

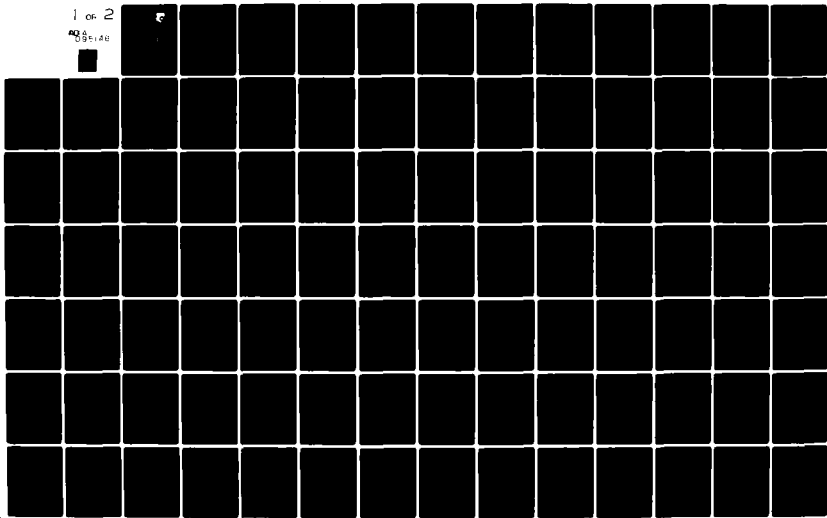
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MARC ANALYSIS RESEARCH CORP PALO ALTO CA  
KNOWLEDGE BASED CONSULTATION FOR FINITE ELEMENT STRUCTURAL ANAL--ETC(U)  
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AFWAL-TR-80-3069 NL

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LEVEL II

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**KNOWLEDGE BASED CONSULTATION FOR FINITE ELEMENT STRUCTURAL ANALYSIS**

J. M. RIVLIN  
M. B. HSU  
P. V. MARCAL

MARC ANALYSIS RESEARCH CORPORATION  
260 SHERIDAN AVENUE, SUITE 200  
PALO ALTO, CALIFORNIA 94306

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Final Report for Period October 1977 - May 1980

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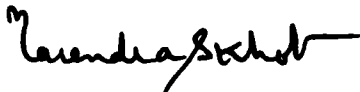
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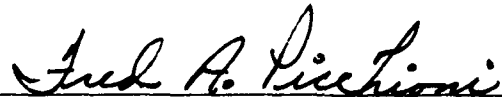
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This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.



NARENDRA S. KHOT,  
Project Engineer



FREDERICK A. PICCHIONI, Lt Col, USAF  
Chief, Analysis & Optimization Branch

FOR THE COMMANDER



RALPH L. KUSTER, JR., Col, USAF  
Chief, Structures & Dynamics Div.

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knowledge base are executed through the use of user input keywords. The consultation system is currently operational on the Prime 400 Computer System.

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FOREWORD

This report describes the work performed by MARC Analysis Research Corporation, Palo Alto, California. The work was sponsored by the Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under contract F33615-78-C3206.

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The contract work was performed between October 1977 and May 1980.

The technical report was released by the Authors in May 1980.

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TABLE OF CONTENTS

SECTION	PAGE
I. INTRODUCTION . . . . .	1
II. KNOWLEDGE BASED CONSULTATION SYSTEM . . . . .	3
1. The Inference Engine and Rules . . . . .	3
2. Command Descriptions . . . . .	6
3. Inference Engine Internals . . . . .	16
III. KNOWLEDGE BASE FOR FINITE ELEMENT STRUCTURAL ANALYSIS . . . . .	19
1. Finite Element Structural Analysis Information . . . . .	20
2. Knowledge Based Rules and Key-Words . . . . .	22
3. Reasoning Steps . . . . .	27
IV. EXAMPLE CONSULTATIONS . . . . .	31
1. Description of the Structure . . . . .	31
2. Pre-analysis and Analysis Stages (Initial Consultation). . . . .	31
3. Execution of the MARC Program . . . . .	34
4. Post-Analysis Stage (Second Consultation) . . . . .	35
5. Reanalysis (Third Consultation) . . . . .	35
V. DISCUSSIONS AND CONCLUSIONS . . . . .	44
REFERENCES . . . . .	46
APPENDIX A. Knowledge Based Rules for Finite Element Structural Analysis . . . . .	47
APPENDIX B. The MARC Program and MARC Elements 3, 5, 7, 11 . . . . .	71
APPENDIX C. List of Conversations During Consultation . . . . .	98

List of Illustrations

Figure 1	Algorithm of Rule Execution . . . . .	17
Figure 2	Flow Diagram of the Consultation System . . . . .	18
Figure 3	Plate with Hole (Sample Problem) . . . . .	42
Figure 4	Schematic of Example Consultations . . . . .	43



List of Tables

Table 1	List of Key Words . . . . .	30
Table 2	MARC Input Data (Sample Problem) . . . . .	36
Table 3	Summary of MARC Results (Sample Problem) . . . . .	38
Table 4	MARC Input Data (Reanalysis) . . . . .	39
Table 5	Summary of MARC Results (Reanalysis) . . . . .	41

## I. INTRODUCTION

In recent years, techniques of 'Heuristic Programming' have been applied to various fields of science and engineering. The DENDRAL program [1] can be used for processing the results from mass and nuclear spectrometry and for the determination of the chemical nature of a substance that was tested. A group involved in Artificial Intelligence at Stanford University developed the program MYCIN [2], for clinical consultation of diseases that require treatment by penicillin and its derivatives. Studies have also been reported to apply knowledge engineering to the field of structural analysis [3], [4]. Results from previous investigations clearly indicate the advantage and usefulness of heuristic programming techniques in dealing with scientific and engineering problems.

The application of finite element methods to structural analysis has long been recognized. A general purpose finite element program such as the MARC program [5] can provide numerical results to a variety of structural problems involving material and geometric non-linearities, thermal effects and anisotropic material properties. A simple description of the MARC program is given in Appendix B.

During this investigation, an attempt has been made to develop a knowledge based consultation system and to establish a finite element structural analysis knowledge base for the use of the MARC program. The backward chaining logic is adopted into the current consultation system and the inference engine in the system is written in Fortran. The use of Fortran allows the incorporation of an interface to existing software. The finite element structural analysis knowledge base is developed for dealing with

information on pre-analysis, analysis, and post-analysis stages of a structural analysis problem. Knowledge based rules are established for the determination of the type of analysis; preparation of input file to the MARC program; and examination of the structural responses. All the rules are executed through the use of keywords. Since the MARC program is a general purpose finite element analysis program, a great number of analysis capabilities are available in the program. During this investigation, however, only a few types of analyses and a number of selected elements were chosen for the knowledge base. Expansion of current knowledge base to include additional types of analyses and other elements can be easily achieved in a future investigation.

In the following sections, the knowledge based consultation system is discussed in Section II and the knowledge base for finite element structural analysis is described in Section III. Application of this consultation system to structural problems is demonstrated in Section IV while an attempt to arrive at some conclusions is given in Section V. In addition, a list of references is compiled in Section VI. Finally, the knowledge based rules and their associated questions are shown in Appendix A and a simple description of the MARC program is given in Appendix B. A list of conversations held during consultations is included in Appendix C.

## II. KNOWLEDGE BASED CONSULTATION SYSTEM

This section outlines the method used to represent a consultant's knowledge of his area of specialization. It is assumed that the consultant or expert has a thorough knowledge of his area of expertise, but that his knowledge in the area of computing is limited. One of the primary motivating criteria used in selecting the knowledge representation was that a non-programmer can easily and directly implement knowledge without the intervention of computing staff.

### 1. The Inference Engine and Rules

The basic backward chaining logic, characteristic to Artificial Intelligence, approaching the problem of knowledge representation was adopted into the current system. The inference engine in the system is written in Fortran. This has one major advantage. It allows the incorporation of an interface to a wealth of existing software. In addition, use of Fortran also allows the addition of sophisticated evaluation routines on which to base decision making by the consultant. This, of course, requires some work on the part of programming personnel, however, frequently such analysis programs are already available and can be easily interfaced to the inference engine. These features allow a natural growth and specialization of the inference engine to a variety of tasks.

The inference engine accepts all information in the form of rules. Rules have the form:

Rule #  
Premise  
Conclusion.

The Rule number is a unique number used to identify a rule. The value of a rule number does not imply execution order. A properly written rule should contain a kernel of knowledge which is true at any time during the execution of the rule set in which it is contained. This means that the premise should solely dictate the validity of the conclusion. In addition, the author of the rules should avoid dependence in rule execution order to produce the desired result.

The modularity of the rule representation makes the sets exceedingly easy to modify. It is usually possible to introduce a new concept into a rule set by simply adding the new criteria required to draw the desired conclusion. This is possible because the execution order of the rules is not specified by the author of the rules, it is implied by the content of the rules themselves.

Once a rule has been chosen for processing it is processed in the following fashion:

- a. The premises of the rule (IF elements) are evaluated in the order in which they appear in the rule. The evaluation of an IF statement may lead to one of three possible results. The statement is true, false or unknown. If the statement is true, evaluation proceeds with the next IF statement. If the statement is false or unknown evaluation of current rule is terminated.

- b. If the statement is true, the conclusion portion of the rule is executed. The conclusion may include the asking of questions, an internal conclusion, or a variety of other tasks. It is expected that permissible actions will be enhanced to suit a variety of situations.
  
- c. The unknown condition results when one of the names referenced in the premise does not have a value associated with it. When the unknown condition occurs the name of the variable causing the condition is saved for back chaining.

The inference engine operates in a goal directed fashion. This means that all activity is directed towards concluding a value for an initially unknown keyword. Backward chaining is then performed from a rule in which the desired keyword is referenced as an assigned variable in the conclusion. Such a rule may be referred to as a goal rule. If the rule is true, then the search is over and the keyword achieves a role. If the rule is false, then another goal rule is found. If the rule is unknown, then the variable causing the unknown condition is used as a directive. This variable name is found as a conclusion variable in another rule. That rule is then executed. Execution proceeds in a directed fashion until a rule containing the initial keyword is found to be true. Figure 1 shows the execution algorithm graphically.

## 2. Command Descriptions

### a. Logic Statements:

RULE, IF, CONCLUDE.

Logic statements are statements which control the execution logic of the rule set. Conventional programming languages allow the user to explicitly define which section of the program is to be executed next. This is the primary difference between the inference engine and conventional programming languages. All execution information is contained in the three available logic statements.

Example: RULE 29

IF WEIGHT IS 'LOW'

CONCLUDE MAN IS 'HUNGRY'

#### (1) RULE:

RULE (NUMBER)

The RULE statement defines a logically related group of statements. Every RULE must contain at least one conclusion. The conclusion is the only means the inference engine has of determining that a rule pertains to a particular topic. In the above example the RULE 29 will never be executed unless a value of 'MAN' is required to achieve a goal. The RULE statement serves to delineate both the end of the previous

rule and the beginning of a new rule. It is also possible to specify a rule with no number. In this instance the rule will be executed once before any other rules are executed. This provides a means for performing initialization.

(2) IF:

IF (expression)                    (operator) (expression)

The IF statement serves to indicate a premise of the rule. There may be multiple IF statements preceding the actions and conclusions of a single rule. Any variable which is determined to be unknown during the evaluation of a rule will be used to back chain to another rule containing an assignment to the unknown variable in its conclusion.

(3) CONCLUDE:

CONCLUDE (variable) (assignment operator) (expression)

Conclusion statements are the basis for the selection of a rule for execution. A rule may be executed whenever one of the conclusions of the rule contains the variable that was determined as unknown in the premise of the previously executed rule. All activation of a rule is done on the basis of the conclusion statements of the rule. For this reason every RULE must contain at least one conclusion or it will



never be activated.

b. Syntactic Constructs:

(1) Variables:

A variable name may contain up to 14 characters. Numerics and operator symbols may not be used in a variable name. Variables do not need to be declared as in a conventional programming language. The type of a variable is determined by the type of data which is assigned to that variable. Variables may be arrays or lists of values. Arrays of up to three dimensions are supported. Any array of more than one dimension must be dimensioned by means of a 'DIM' statement. Variables may also contain lists. This is indicated by the "ADD\_LIST" statement.

(2) Constants:

A constant may be one of three forms: a floating point number, an integer number or a character string. These are indicated by the following example:

(a) 2.33

(b) 233

(c) 'two hundred thirty three'

(3) Expressions:

An expression is formed by operators, variables and constants.

No parenthesis may be used in an expression other than those used to identify array references.

Example:

(a) 'A' + 'B' + 'CDE'

this expression is the same as 'ABCDE'

(b) A = 2.47

A + 3

the expression is the same as 5.47

(c) A(1) = 2.47

A(1) + 3

the expression is the same as 5.47

Expressions are always evaluated in a strict left to right fashion.

(4) Conditional Operators:

Conditional operators are the method of specifying logical relationships between expressions. The possible conditional operators are:

EQ, NE, LT, GT, LE, GE, JS\_IN, IS, JS\_NOT, IS\_NOT\_IN,

ENDING\_IS, ENDING\_ISNT

The definitions of these conditional operators are given below.

- EQ, IS - truth occurs when the expression on the left is equal to the expression on the right.
- NE, IS\_NOT - truth occurs when the expression on the left is not equal to the expression on the right.
- LT - truth occurs when the expression on the left is less than the expression on the right.
- GT - truth occurs when the expression on the left is greater than the expression on the right.
- LE - truth occurs when the expression on the left is less than or equal to the expression on the right.
- GE - Truth occurs when the expression on the left is greater than or equal to the expression on the right.
- IS\_IN - truth occurs when the expression on the left is contained in the list on the right.
- IS\_NOT\_IN - truth occurs when the expression on the left is not contained in the list on the right.
- ENDING\_IS - truth occurs when the ending of the expression is on the left, which must evaluate to a character string, is the same as the expression on the

right.

ENDING\_ISNT - truth occurs when the ending of the expression on the left, which must evaluate to a character string, is the same as the expression on the right.

(5) Assignment Operators:

Assignment operators may be used in "CONCLUDE" and "ACTION" statements. They always specify assignment to the variable on the left. The possible assignment operators are: ADD\_LIST, REMOVE\_LIST, =, IS.

ADD\_LIST - the expression on the right is added as a new element to the list on the left.

REMOVE\_LIST - the expression on the right is searched in the list on the left and removed from that list if it exists.

=, IS - the expression on the right is evaluated and assigned to the variable on the left.

(6) Operators:

Operators connect the variables in an expression. The possible operators are: \*,-,+/,

- \* (numerics only) - multiplication
- (numerics) - subtraction
- (character strings) - removal of first occurrence of character string on the right from expression on the left
- + (numerics) - addition
- + (character strings) - concatenation
- / (numerics only) - division

(7) Additional Action Statements:

The following statements allow the rules to perform useful functions, however, they in no way affect the flow of execution in the way that the CONCLUDE statement does.

ACTION:

ACTION (variable) (assignment operator) (expression)

The action statement is exactly the same as the conclude statement, except that variables referenced are not used to key off the execution of the rule in which the statement occurs.

ASK:

ASK ('question')(# times)(insert)(# variables)(variables)

This inference engine maintains a question file. This file is specified at start up time of the program. The ASK feature allows the rules to ask questions which are specified in detail in another file.

Question - specifies the question name to be used.

#times - the number of times to ask the specified question.

insert - the character string or number to be inserted in the question being asked.

#variables - the number of variables which will receive the information typed in by the user. This number must be the same as the number of fields specified in the question definition file.

variables - the names of the variables to receive the data typed in by the user. If the #times is greater than 1, then the variable will be an array with successive answers appearing in successive elements.

DIM:

DIM (variable) (N1,N2,N3)

The DIM statement dimensions multi-dimensional arrays. N1, N2 and N3 are the maximum bounds of the dimensions. Arrays may have maximum of three dimensions. The DIM statement should only appear in initialization rules. It is only necessary to dimension two-and three-dimensional arrays.

OPEN:

OPEN ('filename') (unit) (record length)

The OPEN statement opens a file of the specified filename on the specified unit number. Unit may be 1, 2 or 3. The record length is negative if an output file is being opened and positive if an input file is being specified. In either case record length is specified in characters.

CLOSE:

CLOSE (unit)

The CLOSE statement closes the file open on the specified unit.

MERGE:

MERGE ('file1') ('file2') ('file3') ('output file')

The MERGE statement merges from 1 to 3 files into the specified output file.

WRITE:

WRITE (unit) (variable1) (variable2) ... : (from to by)

The WRITE statement allows the rules to write to a file. The specified unit must be opened with OPEN command. Variable 1, Variable 2, etc. are arrays containing the data to be written. From to and by form a loop specifying the array elements to write. Each increment of this loop creates 'record' in the output file. The FORMAT for the write is specified on the line following the WRITE statement. It is specified as a standard Fortran FORMAT statement.

Example:

```
CONCLUDE A(1) = 3
CONCLUDE A(2) = 4
CONCLUDE B(1) = 5.1
CONCLUDE B(2) = 5.2
```

```
WRITE 1 A B : 1 2 1
FORMAT (I5,F4.2)
```

The result is:

```
3 5.1
4 5.2
```



### 3. Inference Engine Internals

The internals of the inference engine may be thought of as being divided into two sections. These are the utility module and the logic module. The utility module implements all of the functions necessary to perform the actions of rules. This includes such things as string conversions, file handling, parsing etc. There is also a hash coded data retrieval system associated with this module. All variable names and their respective data are stored in the hash coded data-base. The utility module consists of approximately 80 routines. The logic of the inference engine constitutes the second module. This module consists of the routines which actually make the decisions as to which rule to process and actually pass and process the rules. This of course is heavily dependent on the utility module for most of its functionality.

The following is a brief description of the primary routines involved in the logic process and their functionalities.

Routine	Functionality
CONCLUD	Performs conclusions
ERROR	Central error handling routine
EVAL	Evaluates expressions
BRAINS	Controls execution flow
INRULE	Reads in rules
PROC	Processes a rule
QUERY	Asks user when all else fails
QUEST	Processes a premise
STKRUL	Finds rules relevant to keyword

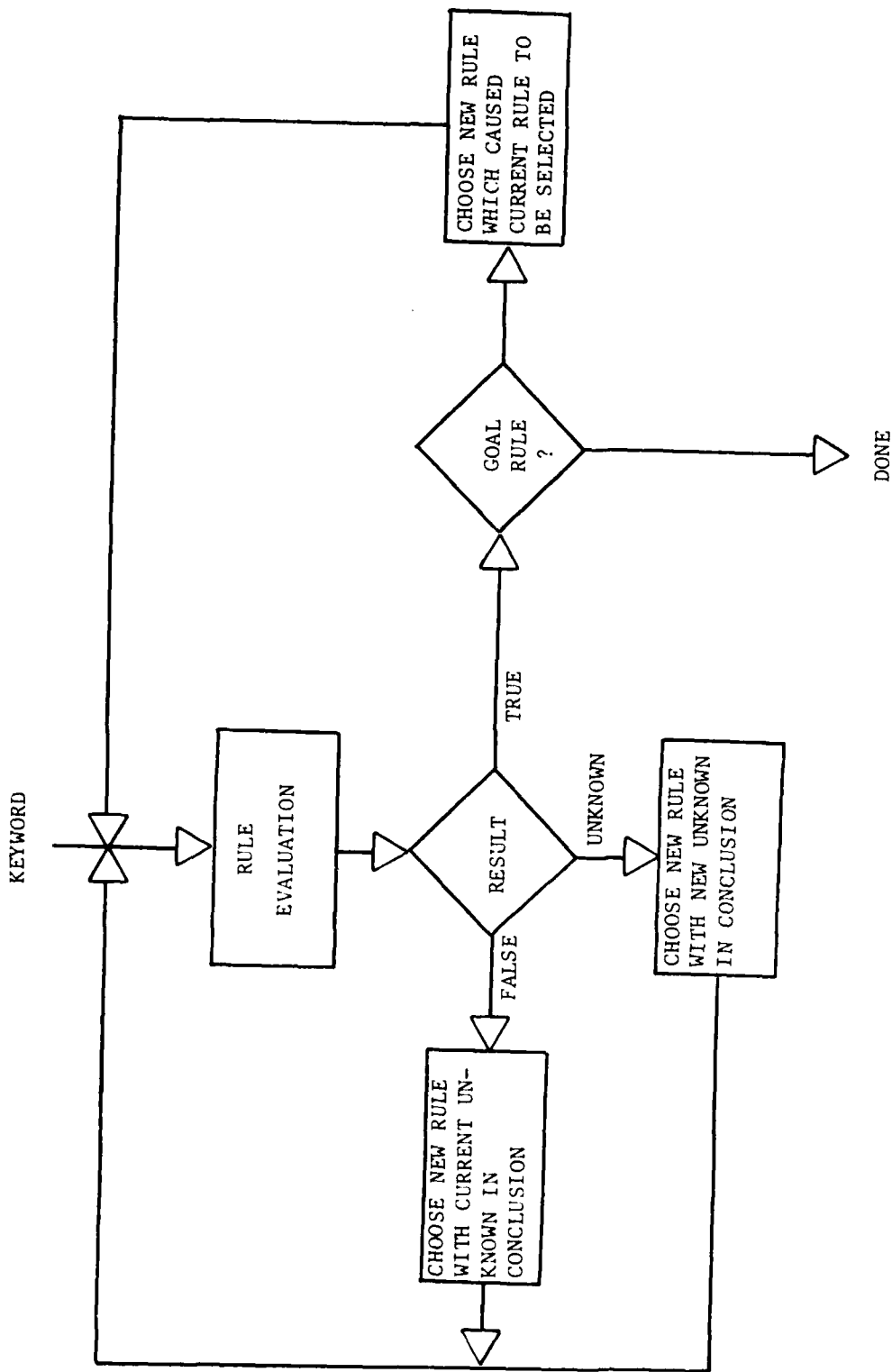


Figure 1 Algorithm of Rule Execution

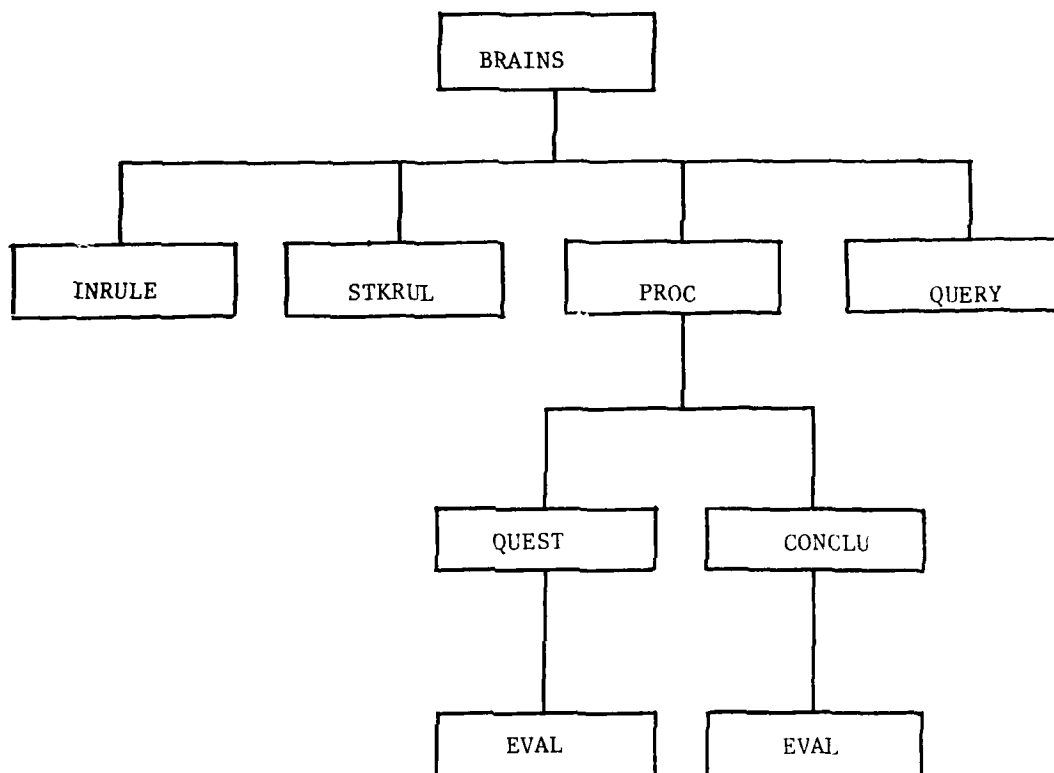


Figure 2 Flow Diagram of the Consultation System

### III. KNOWLEDGE BASE FOR FINITE ELEMENT STRUCTURAL ANALYSIS

In the previous section a knowledge based consultation system has been discussed in great detail. The system asks for a 'keyword' from the user and searches through the rules previously defined in a knowledge data base for an answer. If a conclusion can be drawn from the rules stored in the knowledge base, the system will respond to the user's question (keyword) with a positive answer. Otherwise, the system will indicate that currently it is not possible for the system to answer the user's question for lack of expertise in his question. It is obvious that the knowledge base must be constantly updated because new knowledge is required for dealing with new situations.

The application of finite element methods to structural analysis has long been recognized. During this investigation, an attempt has been made to establish a finite element structural analysis knowledge base for the purpose of demonstrating the use of the current knowledge based consultation system for finite element structural analysis. As an initial attempt, this knowledge base is limited to the use of MARC - a general purpose finite element program [5]. Extension of this knowledge base to include other programs is possible in future investigations. In this section, a description of this finite element structural analysis knowledge base is presented.

1. Finite Element Structural Analysis Information

In a structural analysis, there are at least three principal stages where questions must be answered and decisions must be made by engineers. These stages generally include: (1) pre-analysis, (2) analysis and (3) post-analysis. A summary of necessary information associated with these stages is given below.

a. Pre-Analysis Stage

Prior to performing a structural analysis, the type of analysis and the method of analysis are two most important questions to be answered by an analyst. Since the finite element method has been chosen for the method of analysis in the current investigation, only the type of analysis remains to be determined. Generally, the type of analysis of a structure can be adequately defined by the knowledge of: (a) geometrical configuration of the structure, (b) loading environment, (c) material behavior and (d) time dependency of the structural response. With sufficient knowledge of the geometry, loading, material and expected response of the structure, a specific type of analysis (i.e. static, dynamic, linear-elastic, elastic-plastic, small-displacement, large-displacement, etc.) can be reasonably recommended by an expert consultant. As a result, this set of information is the very first group of data stored in the current finite element structural analysis knowledge base.

b. Analysis Stage

The information in the analysis stage consists of input data of the structural problem to be analyzed and the response (output) of the structural system subjected to given loading conditions. The data is generally numerical data or in the form of alphanumerics. Within the context of finite element analysis, the analyst must usually supply the following information: (a) finite element mesh, in the form of element connectivity and nodal coordinates, (b) material properties (i.e. modulus of elasticity Poisson's ratio, yield stress, etc.), (c) loadings (i.e. mechanical, thermal, point-load, distributed-load, etc.) and displacement boundary conditions, and (d) transient conditions. On the basis of this information, an input-file can be generated for numerical analysis using a finite element structural analysis program (e.g. MARC). The execution of the finite element structural analysis program yields the desired response of the structural system. In the current finite element structural analysis knowledge base this set of information is stored numerically, and transformed into the input format of the MARC program for execution.

c. Post-Analysis Stage

The results of a finite element structural analysis consist of nodal and element quantities. The values associated with nodal points are generally displacements, velocities, accelerations and temperatures while the element quantities are often stresses, strains and temperatures. This set of information can be carefully

studied for adequacy of the analysis and for the recommendation of further analysis. Examination of the analysis results is also included in the current finite element structural analysis knowledge base.

## 2. Knowledge Based Rules and Key-Words

Since the current knowledge based consultation system has been developed on the basis of internal search of knowledge based rules and user input key-words, a set of knowledge based rules and key-words has been established for the finite element structural analysis. A list of the rules is given in Appendix A and all the key-words are listed in Table 1. During a consultation, the user must input the key-words as listed in Table 1 in order to activate the knowledge based rules for recommendations to his problem. No conclusion will be drawn by the consultation system if an inappropriate key-word is used. The key-words must be used one at a time and the order of the key-words may, or may not, be important.

The first group of knowledge based rules are prepared for acquiring alphabetic or numerical information from the user for the understanding of his structural problem by asking the user a general question. As an example in RULE 201 and RULE 202 the information sought for are 'DIMENSIONALITY' of the structure and the total number of elements 'NUMEL' in the mesh, respectively.

```

RULE 201
ASK 'MARCINO1' 1 0 1 DIMENSIONALITY
.
.
CONCLUDE GENERAL_ONE IS 'GIVEN'
RULE 202
ASK 'MARCIN31' 1 0 1 NUMEL
.
.
CONCLUDE GENERAL_TWO IS 'GIVEN'

```

The key-words to be used for activating these rules are GENERAL\_ONE and GENERAL\_TWO and the questions are stored on files 'MARCINO1' and 'MARCIN31', respectively. Further details are given in Appendix A.

```

FILE 'MARCINO1'
MARCINO1GENERAL
OC15
1PLEASE ENTER DIMENSIONALITY OF YOUR
1STRUCTURE: ONE, TWO OR THREE

```

```

FILE 'MARCIN31'
MARCIN31GENERAL
OI
1PLEASE ENTER TOTAL NUMBER OF ELEMENTS IN THE MESH

```

In answering these questions, the user must input either ONE, TWO, or THREE for DIMENSIONALITY and a numerical value (say 10, 10 elements in the mesh) for NUMEL.

The next group of knowledge based rules are intended for decision making on the basis of available information. For example in RULE 1 the GEOMETRY of the structure is concluded to be ONE\_DIMENSIONAL\_BEAM, from the available information that the DIMENSIONALITY of the structure is ONE and the overall THICKNESS of the structure is THIN\_SLENDER. In addition, MARC Element No. 5 (See Appendix B) is chosen (JTYPE = 5) for the finite element mesh and the GEOMETRY\_CHECK is concluded to be OK.



```

RULE 1
IF DIMENSIONALITY IS 'ONE'
IF THICKNESS IS 'THIN_SLENDER'
CONCLUDE JTYPE = 5
WRITE 0 :
FORMAT ('MARC ELEMENT NO 5 SELECTED FOR THE ANALYSIS')
CONCLUDE GEOMETRY_CHECK IS 'OK'
CONCLUDE GEOMETRY IS 'ONE_DIMENSIONAL_BEAM'

```

For the execution of RULE 1, the key-word is either GEOMETRY or GEOMETRY\_CHECK.

The third group of rules are developed for creating an input file for the execution of the MARC Program. An example is shown in RULE 203.

```

RULE 203
OPEN 'INPUT1' 1 80
WRITE 0 :
FORMAT ('SET DEFAULTS MAXALL ETC')
CONCLUDE MAXALL = 10000
CONCLUDE NUMBC = 200
CONCLUDE MPRMAX = 10
CONCLUDE MESHRR = 5
CONCLUDE MCRD = 3
CONCLUDE NBINC = 100
CONCLUDE FACTOR = 0.1
CONCLUDE NWKSLP = 1
WRITE 0 :
FORMAT ('WRITE TITLE CARD ON INPUT1')
WRITE 1 :
FORMAT ('TITLE TEST INPUT FOR AI')
WRITE 1 :
FORMAT ('PRIME,5500024,')
WRITE 0 :
FORMAT ('WRITE SIZING CARD ON INPUT1')
WRITE 1 MAXALL NUMEL NUMNP NUMBC MPRMAX JTYPE : 1 1 1
FORMAT ('SIZING ',I10,5I5)
CONCLUDE P_CARD_ONE IS 'GIVEN'

```

In RULE 203 file 'INPUT1' is opened first for the storage of input data, and then default values (MAXALL = 10000, NUMBC = 200, etc) are pre-set. P\_card images (See Appendix B) of MARC input data (partial) are created and temporarily stored on file 'INPUT1' for final merge. It can be seen that the key-word for the execution of RULE 203 is P\_CARD\_ONE.

After temporary files 'INPUT1', 'INPUT2' and 'INPUT3' being created for P\_CARD M\_card and L\_card images of MARC input data, a merge of these three files into a final input file 'INPUT' takes place. The merge operation is carried out by the execution of RULE 216, using the key-word INPUT\_FILE.

```
RULE 216
CLOSE 1
CLOSE 2
CLOSE 3
MERGE 'INPUT1' 'INPUT2' 'INPUT3' 'INPUT'
CONCLUDE INPUT_FILE IS 'GIVEN'
```

Additional rules have been written for the review of MARC results and for the recommendation of reanalysis. RULE 251 and RULE 252 are two examples. The key-words for these two rules are RESULT\_ONE, RESULT\_TWO, respectively.

```
RULE 251
OPEN 'USDATA' 1 40
READ 1 IR : 1 1 1
FORMAT (15)
READ 1 VMAX : 1 9 1
FORMAT (E15.4)
WRITE 0 :
FORMAT ('READ SUMMARY OF MARC RESULTS FROM USDATA')
CONCLUDE AA = VMAX(1)
CONCLUDE AB = VMAX(2)
CONCLUDE AC = VMAX(3)
CONCLUDE AD = VMAX(4)
CONCLUDE AE = VMAX(5)
CONCLUDE AF = VMAX(6)
CONCLUDE AG = VMAX(7)
CONCLUDE AH = VMAX(8)
CONCLUDE AI = VMAX(9)
CONCLUDE RESULT_ONE IS 'GIVEN'
```

```
RULE 252
WRITE O IF : 1 1 1
FORMAT (RESULTS FOR INCREMENT NO      ',15)
WRITE O AA : 1 1 1
FORMAT ('MAX XX STRAIN IS          ',E15.4)
WRITE O AB : 1 1 1
FORMAT ('MAX YY STRAIN IS          ',E15.4)
WRITE O AC : 1 1 1
FORMAT ('MAX XY STRAIN IS          ',E15.4)
WRITE O AD : 1 1 1
FORMAT ('MAX EQUIV. PLASTIC STRAIN IS      ',E15.4)
WRITE O AE : 1 1 1
FORMAT ('MAX EQUIV. CREEP STRAIN IS        ',F15.4)
WRITE O AF : 1 1 1
FORMAT ('MAX XX STRAIN IS          ',E15.4)
WRITE O AG : 1 1 1
FORMAT ('MAX YY STRESS IS          ',E15.4)
WRITE O AH : 1 1 1
FORMAT ('MAX XY STRESS IS          ',E15.4)
WRITE O AI : 1 1 1
FORMAT ('MAX EQUIV. STRESS          IS      ',E15.4)
CONCLUDE RESULT_TWO IS 'GIVEN'
```

### 3. Reasoning Steps

As mentioned in Section 1, the pre-analysis stage information dictates the type of structural analysis to be performed and the analysis stage information provides input to a finite element analysis program for numerical results. In the current investigation, this information is transferred from the user to the knowledge based consultation system through the execution of knowledge rules activated by key-words. Based on the available information, decisions are generally made directly from the user's input, or from previously derived conclusions. As an example of dealing with the pre-analysis stage information assume that the answers provided by the user to the questions in RULE 201 are:

Dimensionality of the structure	is	TWO
Overall thickness of the structure	is	THIN_FLAT
Type of loading	is	THERMO_MECHANICAL
Time dependency of mechanical loads	is	INDEPENDENT
Temperature level of the structure	is	HIGH
Stress-strain relation of the material	is	NON-LINEAR

Then the following conclusions will be drawn by the consultation system directly from user information.

- a. RULE 101  
MARC ELEMENT NO 3 SELECTED FOR THE ANALYSIS  
GEOMETRY IS 'TWO\_D\_PLANE\_STRESS'
- b. RULE 13  
LOADING IS 'ELEVATED\_THERMO\_MECHANICAL'
- c. RULE 19  
MATERIAL IS 'NON\_LINEAR\_STRESS\_STRAIN'

On the basis of the above conclusions, further decisions are made by the consultation system with regard to the type of analysis:

- d. RULE 23  
ANALYSIS\_TWO IS 'ELASTIC\_PLASTIC'
- e. RULE 26  
ANALYSIS\_THREE IS 'CREEP'

Consequently, a two-dimensional plane-stress, elastic-plastic-creep analysis is recommended to the user for his structural analysis problem by the consultation system. It is obvious from the above example that no numerical input is required for the pre-analysis stage.

In dealing with the analysis-stage information, which is essentially a transformation of a physical model (real structure) into a numerical model (input data) for finite element analysis, the process is usually tedious and cumbersome. The user is always burdened with a large quantity of numerical data and various input formats. The current consultation system only requires necessary information about the structure system from the user, and makes the decisions for the user to comply with the MARC program input requirements. Since the current consultation system does not contain automated capabilities such as mesh generators and built-in material properties, the user must input this group of information through various key-words. Consequently, the user must supply first a number of counters (e.g. number of elements, number of nodes, number of boundary conditions, etc.) and then input additional information sets associated with these counters. An example of this process is that the user defines the number of nodal points (NUMNP) in the mesh by executing RULE 202 using key-word GENERAL\_TWO.

```
RULE 202
:
:
ASK 'MARCIN32' 1 0 1 NUMNP
:
:
```

and then input nodal point coordinates for NUMNP times through the execution of RULE 222 USING KEY-WORD COORDINATES.

```
RULE 222
ASK 'COORDINA' NUMNP 0 4 IDNODE XA XB XC
CONCLUDE COORDINATES IS 'GIVEN'
```

The nodal coordinates  $X$ ,  $Y$ ,  $Z$ ,  $i = 1, 2, \dots, \text{NUMNP}$  are stored in arrays  $XA$ ,  $XB$  and  $XC$ , respectively. The acquisition of nodal point coordinates for  $\text{NUMNP}$  times is decided by the consultation system. Obviously, RULE 202 must be executed before the execution of RULE 222 because the variable  $\text{NUMNP}$  is being used in RULE 222 and must be defined.

The reasoning steps discussed in this section are by no means complex ones. However, these simple decision making procedures serve well to illustrate the use of the knowledge based consultation system for finite element structural analysis.

TABLE 1 KEY-WORD LIST

GENERAL_ONE	GENERAL_TWO	GEOMETRY
LOADING	MATERIAL	ANALYSIS_ONE
ANALYSIS-TWO	ANALYSIS_THREE	ANALYSIS_FOUR
ANALYSIS_FIVE	CONNECTIVITY	COORDINATES
EMT_THICKNESS	THICKNESS_RANGE	BASE_PROPERTY
MATERIAL_RANGE	BOUNDARY_C	POINT_LOAD
DIST_LOAD	WORK_HARDENING	TEMP_EFFECTS
P_CARD_ONE	P_CARD_TWO	P_CARD_THREE
P_CARD_FOUR	M_CARD_ONE	M_CARD_TWO
M_CARD_THREE	L_CARD_ONE	GEOMETRY_CHECK
LOADING_CHECK	MATERIAL_CHECK	ANALYSIS_CHECK
KEY_WORD_LIST	INPUT_FILE	P_CARD_FIVE
L_CARD_TWO	L_CARD_THREE	L_CARD_FOUR
L_CARD_FIVE	RESULT_ONE	RESULT_TWO
RESULT_THREE		

#### IV. EXAMPLE CONSULTATIONS

For the purpose of demonstrating the application of the current consultation system to structural analysis, a two-dimensional plane-stress problem was analyzed using the MARC program. In this section, a description of the problem and the procedure of using the consultation system for structural analysis are discussed. A list of the conversations held during the consultation is given in Appendix C.

##### 1. Description of the Structure

As shown in Fig. 3, the structure is a two-dimensional rectangular thin plate with a circular hole located at the center of the plate. It is subjected to a uniformly distributed tensile load along the major axial direction of the plate. The material properties of the plate are assumed to be: Modulus of Elasticity =  $30 \times 10^6$  psi, Poisson's Ratio = 0.3, Yield stress = 20,000 psi, and the plate thickness is 1.0 inch. Due to the symmetry conditions existing in the problem, only one-quarter of the structure is needed for finite element analysis. A finite element mesh is also shown in Fig. 3 where both the x- and y- axis are lines of symmetry. The mesh consists of 8 elements and 15 nodal points.

##### 2. Pre-analysis and Analysis Stages (Initial Consultation)

Fig. 4 shows a schematic of the consultation procedure. The system initially asks for general information about the structure for the determination of the type of analysis to be performed and then seeks additional information about the finite element model for the preparation of the MARC input file. A summary of this group of information is as follows:



a. General Information

- The structure is two-dimensional.
- The appearance of the structure is thin and flat.
- The loading is mechanical and is independent of time. It is a uniformly distributed load.
- The temperature environment is room temperature.
- The structure consists of one material.
- The thickness of the plate is uniform.
- The structure has two lines of symmetry (x- and y- axis).

b. Finite Element Model

- Element No.	and	Element Connectivity			
1		1	2	5	4
2		2	3	6	5
3		4	5	8	7
4		5	6	9	8
5		7	8	11	10
6		8	9	12	11
7		10	11	14	13
8		11	12	15	14

- Node No.	and	Nodal Coordinates	
1		3.0	0.0
2		4.5	0.0
3		6.0	0.0
4		2.772	1.148
5		4.386	2.574
6		6.0	4.0
7		2.121	2.121
8		4.06	5.06
9		6.0	8.0
10		1.148	2.772
11		2.074	5.386
12		3.0	8.0
13		0.0	3.0
14		0.0	5.5
15		0.0	8.0

- Plate Thickness

1.0

- Material Properties

Modulus of Elasticity =  $30 \times 10$

Poisson's Ratio = 0.3

Yield Stress = 20,000

- Boundary Conditions (at lines of symmetry)

U = 0 at nodes 13, 14, 15 (Horizontal Displacement)

V = 0 at nodes 1, 2, 3 (Vertical Displacement)

- Loading

Traction = 10000 (tension)

Associated Elements 6, 8

Face Identification 6 (see Appendix B)

A MARC input file, generated by the consultation system, is shown in Table 2. This input file is compatible with the analysis recommended by the consultation system: a two-dimensional, plane-stress, linear-elastic analysis using MARC element number 3.

### 3. Execution of the MARC Program

During this investigation, the execution of the MARC program and the summarization of MARC results have been carried out separately from the consultation system. This approach is not always necessary but has certain advantages. An off-line execution of the MARC program frees the consultation system and the user from waiting for the program execution. The system can thus be used for further consultations. After the execution of the MARC program, a summary of MARC results (maximum stresses and strains) is written on a file called 'USDATA'. This file is reviewed by the consultation system for making additional recommendations.

4. Post-Analysis Stage (Second Consultation)

During a post-analysis stage, the consultation system compares stresses and strains with given criteria such as yielding of the material and strain limit requirements set by design codes. A reanalysis is recommended if the built-in limits are violated. It can be seen from Table 2 that the maximum equivalent stress (29,820 psi) in the plate does exceed the yield stress of the material (20,000 psi). The system, therefore, recommends a reanalysis to include the effect of plastic flow in the plate.

5. Reanalysis (Third Consultation)

The procedure of setting up a reanalysis is a repeat of the steps 2, 3, and 4. In the current example, the only additional information required for the reanalysis is:

- The stress-strain relation of the material is non-linear.

The reanalysis results show that the built-in inelastic strain limit (5%) has not been violated. Therefore, a further analysis is not required. As a result, the consultation is completed. MARC input data for the reanalysis is given in Table 4 and a summary of the reanalysis results is shown in Table 5.

TABLE 2 MARC INPUT DATA (SAMPLE PROBLEM)

```

TITLE          TEST INPUT FOR AT
PRIME,5500024.
SIZING         10000      8    15  200   10    3
ALL POINTS
END
CONNECTIVE
  8    5
  1    3    1    2    5    4    0    0    0    0
  2    3    2    3    6    5    0    0    0    0
  3    3    4    5    8    7    0    0    0    0
  4    3    5    6    9    8    0    0    0    0
  5    3    7    8    11   10   0    0    0    0
  6    3    8    9    12   11   0    0    0    0
  7    3   10   11   14   13   0    0    0    0
  8    3   11   12   15   14   0    0    0    0
COORDINATE
  3   15    5
  1   3.00000  0.00000  0.00000
  2   4.50000  0.00000  0.00000
  3   6.00000  0.00000  0.00000
  4   2.77200  1.14800  0.00000
  5   4.38600  2.57400  0.00000
  6   6.00000  4.00000  0.00000
  7   2.12100  2.12100  0.00000
  8   4.06000  5.06000  0.00000
  9   6.00000  8.00000  0.00000
 10   1.14800  2.77200  0.00000
 11   2.07400  5.38600  0.00000
 12   3.00000  8.00000  0.00000
 13   0.00000  3.00000  0.00000
 14   0.00000  5.50000  0.00000
 15   0.00000  8.00000  0.00000
PROPERTY
  1
  0.300E 08 0.300E 00 0.000E 00 0.000E 00 0.000E 00 0.200E 05 0.200E 05
  1    8
GEOMETRY
  1
  1.00000  0.00000  0.00000
  1    8
BOUNDARY C
  6
  1    1    2    2  0.000E 00
  2    2    2    2  0.000E 00
  3    3    2    2  0.000E 00
 13   13    1    1  0.000E 00
 14   14    1    1  0.000E 00
 15   15    1    1  0.000E 00

```

TABLE 2 MARC INPUT DATA (SAMPLE PROBLEM)  
(Continued)

```
TRACTIONS
  1  1
  2  6
  6  8
-10000.0000
  15 0.00000  0.00000  0.00000
CONTROL
  100
  0.100E 00
POST
  9
  1
  2
  3
  27
  37
  11
  12
  13
  17
END OPTION
```

TABLE 3 SUMMARY OF MARC RESULTS (SAMPLE PROBLEM)

RESULTS FOR INCREMENT NO		
MAX XX STRAIN IS	-0.3556E-03	
MAX YY STRAIN IS	0.1010E-02	
MAX XY STRAIN IS	-0.4184E-03	
MAX EQUIV. PLASTIC STRAIN IS		0.0000E 00
MAX EQUIV. CREEP STRAIN IS		0.0000E 00
MAX XX STRESS IS	-0.1000E 05	
MAX YY STRESS IS	0.3157E 05	
MAX XY STRESS IS	-0.4828E 04	
MAX EQUIV. STRESS IS		0.2982E 05

TABLE 4 MARC INPUT DATA (REANALYSIS)

```

TITLE          TEST INPUT FOR AT
PRIME,5500024,
SIZING          10000   8   15  200  10   3
ALL POINTS
SCALE
END
CONNECTIVE
  8   5
  1   3   1   2   5   4   0   0   0   0
  2   3   2   3   6   5   0   0   0   0
  3   3   4   5   8   7   0   0   0   0
  4   3   5   6   9   8   0   0   0   0
  5   3   7   8  11  10   0   0   0   0
  6   3   8   9  12  11   0   0   0   0
  7   3  10  11  14  13   0   0   0   0
  8   3  11  12  15  14   0   0   0   0
COORDINATE
  3  15   5
  1  3.00000  0.00000  0.00000
  2  4.50000  0.00000  0.00000
  3  6.00000  0.00000  0.00000
  4  2.77200  1.14800  0.00000
  5  4.38600  2.57400  0.00000
  6  6.00000  4.00000  0.00000
  7  2.12100  2.12100  0.00000
  8  4.06000  5.06000  0.00000
  9  6.00000  8.00000  0.00000
 10  1.14800  2.77200  0.00000
 11  2.07400  5.38600  0.00000
 12  3.00000  8.00000  0.00000
 13  0.00000  3.00000  0.00000
 14  0.00000  5.50000  0.00000
 15  0.00000  8.00000  0.00000
PROPERTY
  1
  0.300E 08 0.300E 00 0.000E 00 0.000E 00 0.000E 00 0.200E 05 0.200E 05
  1   8
GEOMETRY
  1
  1.00000  0.00000  0.00000
  1   8
BOUNDARY C
  6
  1   1   2   2 0.000E 00
  2   2   2   2 0.000E 00
  3   3   2   2 0.000E 00
 13  13   1   1 0.000E 00
 14  14   1   1 0.000E 00
 15  15   1   1 0.000E 00

```



TABLE 4    MARC INPUT DATA (REANALYSIS)  
(Continued)

TRACTIONS

1    1  
2    6  
6    8  
-10000.0000  
15   0.00000    0.00000    0.00000

CONTROL

100  
0.100E 00

POST

9  
1  
2  
3  
27  
37  
11  
12  
13  
17

END OPTION

PROPORTIONAL INCREMENT

0    0.1000E 00

AUTO LOAD

5

CONTINUE

TABLE 5 SUMMARY OF MARC RESULTS (REANALYSIS)

RESULTS FOR INCREMENT NO	6	
MAX XX STRAIN IS	-0.4191E-03	
MAX YY STRAIN IS	0.1683E-02	
MAX XY STRAIN IS	-0.7739E-03	
MAX EQUIV. PLASTIC STRAIN IS		0.1025E.02
MAX EQUIV. CREEP STRAIN IS		0.0000E 00
MAX XX STRESS IS	-0.1211E 05	
MAX YY STRESS IS	0.2236E 05	
MAX XY STRESS IS	0.4743E 04	
MAX EQUIV. STRESS	IS	0.2002E 05

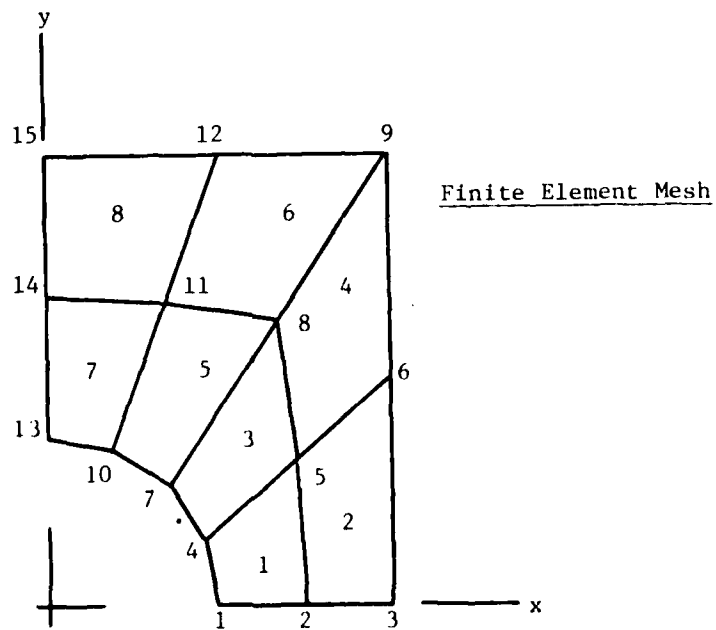
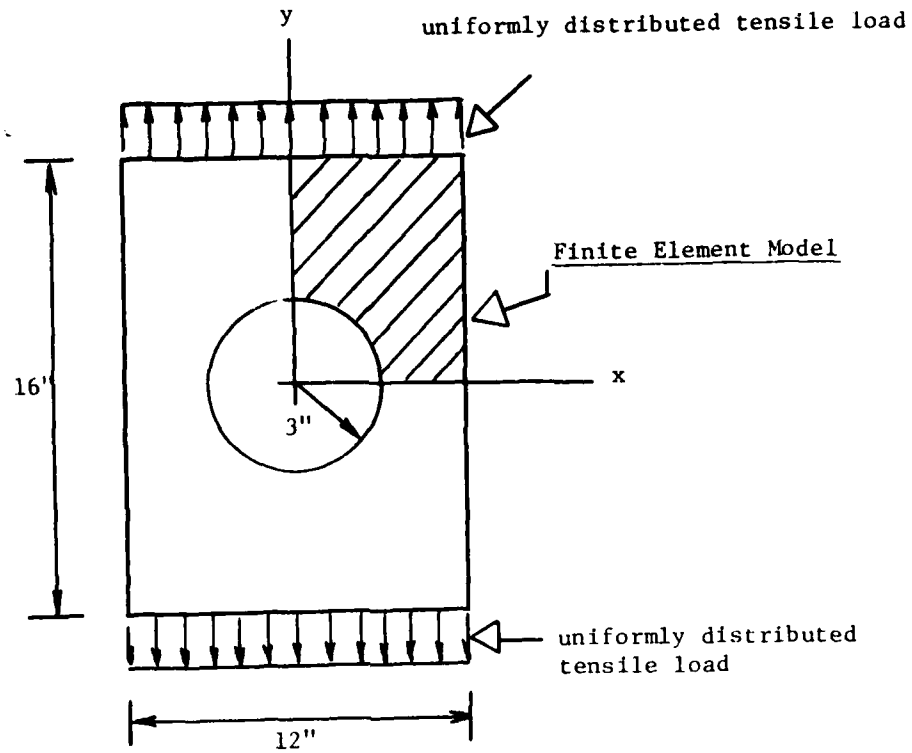


Figure 3 Plate With Hole (Sample Problem)

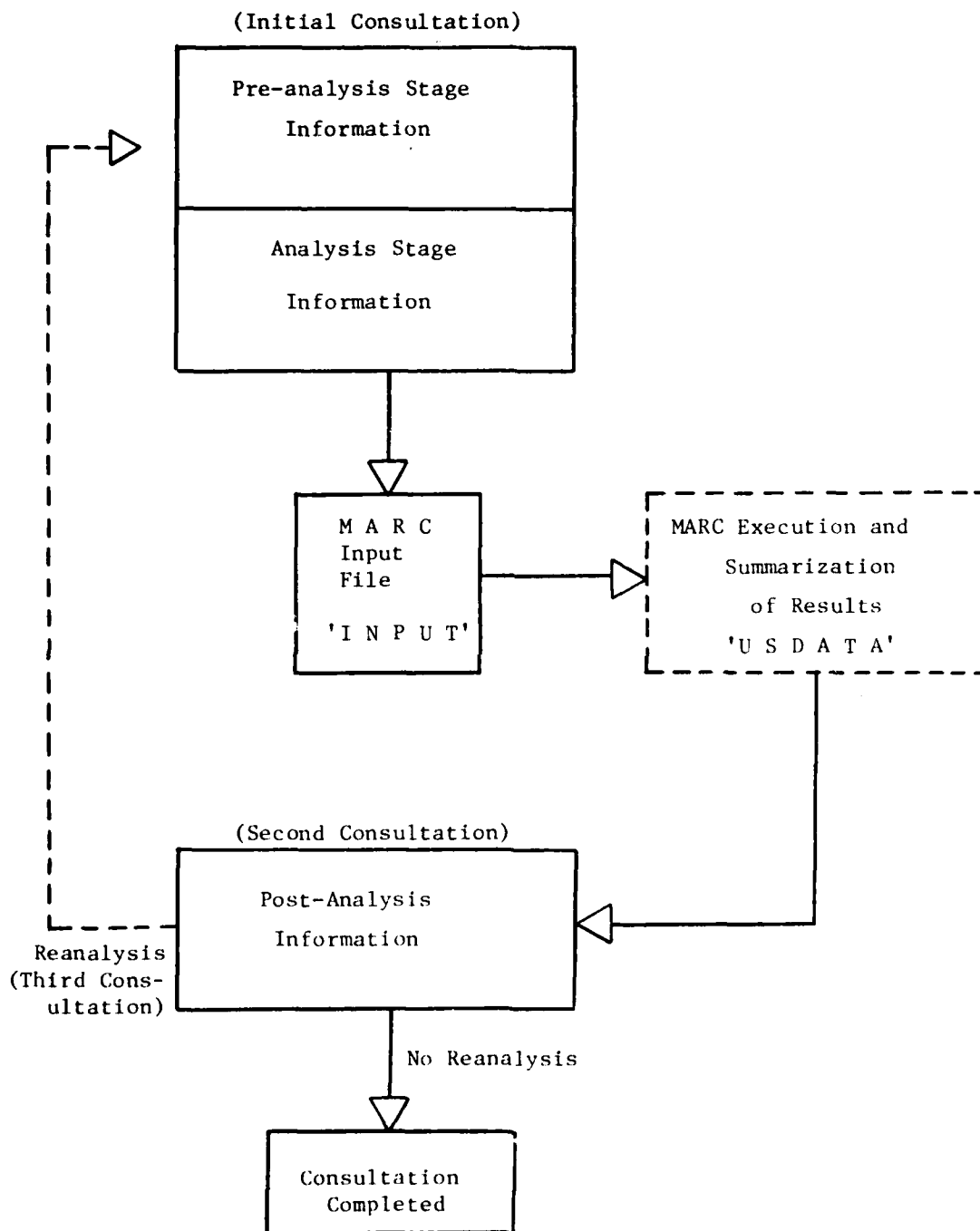


Figure 4 Schematic of Example Consultations

## V. DISCUSSION AND CONCLUSIONS

The consultation system discussed in previous sections is a reasonably well designed system. The flexibility of the inference engine in the system allows the incorporation of an interface to existing software, and the modularity of the rule representation makes the rule sets easy to modify. With the help of a library of commands in the system, a rule set which represents an area of expertise can be conveniently established.

The system provides a simplified approach to the use of a general purpose finite element analysis program. It asks for information about the structure, loading, material, etc., directly from an analyst through sessions of consultations. The questions to be asked by the system during a consultation can be activated using a finite number of keywords. As a further refinement, these keywords can be pre-specified for different classes of problems. The introduction of keywords to the current system greatly reduces the user's work to find out various input formats from numerous pages of information in a Program User's Manual. In addition, the free format input available in the system further helps the user to minimize his input effort.

The current system can help an analyst to perform a reasonable structural analysis with minimized engineering effort. It recommends the type of analysis to be performed; reviews analysis results; and suggests, if necessary, additional reanalysis. As demonstrated in Section IV, after a simple question-answer session between a user and the consultation system, the necessary information for a structural analysis problem has been collected by the system. It not only makes recommendations to the user for

the type of analysis to be performed, but also creates for the user an input file for the execution of the MARC program. Later, in a second consultation, after the completion of the MARC execution, the system reviews the MARC results, checks against built-in stress and strain limits, and makes additional recommendations with regard to the necessity of a reanalysis. Finally, after reviewing the results of the reanalysis, the system recommends that no further analysis is required. The advantage of using a consultation system to economize the engineer effort for a structural analysis is evident.

The current knowledge base contains a limited amount of information about structural configurations and loading environments. Recommendations given by the consultation system are, therefore, restricted to a few analyses and certain elements of the MARC program. The analyses are: elastic, elastic-plastic, creep, dynamic and large displacement. The elements are: two-node straight beam (Element No. 5), four-node quadrilaterals (Elements No. 3 and No. 11), and eight-node brick (Element No. 7). Expansion of current knowledge base to include additional analyses and more elements can be easily achieved in future investigations. In addition, the inclusion of automated data generators into the system will certainly help to minimize the input efforts.

The current system behaves well. However, a continuous growth of the system is highly dependent on both the improvement of the inference engine and the expansion of the knowledge base.

## REFERENCES

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4. Melosh, R. J., Berke, L., Marcal, P. V., "Structural Analysis Consultation Using Artificial Intelligence", the Symposium on Future Trends in Computerized Structural Analysis and Synthesis", Joint Institute for Advancement of Flight Sciences and the National Aeronautics Space Administration, October 30, 1978.
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APPENDIX A

Knowledge Based Rules  
For  
Finite Element Structural Analysis



In this appendix, a list of knowledge based rules for finite element structural analysis and a list of questions associated with these rules are given. These rules and questions were developed for dealing with all three stages (pre-analysis, analysis and post-analysis) of information in a finite element structural analysis. The analysis is assumed to be carried out using the MARC program [5].

In current study, although the format of a knowledge based rule is uniquely defined,

```
RULE NUMBER
(PREMISE)
CONCLUSION
```

the variations of premises in a rule can provide different functions. As an illustration, various functions of the rules are discussed below:

1. Standard Evaluation

This type of rule draws conclusion on the basis of 'TRUE' or 'FALSE' of the premises in the rule. An example is RULE 1:

```
RULE 1
IF DIMENSIONALITY IS 'ONE'
IF THICKNESS IS 'THIN_SLENDER'
CONCLUDE JTYPE = 5
WRITE 0 :
FORMAT ('MARC ELEMENT NO 5 SELECTED FOR THE ANALYSIS')
CONCLUDE GEOMETRY_CHECK IS 'OK'
CONCLUDE GEOMETRY IS 'ONE_DIMENSIONAL_BEAM'
```

The three conclusions in RULE 1 can be successfully arrived at only if the variables DIMENSIONALITY and THICKNESS are defined as ONE and THIN\_SLENDER, respectively.

## 2. Acquisition of Input Data

This type of rule asks the user a specific question for a piece of specific information. The user is obliged to answer the question by inputting appropriate alphabetical or numerical data. RULE 201 and RULE 202 illustrate this application.

```
RULE 201
ASK 'MARCINO1' 1 0 1 DIMENSIONALITY
CONCLUDE GENERAL_ONE IS 'GIVEN'
```

```
RULE 202
ASK 'MARCIN31' 1 0 1 NUMEL
CONCLUDE GENERAL_TWO IS 'GIVEN'
```

The variables to be defined in these rules are DIMENSIONALITY in RULE 201 and NUMEL in RULE 202. An alphabetical data and a numerical data must be supplied by the user for the variables DIMENSIONALITY and NUMEL, respectively. The questions to be answered by the user are stored in files 'MARCINO1' and 'MARCIN31' in the following form:

```
FILE 'MARCINO1'
MARCINO1GENERAL
OC15
1PLEASE ENTER DIMENSIONALITY OF YOUR
2STRUCTURE : ONE, TWO OR THREE
3THE VALUE IS ONE, TWO OR THREE
```

```
FILE 'MARCIN31'
MARCIN31GENERAL
OI
1PLEASE ENTER TOTAL NUMBER OF ELEMENTS IN THE MESH
2THE VALUE IS AN INTEGER
```

We note that the variable DIMENSIONALITY is defined as a character field (C15) and the variable NUMEL is defined as an integer field of free format (I). The integers 1 0 1 appeared in RULE 201 and RULE 202 serve as counters for the question and the variable, respectively.

IF the input data is in the form of arrays, then the counters must be

modified for accommodating the situation. An example is shown in RULE 222 where the coordinates of all the nodal points in the mesh must be supplied by the user.

```
RULE 222
ASK 'COORDINA' NUMNP 0 4 IDNODE XA XB XC
CONCLUDE COORDINATES IS 'GIVEN'
```

It can be seen that the question to be answered by the user is stored in file 'COORDINA', and the nodal coordinates  $X, Y, Z, i = 1, 2, \dots$ , NUMNP are stored in variable arrays XA, XB, XC, respectively. The array IDNODE stores the nodal point identifier while the integers NUMNP 0 4 serve as counters for the question and the arrays, respectively.

The contents on file 'COORDINA' is shown below:

```
COORDINANODE
OI R R RO
1PLEASE ENTER NODAL COORDINATES AS FOLLOWS :
1NODAL NUMBER FOLLOWED BY
1 TWO NODAL COORDINATES FOR NODAL POINT OF TWO
1 DMENSIONAL STRUCTURES OR
1 THREE NODAL COORDINATES FOR NODAL POINT OF THREE
1 DIMENSIONAL STRUCTURES
2THE VALUES ARE : ONE INTEGER FOR NODAL NUMBER
2FOLLOWED BY TWO REAL NUMBERS FOR NODAL POINT OF
2TWO DIMENSIONAL STRUCTURES OR, THREE REAL NUMBERS
2FOR NODAL POINT OF THREE DIMENSIONAL STRUCTURES
```

It asks for one integer (I) and three real numbers from the user NUMNP times. Both the integer and the real numbers are of free format and the third real number (Z) is optional (required for three-dimensional structures only).

### 3. File Manipulations

This type of rule is developed for I/O operations which are necessary for file manipulations. RULE 203 illustrates the creation of an input

file and RULE 216 demonstrates the merge of a number of files into one final file.

```
RULE 203
OPEN 'INPUT1' 1 -80
WRITE 0 :
FORMAT ('SET DEFAULTS MAXALL ETC')
CONCLUDE MAXALL = 10000
CONCLUDE NUMBC = 200
CONCLUDE MPRMAX = 10
CONCLUDE MESHR = 5
CONCLUDE NCRD = 3
CONCLUDE NBINC = 100
CONCLUDE FACTOR = 0.1
CONCLUDE NWKSLP = 1
WRITE 0 :
FORMAT ('WRITE TITLE CARD ON INPUT1')
WRITE 1 :
FORMAT ('TITLE          TEST INPUT FOR AI')
WRITE 1 :
FORMAT ('PRIME,5500024,')
WRITE 0 :
FORMAT ('WRITE SIZING CARD ON INPUT1')
WRITE 1 MAXALL NUMEL NUMNP NUMBC MPRMAX JTYPE : 1 1 1
FORMAT ('SIZING          ',I1C,5I5)
CONCLUDE P_CARD[ONE IS 'GIVEN'

RULE 216
CLOSE 1
CLOSE 2
CLOSE 3
MERGE INPUT1 INPUT2 INPUT3 INPUT
CONCLUDE INPUT_FILE IS 'GIVEN'
```

In addition, Rule 251 reads the summarized MARC results from a file 'USDATA' and Rule 252 shows a summary (maximum strains and stresses) of the analysis to the user for his review.

```

RULE 251
OPEN 'USDATA' 1 40
READ 1 IR : 1 1 1
FORMAT (I5)
READ 1 VMAX : 1 9 1
FORMAT (E15.4)
WRITE O :
FORMAT ('READ SUMMARY OF MARC RESULTS FROM USDATA')
CONCLUDE AA = VMAX(1)
CONCLUDE AB = VMAX(2)
CONCLUDE AC = VMAX(3)
CONCLUDE AD = VMAX(4)
CONCLUDE AE = VMAX(5)
CONCLUDE AF = VMAX(6)
CONCLUDE AG = VMAX(7)
CONCLUDE AH = VMAX(8)
CONCLUDE AI = VMAX(9)
CONCLUDE RESULT_ONE IS 'GIVEN'
RULE 252
WRITE O IR : 1 1 1
FORMAT ('RESULTS FOR INCREMENT NO      ',I5)
WRITE O AA : 1 1 1
FORMAT ('MAX XX STRAIN IS      ',E15.4)
WRITE O AB : 1 1 1
FORMAT ('MAX YY STRAIN IS      ',E15.4)
WRITE O AC : 1 1 1
FORMAT ('MAX XY STRAIN IS      ',E15.4)
WRITE O AD : 1 1 1
FORMAT ('MAX EQUIV. PLASTIC STRAIN IS      ',E15.4)
WRITE O AE : 1 1 1
FORMAT ('MAX EQUIV. CREEP STRAIN IS      ',E15.4)
WRITE O AF : 1 1 1
FORMAT ('MAX XX STRESS IS      ',E15.4)
WRITE O AG : 1 1 1
FORMAT ('MAX YY STRESS IS      ',E15.4)
WRITE O AH : 1 1 1
FORMAT ('MAX XY STRESS IS      ',E15.4)
WRITE O AI : 1 1 1
FORMAT ('MAX EQUIV. STRESS      IS      ',E15.4)
CONCLUDE RESULT_TWO IS 'GIVEN'

```

LIST OF RULES

```
RULE 301
WRITE O :
FORMAT ('THE FOLLOWING IS A KEY_WORD LIST')
WRITE O :
FORMAT ('GENERAL_ONE          GENERAL_TWO          GEOMETRY')
WRITE O :
FORMAT ('LOADING              MATERIAL          ANALYSIS_ONE')
WRITE O :
FORMAT ('ANALYSIS_TWO        ANALYSIS_THREE   ANALYSIS_FOUR')
WRITE O :
FORMAT ('ANALYSIS_FIVE       CONNECTIVITY     COORDINATES')
WRITE O :
FORMAT ('EMT_THICKNESS       THICKNESS_RANGE  BASE_PROPERTY')
WRITE O :
FORMAT ('MATERIAL_RANGE      BOUNDARY_C       POINT_LOAD')
WRITE O :
FORMAT ('DIST_LOAD           WORK_HARDENING   TEMP_EFFECTS')
WRITE O :
FORMAT ('P_CARD_ONE          P_CARD_TWO       P_CARD_THREE')
WRITE O :
FORMAT ('P_CARD_FOUR         M_CARD_ONE       M_CARD_TWO')
WRITE O :
FORMAT ('M_CARD_THREE        L_CARD_ONE       GEOMETRY_CHECK')
WRITE O :
FORMAT ('LOADING_CHECK       MATERIAL_CHECK    ANALYSIS_CHECK')
WRITE O :
FORMAT ('KEY_WORD_LIST      INPUT_FILE       P_CARD_FIVE')
WRITE O :
FORMAT ('L_CARD_TWO          L_CARD_THREE     L_CARD_FOUR')
WRITE O :
FORMAT ('L_CARD_FIVE')
CONCLUDE KEY_WORD_LIST IS 'DISPLACED'
RULE 201
ASK 'MARCINO1' 1 0 1 DIMENSIONALITY
ASK 'MARCINO2' 1 0 1 THICKNESS
ASK 'MARCINO3' 1 0 1 TYPE
ASK 'MARCINO4' 1 0 1 TIME
ASK 'MARCINO5' 1 0 1 TEMPERATURE
ASK 'MARCINO8' 1 0 1 STRESS_STRAIN
CONCLUDE GENERAL_ONE IS 'GIVEN'
RULE 202
ASK 'MARCIN31' 1 0 1 NUMEL
ASK 'MARCIN32' 1 0 1 NUMNP
ASK 'MARCIN38' 1 0 1 NBTHIC
ASK 'MARCIN39' 1 0 1 NTHRNG
ASK 'MARCIN33' 1 0 1 NUMMAT
ASK 'MARCIN34' 1 0 1 NBWKHD
ASK 'MARCIN35' 1 0 1 NBTEMP
ASK 'MARCIN36' 1 0 1 NMARNG
ASK 'MARCIN37' 1 0 1 NBBNDY
ASK 'MARCIN40' 1 0 1 NBPOIN
ASK 'MARCIN41' 1 0 1 NBDIST
ASK 'MARCIN42' 1 0 1 CPTIME
ASK 'MARCIN43' 1 0 1 DTIME
CONCLUDE GENERAL_TWO IS 'GIVEN'
```

```

RULE 203
OPEN 'INPUT1' 1 -80
WRITE 0 :
FORMAT ('SET DEFAULTS MAXALL ETC')
CONCLUDE MAXALL = 10000
CONCLUDE NUMBC = 200
CONCLUDE MPRMAX = 10
CONCLUDE MESHR = 5
CONCLUDE NCRD = 3
CONCLUDE NBINC = 100
CONCLUDE FACTOR = 0.1
CONCLUDE NWKSLP = 1
CONCLUDE NPOST = 12
CONCLUDE NEA = 1
CONCLUDE NEB = 2
CONCLUDE NEC = 3
CONCLUDE NED = 4
CONCLUDE NEE = 5
CONCLUDE NEF = 6
CONCLUDE NSA = 11
CONCLUDE NSB = 12
CONCLUDE NSC = 13
CONCLUDE NSD = 14
CONCLUDE NSE = 15
CONCLUDE NSF = 16
CONCLUDE MAXCYC = 0
CONCLUDE PRATIO = 0.1
CONCLUDE NBAUTO = 10
WRITE 0 :
FORMAT ('WRITE TITLE CARD ON INPUT1')
WRITE 1 :
FORMAT ('TITLE          TEST INPUT FOR AI')
WRITE 1 :
FORMAT ('PRIME,5500024,')
WRITE 0 :
FORMAT ('WRITE SIZING CARD ON INPUT1')
WRITE 1 MAXALL NUMEL NUMNP NUMBC MPRMAX JTYPE : 1 1 1
FORMAT ('SIZING          ',I10.5I5)
WRITE 0 :
FORMAT ('WRITE ALL POINTS CARD ON INPUT1')
WRITE 1 :
FORMAT ('ALL POINTS')
CONCLUDE P_CARD_ONE IS 'GIVEN'
RULE 206
IF TYPE IS 'MECHANICAL'
IF TIME IS 'INDEPENDENT'
IF TEMPERATURE IS 'HIGH'
WRITE 0 :
FORMAT ('WRITE CREEP CARD ON INPUT1')
WRITE 1 :
FORMAT ('CREEP')
CONCLUDE P_CARD_TWO IS 'GIVEN'

```

```

RULE 207
IF TYPE IS 'THERMAL'
IF TIME IS 'INDEPENDENT'
IF TEMPERATURE IS 'HIGH'
WRITE 0 :
FORMAT ('WRITE CREEP CARD ON INPUT1')
WRITE 1 :
FORMAT ('CREEP')
CONCLUDE P_CARD_TWO IS 'GIVEN'
RULE 208
IF TYPE IS 'THERMO_MECHANICAL'
IF TIME IS 'INDEPENDENT'
IF TEMPERATURE IS 'HIGH'
WRITE 0 :
FORMAT ('WRITE CREEP CARD ON INPUT1')
WRITE 1 :
FORMAT ('CREEP')
CONCLUDE P_CARD_TWO IS 'GIVEN'
RULE 209
IF TYPE IS 'MECHANICAL'
IF TIME IS 'DEPENDENT'
WRITE 0 :
FORMAT ('WRITE DYNAMIC CARD ON INPUT1')
WRITE 1 :
FORMAT ('DYNAMIC,2,')
CONCLUDE P_CARD_THREE IS 'GIVEN'
RULE 210
IF THICKNESS IS 'THIN_SLENDER'
WRITE 0 :
FORMAT ('WRITE LARGE DISP CARD ON INPUT1')
WRITE 1 :
FORMAT ('LARGE DISP')
CONCLUDE P_CARD_FOUR IS 'GIVEN'
RULE 214
IF STRESS STRAIN IS 'NON_LINEAR'
IF TIME IS 'INDEPENDENT'
IF TYPE IS 'MECHANICAL'
IF THICKNESS IS NOT 'THIN_SLENDER'
WRITE 0 :
FORMAT ('WRITE SCALE CARD ON INPUT1')
WRITE 1 :
FORMAT ('SCALE')
CONCLUDE P_CARD_FIVE IS 'GIVEN'

```



```

RULE 211
IF STRESS_STRAIN IS 'NON_LINEAR'
WRITE 0 :
FORMAT ('WRITE WORK HARD CARD ON INPUT2')
WRITE 2 NWKSLP WKHRDA WKHRDB : 1 1 1
FORMAT ('WORK HARD'/I5/2E15.5)
CONCLUDE M_CARD_TWO IS 'GIVEN'
RULE 212
IF TYPE IS 'THERMAL'
IF TIME IS 'INDEPENDENT'
IF TEMPERATURE IS 'HIGH'
WRITE 0 :
FORMAT ('WRITE CREEP CARD ON INPUT2')
WRITE 2 :
FORMAT ('CREEP')
WRITE 2 :
FORMAT ('      0  -1  0  0      1.075E-26'/' 5.5')
CONCLUDE M_CARD_THREE IS 'GIVEN'
RULE 213
IF TYPE IS 'THERMO_MECHANICAL'
IF TIME IS 'INDEPENDENT'
IF TEMPERATURE IS 'HIGH'
WRITE 0 :
FORMAT ('WRITE CREEP CARD ON INPUT2')
WRITE 2 :
FORMAT ('CREEP')
WRITE 2 :
FORMAT ('      0  -1  0  0      1.075E-26'/' 5.5')
CONCLUDE M_CARD_THREE IS 'GIVEN'
RULE 220
IF TYPE IS 'MECHANICAL'
IF TIME IS 'INDEPENDENT'
IF TEMPERATURE IS 'HIGH'
WRITE 0 :
FORMAT ('WRITE CREEP CARD ON INPUT2')
WRITE 2 :
FORMAT ('CREEP')
WRITE 2 :
FORMAT ('      0  -1  0  0      1.075E-26'/' 5.5')
CONCLUDE M_CARD_THREE IS 'GIVEN'

```

```

RULE 204
OPEN 'INPUT2' 2 -80
WRITE 0 :
FORMAT ('WRITE END CARD ON INPUT2')
WRITE 2 :
FORMAT ('END')
WRITE 0 :
FORMAT ('WRITE CONNECTIVITY CARD ON INPUT2')
WRITE 2 :
FORMAT ('CONNECTIVI')
WRITE 2 NUMEL MESHR : 1 1 1
FORMAT (2I5)
WRITE 2 IDELMT LTYPE IA IB IC ID IE IG IH II : 1 NUMEL 1
FORMAT (10I5)
WRITE 0 :
FORMAT ('WRITE COORDINATE CARD ON INPUT2')
WRITE 2 :
FORMAT ('COORDINATE')
WRITE 2 NCRD NUMNP MESHR : 1 1 1
FORMAT (3I5)
WRITE 2 IDNODE XA XB XC : 1 NUMNP 1
FORMAT (I5,3F10.5)
WRITE 0 :
FORMAT ('WRITE PROPERTY CARD ON INPUT2')
WRITE 2 :
FORMAT ('PROPERTY ')
WRITE 2 NMARNG : 1 1 1
FORMAT (I5)
WRITE 2 YOUNGS POISON DENSIT COEFFI BASTMP YIELDS YIELDS : 1 1 1
FORMAT (7E10.3)
WRITE 2 IMRNGA IMRNGB : 1 1 1
FORMAT (2I5)
WRITE 0 :
FORMAT ('WRITE GEOMETRY CARD ON INPUT2')
WRITE 2 :
FORMAT ('GEOMETRY ')
WRITE 2 NTHRNG : 1 1 1
FORMAT (I5)
WRITE 2 TA TB TC : 1 1 1
FORMAT (3F10.5)
WRITE 2 ITRNGA ITRNGB : 1 1 1
FORMAT (2I5)
WRITE 0 :
FORMAT ('WRITE BOUNDARY CONDITION CARD ON INPUT2')
WRITE 2 :
FORMAT ('BOUNDARY C')
WRITE 2 NBBNDY : 1 1 1
FORMAT (I5)
WRITE 2 IBRNGA IBRNGB INDDOF INDDOF SPDISP : 1 NBBNDY 1
FORMAT (4I5,E10.3)
WRITE 0 :

```

```

FORMAT ('WRITE TRACTION CARD ON INPUT2')
WRITE 2 :
FORMAT ('TRACTIONS ')
WRITE 2 NBPOIN NBDIST : 1 1 1
FORMAT (2I5)
WRITE 2 NELDID IDFACE ILRNGB ILRNGC DISTFA : 1 NBDIST 1
FORMAT (2I5/2I5/F10.5)
WRITE 2 ILRNGA POINFA POINFB POINFC : 1 NBPOIN 1
FORMAT (I5,3F10.5)
WRITE 0 :
FORMAT ('WRITE CONTROL CARD ON INPUT2')
WRITE 2 :
FORMAT ('CONTROL ')
WRITE 2 NBINC : 1 1 1
FORMAT (I5)
WRITE 2 FACTOR : 1 1 1
FORMAT (E10.3)
WRITE 0 :
FORMAT ('WRITE POST CARD ON INPUT2')
WRITE 2 NPOST NEA NEB NEC NED NEE NEF NSA NSB NSC NSD NSE NSF : 1 1 1
FORMAT ('POST'/I5/I5/I5/I5/I5/I5/I5/I5/I5/I5/I5/I5/I5/I5/I5)
CONCLUDE M_CARD_ONE IS 'GIVEN'
*
RULE 205
OPEN 'INPUT3' 3 -80
WRITE 0 :
FORMAT ('WRITE END OPTION CARD ON INPUT3')
WRITE 3 :
FORMAT ('END OPTION')
CONCLUDE L_CARD_ONE IS 'GIVEN'
RULE 215
IF STRESS STRAIN IS 'NON LINEAR'
IF TIME IS 'INDEPENDENT'
IF TYPE IS 'MECHANICAL'
WRITE 0 :
FORMAT ('WRITE PROPORTIONAL INC CARD ON INPUT3')
WRITE 0 :
FORMAT ('WRITE AUTO LOAD CARD ON INPUT3')
WRITE 3 MINCYC PRATIO : 1 1 1
FORMAT ('PROPORTIONAL INCREMENT'/I5,E15.4)
WRITE 3 NBAUTO : 1 1 1
FORMAT ('AUTO LOAD'/I5/'CONTINUE')
CONCLUDE L_CARD_TWO IS 'GIVEN'
RULE 200
IF TYPE IS 'MECHANICAL'
IF TIME IS 'INDEPENDENT'
IF TEMPERATURE IS 'HIGH'
WRITE 0 :
FORMAT ('WRITE AUTO CREEP CARD ON INPUT3')
WRITE 3 CPTIME DTIME : 1 1 1
FORMAT ('AUTO CREEP'/2E15.4/'CONTINUE')
CONCLUDE L_CARD_THREE IS 'GIVEN'

```

```

RULE 217
IF TYPE IS 'THERMAL'
IF TIME IS 'INDEPENDENT'
IF TEMPERATURE IS 'HIGH'
WRITE 0 :
FORMAT ('WRITE AUTO CREEP CARD ON INPUT3')
WRITE 3 CPTIME DTIME : 1 1 1
FORMAT ('AUTO CREEP'/2E15.4/'CONTINUE')
CONCLUDE L_CARD_THREE IS 'GIVEN'
RULE 218
IF TYPE IS 'THERMO MECHANICAL'
IF TIME IS 'INDEPENDENT'
IF TEMPERATURE IS 'HIGH'
WRITE 0 :
FORMAT ('WRITE AUTO CREEP CARD ON INPUT3')
WRITE 3 CPTIME DTIME : 1 1 1
FORMAT ('AUTO CREEP'/2E15.4/'CONTINUE')
CONCLUDE L_CARD_THREE IS 'GIVEN'
RULE 219
IF TYPE IS 'MECHANICAL'
IF TIME IS 'DEPENDENT'
WRITE 0 :
FORMAT ('WRITE DYNAMIC CHANGE CARD ON INPUT3')
WRITE 3 CPTIME DTIME : 1 1 1
FORMAT ('DYNEMIC CHANGE'/2E15.4/'CONTINUE')
CONCLUDE L_CARD_FOUR IS 'GIVEN'
RULE 225
IF THICKNESS IS 'THIN SLENDER'
IF STRESS_STRAIN IS 'LINEAR'
WRITE 0 :
FORMAT ('WRITE PROPORTIONAL INC CARD ON INPUT3')
WRITE 0 :
FORMAT ('WRITE AUTO LOAD CARD ON INPUT3')
WRITE 3 MINCYC PRATIO : 1 1 1
FORMAT ('PROPORTIONAL INCREMENT'/I5, E15.4)
WRITE 3 NBAUTO : 1 1 1
FORMAT ('AUTO LOAD'/I5/'CONTINUE')
CONCLUDE L_CARD_FIVE IS 'GIVEN'
RULE 216
CLOSE 1
CLOSE 2
CLOSE 3
MERGE 'INPUT1' 'INPUT2' 'INPUT3' 'INPUT'
CONCLUDE INPUT_FILE IS 'GIVEN'
*
```

```

RULE 1
IF DIMENSIONALITY IS 'ONE'
IF THICKNESS IS 'THIN_SLENDER'
CONCLUDE JTYPE = 5
WRITE 0 :
FORMAT ('MARC ELEMENT NO 5 SELECTED FOR THE ANALYSIS')
CONCLUDE GEOMETRY_CHECK IS 'OK'
CONCLUDE GEOMETRY IS 'ONE_DIMENSIONAL_BEAM'
RULE 2
IF DIMENSIONALITY IS 'TWO'
IF THICKNESS IS 'THIN_SLENDER'
CONCLUDE JTYPE = 5
WRITE 0 :
FORMAT ('MARC ELEMENT NO 5 SELECTED FOR THE ANALYSIS')
CONCLUDE GEOMETRY_CHECK IS 'OK'
CONCLUDE GEOMETRY IS 'TWO_DIMENSIONAL_BEAM'
RULE 3
IF DIMENSIONALITY IS 'TWO'
IF THICKNESS IS NOT 'THIN_FLAT'
CONCLUDE JTYPE = 11
WRITE 0 :
FORMAT ('MARC ELEMENT NO 11 SELECTED FOR THE ANALYSIS')
CONCLUDE GEOMETRY_CHECK IS 'OK'
CONCLUDE GEOMETRY IS 'TWO_D_PLANE_STRAIN'
RULE 101
IF DIMENSIONALITY IS 'TWO'
IF THICKNESS IS 'THIN_FLAT'
CONCLUDE JTYPE = 3
WRITE 0 :
FORMAT ('MARC ELEMENT NO 3 SELECTED FOR THE ANALYSIS')
CONCLUDE GEOMETRY_CHECK IS 'OK'
CONCLUDE GEOMETRY IS 'TWO_D_PLANE_STRESS'
RULE 4
IF DIMENSIONALITY IS 'THREE'
IF THICKNESS IS 'THIN_SLENDER'
WRITE 0 :
FORMAT ('THIS TYPE OF GEOMETRY CURRENTLY NOT ACCEPTABLE')
CONCLUDE GEOMETRY IS 'THREE_DIMENSIONAL_BEAM'
RULE 5
IF DIMENSIONALITY IS 'THREE'
IF THICKNESS IS 'THIN_CURVED'
WRITE 0 :
FORMAT ('THIS TYPE OF GEOMETRY CURRENTLY NOT ACCEPTABLE')
CONCLUDE GEOMETRY IS 'THREE_DIMENSIONAL_SHELL'

```

```

RULE 6
IF DIMENSIONALITY IS 'THREE'
IF THICKNESS IS 'THIN_FLAT'
WRITE 0 :
FORMAT ('THIS TYPE OF GEOMETRY CURRENTLY NOT ACCEPTABLE')
CONCLUDE GEOMETRY IS 'THREE_DIMENSIONAL_PLATE'
RULE 7
IF DIMENSIONALITY IS 'THREE'
IF THICKNESS IS 'THICK'
CONCLUDE JTYPE = 7
WRITE 0 :
FORMAT ('MARC ELEMENT NO 7 SELECTED FOR THE ANALYSIS')
CONCLUDE GEOMETRY_CHECK IS 'OK'
CONCLUDE GEOMETRY IS 'THREE_DIMENSIONAL_SOLID'
RULE 102
IF GEOMETRY IS 'UNKNOWN'
WRITE 0 :
FORMAT ('THIS TYPE OF GEOMETRY CURRENTLY NOT ACCEPTABLE')
CONCLUDE GEOMETRY_CHECK IS 'NOT_OK'
RULE 8
IF TYPE IS 'MECHANICAL'
IF TIME IS 'DEPENDENT'
CONCLUDE LOADING_CHECK IS 'OK'
CONCLUDE LOADING IS 'TIME_MECHANICAL'
RULE 9
IF TYPE IS 'MECHANICAL'
IF TIME IS 'INDEPENDENT'
CONCLUDE LOADING_CHECK IS 'OK'
CONCLUDE LOADING IS 'MECHANICAL'
RULE 10
IF TYPE IS 'THERMAL'
IF TEMPERATURE IS 'LOW'
IF TIME IS 'INDEPENDENT'
CONCLUDE LOADING_CHECK IS 'OK'
CONCLUDE LOADING IS 'THERMAL'
RULE 11
IF TYPE IS 'THERMAL'
IF TEMPERATURE IS 'HIGH'
IF TIME IS 'INDEPENDENT'
CONCLUDE LOADING_CHECK IS 'OK'
CONCLUDE LOADING IS 'ELEVATED_THERMAL'
RULE 12
IF TYPE IS 'THERMO_MECHANICAL'
IF TEMPERATURE IS 'LOW'
IF TIME IS 'INDEPENDENT'
CONCLUDE LOADING_CHECK IS 'OK'
CONCLUDE LOADING IS 'THERMO_MECHANICAL'

```

```

RULE 13
IF TYPE IS 'THERMO MECHANICAL'
IF TEMPERATURE IS 'HIGH'
IF TIME IS 'INDEPENDENT'
CONCLUDE LOADING_CHECK IS 'OK'
CONCLUDE LOADING IS 'ELEVATED_THERMO_MECHANICAL'
RULE 14
IF TYPE IS 'THERMAL'
IF TIME IS 'DEPENDENT'
WRITE 0 :
FORMAT ('THIS TYPE OF LOADING CURRENTLY NOT ACCEPTABLE')
CONCLUDE LOADING IS 'UNKNOWN'
RULE 15
IF TYPE IS 'THERMO MECHANICAL'
IF TIME IS 'DEPENDENT'
WRITE 0 :
FORMAT ('THIS TYPE OF LOADING CURRENTLY NOT ACCEPTABLE')
CONCLUDE LOADING IS 'UNKNOWN'
RULE 103
IF LOADING IS 'UNKNOWN'
WRITE 0 :
FORMAT ('THIS TYPE OF LOADING CURRENTLY NOT ACCEPTABLE')
CONCLUDE LOADING_CHECK IS 'NOT OK'
RULE 18
IF STRESS STRAIN IS 'LINEAR'
CONCLUDE MATERIAL_CHECK IS 'OK'
CONCLUDE MATERIAL IS 'LINEAR_STRESS_STRAIN'
RULE 19
IF STRESS STRAIN IS 'NON LINEAR'
CONCLUDE MATERIAL_CHECK IS 'OK'
CONCLUDE MATERIAL IS 'NON_LINEAR_STRESS_STRAIN'
RULE 104
IF MATERIAL IS 'UNKNOWN'
WRITE 0 :
FORMAT ('THIS TYPE OF MATERIAL CURRENTLY NOT ACCEPTABLE')
CONCLUDE MATERIAL_CHECK IS 'NOT OK'
RULE 105
IF ANALYSIS_ONE IS 'UNKNOWN'
CONCLUDE ANALYSIS_CHECK IS 'ANALYSIS IS NOT ELASTIC'
RULE 106
IF ANALYSIS_TWO IS 'UNKNOWN'
CONCLUDE ANALYSIS_CHECK IS 'ANALYSIS IS NOT ELASTIC_PLASTIC'

```

RULE 107  
 IF ANALYSIS\_THREE IS 'UNKNOWN'  
 CONCLUDE ANALYSIS\_CHECK IS 'ANALYSIS IS NOT CREEP'  
 RULE 108  
 IF ANALYSIS\_FOUR IS 'UNKNOWN'  
 CONCLUDE ANALYSIS\_CHECK IS 'ANALYSIS IS NOT DYNAMIC'  
 RULE 109  
 IF ANALYSIS\_FIVE IS 'UNKNOWN'  
 CONCLUDE ANALYSIS\_CHECK IS 'ANALYSIS IS NOT LARGE\_DISPLACEMENT')  
 RULE 22  
 IF STRESS\_STRAIN IS 'LINEAR'  
 CONCLUDE ANALYSIS\_CHECK IS 'OK'  
 CONCLUDE ANALYSIS\_ONE IS 'ELASTIC'  
 RULE 23  
 IF STRESS\_STRAIN IS 'NON\_LINEAR'  
 CONCLUDE ANALYSIS\_CHECK IS 'OK'  
 CONCLUDE ANALYSIS\_TWO IS 'ELASTIC\_PLASTIC'  
 RULE 24  
 IF TYPE IS 'MECHANICAL'  
 IF TIME IS 'INDEPENDENT'  
 IF TEMPERATURE IS 'HIGH'  
 CONCLUDE ANALYSIS\_CHECK IS 'OK'  
 CONCLUDE ANALYSIS\_THREE IS 'CREEP'  
 RULE 25  
 IF TYPE IS 'THERMAL'  
 IF TIME IS 'INDEPENDENT'  
 IF TEMPERATURE IS 'HIGH'  
 CONCLUDE ANALYSIS\_CHECK IS 'OK'  
 CONCLUDE ANALYSIS\_THREE IS 'CREEP'  
 RULE 26  
 IF TYPE IS 'THERMO\_MECHANICAL'  
 IF TIME IS 'INDEPENDENT'  
 IF TEMPERATURE IS 'HIGH'  
 CONCLUDE ANALYSIS\_CHECK IS 'OK'  
 CONCLUDE ANALYSIS\_THREE IS 'CREEP'  
 RULE 27  
 IF TYPE IS 'MECHANICAL'  
 IF TIME IS 'DEPENDENT'  
 CONCLUDE ANALYSIS\_CHECK IS 'OK'  
 CONCLUDE ANALYSIS\_FOUR IS 'DYNAMIC'  
 RULE 28  
 IF THICKNESS IS 'THIN\_SLENDER'  
 CONCLUDE ANALYSIS\_CHECK IS 'OK'  
 CONCLUDE ANALYSIS\_FIVE IS 'LARGE\_DISPLACEMENT'  
 RULE 221  
 ASK 'CONNECTI' NUMEL 0 10 IDELMT LTYPE IA IB IC ID IE IG IH II  
 CONCLUDE CONNECTIVITY IS 'GIVEN'  
 RULE 222  
 ASK 'COORDINA' NUMNP 0 4 IDNODE XA XB XC  
 CONCLUDE COORDINATES IS 'GIVEN'



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RULE 223
ASK 'GEOMELMT' NBTHIC 0 3 TA TB TC
CONCLUDE ELMT_THICKNESS IS 'GIVEN'
RULE 224
ASK 'GEO_RANG' NTHRNG 0 3 IDTHIC ITRNGA ITRNGB
CONCLUDE THICKNESS_RANGE IS 'GIVEN'
RULE 241
ASK 'YOUNG' NUMMAT 0 2 IDMATA YOUNGS
ASK 'POISSON' NUMMAT 0 2 IDMATB POISON
ASK 'DENSITY' NUMMAT 0 2 IDMATC DENSIT
ASK 'COEFF' NUMMAT 0 2 IDMATD COEFFI
ASK 'BASETEMP' NUMMAT 0 2 IDMATE BASTMP
ASK 'YIELD' NUMMAT 0 2 IDMATF YIELDS
CONCLUDE BASE_PROPERTY IS 'GIVEN'
RULE 242
ASK 'WORKHARD' NBWKHD 0 3 IDMATG WKHRDA WKHRDB
CONCLUDE WORK_HARDENING IS 'GIVEN'
RULE 243
ASK 'YOUNTEMP' NBTEMP 0 3 IDMATH FTYOUN TTYOUN
ASK 'POISTEMP' NBTEMP 0 3 IDMATI FTPOIS TTPOIS
ASK 'COEFFTEMP' NBTEMP 0 3 IDMATJ FTCOEF TTCOEF
ASK 'YIELTEMP' NBTEMP 0 3 IDMATK FTYIEL TTYIEL
CONCLUDE TEMP_EFFECTS IS 'GIVEN'
RULE 244
ASK 'MAT_RANG' NMARNG 0 3 IDMATL IMRNGA IMRNGB
CONCLUDE MATERIAL_RANGE IS 'GIVEN'
RULE 261
ASK 'BOUNDCON' NBBNDY 0 4 IBRNGA IBRNGB INDDOF SPDISP
CONCLUDE BOUNDARY_C IS 'GIVEN'
RULE 271
ASK 'POINLOAD' NBPOIN 0 4 ILRNGA POINFA POINFB POINFC
CONCLUDE POINT_LOAD IS 'GIVEN'
RULE 272
ASK 'DISTLOAD' NBDIST 0 5 NELDIS ILRNGB ILRNGC IDFACE DISTFA
CONCLUDE DIST_LOAD IS 'GIVEN'
RULE 251
OPEN 'USDATA' 1 40
READ 1 IR : 1 1 1
FORMAT (I5)
READ 1 VMAX : 1 9 1
FORMAT (E15.4)
WRITE 0 :
FORMAT ('READ SUMMARY OF MARC RESULTS FROM USDATA')
CONCLUDE SIGY = 20050.0
CONCLUDE ELIMIT = 0.05
CONCLUDE AA = VMAX(1)
CONCLUDE AB = VMAX(2)
CONCLUDE AC = VMAX(3)
CONCLUDE AD = VMAX(4)
CONCLUDE AE = VMAX(5)
CONCLUDE AF = VMAX(6)
CONCLUDE AG = VMAX(7)
CONCLUDE AH = VMAX(8)
CONCLUDE AI = VMAX(9)
CONCLUDE RESULT_ONE IS 'GIVEN'

```

```

RULE 252
WRITE O IR : 1 1 1
FORMAT ('RESULTS FOR INCREMENT NO      ',I5)
WRITE O AA : 1 1 1
FORMAT ('MAX XX STRAIN IS      ',E15.4)
WRITE O AB : 1 1 1
FORMAT ('MAX YY STRAIN IS      ',E15.4)
WRITE O AC : 1 1 1
FORMAT ('MAX XY STRAIN IS      ',E15.4)
WRITE O AD : 1 1 1
FORMAT ('MAX EQUIV. PLASTIC STRAIN IS    ',E15.4)
WRITE O AE : 1 1 1
FORMAT ('MAX EQUIV. CREEP  STRAIN IS    ',E15.4)
WRITE O AF : 1 1 1
FORMAT ('MAX XX STRESS IS      ',E15.4)
WRITE O AG : 1 1 1
FORMAT ('MAX YY STRESS IS      ',E15.4)
WRITE O AH : 1 1 1
FORMAT ('MAX XY STRESS IS      ',E15.4)
WRITE O AI : 1 1 1
FORMAT ('MAX EQUIV. STRESS          IS  ',E15.4)
CONCLUDE RESULT_TWO IS 'GIVEN'
RULE 253
IF 'SIGY' LT 'AI'
WRITE O :
FORMAT ('MAX EQUIV STRESS EXCEEDS YIELD')
WRITE O AI SIGY : 1 1 1
FORMAT ('MAX EQUIV STRESS AND YIELD STRESS ARE',2E15.4)
WRITE O :
FORMAT ('AN ELASTIC-PLASTIC ANALYSIS IS RECOMMENDED')
CONCLUDE RESULT_THREE IS 'GIVEN'
RULE 254
IF 'AD' LT 'ELIMIT'
WRITE O :
FORMAT ('MAX PLASTIC STRAIN SMALLER THAN STRAIN LIMIT 0.05')
WRITE O AD ELIMIT : 1 1 1
FORMAT ('MAX PLASTIC STRAIN AND STRAIN LIMIT ARE',2E15.4)
WRITE O :
FORMAT ('NO FURTHER ANALYSIS IS RECOMMENDED')
CONCLUDE RESULT_FOUR IS 'GIVEN'

```

LIST OF QUESTIONS ASSOCIATED WITH RULES

MARCINO1GENERAL

OC15

1PLEASE ENTER DIMENSIONALITY OF YOUR

1STRUCTURE : ONE, TWO OR THREE

2THE VALUE IS ONE, TWO OR THREE

MARCINO2GENERAL

OC15

1PLEASE ENTER OVER ALL THICKNESS OF YOUR

1STRUCTURE: THICK, THIN\_FLAT, THIN\_CURVED, OR

1THIN SLENDER

2THE VALUE IS THICK, THIN\_FLAT, THIN\_CURVED, OR

2THIN SLENDER

MARCINO3GENERAL

OC20

1PLEASE ENTER TYPE OF LOADINGS : MECHANICAL,

1THERMAL, OR THERMO MECHANICAL

2THE VALUE IS MECHANICAL, THERMAL, OR

THERMO MECHANICAL

MARCINO4GENERAL

OC20

1PLEASE ENTER TIME DEPENDENCY OF MECHANICAL LOADINGS :

1DEPENDENT, OR INDEPENDENT

2THE VALUE IS DEPENDENT OR INDEPENDENT

MARCINO5GENERAL

OC20

1PLEASE ENTER TEMPERATURE LEVEL OF YOUR STRUCTURE

1 : HIGH OR LOW

2THE VALUE IS HIGH OR LOW

MARCINO6GENERAL

OC20

1PLEASE ENTER TYPE OF MATERIAL OF YOUR STRUCTURE

1: METAL OR NON METAL

2THE VALUE IS METAL OR NON\_METAL

MARCINO7GENERAL

OC20

1PLEASE ENTER DUCTILITY OF YOUR MATERIAL :

1BRITTLE OR DUCTILE

2THE VALUE IS BRITTLE OR DUCTILE

MARCINO8GENERAL

OC20

1PLEASE ENTER STRESS STRAIN RELATION OF THE

1MATERIAL : LINEAR OR NON\_LINEAR

MARCIN31GENERAL

OI

1PLEASE ENTER TOTAL NUMBER OF ELEMENTS IN THE MESH

2THE VALUE IS AN INTEGER

MARCIN32GENERAL

OI

1PLEASE ENTER TOTAL NUMBER OF NODES IN THE MESH

2THE VALUE IS AN INTEGER

MARCIN33GENERAL  
OI  
1PLEASE ENTER TOTAL NUMBER OF DIFFERENT MATERIALS IN  
1THE MESH  
2THE VALUE IS AN INTEGER  
MARCIN34GENERAL  
OI  
1PLEASE ENTER TOTAL NUMBER OF POINTS IN WORK\_HARDENING  
1SLOPE FUNCTIONS FOR ALL MATERIALS  
2THE VALUE IS AN INTEGER  
MARCIN35GENERAL  
OI  
1PLEASE ENTER TOTAL NUMBER OF POINTS IN TEMPERATURE  
1DEPENDENT MATERIAL FUNCTIONS FOR ALL MATERIALS  
1(MAX. VALUE AMONG ALL PROPERTIES)  
2THE VALUE IS AN INTEGER  
MARCIN36GENERAL  
OI  
1PLEASE ENTER TOTAL NUMBER OF ELEMENT\_RANGE PAIRS  
1FOR ALL MATERIALS IN THE MESH  
2THE VALUE IS AN INTEGER  
MARCIN37GENERAL  
OI  
1PLEASE ENTER TOTAL NUMBER OF SPECIFIED NODAL POINT  
1DEGREES OF FREEDOMS IN THE MESH  
2THE VALUE IS AN INTEGER  
MARCIN38GENERAL  
OI  
1PLEASE ENTER TOTAL NUMBER OF DIFFERENT ELEMENT  
1THICKNESSES IN THE MESH  
2THE VALUE IS AN INTEGER  
MARCIN39GENERAL  
OI  
1PLEASE ENTER TOTAL NUMBER OF ELEMENT\_RANGE PAIRS  
1OF ALL ELEMENT THICKNESSES IN THE MESH  
2THE VALUE IS AN INTEGER  
MARCIN40GENERAL  
OI  
1PLEASE ENTER TOTAL NUMBER OF POINT LOADS (NODE\_RANGE  
1PAIRS) IN THE MESH  
2THE VALUE IS AN INTEGER  
MARCIN41GENERAL  
OI  
1PLEASE ENTER TOTAL NUMBER OF DISTRIBUTED LOADS (ELEMENT\_  
1RANGE PAIRS) IN THE MESH  
2THE VALUE IS AN INTEGER

MARCIN42GENERAL

OR

1PLEASE ENTER TRANSIENT TIME FOR DYNAMIC OR CREEP ANALYSIS

2THE VALUE IS A REAL NUMBER

MARCIN43GENERAL

OR

1PLEASE ENTER TIME INCREMENT FOR DYNAMIC OF CREEP ANALYSIS

2THE VALUE IF A REAL NUMBER

CONNECTIELMT

OI I I I IO IO IO IO IO

1PLEASE ENTER ELEMENT CONNECTIVITY AS FOLLOWS:

1ELEMENT NUMBER AND ELEMENT TYPE FOLLOWED BY

1 TWO NODAL NUMBERS FOR TWO\_NODE BEAM AND AXISYMMETRIC

1 SHELL ELEMENTS OR,

1 FOUR NODAL NUMBERS FOR FOUR NODE PLANE STRESS, PLANE

1 STRAIN, AND AXISYMMETRIC ELEMENTS OR,

1 EIGHT NODAL NUMBERS FOR EIGHT\_NODE THREE DIMENSIONAL

1 BRICK ELEMENTS

2THE VALUES ARE : ONE INTEGER FOR ELEMENT NUMBER FOLLOWED BY

2ONE INTEGER FOR ELEMENT TYPE AND

2 TWO INTEGERS FOR BEAM AND AXISYMMETRIC SHELL

2ELEMENTS OR, FOUR INTEGERS FOR PLANE STRESS, PLANE STRAIN,

2AND AXISYMMETRIC ELEMENTS OR, EIGHT INTEGERS FOR THREE

2DIMENSIONAL BRICK ELEMENTS

COORDINANODE

OI R R RO

1PLEASE ENTER NODAL COORDINATES AS FOLLOWS :

1NODAL NUMBER FOLLOWED BY

1 TWO NODAL COORDINATES FOR NODAL POINT OF TWO

1 DMENSIONAL STRUCTURES OR,

1 THREE NODAL COORDINATES FOR NODAL POINT OF THREE

1 DIMENSIONAL STRUCTURES

2THE VALUES ARE : ONE INTEGER FOR NODAL NUMBER

2FOLLOWED BY TWO REAL NUMBERS FOR NODAL POINT OF

2TWO DIMENSIONAL STRUCTURES OR, THREE REAL NUMBERS

2FOR NODAL POINT OF THREE DIMENSIONAL STRUCTURES

GEOMELMTTHICKNES

OR RO RO

1PLEASE ENTER GEOMETRY DATA OR, ELEMENT THICKNESS AS

1FOLLOWS :

1 GEOMETRY DATA FOR TWO\_NODE BEAM AND AXISYMMETRIC SHELL

1 ELEMENTS OR,

1 ELEMENT THICKNESS FOR PLANE STRESS AND PLANE STRAIN

1 ELEMENTS

2THE VALUES ARE : TWO REAL NUMBERS FOR TWO\_NODE BEAM

2AND AXISYMMETRIC SHELL ELEMENTS OR, ONE REAL NUMBER

2FOR PLANE STRESS AND PLANE STRAIN ELEMENTS

GEO RANGE RANGE

OI I I

1PLEASE ENTER ELEMENT THICKNESS IDENTIFICATION AND

1ELEMENT RANGE PAIR FOR GIVEN THICKNESS

2THE VALUES ARE THREE INTEGERS

YOUNG MATERIAL

OI R

1PLEASE ENTER MATERIAL IDENTIFICATION AND YOUNGS\_  
1MODULUS OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND A REAL NUMBER  
POISSON MATERIAL

OI R

1PLEASE ENTER MATERIAL IDENTIFICATION AND POISSONS\_  
1RATIO OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND A REAL NUMBER  
DENSITY MATERIAL

OI R

1PLEASE ENTER MATERIAL IDENTIFICATION AND DENSITY  
1OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND A REAL NUMBER  
COEFF MATERIAL

OI R

1PLEASE ENTER MATERIAL IDENTIFICATION AND COEFF\_  
1OF THERMAL EXPANSION OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND A REAL NUMBER  
BASETEMPMATERIAL

OI R

1PLEASE ENTER MATERIAL IDENTIFICATION AND BASE  
1(STRESS FREE) TEMPERATURE OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND A REAL NUMBER  
YIELD MATERIAL

OI R

1PLEASE ENTER MATERIAL IDENTIFICATION AND YIELD\_  
1STRESS OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND A REAL NUMBER  
WORKHARDSIG-EPSP

OI R R

1PLEASE ENTER MATERIAL IDENTIFICATION AND EFFECTIVE\_  
1STRESS VS EFFECTIVE PLASTIC STRAIN OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND TWO REAL NUMBERS  
YOUNTEMPYOUNG- T

OI R R

1PLEASE ENTER MATERIAL IDENTIFICATION AND YOUNGS\_  
1MODULUS VS TEMPERATURE OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND TWO REAL NUMBERS  
POISTEMPPOISS -T

OI R R

1PLEASE ENTER MATERIAL IDENTIFICATION AND POISSONS\_  
1RATIO VS TEMPERATURE OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND TWO REAL NUMBERS  
COEFFTEMPCOEFF -T

OI R R

1PLEASE ENTER MATERIAL IDENTIFICATION AND COEFF\_  
1OF THERMAL EXPANSION VS TEMPERATURE OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND TWO REAL NUMBERS

YIELTEMPYIELD -T

OI R R

1PLEASE ENTER MATERIAL IDENTIFICATION AND YIELD\_

1STRESS VS TEMPERATURE OF ALL MATERIALS

2THE VALUES ARE ONE INTEGER AND TWO REAL NUMBERS

MAT\_RANGE RANGE

OI I I

1PLEASE ENTER MATERIAL IDENTIFICATION AND ELEMENT\_

1RANGE PAIRS OF ALL MATERIALS

2THE VALUES ARE THREE INTEGERS

BOUNDCONBOUNDARY

OI I I RO

1PLEASE ENTER NODAL POINT RANGE, DEGREES OF FREEDOM,

1AND SPECIFIED DISPLACEMENT(OPTIONAL, DEFAULT IS 0.0)

1

2THE VALUES ARE THREE INTEGERS AND ONE OPTIONAL REAL

2NUMBER

POINLOADNODE

OI R R R

1PLEASE ENTER NODE NO., POINT LOAD IN FIRST DIRECTION,

1POINT LOAD IN SECOND DIRECTION AND POINT LOAD IN THIRD DIRECTION

2THE VALUES ARE TWO INTEGERS AND THREE REAL NUMBERS

DISTLOADELMT

OI I I I R

1PLEASE ENTER NUMBER OF ELEMENTS,

1ELEMENT RANGE, FACE IDENTIFICATION OF THE

1DISTRIBUTED LOAD AND DISTRIBUTED LOAD

2THE VALUES ARE FOUR INTEGERS AND ONE REAL NUMBER

APPENDIX B

The MARC Program

And

MARC Elements 3, 5, 7, 11



The MARC program is a general purpose finite element structural analysis program [5]. Possible uses of the MARC system include the following: Linear elastic analysis of two- and three-dimensional solids, shells, and beams; and applications where nonlinear material and geometric effects are needed for geometric modeling. Both the linear and nonlinear analysis can be carried out in both the static and dynamic regimes for stress analysis, and also for heat transfer (diffusion) analysis. Mesh generators, graphics, and post-processing aid the user in the preparation of input and the interpretation of results.

The program derives its broad applicability by allowing the user to select from three comprehensive libraries for elements, materials and structural procedures, respectively. The Element Library contains over 60 elements, which allow the user to describe any geometry that may be encountered. The Material Library contains over 35 different material models covering the behavior of most engineering materials through its various modules. This allows simulation of particular physical phenomena, such as temperature cycling, buckling, dynamic transient, etc. The Structural Procedures Library contains about 15 structural procedures.

MARC allows the user to combine any number of components from each of the three libraries and, in doing so, puts the tools to solve almost any structural mechanics problem at the disposal of the user.

The input data for MARC is organized into three basic groups. These groups form a natural subdivision of the data. Each group is then subdivided into various optional blocks of input data. The optional blocks of data within each group have been organized to minimize the input of unnecessary data.

The main idea is to enable the user to specify only the data for the optional blocks that he needs to define his problem. The various blocks of input are referred to here as optional in the sense that many have built-in default values which may be used and is not meant to imply that they are optional in all cases. The input data is divided into the following three groups:

#### PARAMETER CARDS (P\_CARD)

This group of cards is used to allocate the necessary working space for the problem and to set up initial switches which control the flow of the program through the desired analysis. This set of input cards is terminated with an END card.

#### MODEL DEFINITION CARDS (M\_CARD)

This set of data cards is used to read in the initial loading, geometry and material data of the model. It also provides nodal point data such as boundary conditions. In general, the initial model data is provided in this group and control, restart and plot options may also be specified here for further program processing. This data provides the program with the necessary information for determination of an initial elastic solution (zero increment solution in program terminology). This group of cards is terminated with an END OPTION card.

## LOAD INCREMENTATION CARDS (L\_CARD)

This group of cards provide the load incrementation and control of the program after the initial elastic analysis. The group also includes blocks which allow changes in the initial model specifications. Each set of control cards is terminated with a CONTINUE card. This card sends the program back for another increment or series of increments if the auto incrementation features are requested.

Figure B-1 shows the input deck set up and keywords for P\_CARD, M\_CARD and L\_CARD are listed in Tables B-1, B-2 and B-3, respectively.

TABLE B-1 P\_CARD KEYWORDS

<u>KEY WORD</u>	<u>KEY WORD</u>	<u>KEY WORD</u>
ACCUM BUC	FOLLOW FOR	PRINT
ALIAS	FORCDT	QUALIFY
ALL POINTS	FOURIER	R-P FLOW
ANISOTROPI	HEAT	RESTART
APPBC	HYPOELAS	SAVE ELEM
BEAM SECT	INPUT TAPE	SCALE
BUCKLE	ISTRESS	SHELL SECT
CENT	J-INT	SHELL TRAN
COMBINED	KINEMATIC	SIZING
CRACKING	LARGE DISP	SPRINGS
CREEP	LOAD COR	STATE VARS
DIST LOADS	LUMP	STOP
DYNAMIC	MASS POINT	TAPES
ECS	MATERIAL	THERMAL
EDIT	MOHRC	TIE
ELAS FOUND	MOONEY	TITLE
ELASTIC	MESH PLOT	TRANSFORM
ELSTO	NO LOADCOR	UPDATE
END	NOTES	VECSTO
FILMS	ORNL	VECSTO ELAS
FLU LOAD	POST	
FLUXES		

TABLE B-2 M\_CARD KEYWORDS

<u>KEY WORD</u>	<u>KEY WORD</u>	<u>KEY WORD</u>
BC FILL	INIT FILS	PRINT CHOICE
BC GENER	INIT GENER	PROPERTY
BOUNDARY CONDITIONS	INITIAL CONDITIONS	REAUTO
CASE COMBIN	INITIAL STATE	REGEN
CHANGE STATE	J-INTEGRAL	RENUMBER
CONN FILL	MASS FILL	RESTART
CONN GENER	MASS GENER	ROTATION A
CONNECTIVITY	MASSES	SERVO LINK
CONTROL	MESH 2D	SHELL TRANSFORMATION
COORDINATES	BLOCKS	SPRINGS
CRACKING	DEFINE	STRAIN RATE
CREEP	BOUNDARY	TEMPERATURE EFFECTS
DAMPING	CONSTRAINT	THERMAL LOADS
END OPTION	MAPPER	TIE FILL
FLUID SOLID	MERGE	TIE GENER
FILMS	SYMMETRY	TRAC FILL
FLUX FILL	SPECIFIED MODES	TRAC GENER
FLUX GENER	GENERATE	TRACTIONS
FLUXES	NODE CIRCLE	TRANS FILL
FORC DT	NODE FILL	TRANS GENER
FOUNDATION	NODE GENER	TRANSFORMATION
FOURIER	NODE MERGE	TYING
FXORD	OPTIMIZE	UFCONN
GEOMETRY	POST	UFXORD
		WORK HARD

TABLE B-3 L\_CARD KEYWORDS

KEY WORD  
AUTO CREEP  
AUTO LOAD  
AUTO THERM  
BOUNDARY CHANGE  
BUCKLE  
CHANGE STATE  
CONTINUE  
CREEP EXT  
CREEP INCREMENT  
DYNAMIC CHANGE  
FLUXES  
FLUX FILL  
FLUX GENER  
MODEL SHAPE  
PRINT CHOICE  
PROPORTIONAL INCREMENT  
THERMAL LOADS  
TRAC FILL  
TRAC GENER  
TRACTIONS  
TYING CHANGE

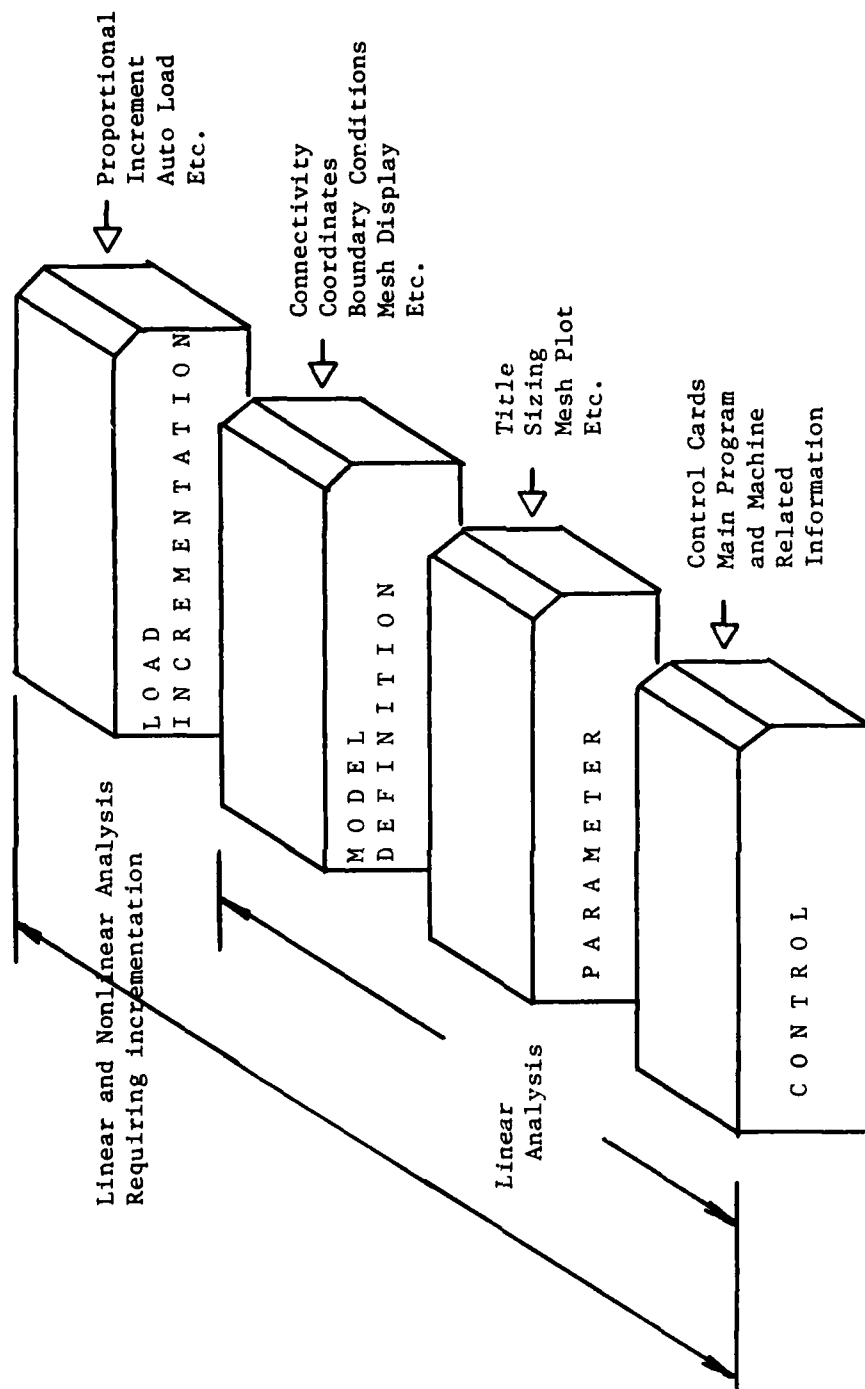


Figure B-1 MARC Input Deck

## BEAM COLUMN -- ELEMENT 5

This element (Figure B-2) is a straight, two-node, rectangular-section beam-column element using linear interpolation parallel to its length, cubic interpolation in the normal direction. (Element 16 is a full cubic beam that is more accurate for many applications).

The degrees of freedom are the u and v displacements, and the right-handed rotation at the two end points of the element. The element stiffness is formed by numerical integration: the strain-stress transformation is formed by a Simpson rule integration using 11 points through the thickness of the element. The stiffness is formed by Gaussian integration along the length of the element using 3 points.

### QUICK REFERENCE

- . TYPE 5

Two-dimensional, rectangular-section, beam-column.

- . CONNECTIVITY

Two nodes per element.

- . GEOMETRY

A rectangular section is assumed. The height is input in the first data field (EGEOM1).

The cross-sectional area in the second data field (EGEOM2)

The third data field is not used.

- . COORDINATES

Two coordinates in the global x and y directions.

- . DEGREES OF FREEDOM

1 = u displacement

2 = v displacement

3 = right-handed rotation

- . TRACTIONS

Pressure is assumed positive in the local y direction. Since this is the only type of distributed load for this element, no specification of load type need be made.



- . OUTPUT OF STRAINS

Two generalized strains, membrane stretching and bending.

- . OUTPUT OF STRESSES

Stresses at each integration point or the centroid. Each of these points will have points equally spaced through its thickness. The stress will be output at each representative point.

The first point is on the positive normal (positive local y) face, the last on the negative face.

- . TRANSFORMATION

Standard transformation will transform first two global degrees of freedom to local degrees of freedom.

- . TYING

No standard tying available, use UFORMS.

- . OUTPUT POINTS

Centroid or three Gaussian integration points if ALL POINTS used.

- . MESH GENERATOR

None available.

- . SECTION STRESS INTEGRATION

Integration through the thickness is performed numerically using Simpson's rule. Use the SHELL SECT parameter card to define the number of integration points -- this number must be odd. 3 points are enough for linear material response -- 7 points for simple plasticity or creep analysis; 11 points for complex plasticity or creep (e.g., dynamic plasticity). The default is 11 points.

- . UPDATING LAGRANGE PROCEDURE AND FINITE STRAIN PLASTICITY

Capability is not available -- use Element 16 instead.

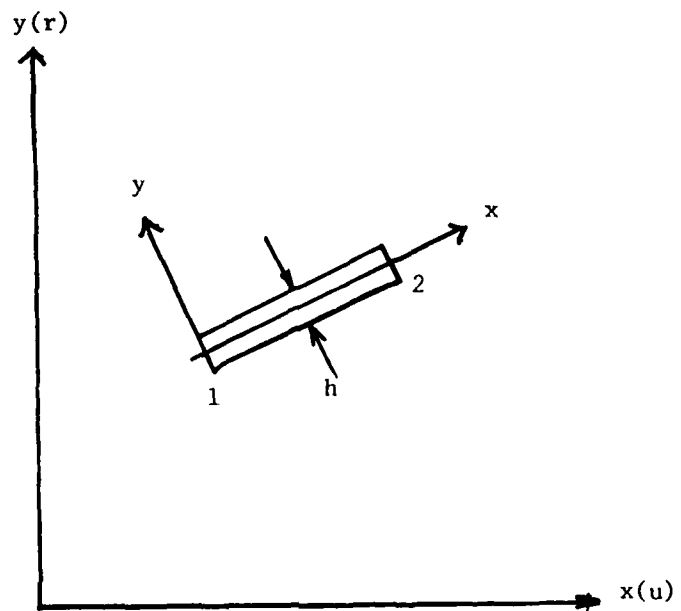


Figure B-2 Beam-Column Element

### PLANE STRESS QUADRILATERAL -- ELEMENT 3

This element (Figure B-3) is a four-node isoparametric arbitrary quadrilateral element (Element 26 is the better element, use it if possible). The element is formed by a mapping from the (x-y) plane to a (g-h) plane. Both the mapping and the displacement assumption take the typical form:

$$x = a_0 + a_1g + a_2h + a_3gh$$

$$u = b_0 + b_1g + b_2h + b_3gh$$

and so forth.

The stiffness of the element is formed by numerical integration using four points as shown in Figure B-3. See Reference 3 in Volume A, Section 7, for further details on this element.

#### QUICK REFERENCE

- TYPE 3

Plane stress quadrilateral.

- CONNECTIVITY

Node numbering must follow right-handed convention.

- GEOMETRY

The thickness is stored in the first data field (EGEOM1). The other two data fields (EGEOM2 and EGEOM3) are not used for this element. Default thickness is 1.

- COORDINATES

Two global coordinates x and y.

- DEGREES OF FREEDOM

1 = u (displacement in the global x direction)

2 = v (displacement in the global y direction)

- TRACTIONS

Load types for distributed loads are defined as follows:

<u>Load Type</u>	<u>Description</u>
0	Uniform pressure distributed on 1-2 face of the element.
1	Uniform body force per unit volume in first coordinate direction.
2	Uniform body force by unit volume in second coordinate direction.
3	Non-uniform pressure on 1-2 face of the element, magnitude supplied through subroutine FORCEM.
4	Non-uniform body force per unit volume in first coordinate direction, magnitude supplied through subroutine FORCEM.
5	Non-uniform body force per unit volume in second coordinate direction, magnitude supplied through subroutine FORCEM.
6	Uniform pressure on 2-3 face of the element.
7	Non-uniform pressure on 2-3 face of the element, magnitude supplied through subroutine FORCEM.
8	Uniform pressure on 3-4 face of the element.
9	Non-uniform pressure on 3-4 face of the element, magnitude supplied through subroutine FORCEM.
10	Uniform pressure on 4-1 face of the element.
11	Non-uniform pressure on 4-1 face of the element, magnitude supplied through subroutine FORCEM.

All pressures are positive when directed into the element. In addition, point loads may be applied at the nodes.

• OUTPUT OF STRAINS

Output of strain at the centroid of the element is:

$$1 = E_{xx}$$

$$2 = E_{yy}$$

$$3 = E_{xy}$$

- . OUTPUT OF STRESSES

Output of stress is the same as for the strain.

- . TRANSFORMATION

The two global degrees of freedom may be transformed to local coordinates.

- . TYING

User UFORMS subroutine.

- . OUTPUT POINTS

Output is available at the centroid or with the ALL POINTS option, at the four numerical integration points shown in Figure B-3.

- . MESH GENERATOR

Use MESH2D option.

- . UPDATING LAGRANGE PROCEDURE AND FINITE STRAIN PLASTICITY

Capability is available - output of stress and strain in global coordinate directions. Thickness will be updated.

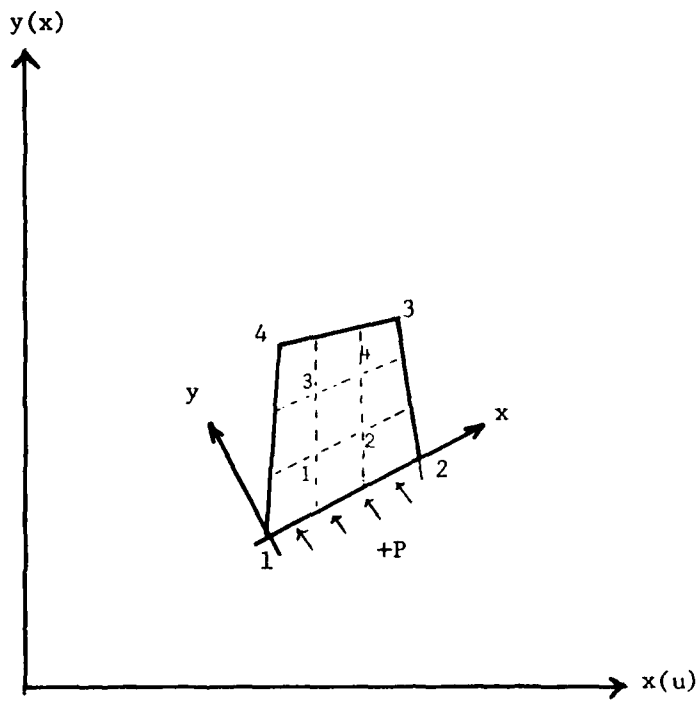


Figure B-3 Plane Stress Quadrilateral

## ARBITRARY QUADRILATERAL PLANE STRAIN - ELEMENT 11

This is the same formulation as element 3 and 10, written for plane-strain (Element 27 is the better element, use it if possible).

### QUICK REFERENCE

- . TYPE 11

Plane strain quadrilateral.

- . CONNECTIVITY

Four nodes per element. Node numbering follows right-handed convention (counterclockwise).

- . GEOMETRY

The thickness is entered in the first data field (EGEOM1). Default the unit thickness. If a nonzero value is entered in the second data field (EGEOM2) the volume strain will be constant throughout the element. That is particularly useful for analysis of approximately incompressible materials and for analysis of structures in the fully plastic range. It is also recommended for creep problems in which it is attempted to obtain the steady solution. For details, see Volume G, Reference XXV.

- . COORDINATES

Two coordinates in the global x and y directions.

- . DEGREES OF FREEDOM

Global displacement degrees of freedom:

1 = z displacement (along symmetry axis)

2 = radial displacement

- . TRACTIONS

Load types for distributed loads as follows:

<u>Load Type</u>	<u>Description</u>
0	Uniform pressure distributed on 1-2 face of the element.
1	Uniform body force per unit volume in first coordinate direction.
2	Uniform body force by unit volume in second coordinate direction.
3	Non-uniform pressure on 1-2 face of the element, magnitude supplied through subroutine FORCEM.
4	Non-uniform body force per unit volume in first coordinate direction, magnitude supplied through subroutine FORCEM.
5	Non-uniform body force per unit volume in second coordinate direction, magnitude supplied through subroutine FORCEM.
6	Uniform pressure on 2-3 face of the element.
7	Non-uniform pressure on 2-3 face of the element, magnitude supplied through subroutine FORCEM.
8	Uniform pressure on 3-4 face of the element.
9	Non-uniform pressure on 3-4 face of the element, magnitude supplied through subroutine FORCEM.
10	Uniform pressure on 4-1 face of the element.
11	Non-uniform pressure on 4-1 face of the element, magnitude supplied through subroutine FORCEM.

All pressures are positive when directed into the element. In addition, point loads may be applied at the nodes.

#### . OUTPUT OF STRAINS

Output of strains at the centroid of the element in global coordinates is:

$$1 = E_{zz}$$

$$2 = E_{rr}$$

$$3 = E_{\theta\theta}$$

$$4 = E_{rz}$$



. OUTPUT OF STRESSES

Same as for strain.

. TRANSFORMATION

Two global degrees of freedom may be transformed into local coordinates.

. TYING

May be tied to axisymmetric shell type 1 using standard tying type 23.

. OUTPUT POINTS

Output is available at the centroid or at the 4 Gaussian points shown in Figure B-4.

. MESH GENERATOR

MESH2D Option.

. UPDATING LAGRANGE PROCEDURE AND FINITE STRAIN PLASTICITY

Capability is available - stress and strain output in global coordinate directions. Reduced volume strain integration recommended. (See GEOMETRY).

. DEGREES OF FREEDOM

Global displacement degrees of freedom:

1 = u direction

2 = v direction

. TRACTIONS

Load types for distributed loads as follows.

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MARC ANALYSIS RESEARCH CORP PALO ALTO CA  
KNOWLEDGE BASED CONSULTATION FOR FINITE ELEMENT STRUCTURAL ANAL--ETC(U)  
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Load TypeDescription

- |    |  |
|----|--|
| 0  | Uniform pressure distributed on 1-2 face of the element.   |
| 1  | Uniform body force per unit volume in first coordinate direction.  |
| 2  | Uniform body force by unit volume in second coordinate direction.  |
| 3  | Non-uniform pressure on 1-2 face of the element, magnitude supplied through subroutine FORCEM.                       |
| 4  | Non-uniform body force per unit volume in first coordinate direction, magnitude supplied through subroutine FORCEM.  |
| 5  | Non-uniform body force per unit volume in second coordinate direction, magnitude supplied through subroutine FORCEM. |
| 6  | Uniform pressure on 2-3 face of the element.   |
| 7  | Non-uniform pressure on 2-3 face of the element, magnitude supplied through subroutine FORCEM.                       |
| 8  | Uniform pressure on 3-4 face of the element.   |
| 9  | Non-uniform pressure on 3-4 face of the element, magnitude supplied through subroutine FORCEM.                       |
| 10 | Uniform pressure on 4-1 face of the element.   |
| 11 | Non-uniform pressure on 4-1 face of the element, magnitude supplied through subroutine FORCEM.                       |

All pressures are positive when directed into the element. In addition, point loads may be applied at the nodes.

. OUTPUT OF STRAINS

Output of strain at the centroid of the element is:

$$1 = E_{xx}$$

$$2 = E_{yy}$$

$$3 = E_{zz} = 0$$

$$4 = E_{xy}$$

. OUTPUT OF STRESSES

Same as for strain.

. TRANSFORMATION

The two global degrees of freedom may be transformed to local degrees of freedom.

. TYING

User subroutine UFORMS.

. OUTPUT POINTS

Output is available at the centroid, or with the ALL POINT Option, at the 4 Gaussian points shown in Figure B-4.

. MESH GENERATOR

MESH2D Option.

. UPDATING LAGRANGE PROCEDURE AND FINITE STRAIN PLASTICITY

Capability is available - stress and strain output in global coordinate direction. Reduced volume strain integration recommended. (See GEOMETRY).

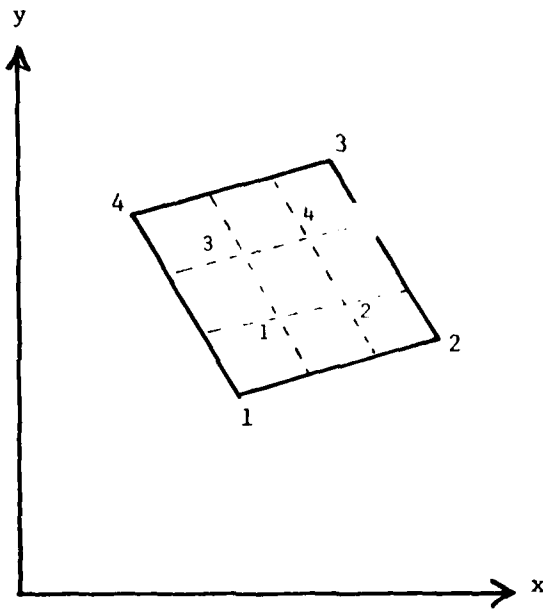


Figure B-4 Gaussian Integration Points for Element Type 11

### THREE-DIMENSIONAL ARBITRARILY DISTORTED CUBE - ELEMENT 7

This is an eight-node isoparametric element (Figure B-5). Element 21 is a better element. Use it if possible. The element is based on the following type of displacement assumption and mapping into a cube in the (g-h-r) space:

$$x = a_0 + a_1g + a_2h + a_3r + a_4gh + a_5hr + a_6gr + a_7ghr$$
$$u = b_0 + b_1g + b_2h + b_3r + b_4gh + b_5hr + b_6gr + b_7ghr$$

The 24 generalized displacements are related to the u-v-w displacements (in global coordinates) at the eight corners of the distorted cube. The strain-displacement relations for this element are written for finite strain, large displacement analysis. The stiffness of the element is formed by numerical integration using eight points defined in the (g-h-r) space.

See Reference 6, Volume A, Section 7, for further details.

#### QUICK REFERENCE

##### . TYPE 7

Eight-node, three-dimensional, first-order isoparametric element (arbitrarily distorted cube).

##### . CONNECTIVITY

Eight nodes per element. Node numbering must follow the scheme below:

Nodes 1, 2, 3 and 4 are corners of one face, given in counterclockwise order when viewed from inside the element. Node 5 is the same edge as node 1, node 6 as node 2, node 7 as node 3, and node 8 as node 4.

##### . GEOMETRY

If a nonzero value is entered in the second data field (EGEOM2), the volume strain will be constant throughout the element. This is particularly useful for analysis of approximately incompressible materials, and for analysis of structures in the fully plastic range. And it is also recommended for creep problems in which it is attempted to obtain the steady state solution. For details see Volume G, Reference XXV.

##### . COORDINATES

Three coordinates in the global x, y and z directions.

. DEGREES OF FREEDOM

Three global degrees of freedom  $u$ ,  $v$  and  $w$  per node.

. TRACTIONS

Distributed loads chosen by value of IBODY as:

- IBODY = 0     Uniform pressure on 1-2-3-4 face.
- IBODY = 1     Non-uniform pressure on 1-2-3-4 face with magnitude supplied by user subroutine FORCEM.
- IBODY = 2     Uniform body force per unit volume in -z direction.
- IBODY = 3     Non-uniform body force per unit volume (e.g., centrifugal force) with magnitude and direction supplied through user subroutine FORCEM.
- IBODY = 4     Uniform pressure on 6-5-7-8 face.
- IBODY = 5     Non-uniform pressure on 6-5-8-7 face (FORCEM).
- IBODY = 6     Uniform pressure on 2-1-5-6 face.
- IBODY = 7     Non-uniform pressure on 2-1-5-6 face (FORCEM).
- IBODY = 8     Uniform pressure on 3-2-6-7 face.
- IBODY = 9     Non-uniform pressure on 3-2-6-7 face (FORCEM).
- IBODY = 10    Uniform pressure on 4-3-7-8 face.
- IBODY = 11    Non-uniform pressure on 4-3-7-8 face (FORCEM).
- IBODY = 12    Uniform pressure on 1-4-8-5 face.
- IBODY = 13    Non-uniform pressure on 1-4-8-5 face (FORCEM).

Pressure forces are positive into element face. Note that for use with this element, FORCEM has the following form:

```
SUBROUTINE FORCEM (P,XYZ,DIR,NN,N)
DIMENSION XYZ (3), DIR(3)
```

User Coding

```
RETURN
END
```

Where:

XYZ(1), XYZ(2), are the (x,y,z) coordinates of the integration point (supplied by the program).  
XYZ(3)

DIR(1), DIR(2), are the (x,y,z) components defining the direction of the force. This array must be defined by the user for IBODY=3, but otherwise, ignored.  
DIR(3)

P is the magnitude of the force (per unit volume) for IBODY=3, or the magnitude of the non-uniform surface pressure that is defined by the user.

NN is the integration point number on the surface to which the load is applied (1 through 4), or in volume (1 through 8).

N is the element number.

This subroutine will be called once per integration point when flagged. The magnitude of load defined by TRACTIONs will be ignored and the FORCEM value will be used instead. For non-uniform surface pressures, values need only be supplied for the four integration points on the face of application. Note that XYZ and N must not be changed.

. OUTPUT OF STRESSES

Output of stress is the same as for strain.

. TRANSFORMATION

Standard transformation of three global degrees of freedom to local degrees of freedom.



- . SHELL TRANSFORMATION

The shell transformation option type 2 may be used to permit easier application of point loads, moments and/or boundary conditions on a node. For a description of the transformation type, see Volume A, Page A2.12-1. Note that if the FOLLOW FORCE option is invoked, the transformations will be based on the updated configuration of the element.

- . TYING

No special tying available.

- . OUTPUT POINTS

Centroid or the eight integration points as shown in Figure B-6.

- . MESH GENERATOR

MARCMESH3D with optimizer and hidden lines removed plotting.

- . CAUTION

As in all three-dimensional analysis a large nodal bandwidth results in long computing times. Use the optimizers either in MARCMESH3D or MARC-OPT as much as possible.

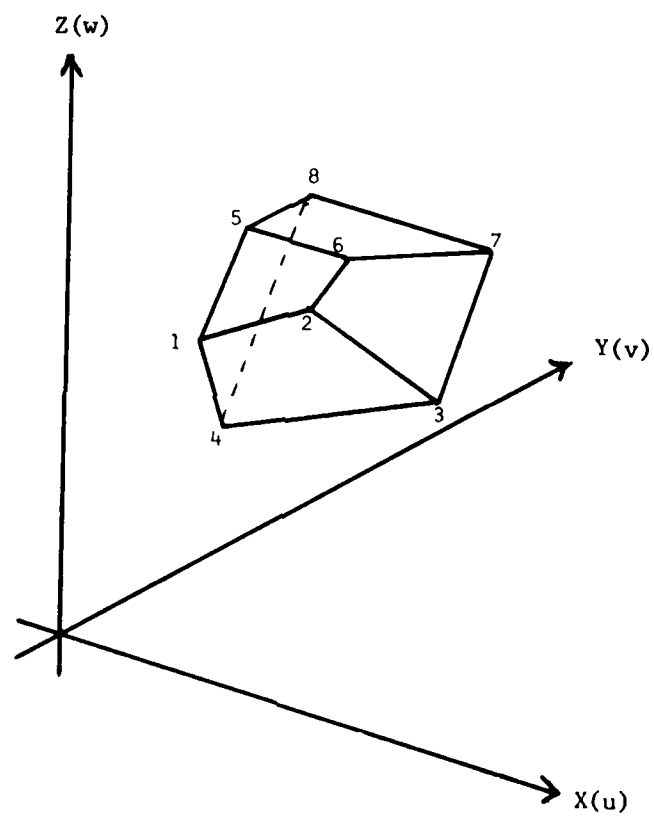


Figure B-5 Arbitrarily Distorted Cube

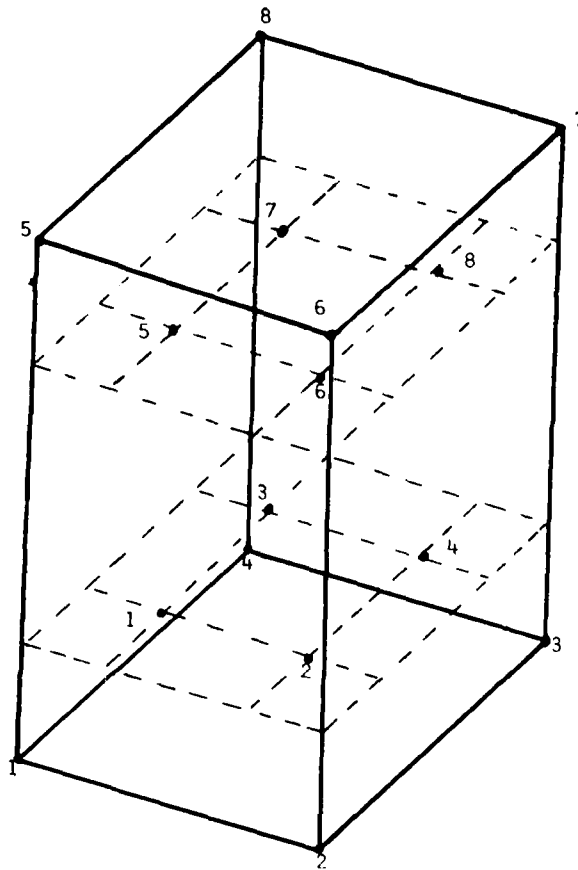


Figure B-6 8-Point Gauss Integration Scheme for Element 7

APPENDIX C

List of Conversations

During a Consultation

For the purpose of demonstrating the use of current consultation system for structural analysis, a two-dimensional structure has been analyzed as discussed in Section IV. The conversations held during the consultation are compiled and listed in this Appendix.

```
SEG JMR>AI>#AI
GO
ENTER DATA BASE FILE NAME :
RESTORE CHECKPOINT?
ENTER RULE FILE NAME: MBHTEST2
INITIALIZING.....
ENTER KEYWORD: GENERAL ONE
PLEASE ENTER DIMENSIONALITY OF YOUR
STRUCTURE : ONE, TWO OR THREE
GENERAL 1: TWO
PLEASE ENTER OVER ALL THICKNESS OF YOUR
STRUCTURE: THICK, THIN_FLAT, THIN_CURVED, OR
THIN_SLENDER
GENERAL 1: THIN_FLAT
PLEASE ENTER TYPE OF LOADINGS . MECHANICAL,
THERMAL, OR THERMO_MECHANICAL
GENERAL 1: MECHANICAL
PLEASE ENTER TIME DEPENDENCY OF MECHANICAL LOADINGS .
DEPENDENT, OR INDEPENDENT
GENERAL 1: INDEPENDENT
PLEASE ENTER TEMPERATURE LEVEL OF YOUR STRUCTURE .
HIGH OR LOW
GENERAL 1: LOW
PLEASE ENTER STRESS STRAIN RELATION OF THE
MATERIAL : LINEAR OR NON_LINEAR
GENERAL 1: LINEAR
RULE # 201 PROCESSED - RESULT WAS TRUE
GENERAL ONE IS GIVEN
ENTER KEYWORD: GEOMETRY
MARC ELEMENT NO 3 SELECTED FOR THE ANALYSIS
RULE # 101 PROCESSED - RESULT WAS TRUE
GEOMETRY IS TWO_D_PLANE_STRESS
ENTER KEYWORD: MATERIAL
RULE # 18 PROCESSED - RESULT WAS TRUE
MATERIAL IS LINEAR_STRESS_STRAIN
ENTER KEYWORD: LOADING
RULE # 9 PROCESSED - RESULT WAS TRUE
LOADING IS MECHANICAL
```

ENTER KEYWORD: GENERAL TWO  
PLEASE ENTER TOTAL NUMBER OF ELEMENTS IN THE MESH  
GENERAL 1: 8  
PLEASE ENTER TOTAL NUMBER OF NODES IN THE MESH  
GENERAL 1: 15  
PLEASE ENTER TOTAL NUMBER OF DIFFERENT ELEMENT  
THICKNESSES IN THE MESH  
GENERAL 1: 1  
PLEASE ENTER TOTAL NUMBER OF ELEMENT RANGE PAIRS  
OF ALL ELEMENT THICKNESSES IN THE MESH  
GENERAL 1: 1  
PLEASE ENTER TOTAL NUMBER OF DIFFERENT MATERIALS IN  
THE MESH  
GENERAL 1: 1  
PLEASE ENTER TOTAL NUMBER OF POINTS IN WORK HARDENING  
SLOPE FUNCTIONS FOR ALL MATERIALS  
GENERAL 1: 0  
PLEASE ENTER TOTAL NUMBER OF POINTS IN TEMPERATURE  
DEPENDENT MATERIAL FUNCTIONS FOR ALL MATERIALS  
(MAX. VALUE AMONG ALL PROPERTIES)  
GENERAL 1: 0  
PLEASE ENTER TOTAL NUMBER OF ELEMENT RANGE PAIRS  
FOR ALL MATERIALS IN THE MESH  
GENERAL 1: 1  
PLEASE ENTER TOTAL NUMBER OF SPECIFIED NODAL POINT  
DEGREES OF FREEDOM IN THE MESH  
GENERAL 1: 6  
PLEASE ENTER TOTAL NUMBER OF POINT LOADS (NODE RANGE  
PAIRS) IN THE MESH  
GENERAL 1: 1  
PLEASE ENTER TOTAL NUMBER OF DISTRIBUTED LOADS (ELEMENT  
RANGE PAIRS) IN THE MESH  
GENERAL 1: 1  
PLEASE ENTER TRANSIENT TIME FOR DYNAMIC OR CREEP ANALYSIS  
GENERAL 1: 0  
PLEASE ENTER TIME INCREMENT FOR DYNAMIC OF CREEP ANALYSIS  
GENERAL 1: 0  
RULE # 202 PROCESSED - RESULT WAS TRUE  
GENERAL TWO IS GIVEN

ENTER KEYWORD: CONNECTIVITY

PLEASE ENTER ELEMENT CONNECTIVITY AS FOLLOWS:

ELEMENT NUMBER AND ELEMENT TYPE FOLLOWED BY

TWO NODAL NUMBERS FOR TWO NODE BEAM AND AXISYMMETRIC SHELL ELEMENTS OR,

FOUR NODAL NUMBERS FOR FOUR NODE PLANE STRESS, PLANE STRAIN, AND AXISYMMETRIC ELEMENTS OR,

EIGHT NODAL NUMBERS FOR EIGHT NODE THREE DIMENSIONAL BRICK ELEMENTS

ELMT 1: 1 3 1 2 5 4

ELMT 2: 2 3 2 3 6 5

ELMT 3: 3 3 4 5 8 7

ELMT 4: 4 3 5 6 9 8

ELMT 5: 5 3 7 8 11 10

ELMT 6: 6 3 8 9 12 11

ELMT 7: 7 3 10 11 14 13

ELMT 8: 8 3 11 12 15 14

RULE # 221 PROCESSED - RESULT WAS TRUE

CONNECTIVITY IS GIVEN

ENTER KEYWORD: COORDINATES

PLEASE ENTER NODAL COORDINATES AS FOLLOWS :

NODAL NUMBER FOLLOWED BY

TWO NODAL COORDINATES FOR NODAL POINT OF TWO DIMENSIONAL STRUCTURES OR,

THREE NODAL COORDINATES FOR NODAL POINT OF THREE DIMENSIONAL STRUCTURES

NODE 1: 1 3. 0.

NODE 2: 2 4.5 0.

NODE 3: 3 6. 0.

NODE 4: 4 2.772 1.148

NODE 5: 5 4.386 2.574

NODE 6: 6 6. 4.

NODE 7: 7 2.121 2.121

NODE 8: 8 4.06 5.06

NODE 9: 9 6. 8.

NODE 10: 10 1.148 2.772

NODE 11: 11 2.074 5.386

NODE 12: 12 3. 8.

NODE 13: 13 0. 3.

NODE 14: 14 0. 5.5

NODE 15: 15 0. 8.

RULE # 222 PROCESSED - RESULT WAS TRUE

COORDINATES IS GIVEN



ENTER KEYWORD: BASE PROPERTY  
 PLEASE ENTER MATERIAL IDENTIFICATION AND YOUNGS  
 MODULUS OF ALL MATERIALS  
 MATERIAL 1: 1 30.E6  
 PLEASE ENTER MATERIAL IDENTIFICATION AND POISSONS  
 RATIO OF ALL MATERIALS  
 MATERIAL 1: 1 0.3  
 PLEASE ENTER MATERIAL IDENTIFICATION AND DENSITY  
 OF ALL MATERIALS  
 MATERIAL 1: 1 0.  
 PLEASE ENTER MATERIAL IDENTIFICATION AND COEFF  
 OF THERMAL EXPANSION OF ALL MATERIALS  
 MATERIAL 1: 1 0.  
 PLEASE ENTER MATERIAL IDENTIFICATION AND BASE  
 (STRESS FREE) TEMPERATURE OF ALL MATERIALS  
 MATERIAL 1: 1 0.  
 PLEASE ENTER MATERIAL IDENTIFICATION AND YIELD  
 STRESS OF ALL MATERIALS  
 MATERIAL 1: 1 20000.  
 RULE # 241 PROCESSED - RESULT WAS TRUE  
 BASE PROPERTY IS GIVEN  
 ENTER KEYWORD: MATERIAL RANGE  
 PLEASE ENTER MATERIAL IDENTIFICATION AND ELEMENT  
 RANGE PAIRS OF ALL MATERIALS  
 EL RANGE 1: 1 1 8  
 RULE # 244 PROCESSED - RESULT WAS TRUE  
 MATERIAL RANGE IS GIVEN  
 ENTER KEYWORD: ELMT THICKNESS  
 PLEASE ENTER GEOMETRY DATA OR, ELEMENT THICKNESS AS  
 FOLLOWS:  
 GEOMETRY DATA FOR TWO NODE BEAM AND AXISYMMETRIC SHELL  
 ELEMENTS OR,  
 ELEMENT THICKNESS FOR PLANE STRESS AND PLANE STRAIN  
 ELEMENTS  
 THICKNESS 1: 1.  
 RULE # 223 PROCESSED - RESULT WAS TRUE  
 ELMN THICKNESS IS GIVEN  
 ENTER KEYWORD: THICKNESS RANGE  
 PLEASE ENTER ELEMENT THICKNESS IDENTIFICATION AND  
 ELEMENT RANGE PAIR FOR GIVEN THICKNESS  
 EL RANGE 1: 1 1 8  
 RULE # 224 PROCESSED - RESULT WAS TRUE  
 THICKNESS RANGE IS GIVEN

ENTER KEYWORD: BOUNDARY C  
PLEASE ENTER NODAL POINT RANGE, DEGREE OF FREEDOM.  
AND SPECIFIED DISPLACEMENT (OPTIONAL, DEFAULT IS 0.0)

BOUNDARY 1: 1 1 2 0.

BOUNDARY 2: 2 2 2 0.

BOUNDARY 3: 3 3 2 0.

BOUNDARY 4: 13 13 2 1 0.

BOUNDARY 5: 14 14 1 0.

BOUNDARY 6: 15 15 1 0.

RULE # 261 PROCESSED - RESULT WAS TRUE

BOUNDARY C IS GIVEN

ENTER KEYWORD: POINT LOAD

PLEASE ENTER NODE NO., POINT LOAD IN FIRST DIRECTION.

POINT LOAD IN SECOND DIRECTION AND POINT LOAD IN THIRD DIRECTION

NODE 1: 15 0. 0. 0.

RULE # 271 PROCESSED - RESULT WAS TRUE

POINT LOAD IS GIVEN

ENTER KEYWORD: DIST LOAD

PLEASE ENTER NUMBER OF ELEMENTS.

ELEMENT RANGE, FACE IDENTIFICATION OF THE  
DISTRIBUTED LOAD AND DISTRIBUTED LOAD

ELMT 1: 2 6 8 6 -10000.

RULE # 272 PROCESSED - RESULT WAS TRUE

DIST LOAD IS GIVEN

ENTER KEYWORD: ANALYSIS ONE

RULE # 22 PROCESSED - RESULT WAS TRUE

ANALYSIS ONE IS ELASTIC

ENTER KEYWORD: ANALYSIS TWO

CANT DO ANYTHING

ENTER KEYWORD: ANALYSIS THREE

CANT DO ANYTHING

ENTER KEYWORD: ANALYSIS FOUR

CANT DO ANYTHING

ENTER KEYWORD: ANALYSIS FIVE

CANT DO ANYTHING

ENTER KEYWORD: P\_CARD ONE

SET DEFAULTS MAXALL ETC

WRITE TITLE CARD ON INPUT1

WRITE SIZING CARD ON INPUT1

WRITE ALL POINTS CARD ON INPUT1

RULE # 203 PROCESSED - RESULT WAS TRUE

P\_CARD ONE IS GIVEN

ENTER KEYWORD: P\_CARD\_TWO  
CANT DO ANYTHING  
ENTER KEYWORD: P\_CARD\_THREE  
CANT DO ANYTHING  
ENTER KEYWORD: P\_CARD\_FOUR  
CANT DO ANYTHING  
ENTER KEYWORD: P\_CARD\_FIVE  
CANT DO ANYTHING  
ENTER KEYWORD: M\_CARD\_ONE  
WRITE END CARD ON INPUT2  
WRITE CONNECTIVITY CARD ON INPUT2  
WRITE COORDINATE CARD ON INPUT2  
WRITE PROPERTY CARD ON INPUT2  
WRITE GEOMETRY CARD ON INPUT2  
WRITE BOUNDARY CONDITION CARD ON INPUT2  
WRITE TRACTION CARDD ON INPUT2  
WRITE CONTROL CARD ON INPUT2  
WRITE POST CARD ON INPUT2  
RULE # 204 PROCESSED - RESULT WAS TRUE  
M\_CARD\_ONE IS GIVEN  
ENTER KEYWORD: M\_CARD\_TWO  
CANT DO ANYTHING  
ENTER KEYWORD: M\_CARD\_THREE  
CANT DO ANYTHING  
ENTER KEYWORD: M\_CARD\_FOUR  
CANT DO ANYTHING  
ENTER KEYWORD: L\_CARD\_ONE  
WRITE END OPTION CARD ON INPUT3  
RULE # 205 PROCESSED - RESULT WAS TRUE  
L\_CARD\_ONE IS GIVEN  
ENTER KEYWORD: L\_CARD\_TWO  
CANT DO ANYTHING  
ENTER KEYWORD: L\_CARD\_THREE  
CANT DO ANYTHING  
ENTER KEYWORD: L\_CARD\_FOUR  
CANT DO ANYTHING  
ENTER KEYWORD: L\_CARD\_FIVE  
CANT DO ANYTHING  
ENTER KEYWORD: INPUT\_FILE  
RULE # 216 PROCESSED - RESULT WAS TRUE  
INPUT\_FILE IS GIVEN

ENTER KEYWORD: RESULT ONE  
READ SUMMARY OF MARC RESULTS FROM USDATA  
RULE # 251 PROCESSED RESULT WAS TRUE  
RESULT ONE IS GIVEN  
ENTER KEYWORD: RESULT TWO  
RESULTS FOR INCREMENT NO 1  
MAX XX STRAIN IS -0.3556E-03  
MAX YY STRAIN IS -0.1010E-02  
MAX XY STRAIN IS -0.4184E-03  
MAX EQUIV. PLASTIC STRAIN IS 0.0000E 00  
MAX EQUIV. CREEP STRAIN IS 0.0000E 00  
MAX XX STRESS IS -0.1000E 05  
MAX YY STRESS IS -0.3157E 05  
MAX XY STRESS IS -0.4828E 04  
MAX EQUIV. STRESS IS 0.2982E 05  
RULE # 252 PROCESSED - RESULT WAS TRUE  
ENTER KEYWORD:

DATE  
FILMED  
-8