN
120 DIM A(NN)
122 REM
123 PRINT:PRINT"The total number of pivots is ";N
124 PRINT:PRINT"Please wait while I da the inversion,"
130 FOR I=1 TO NN
140 INPUT #1,A(I)
150 NEXT I
410 CLOSE : PRINT
412 RE$="N"
415 IF N<15 THEN PRINT"DO YOU WISH TO PRINT THE MATRIX (Y/N) ";
416 INPUT HE%
417 IF RE$="N" THEN GOTO 510
420  IF N>15 THEN PRINT:PRINT"MATRIX IS TOO LARGE TO PRINT.":GOTO 510
430     LPRIMT     CHR$(15):LPRINT:LPRINT:LPRINT"STARTING MATRIX:":LPRINT:LPRINT
440 FOR I=1 TO N
450  LPRINT"I ";
460 FOR J=1 TO N
470  LPRINT USING"####.##";A((I-1)*N+J);
480 NEXT J
490  LPRINT " I"
500 NEXT I
50I LPRINT:LPRINT:LPRINT
510 GOSUB 840
511 REM
512 REM
520 OPEN "O",#1,"INVERSE.DAT"
530 PRINT #1,N,NN
540 FOR I=1 TO N
550 FOR J=1 TO N
560   PRINT #1,AINV((I-1)*N+J)
570 NEXT J
580 NEXT I
590 REM
770 CLOSE
772 LPRINT CHKB!18)
774 RUN "MATRIX3.BAS"
```

```
777 REM
790 REM   ·  This is the end of the main program.
800 REM
810 REM      The two subroutines follow.
820 REM
834 REM
840 REM  Sub. 1.
850 RE$="N"
860  PRINT:PRINT:INPUT"DO YOU WISH TO SEE THE PIVOTING (Y/N)
";RE$
862  PRINT:PRINT
865  IF RE$="Y" AND N>8 THEN PRINT"SORRY MATRIX IS TOO LARGE
TO SHOW PIVOTING...":LPRINT CHR$(18)
868   IF  RE$="Y" AND N<9 THEN PRINT"THE PRINTER IS  IN  THE
COMPRESSED' MODE. ":PRINT
870 NC=2*N
880 DIM 141(N*NC),WK(N*NC),AINV(N*N)
€390 FOR 1=1 TO N
900   FOR J=1 TO NC
910    IF J>N THEN 930
920    WK((I-1)*NC+J)=A((I-1)*N+J):GOTO 950
930    WK((I-1)*NC+J)=0!
940    IF(J-N)=I THEM WK((I-1)*NC+J)=1
950   NEXT J
960 NEXT I
970 FOR R=1 TO N
980    K=R : D=WK((R-1)*NC+K)
990    IF D<>0 THEN 1010
1000  PRINT"SINGULAR  MATRIX   ...  D=0  CHECK THE  BOUNDARY
CONEITIONS.":PRINT:PRINT"THE    PROCESS    STOPS     HERE...
SORRY.":STOP
1010   FOR I=1 TO N
1020   FOR J=1 TO NC
1030     IF I-R THEN 1060
1040     IF WK((R-1)*NC+J)=0 OR WK((I-1)*NC+K)=0 THEN W1((I-
1!*NC+J!=WK(!I-1)*NC+J) : GOTO 1070 : ELSE 1050
1050                        W1((I-1)*NC+J)=WK((I-1)*NC+J)-WK((R-
1)*NC+J)*WK((I-1)*NC+K)/D : GOTO 1070
1060      W1((I-1)*NC+J)=WK((I-1)*NC+J)/D
1070  NEXT J
1080  NEXT I
1110       FOR I=1 TO N
1120       FOR J=1 TO NC
1130         WK((I-1)*NC+J)=W1((I-1)*NC+J)
1140       NEXT J
1150       NEXT I
1155   PRINT:PRINT"PIVOT NUMBER ";R;" OF ";N
1160     IF RE$="Y" AND N<9 THEN GUSUB 1240
1170   NEXT R
1180   FOR I=1 TO N
1190   FOR J=1 TO N
1200   AINV((I-1)*N+J)=WK((I-1)*NC+(J+N))
1210   NEXT J
1220   NEXT I
```

```
1230   RETURN
1240  REM
1260   LPRINT"PIVOT NUMBER ";R;" OF ";N:LPRINT"   "
1270   FOR ZI=1 TO N
1280   FOR ZJ=1 TO NC
1290     LPRINT USING"#####.##";WK((ZI-1)*NC+ZJ);
1300     IF ZJ=N THEN LPRINT " !";
1310  NEXT ZJ
1320 LPRINT ""
1330  NEXT ZI
1340  LPRINT:LPRINT
1350  RETURN
1360 END
```

```
10 REM
20 REM
30 REM  This is 'MATRIX3.BAS'.  It reads the inverted matrix
40 REM  and calculates forces, stresses, etc.
50 REM
60 PRINT CHR$(26)
70 PRINT "This is 'MATRIX3.BAS'                    March 8, 1985."
80 REM
90 OPEN "I",#1,"INVERSE.DAT"
100 INPUT #1,N,NN
110 DIM A(NN)
120 FOR I=1 TO NN : INPUT #1,A(I) : NEXT I
125 CLOSE
128 OPEN "I",#1,"GEOM.DAT"
140 INPUT #1,N1,M1
150 REM
170 DIM X(N1)  :  DIM Y(N1)  : DIM XN(N1) : DIM YN(N1) : DIM
XO(N1) : DIM YO(N1)
180 DIM P1(M1) : DIM P2(M1) : DIM MI(M1)
190 DIM E(M1)  :  DIM AR(M1) : DIM L(M1)  : DIM K(M1)  : DIM
SG(M1)
200 DIM  ST(M1) :  DIM  CT(M1) : DIM  YS(M1) : DIM RS(M1) : DIM
RA(M1)
210 DIM K1(M1) : DIM K2(M1) : DIM K3(M1) : DIM C(N)
220 DIM EX(N) -:  DIM B(N)   : DIM BC(N)  : DIM TE(M1) : DIM
AT(M1)
222 DIM FC(M1) :  DIM D(N1)  : DIM SS(M1) : DIM SR(M1) : DIM
BF(M1)
230 REM
240 FOR I=1 TO N1:INPUT #1,X(I),Y(I) :XO(I)=X(I):YO(I)=Y(I):
NEXT I
250 REM
255 TW=0
260 FOR I=1 TO M1
270                                                    INPUT
#1,P1(I),P2(I),E(I),MI(I),AR(I),L(I),K(I),SG(I),YS(I),RS(I)
275 TW=TW+SG(I)*AR(I)*L(I)
280 NEXT I
310 REM
320 FUR I=1 TO M1 : IMPUT #1,ST(I),CT(I) : NEXT I
330 FOR I=1 TO M1 : INPUT#1,AT(I),TE(I)  : MEXT I
340 FOR I=1 TO N  : INPUT#1,B(I) : MEXT I
350 REM
360 CLOSE
365 FOR I=1 TO N:BC(I)=B(I):NEXT I
370 REM
380  REM  The  following statements are used  to  input.  the
forces
390 REM and the boundary conditions.
400 REM
422  PRINT:PRINT"PLEGSE  INPUT  ALL THE  EXTERNALLY  APPLIED
FORCES"
424 PRINT:PRINT"LET ALL UNKNOWN FORCES =0.":PRINT:PRINT
```

```
430 FOR I=1 TO N STEP 2
440     J=(I+1)/2
450 PRINT:PRINT"What is the force F(";J;")x = ";
460     INPUT C(I)  .
470 PRINT"What is the force F(";J;")y = ";
480     INPUT C(I+1)
490 NEXT ▮
500 ANS$="N"
510 PRINT:PRINT
520 PRINT:INPUT"ARE THESE VALUES CORRECT (Y/N) ";ANS$
530 PRINT:PRINT
540 IF ANS$="N" THEN  GOTO 430
550 IF ANS$<>"N" AND ANS$<>"Y" THEN GOTO 520
560 REM
570 FOR I=1 TO N : EX(I)=C(I):NEXT ▮
580 REM
590 FOR 1=1 TO M1
600 NF=(-1)*AT(I)*TE(I)*AR(I)*E(I)*CT(I)
610 C(2*P1(I)-1)=C(2*P1(I)-1)-NF
620 C(2*P2(I)-1)=C(2*P2(I)-1)+NF
630 REM
640 NF=(-1)*AT(I)*TE(I)*AR(I)*E(I)*ST(I)
650 C(2*P1(I))=C(2*P1(I))-NF
660 C(2*P2(I))=C(2*P2(I))+NF
670 REM
680 NEXT ▮
690 REM
700 FOR I=1 TO N
701 IF B(I)=0 THEN C(I)=0
702 NEXT I
710 REM
720 REM  'This part calculat.~ the di~P lacements.
730 LET BM=0!
740 FOR ▮=1 TO N
750 LET B(I)=0!
760 FOR J=i TO N
770   B(I)=B(I)+A((I-1)*N+J)*C(J)
780 NEXT J
790 REM
800 IF ABS(B(▮)) >BM THEN LET BM=ABS(B(▮?)
810 NEXT ▮
820 REM
830 REM  This part calculates the forces on each member.
840 REM
870 PRINT CHR$(26)
880   PRINT"MEMBER    PIN#(A,B)     U(PIN)      V(P▮N)  "
890   PRINT"======    ---------     ======      ------  "
900   PR▮NT"-----------------------------------------------"
910   PRINT:PRINT
920 FOR I=1 TO M1
930          PRINT        "            ";USING"###";I;:PRINT"
";USING"###";P1(I);:PRINT"
",USING"####.###";B(2*P1(▮)-1);:PRINT"
```

```
";USING"####.###";B(2*P1(I))
940        PRINT"                    ";USING"###";P2(I);:PRINT"
";USING"####.###";B(2*P2(I-1));:PRINT"
";USING"####.###";B(2*P2(I))
950    D(  P1(I) )=B( 2*P1(I)-1 ) * CT(I) + B( 2*P1(I)  )  *
ST(I)
960    D(  P2(I) )=B( 2*P2(I)-1 ) * CT(I) + B( 2*P2(I)  )  *
ST(I)
970   FC(I)=K(I) * ( D( P2(I) ) - D( P1(I) ) ) *1E+06
980   FC(I)=FC(I)-K(I)*AT(I)*TE(I)*L(I)
983     IF   ABS(SS(I))>YS(I)   AND   ABS(SS(I))<=RS(I)   THEN
BF(I)=(-
1E+06)*(5*(3.14159^2)*MI(I)*E(I)*YS(I))/(2*AR(I)*YS(I)*L(I)*
L(I)+3*(3.14159^2)*MI(I)*E(I)):GOTO 990
985   BF(I)=(-1E+06)*(3.14159^2)*MI(I)*E(I)/(L(I)^2)
990   SS(I)=FC(I)/AR(I)
1000  SR(I)=SS(I) / ( E(I) * 1E+06 )
1010   PRINT
1020   PRINT "FORCE(lbs)=";FC(I);"      STRESS(psi)=";SS(I);"
STRAIN=";SR(I)
1022           IF            ABS(SS(I))>YS(I)           THEN
PRINT:PRINT:PRINT"*********************************"
1023    IF   ABS(SS(I))>YS(I)  AND   ABS(SS(I))<=RS(I)   THEN
PRINT"THIS  MEMBER  HAS YIELDED.  IT IS TIME TO PREPARE  FOR
PLASTIC REGION"
1024    IF  ABS(SS(I))>=RS(I)  THEN  PRINT"THIS  MEMBER  HAS
RUPTURED.     *****"
1025  IF  FC(I)<=BF(I)  THEN PRINT"THIS MEMBER  HAS  BUCKLED.
*****"
1026           IF            ABS(SS(I))>YS(I)           THEN
PRINT"*********************************":PRINT:PRINT
1030   PRINT
1040     IF    INT(I/2)=I/2  THEN  INPUT"Hit   <RETURN>   to
continue";A$
1050   PRINT
1060 NEXT I
1070   PRINT:INPUT"Hit <RETURN> to continue...";A$
1080   PRINT CHR$(26)
1090   PRINT:PRINT"OPTIONS:     Select from the following in
the order they are listed.  "
1100   PRINT
1110   PRINT"          1.  SEND INPUT AND RESULTS TO PRINTER
NOW."
1120   PRINT
1130    PRINT"          2.   CREATE  A  GRAPHICS  FILE  FOR
PLOTTER."
.      PRINT"          3. CREATE A GRAPHICS FILE FOR CRT."
1150   PRINT"  "
1160   PRINT"          4. RESTART  (SPECIFY A NEW STRUCTURE!
1170   PRINT"          5. RUN AGAIN WITH NEW FORCES "
.      PRINT"   "
1182   PRINT"          6. DRAW THE GRAPH NOW. "
1184   PRINT"   "
1186   PRINT"          7. PREPARE FOR PLASTIC REGION."
```

```
1188   PRINT"    "
1190   PRINT"          8.  ENTER THE PLASTIC REGION."
1195   PRINT1'    "
1210   PRINT"          9.  QUIT NOW.  FUNCTION COMPLETE. .."
1220   PRINT
1230   LET SELECT=<)!
1232   PRINT:PRINT"Note:    If you wish to select option 6,
you MUST first"
1234        PRINT"=====    select option 3.   "
1240   INPUT"SELECT (1 thru 9): ";SELECT
1250   IF SELECT<1 OR SELECT>9 THEN GOTO 1080
1260 REM
1270 IF SELECT=1 THEN GOSUB 1370
1280 IF SELECT=2 THEN GOSUB 2030
1290 IF SELECT=3 THEN GOSUB 2030
1300 IF SELECT=4 THEN RUN"MATRIX1.BAS"
1310 IF SELECT=5 THEN RUN
1312 IF SELECT=7 THEN GOSUB 3000
1315 IF SELECT=8 THEN GOTO 3045
1320 IF SELECT=& THEN CLEAR : SYSTEM
1340 IF SELECT=9 THEN GOTO 1361
1360 GOTO 1080
1361 OPEN "O",#1,"FILEZ.SUB"
1362 PRINT #1,""
1363 CLOSE
1364 SYSTEM
1370 REM This is the 1st sub.   It prints the results on the
printer-.
1380 REM
1390 PRINT CHR$(26):PRINT: PRINT: PRINT
1400 PRINT"          PLEASE SET THE PRINTER TO A NEW PAGE."
1410   PRINT:PRINT: PRINT"          Hit <RETURN> to start
printing..."
1420 INPUT A$
1435 OPEN "I",#1,"SN.DAT"
1440 INPUT #1,SN : CLOSE
1450 LPRINT
1460                                                  LPRINT"
SEHIAL#";USING"########";SN
1470 LPRINT
1480 LET NS=SN
1490 LET SN=SN+1 : OPEN "O",#1,"SN.DAT"
1500 IF SN>9000 THEN LET SN=1
1510 PRINT #1,SN : CLOSE
1520  LPF:INT:LF'HINT"          ANAL-YSIS OF A  STRUCTURE  BY
'THE FINITE ELEMENT METHOD"
1530                                                  LPF:INT"
-------------------------------------------------------------"
1540  LPRINT:LPRINT"                            (All ~\nitsare
LBS,IN. )":LPRINT
1550  LPRINT"          NUMBER OF PINS= ";N1;"    NUMBER
OF MEMBERS= ";M1
1560 LPRINT
```

```
1570  LPRINT"          PIN#                    (X,Y)                     U
(in)          V (in) "
1580                                                                LFHINT"
-------------------------------------------------------------------------
"
1590 FOE I=1 TO N1
1600 LPR▮NT"          ";USING"###" ;
1610                                                                LPR▮NT"
(";USING"#####.##";X(I);:LPRINT",";USING"#####.##";Y(I);
1620  LPRINT")          ";USING"###. ####";B(2*I-1);:LPRINT"
";USING"###.####";B(2*I)
1630 NEXT ▮
1640 HEM
1,550  LPRINT:LPRINT: LPEINT
1660 LPRINT "        MEMBER#  PINS:  (A,B)  LENGTH (in)  AREA
(in2) E(*1E6) SP.WT."
1670                          LPHINT                                "
--------------------------------------------------------------------.---

1680 FOR 1=1 TO M1
1690          LPRINT"                    ";USING"###"!I;:LPRINT"
";USING"###";P1(I);:LPRINT",";USING"###";P2(I);:LPRINT"
";USING"####.##";L(I);:LPRINT"
";USING"####.##";AR(I);:LPRINT"
";USING"###.##";E(I);:LPRINT"   ";USING"#.####";SG(I)
1700 NEXT ▮
1710 REM
1720 LPRINT:LPRINT:LPRINT
1730  LPR▮NT"        MEMBER#        FORCE (lbs)        STRESS
(psi)          STRAIN "
1740                                                                LFR▮NT"
------------------------------------------------------------------------
"
1750 FOR 1=1 TO Mi
1760          LPRINT"                    ";USING"###";I;:LPRINT"
";USING"######. #";FC(I);:LPRINT"
";USING"######.#";SS(I);:LPRINT"
";USING"###. ######";SR(I)
1770 NEXT ▮
1780 REM
1790 LPR▮NT:LPR▮NT:LPR▮NT"        TEMPERATURES: "
1800 LPR▮NT"        ============="
1810 LPRINT: LPRINT"        ALL TEMPERATURES ARE EQUAL EXCEPT:
1820 LFR▮NT
1830  FUR I=1 TO M1:IF TE(I)<>0 THEN  LPRINT"          MEMBER#
";▮;".        TEMP.=T+";TE(I);"    F.        THERMAL      EXF'.
COEFF.=";AT(I);" (*1E-6)"
1840 NEXT ▮
1850 HEM
1860 LFRINT:LF'RINT
1870 HEM
1880 LF'RINT"        EXTERNAL FORCES:"
1890 LPR▮NT"        ================"
```

```
1900  LPRINT: LPRINT"        ALL EXTERNALLY APPLIED FORCES ARE
ZERO EXCEPT  :"
1910 LPRINT
1920 FOR I=1 TO N STEP 2
1930 J=(I+1)/2
1940  LPRINT"       F(";J;")x  =";EXT(I);"
Lbs."
1950 REM
1960 LPRINT"       F(";J;")y =";EXT(I+1);" Lbs."
1970 NEXT I
1980 LPRINT: LPRINT
1990  LPRINT"       >The total weight of this  structure  is
";USING"#####.##";TW;:LPRINT"  lbs."
2000 LPRINT:LPRINT
2010 RETURN
2020 REM
2030 REM This is the 2nd sub.  It creates a graphics file.
2040 REM This is the scaling routine...
2050 REM
2060 XM=-10000 : XI=10000
2070 YM=-10000 : YI=10000
2080 FOR I=1 TO N1
2090   IF X(I)<XM THEN XM=X(I)
2100   IF Y(I)<YM THEN YM=Y(I)
2110   IF X(I)>XI THEN XI=X(I)
2120   IF Y(I)>YI THEN YI=Y(I)
2130 NEXT I
2140 REM
2160    XD=ABS(ABS(XM)-ABS(XI))
2180    YD=ABS(ABS(YM)-ABS(YI))
2190    XX-YD
2200    IF XD>YD THEN XX=XD
2210 REM
2220 LET MF=BM
2222 OPEN"O",#1, "PLOTTER.DAT"
2223 PRINT #1,MF
2230 FOR I=1 TO N1
2240   X(I)=X(I)-XI
2250   Y(I)=Y(I)-YI
2260   X(I)=X(I)*(8/XX)
2270   Y(I)=Y(I)*(8/XX)
2280   XN(I)=X(I)+B(2*I-1)*MF
2290   YN(I)=Y(I)+B(2*I)*MF
2295  PRINT #1,XN(I),YN(I)
2300 NEXT I
2305 CLOSE
2310 REM
2320 REM
2330 OPEN "O",#1,"FILE2.SUB"
2340 PRINT #1," USER 0 "
2350 IF SELECT =3 THEN PRINT #1,"PRINTER 1 "
2360 IF SELECT=2 THEN PRINT #1,"PRINTER 0 "
2371 PRINT #1,"CHART F-E-M.CMD ,
```

```
2380 IF SELECT=2 THEN PRINT#1,"MBASIC PEN "
2390 IF SELECT=2 THEN PHINT #1,"CHART F-E-M1.CMD "
2400 PRINT #1,"SUBMIT FILE1 "
2410 CLOSE
2420 REM
2430 OPEN "O",#1, "F-E-M. CMD"
2440 PRINT #1," PLOTSX TYPE 16 "
2456 PRINT #1," PLOT 2.5  0  -3 END "
2460 PRINT #1," SMBOLL -.7  9.5  .2  ";CHR$(34);"ANALYSIS OF A STRUCTURE BY THE FINITE ELEMENT METHOD. S.M. ";USING"#####";NS;:PRINT #1,CHR$(34);"  O 99 "
2470 FOR I=1 TO M1
2480  PRINT #1," CIRCLE  ";X(P1(I));"  ";Y(P1(I));" -.09  .1 "
2490  PRINT #1," CIRCLE  ";X(P2(I));"  ";Y(P2(I));" -.09  .1 "
2500   PRINT  #1,"  PLOT  ";X(P1(I));"   ";Y(P1(I));"   3 ";X(P2(I));"  ";Y(P2(I));"  2  END "
2510    XC=( X(P1(I))+X(P2(I)) )/2:  YC=( Y(P1(I))+Y(P2(I)) )/2
2520    PRINT   #1,"   SMBOLL   ";XC;"    ";YC: "    .2 ";CHRB(34);USING"##";I;
2530  PRINT #1,CHR$(34);"  0  99  "
2540 NEXT I
2550 REM
2560 FOR I=1 TO N1
2570    PR▮NT   #1,"   SMBOLL   ";X(I);"    ";Y(I);"    .2 ";CHR$(34);USING":##"; 1;
2580   PR▮NT #1,CHR$134);"   0  99 "
2590  X(I)=X(I)+B(2*I-1)
2600  Y(I)=Y(I)+B(2*I)
2610 NEXT I
2620 REM
2630 IF SELECT=2 'THEN PRINT #1, "EXIT"
2640 IF SELECT=2 THEM CLOSE
2650 IF SELECT=2 THEN OPEN "O",#1,"F-E-M1.CMD"
2660 IF SELECT=2 THEN PRINT #1," PLOTSX TYPE 16  "
2670 IF SELECT=2 THEN PRINT #1," PLOT 2.5  O  -3  END "
2680 FOR I=1 TO M1
2690   PRINT #1," CIRCLE ";XN(P1(I));"  ";YN(P1(I));"  -.09
2700  PRINT #1," CIRCLE ";XN(P2(I));"  ";YN(P2(I));"   -.09
2710   PRINT  #1,"  PLOT   ";XN(P11I));"   ";YN(P1(I));"  3 ";YN(P2(I));"  ";YN(P2(I));"  2   END "
2720 NEXT 1
2730 REM
2740 PRINT #1," EXIT "
2750 REM
2760 CLOSE
2770 RETURN
2780 REM
3000  REM  This is the subroutine that prepares for  plastic analysis.
301l  REM
```

```
3025 RM=0
3028 FOR I=i TO Mi
3029 RA(I)=ABS(SS(I)/YS(I))
3030 IF RA(I)>RM THEN RM=RA(I)
3032 NEXT I
3035 PRINT CHR$(26)
3040 PRINT:PRINT"THE SUGGESTED EXTERNAL FORCES ARE: (LBS)"
3042 FOR I=1 TO N: PRINT:XE=EX(I)/RM: PRINT I,XE:NEXT I
3043 INPUT"Hit the RETURN key to continue";A$:RETURN
3045 OPEN"O",#1,"GEOM.DAT" :PRINT #1,N1,M1
3048 FOR I=1 TO N1:PRINT#1,XO(I),YO(I) : NEXT I
3050 FOR I=1 TO M1:PRINT#1,P1(I),P2(I),MI(I),AR(I),L(I)
3052 FOR I=1 TO M1:PRINT#1,ST(I),CT(I):NEXT I
3053 FOR I=1 TO M1: PRINT#1,AT(I),TE(I) : NEXT I
3054 FOR I=1 TO N :PRINT#1,BC(I) : NEXT I
3055 CLOSE
3060 OPEN "O",#1,"E-MOD.DAT"
3080 FUR I=1 TO M1:PRINT #1,E(I),E(I) : NEXT I
3090 CLOSE
3100 OPEN"O",#1,"SS-SR.DAT"
3110      FOR      I=1      TO      M1           PRINT
#1,SS(I),SR(I),YS(I),RS(I),O,FC(I): NEXT I
3115 FUR I=1 TO N  : PRINT #1,EX(I) : NEXT I
3120 CLOSE
3122 OPEN"O",#1,"FILE1.SUB"
3124 PRINT#1,"F'WINTER O"
3126 PRINT#1,"MBASIC M1"
3128 PRINT#1,"SUBMIT FILE2"
3130 CLOSE
3132 RUN "M1.BAS"
3150 REM          *******    END OF FILE    ********
```

```
10 REM
30 REM   This is 'M1.BAS'   by Evangelos Marinis
50 REM   Updated:  March 28,  1985.
70  REM   It can form a square matrix from data supplied  by
the user.
90  REM    It  can also adjust the matrix according  to  the
boundary
110 REM   conditions.
130 REM
150 REM   Then,   it will save that matrix on disk under  the
name
170  REM   "MATRIX.DAT".  This file will be used as input to
"M2.BAS"
190 REM   which will invert it.
210 OPEN"O",#1,"FILE2.SUE"
230 PRINT #1,""
250 CLOSE
270 REM
290 PRINT CHR$(26)
310  PRINT"This   is 'M1.BAS' which will  form  the  starting
matrix. "
330 PR▮NT :PR▮NT:PRINT
350 OPEN "I",#1,"GEOM.DAT"
370 INPUT #1,N1,M1
390 REM
410 LET N=2*N1
430 NN=N*N
450 DIM A(N*N)
470 FOR I=1 TO N : LET A(I)=0! : NEXT ▮
490   DIM X(N1) : DIM Y(N1)
510 FOE I=1 TO N1: INPUT #1,X(I),Y(I) : NEXT ▮
530 FOR I=1 TO MI
550 PRINT "PIN# ";▮ ;"   X(I)=";
570 PRINT USING"#####.########";X(I);:PRINT "  Y(I)=";
590 PRINT US▮NG"#####.########";Y(▮▮
610 NEXT ▮
630 PRINT:PRINT:PRINT
650 DIM P1(M1) : DIM P2(M1) : DIM MI(M1)
670  DIM OE(M1) :  DIM NE(I):  ▮   AR(M1) :  DIM L(M1):  DIM
YS(M1) : DIM RS(M1)
690 DIM CT(M1) : DIM ST(M1) : DIM AT(M1) : DIM TE(M1)
710 DIM K(M1) : DIM WT(M1) : DIM SG(M1) : DIM VL(M1)
730 DIM K1(M1) : DIM K2(M1) : DIM K3(M1)
750 DIM B(N)
770 REM
790  REM   The following statements input the data  for  the
members.
810 FOR I=1 TO M1
830 INPUT #1,P1(I),P2(I),MI(I),AR(I),L(I),
K(▮),SG(I),YS(I),RS(I)
850 NEXT ▮
870 FOR I=1 TO M1: INPUT #1,ST(I),CT(I) : NEXT I
890 FOR I=1 TO M1: INPUT ▮       ▮       : NEXT I
```

```
910 FOR I=1 TO N : INPUT #1,B(I): NEXT I
930 CLOSE
950 OPEN"I",#1,"E-MOD.DAT"
965 FOR I=1 TO M1:INPUT#1,OE(I),NE(I): NEXT I
967 CLOSE
969 REM
970 PRINT CHR$(26):PRINT:PRINT" 1 .  Continue ...  to change
external load(s)."
975                          PRINT" 2 .  Unload the structure. !
! ! "
977 INPUT SELECT
979 IF SELECT=1 THEN GOTO 1030
980 IF SELECT<>1 AND SELECT<>2 THEN GOTO 976
982  PRINT:PRINT:PRINT"You have selected to remove all
external load(s)."
985 FOR I=1 TO M1:NE(I)=OE(I):NEXT I
990 OPEN"O",#1,"E-MOD.DAT"
991 FOR 1=1 TO M1:PRINT#1,OE(I),NE(I): NEXT I
993 CLOSE
1000  PRINT:PRINT"Please  wait  while  I  set-up  a  new
coefSicient matrix."
1030 FOR I=1 TO M1
1050  LET L(I)=(  (Y(P2(I))-Y(P1(I)) )*(Y(P2(I))-Y(P1(I)))  +
(X(P2(I))-X(P1(I)))*(X(P2(I))-X(P1(I))  ))
1070 LET L(I)=SQR(L!I))
1090 WT(I)=SG(I!*AR(I! *L(I)
1110 LEI K(I)=AR(I)*NE(I)/L(I)
1130 LET CT(I)= ( X(P2(I))-X(P1(I)) ) / L(I)
1150 LET ST(I)= ( Y(P2(I))-Y(P1(I)) ) / L(I)
1170 LET K1(I)=K(I)*CT(I)*CT(I)
1190 LET K2(I)=K(I)*CT(I)*ST(I)
1210 LET K3(I)=K(I)*ST(I)*ST(I)
1230 REM
1250 LET AL=P1(I)
1270 LET BE=P2(I)
1290   A((2*AL-2)*N+(2*AL-1) )=A((2*AL-2)*N+(2*AL-1) )+K1(I)
1310   A((2*AL-2)*N+(2*AL)   )=A((2*AL-2)*N+(2*AL) )+K2(I)
1330   A((2*AL-2)*N+(2*BE-1) )=A((2*AL-2)*N+(2*BE-1))-K1(I)
1350   A((2*AL-2)*N+(2*BE)   )=A((2*AL-2)*N+(2*BE))-K2(I)
1370   A((2*AL-1)*N+(2*AL-1) )=A((2*AL-1)*N+(2*AL-1))+K2(I)
1390   A((2*AL-1)*N+(2*AL)   )=A((2*AL-1)*N+(2*AL))+K3(I)
1410   A((2*AL-1)*N+(2*BE-1) )=A((2*AL-1)*N+(2*BE-1))-K2(I)
1430   A((2*AL-1)*N+(2*BE)   )=A((2*AL-1)*N+(2*BE))-K3(I)
1450   A((2*BE-2)*N+(2*AL-1) )=A((2*BE-2)*N+(2*AL-1))-K1(I)
1470   A((2*BE-2)*N+(2*AL)   )=A((2*BE-2)*N+(2*AL))-K2(I)
1490   A((2*BE-2)*N+(2*BE-1) )=A((2*BE-2)*N+(2*BE-1))+K1(I)
1510   A((2*BE-2)*N+(2*BE)   )=A((2*BE-2)*N+(2*BE))+K2(I)
1530   A((2*BE-1)*N+(2*AL-1) )=A((2*BE-1)*N+(2*AL-1))-K2!I)
1550   A((2*BE-1)*N+(2*AL)   )=A((2*BE-1)*N+(2*AL)!-K3(I!
1570   A((2*BE-1)*N+(2*BE-1) )=A((2*BE-1)*N+(2*BE-1))+K2(I)
1590   A((2*BE-1)*N+(2*BE)   )=A((2*BE-1)*N+(2*BE))+K3(I)
1610 PRINT"                           "
1630 NEXT I
```

```
1650 FOR OC=1 TO N
1670 IF B(OC)=0 THEN GOSUH 1910
1690 NEXT OC
1710  REM This is where the program has formed the A  matrix
and
1730   REM  is  ready to print it on disk along  with  other
information
1750   REM  to  be  used by "MATRIX2.BAS"  for  the  matrix
inversion.
1770  KEM
1790  OPEN "O",#1,"MATRIX.DAT"
1810     LET NN=N*N
1830     PRINT #1,N,NN
1850  FOR I=1 TO NN : PRINT #1,A(I) : NEXT I
1870 CLOSE
1890 RUN"M2.BAS"
1310 REM   This is Subroutine #I.    It changes the A  matrix
according
1930 REM   to the boundary conditions.
1950 REM
1970 LET QQ
1990    FOR J=1 TO N :  LET I1=(QQ-1)*N+J : A(I1)=0! :  NEXT
J
2010 REM
2030    FUR I=1 TO N :  LET I1=(I-1)*N+QQ : A(I1)=0! :  NEXT
I
2050 REM
2070   LET A((QQ-1)*N+QQ)=0
2090   RETURN
2110 REM    ***   END OF FILE    ***
```

```
10 REM
20  REM   This is 'M2.BAS'   by Evangelos Marinis March  10, 1785.
30 REM
40  REM    It  can perform a matrix inversion  on  any  size square matrix
50 REM   up to 30x30.
60 REM
100 OPEN "I",#1,"MATRIX.DAT"
110 INPUT #1,N,NN
120 DIM A(NN)
122 REM
123 PRINT CHR$(26):PRINT:PRINT:PRINT
124   PRINT"            The  matrix  Inversion  routine   has started.":PRINT:PRINT
128    PRINT"            There   is   a   total   of    ";N;" pivots.":PRINT:PRINT
129   PRINT"            Please   Wait   while   I   do   the inversion.":PRINT:PRINT:PRINT
130 FOR 1=1 TO NN
140 INPUT #1,A(I)
150 NEXT I
410 CLOSE
510 GOSUB 1340
520 OPEN "O",#1,"INVERSE.DAT"
530 PRINT #1,N,NN
540 FOR I=1 TO N
550 FOR J=1 TO N
560   PRINT #1,AINV((I-1)*N+J)
570 NEXT J
580 NEXT I
590 REM
770 CLOSE
774 RUN "MS. BAS"
'777 REM
790 REM     This is the end af the main program.
800 REM
810 REM     The two subroutines follow.
820 REM
840 REM  Sub.I -
870 NC=2*N
880 DIM W1!N*NC),WK!N*NC),AINV(N*N)
890 FOR I=1 TO N
900   FOR J=1 TO NC
910    IF J>N THEN 930
920    WK((I-1)*NC+J)=A((I-1)*N+J):GOTO 950
930    WK((I-1)*NC+J)=0!
940    IF(J-N!=I THEN WK(!I-1)*NC+J)=1
950   NEXT J
960 NEXT I
970 FOR R=1 TO N
980    K=R : D=WK((R-1)*NC+K)
990    IF D<>0 THEN 1010
```

```
1000  PRINT"SINGULAR MATRIX   ...    D=0  CHECK THE BOUNDARY
CONDITIONS.":PRINT:PRINT"THE    PROCESS    STOPS     HERE...
SORRY.":STOP
1010   FOR 1=1 TO N
1020   FOR J=l TO NC
1030     IF I=R THEN 1060
1040     IF WK((R-1)*NC+J)=0 OR WK((I-1)*NC+K)=0 THEN W1((I-
1)*NC+J)=WK((I-1)*NC+J) : GOTO 1070 : ELSE 1050
1050                       W1((I-1)*NC+J)=WK((I-1)*NC+J)-WK((R-
1)*NC+J)*WK((I-1)*NC+K)/D : GOTO 1070
1060      W1((I-1)*NC+J)=WK((I-1)*NC+J)/D
1070  NEXT J
1080  NEXT I
1110       FOF: I=1 TO N
1120       FOR J=1 TO NC
1130         WK! (I-1)*NC+J)=W1((I-1)*NC+J)
1140       NEXT J
1150       NEXT I
1155   PRINT:PRINT"PIVOT NUMBER ";R;" OF ";N
1170   NEXT R
1180   FOF: 1=1  TO N
1190   FOR J=1 TO N
1200   AINV((I-1)*N+J)=WK((I-1)*NC+(J+N))
1  1   NEXT J
1220   NEXT I
1230   RETURN
1360 END
```

```
10 REM
20 REM
30 REM   This is 'M3.BAS'.  It reads the inverted matrix
40 REM   and calculates forces, stresses, etc.
50 REM
60 PRINT CHR$(26)
'70 PRINT "This is 'M3.BAS'                              March 28,
1985."
80 REM
90 OPEN "I",#1,"INVERSE.DAT"
100 INPUT #1,N,NN
110 DIM A(NN)
120 FOR I=1 TO NN : INPUT #1,A(I) : NEXT I
130 CLOSE
140 OPEN "I",#1,"GEOM.DAT"
150 'TNPLJT #1,N1,M1
160 DIM X(N1) : DIM Y(N1) : DIM XN(N1) : DIM YN(N1)
170 DIM P1(M1): DIM P2(M1) : DIM MI(M1)
180 I   O    M :DIM NE(M1) :  DIM AR(M1) :  DIM L(M1) :  DIM
K(M1) : DIM SG(M1)
190 DIM ST(M1) :  DIM CT(M1) : DIM YS(M1) : DIM RS(M1) : DIM
RA(M1)
200 DIM K1(M1) :  DIM K2(M1) :  DIM K3(M1) :  DIM C(N):  DIM
BF(M1)
210 DIM EX(N) :  DIM B(N) :  DIM TE(M1) :  DIM AT(M1) :  DIM
PS(M1)
220 DIM FC(M1) :  DIM D(N1) :  DIM SS(M1) : DIM SR(M1) : DIM
BC(N)
230 DIM AA(M1) :  DIM BB(M1) :  DIM CC(M1):  DIM XE(N) : DIM
CF(M1)
240 FOR I=1 TO N1 :  INPUT #1,X(I),Y(I) : NEXT I
%   REM
2b0 FOR I=1 TO M1
270                                                      INPUT
#1,P1(I),P2(I),MI(I),AR(I),L(I),K(I),SG(I),YS(I),RS(I)
280 NEXT I
290 FOR I=1 TO M1 : INPUT #1,ST(I),CT(I) : NEXT I
300 FOR I=1 TO Mi : INPUT#1,AT(I),TE(I)  : NEXT I
310 FOR I=1 TO N  : INPUT#1,B(I) : NEXT I
320 CLOSE
330 OPEN"I",#1,"E-MOD.DAT"
340 FOR I=1 TO M1:INPUT#1,OE(I),NE(I):NEXT I
350 CLOSE
360 OPEN"I",#1,"SS-SR.DAT"
370               FOR              I=1               TO
M1:INPUT#1,SS(I),SR(I),YS(I),RS(I),PS(I)I     :NEXT I
380 FOR I=1 TO N :INPUT#1,XE(I):NEXT I
390 CLOSE
400 REM
410 SELECT=0
420 PRINT CHR$(26):PRINT:PRINT:PRINT:PRINT
430 PRINT"    1.    SPECIFY INCREMENTAL FORCES":PRINT:PRIMT
440 PRINT"    2.    COMPLETELY UNLOAD THE STRUCTURE"
```

```
450 PRINT:PRINT:INPUT"Select   1 or 2 :";SELECT
460 IF  SELECT<>1 AND SELECT<>2 THEW GOTO 420
470 IF SELECT=2 THEN GOTO 680
480 IF SELECT=1 THEN GOTO 500
490 REM
500  REM  The  following statements are used  to  input  the
forces.
510 REM
520  PRINT:PRINT"PLEASE  INPUT ALL  THE  EXTERNALLY  APPLIED
INCREMENTAL FORCES"
530 PRINT:PRINT"LET ALL UNKNOWN FORCES =0.":PRINT:PRINT
540 FOR 1=1 TO N STEP 2
550    J=(I+1)/2
560 PRINT:PRINT"What is the force F(";J;")x = ";
570    INPUT C(I)
580 PRINT"What is the force F(";J;")y = ";
590    INPUT C(I+1)
600 NEXT I
610 ANS$="N"
620 PRINT:PRINT
630 PRINT:INPUT"ARE THESE VALUES CORRECT (Y/N!  ";ANS$
640 PRINT:PRINT
650 IF ANS$="Y" THEN GOTO 730
660 IF ANS$="N" THEN  GOTO 540
670 IF ANS$<>"N" AND ANS$<>"Y" THEN GOTO 630
680 HEM  Do not Erase...  At this point the structure Unloads
Completely.
690 REM
700 FOR I=1 TO MI: NE(I)=OE(I):NEXT I
710 FOR I=1 TO N :C(I)=(-1)*XE(I) : NEXT I
720 REM
730 FOF: I=1 TO N : EX(I)=C(I):NEXT I
740 FOR 1=1 TO N : XE(I)=XE(I)+EX(I) : NEXT I
750 HEM
760 FOE I=1 TO N
770 IF B(I)=0 THEN C(I)=0
780 NEXT I
790 REM
800 REM  This part calculates the displacements.
810 LET BM=0!
820 FOR I=1 TO N
830 LET B(I)=0!
840 FOR J=1 TO N
850   B(I)=B(I)+A((I-1)*N+J)*C(J)
860 NEXT J
870 IF AHS(B(I)) >BM THEN LET BM=ABS(B!I))
880 NEXT I
890 IF SELECT=2 THEN GOTO 990
900 REM
910 HEM  This part calculates the forces on each member.
920 REM
930 FOR I=1 TO M1
```

```
940   IF   PS(I)=0  AND  ABS(SS(I))<=YS(I)   THEN   BF(I)=(-
1E+06)*((3.14159)^2*OE(I)*MI(I))/(L(I)^2)
950  IF  PS(I)=0  AND ABS(SS(I))>YS(I)  THEN  BF(I)=AR(I)*(-
1)*(5*(3.14159^2)*MI(I)*OE(I)*(1E+06)*YS(I))/(2*AR(I)*YS(I)*
(L(I)^2)+3*(3.14159^2)*MI(I)*OE(I)*(1E+06))
960 IF PS(I)<>0 THEN BF(I)=0!
970 NEXT ▮
980 REM
990 REM        REM       FF:▮NT CHR$(26)
1000   PHINY"MEMBER      PIN#(A,B)     U(PIN)      V(PIN) "
1010   PRINT"======    ----------     ======      ------ "
1020   PRINT"----------------------------------------------"
1030   PRINT:PRINT
1040 FOR I=1 TO M1
1050          PR▮NT         "           ";USING"###"; I;:PRINT"
";USING"###";P1(I);:PRINT"
";USING"####.###";B(2*P1(I)-1);:PRINT"
";USING"####.###";B(2*P1(I))
1060        PRINT"               ";USING"###";P2(I);:PRINT"
";USING"####.###";B(2*P2(I)-1);:PRINT"
";USING"####.###";B(2*P2(I))
1070    D(  P1(I)  )=B( 2*P1(I)-1 ) * CT(I)  + B( 2*P1(I) )   *
ST(I)
1080    D( P2(I)  )=B( 2*P2(I)-1 ) * CT(I) + B( 2*P2(I)   )   *
ST(I)
1090   K(I)=AR(I)*NE(I)/L(I)
1100   FC(I)=K(I) * ( D( P2(I) ) - D  ▮      ) ) *1E+06
1110   CF(I)=CF(I)+FC(I)
1120   NS=FC(I)/AR(I)
1130   SR(I)=SR(I)+(NS/(NE(I)*1E+06))
1140      ▮F     PS(▮)>0      AND     ABS(SS(I))<=YS(I)     THEN
SS(I)=SS(I)+NS:NE(I)=OE(I):GOTO 1190
1150      IF    PS(I)<0      AND     ABS(SS(▮))>YS(▮)       AND
ABS(SS(I)+NS)>=ABS(SS(I))                                   THEN
SS(I)=SS(I)+NS:NE(I)=(OE(I)/(2*YS(I)))*(5*YS(I)-
3*ABS(SS(I))):GOTO 1190
1160      ▮F     PS(I)=0      AND     ABS(SS(I))>YS(I)       AND
ABS(SS(▮!+NS)<ABS(SS(I))                                    THEN
PS(I)=SS(I):SS(I)=SS(I)+NS:NE(I)=OE(I):GOTO 1190
1170      IF    PS(I)<>0    AND    ABS(SS(I))<=ABS(PS(I))    AND
ABS(SS(I)+NS)<ABS(PS(I))                                    THEN
NE(I)=OE(I):SS(I)=SS(I)+NS:GOTO 1190
1180     IF    PS(I)<>0    AND    ABS(SS(I))<=ABS(PS(I))     AND
ABS(SS(I)+NS)>=ABS(PS(I))      THEN     SS(I)=SS(I)+NS:PS(I)=0
:NE(I)=(OE(I)/(2*YS(I)))*(5*YS(I)-3*ABS(SS(I))):GOTO 1190
1190   KEM  Do not erase this statement.. ..
1200   PRINT
1210   PRINT "FORCE(lbs)=";CF(I);"     STRESS{psi)=";SS(▮);"
STRAIN=";SR(I):PRINT
1220   IF   ABS(SS(I))>YS(I)   AND   ABS(SS(I))<=RS(I)   THEN
PRINT"THIS MEMBER HAS YIELDED."
1230 IF ABS(SS(▮))>=RS(▮) THEN PR▮NT"*****  TH▮S MEMBER  HAS
RUPTURED.     *****":OE(I)=1E-06:NE(▮!=1E-06
```

```
1240 IF CF(I)<BF(I) OR OE(I)=1E-06 THEN GOTO 1310
1250   PRINT:PRINT"* *** ** **   THIS  MEMBER  HAS   BUCKLED
*** * *** *:PRINT:PRINT
1260  PRINT"MEMBER #";I;'HAS BUCKLED   SHOULD IT BE  REMOVED
FROM THE STRUCTURE ? (Y/N) ';
1270 INPUT A$
1280 IF A$<>"Y" AND A$<>"N" THEN GOTO 1260
1290 IF A$="N" THEN GOTO 1310
1300 IF A$="Y" THEN NE(I)=1E-06 : OE(I)=1E-06
1310  PRINT:PRINT:  IF  INT(I/2)=I/2 THEN INPUT'Hit <RETURN>
to continue";A$
1320   PRINT
1330 NEXT I
1340 OPEN"I",#1,"PLOTTER.DAT"
1350 INPUT#1,MF
1360 FOR I=1 TO N1:INPUT #1,XN(I),YN(I):NEXT I
1370 CLOSE
1380 OPEN"O",#1,'PLOTER.DAT'
1390 PRINT #1,MF
1400 FOR I=1 TO N1
1410   XN(I)=XN(I)+B(2*I-1)*MF
1420   YN(I)=YN(I)+B(2*I)*MF
1430  PRINT #1,XN(I),YN(I)
1440 NEXT I
1450 CLOSE
1460   PRINT:INPUT"Hit <RETURN> to continue...";A$
1470   PRINT CHR$(26)
1480   PRINT:P INT"OPTIONS:     Select from the following in
the order th y are listed. "
1490   PRINT
1500   PRINT"            1.  SEND INPUT AND RESULTS TO PRINTER
NOW."
1510   PRINT
1520    PRINT"            2.   CREATE  A  GRAPHICS  FILE  FOR
PLOTTER."
1530   PRINT            3  CREATE A GRAPHICS FILE FOR CRT '
1540   PRINT"  "
1550   PRINT"           4. RESTART  (ELASTIC REGION)"
1560   PRINT"  "
1570    PRINT"            5.  RUN AGAIN WITH NEW  INCREMENTAL
FORCES ( AND/OR UNLOAD)"
1580   PRINT"   "
1590   PRINT"           6. DRAW THE GRAPH NOW. "
1600   PRINT"   "
1610   PRINT"           7  QUIT NOW  FUNCTION COMPLETE..."
1620   PRINT
1630   LET SELECT=0!
1640   PRINT:PRINT"Note:     If you wish to select option 6,
you must first"
1650         PRINT"=====    select option 2 OR 3."
1660   PRINT:PRINT
1670   INPUT"SELECT (1 thru 7): ";SELECT
1680   IF SELECT<1 OR SELECT>7 THEN GOTO 1470
```

```
1690 REM
1700 IF SELECT=1 THEN GOSUB 1880
1710 IF SELECT=2 THEN GOSUB 2360
1720 IF SELECT=3 THEN GOSUB 2360
1730 IF SELECT=4 THEN
OPEN"O",#1,"FILE1.SUB":PRINT#1,"PRINTER O":PRINT#1,"MHASIC
MATRIX1":PRINT#1,"SUBMIT FILE2":CLOSE:RUN"MATRIX1.BAS"
1740 IF SELECT=5 OR SELECT=6 THEN GOSUB 2640
1750 IF SELECT=5 THEN RUN"M1.BAS"
1760 IF SELECT=6 THEN CLEAR : SYSTEM
1770 IF SELECT=7 THEN GOTO 1790
1780 GOTO 1470
1790 OPEN "O",#1, "FILE2.SUE"
1800 PRINT #1,""
1810 CLOSE
1820 OPEN"O",#1,"FILE1.SUB"
1830 PRINT#1,"PRINTER O"
1840 PRINT#1, "MBAS▮C MATR▮X1"
1850 PRINT#1,"SUBMIT FILEZ"
1860 CLOSE
1870 SYSTEM
1880 REM 'This is the 1st sub.  It prints the results on the
printer.
1890 REM
1900 F'R▮NT CHR$(26):PR▮NT:Pi?▮NT:PR▮NT:LPR▮NT CHR$(15)
1410 PRINT"PLEASE SET THE FRINTER TO A NEW PAGE. "
1920 PRINT:PRINT:PRINT"          Hit <RETURN> to start
printing.. ."
1930 INPUT A$
1940 OPEN "I",#1,"SN.DAT"
1950 INPUT #1,SN : CLOSE
1960 LF'R▮NT:LPR▮NT CHR$(15)
1970                                                   LPR▮NT"
        SER▮AL#";US▮NG"########";
1980 LPRINT
1990 LET NS=SN
2000 LET SN=SN+1 : OPEN "O",#1,"SN.DAT"
2010 IF SN>9000 THEN LET SN=1
2020 PRINT #1,SN : CLOSE
2030 LPRINT:LPRINT"                     ANALYSIS OF A
STRUCTURE BY THE FINITE ELEMENT METHOD"
2040                                                  LPR▮NT"
===================================SN==================="
2050 LPRINT:LPRINT"                                     (All
units are LBS,IN. )":LPRINT
2060 LPR▮NT"                        NUMEEA OF FINS=
";N1;"   NUMBER OF MEMBERS= ";M1
2070 REM
2080 LF'R▮NT:LPR▮NT:LPR▮NT:FOR DU=1 TO N:PRINT B(DU):LF'R▮NT
B(DU),:NEXT DU
2090                                                  LPR▮NT"
EXTERNAL FORCES :"
```

```
2100                                                              LPRINT"
===================":LPRINT
2110  LPRINT"                                        ▮NC             ▮NC
NET        NET"
2120  LPRINT"                     PIN#          FORCE-x        FORCE-y
FORCE-x    FORCE-y     Fixed-x     Fixed-y "
2130                                                              LPRINT"
==================================================================
.......".
2140 FOR I=1 TO N STEP 2
2150 J=(I+1)/2
2160 LPRINT"                 ";USING"####";J;
2170 LPF:▮NT"            ";USING"#####"5EX(I);
2180 LPR▮NT"           ";USING"#####";EX(I+1);
2190 LF'R▮MT"          ";USING"######"; XE▮I);
2200 LPRINT"     ";USING"######";XE(I+1);
2210 NEXT ▮
2220 LPRINT: LPRINT: LPRINT
2230     LPRIMT"                                  ▮NCREM' TL           NET
NET           NEW   ELASTIC      MEMBER       MEMBER      MEMBER"
2240   LPR▮NT"          MEMBER#     FORCE (1bs)    FORCE   (1bs)
STRESS   (psi)      MODULUS!*3E-6)      YIELDED           BUCKLED
RUPTURED"
2250                                                              LPR▮NT"
====--.------------------------------------------------------------
================================================"
2260   LPR▮NT
2270 FOR I=1 TO M1
2280   LPRINT"          ";USING"####";I;
2290   LPRINT"         ":USING"#####" ;FC(I);
23..   LPRINT"          ";USING"######";CF(I);
2310   LPR▮NT"        ";USING"######";SS(I)5
2320   I-PRINT"            ";USING"###.###";NE(I);
2330   NEXT I
2340 REM
2350 LPR▮NT CHR$(18):LPR▮NT CHR$(26):RETURN:REM
2360 REM This is the 2nd sub. It creates a graphics file.
2370 REM
2380 OPEN "O",#1,"FILE2.SUB"
2390 PRINT #1, " USER O "
2400 IF SELECT =3 'THEN PRINT #1, " PRINTER 1 "
2410 IF SELECT=2 THEN PRINT #1,"PRINTER O "
2420 PR▮NT #1," CHART F-E-M1.CMD "
2430 PRINT' #1," SUBMIT FILE1 "
2440 CLOSE
2450 OPEN"O",#1,"FILE1.SUB"
2460 PRINT#1,"USER O"
2470 PRINT#1,"PRINTER O"
2480 PRINT#1,"MBASIC M1"
2490 PRINT#1,"SUBMIT F▮LE2"
2500 CLOSE
2510 REM
2520 OPEN "O",#1,"F-E-M.CMD"
```

```
253   PRINT #1," PLOTSX TYPE 16  "
2540  PRINT #1," PLOT 2.5  0  -3  END "
2550  FOR 1=1 TO M1
2560   PRINT #1," CIRCLE ";XN(P1(I));"  ";YN(P1(I));"  -.09
2570  PRINT #1," CIRCLE ";XN(P2(I));"  ";YN(P2(I));"   -.09
2580   PRINT  #1,"  PLOT   ";XN(P1(I));"   ";YN(P1(I));"  3
";XN(P2(I));"  ";YN(P2(I));"  2   END "
2590  NEXT I
2600 PRINT #1," EXIT "
2610  CLOSE
2620  RETURN
2630 REM
2640  REM This is the subroutine that prepares for the  next
force increments.
2650 REM
2660 OPEN "O",#1,"E-MOD.DAT"
2670 FOR 1=1 TO M1:PRINT#1,OE(I),NE(I):NEXT I
2680 CLOSE
2690 OPEN"O",#1,"SS-SR.DAT"
2700      FUR      1=1      TO      M1              PRINT
#1,SS(I),SR(I),YS(I),RS(I),PS(I),CF(I): NEXT I
2710 FOR I=1 TO N:PRINT#1,XE(I):NEXT I
2720 CLOSE
2730 RETURN
2740 REM          *******    END OF FILE    ********
```

APPENDIX E

Computer System's Directory

```
SDIR A:
00:00:43 A: SDIR     .PRL

Directory For Drive A:   User  0

    Flame       Bytes   Recs   Attributes      Name       Bytes   Recs   Attributes
-------------- ------ ------ ------------ ------------ ------ ------ ------------
$1$      SUB      4k      4 Dir RW        $1$      SUB      4k      4 Dir RW
CHART    COM     32k    234 Sys RO        DIR      PRL      4k     14 Sys RO
DSKRESET PRL      4k      5 Sys RO        DSKRST   PRL      4k      5 Sys RO
E-MOD    DAT      4k      1 Dir RW        EPSNMAP  COM     24k    185 Sys RO
ERA      PRL      4k     15 Sys RO        F-E-M    CMD      8k     35 Dir RW
F-E-M1   CMD      4k     10 Dir RW        FEA      SUB      4k      1 Sys Rbl
FILE0    SUB      4k      1 Sys RO        FILE1    SUB      4k      1 Dir RW
FILE2    SUB      4k      1 Dir RW        GEOM     BAK      4k     15 Dir KW
GEOM     DAT      4k      8 Dir RW        INVERSE  DAT      4k      6 Dir RW
M1       PAS      4k     31 Sys RO        M1       BAK      4k     31 Sys RO
M2       BAS      4k     14 Sys RO        M2       BAK      4k     14 Sys RO
M3       BAK     12k     78 Sys RO        M3       BAS     12k     78 Sys KO
MATRIX   DAT      4k      6 Dir RW        MATRIX1  BAS      8k     51 Sys RO
MATRIX1  BAK      8k     51 Sys RO        MATRIX2  BAK      4k     21 Sys RO
MATRIX2  BAS      4k     21 Sys RO        MATRIX3  BAK     12k     81 Sys RO
MATRIX3  BAS     12k     81 Sys RO        MBASIC   COM     20k    144 Sys RO
MPM      SYS     36k    262 Sys RO        OVERLAYG OVR     36k    275 Sys RO
OVERLAYS OVR     56k    419 Sys RO        PEN      BAS      4k      2 Sys RW
PIP      COM      8k     58 Sys RO        PIP      PRL     12k     77 Sys RO
PLOTER   DAT      4k      1 Dir RW        PLOTLIB  REL     40k    302 Dir RW
PLOTSPEC DAT     12k     68 Sys RW        PLOTTER  DAT      4k      2 Dir RW
PLOTWARE DAT     12k     92 Dir RW        PLOTWRMS OVR      8k     58 Sys RO
PRINTER  PRL      4k      8 Sys RO        RESET    BAS      4k      9 Sys RO
SDIR     PHL     20k    137 Sys RO        SET      PRL      8k     60 Sys RO
SN       DAT      4k      1 Dir RW        SS-SR    DAT      4k      2 Dir RW
STAT     PRL     12k     78 Sys RO        SUBMIT   PRL      8k     42 Sys RO
TYPE     PRL      4k     11 Sys RO        USER     PRL      4k      8 Sys RO
WS       COM     16k    124 Sys RO        WSMSGS   OVR     28k    218 Sys RO
WSOVLY1  OVR     36k    266 Sys RO

Total Bytes     =   620k  Total Records =    3827  Files Found =   57
Total 1k Blocks =   508   Used/Max Dir Entries For Drive A:   62/ 256
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