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ANALYTIC MODELING OF ROCK-STRUCTURE INTERACTION

Vol. 2 Users guide for a computer program

AGBABIAN ASSOCIATES

prepared for Advanced Research Projects Agency Bureau of Mines

APRIL 1973

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USERS GUIDE FOR A COMPUTER PROGRAM FOR ANALYTIC MODELING OF ROCK-STRUCTURE INTERACTION

Final Technical Report Volume 2 April 1973

U. S. BUREAU OF MINES Contract Number H0220035



Sponsored By ADVANCED RESEARCH PROJECTS AGENCY ARPA Order No. 1579, Amend. No. 3 Program Code 2F10

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JEREMY ISENBERG Principal Investigator

AGBABIAN ASSOCIATES Engineering and Applied Sciences Division 250 N. Nash Street El Segundo, California 90245

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USERS GUIDE FOR A COMPUTER PROGRAM FOR ANALYTIC MODELING OF ROCK-STRUCTURE INTERACTION

Final Technical Report Volume 2 April 1973

U. S. BUREAU OF MINES Contract Number H0220035

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JEREMY ISENBERG Principal Investigator

AGBABIAN ASSOCIATES Engineering and Applied Sciences Division 250 N. Nash Street El Segundo, California 90245



FINAL TECHNICAL REPORT

VOLUME 2

No. 3

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Phone Number:	(213) 640-0576
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ng of Rock-Structure Interaction. Users Guide for a Computer Program for Analytic Modeling of Rock-Structure Interaction, Volume 2 of 3, Final Report

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Bureau of Mines under Contract No. H0220035.



TECHNICAL REPORT SUMMARY

The objective of this project is to combine a number of recent advances in finite element theory and computer technology for analyzing cavities and structures in rock. This computer program applies to general three-dimensional structures, considers nonlinear material properties, time dependent properties, gravity loading and sequence of excavation or construction.

The final report for this project is in three volumes as follows:

Volume 1 - "Analytical Modeling of Rock - Structure Interaction." Final Report, April 1973.

- Volume 2 "Users Guide for a Computer Program for Analytic Modeling of Rock - Structure Interaction." Final Report, April 1973.
- Volume 3 "Computer Program for Analytic Modeling of Rock -Structure Interaction." Final Report, April 1973.

All three volumes were prepared by Agbabian Associates, under contract H0220035 with U. S. Bureau of Mines. The project was sponsored by ARPA under ARPA Order Number 1579, Amend. No. 3, Program Code 2F10.

During this contract, work has been almed at producing a useroriented computer program. The work of writing the program was divided into three areas:

- a. Input
- b. Execution and output
- c. Material properties



The Input Section automatically generates the continuum part of the finite element mesh, including joint elements, allows the user to add other elements (beam, shell, truss) to the mesh, plots the result, reduces the bandwidth and reads loads, material properties, and other quantities necessary to the calculation. The Execution Section forms the global stiffness matrix and solves equations of equilibrium for displacements by an implicit method. The material properties are represented by subroutines within the Execution Section, which are written in a modular form so that if the general equations of nonlinear elasticity, viscoelasticity, viscoplasticity, or plasticity do not suit a particular problem they may be easily modified.

One of the guidelines for this project was to consolidate existing finite element technology into a single, general purpose computer program. Accordingly, the program uses existing finite elements, a proven form of the equation of equilibrium, existing material property descriptions, and an existing bandwidth reducer. However, a small amount of new work was done. A new joint element was developed and an existing concept for automatic mesh generation was greatly extended. Also, a form of Choleski decomposition was modified for efficient use of multibuffering, resulting in substantial improvement in efficiency of solving equations of equilibrium using peripheral storage.

During this study, some new work was reported by other ARPA/Bureau of Mines contractors which has been incorporated in the program. Among these are some creep data obtained by W. A. Wawersik of the University of Utah and strength/deformability data for faults by R. E. Goodman, F. E. Heuze, and Y. Ohnishi of the University of Callfornia, Berkeley.

The technical work reported in Volume 1 is divided into two main parts. The first part describes the range of possible application of the computer program to mining engineering problems and reports an extensive analytic study of the Caladay Project hoist room with which experimental data are compared. The second part discusses various aspects of the computer



program and its theoretical basis. Attention is given to the processing of input data and to options available to the user for mesh generation, sequential excavation or construction, automatic bandwidth reduction and plotting of the mesh. Example problems which have been solved during checkout of the program are described.

Volume 2 explains the overall operation of the computer program, defines how input should be submitted to the program, defines the material property models in detail, explains the data stored on each tape and gives flow charts of some subroutines. This input definition is for the version of the program which operates on the UNIVAC 1108. This program is the primary content of Volume 3, and is available on seven track magnetic tape from DDC-TC, U. S. Department of Commerce, Springfield, Virginia 22151, telephone AC (703) 321-8517. The tape is unlabeled, even parity, external BCD and is written at 556 BPI. The tape has constant record sizes, each record being 1920 characters long (24-80 column card images per record). An end of file mark follows the last record on the tape.

Arrangements to obtain copies of Volumes 2 and 3 may also be made through Agbabian Associates, 250 North Nash Street, El Segundo, California 90245, telephone AC (213) 640-0576.

This contract was monitored by Dr. William J. Karwoski, Spokane Mining Research Center, U. S. Bureau of Mines.



FOREWORD

The principal contributors to the computer program described in this report are listed below. All are members of the technical staff of Agbabian Associates.

- A. K. Bhaumik
- K. P. Chuang
- J. M. Clark
- K. T. Dill
- J. Ghaboussi
- J. Isenberg
- E. M. Raney



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INTRODUCTION

The main purpose of this document is to show how the input is prepared for the present computer program. The sequence of user operations, logical units required, format for input data and flow charts for some of the frequently-used subroutines are given. There is also a special section on the input for material properties. The prospective user should refer to the final report entitled, "Analytic Modeling of Rock - Structure Interaction," prepared under ARPA Order No. 1579, Amend. 3 and monitored by the Spokane Mining Research Center, US Bureau of Mines under Contract H0220035. Dr. William J. Karwoski was the project monitor.

This computer program considers static, three-dimensional, nonlinear analyses by the finite element method. Gravity loading and sequence of excavation or construction are also considered. The following types of elements are available:

- a. Beam
- b. Rod
- c. Axisymmetric quad
- d. Plane quad
- e. Three-dimensional hexahedron
- f. Thick shell
- g. Plane slip or joint
- h. Axisymmetric slip or joint

All elements except the beam and thick shell may have nonlinear material properties. The types of nonlinear properties which may be assigned are:

- a. Variable moduli
- b. Elastic or variable modulus with ideal plasticity. Yield function may be isotropic or anisotropic



- c. Nonlinear elastic with ideally plastic fracture criterion and strain hardening cap
- d. Anisotropic variable moduli with anisotropic fracture criterion
- e. Viscoelasticity (Kelvin, Maxwell, three-parameter fluid).
- f. Viscoplasticity

The material properties are submitted as coefficients in an array whose length is 100 decimal locations. The coefficients are substituted into the appropriate equations according to flags. The user may easily change the form of any of the equations by modifying the material property subroutines, which can be done independently of the main line program. Small strains and small displacements are assumed. However, the program is written such that it can be modified to account for geometrical nonlinearity. The main provision in this regard is that the updated coordinates which are needed to form strain/ displacement relationships and the original relationships are available in the computation section of the program.

The computer program was originally intended to solve problems in rock mechanics and mining engineering. Thus, the excavation and construction options are intended to aid analysis of shafts or chambers in rock having nonlinear properties from the start of construction through excavation and installation of temporary supports to the installation of permanent supports. Besides the problems shown in the final report cited above, the program has been applied to the pullout of a cable anchor embedded in soil. This problem uses axisymmetric elements with nonlinear properties and axisymmetric slip elements for slip and debonding.

The program uses the direct stiffness method of structural analysis. Degrees of freedom are defined at nodal points which are at corners of elements. Element stiffnesses are deposited in a global stiffness matrix. Nodal point forces, which include external loads and internal resisting forces are expressed in a global load vector. A form of Choleski decomposition, involving

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triangularization of the global stiffness matrix, reduction of the load vector and back substitution of the reduced load vector into the triangularized stiffness matrix, is used to obtain incremental displacements. The program has several options for performing these operations from which it chooses depending on the available core. According to one option, the stiffness matrix is formed block by block (one bandwidth wide) and stored on peripheral units; it is then retrieved block by block and processed. Under a second option, the stiffness matrix and load vector are formed and reduced in a block-by-block manner and written on peripheral storage in a reduced form. Part of the reduction is performed in local double precision.

These operations require many accesses to peripheral storage. The number of accesses and hence the computer time required for large problems would become prohibitive on small or medium sized computers. In the present program, a multibuffering technique is used which allows data to be transferred to and from peripheral storage while computations are being performed in the main core area. This procedure virtually eliminates wait time for Input/Output operations.

The computer program is divided into three sections which are called Input, Execution, and Output. The responsibility of the user is greatest in the Input section, where the first step is to submit by means of coordinates on cards a key diagram which is the basis of the finite element mesh. The mesh, tributary areas and load coefficients are generated automatically, and the mesh is plotted. At this point the program will, on request, generate a restart tape and terminate execution so the user can examine the mesh he has prepared. Upon restarting, the user may add elements or nodal points, and he may request the bandwidth reducer to attempt reduction of the bandwidth. At this point a new plot of the mesh, which may have been expanded or renumbered or both, may be requested. The last group of data in the Input section includes element activity (an element may initially be inactive, become active, and then become inactive again) as a function of load step, load data (pressures in global directions) and material property data. At this point two tapes, a linkage file, and an element data file, linking Input to the Execution section are generated.

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The Execution section is initialized using the two link tapes created by the input section. The user supplies the number of steps between reformulation of the global stiffness and the load step after which a restart file is to be generated.

To continue execution of a restarted problem, the previous restart tape replaces the linkage file, and the run is continued. Note that reformulation and restart intervals may be changed at this time.

The output is stored on a magnetic tape and is printed, on separate request by the user, by executing the Output section. Output may be requested after a restart has been generated, and after the run is completed.





SECTION 1

DEFINITION OF INPUT DATA

The input data cards for the computer program are described on the following pages.

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
1.0		OPTION SELECTION	
		The following cards control the sequence of operations. Each option card is followed by the data required for execution, which is described in subsequent sections. Options may be stacked, but only in the sequence given below.	
		1. *STAR	
		2. *ADD data	
		3. *EXEC ^{data} 5 3	-
		4. *OUTP	
		5. *EXIT	
		This is a legal sequence allowing	
		1. Mesh generation	
		2. Modify generated mesh	
		 Execute, reforming every fifth step and generate restart at Step 3 	
		 Print stresses, strains, and displacements 	
		5. Termination	
		A second run of the sequence:	
		1. *REST 5 (N)	
		2. *OUTP	11 11 21 2
	467163	3. *EXIT	
	1.54		

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
1.0 (cont)		Allows restart with reformulation every fifth step (optional restart at Step N) followed by output and termination.	
1.1	1	ISTR, IWITIN, NSTP, NRSTRT, TIMER ISTR = "*" control character identifies this card as an option selection	(A1,A4,5X, 2110,F10.0)
		IWITIN = Four-character abbreviation for the option desired	
		<pre>MOD1 = MODIFYalter contents of IWORDS array (see Card Group 2.0) STAR = STARTcall automesh to generate the mesh (see Card Group 3.0) ADD = Call automesh to add to an exist- ing mesh (see Card Group 4.0) EXEC = EXECUTEinitiate calculation (no additional cards required) REST = RESTARTrestart calculation (no additional cards required) OUTP = OUTPUTbegin output (no addi- tional cards required) EXIT = End of run</pre>	
	A	ISTP, NRSTRT, TIMER are used only by option EXEC and REST and should be blank for all others.	
	Ν	<pre>ISTP = Step count for reformulation of the global stiffness, [K] will be reformed at every NSTPth cycle, must be > 0.</pre>	

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DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
1.1 (cont)	Lards	<pre>NRSTRT = Restart flag. A restart tape will be generated after step NRSTRT and calcula- tion will be terminated. When restart is requested, the code prints a message indicating which file contains restart data. A run may be continued from this point by mounting this restart tape as the LINK tape (see Appendix C) and requesting option *REST.</pre> TIMER = Restart interval in seconds. A restart tape will be generated after TIMER seconds of execution, and the run will continue. Restart tape units are switched among available units. A restart unit is not released until a new restart tape has been written.	Format

DE INITION OF INPUT FOR BUTEAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
2.0		INPUT FOR ALTERING IWORDS VIA OPTION "MODI". A DESCRIPTION OF IWORDS IS GIVEN IN APPENDIX A.	
2.1	variable	JTYPE, N	(A1, 14)
		JTYPE = Flag for type of alteration	
		= 1 , value to be altered is integer (see 2.2)	
		= H , value to be altered is Hollerith (see 2.3)	
		= E , end of data for MODI	
		N = Number of cards to be read	
		Each JTYPE card must be followed by N cards con-	
		taining data used to reset entries in the IWORDS	
		array. These cards are defined in Groups 2.2 and	
		2.3.	
2.2		INPUT CARDS FOR INTEGER DATA (JTYPE=1)	(215)
	N	JWD, IWD	(=,)/
		Set IWORDS (JWD) = IWD	
2.3		INFUT CARDS FOR HOLLERITH DATA (JTYPE=H)	(15, 18,
	N	JWD, IHOL	A4)
		IF (JWD ≠ 43), set IWORDS (JWD) = IHOL	
		<pre>IF JWD = 43, read a new header card into IWORDS (43)-IWORDS (62). Card 2.3.1 must immediately follow the card with JVD = 43.</pre>	
2.3.1	1	(IWD(I), I = 43, 62)	(20A4)

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.0		AUTOMESH INPUT DATAOPTION "START"	
3.1	1	(HED(1), I = 1, 20)	(20A4)
3.2	1	 HED = A 80-column label of alphameric characters used to identify the problem. This label will appear at the top of each printed output page NSPANY, NSPANX, NSPANZ, NMIDPT, NCOMFS, NCOMNP, ICOOR, NUMMAT, IPLOT, NSLIP, NPELAD, ITSHEL, IRENUM JPLOT LOUAD 	(1515)
		NSPANY, NSPANX, NSPANZ = Number of "spans" or "blocks" in the x, y, and z directions, respectively, in the "key diagram." NSPANZ is not meaningful in a two-dimensional problem, and the corresponding field must be left blank.	
		NCOMFS = Number of faces (3-D case) or sides (2-D case) to be formed by the face- or side-joining process described in card group 3.11 (page 16).	
		NCOMNP > Number of pairs of nodal points which will be joined by the face- or side-joining process in Card Group 3.11 (page 16).	
		<pre>ICOOR = A numeric flag specifying the units of length in which the input data is glven. = 0 if the units are in feet</pre>	
		= 1 if the units are in inches	

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Group	No. of Cards	Data and Definitions	Fortran Format
3.2 (cont)		If units selected are feet, the code converts all coordinates and areas into inches. Material property data is not converted and is expected to be given in inches. All final mesh data is expressed in inches.	
		NUMMAT = Number of different materials in the finite element mesh.	
		<pre>IPLOT = A numeric flag specifying if the gen- erated mesh is to be plotted.</pre>	
		<pre>= 0 if the mesh is not to be plotted = 1 if the mesh is to be plotted</pre>	
		<pre>NSLIP = A numeric flag signifying the presence of slip elements = 0 if no slip elements are in the mesh = 1 if there are slip elements in the mesh</pre>	
		When slip elements are present in a mesh, two runs must be performed. The actual number of slip elements is specified only in the second part of the run as explained in Card Group 4.1.	
	N	<pre>IPELAD = A numeric flag specifying if there are nodal points and/or elements to be man- ually added in the second part of the run. = 0 if there are no nodal points and/or elements to be manually added</pre>	

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and a

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.2 (cont)		 = 1 if there are nodal points and/or elements to be added. The actual number of nodal points and/or elements to be added are specified in Card Group 4.1. ITSHEL = A numeric flag signifying if there are 	
		shell elements involved in the mesh.	
		= 0 if there are shell elements	
		NOTE: If NSLIP, NPELAD, or ITSHEL are different from zero, a restart tape will be generated and option ADD must be run to complete the mesh.	
		<pre>IRENUM = A numeric flag specifying if the final mesh, including all the manually added nodal points, elements, and slip elements is to be renumbered for possible smaller bandwidth. = 0 if the mesh is not to be renumbered. > 0 , IRENUM minutes will be allowed for</pre>	
		the minimization	
		JPLOT = A numeric flag that specifies if the renumbered mesh is to be plotted. This is the final mesh which will be used in the numerical calculation.	
		= 0 if the final mesh is not to be plotted = 1 if the final mesh is to be plotted	

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.2 (cont)		<pre>IQUAD = This variable is significant only in a two-dimensional run in which the mesh is automatically generated. It specifies if the quadrilaterals generated are plane strain, plane stress, or axisymmetric.</pre>	
		= -3 or left blank. Quadrilaterals are plane strain.	
		= 3 if the quadrilaterals are plane stress.	
		= 4 if the quadrilaterals are axisymmetric.	
3.3	As req'd	X (I, J) (or R(I,J) if axisymmetric mesh) in a 2-D case and	(8FI0.0)
		X (I, J, K) in a 3-D case	
		X = X coordinates of the key diagram. Eight coordinates are given on a card, for as many cards as are necessary to define all the nodal points in the key diagram. They are given in the order: from the top to the bottom, from the left to the right, and in the 3-D case, from the front to the rear of the key diagram.	
3.4	As req'd	Y (I, J) (or Z(I, J) if axisymmetric mesh) in a 2-D case and	(8FI0.0)
		Y (I, J, K) in a 3-D case	
		Y = Y coordinates of the key diagram. Given in the order as stated in X.	

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.5	As req'd	Z (I, J, K) for a 3-D case only	(8F10.0)
		Z = Z coordinates in the key diagram. Given in the order as stated in X.	
3.6	NMI DPT	I, J, X (I,J), Y(I,J) in a 2-D case and I, J, K, X(I, J, K), Y (I, J, K), Z (I, J, K) in a 3-D case	(215,2F10.0) (315,3F10.0)
		I, J, K = positions, i.e., row, column and plane (or layer) numbers of a midpoint in the 2-D or 3-D array of nodal points and midpoints in the key diagram. As an example, in the 2-D key diagram shown below, Midpoints a and b occupy the positions (3,6) and (4,3), respectively. ROW 1 Image: Column and bound an	

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	lio. of Cards	Data and Definitions	Fortran Format
3.6 (cont)		As another example, in the 3-D key diagram shown below Midpoints <i>c</i> and <i>d</i> have the positions (5, 4, 1) and (1, 5, 4), respectively. MIDPOINT d	
		(1,5,4) $(1,5,4)$ $(1,5$	
3.7	As req'd	<pre>((MAT (1, J), 1 = 1, NSPANY), J = 1, NSPANX) in a 2-D case and ((MAT (1, J, K), 1 = 1, NSPANY), J = 1, NSPANX), K = 1, NSPANZ) in a 3-D case MAT = Material number of a block in the key diagram, 16 numbers per card for as many cards as are necessary for all blocks. The material numbers of the blocks are given by following the arrangement of the blocks from the top to the bottom, from the left to the</pre>	(1615)

AJA FORM NO. 1075

15

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.7 (cont)		right, and then from the front to the rear in the key diagram. The material numbers must always start with 1, and a zero implies a void or a cutout.	
3.8	As req'd	<pre>(NDY (1), I = 1, NSPANY) NDY (1) = Number of divisions the blocks located in the 1th row of the key diagram are to be subdivided into in the y direction, 16 numbers per card.</pre>	(1615)
3.9	As req'd	<pre>(NDX (1), I = 1, NSPANX) NDX (1) = Number of divisions the blocks located in the lth column of the key diagram are to be subdivided into in the x direction, 16 numbers per card.</pre>	(1615)
3.10	As req'd	<pre>(NDZ (1), I = 1, NSPANZ) for a 3-D case only NDZ (1) = Number of divisions the blocks in the</pre>	(1615)
3.11	NCOMF S	N1, N2, M1, M2 for a 2-D case and N1, N2, N3, M1, M2, M3 for a 3-D case In a 2-D case: N1, N2 = The end points of a mesh line, or a seg- ment of a mesh line, which is to be fused with another mesh line with end points M1 and M2 as defined next. N1, N2, M1, and M2 are temporary nodal point numbers that are used only in this card group to define nodal	(415)

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.11 (cont)		 points to be joined in the key diagram. The nodal points are numbered from the top to the bottom and from the left to the right as illustrated in the example given below. M1, M2 = The end points of a second mesh line, or segment of a mesh line, which is to be fused with the first one. Naturally, there must be the same number of nodal points on this line as on the first line defined by N1 and N2. The two mesh lines are joined or fused in such a manner that M1 joins N1 and M2 joins N2. As an example, a rectangular mesh with a crack or a slip surface as shown in the figure below is the result of using the accompanying key diagram and specifying that mesh line 2-6 is to be fused with mesh line 3-7. Naturally, Nodal Points 2, 6, and 10 in the key diagram have to be given the same coordinates as Nodal Points 3, 7, and 11, respectively, in order to get the result indicated in the final mesh. 	

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DEFINITION OF INPUT FOR BUREAU OF MINES CODE



DEFINITION OF INPUT FOR BUREAU OF MINES CODE



DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.11 (cont)		In the 3-D example below, NCOMNP would equal the total number of nodes generated on face N1-N2-N3 (which must, of course, equal those on M1-M2-M3).	
		In a 3-D case: N1, N2, N3 = Three corners of a four-sided face which is to be fused with another face as defined by the corner points M1, M2, and M3, as explained below. N1, N2 M3 are temporary nodal point numbers that are used only in this card group to define nodal point to be joined in the key diagram. The nodal points are numbered from the top to the bottom, from the left to the right, and from the front to the rear of the key diagram. The three points, N1, N2, and N3 must be so specified that N1 represents the corner formed by the two sides N1-N2 and N1-N3, as shown in the following illustration.	
		N1, M2, M3 = Three corners of a second four-sided face which is to be fused with the first fact as described above. The fusion takes place	e

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.11 (cont)		in such a manner that M1, M2, and M3 coincide with N1, N2, and N3, respectively, as illus- trated in the above figure.	
3.12	1	(ISIDE(I), $I = 1, 4$), NN for a 2-D case and (ISIDE(I), $I = 1, 6$), NN for a 3-D case	(411, 6X, 15) (611, 4X, 15)
		In a 2-D case: ISIDE(1) = A number, 1 through 4, representing any one of the four sides of a key diagram for which boundary codes are to be automatically generated by the program. The top side is designated 1, the bottom 2, the left 3, and the right 4, and these numbers may be given in any order. Thus, 2400 has the same effect as 0402; both of them say that boundary codes are to be automatically generated for the bottom and the right side of the key diagram only. It must be emphasized that boundary codes can be automatically generated only for those cases in which the sides designated conform to the following requirements. For a side of the mesh which corresponds to either the top or the bottom side of the key diagram, the side must be parallel to the x-axis, and for a side of the mesh which corresponds to either the left or the right side of the key diagram, the side must be parallel to the y-axis. A blank card, however, has to be supplied, even when no such automatic generation is desired.	

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DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.12 (cont)		<pre>In a 3-D case: ISIDE(1) = A number, 1 through 6, representing any one of the six side faces of a key diagram for which boundary codes are to be automati- cally generated by the program. The front face is designated 1, the rear, 2, the top 3, the bottom 4, the left 5, and the right 6. All the rest of the comments given above for the 2-D case also apply to this case. As before, a blank card must be supplied even when no such generation is desired.</pre>	
		Both in a 2-D and a 3-D case: NN = Total number of nodal points for which boundary codes are to be read in manually. Refer to the explanation given in the next card group.	
3.12.1	NN	<pre>J, (KODE (1, J), I = 1, 6) J = Final nodal point number of a nodal point whose boundary codes are to be manually read in. KODE = Boundary condition codes for the six degrees of freedom associated with the nodal point. = 0 when the degree of freedom is not constrained. = 1 when the degree of freedom is constrained. Thus, a card which reads 25 011101 says that at Nodal Point 25 only the x-displacement and the y-rotation are left unconstrained.</pre>	(15, 1X, 611)

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.13	1	(ISIDE (I), $I = 1$, 4), NN for a 2-D case and	(411, 6X, 15)
		(ISIDE (I), I = 1, 6), NN for a 3-D case	(611, 4X, 15)
		Numbers specified in this card group parallel those given in Card Group 3.12. The only difference is	
		that the numeric flags given in ISIDE array here designate the sides or faces for which the nodal	
		tributary areas and load coefficients are to be	31
		total number of nodal points for which tributary	
		areas and load coefficients are to be read in manually from the next card group. All other	
		comments given in Card Group 3.12 apply. As before, a blank card must be supplied even when	
		no such automatic generation is desired.	
		(The code cannot generate tributary areas for axisymmetric elements.)	
3.14	NN	J, (TA (I, J), $I = 1, 3$)	(15,3F10.0)
		J = Final nodal point number.	
		TA = Three tributary areas associated with the three components of the nodal force acting at Nodal Point J. They should be in square	
		ft, if the coordinates of the nodal points in the key diagram have been specified in	
		feet. In the code, the x-component of the	
		example, is defined as	
		P _x · TA (I, J) · C(I, J)	

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.14 (cont)		where P _x is the horizontal pressure for the system to be specified later.	
3.15	0~4	C1, C2 for a 2-D case and	(2F10.0)
	0 ~ 6	(CC (I), I = 1, 4) for a 3-D case	(4F10.0)
		In a 2-D case:	
		C1, C2 = The values of the load coefficient at the two ends of the corresponding edge specified in the last card group. One such card must be supplied for each one of the edges specified in the ISIDE array, and these cards must be arranged in the same order as the edges are mentioned in the ISIDE array. The following figure defines the corners the two C-values are referred to for each one of the four edges: EDGE DESIGNATION C1 C	
DEFINITION OF INPUT FOR

BUREAU OF MINES CODE

Group	No. of Cards	Data and Definitions	Fortran Format
3.15 (cont)		As an example, if ISIDE in Card Group 3.13 read 3100, or 0301, or 0031 (as long as 3	
		precedes 1, that is), one would be specifying the following variation in the C coefficient by providing the following two cards in this card group.	
		First card: 1.5 2.5 Second card: -1.5	
		1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5	
		card group is expected by the program.	
		<pre>in a 3-D case: CC (1) ~ CC (4) = The values of the load coeffi- cient at the four corners of the corresponding side face specified in Card Group 3.13. All the comments given above for the 2-D case apply. The following figures define the points of definition of the four coefficients for each side face.</pre>	



DEFINITION OF INPUT FOR BUREAU OF MINES CODE

DEFINITION OF INPUT FOR

BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.16	NN	J, (C(I, J), I = 1, 3)	(15,3F10.0)
		J = Final nodal point number	
		C = Three load coefficients associated with the three components of the nodal force acting at Nodal Point J.	
3.17	1	(VIEW (I), I = 1, 6) for a 3-D case only	(6F10.0)
		<pre>VIEW (1 ~ 3) = Direction cosines of the horizon which extends from the left toward the right.</pre>	
		VIEW $(4 ~ 6) =$ Direction cosines of the view vector (line of sight).	
		The plot controls specified in this card group are for the plot of the mesh automatically gen- erated by the program. No cards are expected in this and the following two card groups in case IPLOT = 0.	
3.17.1	1	QSIZE, HTNODE, HTELE, NCUT	(3F10.0,
	-	QSIZE = Width in inches of the paper to be used if different from the default value of 10.6 in.	110)
		HTNODE = Height in inches of the nodal point numbers if different from the default value of 0.07 in.	
		HTELE = Height in inches of the element numbers if different from the default value of 0.08 in.	
		If IPLOT = 0 this card is not supplied.	

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DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.17.1 (cont)	1	NCUT = Number of sections to be defined in the next card group which will define the portion of the mesh to be plotted.	
		As has been noted, this card group is provided only when IPLOT = 1.	
3.17.2	NCUT	((XCUT (I, J), I = 1, 6), J = 1, NCUT)	(6F10.0)
		XCUT (1 \sim 3, J) = Cartesian coordinates of a point on the Jth cut plane.	
		XCUT (4 ~ 6, J) = Direction cosines of a normal to the cut plane. The normal must be speci- fied in such a manner that it points toward the side of the cut plane which is to be plotted.	
		This card group is provided only when IPLOT = 1. For a run which does not contain any nodal points, elements or slip elements to be manually added, the next card group to be supplied is Card Group 4.5.	
4.0		AUTOMESH RESTART DATA (OPTION "ADD")	
4.1		NSLIP, NNPADD, NELADD, NOBB, NOMMAT NSLIP = Number of generated elements to be assigned as slip elements in Card Group 4.2. NNPADD = Total number of nodal points to be added. NELADD = Total number of elements to be added. NOBB = Number of bar and beam elements to be added (also included in NELADD)	(515)

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DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.1 (cont)		NUMMAT = Number of material property sets to be supplied	
4.2	NSLIP	(NESLIP(N), SLIPDA(1,N), (IIJJ(J,N), $J = 1,2$), (SLIPDA(J,N), $J = 2,3$), $N = 1$, NSLIP) for a 2-D case and	(515, F10.0)
		(NESLIP(N), SLIPDA(1,N), (IIJJ(J,N), J = 1,4), (SLIPDA(J,N), J = 2,3), N = 1, NSLIP)	(715, F10.0)*
		NESLIP(N) = Element number of an existing element (automatically generated in the first run) which is to be associated with a slip element SLIPDA(1,N) = A numeric flag designating the side (2-D) or face (3-D) which constitutes part of the slip surface. The following figures de- fine the numeric designation. Which corner nodal point is called 1,J,K, etc., can be determined by referring to the printout of th first run.	e

*Not implemented.

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.2 (cont)		<pre>IIJJ = The nodal poin numbers of the nodal points which are located on the other side of the slip surface, directly opposite to the nodal points constituting the corners of the side or side face designated by ISLIP.</pre>	
		In the case of a 2-D problem, there are two such points for each slip element, and in the case of a 3-D problem, there are four such points for each element. These additional nodal points must be specified in the follow- ing order of the pairing nodal points:	
		2-D case: ISLIP = 1 1, J ISLIP = 2 J, K ISLIP = 3 K, L ISLIP = 4 L, 1	
		<pre>3-D case: ISLIP = 1</pre>	
		respectively, of the associated sline element located on the slip surface.	

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.3	NELADD	ITYPE, (IX (I), I = 1, 8), MAT	(1015)
		-3 = Quadrilateral under plane strain	
		-1 = Bar under plane strain condition	
		1 = Bar under plane stress condition	
		2 = Beam element	
		3 = Quadrilateral under plane stress condition	
		4 = Axisymmetrical element	
		5 = Brick element	
		6 = Thick shell element	s i lug
		7 = Quadrilateral-slip element	1511
		8 = Brick-slip element	1.1.1
		9 = Axisymmetric slip element	
	\sim	<pre>IX = Element connectivity array. The nodal points must be given in the following sequence:</pre>	
		Bars: Either end first	
		Beams: The two ends and then the reference point	

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.3 (cont)		Quadrilaterals: I, J, K, L in the counter- clockwise sense as shown in the figure on Page 36. Bricks: I, J, K, L, II, JJ, KK, LL, as shown in the second figure on Page 36. Notice that when the brick is viewed in such a manner that the front face, I-J-K-L, is closer to the viewer, I-J-K-L, follow the clockwise sense, and that II on the rear face is located on the same edge	
		as I, etc. Thick shells: The 16 nodal points involved are specified in the sequence pictured in the following figure: $\frac{11}{4} \frac{12}{12} \frac{7}{14} \frac{9}{9} \frac{2}{15}$	
		Quad-slip and axisym-slip elements: 1,J, K, L for the quadrilateral in the sequence already explained, and then the two additional nodal points as explained under Card Group 4.2, Item IIJJ.	

DEFIN'TION OF .NPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.3 (cont)		Brick-slip elements: [*] Eight nodes of the brick, I, J, K, L, II, JJ, KK, LL followed by the four additional nodes as explained under Card Group 4.2, Item IIJJ.	
		Notice that when the number of nodal points involved is less than eight, some fields on the card are skipped before MAT is specified. However, when the number of nodal points exceeds eight, as in a thick-shell element, the extra nodal points are punched on an additional card in the format (815). The reading of this extra card is con- trolled by the value of ITYPE.	
4.4	NNPADD	MAT = Material number of the element (KODE (1), $I = 1, 6$), X, Y, Z, (TA (1), $I = 1, 3$), (COEE (1), $I = 1, 2$)	(611, 2X, 9F8.0)
		These are data for the addition of nodal points. KODE = Six single-digit numeric flags specifying the constrained condition on the six degrees of freedom at the nodal point. 0 means uncon- strained and 1 means constrained. The six degrees of freedom are arranged in the follow- ing order: 1 x-displacement 2 y-displacement 3 z-displacement 4 x-rotation (rotation about the x-axis)	

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DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.4 (cont)		5 y-rotation 6 z-rotation	
		x, y, $z = Cartesian$ coordinates of the nodal point.	
		TA = Tributary areas associated with the three components of the external pressure acting at the point.	
		COEF = Values of the C coefficient associated with the three external pressure components. The x component of the nodal force acting at a point, for example, is eventually computed as $F_x = P_x \cdot TA_x \cdot COEF_x$	
		where P _x is the x component of the externa pressure.	1
4.5	1	NACTIV	(15)
		NACTIV = Number of elements with activity supplied.	
4.5.1	NACTIV	NEL, ION, IOFF	(315)
		NEL = Element number	
		<pre>ION = Step number at which element becomes active</pre>	
		<pre>IOFF = Step number at which element becomes inactive</pre>	
4.6	1	<pre>IDLFLG, NDLINC, (DCOSGR (1), I = 1, 3) IDLFLG = 1, output is relative to dead loading</pre>	(215,3F10.0

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.6 (cont)		DCOSGR = Coefficients of gravity load in X, Y, and Z directions	
		Dead-load components in the X, Y, and Z direction are computed via	
		DCOSGR _X * p * volume	
		DCOSGR _y * p * volume	1. S.
		DCOSGR _Z * p * volume	
4.7	1	NLSTEP	(15)
		NLSTEP = Maximum number of live-load steps	
4.7.1	NLSTEP	TIME, PX, PY, PZ	(4F10.0)
		Time = Time associated with load step	
		PX, PY, PZ = Pressure loads in X, Y, and Z directions	
		The following three groups of cards are similar to Card Group 3.17. They provide controls for the plotting of the final mesh, after any nodal point and/or element renumbering has been performed.	
4.8	1	(VIEW (I), I = 1, 6) for a 3-D case only	(6F10.0)
4.8.1	1	QSIZE, HTNODE, HTELE, NCUT	(3F10.0, 110)
4.8.2	NCUT	((XCUT (I,J), I = 1,6), J = 1, NCUT)	(6F10.0)
4.9		Material PropertiesNUMMAT sets (see Appendix B)	
4.9.1	1	B, G, RHO	3F10.0
		B = Bulk modulus	
		G = Shear modulus RHO = Density	

DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.9.2	1	NISO, NPL, NVISC, ITER, NSPLIT, NITER	(6110)
		NISO = Isotropic flag	
		NPL = Plasticity flag	
		NVISC = Viscoelastic flag	
		ITER = Iteration flag	
		NSPLII = Number of splits	
1		NITER = Number of Iterations	
4.9.3	1	DELTA, CONV, NVM	(2F10.0,110)
		DELTA = Split criterion	
		CONV = Convergence criterion	
		NVM = Variable modulus flag	
4.9.4	3	(GCOEF (I), I = 1, 20)	(3(8F10.0))
		Shear modulus coefficients	
4.9.5	9	(BCOEF (I), I = 1, 40), (YCOEF (I), I = 1, 25)	(7(8F10.0), 3F10.0,2110, 3F10.0/F10.
		BCOEF = Bulk modulus coefficients	
		YCOEF = Inelasticity coefficients	
4.10	NOBB	Additional data for bars and beams	
		((ADBB (I, J), I = 1, 8), J = 1, NOBB)	(6F10.0,
		ADBB $(1 \ 8, J)$ = The additional element data	2110)
		required for the Jth bar or beam element.	
		Cards in this card group must be so arranged	
		that each card comes up in the same sequence	
		as the corresponding element card is encoun-	
		tered in Card Group 4.3.	

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DEFINITION OF INPUT FOR BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
Card Group 4.10 (cont)	No. of Cards	Data and DefinitionsIn the case of a bar element, ADBB (1, J) = cross- sectional area of the bar.ADBB (2, J) = Initial stress in the bar.In the case of a beam element, ADBB (1, J) = A_x , the cross-sectional area of the beam.ADBB (2, J) = A_y , the shear area with respect to the local y-axis.ADBB (2, J) = A_y , the shear area with respect to the local y-axis.ADBB (2, J) = A_y , the shear area with respect to the local y-axis.ADBB (3, J) = A_z , the shear area with respect to the local z-axis.ADBB (4, J) = I_2 , the second moment of the cross- sectional area with respect to the local y-axis.ADBB (5, J) = I_3 , the moment of the cross-sectional areas with respect to the local z-axis.ADBB (6, J) = I_{xy} or J, the polar moment of inertia of the cross-section. If this field is left blank J will be computed as J = $I_2 + I_2$.	Fortran Format
		ADBB (7, J) and ADBB (8, J) = The two end-release codes for the beam.	

APPENDIX A

CONTENTS OF IWD COMMON BLOCK

Common block IWD contains constants and variables used throughout the program. The user may reset the default values listed below by involving option "MODI" (see Card Group 2.0 in the data definition).

Location	Name	108 Default Value	Meaning
1	IWCD	5	Card reader unit number
2	IWPRT	6	Printer unit number
3	IWPUNC	-3	Punch unit number
4	IWCOMP	1108	Computer code
5	IWSRUN	0	Debug flag
6	IWCORE	27000	Length of BMCALC common
7	IWDEOF	4HDEOF	End of file word
8	IWBLNK		Hollerith code for blank
9	IWITIN	(not set)	Current itinerary option
10	IWRUN(1)	4HMOD1	Allowable itinerary options
11	IWRUN(2)	4HSTAR	
12	IWRUN(3)	3HADD	
13	IWRUN(4)	4HEXEC	
14	IWRUN(5)	4HREST	
15	IWRUN(6)	4HOUTP	
16	IWRUN (7)	4HEXIT	
17-19		(Not used)	
20	IWNRUN	10	Length of IWRUN
21	IWTAPE	8	Number of tape units
22	IWDRUM	9	Number of drum units
23	IWLUN(1)	9	Tape or drum logical unit numbers
24	IWLUN (2)	11	
25	IWLUN (3)	13	
26	IWLUN (4)	7	
27	IWLUN (5)	12	
28	IWLUN (6)	14	
29	IWLUN (7)	8	
30	IWLUN (8)	10	

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Location	Name	1108 Default Value	Meaning
Looderon	<u>indine</u>	Varue	nearring
31	IWLUN(9)	21	(Tape or drum logical unit
32	IWLUN(10)	22	namber y
33	IWLUN(11)	38	
34	IWLUN(12)	39	
35	I WLUN (13)	40	
36	I WLUN (14)	41	
37	IWLUN(15)	42	the second s
38	IWLUN(16)	43	
39	IWLUN(17)	44	
40	IWLUN(18)	0	
41	I WLUN (19)	0	
42	I WLUN (20)	0	
43-62	WHDR (1) - WHDR (20)	Blanks	Contain run title
63	I WNN P	Not set	Number of node points
64	IWNEL	Not set	Number of elements
65	IWNMAT	Not set	Number of materials
66	IWBAND	Not set	Bandwidth
67	IWNEQ	Not set	Number of equations (DOF's)
68	IWNLDB	Not set	Number of entries/load coefficient block
69	IWNREC	Not set	Number of load coefficient blocks
70	IWNCF	3	Number of columns in load vector
71	IWNEQB	Not set	Number of equations/block
72	IWNEU	Not set	Size of element data block
73	IWERR	0	Error flag
74	IWLPPG	50	Maximum lines/page
75	IWKEN	27000	Length of ATOMSH common
76-100	IWDUM	Not used	
101	LMSTRT	21	Pointer to start of LM array
102	NRSTRT	Not set	Restart step number



Location	Name	1108 Default Value	Meaning
103	TIMER	Not set	Restart time interval
104	NSTP	99999	Reformulation interval
105	MAXSTP	Not set	Maximum number of load steps
106	NLDI	Not set	Number of dead load increments
107	NCOL	4	Number of columns in load



APPENDIX B

DEFINITION OF MATERIAL PROPERTY COEFFICIENTS

The coefficients which define the stress/strain properties for each material (N) are stored in an array COEFF(I,N), I = 1,100. The COEFF array is divided into three main sections as follows:

1.	COEFF(I,N), I = 1,15	Set linear elastic, isotropic moduli
		select options for material models,
		select coefficients controlling inte-
		gration of stress/strain relations
2.	COEFF(I,N), I = 16-35	Coefficients defining variable shear
		moduli

COEFF(I,N), I = 36-75 Coefficients defining variable bulk moduli

3. COEFF(I,N), I = 76-100 Coefficients defining inelastic models (plasticity, viscoplasticity, viscoelasticity)

Although the properties are initially read into the COEFF array, they are subsequently transferred into dimensionless variables and one dimensional working arrays whose names suggest their meaning as shown in the input definition. Thus:

Shear Modulus(G)	COEFF(1,N), 1 = 16,35)	=	GCOF(1), $I = 1,20$
Bulk Modulus(B)	COEFF(I,N), I = 36,75)	=	BCOF(1), I = 1,40
Inelasticity Coefficients(Y)	COEFF(I,N), I = 76,100)	=	YCOF(1), 1 = 1.25

To make writing formulas easier in the following discussion, the notation G, B, and Y is used to indicate the various coefficients. Thus

> G_1 to G_{20} = Shear modulus coefficients B_1 to B_{40} = Bulk modulus coefficients Y_1 to Y_{29} = Inelasticity coefficients



The dimensions of the material properties are expressed in the inch-pound-second system.

ELASTIC MODULI AND CONTROL COEFFICIENTS (COEFF(1,N), I = 1,15)

COEFF(1,N) (B)	Elastic bulk modulus; constant value to be used for isotropic material. May be used with plastic viscoplastic or viscoelastic material.
COEFF(2,N) (G)	Elastic shear modulus; constant value to be used for isotropic material. May be used with plastic, viscoplastic or viscoelastic material.
COEFF(3,N) (RHO)	= Mass density
COEFF(4,N) (NISO)	= Anisotropy flag
la le il e	= 0 Isotropic
	= 1 Elastic, ideally plastic with anisotropic yield function suggested by Hill
	= 2 Anisotropic moduli with anisotropic fracture criterion
COEFF(5,N)	= Inelasticity flag
(NPL)	= O Elastic
	= 1 Ideaily plastic
	= 2 Strain hardening (cap model)
COEFF(6,N)	= Viscous property flag
(NVISC)	= 0 Inviscid
	= 1 Viscoplastic
	= 2 Viscoelastic



COEFF(7,N)Iteration flag. The integration of nonlinear (ITER) stress/strain relations may require iteration if tangent moduli are implicit functions of stress and strain components. This is especially true of the cap model and sometimes true of variable moduli models. For iteration 0 0 No iteration COEFF(8,N)= Strain subdivision flag for viscoplastic materials. (NSPLIT) To compute stress relaxation correctly, the strain increment is subdivided into NSPLIT smaller increments. This number, which may need to be as high as 50, applies to viscoplastic materials only. COEFF(9,N)Number of iterations. This flag is used with (NUMITR) ITER = 0. Iteration proceeds until convergence is reached within a prescribed tolerance (see CONV below) or until the number of iterations equals NUMITR. May be about 8 to 10. COEFF(10,N)= Strain subdivision flag for materials other than (SPLIT) viscoplastic. Subdivision may occur when a trial stress increment exceeds a predetermined value or when the trial stress state should be exactly on a yield surface but if off by greater than a predetermined value. DELTA > 0. for strain subdivision whenever $|d\sigma_{ij}|$ trial > DELTA. In this case, d i are divided into DELTA subincrements.

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DELTA < 0. for strain subdivision whenever

$$F = \left| \frac{f(\sigma_{ij})trial}{\left(\sqrt{J'_2}\right)trial} - 1 \right| > CONV$$

where

 $f(\sigma_{ij})_{trial}$ is the value of $\sqrt{J_2}$ on the current yield surface, and $\sqrt{J_2}$ is the trial value of the second invariant of the stress deviator.

In this case, the number of strain subincrements is

where

 $\left| \begin{pmatrix} d\sigma \\ ij \end{pmatrix}_{max} \right|$ is the largest of the trial stress increments.

To avoid subdividing strain increments, set DELTA >> $|(d\sigma_{ij})_{max}|_{trial}$

COEFF(11,N)=Criterion for convergence of iteration (see ITER).(CONV)Also used to control strain subdivisions (see
NSPLIT). Convergence is defined if

where

$$a = \left[\left| d\sigma_{11} \right| + \left| d\sigma_{22} \right| + \left| d\sigma_{33} \right| \right] previous$$

$$b = \left[\left| d\sigma_{11} \right| + \left| d\sigma_{22} \right| + \left| d\sigma_{33} \right| \right] current$$

$$step$$



COEFF(12,N)	=	Variable modulus flag	
	=	0 For constant moduli (uses B and G abo	ove)
	=	1 For variable moduli	

COEFF(13,N), COEFF(14,N), COEFF(15,N) are presently unused.

SHEAR MODULI COEFF(16,N) through COEFF(35,N) (GC)F(1) through GC)F(20))

Case 1	(Isotropic, constant moduli)
$(N^{1}SO = 0, NVM = 0)$	GCOF(1) through $GCOF(20) = 0$

Case 2	(Isotropic, variable moduli)
(N1SO = 0, NVM = 1)	Shear moduli are defined to be a function
	of the elastic component of volumetric
	strain µ.

Loading $(\mu < \mu_{max} \leq 0)$ where μ_{max} is the smallest previous value of μ .

$$G = G_2 - (G_2 - G_1) \exp(-\mu/G_2)$$

<u>Unloading/Reloading</u> $(\mu_{max} < \mu \le 0)$

 $G = G_2 - (G_2 - G_1) \exp(-\mu_{max}/G_3)$

Tension $(\mu > 0)$

 $G = G_{10}$

For Case 2

 $COEFF(N, 16) = G_1$ $COEFF(N, 17) = G_2$ $COEFF(N, 18) = G_3$ $COEFF(N, 25) = G_{10}$

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Case 3 (Constant, anisotropic moduli, (N1SO = 1, NVM = 0) may be used with anisotropic yield criterion of Hill).

 $COEFF(N, 16) = G_{12}$ $COEFF(N, 17) = G_{13}$ $COEFF(N, 18) = G_{23}$

Case 4

(N1SO = 2, NVM = 1)

(Variable anisotropic moduli to be used with anisotropic fracture criterion of Jaeger. May be used for plane geometry only. Data on fracture criteria must be specified through JCOF. Fracture occurs when

$$f = (\sigma_1 - \sigma_3) - \left(\frac{2a_0 - 2a_1\sigma_3}{a_1 - \sqrt{a_1^2 + 1}}\right) < 0$$

elastic $(f \ge 0)$

 $COEFF(N,16) = G_{12} \text{ (elastic)}$ $COEFF(N,17) = G_{13} \text{ (elastic)}$ $COEFF(N,18) = G_{23} \text{ (elastic)}$

inelastic (f \leq 0)

 $COEFF(N,19) = G_{12} \text{ (inelastic)}$ $COEFF(N,20) = G_{13} \text{ (inelastic)}$ $COEFF(N,21) = G_{23} \text{ (inelastic)}$



BULK MODULI/YOUNG'S MODULI AND POISSON RATIO COEFF(36,N) through COEFF(75,N) (BCOF(1) through BCOF(40))

Case 1	(Isotropic, constant moduli)
(N1SO = 0, NVM = 0)	BCOF(1) through $BCOF(40) = 0$.
Case 2	(Isotropic, variable moduli)
(N1SO = 0, NVM = 1)	Bulk moduli are defined to be a function of the elastic component of volumetric
	strain µ.

Loading ($\mu < \mu_{max} \leq 0$) where μ_{max} is the smallest previous value of μ

$$B = B_1 - (B_1 - B_2) \exp(\mu/B_L)$$

<u>Unloading/Reloading</u> $(\mu_{max} < \mu \leq 0)$

 $B = \overline{B} + (B_1 - \overline{B}) \mu / B_5$

where

$$\overline{B} = \text{Lesser of} \begin{cases} B_2 - (B_1 - B_2)\mu_{\text{max}}/B_5 \\ B_1 \end{cases}$$

Tension $\mu > 0$

 $B = B_{10}$

For Case 2

$$COEFF(N,36) = B_{1}$$

$$COEFF(N,37) = B_{2}$$

$$COEFF(N,38) = B_{3} \text{ (presently not used)}$$

$$COEFF(N,39) = B_{4}$$

$$COEFF(N,40) = B_{5}$$

$$COEFF(N,45) = B_{10}$$

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Case 3(Constant anisotropic moduli. May be(N1S0 = 1, NVM = 0)used with anisotropic yield criterion of Hill)

COEFF(N,36)	-	^B 1	=	E ₁
COEFF(N,37)	-	^B 2	=	^v 12
COEFF(N,38)	-	^B 3	=	^v 13
COEFF(N,39)	=	в ₄	=	^B 2
COEFF(N,40)	=	^B 5	=	^v 21
COEFF(N,41)	=	⁸ 6	=	^v 23
COEFF(N,42)	=	^B 7	=	E3
COEFF(N,43)	=	^B 8	=	^v 31
COEFF(N,44)	=	Bg	=	V 32

Case 4

(N1SO = 2, NVM = 1)

(Variable anisotropic moduli to be used with anisotropic fracture criterion of Jaeger, may be used for plane geometry only. Data on fracture criteria must be specified through YCOF. Fracture occurs when

$$= (\sigma_1 - \sigma_3) - \left(\frac{2a_0 - 2a_1\sigma_3}{a_1 - \sqrt{a_1^2} + 1}\right) < 0$$

elastic $(f \ge 0)$

$$COEFF(N,36) = B_{1} = E_{1}$$

$$COEFF(N,37) = B_{2} = v_{12}$$

$$COEFF(N,38) = B_{3} = v_{13}$$

$$COEFF(N,39) = B_{4} = E_{2}$$

$$COEFF(N,40) = B_{5} = v_{21}$$

$$COEFF(N,41) = B_{6} = v_{23}$$

f



COEFF(N,42)	=	⁸ 7	=	Е 3
COEFF(N,43)	=	⁸ 8	=	٢٤ ٧
COEFF(N,44)	=	^B 9	=	32

inelastic (f < 0)

COEFF(N,46)	=	^B 11	=	E ₁			
COEFF(N,47)	=	^B 12	=	^v 12			
COEFF(N,48)	-	^B 13	=	^v 13			
COEFF(N,49)	=	^B 14	=	E2			
COEFF(N,50)	=	^B 15	=	^v 21			
COEFF(N,51)	=	^B 16	=	^v 23			
COEFF(N,52)	=	^B 17	=	E3			
COEFF(N,53)	=	^B 18	=	^v 31			
COEFF(N,54)	=	^B 19	=	^v 32			
COEFF(N,55)	thr	ough	COE	FF(N,65)	not u	sed.	
COEFF(N,66)	thr	ough	COE	FF(N,74)	conta	in	
direction co	osin	es fo	or a	nisotrop	ic mat	erials a	as
follows							



		X	Y	Z
AXIS ROPY	۲ï	^B 31	^B 34	^B 37
CI PAL VI SOTE	Y١	^B 32	^B 35	^B 38
PRING	TZ A	^B 33	^B 36	^B 39



1

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COEFF(N,66)	=	^B 31
COEFF(N,67)	-	^B 32
COEFF(N,68)	-	^B 33
COEFF(N,69)	=	^B 34
COEFF(N,70)	=	^B 35
COEFF(N,71)	=	^B 36
COEFF(N,72)	=	^B 37
COEFF(N,73)	=	^B 38
COEFF(N,74)	=	^B 39
COEFF(N,75)	-	B ₄₀ = PSI (CCW angle from major principal stress axis to bedding planes at which
		cohesion of anisotropic rock

is a minimum)

COEFFICIENTS DEFINING INELASTICITY

COEFF(N,76) through COEFF(N,100) (YCOF(1) through YCOF(25))

Case 1	Elastic, ideally plastic yield criterion.				
(NPL = 1)	Two functions are available, depending on				
	value of ITYPE = $COEFF(N, 95)$.				

For ITYPE # 2, material may be isotropic or anisotropic (Hill's criterion) depending on values of coefficients. Principal directions of anisotropy are submitted through direction cosines in BCOF. For ITYPE = 2, criterion is that used with cap model, but cap is not available unless NPL = 2.

$(NPL = 1, ITYPE \neq 2)$	Polynominal yield surface, with von Mises				
	limit at high pressure, in terms of J_1^* , $\sqrt{J_2^*}$				

$$J_{1}^{\pi} = Y_{1}\sigma_{11} + Y_{2}\sigma_{22} + Y_{3}\sigma_{33}$$

$$\sqrt{J_{2}^{\pi}} \approx \left\{ \frac{1}{6} \left[Y_{4} \left(\sigma_{11} - \sigma_{22} \right)^{2} + Y_{5} \left(\sigma_{22} - \sigma_{33} \right)^{2} + Y_{6} \left(\sigma_{33} - \sigma_{11} \right)^{2} + Y_{7}\sigma_{13}^{2} + Y_{8}\sigma_{23}^{2} + Y_{9}\sigma_{12}^{2} \right] \right\}^{1/2}$$

for $J_1^{\dagger} > Y_{10}$

$$f_{1} (J_{1}^{*}, \sqrt{J_{2}^{*}}) = Y_{11} + Y_{12}J_{1}^{*} + Y_{13} (J_{1}^{*})^{2} + Y_{14} (J_{1}^{*})^{3} - \sqrt{J_{1}^{*}} \ge 0$$

for $J_{1}^{*} \le Y_{10}$

$$f_2(J_1^*,\sqrt{J_2^*}) = Y_{16} - \sqrt{J_2^*} \ge 0.$$

$$(NPL = 1, ITYPE = 2)$$

This perfectly plastic yield surface is the same as that used with the cap. Cap is not used. Anisotropy is not recommended, $J_1^* = J_1$ and $J_2^{'*} = J_2^{'}$; hence, Y_1 through $Y_9 = 0$.

The perfectly plastic yield criterion is prescribed by

for $J_1 > Y_{10}$

$$f_1 = Y_{11} (1 - \left|1 - \frac{J_1}{Y_{10}}\right|^2) + Y_{12} - \sqrt{J_2'} \ge 0$$

for $J_1 \stackrel{<}{=} Y_{10}$

 $f_1 = Y_{11} + Y_{12} - \sqrt{J_2'} \ge 0$



Case 2 (NPL = 2, ITYPE = 2)

Cap model for rock.

Perfectly plastic yield criterion is the same as that given above for NPL = 1, ITYPE = 2. In addition a cap is prescribed by

$$f_2 = (J_1 - V)^2 + P^2 (J_2 - Q) = 0$$

where

$$V = L + P^{2} \chi (L) X' (L)$$
$$Q = [\chi(L)]^{2} \{1 + P^{2} [\chi'(L)]^{2}\}$$

for $L \leq Y_{10}$

$$X(L) = Y_{11} (1 - [1 - \frac{L}{Y_{10}}]^{2} + Y_{12}$$
$$X'(L) = \frac{2Y_{11}}{Y_{10}} (1 - L/Y_{10})$$

for $L > Y_{10}$

$$X(L) = Y_{11} + Y_{12}$$

 $X'(L) = 0.$

and

$$L = Y_{13} \int_{0}^{t} \left(1 - \frac{\sqrt{J_{2}^{'}}}{\sqrt{J_{2}^{'}} - f_{1}}\right)^{2} \sqrt{\tilde{I}_{2}^{P}} dt$$

$$P = Y_{14}$$



For Cases 1 and 2.

COEFF(N,76)	=	Y ₁
COEFF(N,77)	÷,	Y ₂
COEFF(N,78)	=	Y ₃
COEFF(N,79)	=	Y ₄
COEFF(N,80)	=	Y ₅
COEFF(N,81)	=	Y ₆
COEFF(N,82)	=	Y ₇
COEFF(N,83)	=	Y ₈
COEFF(N,84)	=	۲ ₉
COEFF(N,85)	-	Y ₁₀
COEFF(N,86)	=	Y ₁₁
COEFF(N,87)	=	Y ₁₂
COEFF(N,88)	=	Y ₁₃
COEFF(N,89)	=	Y ₁₄
COEFF(N,90)	=	Y ₁₅
COEFF(N,91)	=	Y ₁₆
COEFF(N,92)	thro	ough COEFF(N,94) not used.
COEFF(N,95)	Ħ	ITYPE
COFFE(N O()		1 commuter a

COEFF(N,96) through COEFF(N,100) not used.

Case 3 (NPL = 1, NVISC = 1)

(Viscoplasticity. May be used only with isotropic moduli and an isotropic perfectly plastic yield criterion of the type described in Case 1 (ITYPE \neq 2) above.





for $J_1 > Y_{10}$

$$f_1(J_1, J_2) = Y_{11} + Y_{12}J_1 + Y_{13}J_1^2 + Y_{14}J_1^3 - J_2' \ge 0$$

for $J_1 \leq Y_{10}$

$$f_1(J_1, J_2') = Y_{16} - J_2' \ge 0$$

The viscoplastic strain rate is given by

$$\dot{\varepsilon}_{ij}^{P'} = Y_{17} \phi(f_1) \frac{\partial f}{\partial \sigma_{ij}}$$

for Case 3

COEFF(N,76) through COEFF(N,84) = 1.0 COEFF(N,85) = Y_{10} COEFF(N,86) = Y_{11} COEFF(N,87) = Y_{12} COEFF(N,88) = Y_{13} COEFF(N,89) = Y_{14} COEFF(N,90) = Y_{15} COEFF(N,91) = Y_{16} COEFF(N,92) = Y_{17} COEFF(N,93) through COEFF(N,100) are not used.



Case 4 (N1SO = 2, NVM = 1) (Anisotropic fracture criterion of Jaeger which may be used with anisotropic variabic moduli. May be used with plane geometry only. The fracture criterion is

$$(\sigma_1 - \sigma_3) - \frac{2a_0 - 2Y_{14}\sigma_3}{Y_{14} - \sqrt{Y_{14}^2} + 1} \le 0$$

The coefficients a and a are functions of fracture parameters which are submitted through YCOF. The appropriate parameters are selected by referring to two angles as follows:

- BETA (computed internally) = CCW angle from direction of major principal stress to the direction of the bedding planes.
- PSI = BCOF(40) = Orientation of BETA at which a_0 is a minimum. Usually assumed to be 30° (expressed in radians).

Principal directions of anisotropy are submitted through direction cosines in BCOF.

For 0 < PSI < BETA

$${}^{4}_{0} = {}^{2}_{11} - {}^{2}_{12} [\cos 2 (PSI - BETA)]$$

For BETA < PSI < 90°

 $a_0 = Y_{17} - Y_{18} [\cos 2 (PSI - BETA)]$



For Case 4

COEFF(N,76) through COEFF(N,84) = 1.0 COEFF(N,85) is not used. COEFF(N,86) = Y_{11} COEFF(N,87) = Y_{12} COEFF(N,88) = Y_{13} COEFF(N,88) = Y_{14} COEFF(N,89), COEFF(N,30) are not used COEFF(N,91) = Y_{17} COEFF(N,92) = Y_{18} COEFF(N,93) = Y_{19}

COEFF(N,94) through COEFF(N,100) are not used

Case 5 (NVISC = 2) (Viscoelasticity. May be used only with isotropic moduli. Kelvin and Maxwell elements are available. Creep may be specified either in volumetric strain or in shear strain or in both simultaneously depending on the values of NVOL and NDEV.

Kelvin Element

$$\varepsilon_{t+\Delta t}^{c} = \varepsilon_{t}^{c} \exp((-a_{1}\Delta t)) + \sigma_{t} \frac{a_{2}}{a_{1}} (1 - \exp((-a_{1}\Delta t)))$$

creep in volumetric strain (NVOL = 3)

$$a_{1} = \frac{K}{n_{bulk}} = Y_{4}$$
$$a_{2} = \frac{1}{n_{bulk}} = Y_{5}$$





creep in shear strain (NDEV = 3)

$$a_1 = \frac{G}{\eta_{shear}} = Y_7$$

$$a_2 = \frac{1}{n_{shear}} = Y_8$$

Maxwell Element

$$\varepsilon_{t+\Delta t} = \varepsilon_t^c + (a_2 \Delta t + a_1) \sigma_{t+\Delta t} - a_1 \sigma_t$$

creep volumetric strain (NVOL = 2)

 $a_1 = \frac{1}{K} = 1/COEFF(1,N)$

$$a_2 = n_{bulk} = Y_3$$

creep in shear strain (NDEV = 2)

 $a_1 = 1/G = 1/COEFF(2,N)$

3-Parameter Fluid

$$\varepsilon_{t+\Delta t}^{c} = \varepsilon_{t}^{c} + a_{1}\varepsilon_{t} + a_{2}\sigma + a_{3}\sigma$$



creep in bulk (NVOL = 1)

$$a_{1} = \frac{n_{2}bulk}{K} \left[1 - \exp\left(-\frac{K}{n_{2}bulk}\Delta t\right) \right]$$

$$a_{2} = \frac{1}{n_{1}bulk} \left[\Delta t - \frac{n_{2}bulk}{K} \left(1 - \exp\left(-\frac{K}{n_{2}bulk}\Delta t\right) \right) \right]$$

$$a_{3} = \frac{n_{1}bulk + n_{2}bulk}{n_{1}bulk K} \left[\Delta t - \frac{n_{2}bulk}{K} \left(1 - \exp\left(-\frac{K}{n_{2}bulk}\Delta t\right) \right) \right]$$

$$\frac{K}{n_{2}bulk} = Y_{3}$$

$$\frac{1}{n_{1}bulk} = Y_{4}$$

$$\frac{1}{n_{2}bulk} = Y_{5}$$
(reep in shear (NDEV = 1))
$$a_{1} = \frac{n_{2}shear}{G} \left[1 - \exp\left(-\frac{G}{n_{2}shear}\Delta t\right) \right]$$

$$a_{2} = \frac{1}{n_{1}shear} \left[\Delta t - \frac{n_{2}shear}{G} \left(1 - \exp\left(-\frac{G}{n_{2}shear}\Delta t\right) \right) \right]$$

$$a_{3} = \frac{n_{1}shear}{n_{1}shear} \left[\Delta t - \frac{n_{2}shear}{G} \left(1 - \exp\left(-\frac{G}{n_{2}shear}\Delta t\right) \right) \right]$$

$$\frac{G}{n^2 \text{shear}} = Y_6$$

 $\frac{1}{n_{1} \text{shear}} = Y_{7}$ $\frac{1}{n_{2} \text{shear}} = Y_{8}$

For Case 5

1

COEFF(N,76), COEFF(N,77) not used COEFF(N,78) = Y_3 COEFF(N,79) = Y_4 COEFF(N,80) = Y_5 COEFF(N,81) = Y_6 COEFF(N,82) = Y_7 COEFF(N,83) = Y_8 COEFF(N,84) through COEFF(N,100) not used.



APPENDIX C

FILE USAGE

Logical Unit Number	Name		Contents and	d Description
9	LINK	1. Link tape	contains da	ta on the problem size,
		loading an	d material j	properties.
		Record 1	- I WHDR (20)) - run title
		(38 words)	IWNNP	- number of nodes
			IWNEL	- number of elements
			IWNMAT	- number of materials
			I WBAND	- bandwidth
			IWNEQ	- number of equations
			MAXSTP	- number of live loads
			NLDI	 number of dead load increments
			IRELT	 number output/deadload flag
			NTYPE (10)) - number of elements of each type
		Record 2	- iD array	(relates node points to
		(6*1WNNP)	degrees	of freedom)
		Record 3 (3*iWNNP)	- Load coe	fficients
		Record 4 (4-MAXSTP)	- Live load	ds-Time, P _x , P _y , P _z
		Record 5 (100*1WNMA	- Material T)	properties
		2. On restart restart ta files rema	ed runs, the pe is mounte in as before	e previously generated ed as LINK, and all other e.


Logical Unit Number	Name	<u>c</u>	Contents and Description
11	LEU	Element data element. Al the maximum are present tion of each	tape contains one record for each I records are the same size, which is length required for the elements which (see appendix D for complete descrip- element).
13	LOUT	Output data 1	ape.
		Record 1 - (22 words) Record 2 - (6*IWNNP)	IWHDR(20) - run title IWNNP - number of nodes iWNEL - number of elements ID array relating nodes to degrees of freedom
		Record 3 - (4 words)	IWBAND - bandwidth iWNEQ - total DOFs IWNEQB - DOFs/block NBLOCK - number of blocks
		Records 4 - step, writte	N contain output data for each load n as requlred. Each record is IWNEQB+2

step, written as required. Each record is IWNEQB+2 or 23 words long, whichever is greater. The first words of a record contains the time corresponding to this load step and word 2 is a signal whether the record is displacement data (if = 0) or element data (= number of elements in the block). If the record is an element record, each element consists of:

- 1. element number
- 2. element type
- 3. yield factor
- 4. stress (6 words)
- 5. strain (12 words)

Element data is packed 21 words at a time into an output block.

١



Logical Unit Number	Name	Contents and Description
7	LRST1	These files are used alternately (as required by
12	LFKI	the whims of the code) to contain: 1) the global
14	LFKO	stiffness, written as NBLOCK+1 records of IWBAND*
		NEQB words or 2) Restart data. If restart is used,
		the file must hold:
		1. 65 words of common data
		2. 70 words of control data
		3. 20 words of array addresses
		4. Live load and material properties
		(4*MAXSTP and 100* IWMAT words)
		5. Global stiffness (IWBAND*NEQB) NBLOCK
		6. Load/displacement (IWNCF*NEQB) sets
		 Stress history (≤ 248 words/element, IWNEL records)
		8. Load coefficients (3* number of loaded Nodes + 1
20	LSTRI)	Stress history data, written 1 record per element
21	LSTRO	(at most 248 words/element)
T38	LFIN)	Contain the force vector, total displacement, and
† 39	LFOUT	incremental displacement. NBLOCK + 1 records
		IWNCF*IWNEQB long
40	LOAD	Load coefficients, three words for each loaded node,
		written in blocks of NLDB nodes
+41	LTMP1)	Contain element stiffness data which overflow global
†42	LTMP2	stiffness blocks. At most 325 words per record,
		< NUMEL records
+43.	LTP1)	Used by DECOMP to store terms which overflow to stiff.
+44	LTP2	ness blocks. Requires at most IWBAND ² + NEQ words
	,	

[†]These files are not needed for a core contained (NBLOCK = 1) problem

Length, words



APPENDIX D

CONTENTS OF ELEMENT TAPE

For all elements

I B	(1)	=	Element number	1
I B	(2)	=	Element type	1
I B	(3)	#	Step element becomes active	1
I B	(4)	=	Step element goes inactive	1
I B	(5)	=	Minimum DOF for this element	1
IB	(6)		Maximum DOF for this element	1
I B	(7)	=	Material number	1
ΙB	(8)-IB (11)	=	Volume of element*	4
I B	(12)	=	(Not used)	1
I B	(13)-IB (21)	-	Direction cosines	9

This part of the data is constant for all elements. Format for remaining data is similar for each element.

The LM array always starts at IB (LMSTRT + 1) Dead loads always start at IB (ND + LMSTRT + 1) B-matrix always starts at IB (2 * ND+LMSTRT + 1) LMSTRT is presently set to 21.

Following the B-matrix are data for slip elements.

^{*}IB (8)-IB (11) contain partial volumes for axisymmetric elements. IB (8) contains total volume for all others.



Element Type <u>+</u> 1	1-D Bar ND = 6	
IB (22) -	DOF X1	Length 6
23 -	DOF X2	
24 -	DOF Y1	
25 -	DOF Y2	
26 -	DOF Z	
27 -	DOF Z2	
IB (28) -	X ₁ dead load	6
29 -	X ₂ dead load	
30 -	Y ₁ dead load	
31 -	Y2 dead load	
32 -	Z ₁ dead load	
33 -	Z ₂ dead load	
IB (34) - (39)	[B] matrix (6 x 1)	6
IB (40 - 45)	[B] matrix at center of element	6
IB (46) initia	lstress	1



Element Type	2	Beam ND = 12	
			Length
IB (22-33)	-	DOF's	12
		x ₁ , y ₁ , z ₁ , θ _{x_i} , θ _{y_i} , θ _{z₁}	
		$x_2, y_2, z_2, \theta x_2, \theta y_2, \theta z_2$	
IB (34-45)	-	Dead load components corresponding	
		to DOF's	12
IB (46-189)	-	Force-displacement transform	144
IB (190-267)	-	Element stiffness [k]	



Element Type ± 3 , 4 2-D Quad or Axisym ND = 8

I B	(22-29)	DOF's	Length
		x ₁ , x ₂ , x ₃ , x ₄ , y ₁ , y ₂ , y ₃ , y ₄	8
B	(30-37)	Dead load components	8
B	(38-109)	[B] matrix as 3 x 24	72
B	(110-127)	[B] at center of element as 3×6	18

Element Type	= 5 3-D Brick ND = 24	
IB (22-45)	DOF's	24
	$X_{i} = 1, 8$	
	$Y_{i} = 1, 8$	
	$Z_{i} = 1, 8$	
IB (46-69)	Dead load components	24
IB (70-333)	[B] matrix, or $3 \times 11 \times 8$	288
IB (334-366)	[B] at element center	33



Element Type 6	Thick Shell ND	= 48
		Length
IB (22-69)	NDOF's	48
	(X_{i}, Y_{i}, Z_{i}) $i = 1, 16$	
IB (70-117)	Dead load components	48
IB (118-405)	ε -u transform, or 6 x 4	8 288

Each thick shell element record is followed by five records containing [k] for the element:

B	(1)	Highest DOF for this group, ND1	1	
B	(2-(ND1 + 1))	DOF's	ND 1	
ΙB	((ND1 + 2)-325) Rows of [k]		

The first four records each contain six rows of [k], with the last 24 rows in record 5.

Values of ND1 for the five records are

record	ND1
1	48
2	42
3	36
4	30
5	24



Ele	ement Types 7	and 9 2-D or Axisym w/slip ND	= 12
			Length
IB	(22-29)	DOF's for parent element	8
		x ₁ , x ₂ , x ₃ , x ₄ , Y ₁ , Y ₂ , Y ₃ , Y ₄	
I B	(30-33)	DOF's on adjolning slip	4
I B	(34-41)	Dead loads on parent element	8
I B	(42-45)	Dead loads on adjoining slip	4
I B	(46-117)	[B] for parent element	72
I B	(118-135)	[B] at center of parent	18
I B	(136)	Face number of slip element	1
IB	(137)	Material number of slip	1
I B	(138-141)	Coordinates of slip surface	4
		x ₁ , x ₂ , y ₁ , y ₂	
I B	(146)	Slip thickness	1



Element Type 8	3-D with Slip [*] ND = 36	
		Length
IB (12-45)	DOF's for parent	24
	$X_{i}, i = 1, 8$	
	$Y_{1}, i = 1, 8$	
	$Z_{i}, i = 1, 8$	
IB (46-57)	DOF's for slip surface	12
IB (58-81)	Dead local components for parent	24
IB (83-93)	Dead load components for slip	12
IB (94-357)	B matrix for parent	288
IB (358-390)	B at center of parent	33
IB (391)	Face number	1
B (392)	Material number	1
B (393-404)	Coordinates of slip	12
B (405)	Thickness	

*Not implemented

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APPENDIX E

FLOW CHART OF SUBROUTINE TDRUM--PROCESS ELEMENT STIFFNESS WHICH OVERFLOWED PREVIOUS GLOBAL STIFFNESS BLOCKS

START TORUM ADDS THE OV C ERFLOW ELEMENT K-BLOCKS INT 0 THE GLOBAI CP 30 С STIFFNESS, IF NE CESSARY, OVERFLOW IS WRITTE N TO THE CP 40 C CURRENT TEMPORARY FILE FOR FOLLOWING BLOCKS. CP 50 COMMON /IWD/IWCD, IWPRT, IW PUNC, INCOMP, INSRIN, INCORE , INDEOF, INBLNK, INITIN, INR UN(10), IWNRUN, IWTAPE, IWDR UM. IMLUN (20) . IMHDR (20) . IW NP, TWNEL, TWNAT, TWBAND, I WNEG, IWNLDB, IWNREC, IWNCF, INNEGB, INNEU, IVERR, IVLPPG . IWKEN, IWDUM (25), LMSTRT, N RSTRT, ITMER, NSTP, MAXSTP, N LDT, NCOL COMMON /BMMEISC/LINK, LEU, L OUT, LRST1, LFKI, LFKO, LSTRO LSTRI, LFIN, LFOUT, LOAD, LT MP1.LTMP2.LTP1.LTP2.NBLOC K.NBUF.NTMP.NOUT.IVOUT.TO UT NSTR NLDB NREC MEGB N EOB4, KFRRM, KCHNG, FIRST, NS TEP, TIME, NEL, NELTYP, NELMA T.ND.LM. IB. NOFEL1, NOFEL2, NDFK1, NDFK2, NDFW1, NDFW2, N DFIL, NDFOT2, IEU, IELK, IKC, N.F. N.FIN, ISTFIN, ISTFOT, I STKW, IWRT, IST1, ITMP1, ITMP 2. IWRK, IFI, ISCA, NWA, JRESB , IWRF, BMDUM (7) DIMENSION ELK(1), ELK2(1), AK(1) EQUIVALENCE (D.NJ) 71













APPENDIX F

FLOW CHART OF SUBROUTINE BSTIF ASSEMBLES GLOBAL STIFFNESS MATRIX

START R-7215-2-2701 COMMON /IVD/IVCD, IVPRT, IV DATA NINT/1.0.4.4.8.0.4.8 PUNC, IWCOMP, IWSRUN, IWCORE .4.0/ INDEOF, THE NK, TYTTTN, THR UN(10), IWNRUN, IVTAPE, IWDR DATA NAR/1.0.5.4.6.0.3.6. UM, TVLUN (20), TVHDR (20), TV 4.0/ NP, IWNEL, IWNMAT, IWBAND, I WNEQ, IWNLDB, IWNREC, IWNCF, IVNEOB, IVNEU, IVERR, IVLPPG DATA NAC/6.0.12.12.33.0.1 . IWKEN, IWDUM (25), UMSTRT, N 2.33.12.0/ RSTRT, TIMER, NSTP, MAXSTP, N LDT NCOL DATA NBCK/6,0,24,24,88,0, 24.88.24.0/ COMMON /BMMISC/LINK, LEU, L OUT.LRST1.LFKI.LFKO.LSTRO DATA INCM/0.0.2.2.3.0.2.3 LSTRI, LFIN, LFOUT, LOAD, LT ,2.0/ MP1.LTMP2.LTP1.LTP2.NBLOC K.NBUF.NTMP.NOUT.IVOUT.IO С FORM ELEMENT STIF UT, NSTR, NLDB, NREC, MNEQB, N **FNFSS** EQB4.KFRRM.KCHNG.FIRST.NS AT 220 TEP, TIME, NEL, NELTYP, NELMA T.ND.LM.IB.NDFEL1.NDFEL2. С BEAM ELEMENTS -- M NDFK1, NDFK2, NDFV1, NDFV2, N OVE FROM E/U INPUT ARRAY DFI1, NDFOT2, IEU, IELK, IKC, AT 230 N.F. M.F.IN, ISTFIN, ISTFOT, T STKW. IWRT. IST1. ITMP1. ITMP С THK-SHELL - ISSLE 2. IWRK IFI ISCA WA JRESB DB READ ON E/U, FOLLOWED B IWRF BMDUM(7) Y MOVE AT 240 С ALL OTHERS COME F DTMENSTON EU(1), FI K(1), FI ROM SUBROUTINE'S $K_{2}(1)$, IR(1), AK(1), C(6.8)AT 250 С ELEMENT STIFFNESS ES ARE STORED AS FOLLOWS DIMENSION NINT (10) NAR (10 AT 260), NBCK (10), NAC (10), INCM (1 0) С EK(1) - NO OF DFS AT 270 EQUIVALENCE (NEU, IWNEU) С EK(2)-EK(ND+1) - DOF LIST EQUIVALENCE (MBAND, IWBAND AT 280 2 EQUIVALENCE (ND,D) 78



and the









81





83



APPENDIX G

FLOW CHART OF SUBROUTINE ELPL--COMPUTES GENERALIZED STRESS/STRAIN RELATIONS AND COMPUTES STRESSES



























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