

***A COMPUTERIZED
WOOD
ENGINEERING
SYSTEM:
Purdue
Plane
Structures
Analyzer***

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Abstract

This report gives directions, with an example, for using a computerized system to analyze plane wood framed structures. An infinite variety of structural types is covered by the method, which isolates and identifies a mathematical model or analog that is created to represent the prototype structure. Although the analog members are bar elements, either pinned or fixed to joint points, methods are discussed for simulating a wide variety of structural situations through the use of what are called fictitious members. A special type of reaction reduces the analog by half for cases in which the structure and its loads are symmetrical.

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Foreword

The author is currently associated with the Forest Products Laboratory to appraise research needs in housing and light frame construction. This problem analysis is a part of continuing efforts of the Forest Products Laboratory and the wood industries to maintain coordinated and efficient research activities. One finding, clearly established in interviews with scientific and industrial personnel, is that more thorough computer aids for wood engineering must be created to further the efficient and economic use of the wood resource. This document, although prepared by the author in his regular university activity, provides an example of such an aid. It has, therefore, been published by the Forest Products Laboratory because of its special pertinence to the appraisal program in process.

Acknowledgment

The system presented here, like many similar works, is derived from the efforts of many people. In 1966 Gregory F. Reardon, a visiting engineer from the Commonwealth Scientific and Industrial Research Organization of Australia, wrote the first basic portion of the computer program from a problem formulation by the author. Upon completion of Reardon's work, Forrest E. Goodrick of the Purdue Wood Research Laboratory staff added further improvements and refinements to the system until 1969. Since that time Larry A. Beineke and Quentin B. Comus, also of the Purdue staff, have been active participants in a complete revision and expansion of the system. The main thrust in this final phase was to eliminate the need for mastery of matrix analysis by the user while producing the specific analytic detail of main interest to the designer. This work is, therefore, the product of a team effort which would not have been possible without the skills and cooperation of each participant.

A COMPUTERIZED WOOD ENGINEERING SYSTEM: Purdue Plane Structures Analyzer¹

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INTRODUCTION

This document is intended as a guide for using a computerized matrix analysis system for plane wood structures. An unlimited number of types of plane frames, arches, trusses, continuous beams, etc. can be analyzed and checked against certain built-in design considerations. There are, of course, limitations as with all systems, but the user has unprecedented freedom to create a mathematical model to simulate the mechanical action of the real structure. The computer accepts the input description of the analog and automatically performs an analysis regardless of the degree of complexity; it provides useful strength and deflection data in output tables.

The matrix analysis of structures is a convenient procedure that permits use of the extreme capabilities of digital computers to perform structural engineering tasks that were formerly impossible because of time and cost requirements. The topic has developed to the textbook stage (2,3,5)³ and great quantities of journal articles on the subject can be found in the engineering literature. Because of the prolific supply of background material, this document does not discuss theory or computer program details but rather presents the instructions for using a matrix analysis program tailored to the needs of wood engineering.

Like all matrix methods, the one used here is based on traditional structural theory that has been refined and accumulated since the beginning of engineering history. Specifically, this is a stiffness method solution based on a virtual energy formulation. The theoretical structure treated is made up of prismatic, elastic members that are either pinned or rigidly connected to dimensionless joints. The traditional reactions in any number and mixture can be used along with a somewhat unique type of reaction designed to simplify symmetrical structures. Shear deflection in the members is recognized in the main solution on the basis of a shear modulus set at 1/20 of the modulus of elasticity. This necessary simplification stems from the scarcity of shear modulus data rather than from lack of program capability.

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²The Laboratory is maintained at Madison, Wis., in cooperation with the University of Wisconsin.

³Underlined numbers in parentheses refer to the List of References at the end of the report.

Many highly sophisticated matrix programs have been perfected for aerospace and less exotic applications. The purpose in creating still another one was to meet specific needs of wood engineering and to develop a system that could be used without preparatory study of either programming or matrix methods.

Engineering analysis of even the simplest structure is actually an analysis of a mathematical model that is presumed to simulate the behavior of the real structure. The model or analog is given special emphasis in this document since its creation is a key step in processing, and clearly delineates the degree of precision used in the analysis. A given real structure can have many analogs depending on the need for knowledge of behavior of the structure under load and on how well the actual loads and material properties are known.

Engineering judgment and experience are applied in the creation of the analog-- the computer system then takes over and produces exact answers for that analog. Once the existence of the analog is recognized, it becomes clear that the computer program can provide far more thorough analyses than are currently available by other means. In many cases structural types that could not previously be economically designed through calculation can now be analyzed as an alternative to trial experience or tests.

Treatment of partially rigid joints and their influence on the distribution of actions and displacements in the rest of the structure has been a topic of wood engineering research for many years. This development is still in the laboratory stage, however, and the kinds of presently defined requirements in terms of numerical data are not yet available in published tabular form. It is possible, however, to determine joint characteristics through tests and then create a linear analog to approximate the joint using what are called fictitious members or member groups.

The question of memory storage requirements frequently governs the usefulness of a computer program. The final section of this report, "Special Topics," lists the item changes that can be made to either reduce the storage requirement or increase the problem capacity if the storage is not a limiting factor. Storage reduction does, of course, reduce the maximum size of problem that can be solved. As the program is presently set up in the appendix, it can be run with a central memory requirement of 37,000 (octal) words in the Purdue University CDC 6500 computer.

ANALOG OF A REAL STRUCTURE

No actual structure has ever been subjected to a complete mechanical analysis in every detail. An analog or model of the real structure is created which is amenable to mathematical treatment and the stresses and displacements calculated for the analog are attributed to the prototype it represents. Sometimes the analog is sketched separately from the real structure and at other times its existence is only implied by the analyst's choice of mathematical method. In any event, an analog is always present in the scheme of solution whether recognized as such or not. An ideal illustration is provided by the floor joist.

The usual floor joist rests on a sill at the outside wall and on an interior girder at the other end, figure 1. Support is provided by bearing over substantial areas on the sill and the girder, which means that the actual reactions are provided by a distribution of stress over each area and not by the idealized reaction forces that allow only for support at selected points. These reaction forces are supposed to occur at the centroid of the actual distribution of stress and are located by the judgment of the engineer or by a specification based on the judgment and experience of many engineers.

The assumed placement of these reaction forces in a given case is a first step in creating the analog of the joist. The next step has to do with lateral anchorage. A symbolic pin is placed at one support, as at the left in the analog in figure 1, and a roller is placed at the other support. This makes the analog statically determinate and thus amenable to simple solution. Then, as a final step, the joist itself is modeled

as a line representing an idealized bending member stretching only between the reaction points. This line is assigned mathematical quantities of area, moment of inertia, strength, and modulus of elasticity which, with some relatively simple elastic theory, are used to calculate stresses and deflections. The anisotropic, viscoelastic, hygroscopic, and variable attributes of wood joists are usually treated on a lumped average basis or neglected as being impertinent to the degree of precision needed in ordinary engineering applications. Furthermore, local stress distributions in the vicinity of application of heavy loads and near the reactions are seldom recognized in the design of this type of structural member. The simple end product is, however, a workable model of the prototype insured by years of testing and experience and has endured for decades.

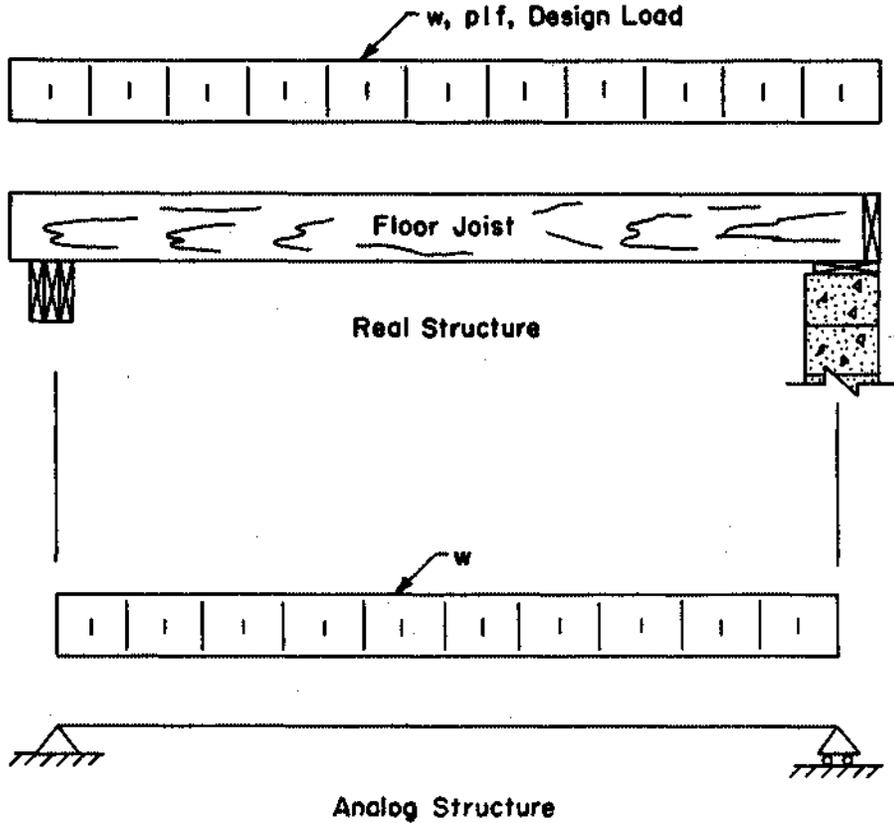


Figure 1.--An actual floor joist is compared (above) with its traditional analog (below). Theoretical point reactions that provide equilibrium are inserted at assumed centroidal locations of the actual reactions: The stress distributions and deflections are calculated according to established beam theory that is built on a substantial list of assumptions. Careful experiments show that this analog only approximates the mechanical behavior of the real beam.

(M 139 732)

The purpose of the joist illustration is to highlight the existence of the analog in an extremely common analytical situation. In such a case the recognition may be superfluous but more complex structures such as trusses, frames, and arches require more complete treatment. Recognition of the assumptions made and the method of analysis used actually prescribes the analog which is the key vehicle in the computerized system presented here. The engineer, using his own knowledge and experience, sets up the appropriate analog to represent the real structure. From that point, the computer program automatically produces a complete analysis.

The analog used consists of single line, or bar, members joined together at dimensionless joints that are called points in the text, and has four types of reactions. Each member can have any vertical and horizontal uniform loading along with three concentrated loads, each independently oriented in any desired direction. Also, forces and moments can be applied at any joint point. This provides for an infinite variety of structural compositions, loading, and reaction conditions. The degree of internal or external redundancy in member support is immaterial and treated automatically by the single program.

As a beginning in familiarization, an analog frame is presented and then followed by a simple truss for which the analog is constructed (section on "Analog Details"). Further detail including loading follows. The succeeding two sections take an example problem through all steps including the details of preparation and interpretation of the computer analysis.

Figure 2 shows an analog with key symbols that are used to describe it. The numbers in circles represent joint points, or points as they are called in subsequent text. A point occurs where members come together or terminate at a reaction. It is well to think of the points as real objects although they are dimensionless, Point 1 for the analog exists at the foot of the left leg member. The leg fastens to the point from above and a fixed reaction from below. Members extend from one point to another and are arbitrarily assigned a direction as indicated by arrows through the member identification numbers in figure 2. This direction assignment is made to facilitate understanding of the computer results. Member ends are labeled negative and positive in the computer output; if the member is viewed as horizontal with the arrow pointing right, it is in what is called its "standard position" with the negative end at left and positive at right. The numbering of points and numbering and assigning direction to the members can be done in any way the analyst wishes with only the following two guiding remarks:

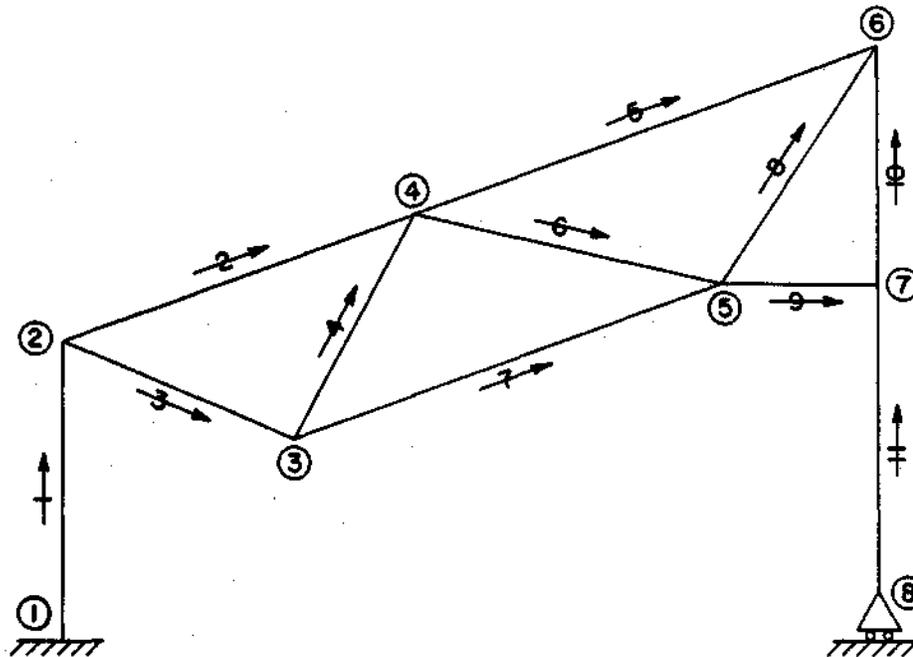


Figure 2.--An analog is shown for a framed structure. The numbered members are represented by lines that have positive and negative ends. Member intersections with other members or with reactions occur at points indicated by numbers in circles.

(M 139 737)

First, it is desirable to number points in a pattern that minimizes the numerical difference between points that are connected by members in larger structures. This is discussed in more detail under "points" in the next section. The second remark concerns member direction assignment. Experience has shown that it is more convenient to assign left to right directions to all sloping and horizontal members since they are then easier to imagine in "standard position" while interpreting results.

The next step in familiarization is keyed to figure 3, which shows a king-post truss in actual form and a possible analog below. The relatively deep upper chord and lack of miter in the lower chord at the heel create substantial eccentricity in the joint. The analog can be constructed, so as to reflect this eccentricity by the placement of short, stiff vertical members aligned with the vertical reactions to connect upper to lower chords. The other members are placed on the gage lines of the truss, which reproduces the geometric influences of axial forces in the prototype. The joint connecting the post to the lower chord in the truss is relatively small and presumed to exert little or no moment resistance.

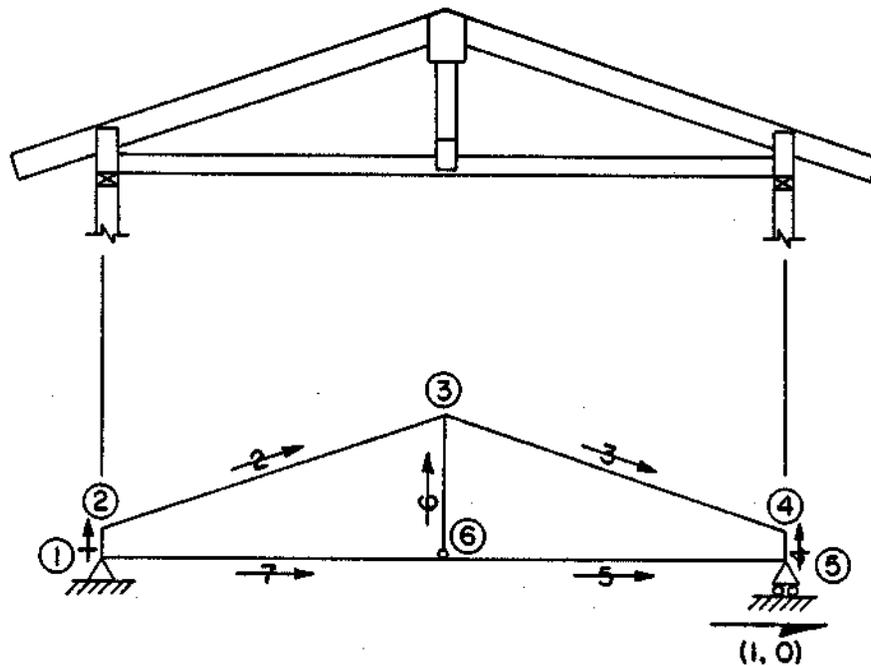


Figure 3.--An analog for the king-post truss is shown in the sketch immediately below it. The lower chord-post connection is presumed to have low rotational resistance and, hence, pinlike behavior. The other joints are presumed to be relatively rigid with the further characteristic of substantial eccentricity in the heel joints.

(M 139 734)

The symbol at the lower end of the analog member representing the post in the prototype denotes that it is pin-connected to the chord as an approximation of the low moment resistance of the actual connection. Analog reactions complete the description of the structure to the present degree. The pin reaction at left is conventional as is the roller at right. The arrow under the roller represents a vector giving the roller's direction of movement and the numbers in parentheses are \underline{x} and \underline{y} components of this vector. Roller directions, which are completely optional, are fed to the computer by the use of such vector components. The top chord extensions creating the overhang are not represented in the analog since the equivalent load effects from these cantilevers

can be applied as forces and moments at points 2 and 4. These extensions can, of course, be put in as members in an alternate version of the analog if more detailed information concerning them is needed.

Figure 4 represents a more extensive use of an array of points and analog members to simulate the action of a relatively large, rigid unit in the structure. The heavily gusseted truss heel joint shown in figure 4 will deform only slightly in comparison with the members. The analog configuration of members 1, 2, and 17 is a geometric configuration that simulates this joint. It is common practice to give these analog members the same cross-section dimensions as the actual members but to increase their Young's modulus by a factor of 5 to 10 to provide the desired rigidity in the assembly.

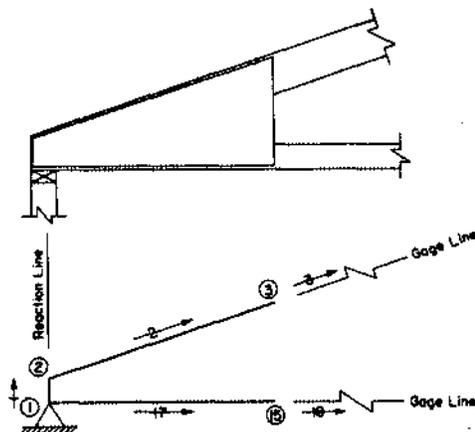


Figure 4.--The heavily gusseted heel assembly shown above is represented by the analog shown below. Members 1, 2, and 17 provide a configuration that simulates the action of the prototype.

(M 139 747)

Analog members used in this way are henceforth referred to as fictitious members to distinguish them from those that simulate actual members. The fictitious member groups may be assembled in many different ways and to varying degrees of sophistication according to the needs of the engineer in reproducing the real structure into the analog. For instance, a third fictitious member could be placed between points 3 and 15 in the analog of figure 4 and the stiffness of members 1, 2, and 17 reduced since this added member would take over the simulation of a substantial portion of the influence of the gusset plates. Carrying this process still further, several additional evenly spaced vertical members could be inserted to wholly represent the action of the gusset plates while members 2 and 17 could then be reduced to the role of the chord sections lying within the joint. The degree of reproduction of the actual structure by the analog is, thus, a matter of need for detail and availability of information concerning the material and fastenings. It must be kept in mind, however, that increased sophistication of the analog increases the costs of preparation for computer analysis and the analysis itself. The qualities of all of the input information available and the needs for accuracy in the analysis will, therefore, govern jointly in making final decisions on the quality of the analog to be used.

ANALOG DETAILS

The analog used in the system presented here consists of points, members, reactions, and applied loads. These parts are discussed in the order named. In succeeding sections an example is taken from a real structure through the preparation of computer input to interpretation of the answers obtained.

Points

Points are used to describe the location of member terminals either with other members, at a reaction, or as the end of a cantilevered member. An arbitrary origin for a grid is chosen and the \underline{x} and \underline{y} locations, in inches, of each point are fed into the computer. The array of all points provides the first information to the computer about how the structure is to be built.

Although a point has no physical dimensions and a line has no width, it is helpful to form mental pictures of them as objects of substance to visualize how the analog parts act upon one another. Members are fastened to points either rigidly, as member \underline{n} in figure 5, or as if pinned, as member \underline{m} . The positive end of member \underline{n} will rotate exactly with the point while the negative end of member \underline{m} can rotate independently of the point. Reactions are also either rigidly attached or pinned to the points at which they occur.

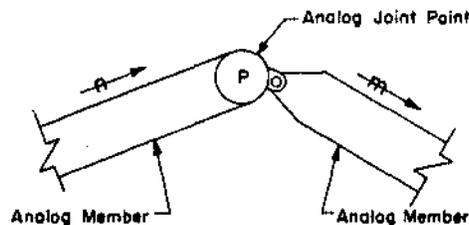


Figure 5.--The analog line for member \underline{n} joins the point \underline{p} in a rigid fashion so that the positive end of \underline{n} must rotate with \underline{p} . The negative end of \underline{m} , on the other hand, is independent of \underline{p} as far as rotation is concerned. The lines representing members \underline{m} and \underline{n} along with the point \underline{p} have been imaginarily enlarged to provide a picture of their interaction.

(M 139 742)

A point always occurs between a member end or junction of members and a reaction. This is shown in figure 6 where a rigid ground connection is visualized as attached firmly to the bottom of point 1 which, in turn, is firmly attached to the lower end of member 1. The other case shown in figure 6 is that of a roller which is fastened to the bottom of point 4 in such a way as to be free to rotate while the point itself is fastened rigidly at its top to member 3.

The computer reports point rotation as one of the products of its solution. This gives rise to a firm rule that each point must be rigidly attached to at least one member end to prevent unstable rotation of the point. More members may also be rigidly attached to that same point, and in such a case all those that are rigidly fastened will rotate together as in a rigid joint and the point rotation reported will be that of the joint assembly.

Point numbering can be a critical matter in certain larger structures. The computer program solves a set of equations derived from what is called a banded matrix. The band width is influenced by the differences between point numbers for points connected by members.

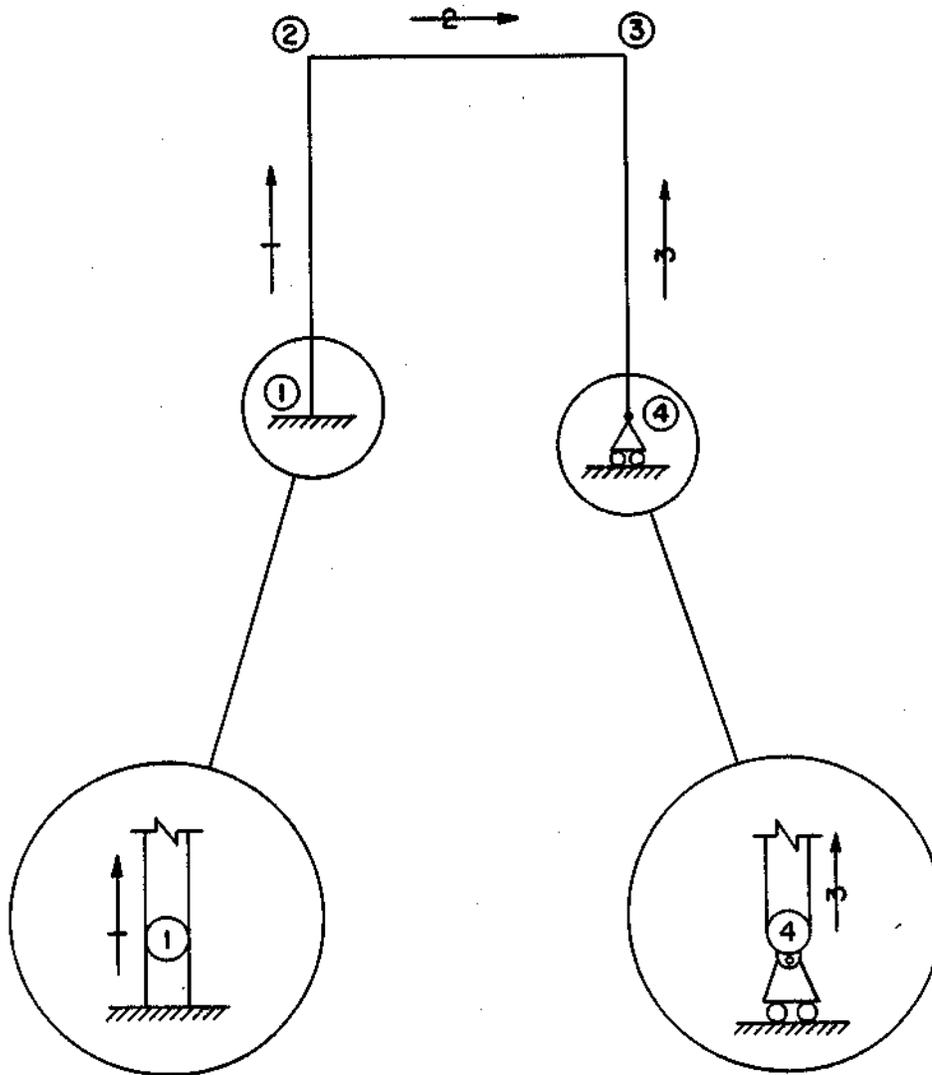
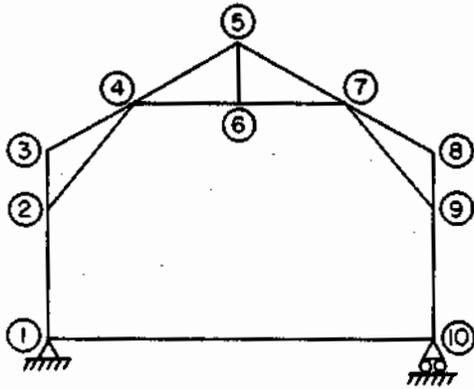


Figure 6.--An analog of a simple frame is shown with enlarged details indicating the way members and reactions are fastened to points. The members must be firmly attached to points 1 and 4 to transmit the influence of the reactions into the rest of the structure.

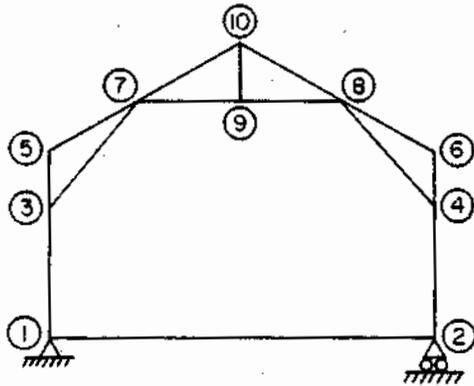
(M 139 727)

The solution is completed in a minimum time, and at minimum cost, when the greatest difference between connected point numbers is minimized. Figure 7a shows a structure that has a member connected between points 1 and 10, producing a difference of nine, which is large for a structure consisting of only ten points. Figure 7b shows the same structure renumbered so that the maximum difference between any of the connected points is only four. This was accomplished by weaving back and forth from left to right with the numbering rather than going around the structure in a circular path. The infinite variety of structures that can be treated by this system prohibits the creation of specific rules for point numbering and it must be left to the user to avoid obvious large differences where possible.

In summary, all member ends or junctions must be attached at a point; all reactions act on points, and at least one member must be attached rigidly to each point. Point numbering should avoid large differences in numbers at connected points.



a. Inefficient point numbering



b. Efficient point numbering

Figure 7.--The matrix solution is accomplished most easily by the computer when low differences are maintained between point numbers connected by members. The bottom member in (a) connects points that differ by nine and is inefficient. The numbering in (b) for the same structure shows a maximum difference of only four (7-3 and 8-4).

(M 139 728)

Members

Members are straight lines stretching between points and are assigned the following properties by the analyst :

E, psi--Modulus of elasticity

G, psi--Modulus of rigidity. This quantity is taken as $1/20$ of E in the program as an approximation since G is rarely available for structural lumber,

T, in.--Thickness of actual members in the direction perpendicular to the plane of the structure.

H, in.--Depth of actual members in the plane of the structure,

Note: (T and H are convenient dimensions for wood frames which are almost always composed of rectangular parts. Given the properties of some other section, equivalent T and H values can be calculated that will permit an analysis although all of the computer answers may not be pertinent.)

□_b, psi--Allowable normal duration bending stress for the lumber grade used.

□_c, psi--Allowable normal duration compression stress parallel to grain.

□_T, psi--Allowable normal duration tensile stress parallel to grain.

Chord Laterally Supported--This designation is used in finding allowable column stresses in meeting the design criteria built into the program. This designation denotes that the chord is supported so that the H dimension is critical with regard to a buckling failure. Column length is 0.8 times member length,

Chord Laterally Unsupported--This designation denotes a chord member in which T is the critical dimension for buckling. Column length is 0.8 times member length.

Web Laterally Supported--T is the critical buckling dimension and column length is calculated as 0.9 times the member length.

Web Laterally Unsupported--T is the critical buckling dimension and column length is calculated as 0.9 times member length.

End Conditions--The member may be pinned or rigidly attached to its negative and positive end points.

Note: (If the member is fictitious, E, T, H, and the end conditions are the principal items used. The compressive and tensile stress values along with member type and lateral support designations are left blank since these are redundant. The bending stress input is used, in this case, to code whether or not shear deflection is to be imposed on the fictitious member.)

The above information is grouped in sets called member groups, one for each member type in the structure. Each member in the analog structure is assigned to its appropriate member group for the analysis.

For convenience, members should be viewed in the "standard position" which has the negative end at left and positive end at right according to the arrow through the member number on the analog sketch. Member 3 from figure 3 is shown in figure 8 in the standard position to which all sign interpretations are referred. The arrows at the negative and positive end show the directions of positive quantities of axial force, shear, and moment. These quantities when referred to as a group are called end actions. Positive shears, figure 8, are up on both ends and positive moment is counterclockwise on both ends and both positive axial forces are to the right. A tensile axial force appears, then, as negative at the left end and positive at the right. Although this is momentarily confusing when viewed against the traditional sign conventions of structural analysis, the system has a mathematical basis necessary for the computer to maintain simultaneous control of all member end actions.

In the input data, each member is properly placed for the computer by designating the points that establish its line--the negative end point and the positive end point. The fastenings of the members to the end points are also designated as rigid or pinned. The example in the succeeding section illustrates how these and the member property data are entered.



Figure 8.--Member 3 from figure 3 is shown in the standard position which is horizontal with the member arrow pointing left to right. Negative and positive ends are identified as marked and the end arrows show the direction of positive values of axial force, shear, and moment from the computer output.

(M 139 745)

Reactions

Four types of reactions are available and have the names PIN, FIX, ROLL, and FIRL. The first three are traditional in structural engineering and well understood. The fourth serves a special purpose of halving the problem size when the structure and its loads are symmetrical.

The four reaction types are shown in figure 9. Each reaction is attached to the point which, in turn, is attached to the member assembly. As with points, the reactions are sketched with apparent physical dimensions but, in terms of the mathematical analysis, they have no size and their effect is centered on the point to which they are attached. The PIN reaction is attached to the point so that the point cannot move horizontally or vertically but permits the point's rotation. The FIX reaction does not permit point movement of any type. The ROLL reaction permits the point to move in the direction given by the vector having components \underline{x} and \underline{y} as shown in figure 9 but does not allow movement in the direction perpendicular to this vector. The FIRL reaction is identical to ROLL except for the further restriction that it does not permit point rotation. The use of FIRL is illustrated with an example in "Special Topics."

There is no restriction on the number and types of reactions used in constructing the analog.

Loads

Each member may carry a horizontal component of uniform load (given in pounds per linear inch on the vertical projection), a vertical component of uniform load (given in pounds per linear inch on the horizontal projection), and three concentrated loads (in pounds) that may be placed independently anywhere along the member and in any direction. The \underline{x} and \underline{y} coordinate grid system describing the points is also used to describe the locations in space where the concentrated loads are applied on the members.

An example of a member with the maximum number and types of load is shown in figure 10. The horizontal and vertical uniform load components of this member, numbered 14, would be fed into the computer as 1.5 pli (pounds per linear inch) and -5.0 pli, respectively. The algebraic signs with these and the subsequent concentrated load components are in accordance with the established x,y grid system. Concentrated loads are always numbered from the negative end of the member and up to three are permitted. Load 1 would be entered as occurring on member 14 at the location $x = 105.0$ inches, $y = 43.0$ inches and would have a horizontal component of 141.4 pounds and a vertical of -141.4 pounds. Load 2 would likewise be identified with member 14 occurring at 150.0 inches, 58.0 inches with components of 134.2 pounds, 268.4 pounds. The third load on member 14 at 180.0 inches, 68.0 inches. has no horizontal component and a vertical of -400.0 pounds. Only those members that are loaded and only nonzero loads are entered into the computer; all others are automatically treated as being zero.

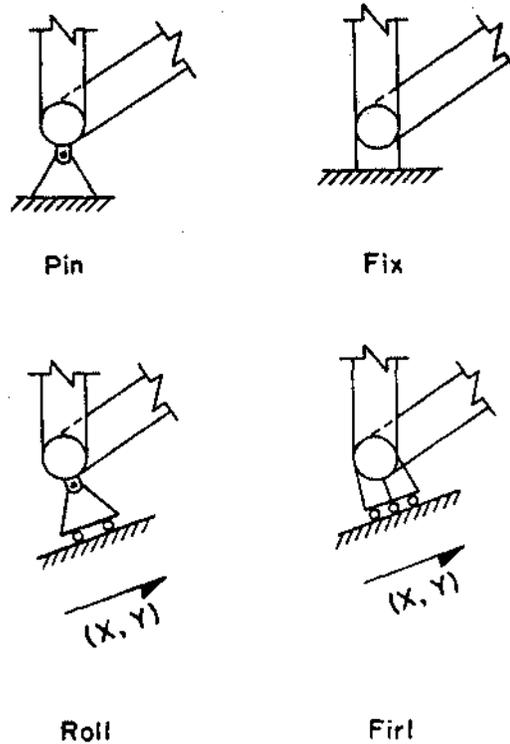


Figure 9.--The four reaction types available for analog use are shown with points, member lines, and reaction attachments enlarged in imaginary fashion to illustrate the mechanical action among the parts. In all cases the members from the structure lying above are attached rigidly to the point.

(M 139 733)

INPUT INSTRUCTIONS FOR USING PROGRAM WITH AN EXAMPLE

The media of communication with the computer are punched cards or special typewriter input and printed output from either a line printer or the typewriter. This program is set up for either type of operation through confinement of all input and output within the first 68 columns available. The input will be discussed here in terms of card columns, each containing one input symbol, and groups of columns called fields. These columns are identical, for purposes of discussion, to print positions on the typewriter. The printed output in either case is identical in appearance except for type style.

The card columns are numbered beginning with one. A group of columns is designated to carry each piece of input information. Numerical information divides into two types: One consists of integers that are used to number an item such as a member or to tell how many items are to be used; the other type is a measurement of quantity requiring a decimal point. The integers will be identified, which means that all other numbers not so designated will require recognition of the decimal. Consider, for instance, that one of the latter number types is to be entered in the five-column field (cols. 13 through 17) and that it is a dimension of 23 inches. The machine expects the dimension to be in inches but will scan the field to see if a decimal is supplied. If none is found, a decimal will be supplied immediately after column 17. The number could be entered in the five-column field of the card as 23.0b where b stands for blank. It could also be entered as b23.0 or bb23. or as bbb23 where, in the last case, the decimal would be supplied by the machine. The example data coding later on should provide adequate familiarity with the proper entry of information,

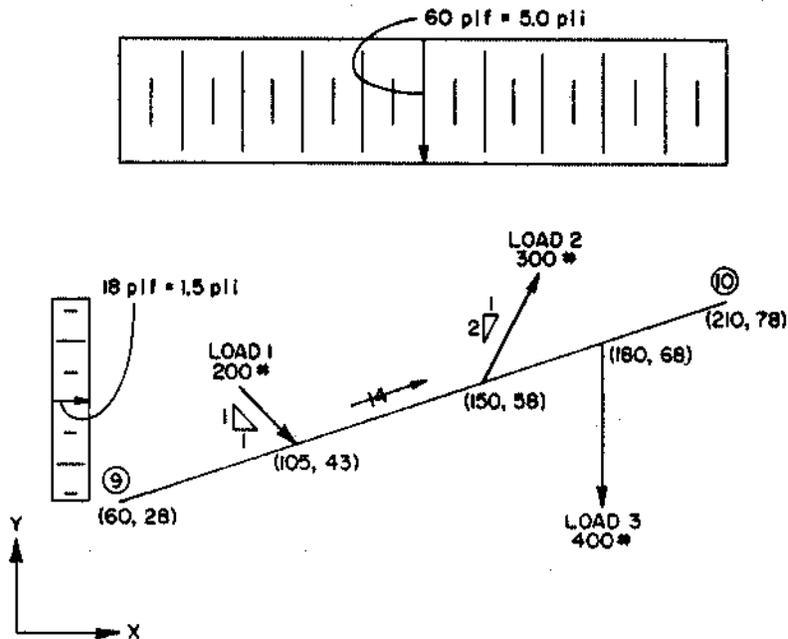


Figure 10.--A typical member, numbered 14, is shown with the maximum number of loads that can be applied to a member in the computer analysis. Each of the two uniform loads and each of the concentrated loads is independent of the others and can have any values. Inch and pound dimensions are always used. The five number pairs enclosed in parentheses are (x,y) coordinates of points 9 and 10 and locations where the concentrated loads intersect the member.

(M 139 741)

Pounds and inches are used throughout on both input and output. This maintains a degree of simplicity in the system and eliminates confusion by having one simple rule on dimensions.

Figure 11 shows the structure to be analyzed. The single slope truss is attached to a heavy wall at left and rests on a sloped frame wall at right. The construction and details were chosen primarily to illustrate several features of program usage with little consideration given to practical value of the structure. The framework consists of two grades of 2 by 4 lumber--one for the chords and the other for web members. The lumber properties used are assumed as an illustration that any such set of values can be entered as required by the engineer,

The connections in this example are not detailed as to actual sizes, materials, etc., but are presumed to be rigid for analytical purposes except for the end fastenings of the sloped diagonal. The end connections on this member are presumed to be more accurately portrayed by pin connections. The height and rigidity of the heel joint are such that eccentric effects should be considered in the analysis. It is further presumed to have been specified that roof sheathing will be nailed directly to the upper chord, which provides adequate lateral support to prevent buckling in the narrow dimension. The lower chord, on the other hand, is presumed to have no attached ceiling or other means of lateral support. A uniform snow load is imposed on the upper chord and a concentrated load from planned interior equipment appears on the lower chord. As is traditional with light wood framing, body force loads have been neglected although their inclusion in the vertical uniform member loads would have been a simple process.

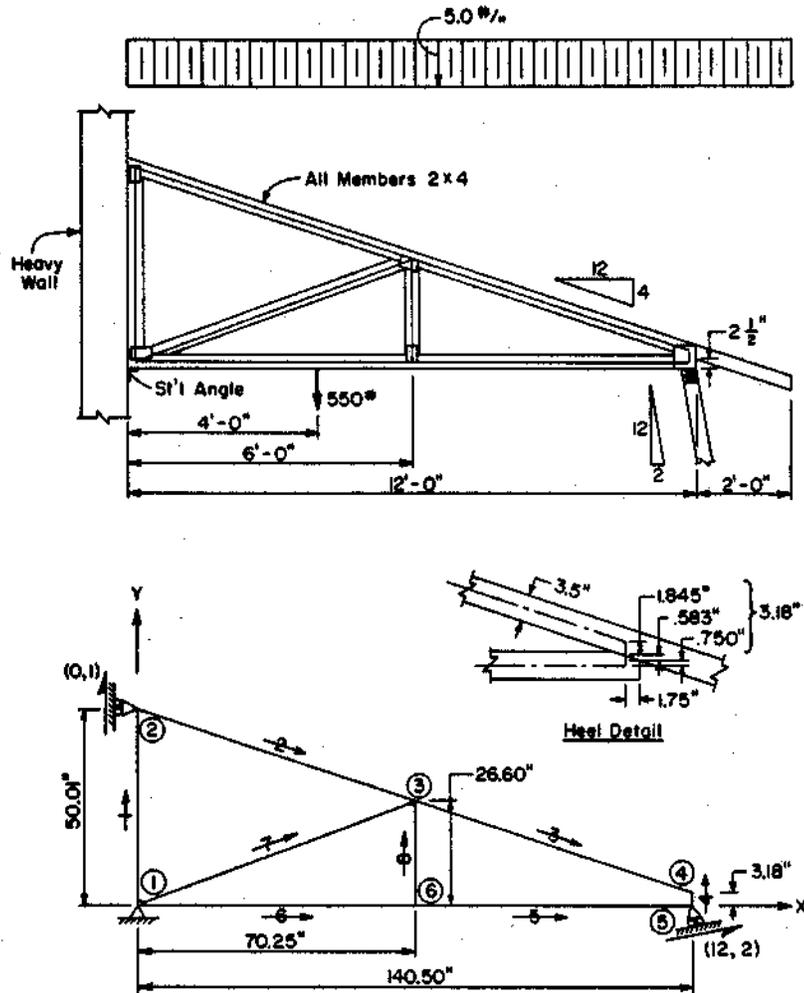


Figure 11.--The example frame in the upper portion is attached to a heavy wall at its inner end and to a sloped frame wall at its outer end. A heel detail and an analog without loads are shown below. The joint plates are not detailed but are assumed to provide substantial rigidity except at the ends of the diagonal web member.

(M 139 740)

The analog of the structure, except for loads, appears in the lower portion of figure 11 with dimensions needed for coding. The points have been numbered, appropriate reactions assigned, and members located on or close to the gage lines of the real structure.

The heel eccentricity of 3.18 inches is the vertical distance between upper and lower chord gage lines at the assumed location of the right roller reaction, point 5. The heel detail sketch gives the composition of this dimension.

The lower left corner of the frame rests on a steel angle and its connection is approximated by a PIN at point 1. The attachment of the upper left corner of the frame to the wall is assumed to allow sufficient vertical slip to make a vertical ROLL reaction suitable at point 2 with its direction designated by the vector components (0,1) in parentheses. The supporting frame wall at right is sloped and presumed to provide pin action at the truss and also at its lower end connection to the foundation. The upper end of this wall is, therefore, free to move with the truss heel in the direction of the roller arrow with vector components (12,2) shown at point 5 in the analog.

Member 7 in the analog reflects the pin-end condition presumed in its counterpart in the real structure. It can be seen that member 7 does not exactly match the gage line of its counterpart but has been drawn exactly through points 1 and 3. The small difference is of little consequence for normal engineering purposes but the use of an extra short member making member 1 into two members would have permitted more precise location of analog member 7 if necessary.

The overhang created by the upper chord extension is omitted in the figure 11 analog since the influence of the cantilevered upper chord uniform load can be introduced as a force and a moment at point 4. These forces and the other loads are shown in figure 12 which depicts the loading used in this example. An alternative analog requiring one more point and member to simulate the overhang is shown in figure 13. This, however, is a different problem from the computational standpoint and is shown only to further illustrate the flexibility available in analog construction.

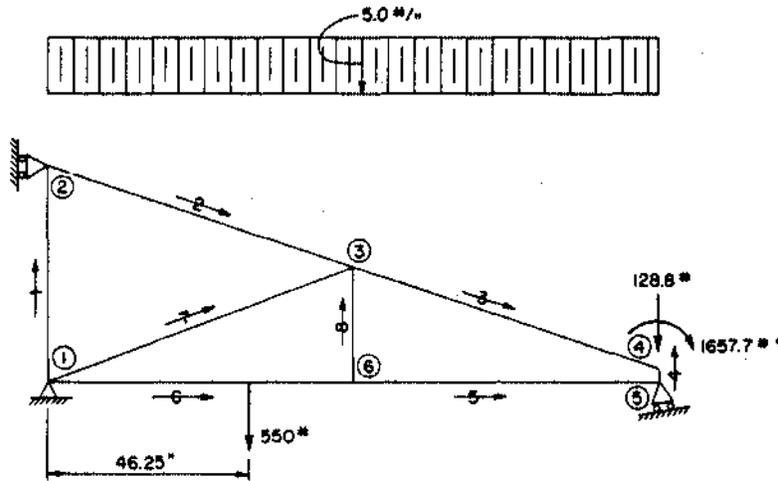


Figure 12.--The analog for the example frame is shown completed with loads. The uniform load is associated with members 2 and 3. Its effect on the overhang of the real structure is simulated with the force and moment applied at point 4.

(M 139 730)

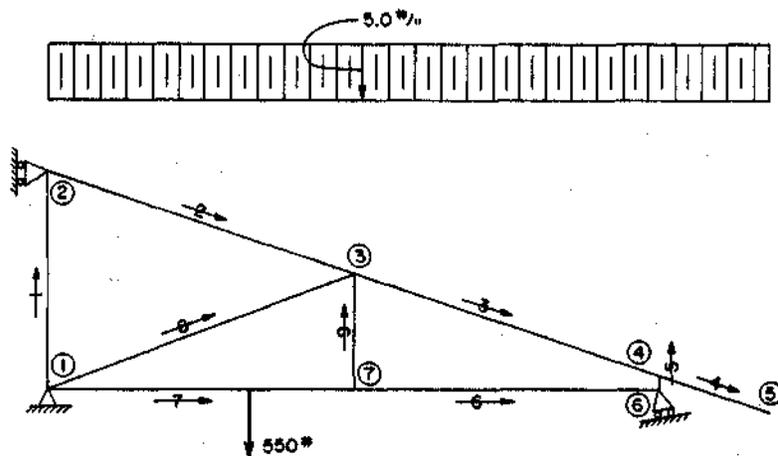


Figure 13.--The overhang of the actual structure has been reproduced in this analog at the expense of an added point and member. The uniform load is now directly applied to member 4. This more complete analog would be useful in the event that deflections of the overhang must be known.

(M 139 731)

Engineering judgment has been involved between the original structure and the analog construction. From this point onward the analytical system takes over and produces a complete virtual energy solution for the analog. This is accomplished in seconds at relatively low cost.

The critical student will note inefficiency of point numbering in this example in terms of the discussion under "Points." This is not a serious matter in such a small structure but can become so with larger ones.

Input data cards have been given names which are used below as subtitles preceding the discussion of each. Some card types always appear singly while others are repeated. In the latter cases a special identification consisting of the integer 1 in a designated column signifies the last card of the group. The cards are stacked in the order discussed here and placed in the program following the END card number F460 as shown in the program listing in the appendix. More than one structure can be analyzed in a given computer run by stacking succeeding data sets behind each other. A last card carrying ENDDCALC punched in its first eight columns is placed after the last data card for a given run. This last card is used to terminate the computer operation.

In the example cards which follow, each column entry is shown in order with the symbol b used to denote a blank.

Identification Card (Single)

Any keyboard characters can be used to identify the particular analysis being processed except the sequence ENDDCALC in columns 1 through 8. Columns 1 through 68 can be used.

ExampleCardEntry: EXAMPLEbSHEDbFRAME,4/12bSLOPE,b2bxb4bCONSTbb...b
Comment: Some computer installations may not allow certain character usage such as E period.

Problem Size Card (Single)

Columns 1-2--Integers: Number of points used in the analog. This and all other integer numbers must be right justified. For example, if six points were used, the proper entry would be b6 not 6b in this field. Blanks are interpreted as zeros in all cards.

Columns 3-4--Integers: Number of members used in the analog.

Columns 5-6--Integers: Number of ROLL reactions used in the analog.

Columns 7-8--Integers: Number of PIN and FIRL reactions in the analog.

Columns 9-10--Integers: Number of FIX reactions used in the analog.

Comment: Vertical lines appear in the example card entries to separate the item fields for the reader; they need not be drawn on the card nor be designated in any fashion.

Example: b6|b8|b2|b1|bb

Member Data Cards (May be Multiple)

These cards describe the member materials, sizes, and use type such as web and chord.

Columns 1-2--Integers: Member group number beginning with b1. Each different description of member material creates a so-called member group and thus requires a separate card.

Columns 3-7--Thickness in inches of the member in the direction perpendicular to the plane of the structure.

Columns 8-12--Depth in inches of the member in the plane of the structure.

Columns 13-18--Modulus of elasticity in pounds per square inch of the member material. This is a unique type of number because of size and is entered in a special form. The modulus of elasticity of 1,760,000 could be written 1.76×10^6 . The computer recognizes a number like the latter except that it is written 1.7636 in the six-column field. All moduli of elasticity are entered in this special form.

Columns 19-22--Normal duration allowable bending stress in pounds per square inch. This and the following two entries come from lumber grade tables such as are found in the NDS (1) and are entered as whole numbers with the decimal supplied by the machine at the right-hand side of the field. This field is left blank if the member is fictitious and not subject to shear deflection. If shear deflection is to be included in a fictitious member, any nonzero entry will suffice although it is convenient to use a number like 9,000 which is obviously not a wood stress value.

Columns 23-26--Normal duration allowable compression stress in pounds per square inch. This field is left blank if the member is fictitious.

Columns 27-30--Normal duration allowable tensile stress in pounds per square inch. This field is left blank if the member is fictitious.

Column 31, Integer--Type use classification for nonfictitious members with the following code :

Example:	b1	b1.5b	b3.5b	1.80E6	1600	1450	1300	0	b
	b2	b1.5b	b3.5b	1.80E6	1600	1450	1300	1	b
	b3	b1.5b	b3.5b	1.80E7	9000	bbbb	bbbb	b	b
	b4	b1.5b	b3.5b	1.60E6	1200	1000	b900	3	1

Stress Factor Card (Single)

The factor that adjusts normal stresses to the design duration of load in accordance with sections 203 and 204 of the NDS (1) is normally entered in columns 1 to 4 of this card, Any other general strength alteration influences applicable to the entire structure, such as the use of fire-retardant-treated lumber, can also be combined into this one factor. The tabular allowable stresses from the previous card group are each multiplied by the factor prior to use within the program.

Example: 1.15 (Snow load increase)

Point Location Cards (Multiple)

This card set gives the x,y coordinates of the points from the chosen origin. These numbers can be negative in appropriate cases.

Columns 1-2--Integers: Point number as shown on the analog.

Columns 3-9--The x coordinate of the point in inches.

Columns 10-16--The y coordinate of the point in inches.

Column 17--Last card indicated by 1 in this column.

Example:	b1	bb0.0bb	bb0.0bb	b
	b2	bb0.0bb	b50.01b	b
	b3	b70.25b	b26.60b	b
	b4	140.50b	bb3.18b	b
	b5	140.50b	bb0.0bb	b
	b6	b70.25b	bb0.0bb	1

Comment: The origin for this structure was chosen as point 1 and all coordinates were then positive. Any other origin could have been used, however. The decimal point in the coordinate entries is in the center of the seven-column field. This is not a rule--the numbers can be shifted variously left or right as long as they remain within the field expected by the computer.

Structure Assembly Cards (Multiple)

These cards tell how the members are placed in the array of points to build the structure, which ends are negative and positive, and how the ends connect to the points.

Columns 1-2--Integers: Member number.

Columns 3-4--Integers: Point location of the negative end of the member.

Columns 5-6--Integers: Point location of the positive end of the member.

Columns 7-8--Integers: Member group number according to the numbering designated in the MEMBERDATACARDS.

Column 9--Condition of negative member end connection to the point, 0 = rigidly connected, 1 = pin connected.

Column 10--Condition of positive member end connection to the point, 0 = rigidly connected, 1 = pin connected.

Column 11--Last card indicator which is 1 for the last card and blank otherwise.

Example:

b1	b1	b2	b4	0	0	b
b2	b2	b3	b1	0	0	b
b3	b3	b4	b1	0	0	b
b4	b5	b4	b3	0	0	b
b5	b6	b5	b2	0	0	b
b6	b1	b6	b2	0	0	b
b7	b1	b3	b4	1	1	b
b8	b6	b3	b4	0	0	1

Comment: Reference to the analog in figure 11 and the MEMBER DATA CARDS produces the eight lines of coding, one for each member.

Reaction Cards (Normally Multiple)

These cards locate the reactions at their respective points, give the types, and designate the directions of roller movement when pertinent.

Columns 1-2--Integers: The point number at which the reaction occurs.

Columns 3-6--Names: The name of the kind of reaction from among the four types which are PIN, FIX, ROLL, and FIRL,. This name must be right justified in the four-column field. bPIN is correct while PINb is not.

Columns 7-11--Horizontal component of the vector describing the direction in which rollers are free to move, This field is blank in the case of PIN or FIX.

Columns 12-16--Vertical component of the vector describing the direction in which rollers are free to move. This field is blank in the case of PIN or FIX.

Columns 17--Last card indicator which is 1 for the last card and blank otherwise.

Example:

b1	bPIN	bbbb	bbbb	b
b2	ROLL	b0.0b	b1.0b	b
b5	ROLL	12.0b	b2.0b	1

Comment: The roller direction arrows could have been exactly reversed without changing the problem or its solution, In such a case the roller at point 2 would have the direction x 5 0.0 and y = -1.0 and the roller at point 5 would have the direction x = -12.0 and y = -2.0.

The FIRL reaction, which is neither common to structural engineering texts nor discussed in this report up to the present, is discussed fully with an example in "Special Topics."

Loading Types Card (Single)

The machine must be instructed as to which types of load to expect among the three types which are: uniform on members, concentrated on members, and forces and moments at points. This card causes the machine to skip certain operations in the event that one or two of the types are missing.

Column 1--One if there is at least one concentrated load on the structure and otherwise zero.

Column 2--One if there is at least one uniform load on the structure and otherwise zero.

Column 3--One if there is at least one load applied directly to some point on the structure and otherwise zero.

Example: 111

Comment: All load types are present on the example. If, for instance, the concentrated load were missing from member 6, figure 12, the column 1 entry would be zero while columns 2 and 3 would remain set at 1. If there were no overhang to the right of point 4, the force of 128.8 pounds and the 1657.7 pound-inch moment, figure 12 would not exist and the column 3 entry would, consequently, be zero.

Concentrated Load Cards (May be Multiple When Present)

These cards identify the member, load number, and point of contact of the load on the member as well as giving components of the load. The loads are numbered in sequence, up to the allowable number of three per member, beginning at the negative end of the member. One card is required for each load.

Columns 1-2--Integers: Member number carrying the load concerned,

Column 3--Load number 1, 2, or 3.

Columns 4-9--Horizontal, or \underline{x} , component of the load force in pounds,

Columns 10-15--Vertical, or \underline{y} , component of the load force in pounds.

Columns 16-22--Horizontal, or \underline{x} , coordinate in inches of the point of contact of the load on the member.

Columns 23-29--Vertical, or \underline{y} , coordinate in inches of the point of contact of the load on the member.

Column 30--Last card indicator which is one for the last concentrated load card and blank otherwise.

Example: $b6|1|bb0.0b|-550.0|b46.25b|bb0.0bb|1$

Comment: The single card in this example carries the last-card indication. The coordinates entered in columns 16 through 29 must refer to the same origin as that used for the POINT LOCATION CARDS. In addition, the algebraic sign of the concentrated loads must be in agreement with this coordinate system, i.e., upward acting loads are positive and downward acting loads are negative.

Uniform Load Cards (May be Multiple When Present)

These cards identify the loaded member and give the horizontal and vertical uniform load components for that member. One card is required per loaded member.

Columns 1-2--Integers: Member number carrying the load concerned.

Columns 3-7--Horizontal component of load in pounds per linear inch on the vertical projection.

Columns 8-12--Vertical component of load in pounds per linear inch on the horizontal projection,

Column 13--Last card indicator which is one for the last uniform load card and blank otherwise.

Example: $b2|b0.0b|-5.0b|b$
 $b3|b0.0b|-5.0b|1$

Comment: The algebraic signs on horizontal and vertical components of uniform load are the same as for vectors to the right and up are positive, respectively, to agree with the originally chosen x,y coordinate system.

Point Load Cards (May be Multiple
When Present)

These cards accommodate loads that occur at points. These loads may be horizontal force, vertical force, moment, or any combination of the three. One card is required for each load.

Columns 1-2--Integers: Point number carrying the load concerned.

Column 3--The type of load which is coded as 1 for a force in x direction, 2 for a force in the y direction and 3 for a moment.

Columns 4-11--The force in pounds or moment in pound-inches, whichever is the case. Forces are positive to the right and upward to agree with the x,y system. Positive moments are counterclockwise.

Column 12--Last card indicator which is One for the last-point load card and blank otherwise.

Example: $\begin{array}{l|l|l} b4 & 2 & -128.8bb \\ b4 & 3 & -1657.7b \end{array} | b$

Experience has shown that the development of an input data form is well worthwhile. A block table of rows and columns is drawn up for each card type with adequate labeling and reminder information. Each row represents a card to be punched and the columns are marked to correspond with card columns. The columns are grouped with appropriate headings to indicate the variables to be recorded. Once the data are entered on this form, they can be read directly by the keypunch operator to produce the input cards.

INTERPRETATION OF PROGRAM OUTPUT WITH AN EXAMPLE

After the data cards are completed, assembled in the order given in the previous section, and run in the data section of the program with an ENDDCALC card, a printed report is produced either by line printer or on the typewriter. The report for the example is reproduced here in sections and accompanied by discussion as appropriate.

The first portion of the report gives the identification exactly as recorded on the IDENTIFICATION CARD followed by tabular summaries of all of the input information. The presence of a minus sign preceding a zero has no significance in any of this output material.

EXAMPLE SHED FRAME, 4/12 SLOPE, 2 X 4 CONST

NUMBER OF POINTS = 6
NUMBER OF MEMBERS = 4
NUMBER OF ROLLER SUPPORTS = 2
NUMBER OF PINNED OR FIXL SUPPORTS = 1
NUMBER OF FIXED SUPPORTS = -0

ALLOWABLE MEMBER STRESSES IN PSI, NORMAL LOAD DURATION

MEM. GROUP	USE TYPE	ALLOWABLE			WIDTH	DEPTH	MODULUS OF ELASTICITY
		BEND	COMP	TENS			
1	CS	1600	1450	1300	1.500	3.500	1.800E+06
2	CU	1600	1450	1300	1.500	3.500	1.800E+06
3	CS	9000	-0	-0	1.500	3.500	1.800E+07
4	WU	1200	1000	900	1.500	3.500	1.600E+06

THE LOAD DURATION FACTOR IS 1.15

POINT COORDINATES

POINT NO.	X-COORD (IN)	Y-COORD (IN)
1	0.000	0.000
2	0.000	50.010
3	70.250	26.600
4	140.500	3.180
5	140.500	0.000
6	70.250	0.000

MEMBER LAYOUT

MEMBER NUMBER	NEGATIVE END		POSITIVE END		MEMBER GROUP
	POINT	CONDITION	POINT	CONDITION	
1	1	RIGID	2	RIGID	4
2	2	RIGID	3	RIGID	1
3	3	RIGID	4	RIGID	1
4	5	RIGID	4	RIGID	3
5	6	RIGID	5	RIGID	2
6	1	RIGID	6	RIGID	2
7	1	PINNED	3	PINNED	4
8	6	RIGID	3	RIGID	4

REACTION CONDITIONS

POINT NUMBER	REACTION TYPE	HORIZ DISPL	VERT DISPL
1	PIN	-0.00	-0.00
2	ROLL	0.00	1.00
5	ROLL	12.00	2.00

MEMBER PROPERTIES

MEMBER NUMBER	LENGTH (IN)	WIDTH (IN)	DEPTH (IN)	MODULUS OF ELASTICITY
1	50.010	1.500	3.500	1.600E+06
2	74.048	1.500	3.500	1.800E+06
3	74.051	1.500	3.500	1.800E+06
4	3.180	1.500	3.500	1.800E+07
5	70.250	1.500	3.500	1.800E+06
6	70.250	1.500	3.500	1.800E+06
7	75.117	1.500	3.500	1.600E+06
8	26.600	1.500	3.500	1.600E+06

THE STRUCTURE HAS CONCENTRATED LOADS AS FOLLOWS

MEMBER NUMBER	LOAD NUMBER	HORIZ COMP (LBS)	VERT COMP (LBS)	HORIZ COORD (IN)	VERT COORD (IN)
6	1	0.0	-550.0	46.25	0.00

THE STRUCTURE HAS UNIFORM LOADS AS FOLLOWS

MEMBER NUMBER	HORIZ COMP (PLI)	VERT COMP (PLI)
2	0.000	-5.000
3	0.000	-5.000

THE STRUCTURE HAS POINT LOADS AS FOLLOWS

POINT NUMBER	DIRECTION OF LOAD	LOAD IN LBS OR IN-LBS AS APPROPRIATE
4	2	-128.8
4	3	-1657.7

The results follow the data in three sections; the first gives reactions, the second is devoted to strength analysis, and the third to deflections.

The first grouping gives the values of the reactions on the structure.

*** REACTIONS ***

REACTION POINT	HOR. COMP. (LBS)	VERT. COMP. (LBS)	MOMENT (IN-LBS)
1	893.493	1004.055	.000
2	-830.619	-.000	.000
5	-62.874	377.245	-.000

The next grouping lists the member end actions by members and ends using the sign convention established in figure 7. The end actions for member 3 are given in figure 14 to show this interpretation.

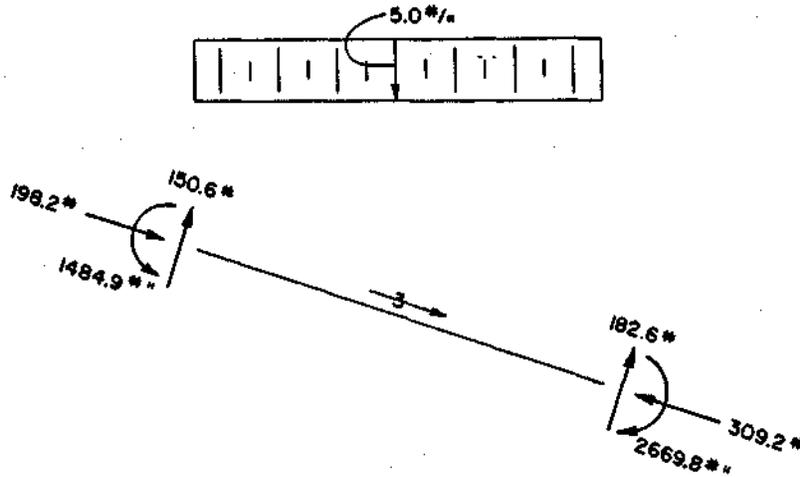


Figure 14.--Member 3 from the analog of the example frame is shown with its load and the end actions from the answer table. Directions on the end actions are determined from algebraic signs in the answer table interpreted according to positive directions shown in figure 7.

(M 139 729)

*** STRENGTH ANALYSIS ***

MEMBER NUMBER	LOCATION	MEMBER END ACTIONS		
		AXIAL (LBS)	SHEAR (LBS)	MOMENT (IN-LBS)
1	NEG END	416.683	-81.405	-2408.176
	POS END	-416.683	81.405	-1662.903
2	NEG END	-842.583	158.640	1662.903
	POS END	731.536	174.595	-2253.617
3	NEG END	198.151	150.609	1484.908
	POS END	-309.240	182.611	-2669.815
4	NEG END	399.841	235.613	-262.867
	POS END	-399.841	-235.613	1012.115
5	NEG END	-172.738	22.595	1324.451
	POS END	172.738	-22.595	262.867
6	NEG END	-319.792	158.588	2408.176
	POS END	319.792	391.412	-4467.359
7	NEG END	1210.303	0.000	0.000
	POS END	-1210.303	0.000	0.000
8	NEG END	-414.007	147.053	3142.908
	POS END	414.007	-147.053	768.708

Using the loads on the member and its end actions, an analysis of combined stress is made at each of NDIV equally spaced locations along nonfictitious members. The number NDIV is set at 25 in the program listing in the appendix (line A260 of the program) and may be increased or decreased according to the need for precision. At each location

$$\text{INTERACTION EQUATION} = \frac{F_b}{\sigma_b} + \frac{F_a}{\sigma_a}$$

is calculated and the greatest value of this equation and its location is reported in the following table for each member to which a complete list of allowable stresses have been assigned through the MEMBER DATA CARDS. The values of bending stress, F_b , and axial stress, F_a , are also listed in this table.

F_b = Bending stress in pounds per square inch calculated as moment divided by section modulus on the basis of a rectangular section of thickness T and depth H . A positive value of this stress is associated with tension on the bottom side of a member viewed in standard position.

σ_b = Normal duration allowable bending stress times the entry in the STRESS FACTOR CARD.

F_a = Axial stress in pounds per square inch calculated by dividing the axial force by the area $T \times H$ square inches. A positive value of this stress is associated with tension in the member.

σ_a = σ_T if $\frac{F_a}{A}$ is positive.
 = σ_c if $\frac{F_a}{A}$ is negative and $\sigma_c \leq \sigma'_c$
 = σ'_c if $\frac{F_a}{A}$ is negative and $\sigma'_c < \sigma_c$

σ_T = Normal duration allowable tensile stress times the entry in the STRESS FACTOR CARD.

σ_c = Normal duration allowable compression stress times the entry in the STRESS FACTOR CARD.

σ'_c = $0.3E/(\frac{L'}{d})^2$ times the entry in the STRESS FACTOR CARD where:
 E = modulus of elasticity of the analog member.

$\frac{L'}{d}$ = 0.8 x Analog Member Length/H for a laterally supported chord member.

= 0.8 x Analog Member Length/T for a laterally unsupported chord member.

= 0.9 x Analog Member Length/H for a laterally supported web member.

= 0.9 x Analog Member Length/T for a laterally unsupported web member.

The calculated values of $\frac{L'}{d}$ are reported to the nearest whole number in the right-hand column of the grouping below. A reminder message is printed if $\frac{L'}{d}$ exceeds 50 for a compression member or if $\frac{L'}{d}$ exceeds 80 for a tension member. The design considerations used in the construction of this grouping are guides only. Due to differences in various codes and specifications it may be necessary to make separate calculations of σ'_c when the value of the INTERACTION EQUATION is close to or exceeds 1. Fictitious members are omitted from the listing that appears in the output as follows,

INTERACTION ANALYSIS

MEM.	MEM. TYPE	MAX. VALUE INTER. EQN.	LOC. FROM NEG. END (IN)	MAX. STRESSES		L/D
				BENDING (PSI)	AXIAL (PSI)	
1	WU	.699	0.0	786.3	-79.4	30
2	CS	.493	74.0	-735.9	139.3	17
3	CS	.509	74.1	-871.8	-58.9	17
5	CU	.257	0.0	-432.5	32.9	37
6	CU	.879	45.0	1541.9	60.9	37
7	WU	.848	75.1	0.0	-230.5	45
8	WU	.820	0.0	-1026.3	78.9	16

The next grouping is a shear stress analysis of nonfictitious members reporting maximum values of shear stress on the rectangular T x H member section as determined by examination of the same locations along the member as for the interaction analysis. Member lengths are also listed in the right-hand column as a handy reference for this and the preceding listings.

SHEAR STRESS ANALYSIS

MEMBER	MAX. SHEAR STRESS (PSI)	LOC. FROM NEG. END (IN)	MEMBER LENGTH (IN)
1	-23.3	50.0	50.0
2	-49.9	74.0	74.0
3	-52.2	74.1	74.1
5	6.5	70.2	70.2
6	-111.8	70.2	70.2
7	0.0	75.1	75.1
8	42.0	26.6	26.6

The last section of the report, consisting of two more groupings, is concerned with deflections. The first lists the results of a deflection analysis at each of the NDIV locations as chosen previously. The greatest value of deflection in magnitude and its location are reported along with the member length. Positive deflections are upward when the member is viewed in standard position. Recognition of the shear modulus is not included in these calculations although it has been recognized in the main solution of the structure.

*** DEFLECTION ANALYSIS ***

MAXIMUM MEMBER DEFLECTIONS

MEMBER	MAX. DEFL. (IN)	LOC. FROM NEG. END (IN)	MEMBER LENGTH (IN)
1	-.020	14.0	50.0
2	-.058	38.5	74.0
3	-.049	29.6	74.1
5	-.028	0.0	70.2
6	-.155	39.3	70.2
7	.024	75.1	75.1
8	.012	10.6	26.6

In the three preceding groupings one maximum value is reported for each member and is the one closest to its positive end if the same maximum value occurs more than once, For instance, if shear stress is constant along the entire length of a member, the maximum will be reported as located at the positive end.

The last table gives displacements of the points to which members and reactions join. Shear deformation using $G = E/20$ has been included in the designated members in the determination of these values. The rotation values are printed in exponential form with an exponent for a 10 multiplier given to the right of the letter E. This is done to accommodate the wide scale range encountered in these numbers. The second column serves a double purpose: If the point has a roller attached, the displacement is given in the direction of the roller arrow rather than in the horizontal direction as in the case of an unrestrained point. For instance, the interpretation here is that point 2 moved down the wall 0.002 inch while point 5 moved up the 2/12 incline a distance of 0.004 inch.

POINT DISPLACEMENTS

POINT NUMBER	DISPL., IN DIR. OF ROLLER (IN)	HORIZ. OR OF ROLLER (IN)	DISPLACEMENT, VERTICAL. (IN)	DISPLACEMENT, ROTATIONAL ((RADIAN))
1	0.000	0.000	0.000	-3.259E-03
2	-.002	0.000	0.000	-1.086E-03
3	-.002	-.027	-.027	-3.334E-04
4	.005	.001	.001	-4.953E-04
5	.004	0.000	0.000	-5.163E-04
6	.002	-.028	-.028	3.349E-03

Data from the deflection groupings can be combined to indicate how the member moves in space and deforms under load. This has been done in the case of member 3 in figure 15 which shows the position of the member in space before and after loading. Many times the deflection at a particular location on a member in the structure must be known quite precisely. This information can be obtained directly by constructing the analog with a point at the location in question and the original member broken into two members rigidly fastened to the point. The desired displacements will then appear in the last grouping of the report opposite the specified point number.

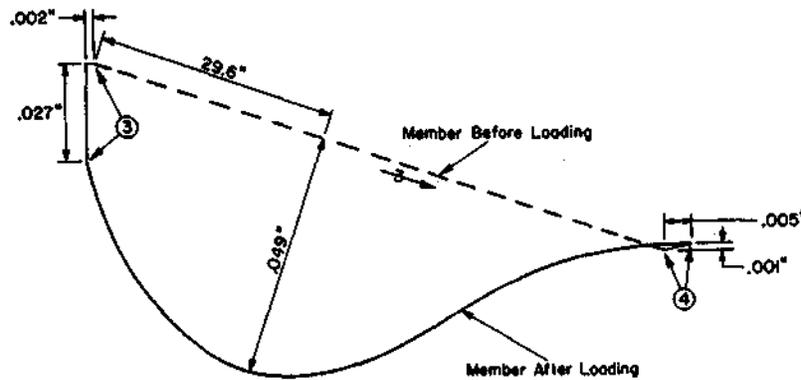


Figure 15.--Member 3 from the analog of the example frame is shown in the before and after loading position with deflections drawn to an exaggerated scale. The point displacement and maximum member deflection groupings provide the data for this sketch.

(M 139 744)

The analysis of the one example analog is now complete. If other analog data groups were stacked behind the first, subsequent reports in the same form as the example would appear in the order entered.

The designer will note that many useful facts can be derived from these groupings. For instance the lower chord, consisting of members 5 and 6, is nearly loaded to its limit according to the interaction analysis. The upper chord, on the other hand, does not need the quality of lumber supplied. With a few card changes, the data can be rerun to obtain new answers if desired. Of particular significance in this regard, the load cards are independent entities and it is a small matter to change these around from one run to another to examine as many load cases as the engineer deems necessary to insure the adequacy of the design.

SPECIAL TOPICS

FIRL Reaction

This reaction behaves like the ROLL reaction with the added restriction of being rigidly attached to the point. Figure 16 illustrates the comparative restraints of the two related types in a simple situation. The principal use of the FIRL is to reduce the problem size when the structure and loads are symmetrical except for minor reaction details.

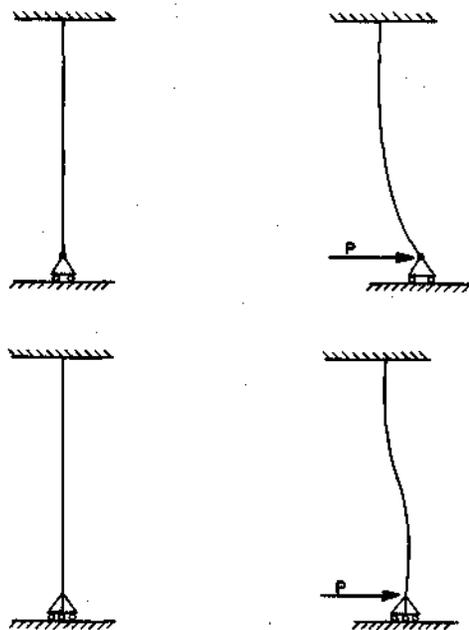


Figure 16.--The conventional ROLL reaction, as shown in the upper sketches, permits rotation of the point at the end of a member while also permitting displacement in the direction of the roller surface. The FIRL reaction, shown below, restrains the member end point but still permits displacement in the direction of the roller surface.

(M 139 743)

Figure 17 provides an example of application. The beam at the top is symmetrical about the vertical centerline and all vertical displacements in the left half are identical to those in the same relative position in the right half. Also, all horizontal displacements in

the structure are symmetrical relative to the vertical centerline even though they are asymmetrical with respect to the ground. The internal actions and displacements in half of this structure can be duplicated by using the analog containing a FIRL reaction as shown in the lower portion of figure 17. The problem size is reduced in terms of program preparation and computing time while complete information about the original structure can be obtained. The horizontal displacements in the second analog refer to point 2, which is the centerline in the original structure. Aside from this, all other necessary information can be read directly from the computer printout.

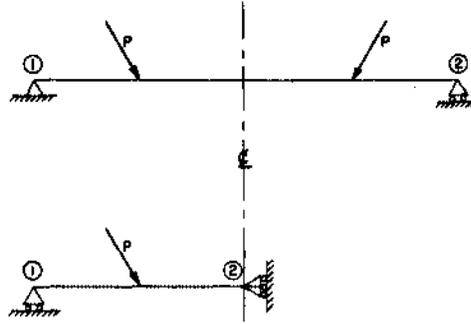


Figure 17.--The symmetrical structure and loading shown above can be duplicated, for analytical purposes, with the half structure below through the use of a FIRL reaction. Horizontal displacements in the lower sketch are, however, referenced to point 2 which lies on the line of symmetry.

(M 139 748)

The example just discussed has the main mission of illustrating the principle and does not accurately portray the possible magnitude of savings in time and effort. Figure 18 shows a more realistic application in which the problem size reduction is noteworthy. The symmetrical truss and loading shown in the upper portion requires 13 points, 4 point loads, and 23 members of which six carry uniform loads. By splitting the structure at the centerline and using two FIRL reactions at the cut, the problem now requires only 8 points, 2 point loads, and 12 members with three carrying uniform loads. The horizontal displacements must, of course, be corrected to relate the full to the half structure in this regard. The latter problem is of such minor magnitude, however, that significant advantage is realized by the use of the FIRL reactions in symmetrical structures.

Further Comment on Flexibility of Program Application

As has been mentioned previously, the scope of application of the system is actually infinite in terms of the configurations of structure and combinations of loading that can be devised. It is only feasible at this point, therefore, to use a pair of illustrations to stimulate a proper perspective in this regard. The only limit, other than computer capacity, is the user's imagination in creating models that simulate the real structure within the bounds of a pin-rigid analog with elastic, prismatic members.

An asymmetrical nonprismatic arched structure, such as might be constructed by lamination, is shown in figure 19 with a possible analog. It is established practice in structural engineering to approximate tapering members with a series of prismatic ones, a natural and easy procedure with the system described here. Once the decision as to the number of prismatic parts that should be used in the approximation is made, the assembly of the analog is a simple matter. The right-hand side of the structure requires deeper consideration, however, since the real member is curved as well as being tapered. Again, the matter

of degree of approximation is decided by the engineer and the actual member is simulated by a series of short, straight members of suitably varying section properties. The analog illustrated could be expanded or contracted in detail according to need. If many structures of this general type were to be designed, one of them could be analyzed several times with increasing numbers of parts in the analog to find that degree of complexity required to obtain satisfactory answers.

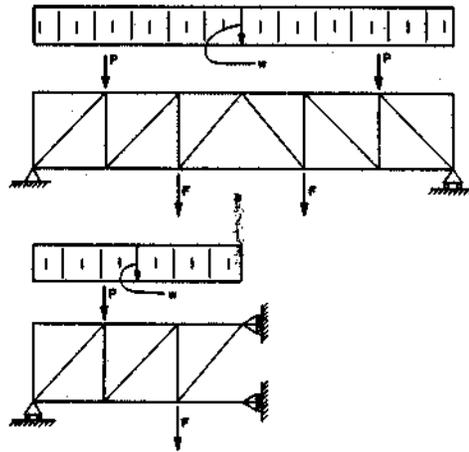


Figure 18.--A more complicated symmetrical structural situation is shown in which the use of a FIRC reaction can substantially reduce the tasks of preparing input and interpreting output from the program. The full structure is shown above with the reduced equivalent structure below.

(M 139 738)

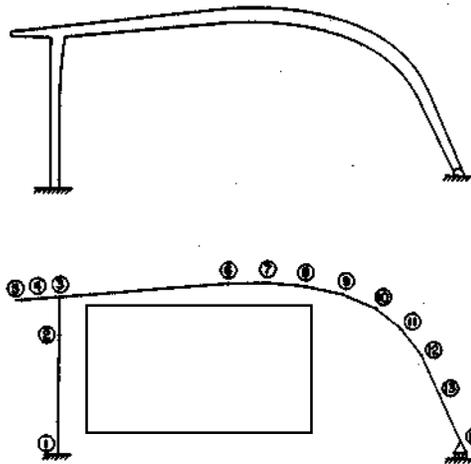


Figure 19.--Curved and tapered frames can be approximated with prismatic segments as illustrated in the analog below the structure. The number of approximating segments can be increased or decreased according to accuracy requirements.

(M 139 739)

An asymmetrical truss bolted to a single pole rigidly implanted in the ground is shown in figure 20. An accurate analysis of this structure by traditional methods is a difficult and costly process. The computer system, on the other hand, can treat this structure with whatever degree of precision is built into the analog. One possible analog is shown in the lower portion of figure 20 with special details. The tapered pole is simulated by a series of four prismatic members of rectangular section, having section properties related to average properties at comparable portions of the pole class used. The analog length

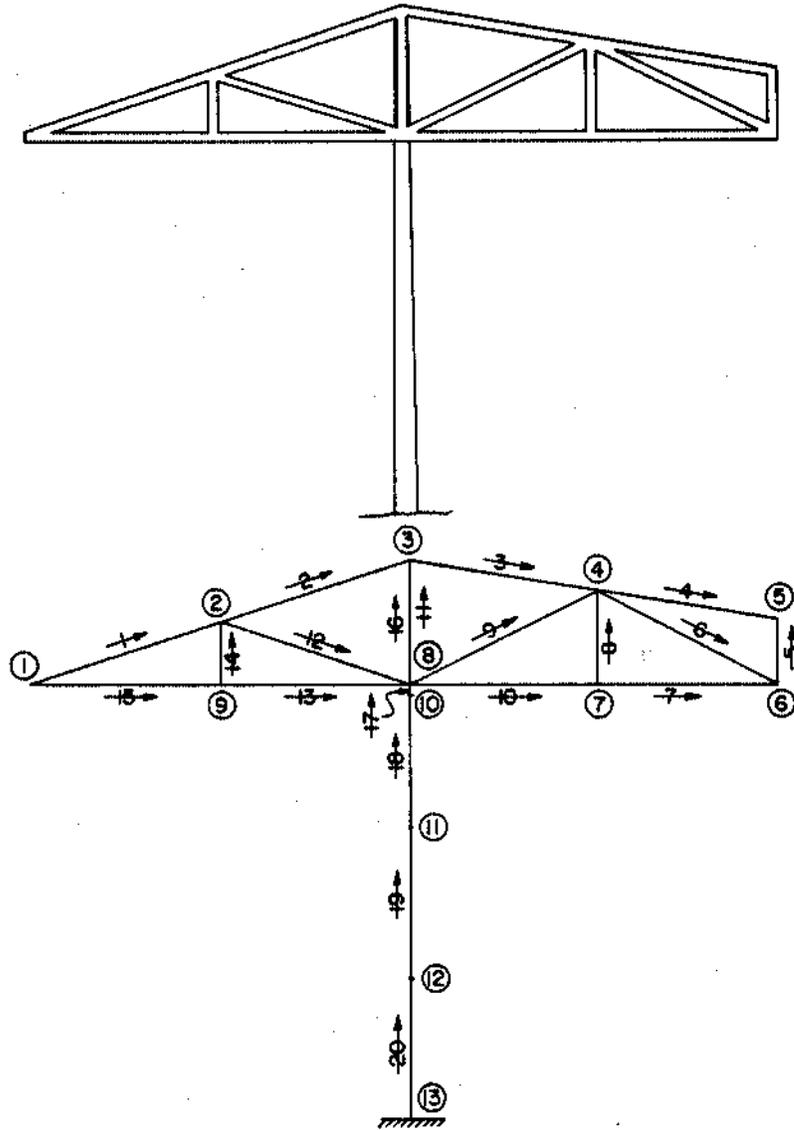


Figure 20.--A truss with all joints sufficiently restrained to be presumed rigid is fastened to a pole with suitable timber connectors at the upper and lower chord. These connectors are presumed to act as pins. The analog drawn below shows member 11, representing the truss post, superimposed over member 16 representing the pole. Member 11 fastens to points 3 and 8 while member 16 extends from point 3 to point 10. Further detail in this regard is shown in the succeeding figure.

(M 139 736)

of the pole can be extended below the groundline to its fixed reaction to compensate for imperfect fixation near the surface of the earth. The analog detail in the area where the pole and the central vertical web member of the truss are superimposed is shown in figure 21. Points 3 and 8 are both junctions for rigid connection of truss members as shown in the upper sketch of the latter figure. The pole, shown in a sketch at right, is pinned to point 3 and should be pinned to point 8 but continuous in passing through this point. To accomplish this within the rules of the analytical system, point 10 is created a short distance, say 2 inches, below 8 and the pole is made up of analog members that join rigidly at 10 only. A short fictitious member is then rigidly connected to 10 and extended to 8 where it is pinned. This superimposed arrangement of members is acceptable to the computer system and reasonably simulates the mechanical behavior of the truss-pole assembly.

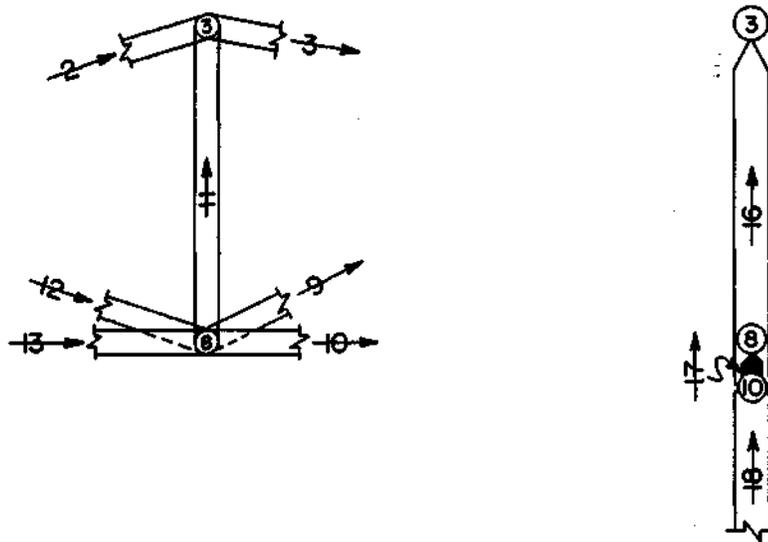


Figure 21.--The central region of the truss analog, shown with exaggerated points and lines at left, has all members rigidly attached to points 3 and 8. Member 16, representing the pole lying behind the center post of the truss and shown at right, is pinned to point 3 but passes by 8 and is rigidly connected to 10 a short distance beyond. The pole immediately below the truss is represented by member 18 which is also rigidly attached to point 10. The pin-type timber connection between the pole and the lower chord panel of the truss is simulated by the short member 17 rigidly attached to point 10 and pinned to point 8.

(M 139 735)

The length of the short fictitious member in the previous example raises a question of importance to the program user. Frequently, as in this case, shortening a fictitious member increases the duplication of reality until a limit of zero is reached. In the matrix solution used an inversion process is performed which makes the range of member lengths from longest to shortest a potentially critical matter and the inversion cannot be completed within a reasonable time limit. In such a case, the computer keeps trying but cannot determine final answers for the structure. An increase in the length of the short fictitious member or variation of some other parameter to decrease its stiffness will correct the difficulty. Short members in the order of one-half inch have been successfully run with long members of over 100 inches having the same cross section, and ratios of modulus of elasticity of 1 to 100 have been run successfully with this program.

Altering Program to Accommodate
Different Problem Sizes

This program, like all others, requires storage in the central memory of the machine. This storage requirement, in part, depends on the maximum size of problem expected. DIMENSION and COMMON statements in the program lay aside storage sufficient to handle a maximum-size problem each time the program is run. Variation in computer sizes, costs, and normal problem sizes are possible reasons for change in this capacity either upward or downward.

The program is currently set up for N = 18 points, R = 16 possible reaction points, M = 23 members, G = 10 member data groups, P = 51 point displacements, and L = 26 locations for strength and deflection analysis per member. In the case of point displacements, one horizontal, one vertical, and one rotational displacement occur at each point if not restrained by a reaction. Thus, in general, $P = 3N - 3$.

Capacity change requires alterations in the DIMENSION and COMMON cards found at the beginning of the main program and at the beginning of each of the five subroutines. Each FORTRAN name that must be altered is given in the following list with the appropriate letter symbol in the place of the number found in the actual program. To change capacity, replace the number now in the program with the desired new one. For example, to allow for 20 points, go through the list and change the present N = 18 to N = 20. Remember also that the addition of two points introduces six more possibilities for point displacement so that it is wise to change P from 51 to 57 everywhere also. Further, with the expanded point capacity, it is advisable to check the number of members that can be processed also. If the number of analysis stations, L, is changed, the statement NDIV = 25 found early in the main program must also be changed accordingly ($L = NDIV + 1$).

Main Program - DIMENSION Changes

AA (M, 3)	P (M, 6)	SIGT (M)	AT (G)	FX (L)
AL (M)	PF (M, 6)	SIGTA (M)	AH (G)	X (L)
ALA (M)	PO (M, 6)	T (M)	AE (G)	XD (L)
E (M)	Q (M, 3, 2)	XQ (M, 3, 2)	ASIGM (G)	Y (L)
EA (M)	QMA (M, E, 2)	W (M, 2)	ASIGT (G)	HR (R)
EKS (M)	SIGC (M)	WMA (M, 2)	ASIGC (G)	NRE (R)
EI (M)	SIGCA (M)	TAU (M)	MYTYPE1 (G)	RT (R)
H (M)	SIGM (M)	MTYPE (M)		VR (R)
MEM (M)	SIGMA (M)	FO (P)		

Main Program - COMMON Changes

K (P, P)	FF (P)	C3 (M)	AFF (N, 3)	D (M, N)
BETA (6, P)	U (P)	C6 (M)	C (N, 3, 3)	XM (N, 2)
	F (P)			

Subroutine REDUCE - DIMENSION Change

MHOLD (P)

Subroutine REDUCE - COMMON Change

K (P, P)

Subroutine SYMSOL - DIMENSION Change

FO (P)

Subroutine SYMSOL - COMMON Changes

A (P,P)	FF (P)	F(P)	C6(M)	C (N,3,3)	D(M,N)
BETA(6, P)	U(P)	C3 (M)	AFF (N,3)	XM(N, 2)	

Subroutine MEMTRAN - DIMENSION Change

AL (M)

Subroutine MEMTRAN - COMMON Changes

C3(M)	D(M,N)	XM(N,2)	BETA(6,P)	U(P)
C6(M)	C (N,3,3)	AFF (N,3)	FF(P)	F (P)

Subroutine TRNSLT - COMMON Changes

C3(M)	D(M,N)	C(N, 3, 3)	BETA(6,P)	U(P)
C6(M)	AFF (N,3)	XM (N,2)	FF(P)	F (P)

Subroutine CALKAP - DIMENSION Changes

AL (M)	EA(M)	H(M)
E (M)	EI (M)	T (M)

Subroutine CALKAP - COMMON Changes

C3(M)	D(M,N)	XM (N,2)	FF (P)	AFF (N,3)
C6(M)	C (N,3,3)	BETA (6,P)	U (P)	F (P)

Adaptation of the Program to a Particular Computer

The program was developed using the CDC 6500 system at Purdue University and may require adjustment to run on other computers. These adjustments, when required, should be readily apparent to a programmer and should not require changes in fundamental structure of the program. As the program now stands, division by zero can occur but the result is not used. Proper measures should be taken in systems that are set up to stop processing as the result of such an occurrence.

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1967. The finite element method in structural and continuum mechanics. McGraw-Hill, New York.

APPENDIX: LISTING OF FORTRAN PROGRAM

	PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)	A	20
C		A	30
C	MASTRUC 15/1	A	40
C	REAL M,K,KAPPA,IDENT	A	50
	DIMENSION AA(23,3), AL(23), ALA(23), E(23), EA(23), EKS(23), EI(23,	A	60
	1), H(23), MEM(23), P(23,6), PF(23,6), PO(23,6), Q(23,3,2), QMA(23,	A	70
	23,2), SIGC(23), SIGCA(23), SIGM(23), SIGMA(23), SIGT(23), SIGTA(23,	A	80
	3), T(23), TAU(23), XQ(23,3,2), W(23,2), WMA(23,2), MTYPE(23)	A	90
	DIMENSION FO(51)	A	100
	DIMENSION FX(26), X(26), XD(26), Y(26)	A	110
	DIMENSION HR(16), NRE(16), RT(16), VR(16)	A	120
	DIMENSION AE(10), AH(10), ASIGC(10), ASIGM(10), ASIGT(10), AT(10),	A	130
	I MTYPE1(10)	A	140
	DIMENSION A(3), B(3), IDENT(17), POQ(6), POW(6), QM(3,2),	A	150
	IWM(2)	A	160
	COMMON /B1/ K(51,51)	A	170
	COMMON BETA(6,51),FF(51),U(51),F(51)	A	180
	COMMON C3(23),C6(23)	A	190
	COMMON AFF(18,3),C(18,3,3),XM(18,2)	A	200
	COMMON D(23,18)	A	210
	COMMON KAPPA(6,6),RM(3,3)	A	220
	DATA PIN,FIX,PINNED,RIGID/4H PIN,4H FIX,6HPINNED,5HRIGID/	A	230
	DATA CS,CU,WS,WU/2HCS,2HCU,2HWS,2HWU/	A	240
	DATA FIRL,ENDD,CALC/4HFIRL,4HENDD,4HCALC/	A	250
	NDIV=25	A	260
	DIV=NDIV	A	270
	101 READ (5,102) IDENT,NP,NM,NR,NPIN,NF	A	280
	102 FORMAT (17A4/5I2)	A	290
	IF (IDENT(1),EQ,ENDD,AND,IDENT(2),EQ,CALC) STOP	A	300
	NC=NP*3-NR-NPIN*2-NF*3	A	310
	DO 108 I=1,NM	A	320
	SIGC(I)=0.0	A	330
	SIGCA(I)=0.0	A	340
	SIGM(I)=0.0	A	350
	SIGMA(I)=0.0	A	360
	SIGT(I)=0.0	A	370
	SIGTA(I)=0.0	A	380
	DO 103 JJ=1,3	A	390
	DO 103 KK=1,3	A	400
	RM(JJ,KK)=0.0	A	410
	103 CONTINUE	A	420
	DO 104 KAY=1,NP	A	430
	104 D(I,KAY)=0.0	A	440
	DO 106 J=1,3	A	450
	DO 105 I=1,2	A	460
	105 Q(I,J,L)=0.0	A	470
	XQ(I,J,1)=0.0	A	480
	106 XQ(I,J,2)=0.0	A	490
	DO 107 J=1,2	A	500
	107 W(I,J)=0.0	A	510
	DO 108 J=1,6	A	520
	108 P(I,J)=0.0	A	530
	DO 109 I=1,NC	A	540
	FF(L)=0.0	A	550
	FO(L)=0.0	A	560
	U(L)=0.0	A	570
	DO 109 LP=1,NC	A	580

109	K(L,LP)=0.0	A	590
	DO 110 I=1,NP	A	600
	XM(I,1)=0.0	A	610
	XM(I,2)=0.0	A	620
	DO 110 JJ=1,3	A	630
	AFF(I,JJ)=0.0	A	640
	DO 110 KK=1,3	A	650
	C(I,JJ,KK)=0.0	A	660
110	CONTINUE	A	670
	KOUNT=0	A	680
	NO=0	A	690
	KOUNT2=0	A	700
C		A	710
C	WRITE INITIAL INPUT AND MEMBER GROUP HEADINGS.	A	720
C		A	730
	WRITE (6,111) IDENT,NP,NM	A	740
111	FORMAT (1H1,17A4/, 45H=====	A	750
	1., 26H=====,///1X, 19HNUMBER OF POINTS = ,13/	A	760
	2/1X, 20HNUMBER OF MEMBERS = ,13/)	A	770
	WRITE (6,112) NR,NPIN,NF	A	780
112	FORMAT (1X, 28HNUMBER OF ROLLER SUPPORTS = ,12,///1X, 9HNUMBER OF,	A	790
	1 27H PINNED OR FIRC SUPPORTS = ,12,///1X, 25HNUMBER OF FIXED SUPPORT	A	800
	2S , 2H= ,12/)	A	810
	WRITE (6,113)	A	820
113	FORMAT (///, 50H ALLOWABLE MEMBER STRESSES IN PSI, NORMAL LOAD DUR	A	830
	1, 5HATION,///1X, 4HMEM.,5X, 3HUSE,9X, 9HALLOWABLE,29X, 10HMODUL	A	840
	2US OF,///1X, 5HGROUP,4X, 4HTYPE,4X, 4HBEND,3X, 4HCOMP,3X, 4HTEN	A	850
	3S,5X, 5HWIDTH,5X, 5HDEPTH,4X, 10HELASTICITY,/))	A	860
C		A	870
C	READ AND WRITE MEMBER GROUP INFORMATION AND LOAD FACTOR.	A	880
C		A	890
114	READ (5,115) MG,AT(MG),AH(MG),AE(MG),ASIGM(MG),ASIGC(MG),ASIGT(MG)	A	900
	1,MTYPE1(MG),NOM	A	910
115	FORMAT (I2,2F5.0,E6.0,3F4.0,2I1)	A	920
	IF (MTYPE1(MG).EQ.0) TYPE1=CS	A	930
	IF (MTYPE1(MG).EQ.1) TYPE1=CU	A	940
	IF (MTYPE1(MG).EQ.2) TYPE1=WS	A	950
	IF (MTYPE1(MG).EQ.3) TYPE1=WU	A	960
	WRITE (6,116) MG,TYPE1,ASIGM(MG),ASIGC(MG),ASIGT(MG),AT(MG),AH(MG)	A	970
	1,AE(MG)	A	980
116	FORMAT (2X,I2,7X,A2,5X,F4.0,3X,F4.0,3X,F4.0,4X,F6.3,4X,F6.3,4X,E9.	A	990
	13)	A	1000
	IF (NOM.EQ.0) GO TO 114	A	1010
	READ (5,117) FACTOR	A	1020
117	FORMAT (F4.0)	A	1030
	WRITE (6,118) FACTOR	A	1040
118	FORMAT (///, 28H THE LOAD DURATION FACTOR IS,F5.2)	A	1050
	JN=0	A	1060
C		A	1070
C	LOAD D MATRIX	A	1080
C	I,J SUBSCRIPTS ARE FOR NEGATIVE MEMBER END.	A	1090
C	I,JJ SUBSCRIPTS ARE FOR POSITIVE MEMBER END.	A	1100
C		A	1110
	KOUNT=0	A	1120
C		A	1130
C	READ AND WRITE POINT COORDINATES AND MEMBER LAYOUT.	A	1140
C		A	1150
119	READ (5,120) I,XM(I,1),XM(I,2),LAST	A	1160
120	FORMAT (I2,2F7.0,I1)	A	1170
	KOUNT=KOUNT+1	A	1180
	IF (LAST.EQ.0) GO TO 119	A	1190
	IF (KOUNT.LT.NP.OR.KOUNT.GT.NP) WRITE (6,121)	A	1200

121	FORMAT (1H0, 46HERROR IN DATA DECK. NUMBER OF POINTS DOES NOT , 32	A 1210
	1HAGREE WITH THE NUMBER SPECIFIED.)	A 1220
	WRITE (6,122) (1,XM(1,1),XM(1,2),I=1,NP)	A 1230
122	FORMAT (///1X, 17HPPOINT COORDINATES,///, 28H POINT X-COORD Y-	A 1240
	1COORD,/, 28H NO. (1N) (1N) ,//(2X,I3,F12.3,F11.3))	A 1250
	WRITE (6,123)	A 1260
123	FORMAT (///1X, 13HMEMBER LAYOUT,///, 7H MEMBER,8X, 12HNEGATIVE END	A 1270
	1,11X, 12HPOSITIVE END,8X, 6HMEMBER,/, 7H NUMBER,5X, 18HPPOINT	A 1280
	2CONDITION,5X, 18HPPOINT CONDITION,6X, 5HGROUP,/))	A 1290
	KOUNT=0	A 1300
124	READ (5,125) I,J,JJ,MGR,C3(1),C6(1),LAST	A 1310
125	FORMAT (4I2,2F1.0,11)	A 1320
	D(1,J)=-1.0	A 1330
	D(1,JJ)=1.0	A 1340
	T(1)=AT(MGR)	A 1350
	H(1)=AH(MGR)	A 1360
	F(1)=AE(MGR)	A 1370
	MTYPE(1)=MTYPE1(MGR)	A 1380
	SIGM(1)=FACTOR*ASIGM(MGR)	A 1390
	SIGC(1)=FACTOR*ASIGC(MGR)	A 1400
	SIGT(1)=FACTOR*ASIGT(MGR)	A 1410
	IF (C3(1).EQ.1.0) SEE3=PINNED	A 1420
	IF (C6(1).EQ.1.0) SEE6=PINNED	A 1430
	IF (C3(1).EQ.0.0) SEE3=RIGID	A 1440
	IF (C6(1).EQ.0.0) SEE6=RIGID	A 1450
	WRITE (6,126) I,J,SEE3,JJ,SEE6,MGR	A 1460
126	FORMAT (3X,I2,8X,I2,8X,A6,7X,I2,8X,A6,9X,I2)	A 1470
	IF (LAST.NE.0) GO TO 127	A 1480
	KOUNT=KOUNT+1	A 1490
	GO TO 124	A 1500
127	IF (KOUNT.LT.NM-1.OR.KOUNT.GE.NM) WRITE (6,128)	A 1510
128	FORMAT (1H0, 47HERROR IN DATA DECK. NUMBER OF MEMBERS DOES NOT , 3	A 1520
	12HAGREE WITH THE NUMBER SPECIFIED.)	A 1530
C		A 1540
C	READ AND WRITE REACTION POINT CONDITIONS.	A 1550
C		A 1560
	DO 129 I=1,NM	A 1570
	EA(I)=E(I)*T(I)*H(I)	A 1580
129	EI(I)=EA(I)*H(I)**2/12.0	A 1590
	DO 130 I=1,NP	A 1600
	DO 130 J=1,3	A 1610
130	C(I,J,J)=1.0	A 1620
	WRITE (6,131)	A 1630
131	FORMAT (///, 20H REACTION CONDITIONS,///, 28H POINT REACTION	A 1640
	1 HORIZ. 8H VERT,/, 37H NUMBER TYPE DISPL DISPL./)	A 1650
	IK=0	A 1660
	KOUNT=0	A 1670
132	READ (5,133) NREACT,REACT,HOR,VERT,LAST	A 1680
133	FORMAT (1P,A4,2F5.0,11)	A 1690
	WRITE (6,134) NREACT,REACT,HOR,VERT	A 1700
134	FORMAT (2X,I3,7X,A4,F11.2,F9.2)	A 1710
	IK=IK+1	A 1720
	NRE(IK)=NREACT	A 1730
	IF (REACT.EQ.PIN) GO TO 135	A 1740
	IF (REACT.EQ.FIX) GO TO 136	A 1750
	C(NREACT,2,2)=0.0	A 1760
	C(NREACT,1,1)=HOR/SQRT(HOR**2+VERT**2)	A 1770
	C(NREACT,2,1)=VERT/SQRT(HOR**2+VERT**2)	A 1780
	IF (REACT.EQ.FIRL) GO TO 137	A 1790
	C(NREACT,3,2)=1.0	A 1800
	GO TO 137	A 1810
135	C(NREACT,1,1)=0.0	A 1820

	C(NREACT,2,2)=0.0	A 1830
	C(NREACT,3,1)=1.0	A 1840
	GO TO 137	A 1850
136	C(NREACT,1,1)=0.0	A 1860
	C(NREACT,2,2)=0.0	A 1870
	C(NREACT,3,3)=0.0	A 1880
137	KOUNT=KOUNT+1	A 1890
	IF (LAST.EQ.0) GO TO 132	A 1900
	IF (KOUNT.LT.NR+NPIN+NF.OR.KOUNT.GT.NR+NPIN+NF) WRITE (6,138)	A 1910
138	FORMAT (1H0, 49HERROR IN DATA DECK. NUMBER OF REACTIONS DOES NOT ,	A 1920
	1 32HAGREE WITH THE NUMBER SPECIFIED.)	A 1930
C		A 1940
C	READ IN LOADS.	A 1950
C		A 1960
	READ (5,139) ICON,IUN,ISYST	A 1970
139	FORMAT (3I1)	A 1980
	IF (ICON.EQ.0) GO TO 142	A 1990
140	READ (5,141) I,J,Q(I,J,1),Q(I,J,2),XQ(I,J,1),XQ(I,J,2),NEXT	A 2000
141	FORMAT (I2,I1,2F6.0,2F7.0,I1)	A 2010
	IF (NEXT.EQ.0) GO TO 140	A 2020
142	IF (IUN.EQ.0) GO TO 145	A 2030
143	READ (5,144) I,W(I,1),W(I,2),NIX	A 2040
144	FORMAT (I2,2F5.0,I1)	A 2050
	IF (NIX.EQ.0) GO TO 143	A 2060
145	IF (ISYST.EQ.0) GO TO 148	A 2070
146	READ (5,147) I,J,AFF(I,J),NON	A 2080
147	FORMAT (I2,I1,F8.0,I1)	A 2090
	IF (NON.EQ.0) GO TO 146	A 2100
	IKON=1	A 2110
	CALL TRNSLT (I,NP,IKON,JA)	A 2120
148	CONTINUE	A 2130
C		A 2140
C		A 2150
C	START OF MEMBER LOOP.	A 2160
C		A 2170
C		A 2180
	DO 161 I=1,NM	A 2190
	DO 149 J=1,6	A 2200
	POW(J)=0.0	A 2210
149	POQ(J)=0.0	A 2220
	WM(1)=0.0	A 2230
	WM(2)=0.0	A 2240
	CALL MEMTRAN (I,NP,AL)	A 2250
	AL1=AL(I)	A 2260
	AL2=AL1*AL1	A 2270
	AL3=AL2*AL1	A 2280
	DO 150 J=1,6	A 2290
	DO 150 L=1,6	A 2300
150	KAPPA(J,L)=0.0	A 2310
	IF (SIGM(I).EQ.0.0) G=1000.0*E(I)	A 2320
	IF (SIGM(I).NE.0.0) G=E(I)/20.0	A 2330
	CALL CALKAP (EA,E1,E,T,H,AL,I,G)	A 2340
	IKON=0	A 2350
	CALL TRNSLT (I,NP,IKON,JA)	A 2360
C		A 2370
C	CALCULATE STRUCTURE STIFFNESS MATRIX.	A 2380
C		A 2390
	DO 151 J=1,JA	A 2400
	DO 151 L=1,6	A 2410
	DO 151 JC=1,JA	A 2420
	DO 151 LC=1,6	A 2430
151	K(J,JC)=K(J,JC)+BETA(L,J)*KAPPA(L,LC)*BETA(LC,JC)	A 2440

C		A 2450
C	CHECK FOR CONCENTRATED LOADS. IF NONE, SKIP TO UNIFORM LOADS.	A 2460
C		A 2470
	DO 155 JD=1,3	A 2480
	DO 155 KAY=1,2	A 2490
	QM(JD,KAY)=0.0	A 2500
	IF (Q(I,JD,KAY).EQ.0.0) GO TO 155	A 2510
	DO 152 J=1,NP	A 2520
	IF (D(I,J).EQ.-1.) GO TO 153	A 2530
152	CONTINUE	A 2540
153	A(JD)=SQRT((XQ(I,JD,1)-XM(J,1))**2+(XQ(I,JD,2)-XM(J,2))**2)	A 2550
	B(JD)=AL1-A(JD)	A 2560
	DO 154 J=1,2	A 2570
	DO 154 L=1,2	A 2580
154	QM(JD,J)=QM(JD,J)+RM(J,L)*Q(I,JD,L)	A 2590
	POQ(1)=POQ(1)-QM(JD,1)*B(JD)/AL1	A 2600
	POQ(2)=POQ(2)-QM(JD,2)*B(JD)**2*(3.0*A(JD)+B(JD))/AL3+C3(I)*	A 2610
1	1.5*QM(JD,2)*A(JD)*B(JD)**2/AL3-C6(I)*1.5*QM(JD,2)*B(JD)*A(J	A 2620
2	D)**2/AL3+C3(I)*C6(I)*0.5*QM(JD,2)*B(JD)*(5.0*A(JD)**2+7.0*A	A 2630
3	(JD)*B(JD)+4.0*B(JD)**2)/AL3	A 2640
	POQ(3)=POQ(3)-QM(JD,2)*A(JD)*B(JD)**2/AL2+C3(I)*QM(JD,2)*A(J	A 2650
1	D)*B(JD)**2/AL2-C6(I)*0.5*QM(JD,2)*B(JD)*A(JD)**2/AL2+C3(I)*	A 2660
2	C6(I)*0.5*QM(JD,2)*B(JD)*A(JD)**2/AL2	A 2670
	POQ(4)=POQ(4)-QM(JD,1)*A(JD)/AL1	A 2680
	POQ(5)=POQ(5)-QM(JD,2)*A(JD)**2*(3.0*B(JD)+A(JD))/AL3-C3(I)*	A 2690
1	1.5*QM(JD,2)*A(JD)*B(JD)**2/AL3+C6(I)*1.5*QM(JD,2)*B(JD)*A(J	A 2700
2	D)**2/AL3+C3(I)*C6(I)*0.5*QM(JD,2)*A(JD)*(4.0*A(JD)**2+7.0*A	A 2710
3	(JD)*B(JD)+5.0*B(JD)**2)/AL3	A 2720
	POQ(6)=POQ(6)+QM(JD,2)*B(JD)*A(JD)**2/AL2+C3(I)*0.5*QM(JD,2)	A 2730
1	*A(JD)*B(JD)**2/AL2-C6(I)*QM(JD,2)*B(JD)*A(JD)**2/AL2-C3(I)*	A 2740
2	C6(I)*0.5*QM(JD,2)*A(JD)*B(JD)**2/AL2	A 2750
155	CONTINUE	A 2760
C		A 2770
C	CHECK FOR UNIFORM LOADS ON MEMBER (I)	A 2780
C		A 2790
	IF (W(I,1).EQ.0.0.AND.W(I,2).EQ.0.0) GO TO 156	A 2800
	WM(1)=W(I,2)*RM(1,2)*ABS(RM(1,1))+W(I,1)*RM(1,1)*ABS(RM(1,2))	A 2810
	WM(2)=W(I,2)*RM(1,1)*ABS(RM(1,1))-W(I,1)*RM(1,2)*ABS(RM(1,2))	A 2820
	GO TO 157	A 2830
156	WM(1)=0.0	A 2840
	WM(2)=0.0	A 2850
157	CONTINUE	A 2860
	POW(1)=-WM(1)*AL1*0.5	A 2870
	POW(2)=-WM(2)*AL1*0.5+C3(I)*WM(2)*AL1/8.0-C6(I)*WM(2)*AL1/8.0	A 2880
	POW(3)=-WM(2)*AL2/12.0+C3(I)*WM(2)*AL2/12.0-C6(I)*WM(2)*AL2/24.0	A 2890
1	0+C3(I)*C6(I)*WM(2)*AL2/24.0	A 2900
	POW(4)=POW(1)	A 2910
	POW(5)=-WM(2)*AL1*0.5-C3(I)*WM(2)*AL1/8.0+C6(I)*WM(2)*AL1/8.0	A 2920
	POW(6)=WM(2)*AL2/12.0-C6(I)*WM(2)*AL2/12.0+C3(I)*WM(2)*AL2/24.0	A 2930
1	-C3(I)*C6(I)*WM(2)*AL2/24.0	A 2940
	DO 158 L=1,6	A 2950
158	PO(I,L)=POW(L)+POQ(L)	A 2960
	DO 159 J=1,NC	A 2970
	DO 159 L=1,6	A 2980
159	FO(J)=FO(J)+BETA(L,J)*PO(I,L)	A 2990
	IF (SIGC(I).EQ.0.0) GO TO 161	A 3000
	JN=JN+1	A 3010
	DO 160 JE=1,3	A 3020
	AA(JN,JE)=A(JE)	A 3030
	QMA(JN,JE,1)=QM(JE,1)	A 3040
160	QMA(JN,JE,2)=QM(JE,2)	A 3050
	WMA(JN,1)=WM(1)	A 3060

WMA(JN,2)=WM(2)	A 3070
SIGMA(JN)=SIGM(1)	A 3080
SIGCA(JN)=SIGC(1)	A 3090
SIGTA(JN)=SIGT(1)	A 3100
ALA(JN)=AL(1)	A 3110
MEM(JN)=1	A 3120
161 CONTINUE	A 3130
C	A 3140
C	A 3150
C END OF MEMBER LOOP.	A 3160
C	A 3170
C	A 3180
C WRITE MEMBER PROPERTIES AND LOADS.	A 3190
C	A 3200
WRITE (6,162) (I,AL(I),T(I),H(I),E(I),I=1,NM)	A 3210
162 FORMAT (///1X, 17HMEMBER PROPERTIES,/, 9H MEMBER,7X, 6HLENGTH	A 3220
1,7X, 5HWIDTH,7X, 5HDEPTH,4X, 10HMODULUS OF,/, 9H NUMBER,7X,	A 3230
26H (IN),7X, 6H (IN),6X, 19H (IN) ELASTICITY,/(5X,12,7X,F8.3	A 3240
3,F12.3,F12.3,E13.3))	A 3250
IF (ICON.EQ.0) GO TO 166	A 3260
WRITE (6,163)	A 3270
163 FORMAT (///, 48H THE STRUCTURE HAS CONCENTRATED LOADS AS FOLLOWS,/,	A 3280
17, 16H MEMBER LOAD,6X, 30HHORIZ VERT HORIZ VERT,/, 53	A 3290
2H NUMBER NUMBER COMP COMP COORD,22X, 9H(L	A 3300
3BS) , 5H(LBS),3X, 15H (IN) (IN) ,/)	A 3310
DO 165 I=1,NM	A 3320
DO 165 J=1,3	A 3330
IF (Q(I,J,1).EQ.0.0.AND.Q(I,J,2).EQ.0.0) GO TO 165	A 3340
WRITE (6,164) I,J,Q(I,J,1),Q(I,J,2),XQ(I,J,1),XQ(I,J,2)	A 3350
164 FORMAT (3X,13,7X,13,F11.1,F9.1,F9.2,F8.2)	A 3360
165 CONTINUE	A 3370
166 CONTINUE	A 3380
IF (IUN.EQ.0) GO TO 170	A 3390
WRITE (6,167)	A 3400
167 FORMAT (///, 43H THE STRUCTURE HAS UNIFORM LOADS AS FOLLOWS,/, 5	A 3410
1H MEM, 24HBER HORIZ VERT,/, 29H NUMBER COMP	A 3420
2 COMP,13X, 17H(PLI) (PLI),/)	A 3430
DO 169 I=1,NM	A 3440
IF (W(I,1).EQ.0.0.AND.W(I,2).EQ.0.0) GO TO 169	A 3450
WRITE (6,168) I,W(I,1),W(I,2)	A 3460
168 FORMAT (3X,13,F12.3,F12.3)	A 3470
169 CONTINUE	A 3480
170 CONTINUE	A 3490
IF (ISYST.EQ.0) GO TO 174	A 3500
WRITE (6,171)	A 3510
171 FORMAT (///, 41H THE STRUCTURE HAS POINT LOADS AS FOLLOWS,/, 6H	A 3520
1POINT,5X, 9HDIRECTION,5X, 21HLOAD IN LBS OR IN-LBS,/, 7H NUMBER,	A 3530
25X, 9HOP LOAD ,7X, 14HAS APPROPRIATE,/))	A 3540
DO 173 I=1,NP	A 3550
DO 173 J=1,3	A 3560
IF (AFF(I,J).EQ.0.0) GO TO 173	A 3570
WRITE (6,172) I,J,AFF(I,J)	A 3580
172 FORMAT (3X,12,10X,11,16X,F8.1)	A 3590
173 CONTINUE	A 3600
174 CONTINUE	A 3610
DO 175 J=1,NC	A 3620
175 F(J)=FF(J)-F0(J)	A 3630
C	A 3640
C INVERT STIFFNESS MATRIX AND CALCULATE POINT DISPLACEMENTS.	A 3650
C	A 3660
CALL REDUCE (NC,MBW)	A 3670
CALL SYMSOL (NC,MBW)	A 3680

DO 178 I=1,NM	A 3690
CALL MEMTRAN (I,NP,AL)	A 3700
IF (SIGM(I).EQ.0.0) G=1000.0*E(I)	A 3710
IF (SIGM(I).NE.0.0) G=F(I)/20.0	A 3720
CALL CALKAP (EA,EI,E.T.H.AL,I,G)	A 3730
IKON=0	A 3740
CALL TRNSLT (I,NP,[KON,JA)	A 3750
DO 177 J=1,6	A 3760
DO 177 L=1,NC	A 3770
SUM=0.0	A 3780
DO 176 KA=1,6	A 3790
176 SUM=SUM+KAPPA(J,KA)*BETA(KA,L)	A 3800
177 P(I,J)=P(I,J)+SUM*U(L)	A 3810
178 CONTINUE	A 3820
C	A 3830
C CALCULATE TOTAL MEMBER END ACTIONS AND REACTIONS.	A 3840
C	A 3850
DO 179 I=1,NM	A 3860
DO 179 J=1,6	A 3870
179 PF(I,J)=P(I,J)+P0(I,J)	A 3880
DO 181 J=1,IK	A 3890
NREAC=NRE(J)	A 3900
HR(NREAC)=-AFF(NREAC,1)	A 3910
VR(NREAC)=-AFF(NREAC,2)	A 3920
RT(NREAC)=-AFF(NREAC,3)	A 3930
DO 181 I=1,NM	A 3940
IF (D(I,NREAC).EQ.1.0) GO TO 180	A 3950
IF (D(I,NREAC).EQ.0.0) GO TO 181	A 3960
CALL MEMTRAN (I,NP,AL)	A 3970
HR(NREAC)=HR(NREAC)+RM(I,1)*PF(I,1)-RM(I,2)*PF(I,2)	A 3980
VR(NREAC)=VR(NREAC)+RM(I,2)*PF(I,1)+RM(I,1)*PF(I,2)	A 3990
RT(NREAC)=RT(NREAC)+PF(I,3)	A 4000
GO TO 181	A 4010
180 CALL MEMTRAN (I,NP,AL)	A 4020
HR(NREAC)=HR(NREAC)+RM(I,1)*PF(I,4)-RM(I,2)*PF(I,5)	A 4030
VR(NREAC)=VR(NREAC)+RM(I,2)*PF(I,4)+RM(I,1)*PF(I,5)	A 4040
RT(NREAC)=RT(NREAC)+PF(I,6)	A 4050
181 CONTINUE	A 4060
WRITE (6,182)	A 4070
182 FORMAT (///31H *****8H RESULTS,31H *****	A 4080
1*****///)	A 4090
WRITE (6,183)	A 4100
183 FORMAT (///27X,17H*** REACTIONS ***///)	A 4110
WRITE (6,184)	A 4120
184 FORMAT (11X, 8HREACTION,6X, 10HHOR. COMP.,4X, 11HVERT. COMP.,6X,	A 4130
1 4HMOME, 2HNT,12X, 5HPOINT,9X, 5H(LBS),11X, 5H(LBS),8X, 8H(I	A 4140
2N-LBS),/)	A 4150
DO 186 J=1,IK	A 4160
NREAC=NRE(J)	A 4170
WRITE (6,185) NREAC,HR(NREAC),VR(NREAC),RT(NREAC)	A 4180
185 FORMAT (13X,12,9X,F10,3,5X,F9,3,6X,F10,3)	A 4190
186 CONTINUE	A 4200
WRITE (6,187)	A 4210
187 FORMAT (///22X,25H*** STRENGTH ANALYSIS ***///)	A 4220
IND=1	A 4230
WRITE (6,188)	A 4240
188 FORMAT (26X, 18HMEMBER END ACTIONS,/, 20H MEMBER LOCATION, 40	A 4250
1H AXIAL SHEAR MOMENT,/, 8H NUMBER,20X, 5H(I	A 4260
2LBS),8X, 20H(LBS) (IN-LBS),/)	A 4270
189 WRITE (6,190) IND,(PF(IND,J),J=1,3)	A 4280
190 FORMAT (3X,13,6X, 7HNEG END,F14,3,F13,3,F14,3)	A 4290
WRITE (6,191) (PF(IND,N),N=4,6)	A 4300

191	FORMAT (12X, 7HPOS END,F14.3,F13.3,F14.3/)	A 4310
	IND=IND+1	A 4320
	IF (IND.GT.NM) GO TO 192	A 4330
	GO TO 189	A 4340
C		A 4350
C	BEGIN MEMBER INTERACTION AND SHEAR STRESS ANALYSIS LOOP.	A 4360
C		A 4370
192	DO 205 JX=1,JN	A 4380
	ACT=0.0	A 4390
	ITRIP=0	A 4400
	MI=MEM(JX)	A 4410
	TAU(MI)=0.0	A 4420
	NDI=NDIV+1	A 4430
	DO 199 L=1,NDI	A 4440
	X(L)=(FLOAT(L)-1.0)*ALA(JX)/DIV	A 4450
	IF (QMA(JX,1,1).EQ.0.0.AND.QMA(JX,1,2).EQ.0.0) GO TO 193	A 4460
	IF (X(L).LE.AA(JX,1)) GO TO 193	A 4470
	IF (QMA(JX,2,1).EQ.0.0.AND.QMA(JX,2,2).EQ.0.0) GO TO 194	A 4480
	IF (X(L).LE.AA(JX,2)) GO TO 194	A 4490
	IF (QMA(JX,3,1).EQ.0.0.AND.QMA(JX,3,2).EQ.0.0) GO TO 195	A 4500
	IF (X(L).LE.AA(JX,3)) GO TO 195	A 4510
	A1=QMA(JX,1,2)	A 4520
	A2=QMA(JX,2,2)	A 4530
	A3=QMA(JX,3,2)	A 4540
	B1=QMA(JX,1,1)	A 4550
	B2=QMA(JX,2,1)	A 4560
	B3=QMA(JX,3,1)	A 4570
	GO TO 196	A 4580
193	A1=0.0	A 4590
	A2=0.0	A 4600
	A3=0.0	A 4610
	B1=0.0	A 4620
	B2=0.0	A 4630
	B3=0.0	A 4640
	GO TO 196	A 4650
194	A1=QMA(JX,1,2)	A 4660
	A2=0.0	A 4670
	A3=0.0	A 4680
	B1=QMA(JX,1,1)	A 4690
	B2=0.0	A 4700
	B3=0.0	A 4710
	GO TO 196	A 4720
195	A1=QMA(JX,1,2)	A 4730
	A2=QMA(JX,2,2)	A 4740
	A3=0.0	A 4750
	B1=QMA(JX,1,1)	A 4760
	B2=QMA(JX,2,1)	A 4770
	B3=0.0	A 4780
196	FX1=ABS((PF(MI,2)*X(L)+0.5*WMA(JX,2)*X(L)**2+A1*(X(L)-AA(JX,	A 4790
1	1))+A2*(X(L)-AA(JX,2))+A3*(X(L)-AA(JX,3))-PF(MI,3))*6.0/(SIG	A 4800
2	MA(JX)*T(MI)*H(MI)**2))	A 4810
	PX=-PF(MI,1)-WMA(JX,1)*X(L)-B1-B2-B3	A 4820
	IF (MTYPE(MI).EQ.0) ELOD=0.8*ALA(JX)/H(MI)	A 4830
	IF (MTYPE(MI).EQ.1) ELOD=0.8*ALA(JX)/T(MI)	A 4840
	IF (MTYPE(MI).EQ.3) ELOD=0.9*ALA(JX)/T(MI)	A 4850
	IF (MTYPE(MI).EQ.2) ELOD=0.9*ALA(JX)/H(MI)	A 4860
	IF (PX.GE.0.0) GO TO 197	A 4870
	IF (ELOD.GT.50.0) ITRIP=1	A 4880
	STRES=0.3*E(MI)*FACTOR/ELOD**2	A 4890
	IF (STRES.GE.SIGCA(JX)) SIGP=SIGCA(JX)	A 4900
	IF (STRES.LT.SIGCA(JX)) SIGP=STRES	A 4910
	GO TO 198	A 4920

197	SIGP=SIGTA(JX)	A 4930
	IF (ELOD.GT.80.0) ITRIP=2	A 4940
198	FX2=ABS(PX/(SIGP*T(MI))*H(MI))	A 4950
	FX(L)=FX]+FX2	A 4960
	IF (FX(L).GT.ACT) ACT=FX(L)	A 4970
	IF (FX(L).EQ.ACT) EXX=X(L)	A 4980
	IF (FX(L).EQ.ACT) BEND=((PF(MI,2)*X(L)+.5*WMA(JX,2)*X(L)**2+	A 4990
1	A1*(X(L)-AA(JX,1))+A2*(X(L)-AA(JX,2))+A3*(X(L)-AA(JX,3))-PF(	A 5000
2	MI,3))*6.)/(T(MI)*H(MI)**2)	A 5010
	IF (FX(L).EQ.ACT) AXIAL=PX/(H(MI)*T(MI))	A 5020
	SHEAR=(3.0*(PF(MI,2)+WMA(JX,2)*X(L)+A1+A2+A3))/(2.0*T(MI)*H(	A 5030
1	MI))	A 5040
	IF (ABS(SHEAR).GT.ABS(TAU(MI))) TAU(MI)=SHEAR	A 5050
	IF (ABS(SHEAR).EQ.ABS(TAU(MI))) EKS(MI)=X(L)	A 5060
199	CONTINUE	A 5070
	IF (KOWNT.EQ.1) GO TO 201	A 5080
	WRITE (6,200)	A 5090
200	FORMAT (//13X, 43H INTERACTION ANALYSIS ,//32	A 5100
	1X, 9HLOC, FROM,7X, 13HMAX, STRESSES,/9X, 4HMEM,,3X, 10HMAX, VALU	A 5110
	2E,6X, 8HNEG, END,6X, 7HBENDING,5X, 5HAXIAL,/1X, 4HMEM,,4X, 4H	A 5120
	3TYPE,3X, 11HINTER, EQN,,7X, 4H(IN),9X, 5H(PSI),6X, 5H(PSI),4X,	A 5130
	4 3HL/D,/))	A 5140
	KOWNT=1	A 5150
201	IF (ITRIP.EQ.1) WRITE (6,202) MEM(JX)	A 5160
202	FORMAT (2X,12,5X, 43HL/D RATIO FOR COMPRESSION MEMBER EXCEEDS 50)	A 5170
	IF (ITRIP.EQ.2) WRITE (6,203) MEM(JX)	A 5180
203	FORMAT (2X,12,5X, 39HL/D RATIO FOR TENSION MEMBER EXCEEDS 80)	A 5190
	IF (MTYPE(MI).EQ.0) TYPE2=CS	A 5200
	IF (MTYPE(MI).EQ.1) TYPE2=CU	A 5210
	IF (MTYPE(MI).EQ.2) TYPE2=WS	A 5220
	IF (MTYPE(MI).EQ.3) TYPE2=WU	A 5230
	IF (ELOD.LT.1.0) ELOD=0.0	A 5240
	WRITE (6,204) MEM(JX),TYPE2,ACT,EXX,BEND,AXIAL,ELOD	A 5250
204	FORMAT (2X,12,6X,A2,8X,F5,3,9X,F5,1,7X,F7,1,3X,F7,1,3X,F3,0)	A 5260
205	CONTINUE	A 5270
C		A 5280
C	END MEMBER INTERACTION AND SHEAR STRESS ANALYSIS LOOP.	A 5290
C		A 5300
	DO 209 JX=1,JN	A 5310
	MI=MEM(JX)	A 5320
	IF (NO.EQ.1) GO TO 207	A 5330
	WRITE (6,206)	A 5340
206	FORMAT (//24X, 21HSHEAR STRESS ANALYSIS,//16X, 10HMAX, SHEAR,5X,	A 5350
	19HLOC, FROM,5X, 6HMEMBER,/18X, 6HSTRESS,7X, 8HNEG, END,6X, 6HL	A 5360
	2LENGTH,/5X, 6HMEMBER,7X, 5H(PSI),10X, 4H(IN),9X, 4H(IN),/)	A 5370
	NO=1	A 5380
207	WRITE (6,208) MEM(JX),TAU(MI),EKS(MI),ALA(JX)	A 5390
208	FORMAT (7X,12,9X,F6,1,9X,F5,1,8X,F5,1)	A 5400
209	CONTINUE	A 5410
C		A 5420
C	BEGIN MEMBFR DEFLECTION CALCULATION LOOP.	A 5430
C		A 5440
	DO 222 JX=1,JN	A 5450
	MI=MFM(JX)	A 5460
	CALL MEMTRAN (MI,NP,AL)	A 5470
	IKON=0	A 5480
	CALL TRNSLT (MI,NP,IKON,JA)	A 5490
	DF5=0.0	A 5500
	DF2=0.0	A 5510
	DO 210 J=1,NC	A 5520
	DF2=DF2+BETA(2,J)*U(J)	A 5530

210	DF5=DF5+BETA(5,J)*U(J)	A 5540
	DELTA=0.0	A 5550
	DO 218 L=1,NDI	A 5560
	XD(L)=(FLOAT(L)-1.0)*ALA(JX)/DIV	A 5570
	Y1=((WMA(JX,2)*ALA(JX)**3)/24.0-PF(MI,6)*ALA(JX)/6.0+PF(MI,3)*ALA(JX)/3.0)*XD(L)-PF(MI,3)*XD(L)**2*(1.0+(ALA(JX)-XD(L))	A 5580
1		A 5590
2	)/(2.0*ALA(JX))/3.0+PF(MI,6)*XD(L)**3/(6.*ALA(JX))-WMA(JX,2)	A 5600
3	*XD(L)**3*(2.0*ALA(JX)-XD(L))/24.0)/EI(MI)	A 5610
	Y2=DF2+(DF5-DF2)*XD(L)/ALA(JX)	A 5620
	IF (QMA(JX,1,2).EQ.0.0) GO TO 211	A 5630
	IF (XD(L).LE.AA(JX,1)) GO TO 212	A 5640
	IF (QMA(JX,2,2).EQ.0.0) GO TO 213	A 5650
	IF (XD(L).LE.AA(JX,2)) GO TO 214	A 5660
	IF (QMA(JX,3,2).EQ.0.0) GO TO 215	A 5670
	IF (XD(L).LE.AA(JX,3)) GO TO 216	A 5680
	Y31=QMA(JX,1,2)*AA(JX,1)*((2.0*ALA(JX)**2+AA(JX,1)**2)*XD(L)	A 5690
1	-3.*ALA(JX)*XD(L)**2+XD(L)**3-AA(JX,1)**2*ALA(JX))/(6.0*ALA(	A 5700
2	JX)*EI(MI))	A 5710
	Y32=QMA(JX,2,2)*AA(JX,2)*((2.0*ALA(JX)**2+AA(JX,2)**2)*XD(L)	A 5720
1	-3.*ALA(JX)*XD(L)**2+XD(L)**3-AA(JX,2)**2*ALA(JX))/(6.0*ALA(	A 5730
2	JX)*EI(MI))	A 5740
	Y33=QMA(JX,3,2)*AA(JX,3)*((2.0*ALA(JX)**2+AA(JX,3)**2)*XD(L)	A 5750
1	-3.*ALA(JX)*XD(L)**2+XD(L)**3-AA(JX,3)**2*ALA(JX))/(6.0*ALA(	A 5760
2	JX)*EI(MI))	A 5770
	GO TO 217	A 5780
211	Y31=0.0	A 5790
	Y32=0.0	A 5800
	Y33=0.0	A 5810
	GO TO 217	A 5820
212	Y31=QMA(JX,1,2)*(AA(JX,1)*((2.0*ALA(JX)-AA(JX,1))*(ALA(JX)-AA	A 5830
1	(JX,1))*XD(L)-(ALA(JX)-AA(JX,1))*XD(L)**3)/(6.*ALA(JX)*EI(MI	A 5840
2	))	A 5850
	Y32=QMA(JX,2,2)*(AA(JX,2)*((2.0*ALA(JX)-AA(JX,2))*(ALA(JX)-AA	A 5860
1	(JX,2))*XD(L)-(ALA(JX)-AA(JX,2))*XD(L)**3)/(6.*ALA(JX)*EI(MI	A 5870
2	))	A 5880
	Y33=QMA(JX,3,2)*(AA(JX,3)*((2.0*ALA(JX)-AA(JX,3))*(ALA(JX)-AA	A 5890
1	(JX,3))*XD(L)-(ALA(JX)-AA(JX,3))*XD(L)**3)/(6.*ALA(JX)*EI(MI	A 5900
2	))	A 5910
	GO TO 217	A 5920
213	Y31=QMA(JX,1,2)*AA(JX,1)*((2.0*ALA(JX)**2+AA(JX,1)**2)*XD(L)	A 5930
1	-3.*ALA(JX)*XD(L)**2+XD(L)**3-AA(JX,1)**2*ALA(JX))/(6.0*ALA(	A 5940
2	JX)*EI(MI))	A 5950
	Y32=0.0	A 5960
	Y33=0.0	A 5970
	GO TO 217	A 5980
214	Y31=QMA(JX,1,2)*AA(JX,1)*((2.0*ALA(JX)**2+AA(JX,1)**2)*XD(L)	A 5990
1	-3.*ALA(JX)*XD(L)**2+XD(L)**3-AA(JX,1)**2*ALA(JX))/(6.0*ALA(	A 6000
2	JX)*EI(MI))	A 6010
	Y32=QMA(JX,2,2)*(AA(JX,2)*((2.0*ALA(JX)-AA(JX,2))*(ALA(JX)-AA	A 6020
1	(JX,2))*XD(L)-(ALA(JX)-AA(JX,2))*XD(L)**3)/(6.*ALA(JX)*EI(MI	A 6030
2	))	A 6040
	Y33=QMA(JX,3,2)*(AA(JX,3)*((2.0*ALA(JX)-AA(JX,3))*(ALA(JX)-AA	A 6050
1	(JX,3))*XD(L)-(ALA(JX)-AA(JX,3))*XD(L)**3)/(6.*ALA(JX)*EI(MI	A 6060
2	))	A 6070
	GO TO 217	A 6080
215	Y31=QMA(JX,1,2)*AA(JX,1)*((2.0*ALA(JX)**2+AA(JX,1)**2)*XD(L)	A 6090
1	-3.*ALA(JX)*XD(L)**2+XD(L)**3-AA(JX,1)**2*ALA(JX))/(6.0*ALA(	A 6100
2	JX)*EI(MI))	A 6110
	Y32=QMA(JX,2,2)*AA(JX,2)*((2.0*ALA(JX)**2+AA(JX,2)**2)*XD(L)	A 6120
1	-3.*ALA(JX)*XD(L)**2+XD(L)**3-AA(JX,2)**2*ALA(JX))/(6.0*ALA(	A 6130
2	JX)*EI(MI))	A 6140
	Y33=0.0	A 6150

	GO TO 217	A 6160
216	Y31=QMA(JX,1,2)*AA(JX,1)*((2.0*ALA(JX)**2+AA(JX,1)**2)*XD(L)	A 6170
1	-3.*ALA(JX)*XD(L)**2+XD(L)**3-AA(JX,1)**2*ALA(JX))/(6.0*ALA	A 6180
2	JX)*EI(MI))	A 6190
	Y32=QMA(JX,2,2)*AA(JX,2)*((2.0*ALA(JX)**2+AA(JX,2)**2)*XD(L)	A 6200
1	-3.*ALA(JX)*XD(L)**2+XD(L)**3-AA(JX,2)**2*ALA(JX))/(6.0*ALA	A 6210
2	JX)*EI(MI))	A 6220
	Y33=QMA(JX,3,2)*(AA(JX,3)*((2.0*ALA(JX)-AA(JX,3))*(ALA(JX)-AA	A 6230
1	(JX,3))*XD(L)-(ALA(JX)-AA(JX,3))*XD(L)**3)/(6.*ALA(JX)*EI(MI	A 6240
2	))	A 6250
217	Y3=Y31+Y32+Y33	A 6260
	Y(L)=Y1+Y2+Y3	A 6270
	IF (ABS(Y(L)).GT.ABS(DELTA)) DELTA=Y(L)	A 6280
	IF (ABS(Y(L)).EQ.ABS(DELTA)) EX=XD(L)	A 6290
218	CONTINUE	A 6300
	IF (KOUNT2.EQ.1) GO TO 220	A 6310
	WRITE (6,219)	A 6320
219	FORMAT (//21X,27H*** DEFLECTION ANALYSIS ***//22X, 26HMAXIMUM MEM	A 6330
	1BER DEFLECTIONS, //38X, 9HLOC. FROM, 5X, 6HMEMBER, /23X, 10HMAX. DE	A 6340
	2FL, 5X, 8HNEG. END, 6X, 6HLENGTH, /12X, 6HMEMBER, 8X, 4H(IN), 10X,	A 6350
3	4H(IN), 9X, 4H(IN), /)	A 6360
	KOUNT2=1	A 6370
220	WRITE (6,221) MI, DELTA, EX, ALA(JX)	A 6380
221	FORMAT (14X, 12, 9X, F6, 3, 9X, F5, 1, 8X, F5, 1)	A 6390
222	CONTINUE	A 6400
C		A 6410
C	END MEMBER DEFLECTION CALCULATION LOOP.	A 6420
C		A 6430
	IKON=2	A 6440
	CALL TRNSLT (I, NP, IKON, JA)	A 6450
	WRITE (6,223)	A 6460
223	FORMAT (///25X, 19HPOINT DISPLACEMENTS, //14X, 17HDISPL., HORIZ. OR	A 6470
1	5X, 13HDISPLACEMENT, 5X, 13HDISPLACEMENT, //3X, 5HPOINT, 6X, 11HIN	A 6480
2	DIR. OF, 6HROLLER, 7X, 8HVERTICAL, 9X, 10HROTATIONAL, /3X, 6HNUM	A 6490
3	BER, 11X, 4H(IN), 16X, 4H(IN), 11X, 9H(RADIANS), /)	A 6500
	DO 225 I=1, NP	A 6510
	WRITE (6,224) I, C(I,3,1), C(I,3,2), C(I,3,3)	A 6520
224	FORMAT (5X, 12, 12X, F6, 3, 13X, F6, 3, 10X, E10, 3)	A 6530
225	CONTINUE	A 6540
	GO TO 101	A 6550
	END	A 6560
	SUBROUTINE REDUCE (NC, MBW)	B 10
	INTEGER M, JN	B 11
	REAL K	B 20
	DIMENSION MHOLD(51)	B 30
	COMMON /B1/ K(51,51)	B 40
	DO 104 I=1, NC	B 50
	M=NC	B 60
101	IF (K(I,M).NE.0.0) GO TO 102	B 70
	IF (M.EQ.1) GO TO 103	B 80
	M=M-1	B 90
	GO TO 101	B 100
102	MHOLD(I)=M-I+1	B 110
	GO TO 104	B 120
103	MHOLD(I)=0	B 130
104	CONTINUE	B 140
	MBW=0	B 150
	DO 105 I=1, NC	B 160
	IF (MHOLD(I).GT.MBW) MBW=MHOLD(I)	B 170
105	CONTINUE	B 180
	NIP=0	B 210
	DO 109 IN=1, NC	B 220

	DO 108 JN=1,MM	B	230
	JP=JN+NIP	B	240
	IF (JP.GT.NC) GO TO 107	B	250
	K(IN,JN)=K(IN,JP)	B	260
	GO TO 108	B	270
	K(IN,JN)=0,0	B	280
107	CONTINUE	B	290
	NIP=NIP+1	B	300
109	CONTINUE	B	310
	RETURN	B	320
	END	B	330
	SUBROUTINE SYMSOL (NN,MM)	C	10
	INTEGER K	C	11
	COMMON /B1/ A(51,51)	C	20
	COMMON BETA(6,51),FF(51),U(51),F(51)	C	30
	COMMON C3(23),C6(23)	C	40
	COMMON AFF(18,3),C(18,3,3),XM(18,2)	C	50
	COMMON D(23,18)	C	60
	COMMON KAPPA(6,6),RM(3,3)	C	70
	DIMENSION CS(16), FO(51)	C	80
C		C	90
C	INPUT LOADS	C	100
C		C	110
	DO 101 I=1,NN	C	120
101	U(I)=F(I)	C	130
C		C	140
	N=0	C	150
102	N=N+1	C	160
C		C	170
C	REDUCE NTH EQUATION	C	180
C		C	190
C	1. DIVIDE RHS BY DIAGONAL	C	200
C		C	210
	U(N)=U(N)/A(N,1)	C	220
C		C	230
C	2. CHECK FOR LAST EQUATION	C	240
C		C	250
	IF (N-NN) 103,108,103	C	260
C		C	270
C	3. DIVIDE NTH EQUATION BY DIAGONAL	C	280
C		C	290
103	DO 104 K=2,MM	C	300
	CS(K)=A(N,K)	C	310
104	A(N,K)=A(N,K)/A(N,1)	C	320
C		C	330
C	4. REDUCE REMAINING EQUATIONS	C	340
C		C	350
	DO 107 L=2,MM	C	360
	I=N+L-1	C	370
	IF (NN-1) 107,105,105	C	380
105	J=0	C	390
	DO 106 K=L,MM	C	400
	J=J+1	C	410
106	A(I,J)=A(I,J)-CS(L)*A(N,K)	C	420
	U(I)=U(I)-CS(L)*U(N)	C	430
107	CONTINUE	C	440
	GO TO 102	C	450
C		C	460
C	BACK SUBSTITUTION	C	470
C		C	480
108	N=N-1	C	490
C		C	500

C	1. CHECK FOR FIRST EQUATION	C 510
C		C 520
	IF (N) 109,112,109	C 530
C		C 540
C	2. CALCULATE THE UNKNOWN	C 550
C		C 560
	109 DO 111 K=2,MM	C 570
	L=N+K-1	C 580
	IF (NN-L) 111,110,110	C 590
	110 U(N)=U(N)-A(N,K)*U(L)	C 600
	111 CONTINUE	C 610
	GO TO 108	C 620
	112 RETURN	C 630
	END	C 640
	SUBROUTINE MEMTRAN (I,NP,AL)	D 10
	REAL M	D 20
	DIMENSION AL(23), M(2)	D 30
	COMMON BETA(6,51),FF(51),U(51),F(51)	D 40
	COMMON C3(23),C6(23)	D 50
	COMMON AFF(18,3),C(18,3,3),XM(18,2)	D 60
	COMMON D(23,18)	D 70
	COMMON KAPPA(6,6),RM(3,3)	D 80
	M(1)=0.0	D 90
	M(2)=0.0	D 100
	DO 1L=1,NP	D 110
	M(1)=M(1)+D(1,L)*XM(L,1)	D 120
	1 M(2)=M(2)+D(1,L)*XM(L,2)	D 130
	AL(1)=SQRT(M(1)**2+M(2)**2)	D 140
	RM(1,1)=M(1)/AL(1)	D 150
	RM(1,2)=M(2)/AL(1)	D 160
	RM(2,1)=-RM(1,2)	D 170
	RM(2,2)=RM(1,1)	D 180
	RM(3,3)=1.0	D 190
	RETURN	D 200
	END	D 210
	SUBROUTINE TRNSLT (I,NP,IKON,JA)	E 10
C		E 20
C	CALC BETAS OR TRANS FORCES OR TRANS DISPLS	E 30
C		E 40
	COMMON BETA(6,51),FF(51),U(51),F(51)	E 50
	COMMON C3(23),C6(23)	E 60
	COMMON AFF(18,3),C(18,3,3),XM(18,2)	E 70
	COMMON D(23,18)	E 80
	COMMON KAPPA(6,6),RM(3,3)	E 90
	JA=0	E 100
	DO 116 JB=1,NP	E 110
	IF (C(JB,3,3).EQ.0.0) GO TO 116	E 120
	IF (C(JB,2,2).EQ.1.0) GO TO 102	E 130
	IF (C(JB,3,2).EQ.1.0) GO TO 101	E 140
	IFLAG=1	E 150
	GO TO 103	E 160
101	IFLAG=2	E 170
	GO TO 103	E 180
102	IFLAG=3	E 190
103	CONTINUE	E 200
	LA=JA	E 210
	IF (IKON.EQ.1) GO TO 105	E 220
	IF (IKON.EQ.2) GO TO 110	E 230
C		E 240
C	LOAD BETA MATRIX FROM C MATRICES	E 250
C		E 260
	DO 104 J=1,3	E 270

	DO 104 L=1,IFLAG	E 280
	JA=LA+L	E 290
	BETA(J,JA)=0.0	E 300
	BETA(J+3,JA)=0.0	E 310
	DO 104 KA=1,3	E 320
	IF (D(I,JB).EQ.0.0) GO TO 104	E 330
	IF (D(I,JB).EQ.-1.) BETA(J,JA)=BETA(J,JA)+RM(J,KA)*C(JB,KA,L	E 340
1	)	E 350
	IF (D(I,JB).EQ.1.) BETA(J+3,JA)=BETA(J+3,JA)+RM(J,KA)*C(JB,K	E 360
1	A,L)	E 370
104	CONTINUE	E 380
	GO TO 116	E 390
C		E 400
C	TRANSLATION JOINT TO SYSTEM COORDINATES	E 410
C		E 420
105	DO 109 L=1,IFLAG	E 430
	JA=LA+L	E 440
	IF (IFLAG.EQ.3) GO TO 108	E 450
	IF (C(JB,1,1).NE.0.0.OR.C(JB,2,1).NE.0.0) GO TO 107	E 460
106	FF(JA)=AFF(JB,3)	E 470
	GO TO 109	E 480
107	IF (IFLAG.EQ.1) GO TO 108	E 490
	IF (L.EQ.1) GO TO 108	E 500
	GO TO 106	E 510
108	FF(JA)=AFF(JB,L)	E 520
109	CONTINUE	E 530
	GO TO 116	E 540
C		E 550
C	TRANSLATION SYSTEM COORDINATES TO JOINTS	E 560
C		E 570
110	DO 115 L=1,IFLAG	E 580
	JA=LA+L	E 590
	IF (IFLAG.EQ.3) GO TO 114	E 600
	IF (C(JB,1,1).NE.0.0.OR.C(JB,2,1).NE.0.0) GO TO 112	E 610
	C(JB,3,1)=0.0	E 620
111	C(JB,3,2)=0.0	E 630
	C(JB,3,3)=U(JA)	E 640
	GO TO 115	E 650
112	IF (IFLAG.EQ.1) GO TO 113	E 660
	IF (L.EQ.1) GO TO 114	E 670
	GO TO 111	E 680
113	C(JB,3,3)=0.0	E 690
114	C(JB,3,L)=U(JA)	E 700
115	CONTINUE	E 710
116	CONTINUE	E 720
	RETURN	E 730
	END	E 740
	SUBROUTINE CALKAP (EA,EI,E,T,H,AL,I,G)	F 10
	REAL KAPPA,A	F 20
	DIMENSION AL(23), E(23), EA(23), EI(23), H(23), T(23)	F 30
	COMMON BETA(6,51),FF(51),U(51),F(51)	F 40
	COMMON C3(23),C6(23)	F 50
	COMMON AFF(18,3),C(18,3,3),XM(18,2)	F 60
	COMMON D(23,18)	F 70
	COMMON KAPPA(6,6),RM(3,3)	F 80
	A=T(1)*H(1)	F 90
	S=(T(1)*H(1)**3)/12.0	F 100
	IF (C3(1).EQ.0.0.AND.C6(1).EQ.0.0) GO TO 101	F 110
	IF (C3(1).EQ.1.0.AND.C6(1).EQ.0.0) GO TO 102	F 120
	IF (C3(1).EQ.0.0.AND.C6(1).EQ.1.0) GO TO 103	F 130
	KAPPA(2,2)=0.0	F 140
	KAPPA(3,2)=0.0	F 150

KAPPA(3,3)=0.0	F 160
GO TO 104	F 170
101 KAPPA(2,2)=12.0*E1(I)/(AL(I)**3+12.0*E1(I)*AL(I)/(G*A))	F 180
KAPPA(3,2)=6.0*E1(I)/(AL(I)**2+12.0*E1(I)/(G*A))	F 190
KAPPA(3,3)=(4.0*E1(I)/AL(I))*((3.0*E1(I)+G*A*AL(I)**2)/(12.0*E1(I)	F 200
1+G*A*AL(I)**2))	F 210
GO TO 104	F 220
102 KAPPA(2,2)=3.0*E1(I)/(AL(I)**3+3.0*E1(I)*AL(I)/(G*A))	F 230
KAPPA(3,2)=0.0	F 240
KAPPA(3,3)=0.0	F 250
GO TO 104	F 260
103 KAPPA(2,2)=3.0*E1(I)/(AL(I)**3+3.0*E1(I)*AL(I)/(G*A))	F 270
KAPPA(3,2)=3.0*E1(I)/(AL(I)**2+3.0*E1(I)/(G*A))	F 280
KAPPA(3,3)=3.0*E1(I)/(AL(I)+3.0*E1(I)/(G*A*AL(I)))	F 290
104 KAPPA(1,1)=EA(I)/AL(I)	F 300
KAPPA(4,4)=KAPPA(1,1)	F 310
KAPPA(5,5)=KAPPA(2,2)	F 320
KAPPA(4,1)=-KAPPA(1,1)	F 330
KAPPA(5,2)=-KAPPA(2,2)	F 340
KAPPA(5,3)=-KAPPA(3,2)	F 350
KAPPA(6,2)=AL(I)*KAPPA(2,2)-KAPPA(3,2)	F 360
KAPPA(6,3)=AL(I)*KAPPA(3,2)-KAPPA(3,3)	F 370
KAPPA(6,5)=-KAPPA(6,2)	F 380
KAPPA(6,6)=AL(I)*KAPPA(6,2)-KAPPA(6,3)	F 390
DO 105 J=1,6	F 400
DO 105 L=1,6	F 410
IF (L.LE.J) GO TO 105	F 420
KAPPA(J,L)=KAPPA(L,J)	F 430
105 CONTINUE	F 440
RETURN	F 450
END	F 460