Finite Element Method Package of Learner Programs (FEMPAC)

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Finite Element Method Package

of

Learner Programs

(FEMPAC)

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PREFACE

The purpose of FEMPAC is to facilitate the solution of learner-level problems by the finite element method student. In order to accomplish this purpose the program inputs and options available have been kept as simple as possible. The package is structured such that no programming experience should be necessary for its use.

The purpose of FEMPAC is not to make possible solution of highly complex or large problems, although it is structured as efficiently as possible and has considerable capability for large problems. The principal virtue is the variety of continuum and structural-type problems which can be solved through this package.

This version of FEMPAC is not considered final or complete. Work will continue to improve, refine, and add capabilities to the system.

This User's Manual is an attempt to present as concisely as possible the purposes and procedures for the problems and the necessary inputs. Extensive use is made of example problems illustrated with both input and output examples.

INTRODUCTION

A person with a finite element problem is especially eager to have a dependable computer package requiring a minimum of concern for system details outside the scope of his/her primary interest. Most commercial finite element programs are directed at the solution of very large problems stemming from corporate or industry design needs. The software supplied by computer manufacturers and others is proprietary and very expensive. More often than not, their documentation is not designed for a novice user. The typical learner-user of the finite element method in a university environment has small- or medium-scale problems and is not inclined to spend a great deal of time learning about programming and computer systems for problem solution.

The objectives in designing a Finite Element Method PACkage (FEMPAC) of learner programs have been to stress ease of use, variety in problem types which can be solved, commonality of input between problem types, and minimization of computer experience needed.

The programs in this package are not highly sophisticated programs. They are not intended to compete with commercially available programs for detailed research and design. These programs are intended to solve learner-level problems in a variety of application areas. This package is intended to minimize the amount of classroom time required to explain use of the programs. This package should be useful not only in finite element method instruction, but also in other engineering courses where problem solutions are needed.

Many of the programs used in this text are modifications of those given by Segerlind (1976).[1] The Segerlind text is highly recommended for those desiring to gain a basic understanding of the finite element method.

[1/] Segerlind, L.J., 1976. Applied Finite Element Analysis, John Wiley & Sons, Inc., New York.

CONTENTS

1. PACKAGE DESCRIPTION

1.1 DESCRIPTION OF AVAILABLE PROGRAMS

This package is built up of two types of programs. The first type is support programs which are intended to facilitate development and display of input data, and display and analysis of results. The second type is application programs, each intended to solve problems in one specific application area. Detailed description of options available, input required, and sample applications are included for each program in the following chapters of this manual.

Support programs include automatic grid generation for programs using the simple three-node linear triangular element. The program has an option for renumbering nodes to minimize storage requirements. Grid plotting on the line printer is also available for programs using the simple linear triangular element with or without automatic grid generation. Result plotting is available for both nodal values and element resultants for pertinent variables within each application program. More detailed description of grid and result plotting are given in Chapters 4 and 5 respectively.

Application programs available and support options available for each are summarized in Table 1.1. More detail on each application program is given in Chapter 3 of this manual.

1.2 FLOW CHART OF PACKAGE

The following flow chart describes the general flow during execution of FEMPAC. Decisions are made by the program based on the Main Control Parameters input by the user. These control parameters are described in Section 1.4.

1.3 DESCRIPTION OF INPUT METHOD - FORMAT FREE INPUT

The main obstacle encountered in applying this package is communicating the correct information to the computer. In computer programming, information is transferred from external devices (the card reader, normally) to internal storage by means of read statements. The transfer of information into the computer is called INPUT, a term that appears frequently in this manual.

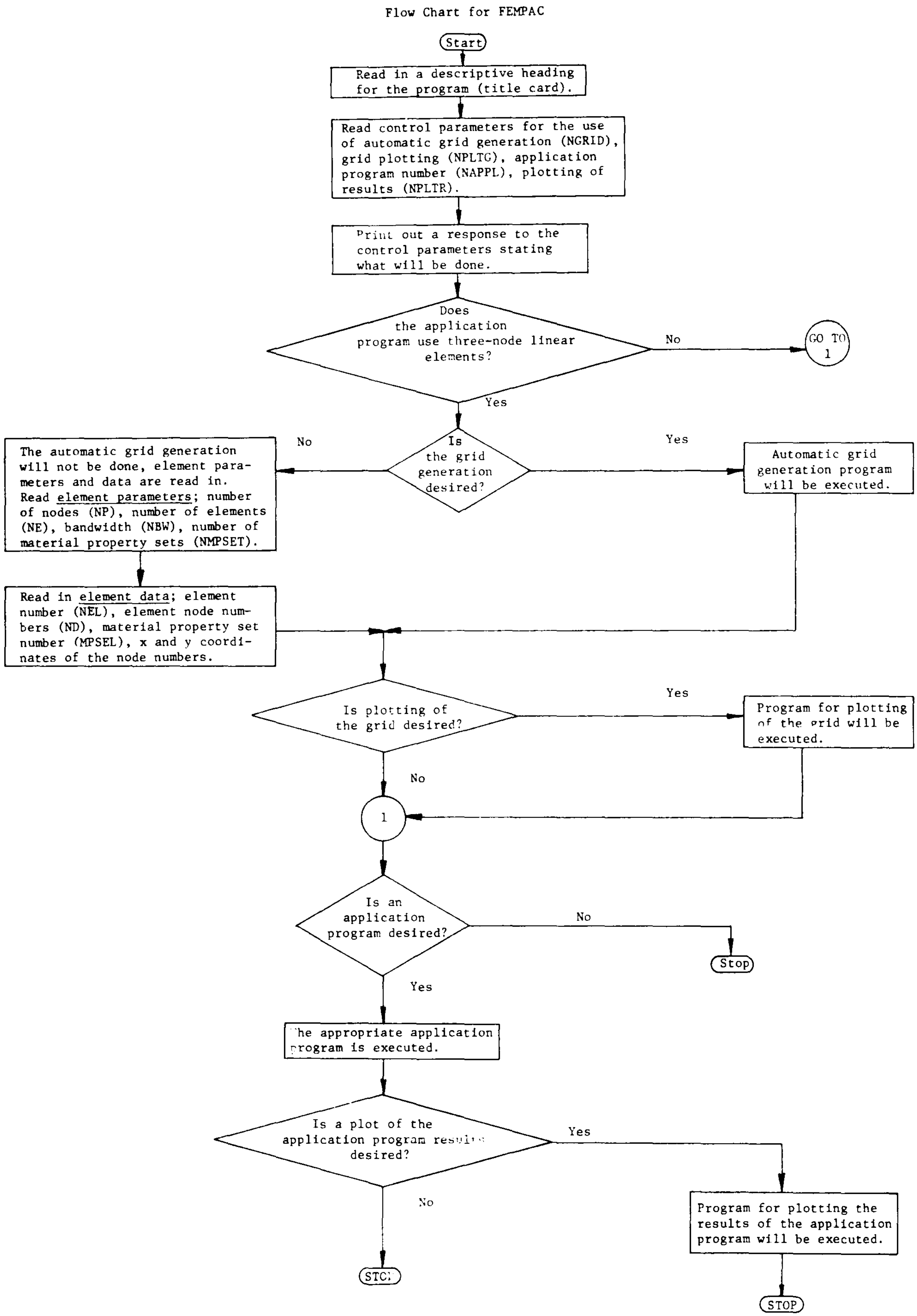
There are two possible modes of input available for this package. The first is FORMATTED INPUT. Formatted information is prepared on a card in a format specified by a format statement in the computer program and can not be deviated from. This form of input is not used here, but alternative read statements for its implementation are included in the programs as comments. A specified format makes the preparation of input data an error-prone, space-counting affair. The second mode of input eliminates these problems by making data input format free, hence it is called FORMAT-FREE INPUT. The input values are separated only by a delimiter which normally is a comma or blank space. One disadvantage in using this type of input is the need for extra zero values on a card to terminate data input.

Table 1.1

Programs Available in FEMPAC

Program	Application Prog. No. (NAPPL)	Capabilities	Element Type	Available Support Options		
				Grid Generation	Grid Plotting	Result Plotting
2-D Elasticity	1	Two-dimensional plane stress and plane strain problems with optional thermal stresses.	linear triangle	Yes	Yes	Yes
2-D Heat Transfer	2	Two-dimensional steady state heat transfer with surface convection or specified boundary temperatures and internal heat sources.	linear triangle	Yes	Yes	Yes
2-D Ground Water Flow	3	Two-dimensional steady state field problem with sources and/or sinks, seepage can be included for ground water flow.	linear triangle	Yes	Yes	Yes
Torsion of Non-circular Shaft	4	Calculates shear stresses in non-circular shaft for given torsional input.	linear triangle	Yes	Yes	Yes
2-D Transient Heat Transfer	5	Two-dimensional transient heat transfer with surface convection or specified boundary temperatures and internal heat generation.	linear triangle	Yes	Yes	Yes
Truss	6	Simple trusses.	linear element	No	No	No

Figure 1.1

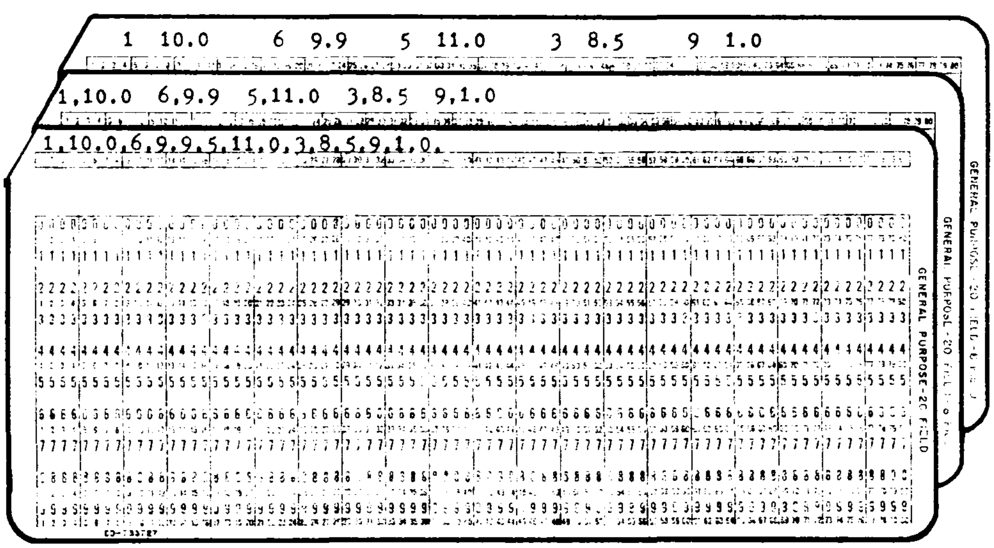

Flow Chart for FEMPAC
Start
Read in a descriptive heading for the program (title card).
Read control parameters for the use of automatic grid generation (NGRID), grid plotting (NPLTG), application program number (NAPPL), plotting of results (NPLTR).
Print out a response to the control parameters stating what will be done.
Does the application program use three-node linear elements?
No
GO TO 1
Yes
Is the grid generation desired?
No
Yes
The automatic grid generation will not be done, element parameters and data are read in. Read element parameters; number of nodes (NP), number of elements (NE), bandwidth (NBW), number of material property sets (NMPSET).
Automatic grid generation program will be executed.
Read in element data; element number (NEL), element node numbers (ND), material property set number (MPSEL), x and y coordinates of the node numbers.
Is plotting of the grid desired?
Yes
Program for plotting of the grid will be executed.
No
1
Is an application program desired?
No
Stop
Yes
The appropriate application program is executed.
Is a plot of the application program results desired?
Yes
Program for plotting the results of the application program will be executed.
No
STOP
STOP

Both modes of input require an input list in the read statements of the program. The input list specifies the variable names or arrays to which the data items are to be transferred and the order of their transmission. Thus, care must be taken to insure that input values are in the correct order on the data cards, so that the values will be stored in locations to which the corresponding variables refer.

Format-free input is very versatile, allowing the users to space the input data to their advantage in terms of readability and/or space used. The following are some <u>conventional</u> rules governing format-free input. The delimiters divide the card up into what are known as fields. Either a blank or a comma following the value are commonly used as delimiters. Leading blanks in a field and blanks following the last delimiter on a card are ignored. A value cannot be continued from one card to another since each card is considered individually. This also implies that the last value on the card doesn't need a delimiter after it.

Two types of variables used in the programs are real and integer. Usually the input values must be of the same type as the variables to which they refer. This is why there is a need to include the decimal points in some input values even though they are whole numbers.

Examples: The following three cards show possible ways of inputting the numbers 1, 10.0, 6, 9.9, 5, 11.0, 3, 8.5, 9, 1.0 under format-free input.



1.4 DEFINITION OF MAIN CONTROL PARAMETERS

Flow of the program and options executed is controlled by parameters on the main control parameters card. The control parameters by the order in which they appear on the main parameter card are:

NGRID - Controls use of automatic grid generation option.

NGRID = 0 implies auto-grid generation will not be used and that the user will input the element data for the problem. The user should see Section 1.6 or the appropriate application program section for description of the element data.

NGRID = 1 implies the grid generation option will be executed. The user should see Chapter 2 for description of the input necessary for auto-grid generation.

NPLTG - Controls option of plotting of grid. The grid plot program produces a line printer plot of the nodal locations. Chapter 4 describes and shows an example of the output available through this option.

NPLTG = 0 No plot is produced.

NPLTG = 1 Plot is produced.

NAPPL - Controls the selection of the appropriate application program. Table 1.1 gives a summary of the application programs available. The user is referred to the appropriate section of Chapter 3 for description of the necessary input for each application program.

NAPPL = 0 implies that no application program will be executed. This is a useful option for the user making a preliminary run of grid generation for determination of boundary nodes and locations of nodes for development of boundary value and/or initial value inputs required for the application programs.

Summary of Application Programs

NAPPL	Program
0	No program executed
1	Elasticity
2	Heat transfer
3	Ground water flow
4	Torsion
5	Transient heat transfer
6	Truss analysis

NPLTR - Controls option of plotting of results. The result plotting program produces line printer plots of pertinent variables. Chapter 5 describes and shows an example of the output available through this option.

NPLTR = 0 No plots are produced.

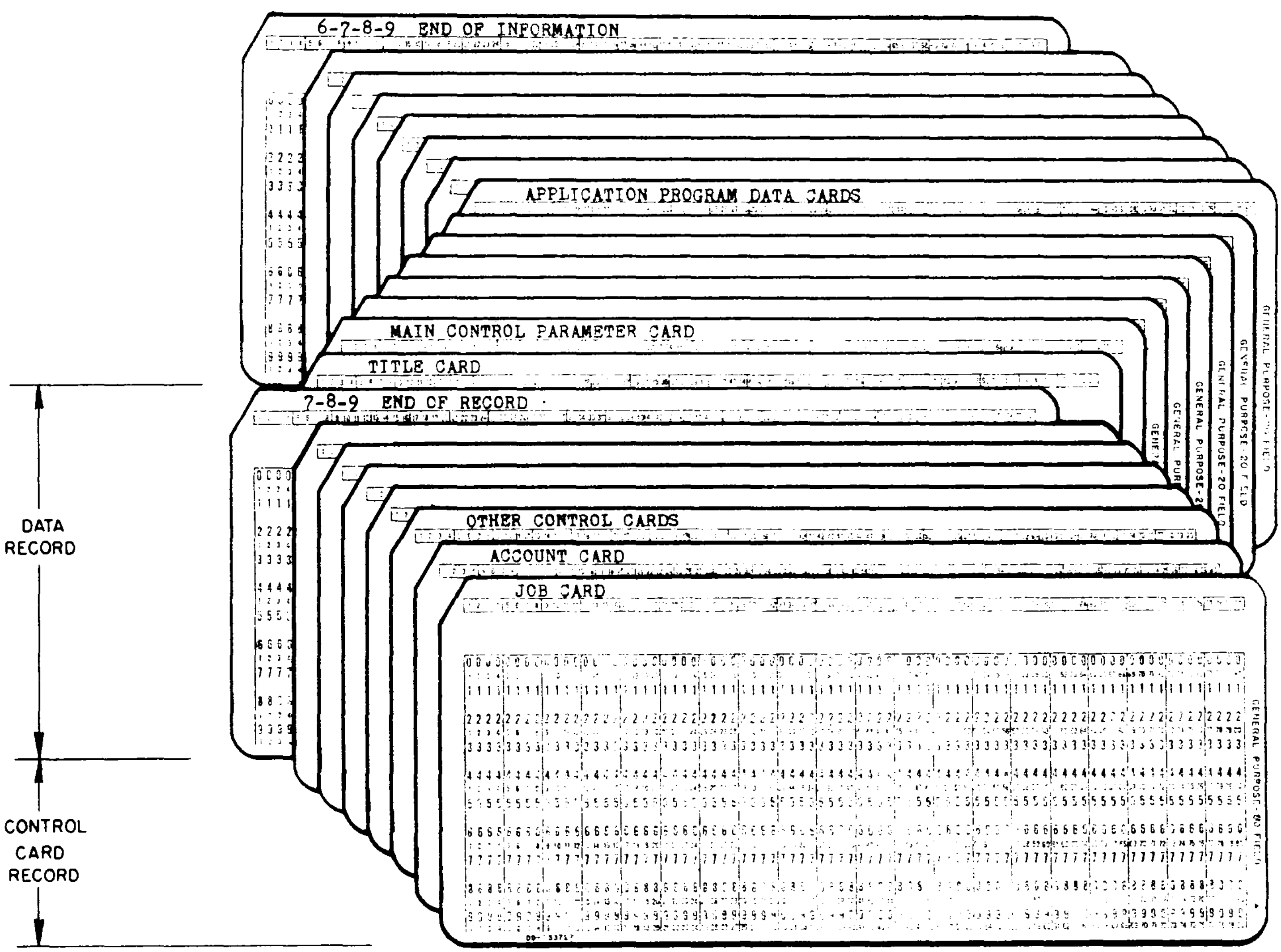
NPLTR = 1 Plots are produced.

Sample Main Control Parameter Card

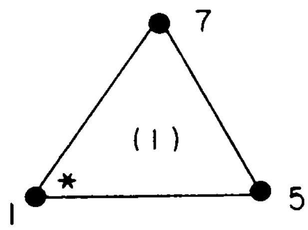
```
1, 1, 2, 0
```

would imply NGRID = 1, auto-grid generation to be executed; NPLTG = 1 grid will be plotted; NAPPL = 2 - application program 2; heat transfer, will be executed; NPLTR = 0 - results plotting will not be executed.

1.5 SCHEMATIC OF DECK STRUCTURE FOR FEMPAC



1.6 ELEMENT DATA AND CONTROL PARAMETERS FOR ELEMENT DATA FOR THREE-NODE LINEAR TRIANGULAR ELEMENT.



The purpose of this section is to describe the element data and control parameters for element data for programs which use the three-node linear triangular element. Description of element data for other element types will be given in the application programs where they are used. For all programs in this package, the element data establishes the element number, node numbers for the element, the material properties set for the element, and the coordinates of the nodes for each element making up the region under study.

1.6.1 Element Data for Linear Triangular Element

The element data for programs using linear triangular elements can either be input for each element by the user or can be generated through the automatic grid generation program.

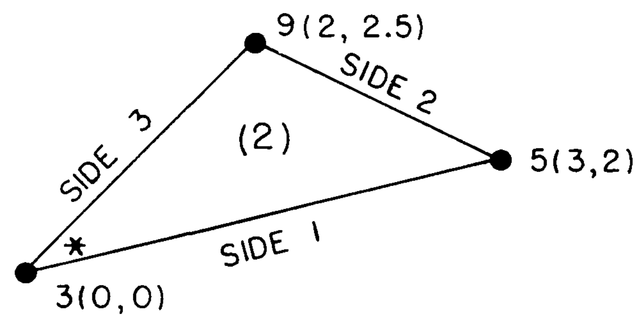
Element data for each element is input in the following order:

(1) NE - element number
(2) ND - three node numbers counterclockwise from first node.
(3) MPSEL - material property set number for the element.
(4) X1, Y1, X2, Y2, X3, Y3 - X and Y coordinates counterclockwise from first node.

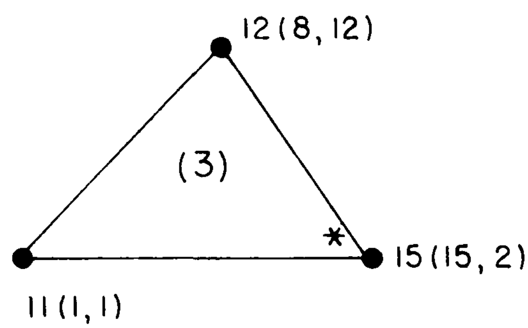
Node numbers are input in order counterclockwise from an arbitrarily selected starting node. It is convenient to record which node is being used for the first node by using an asterisk (*) at that node. Nodal coordinates are also input following a counterclockwise pattern: X1, Y1 for starting node; X2, Y2 for next node counterclockwise on the element; X3, Y3 for the final node. When element side numbering is necessary, as in heat transfer application, the sides are numbered counterclockwise from the starting node with side one being the side between the starting node and the second node.

The parameter MPSEL is used to select the appropriate set of material properties from the material properties table established.

Sample Elements:



NE	ND			MPSEL	X1	Y1	X2	Y2	X3	Y3
2	3	5	9	1	0.0	0.0	3.0	2.0	2.0	2.5



NE	ND			MPSEL	X1	Y1	X2	Y2	X3	Y3
3	15	12	11	1	15.0	2.0	8.0	12.0	1.0	1.0

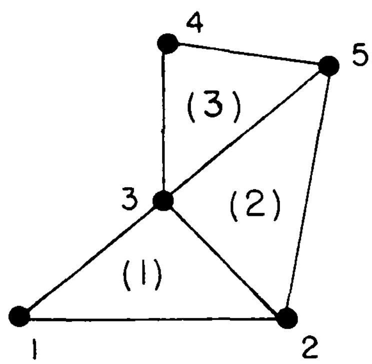
1.6.2 Control Parameters for Element Data

Control parameters for element data for programs using linear triangular elements establishes the size of the problem and the number of material properties sets to be used. The element data control parameters for these cases include, by order of input:

NE	-	number of elements
NP	-	number of nodes
NBW	-	bandwidth* = maximum difference in node numbers within any element + 1.
NMPSET	-	number of material properties sets to be input

If automatic grid generation is used, these parameters are input to the application program by the grid generation program. If the user inputs the element data, a card including the Control Parameters for Element Data must be input with the parameters listed above.

Sample bandwidth determination



Bandwidth = (5-2) + 1 = 4

1.7 MATERIAL PROPERTIES TABLES

A common procedure has been established for input of material properties for all application programs in this package. A table of sets of material properties is established and stored. Material properties for a region or for an element are then selected by referring to the set number of the desired set of material properties. Table 1.2 shows what properties are included in a material properties sets for each application program. The table is sized for five parameters in each material properties set. Some applications do not require five parameters. Zero values must be used to specify the unused parameters in those material properties sets in application programs not requiring all five parameters. Up to twenty sets of material properties may be input. Each set must be input on a separate card. The number of material properties sets to be input is controlled by the parameter NMPSET which is input either through the automatic grid generation program or within the element data control parameters. Sets are numbered by order of their input.

*Note this is bandwidth assuming one degree of freedom (unknown) at a node. Application programs automatically adjust bandwidth for number of unknowns at a node.

Table 1.2. Material Property Sets

Application Program	Material property (1)	Material property (2)	Material property (3)	Material property (4)	Material property (5)
2-D Stress analysis	Young's modules	Poisson's ratio	Coef. of thermal expansion	Equilibrium temperature of body	Thickness of body
	(EM)	(PR)	(ALPHA)	(TEMP)	(T)
2-D Heat transfer	Conductivity X - direction	Conductivity Y - direction	Convection coefficient	Fluid temperature	N/A
	(KXX)	(KYY)	(H)	(TINF)	(0.0)
Groundwater	Transmissivity X - direction	Transmissivity Y - direction	N/A	N/A	N/A
	(TXX)	(TYY)	(0.0)	(0.0)	(0.0)
Torsion	Shear modules	Shaft length	Number axis of sym. *2	N/A	N/A
	(G)	(SL)	(PCT)	(0.0)	(0.0)
2-D Transient heat transfer	Conductivity X - direction	Conductivity Y - direction	Convection coefficient	Fluid temperature	Specific heat*density
	(KXX)	(KYY)	(H)	(TINF)	(CRHO)
Simple truss	Elastic modulus	Coefficient of thermal expansion	Cross-section area	N/A	N/A
	(EM)	(ALPHA)	(AREA)	(0.0)	(0.0)

Consider an example of input of two material properties sets for 2-D Heat Transfer.

Set 1			Set 2		
KXX	=	350.0	KXX	=	600.0
KYY	=	300.0	KYY	=	500.0
H	=	0.1	H	=	0.5
TINF	=	50.0	TINF	=	60.0

The material properties input would appear as

Set 2 `600.0,    500.0,    0.50,    60.0,    0.0`

Set 1 `350.0,    300.0,    0.1,    50.0,    0.0`

2. AUTOMATIC GRID GENERATION PROGRAM

2.1 PURPOSE

This program can be used to automatically generate element data for application programs which use only the three-node linear triangular elements (see Table 1.1). Incorrect element data is one of the major sources of error when running finite element programs. Preparation of element data is time-consuming and tedious without the aid of a program such as this.

This program is intended to help the finite element user by reduction of time and errors in element data preparation. The output of this program, element data (element numbers, node numbers, material properties index, nodal coordinates), is printed out, can be graphically displayed, is automatically stored for use by an application and plotting programs, and can be punched on cards.[1]

This program is capable of generating up to 300 elements.

2.2 INPUT REGION DESCRIPTION

The input region for the program is the quadratic quadrilateral. This region is quite versatile; it can be used as rectangle, general quadrilateral, or as a triangle (see Fig. 2.1). Two sides of the quadrilateral are used to define one side of a triangular region.

The eight nodes that define a region are numbered counterclockwise from an arbitrarily-selected corner node. The sides are also numbered counterclockwise from the same starting point. (It is convenient to mark the starting point with an *.) See Fig. 2.1 for sample regions.

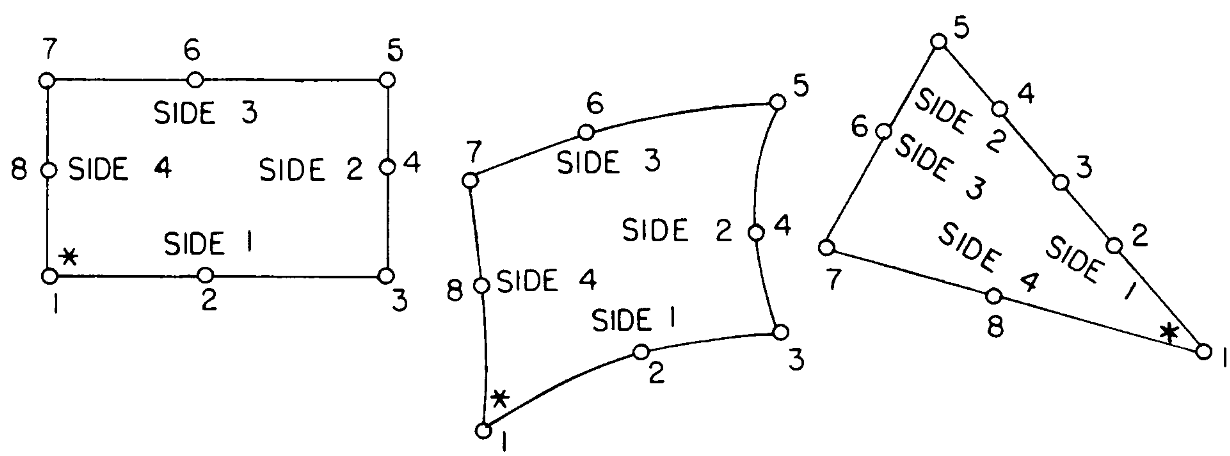


Fig. 2.1. Quadratic Quadrilateral for Grid Generation Input.

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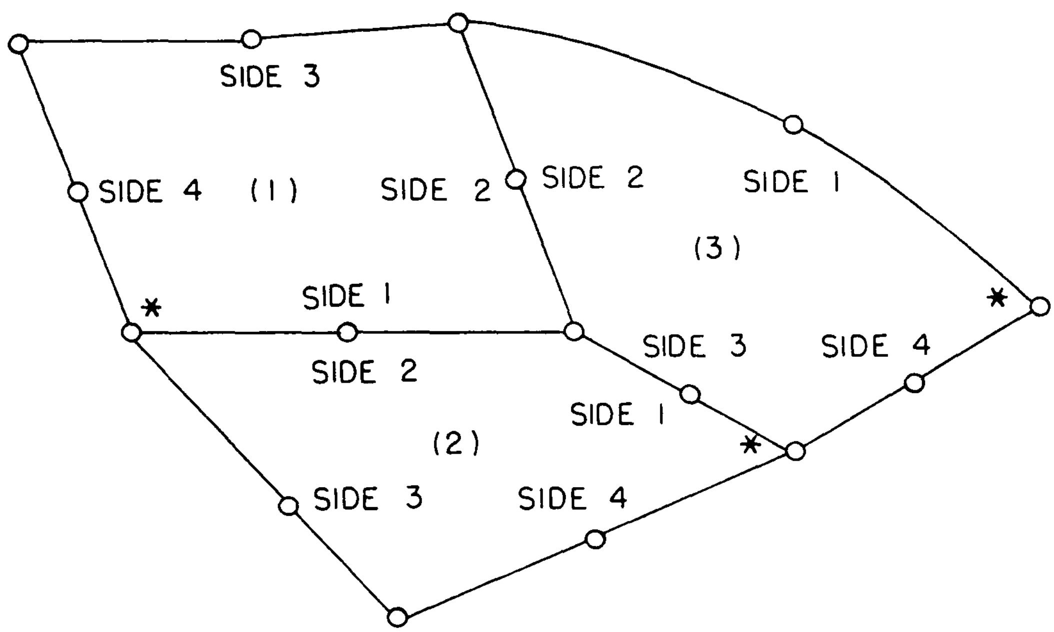
[1]/Further information on grid generation and more details on program operation can be found in Segerlind, 1976. Applied Finite Element Analysis, John Wiley & Sons, Inc., New York.

2.3 REGION CONNECTIVITY

Generally modeling the body or domain requires several input quadrilateral regions connected to one another along one or more sides. Having common boundaries between two regions requires that certain information be provided to insure that the nodes on the common boundaries have the same numbers regardless of which region is being considered. This is done by inputting "connectivity data." The connectivity data conveys to the computer how the regions are connected.

The connectivity data for a single region consists of four numbers, one for each side. Each value is the number of the region connected to a particular side. The determination of the connectivity data is probably best illustrated through an example as in the region shown below.



The region numbers, (1) through (3), and starting nodes have been assigned. Therefore, the side number for each region is known. The connectivity data for the 3-region body is as follows:

	Side			
Region	1	2	3	4
(1)	2	3	0	0
(2)	3	1	0	0
(3)	0	1	2	0

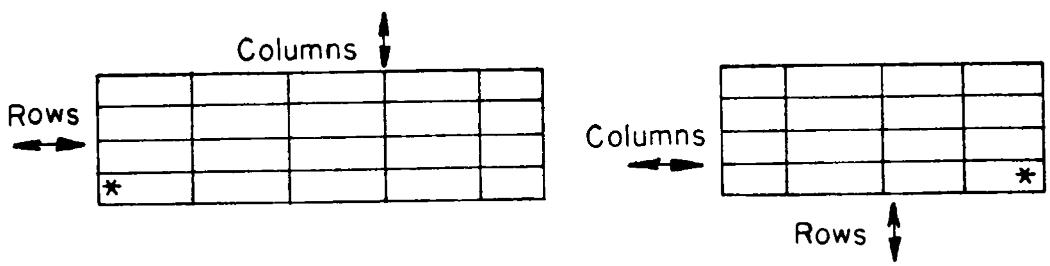
The first line of the data reads, side 1 of region 1 is connected to region 2, and side 2 of region 1 is connected to region 3. The zero indicates sides which are not connected to another region.

2.4 MATERIAL PROPERTIES SETS

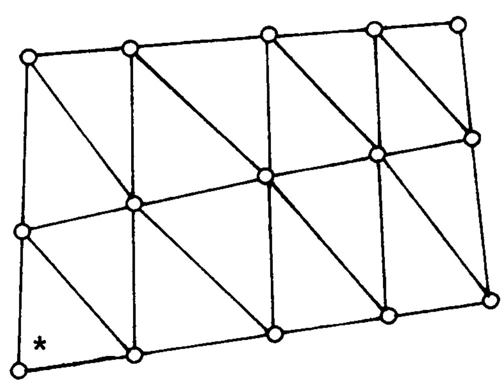
A material properties set consists of five numbers specifying the material properties needed for the application program to be used. Up to twenty material properties sets may be used. Each input region for grid generation is given one of the material properties sets. Unused numbers within a set should be input as zeros. Table 1.2 shows the material properties sets for each of the application programs. Each application program write-up also discusses the material properties sets for its specific application.

2.5. REGION DATA

A region data card is read for each region. The information on the card includes the input region number (NRG), the material property set desired (MPS), the number of rows of nodes (NROWS) and columns of nodes (NCOL) desired and the 8 node numbers used to define the quadrilateral. Rows of nodes and columns of nodes are defined relative to the starting node as shown below:



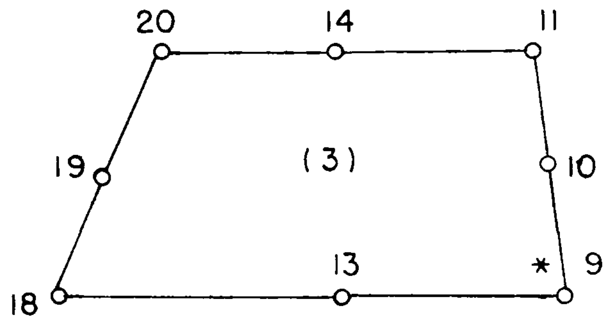
The program will subdivide the region into (NROWS -1)*(NCOL-1)*2 elements. For example, for NROWS=3 and NCOL=5, the region would be subdivided into 16 elements as shown below.



Number of rows of nodes (NROWS) and columns of nodes (NCOL) are limited to a maximum of twelve for any one input region. Total number of elements generated for all input regions is limited to three hundred elements.

Care must be taken in specifying row and columns so that continuity is maintained between regions, i.e., adjoining regions must have the same number of nodes on the common boundary.

Assume the region shown below was extracted from a body being discretized. The region data for the region is shown, assuming that a subdivision of 4 rows of nodes and 3 columns of nodes is desired.



NRG-Region Number	MPS-matl. Prop. set.	NROWS-4 rows of nodes	NCOL-3 cols. of nodes	Node number ccw from starting node							
3,	1,	4,	3,	9,	10,	11,	14,	20,	19,	18,	13

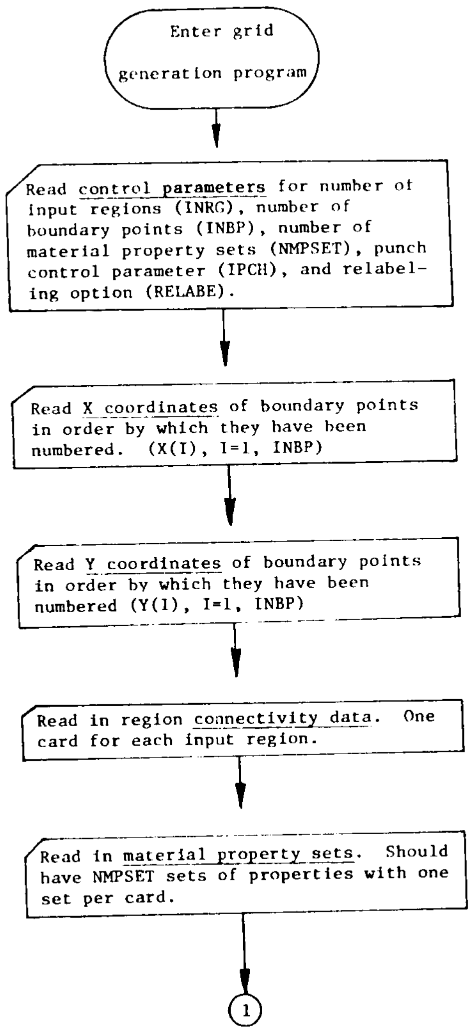
2.6 CONTROL PARAMETERS

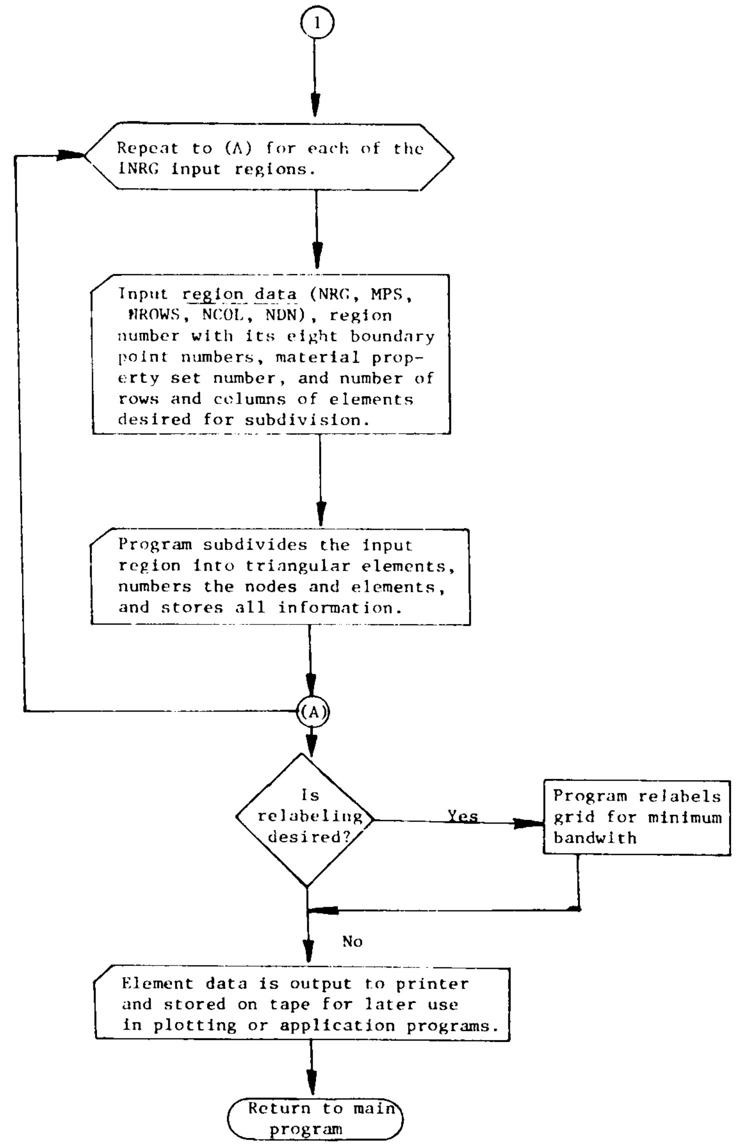
Control parameters read in the grid program consist of 1) the number of input regions to be used (INRG), number of boundary points for defining the region (INBP), number of material properties sets to be input (NMPSET), punch control option (IPCH=0 no punch, =1 punch), and relabeling option control (RELABE=0 relabel, = 1 no relabel).

Sample Grid Parameter Card

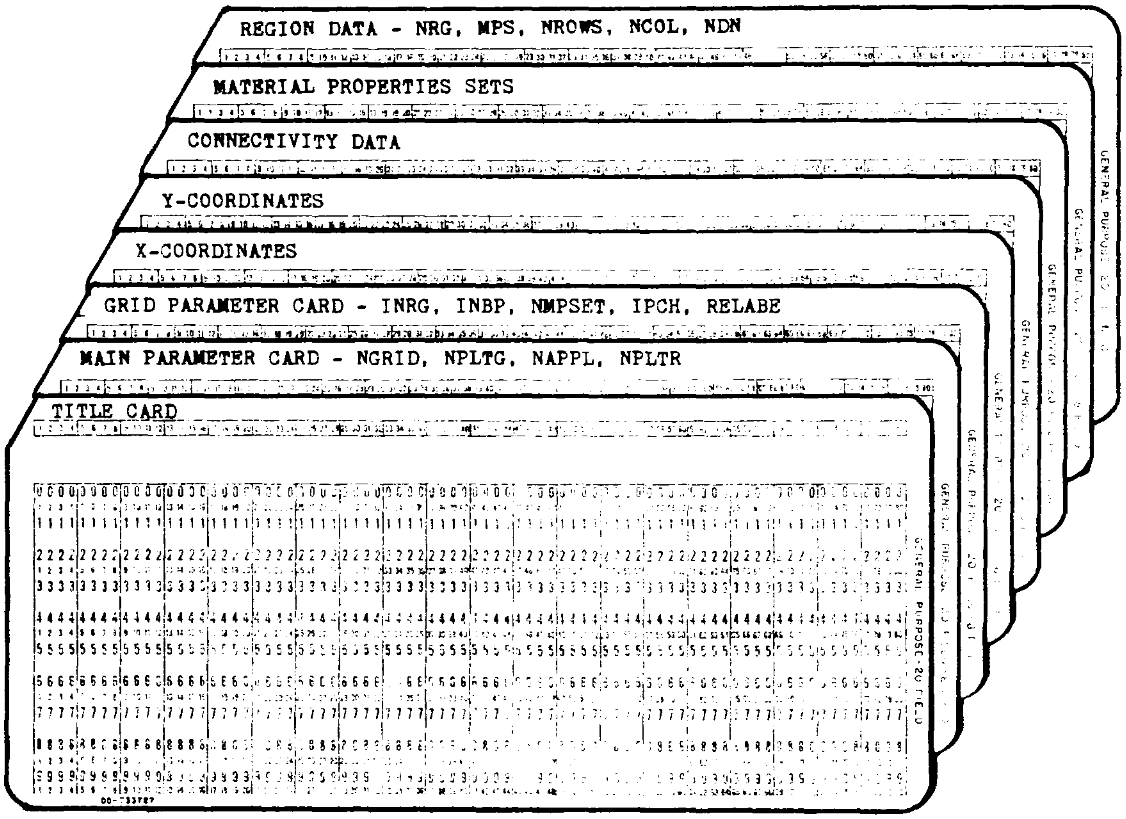
INRG - No. of Regions	INBP - No. Bndry. Points	NMPSET - No. Matl. Sets	IPCH	RELABE
3,	16,	2,	0,	0

2.7 General Flow Diagram for Grid Generation





2.8 SUMMARY OF INPUT AND ORDER OF INPUT



2.9 DEFINITION AND LIMITS FOR INPUT VARIABLES

INBP = total number of boundary nodes
$\leq$ 100

INRG = total number of input regions to be subdivided
$\leq$ 20

IPCH = control for punched out of element data
IF IPCH = 0 no punch
= 1 punch output given

JT = array of connectivity data
= JT(INRG,4)

JT(A,B)		Side number B			
		1	2	3	4
Region No. A	1	X			
	2				
	3				
	⋮ INRG				

Side B of region number A is connected to region number X.
(See connectivity of data description and example problem).

MTPROP = Material properties arranged by sets of five values
$\leq$ 20 sets (see material properties description Section 1.7).

MPS = Material properties set number corresponding to a particular region

NCOL = Number of columns of nodes for subdivision
$\leq$ 12

NDN(I) = 8 node numbers used to define an input region, I = 1 to 8

NMPSET = Number of material properties sets
$\leq$ 20

NRG = Region number

NROWS = Number rows of nodes for subdivision
$\leq$ 12

RELABE = Control parameter for relabel for minimum bandwidth

IF RELABE = 1 the nodes are not relabeled
= 0 the nodes are relabeled

XP,YP = The global coordinators of input boundary nodes

2.10 SAMPLE PROBLEM

The region shown in Fig. 2.2(a) is to be discretized (divided into elements) using automatic grid generation. Figure 2.2(b) shows the body divided into three quadratic quadrilaterals for input to the grid program. Each boundary node has been numbered and the starting node for each element has been designated. Only grid generation is desired for this problem. Figure 2.3 shows the input used for this problem. It is assumed that regions (1) and (3) are to be divided into 3 rows and 2 columns of nodes, and that region (2) is to be divided into 3 rows and 3 columns of nodes.

Output of the grid generation program is shown in Figure 2.4 followed by a sketch of the discretized region, Figure 2.5.

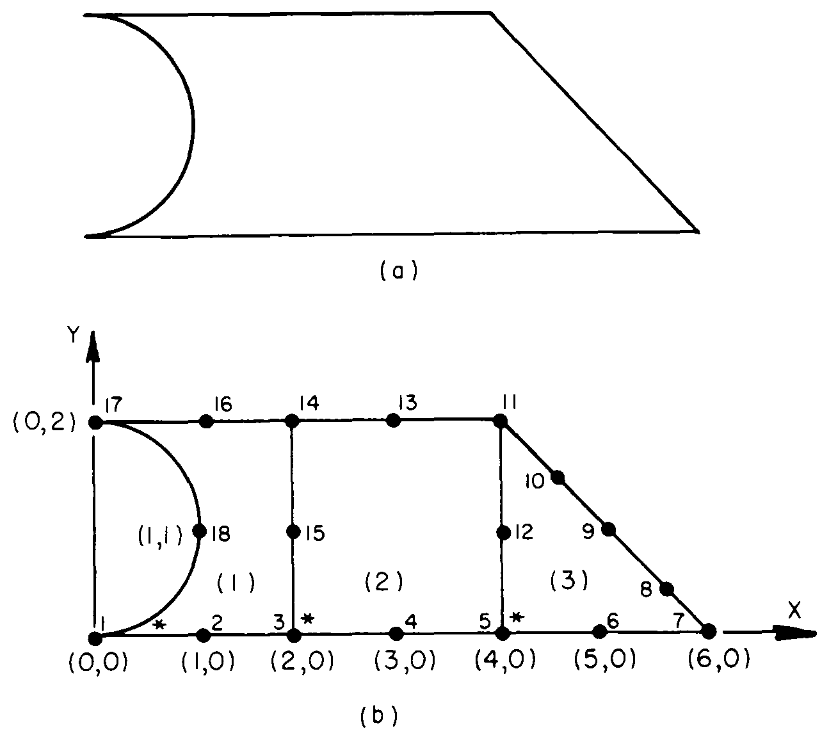


Fig. 2.2 Region for Auto-Grid Generation

Fig. 2.3 Grid Generation Input

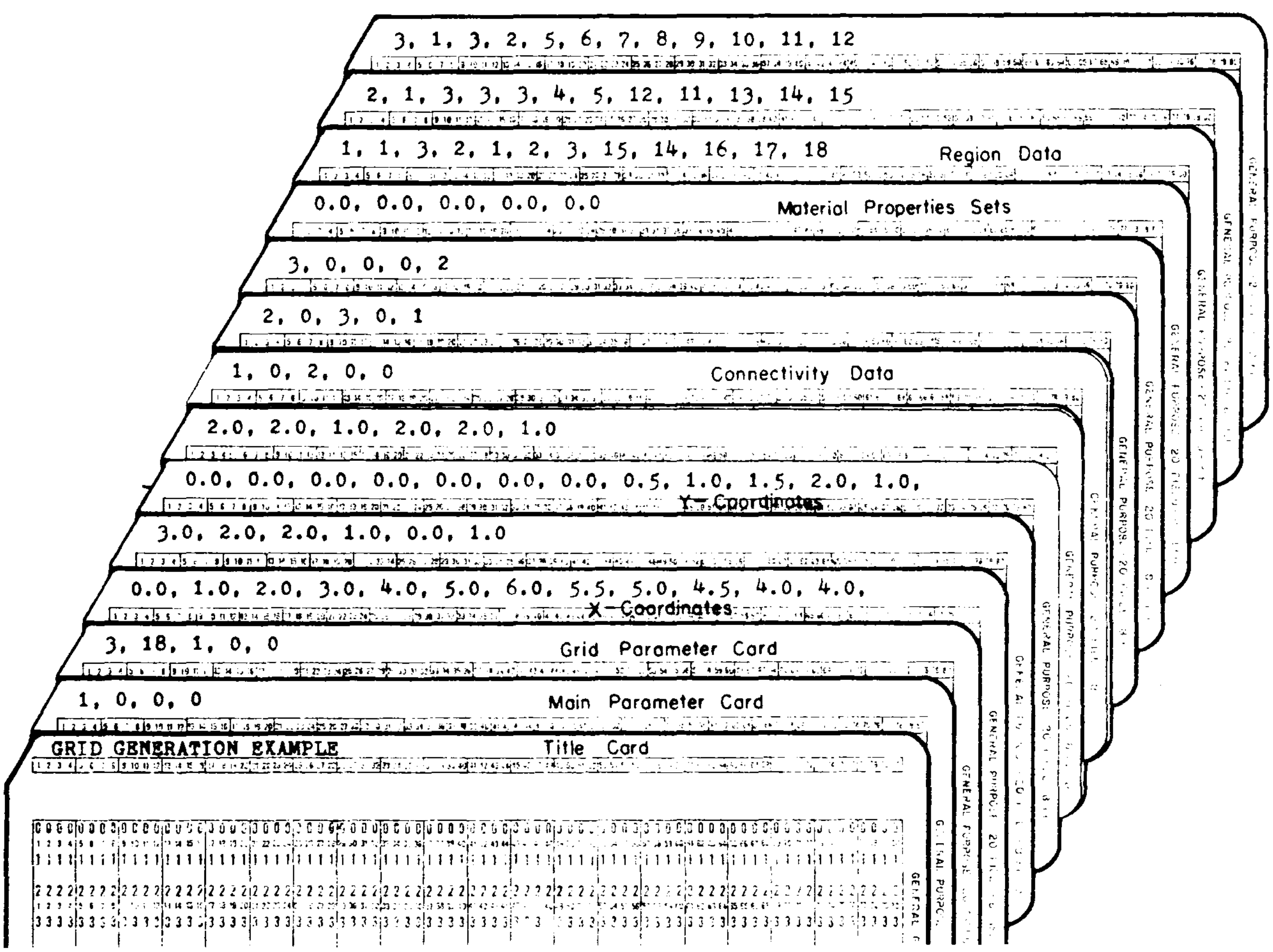


Fig. 2.4 Output for Grid Generation Example

GRID GENERATION EXAMPLE

THE GRID WILL BE AUTOMATICALLY GENERATED

GLOBAL COORDINATES

NUMBER	X COORD	Y COORD
1	0	0
2	1.00	0
3	2.00	0
4	3.00	0
5	4.00	0
6	5.00	0
7	6.00	0
8	5.50	.50
9	5.00	1.00
10	4.50	1.50
11	4.00	2.00
12	4.00	1.00
13	3.00	2.00
14	2.00	2.00
15	2.00	1.00
16	1.00	2.00
17	0	2.00
18	1.00	1.00

CONNECTIVITY DATA

	SIDE			
REGION	1	2	3	4
1	0	2	0	0
2	0	3	0	1
3	0	0	0	2

MATERIAL PROPERTIES

SET	MAT PROP 1	MAT PROP 2	MAT PROP 3	MAT PROP 4	MAT PROP 5
1	0	0	0	0	0

REGION DATA

REGION	ROWS	COLS	MATERIAL SET	INPUT REGION NODE NO.							
1	3	2	1	1	2	3	15	14	16	17	18
2	3	3	1	3	4	5	12	11	13	14	15
3	3	2	1	5	6	7	8	9	10	11	12

NODE NUMBERS
OF SUBDIVIDED REGION

1

1	3
2	4
5	6

2

3	7	10
4	8	11
6	9	12

3

10	13
11	14
12	15

ELEMENT DATA, REGION 1 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
1	2	4	3	1.0000	1.0000	2.0000	1.0000	2.0000	2.0000
2	2	3	1	1.0000	1.0000	2.0000	2.0000	0	2.0000
3	5	6	2	0	0	2.0000	0	1.0000	1.0000
4	6	4	2	2.0000	0	2.0000	1.0000	1.0000	1.0000

ELEMENT DATA, REGION 2 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
5	4	8	7	2.0000	1.0000	3.0000	1.0000	3.0000	2.0000
6	4	7	3	2.0000	1.0000	3.0000	2.0000	2.0000	2.0000
7	8	11	10	3.0000	1.0000	4.0000	1.0000	4.0000	2.0000
8	8	10	7	3.0000	1.0000	4.0000	2.0000	3.0000	2.0000
9	6	9	8	2.0000	0	3.0000	0	3.0000	1.0000
10	6	8	4	2.0000	0	3.0000	1.0000	2.0000	1.0000
11	9	12	11	3.0000	0	4.0000	0	4.0000	1.0000
12	9	11	8	3.0000	0	4.0000	1.0000	3.0000	1.0000

ELEMENT DATA, REGION 3 MAT. PROP. SET = 1

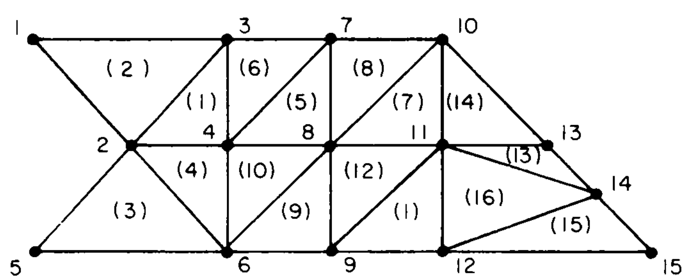
NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
13	11	14	13	4.0000	1.0000	5.5000	.5000	5.0000	1.0000
14	11	13	10	4.0000	1.0000	5.0000	1.0000	4.0000	2.0000
15	12	15	14	4.0000	0	6.0000	0	5.5000	.5000
16	12	14	11	4.0000	0	5.5000	.5000	4.0000	1.0000

NUMBER OF ELEMENTS = NE = 16

NUMBER OF NODES = NP = 15

BANDWIDTH = NBW = 5

Fig. 2.5 Discretized Region from Grid Generation



3. APPLICATION PROGRAMS

3.1 TWO-DIMENSIONAL ELASTICITY

3.1.1 Introduction

This program can be used to analyze two-dimensional bodies subjected to boundary forces and/or displacements. The user must specify if the problem under consideration is a plane stress case or a plane strain case. The program uses simple linear triangular elements only. Automatic grid generation can be used with the program. Thermal stresses may be included by inputting temperature values for the elements.

3.1.2 Material Properties Description

The material properties sets for this program include, in the following order

EM - Elastic Modulus
PR - Poisson's ratio
ALPHA - Coefficient of thermal expansion
TEMP - Initial steady-state, temperature for body
T - Thickness of the element, must equal 1.0 for plane stress case

Any compatible set of units may be used. Up to twenty sets of material properties may be input.

3.1.3 Control Parameters for Two-Dimensional Elasticity

Control parameters read in during the application program section for 2-D elasticity are

1) Control for problem type (ITYPE)
   ITYPE = 0 - plane stress
   = 1 - plane strain

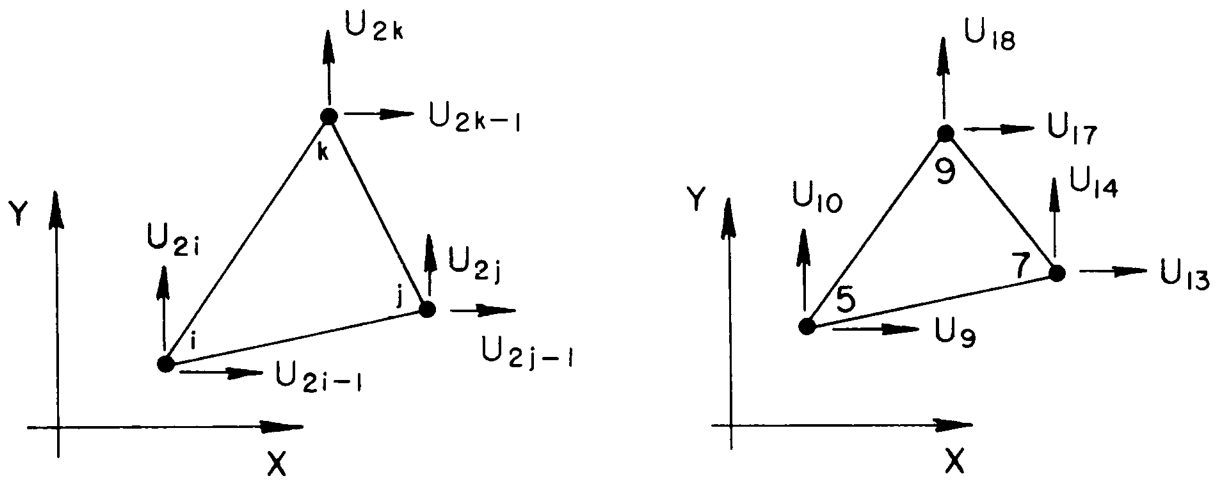
2) Control parameter for input of element temperatures (ITEMP)
   ITEMP = 0 - no temperature input
   = 1 - temperature input for each element. See Section 3.1.4.

3.1.4 Element Temperatures

Average temperature for each element may be input for calculation of thermal stresses. This requires specifying the control parameter ITEMP = 1 and input the average element temperatures ordered by element number. The temperature difference between the initial steady-state temperature (TEMP) and the average element temperature is used to calculate the thermal stress.

3.1.5 Vector Components

Two-dimensional elasticity is complicated by having a vector unknown, displacement. For both the plane strain and plane stress cases the displacement is expressed as the sum of the component in the X and Y coordinate directions. The figures below demonstrate how the components at each node are expressed. At each node two degrees of freedom (global degrees of freedom) are used. They are two times the node number for the Y-component and two times node number minus one for the X-component.

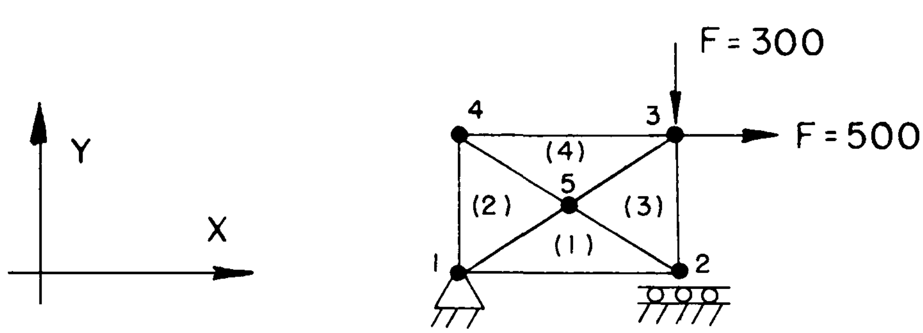


Input of force values and known nodal displacements are also keyed to the appropriate global degree of freedom.

3.1.6 Boundary Values

Boundary conditions are input in two sections. The first is nodal forces. The second is known displacements. Both are input by the global degrees of freedom at each node and the value of the vector component parallel to the direction of that degree of freedom.[1] Each card must have six sets consisting of global degree of freedom and associated values. If a complete card is not needed, the remaining sets are specified with zero values. If an even multiple of 6 sets occurs or no values are to be input, a card with 6 sets of zeros (12 zeros) must follow to terminate that section of data input.

For the simple region shown below



the nodal forces would be

```
6, -300.0, 5, 500.0, 0, 0.0, 0, 0.0, 0, 0.0, 0, 0.0
```

[1] Global degrees of freedom at each node refers to nodes after grid generation when automatic grid generation is used. A preliminary run of auto-grid generation may be necessary to determine nodes for boundary conditions.

and the known nodal values (displacements).

```
1, 0.0, 2, 0.0, 4, 0.0, 0, 0.0, 0, 0.0, 0, 0.0
```

Note sign convention has been established such that forces and displacements in the positive coordinate direction are assumed positive. Those in the opposite direction are assumed negative.

3.1.7 Input Description

Table 3.1.1 shows the inputs required for two possible cases using 2-D elasticity. The first, auto-grid case, assumes the use of the automatic grid generation program. The second, non-auto-grid case, assumes the user will input the element data from cards.

3.1.8 Sample Problem

The body for a sample plane stresses problem is shown in Fig. 3.1.1. The body is a thin plate fixed at one end and subjected to a pressure force along a portion of the top side. Fig. 3.1.2 shows the region subdivided for automatic grid generation. Fig. 3.1.3 shows the input using automatic grid generation for the problem. Figure 3.1.4 shows the grid generation by the program. Figure 3.1.5 shows the output of the program.

Figure 3.1.6 shows the input for the same grid as shown in Figure 3.1.4 but not using automatic grid generation.

Figure 3.1.1 Example Problem 2-D Elasticity-Plane Stress

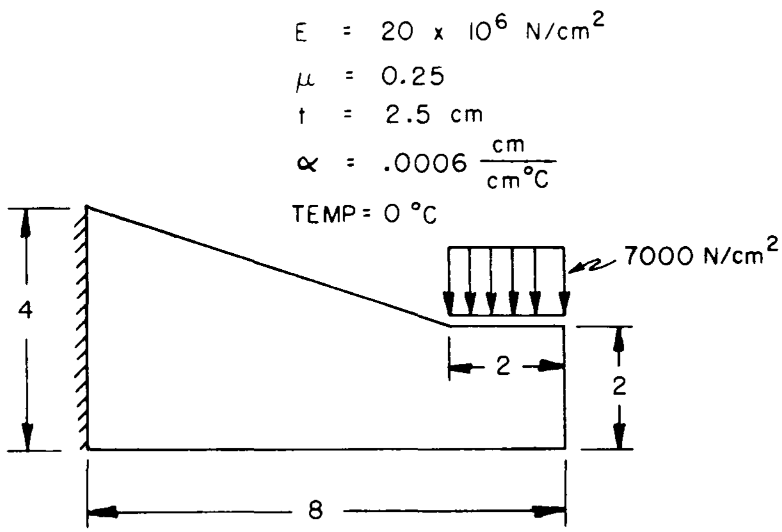


Table 3.1.1 Program Input for 2-D Elasticity

(common)

Title Card - up to 80 alpha-numeric characters for identification of problem

or

Auto-grid case:

Main Parameter Card - See Section 1.4 for this case
- NGRID = 1
- NPLTG = 0 or 1
- NAPPL = 1
- NPLTR = 0 or 1

Grid Generation Input Data - includes material properties sets - See Section 3.1.2

Non-auto-grid case:

Main Parameter Card - See Section 1.4 for this case
- NGRID = 0
- NPLTG = 0 or 1
- NAPPL = 1
- NPLTR = 0 or 1

Control Parameters for Element Data - by order of input.
- NE - number of elements
- NP - number of nodes
- NBW - bandwidth assuming 1 d.o.f. per node
- NPSET - number of material properties sets

Material Properties Sets - NMPSET sets; see Section 3.1.2 for description

Element Data - for each element, by order of input, see Section 1.6.
- NE - element number
- ND - 3 node numbers counterclockwise from 1st node
- MPSEL - material properties set number the element
- X1,Y1,X2,Y2,X3,Y3 - X and Y coordinates counterclockwise from first node.

(common)

Control Parameters for Application - See Section 3.1.3
- ITYPE = 0 plane stress
  - 1 plane strain
- ITEMP = 0 no temperature input
  - 1 element temperature to be input

Average Element Temperature - read only if ITEMP = 1, average temperature for each element in order by element number.

Nodal Forces - read sets of global degree of freedom associated with force and value, with 6 sets per card - terminate with global d.o.f. = 0, value = 0.0 for remainder of card. See Sections 3.1.5 and 6.

Specified Nodal Values - reads sets of global degree of freedom associated with displacement and value of displacement with 6 sets per card - terminate with global d.o.f. = 0, value = 0.0 for remainder of card. See Sections 3.1.5 and 6.

Fig. 3.1.2 Regions for Auto-Grid Generation

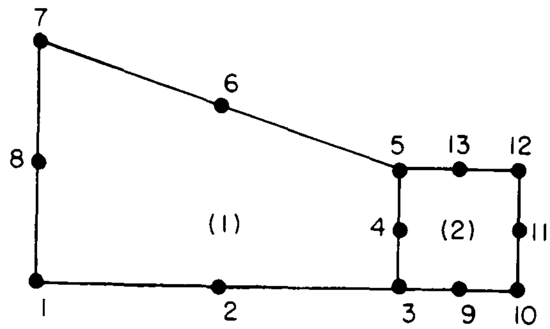


Fig. 3.1.3 Sample Input with Auto-Grid Generation

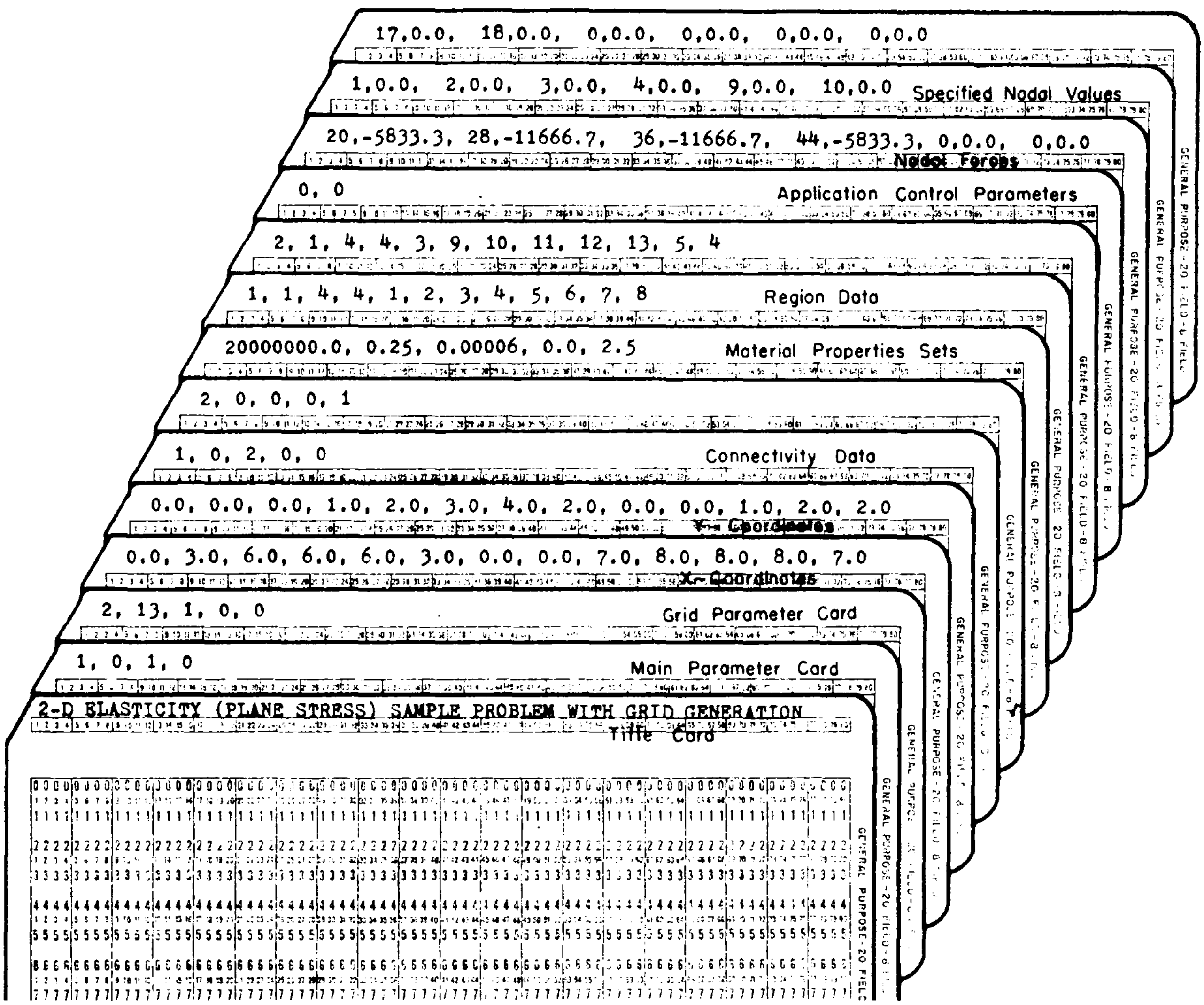


Fig. 3.1.4 Grid Generated for Elasticity Problem

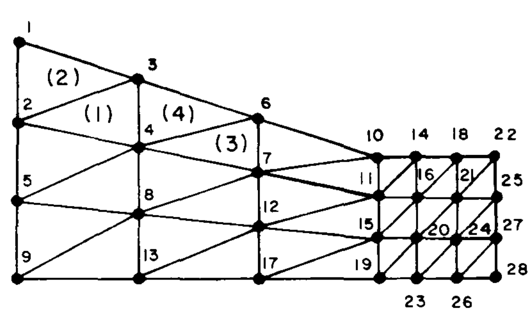


Fig. 3.1.5 Output for Elasticity Example with Grid Generation

2-D ELASTICITY (PLANE STRESS) SAMPLE PROBLEM WITH GRID GENERATION

THE GRID WILL BE AUTOMATICALLY GENERATED

APPLICATION PROGRAM STRESS ANALYSIS WILL BE SOLVED

GLOBAL COORDINATES

NUMBER	X COORD	Y COORD
1	0	0
2	3.00	0
3	6.00	0
4	6.00	1.00
5	6.00	2.00
6	3.00	3.00
7	0	4.00
8	0	2.00
9	7.00	0
10	8.00	0
11	8.00	1.00
12	8.00	2.00
13	7.00	2.00

CONNECTIVITY DATA

	SIDE			
REGION	1	2	3	4
1	0	2	0	0
2	0	0	0	1

MATERIAL PROPERTIES

SET	MAT PROP 1	MAT PROP 2	MAT PROP 3	MAT PROP 4	MAT PROP 5
	EM	PR	ALPHA	TEMP	T
1	.2000E+08	.2500E+00	.6000E-04	0	.2500E+01

REGION DATA

REGION	ROWS	COLS	MATERIAL SET	INPUT REGION NODE NO.							
1	4	4	1	1	2	3	4	5	6	7	8
2	4	4	1	3	9	10	11	12	13	5	4

NODE NUMBERS
OF SUBDIVIDED REGION

1

1	3	6	10
2	4	7	11
5	8	12	15
9	13	17	19

2

10	14	18	22
11	16	21	25
15	20	24	27
19	23	26	28

ELEMENT DATA, REGION 1 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
1	2	4	3	0	2.6667	2.0000	2.2222	2.0000	3.3333
2	2	3	1	0	2.6667	2.0000	3.3333	0	4.0000
3	4	7	6	2.0000	2.2222	4.0000	1.7778	4.0000	2.6667
4	4	6	3	2.0000	2.2222	4.0000	2.6667	2.0000	3.3333
5	7	11	10	4.0000	1.7778	6.0000	1.3333	6.0000	2.0000
6	7	10	6	4.0000	1.7778	6.0000	2.0000	4.0000	2.6667
7	5	8	4	0	1.3333	2.0000	1.1111	2.0000	2.2222
8	5	4	2	0	1.3333	2.0000	2.2222	0	2.6667
9	8	12	7	2.0000	1.1111	4.0000	.8889	4.0000	1.7778
10	8	7	4	2.0000	1.1111	4.0000	1.7778	2.0000	2.2222
11	12	15	11	4.0000	.8889	6.0000	.6667	6.0000	1.3333
12	12	11	7	4.0000	.8889	6.0000	1.3333	4.0000	1.7778
13	9	13	8	0	0	2.0000	0	2.0000	1.1111
14	9	8	5	0	0	2.0000	1.1111	0	1.3333
15	13	17	12	2.0000	0	4.0000	0	4.0000	.8889
16	13	12	8	2.0000	0	4.0000	.8889	2.0000	1.1111
17	17	19	15	4.0000	0	6.0000	0	6.0000	.6667
18	17	15	12	4.0000	0	6.0000	.6667	4.0000	.8889

ELEMENT DATA, REGION 2 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
19	11	16	14	6.0000	1.3333	6.6667	1.3333	6.6667	2.0000
20	11	14	10	6.0000	1.3333	6.6667	2.0000	6.0000	2.0000
21	16	21	18	6.6667	1.3333	7.3333	1.3333	7.3333	2.0000
22	16	18	14	6.6667	1.3333	7.3333	2.0000	6.6667	2.0000
23	21	25	22	7.3333	1.3333	8.0000	1.3333	8.0000	2.0000
24	21	22	18	7.3333	1.3333	8.0000	2.0000	7.3333	2.0000
25	15	20	16	6.0000	.6667	6.6667	.6667	6.6667	1.3333
26	15	16	11	6.0000	.6667	6.6667	1.3333	6.0000	1.3333
27	20	24	21	6.6667	.6667	7.3333	.6667	7.3333	1.3333
28	20	21	16	6.6667	.6667	7.3333	1.3333	6.6667	1.3333
29	24	27	25	7.3333	.6667	8.0000	.6667	8.0000	1.3333
30	24	25	21	7.3333	.6667	8.0000	1.3333	7.3333	1.3333
31	19	23	20	6.0000	0	6.6667	0	6.6667	.6667
32	19	20	15	6.0000	0	6.6667	.6667	6.0000	.6667
33	23	26	24	6.6667	0	7.3333	0	7.3333	.6667
34	23	24	20	6.6667	0	7.3333	.6667	6.6667	.6667
35	26	28	27	7.3333	0	8.0000	0	8.0000	.6667
36	26	27	24	7.3333	0	8.0000	.6667	7.3333	.6667

NUMBER OF ELEMENTS = NE = 36

NUMBER OF NODES = NP = 28

BANDWIDTH = NBW = 6

BOUNDARY VALUES

NODAL FORCES

20	-.58333E+04	28	-.11667E+05	36	-.11667E+05	44	-.58333E+04

PRESCRIBED NODAL VALUES

1	0	2	0	3	0	4	0	9	0	10	0
17	0	18	0								

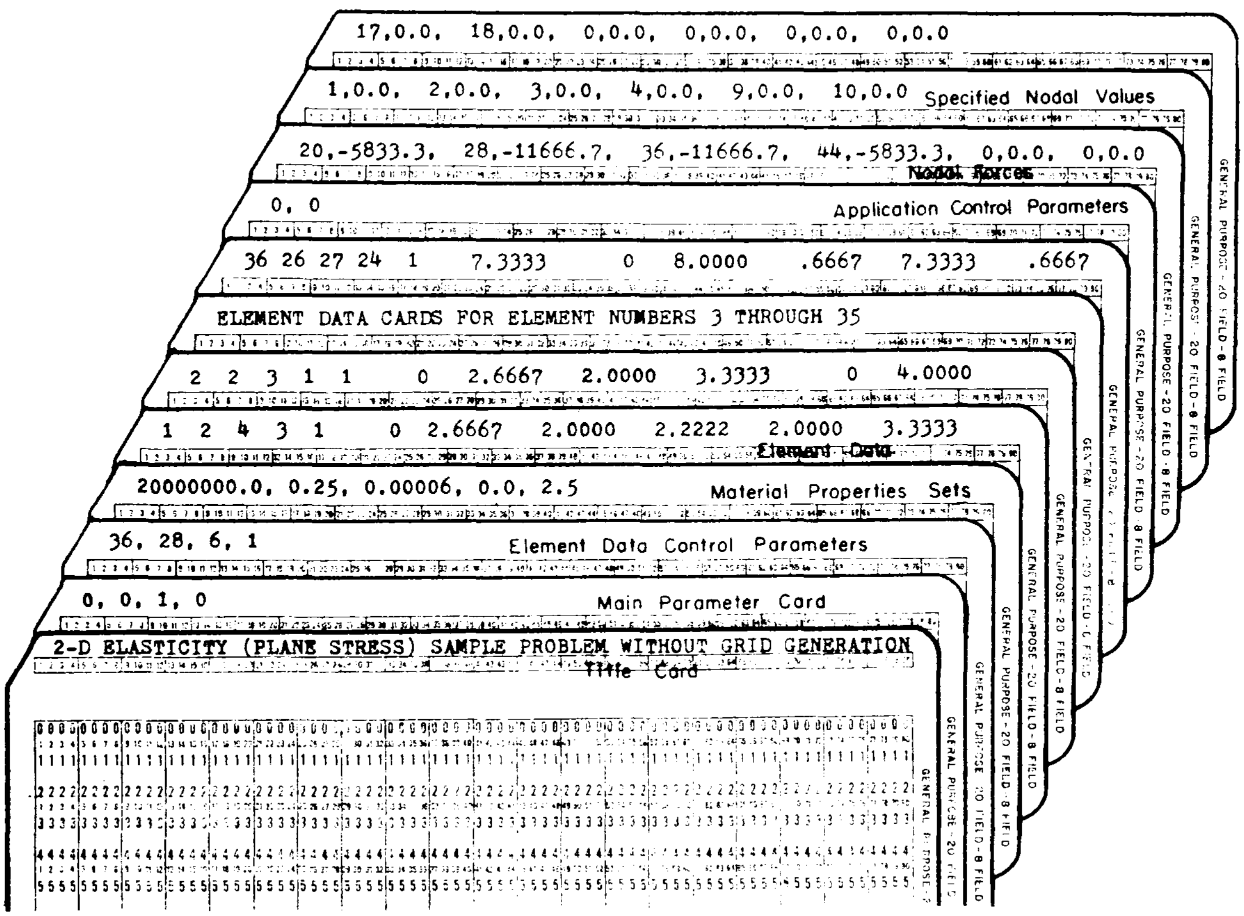
NODAL VALUES

1	0	2	0	3	0	4	0	5	.19287E-02	6	-.22636E-02
7	.67833E-03	8	-.21403E-02	9	0	10	0	11	.29784E-02	12	-.75620E-02
13	.45845E-03	14	-.75529E-02	15	-.88486E-03	16	-.21883E-02	17	0	18	0
19	.22085E-02	20	-.16345E-01	21	-.71078E-03	22	-.16278E-01	23	-.21960E-02	24	-.76640E-02
25	-.27681E-02	26	-.24751E-02	27	.25978E-02	28	-.20011E-01	29	-.35855E-02	30	-.16320E-01
31	-.61771E-03	32	-.19840E-01	33	-.50472E-02	34	-.78803E-02	35	.27642E-02	36	-.23543E-01
37	-.65080E-02	38	-.16445E-01	39	-.36910E-02	40	-.19778E-01	41	-.53880E-03	42	-.23352E-01
43	.28298E-02	44	-.26920E-01	45	-.68493E-02	46	-.19819E-01	47	-.37280E-02	48	-.23256E-01
49	-.48820E-03	50	-.26717E-01	51	-.69783E-02	52	-.23250E-01	53	-.37235E-02	54	-.26609E-01
55	-.69979E-02	56	-.26589E-01								

ELEMENT STRAINS AND STRESSES

ELEMENT	EXX	EYY	GXY	SXX	SYY	TXY	S1	S2	TMAX	ANGLE (DEGREES)
1	.5892E-03	-.1110E-03	.3054E-04	.1198E+05	.7750E+03	.2443E+03	.1198E+05	.7697E+03	.5607E+04	.1249E+01
2	.9644E-03	0	-.1132E-02	.2057E+05	.5143E+04	-.9055E+04	.2475E+05	.9626E+03	.1190E+05	-.2478E+02
3	.5201E-03	-.1019E-04	.1264E-03	.1104E+05	.2556E+04	.1011E+04	.1116E+05	.2437E+04	.4361E+04	.6704E+01
4	.9000E-03	-.1110E-03	-.1561E-02	.1861E+05	.2432E+04	-.1249E+05	.2540E+05	-.4357E+04	.1488E+05	-.2853E+02
5	.3885E-03	-.1009E-03	-.6098E-05	.7749E+04	-.8147E+02	-.4878E+02	.7749E+04	-.8178E+02	.3916E+04	-.3569E+00
6	.5600E-03	-.1019E-04	-.1560E-02	.1189E+05	.2769E+04	-.1248E+05	.2062E+05	-.5957E+04	.1329E+05	-.3496E+02
7	-.2861E-03	.4321E-04	.3175E-03	-.5873E+04	-.6041E+03	.2540E+04	.4209E+03	-.6898E+04	.3660E+04	.6802E+02
8	.3392E-03	0	-.1070E-02	.7235E+04	.1809E+04	-.8561E+04	.1350E+05	-.4459E+04	.8981E+04	-.3621E+02
9	-.3238E-03	.1250E-03	.2623E-03	-.6240E+04	.9392E+03	.2098E+04	.1507E+04	-.6809E+04	.4158E+04	.7485E+02
10	.2027E-03	.4321E-04	-.1290E-02	.4555E+04	.2003E+04	-.1032E+05	.1368E+05	-.7119E+04	.1040E+05	-.4148E+02
11	-.2156E-03	.6367E-04	-.9085E-05	-.4261E+04	.2083E+03	-.7268E+02	.2095E+03	-.4262E+04	.2236E+04	-.8907E+02
12	.7899E-04	.1250E-03	-.1349E-02	.2352E+04	.3087E+04	-.1079E+05	.1351E+05	-.8075E+04	.1079E+05	-.4598E+02
13	-.1384E-02	.2581E-03	.4573E-03	-.2815E+05	-.1876E+04	.3659E+04	-.1376E+04	-.2865E+05	.1364E+05	.8222E+02
14	-.4424E-03	0	-.1094E-02	-.9438E+04	-.2360E+04	-.8753E+04	.3543E+04	-.1534E+05	.9442E+04	-.5601E+02
15	-.1140E-02	.2433E-03	.5050E-03	-.2301E+05	-.8880E+03	.4040E+04	-.1732E+03	-.2373E+05	.1178E+05	.7997E+02
16	-.4672E-03	.2581E-03	-.1014E-02	-.8591E+04	.3014E+04	-.8114E+04	.7187E+04	-.1276E+05	.9976E+04	-.6278E+02
17	-.7304E-03	.1867E-03	.1014E-03	-.1459E+05	.8757E+02	.8115E+03	.1323E+03	-.1463E+05	.7382E+04	.8684E+02
18	-.3384E-03	.2433E-03	-.1094E-02	-.5921E+04	.3385E+04	-.8749E+04	.8641E+04	-.1118E+05	.9909E+04	-.5900E+02
19	.1396E-03	-.2559E-03	-.5203E-03	.1614E+04	-.4714E+04	-.4162E+04	.3678E+04	-.6778E+04	.5228E+04	-.2638E+02
20	.5840E-03	-.1009E-03	-.1120E-02	.1192E+05	.9612E+03	-.8957E+04	.1694E+05	-.4059E+04	.1050E+05	-.2927E+02
21	.1184E-03	-.2871E-03	-.3123E-03	.9938E+03	-.5494E+04	-.2498E+04	.1844E+04	-.6345E+04	.4095E+04	-.1880E+02
22	.2496E-03	-.2559E-03	-.4748E-03	.3959E+04	-.4128E+04	-.3798E+04	.5464E+04	-.5632E+04	.5548E+04	-.2160E+02
23	.7590E-04	-.3052E-03	-.7101E-04	-.8770E+01	-.6107E+04	-.5681E+03	.4370E+02	-.6159E+04	.3102E+04	-.5277E+01
24	.9841E-04	-.2871E-03	-.1116E-03	.5681E+03	-.5601E+04	-.8930E+03	.6948E+03	-.5727E+04	.3211E+04	-.8074E+01
25	-.1583E-03	-.9297E-04	-.5769E-03	-.3874E+04	-.2828E+04	-.4615E+04	.1294E+04	-.7995E+04	.4644E+04	-.4823E+02
26	.1396E-03	.6367E-04	-.1031E-02	.3318E+04	.2103E+04	-.8252E+04	.1098E+05	-.5563E+04	.8274E+04	-.4289E+02
27	-.5539E-04	-.1438E-03	-.4322E-03	-.1948E+04	-.3362E+04	-.3457E+04	.8735E+03	-.6184E+04	.3529E+04	-.3922E+02
28	.1184E-03	-.9297E-04	-.6567E-03	.2029E+04	-.1352E+04	-.5254E+04	.5858E+04	-.5180E+04	.5519E+04	-.3608E+02
29	.6641E-05	-.1622E-03	-.1765E-03	-.7235E+03	-.3425E+04	-.1412E+04	-.1205E+03	-.4028E+04	.1954E+04	-.2313E+02
30	.7590E-04	-.1438E-03	-.2642E-03	.8524E+03	-.2662E+04	-.2114E+04	.1844E+04	-.3653E+04	.2749E+04	-.2513E+02
31	-.5119E-03	.6093E-04	-.3237E-03	-.1060E+05	-.1430E+04	-.2590E+04	-.7493E+03	-.1128E+05	.5264E+04	-.7526E+02
32	-.1583E-03	.1867E-03	-.8031E-03	-.2382E+04	.3139E+04	-.6425E+04	.7371E+04	-.6614E+04	.6993E+04	-.5662E+02
33	-.1936E-03	-.9025E-05	-.2705E-03	-.4177E+04	-.1225E+04	-.2164E+04	-.8172E+02	-.5320E+04	.2619E+04	-.6215E+02
34	-.5539E-04	.6093E-04	-.4786E-03	-.8568E+03	.1004E+04	-.3829E+04	.4014E+04	-.3866E+04	.3940E+04	-.5183E+02
35	-.2932E-04	-.2932E-04	-.9772E-04	-.7818E+03	-.7818E+03	-.7818E+03	.1408E-08	-.1564E+04	.7818E+03	.9000E+02
36	.6641E-05	-.9025E-05	-.1540E-03	.9355E+02	-.1571E+03	-.1232E+04	.1206E+04	-.1270E+04	.1238E+04	-.4210E+02

Fig. 3.1.6 Input for Elasticity Example Without Grid Generation



3.2 TWO-DIMENSIONAL HEAT TRANSFER

3.2.1 Introduction

This program calculates the temperature distribution in two-dimensional bodies subjected to either prescribed boundary temperatures or surface convections. The body may have internal heat sources or sinks. The program uses only simple linear triangular elements. Automatic grid generation can be used with this program.

3.2.2 Material Properties Description

The material property sets for this program include, in the following order,

KXX - Thermal conductivity in the X-direction
KYY - Thermal conductivity in the Y-direction
H - Surface convection coefficient
TINF - Fluid temperature at a distance from the convection surfaces
1 Dummy Variable - = 0.0.

Any compatible set of units may be used. Up to twenty sets of material properties may be input.

3.2.3 Convection Data

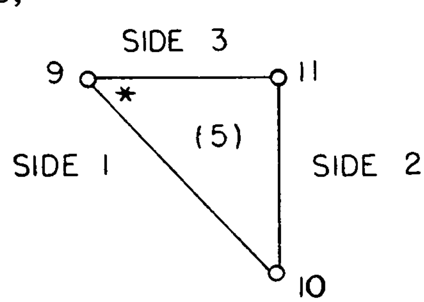
Data establishing sides of elements that are surfaces with convection may be input. The element number and the number of the side or sides having convection must be input for each element which has surface convection. Sides are numbered 1, 2, and 3, counterclockwise from the first input node for the element.

A maximum of two sides may have convection, therefore, the data is input as:

element no., 1^{st} side for convection, 2^{nd} side for convection

If only one side has convection, a zero value is entered in the second side for convection location.

Assuming that element 5 shown below has surface convection on side 2 and side 3,



*designates first input node

the convection data appears as

```
5, 2, 3
```

This data set must be terminated with a card with element number and side numbers equal to zero, i.e.,

```
0, 0, 0
```

IF NO CONVECTION OCCURS for the problem, a card with zero values,

`0, 0, 0` must be input for the convection data.

Convection data must be ordered by element numbers.

3.2.4 Boundary Values

Boundary conditions are input in two sections. First, the nodal forces which in this case would be line heat sources of sinks (heated added considered positive). Second, specified nodal values which would be known nodal temperatures.

Nodal forces and nodal values are both input in sets of node number and associate value with six sets per card.[1] If a complete card is not needed, the remaining sets should be specified with zero values. If an even multiple of 6 sets occurs or no values are to be input, a card with 6 sets of zero values (12 zeros) must follow to terminate that section of input data.

Consider the following example if the temperature at node 5, 7, 9, 12, and 14 were all known to be 80.0 degrees, the specified nodal values would read

```
5, 80.0, 7, 80.0, 9, 80.0, 12, 80.0, 14, 80.0, 0, 0.0
```

3.2.5 Input Description

Table 3.2.1 shows the inputs required for the two possible cases using 2-D Heat Transfer. The first case, auto-grid case, assumes use of the automatic grid generation program. The second case, non-auto-grid case, assumes the user will input the element data from cards. The element data must be ordered by element number for this program.

1/ A preliminary run of the auto-grid generation may be necessary to determine nodes for boundary conditions.

Table 3.2.1 Program Input for 2-D Heat Transfer

(common)

Title Card - up to 80 alpha-numeric characters for identification of problem

or

Auto-grid case:

Main Parameter Card - See Section 1.4 for this case
- NGRID = 1
- NPLTG = 0 or 1
- NAPPL = 2
- NPLTR = 0 or 1

Grid Generation Data - includes material properties sets - see Section 3.2.2

Non-auto-grid case:

Main Parameter Card - See Section 1.4 for this case
- NGRID = 0
- NPLTG = 0 or 1
- NAPPL = 2
- NPLTR = 0 or 1

Control Parameters for Element Data - by order of input
- NE - number of elements
- NP - number of nodes
- NBW - bandwidth
- NMPSET - number of material properties sets

Material Properties Sets - NMPSET sets, see Section 3.2.2 for description

Element Data - for each element, by order of input, see Section 1.6.
- NEL - element number
- ND - node numbers counterclockwise from first node
- MPSEL - material properties set number for the element
- X1,Y1,X2,Y2,X3,Y3 - X and Y coordinates counterclockwise from first node

Convection Data - element no., sides for convection. Terminate with element no. = 0. See Section 3.2.3.

Nodal Forces - values for a source of sink by node - read in sets of (node number, value) with 6 sets per card. Terminate with node no. = 0 and value = 0.0 for remainder of card. See Section 3.2.4.

Specified Nodal Values - values for known temperatures by node - read in sets of (node number, value) with 6 sets per card. Terminate with node no. = 0 and value = 0.0 for remainder of card. See Section 3.2.4.

3.2.6 Sample Problem

The body shown in Figure 3.2.1 has three sides exposed to air for convection and the curved surface at a constant temperature of 200^o. Due to symmetry only half of the body will be subdivided for study. Figure 3.2.2 shows the region for automatic grid generation. Figure 3.2.3 shows the input using automatic grid generation for the problem. Figure 3.2.4 shows the grid generated for the problem. Figure 3.2.5 shows the output of the problem.

Figure 3.2.6 shows the input for the same grid as shown in Figure 3.2.4 but not using automatic grid generation.

Fig. 3.2.1 Sample Problem for Heat Transfer

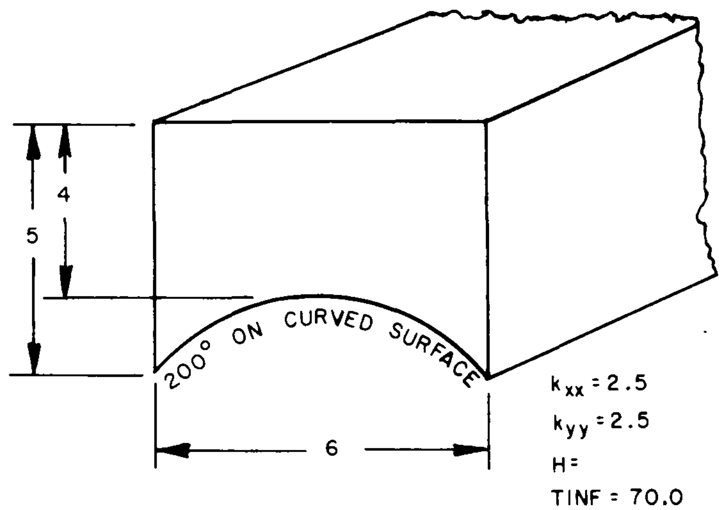


Fig. 3.2.2 Region for Automatic Grid Generation

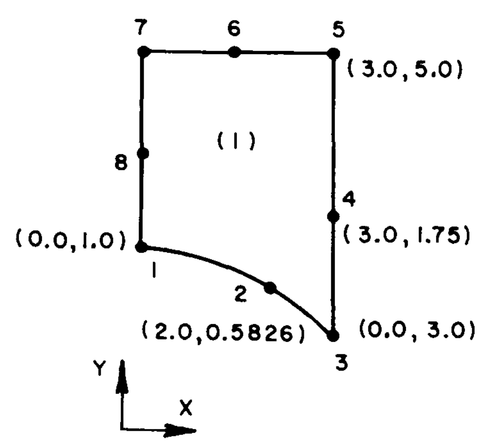
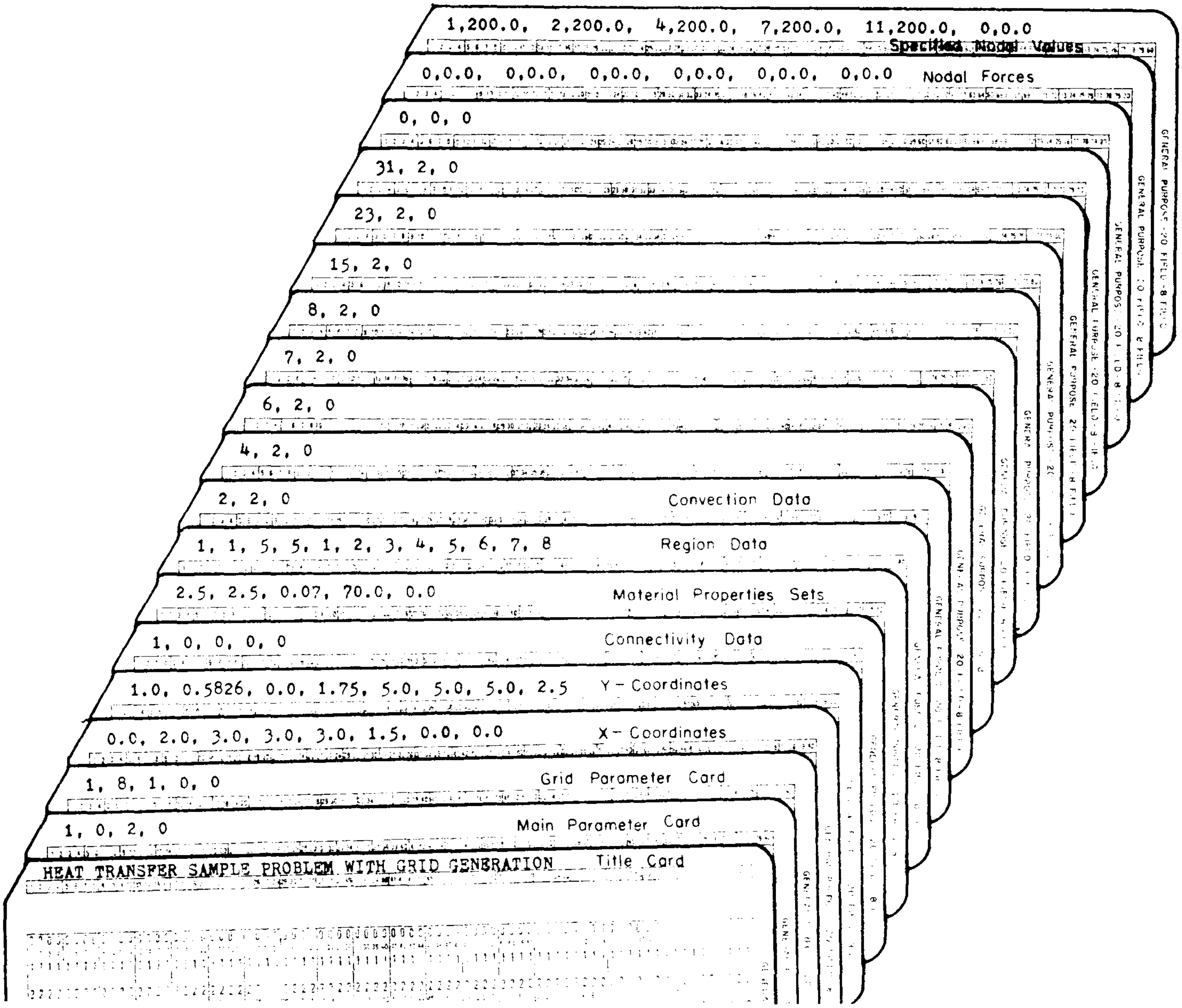


Fig. 3.2.3 Input for Heat Transfer Example with Grid Generation



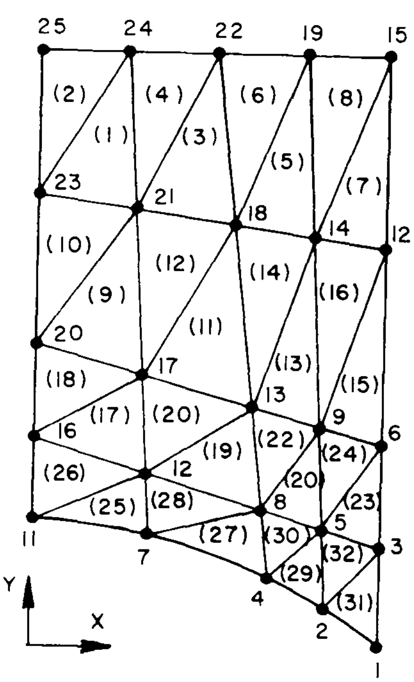


Fig. 3.2.4 Grid Generated for Heat Transfer Example

Fig. 3.2.5 Output for Heat Transfer Example with Grid Generation

HEAT TRANSFER SAMPLE PROBLEM WITH GRID GENERATION

APPLICATION PROGRAM HEAT TRANSFER WILL BE SOLVED

GLOBAL COORDINATES

NUMBER	X COORD	Y COORD
1	0	1.00
2	2.00	.58
3	3.00	0
4	3.00	1.75
5	3.00	5.00
6	1.50	5.00
7	0	5.00
8	0	2.50

CONNECTIVITY DATA

REGION	SIDE 1	2	3	4
1	0	0	0	0

MATERIAL PROPERTIES

SET	MAT PROP 1	MAT PROP 2	MAT PROP 3	MAT PROP 4	MAT PROP 5
	KXX	KYY	H	TINF	N/A
1	.2500E+01	.2500E+01	.7000E-01	.7000E+02	0

REGION DATA

REGION	ROWS	COLS	MATERIAL SET	INPUT REGION NODE NO.							
1	5	5	1	1	2	3	4	5	6	7	8

NODE NUMBERS
OF SUBDIVIDED REGION

1

25	24	22	19	15
23	21	18	14	10
20	17	13	9	6
16	12	8	5	3
11	7	4	2	1

ELEMENT DATA, REGION 1 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
1	23	21	24	0	3.6250	.8438	3.5311	.7500	5.0000
2	23	24	25	0	3.6250	.7500	5.0000	0	5.0000
3	21	18	22	.8438	3.5311	1.6250	3.4269	1.5000	5.0000
4	21	22	24	.8438	3.5311	1.5000	5.0000	.7500	5.0000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

5	18	14	19	1.6250	3.4269	2.3438	3.3124	2.2500	5.0000
6	18	19	22	1.6250	3.4269	2.2500	5.0000	1.5000	5.0000
7	14	10	15	2.3438	3.3124	3.0000	3.1875	3.0000	5.0000
8	14	15	19	2.3438	3.3124	3.0000	5.0000	2.2500	5.0000
9	20	17	21	0	2.5000	.9375	2.3435	.8438	3.5311
10	20	21	23	0	2.5000	.8438	3.5311	0	3.6250
11	17	13	18	.9375	2.3435	1.7500	2.1663	1.6250	3.4269
12	17	18	21	.9375	2.3435	1.6250	3.4269	.8438	3.5311
13	13	9	14	1.7500	2.1663	2.4375	1.9685	2.3438	3.3124
14	13	14	18	1.7500	2.1663	2.3438	3.3124	1.6250	3.4269
15	9	6	10	2.4375	1.9685	3.0000	1.7500	3.0000	3.1875
16	9	10	14	2.4375	1.9685	3.0000	3.1875	2.3438	3.3124
17	16	12	17	0	1.6250	1.0313	1.4371	.9375	2.3435
18	16	17	20	0	1.6250	.9375	2.3435	0	2.5000
19	12	8	13	1.0313	1.4371	1.8750	1.2182	1.7500	2.1663
20	12	13	17	1.0313	1.4371	1.7500	2.1663	.9375	2.3435
21	8	5	9	1.8750	1.2182	2.5313	.9683	2.4375	1.9685
22	8	9	13	1.8750	1.2182	2.4375	1.9685	1.7500	2.1663
23	5	3	6	2.5313	.9683	3.0000	.6875	3.0000	1.7500
24	5	6	9	2.5313	.9683	3.0000	1.7500	2.4375	1.9685
25	11	7	12	0	1.0000	1.1250	.8119	1.0313	1.4371
26	11	12	16	0	1.0000	1.0313	1.4371	0	1.6250
27	7	4	8	1.1250	.8119	2.0000	.5826	1.8750	1.2182
28	7	8	12	1.1250	.8119	1.9750	1.2182	1.0313	1.4371
29	4	2	5	2.0000	.5826	2.6250	.3119	2.5313	.9683
30	4	5	8	2.0000	.5826	2.5313	.9683	1.8750	1.2182
31	2	1	3	2.6250	.3119	3.0000	0	3.0000	.6875
32	2	3	5	2.6250	.3119	3.0000	.6875	2.5313	.9683

NUMBER OF ELEMENTS = NE = 32

NUMBER OF NODES = NP = 25

BANDWIDTH = NBW = 6

CONVECTION FROM SIDE 2 OF ELEMENT 2
CONVECTION FROM SIDE 2 OF ELEMENT 4
CONVECTION FROM SIDE 2 OF ELEMENT 6
CONVECTION FROM SIDE 2 OF ELEMENT 7
CONVECTION FROM SIDE 2 OF ELEMENT 8
CONVECTION FROM SIDE 2 OF ELEMENT 15
CONVECTION FROM SIDE 2 OF ELEMENT 23
CONVECTION FROM SIDE 2 OF ELEMENT 31

BOUNDARY VALUES

NODAL FORCES

PRESCRIBED NODAL VALUES

1	.20000E+03	2	.20000E+03	4	.20000E+03	7	.20000E+03	11	.20000E+03

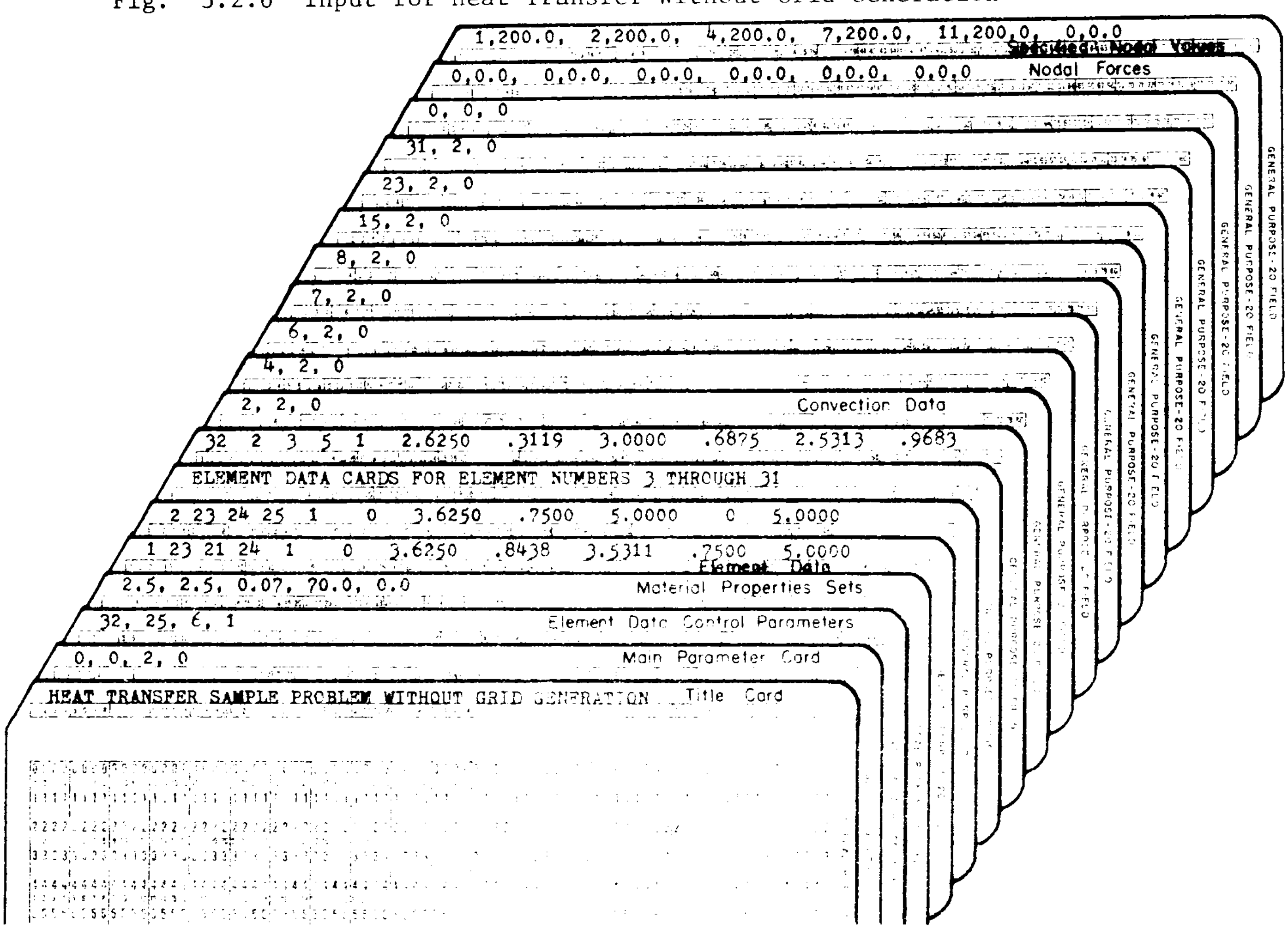
NODAL VALUES

1	.20000E+03	2	.20000E+03	3	.19597E+03	4	.20000E+03	5	.19561E+03	6	.18900E+03
7	.20000E+03	8	.19568E+03	9	.18943E+03	10	.19127E+03	11	.20000E+03	12	.19575E+03
13	.18991E+03	14	.18254E+03	15	.17438E+03	16	.19534E+03	17	.19016E+03	18	.18354E+03
19	.17635E+03	20	.18982E+03	21	.18411E+03	22	.17777E+03	23	.18408E+03	24	.17862E+03
25	.17892E+03										

ELEMENT RESULTANTS

ELEMENT	GRAD(X)	GRAD(Y)	AVE TEMP
1	-.39042E+00	-.37570E+01	.18227E+03
2	-.38803E+00	-.37583E+01	.18054E+03
3	-.12292E+01	-.37666E+01	.19180E+03
4	-.11430E+01	-.38050E+01	.19017E+03
5	-.19859E+01	-.37803E+01	.18081E+03
6	-.18886E+01	-.38190E+01	.17922E+03
7	-.26626E+01	-.38023E+01	.17940E+03
8	-.26275E+01	-.38159E+01	.17776E+03
9	-.49315E+00	-.51352E+01	.18803E+03
10	-.53955E+00	-.50972E+01	.18600E+03
11	-.14407E+01	-.51962E+01	.18787E+03
12	-.14215E+01	-.52085E+01	.18593E+03
13	-.22182E+01	-.52769E+01	.18729E+03
14	-.22239E+01	-.52739E+01	.18533E+03
15	-.28468E+01	-.53771E+01	.18657E+03
16	-.29530E+01	-.53281E+01	.18441E+03
17	-.73732E+00	-.62446E+01	.19375E+03
18	-.68892E+00	-.63077E+01	.19177E+03
19	-.17205E+01	-.63140E+01	.19378E+03
20	-.16908E+01	-.63432E+01	.19194E+03
21	-.25514E+01	-.64206E+01	.19357E+03
22	-.25480E+01	-.64231E+01	.19167E+03
23	-.31668E+01	-.65557E+01	.19353E+03
24	-.32786E+01	-.64887E+01	.19135E+03
25	-.11657E+01	-.69735E+01	.19858E+03
26	-.95899E+00	-.74611E+01	.19703E+03
27	-.18782E+01	-.71656E+01	.19856E+03
28	-.19209E+01	-.70867E+01	.19714E+03
29	-.30870E+01	-.71287E+01	.19854E+03
30	-.29125E+01	-.73690E+01	.19710E+03
31	-.48801E+01	-.58664E+01	.19866E+03
32	-.35497E+01	-.71948E+01	.19719E+03

Fig. 3.2.6 Input for Heat Transfer Without Grid Generation



3.3 GROUNDWATER FLOW

3.3.1 Introduction

This program can be used to analyze two-dimensional irrotational flow of ideal fluids which includes groundwater flow. The program description will be given in terms of the groundwater flow case. The program uses only simple linear triangular elements. Automatic grid generation can be used with this program.

3.3.2 Material Properties Description

The material property sets for this program include, in the following order,

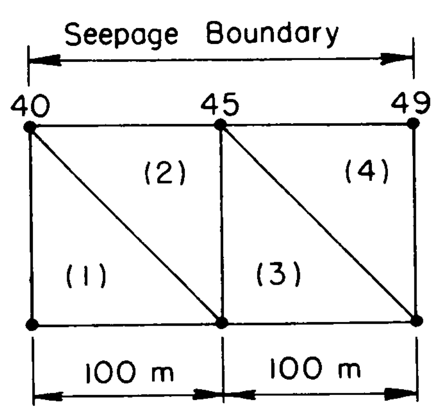
TXX - transmixxivity in the X direction
TYY - transmissivity in the Y direction

Dummy Variable 1 - = 0.0
Dummy Variable 2 - = 0.0
Dummy Variable 3 - = 0.0

Any compatible set of units may be used.
Up to twenty sets of material properties may be input.

3.3.3 Seepage Input

Values for seepage into or out of the region under study are input as nodal forces on the boundary nodes. The seepage along the side of the element is calculated and then 1/2 allotted to each node. Seepage into the region is considered positive. Consider the example below:



Assume infiltration rate = 0.30 m^3/day/m into region.

Seepage for each element = 0.30 m^3/day/m*100m

= 30 m^3/day

Seepage by node =	40	15 m^3/day
	45	30 m^3/day
	49	15 m^3/day

The seepage values would be input as nodal forces at nodes 40, 45, and 49.

3.3.4 Boundary Values

Boundary conditions are input in two sections. First, the nodal forces which for the groundwater case would be nodal values for seepage and pumping (fluid added to region assumed positive). Second, specified nodal values, which would be known nodal potentials.

Nodal forces and nodal values are both input by node number and associated value with six sets per card.[1/] Each card must have 6 sets of node number and associated value. If a complete card is not needed, the remaining sets should be specified with zero values. If an even multiple of 6 sets occurs or no values are to be input, a card with 6 sets of zero values (12 zeros) must follow to terminate that section of input data. Nodal forces for the example shown in the previous section would appear as

```
40,  15.0,   45,  30.0,   49,   15.0   0,0.0,  0,0.0,  0,0.0
```

Consider the case where nodes 12, 15, 19, and 21 are known to have potential values of 100.0, 115.0, 115.0, and 114.0, respectively.
The specified nodal values would appear as

```
12,  100.0,  15,  115.0,  19,  115.0,  21,  114.0   0,   0.0,   0,   0.0
```

3.3.5 Input Description

Table 3.3.1 shows the inputs required for the two possible cases using this program. The first case, auto-grid case, assumes use of the automatic grid generation program. The second case, non-auto-grid case, assumes the user will input the element data from cards.

3.3.6 Sample Problem

Figure 3.3.1 shows a region for study. Water infiltrates into the region from a stream on two sides. Heads are known at a number of locations on the boundary of the region. Linear interpolation will be used to obtain nodal values on the sections of the boundary with given potentials. Figure 3.3.2 shows the region divided for automatic grid generation. Figure 3.3.3 shows the input using automatic grid generation. Figure 3.3.4 shows the grid generated. Figure 3.3.5 shows the output of the program.

Figure 3.3.6 shows the input for the same grid as shown in Figure 3.3.4 but not using automatic grid generation. Figure 3.3.7 shows the output of the program.

[1/] A preliminary run of auto-grid generation may be necessary to determine nodes for boundary conditions.

Table 3.3.1 Program Input for Groundwater

(common)

Title Card - up to 80 alpha-numeric characters for identification of problem

or

Auto-grid case:

Main Parameter Card - see Section 1.4 for this case
NGRID = 1
NPLTG = 0 or 1
NAPPL = 3
NPLTR = 0 or 1

Grid Generation Data
includes material properties sets - See Section 3.3.2.

Non-auto-grid case

Main Parameter Card - see Section 1.4
for this case NGRID = 0
NPLTR = 0
NAPPL = 3
NPLTR = 0 or 1

Control Parameters for Element Data - by order of input.
NE - number of elements
NP - number of nodes
NBW - bandwidth
NMPSET - number of material properties sets

Material Properties Sets
- NMPSET sets, see Section 3.3.2 for description

Element Data - for each element, by order of input, see Section 1.6.
NEL- element number
ND - node numbers counterclockwise from first node
MPSEL - material properties set number for the element
X1,Y1,X2,Y2,X3,Y3 - X and Y coordinates counterclockwise from first node

Nodal Forces - values for pumping and seepage by node - read in sets of (node number, value) with 6 sets per card. Terminate with Node No. = 0, Value = 0.0 for remainder of card. See Section 3.3.4.

Specified Nodal Values - values for known potentials by node-read in sets of (node, number, values) with 6 sets per card. Terminate with Node No. = 0, Value = 0.0 for remainder of card. See Section 3.3.4.

Fig. 3.3.1 Sample Problem for Groundwater Flow

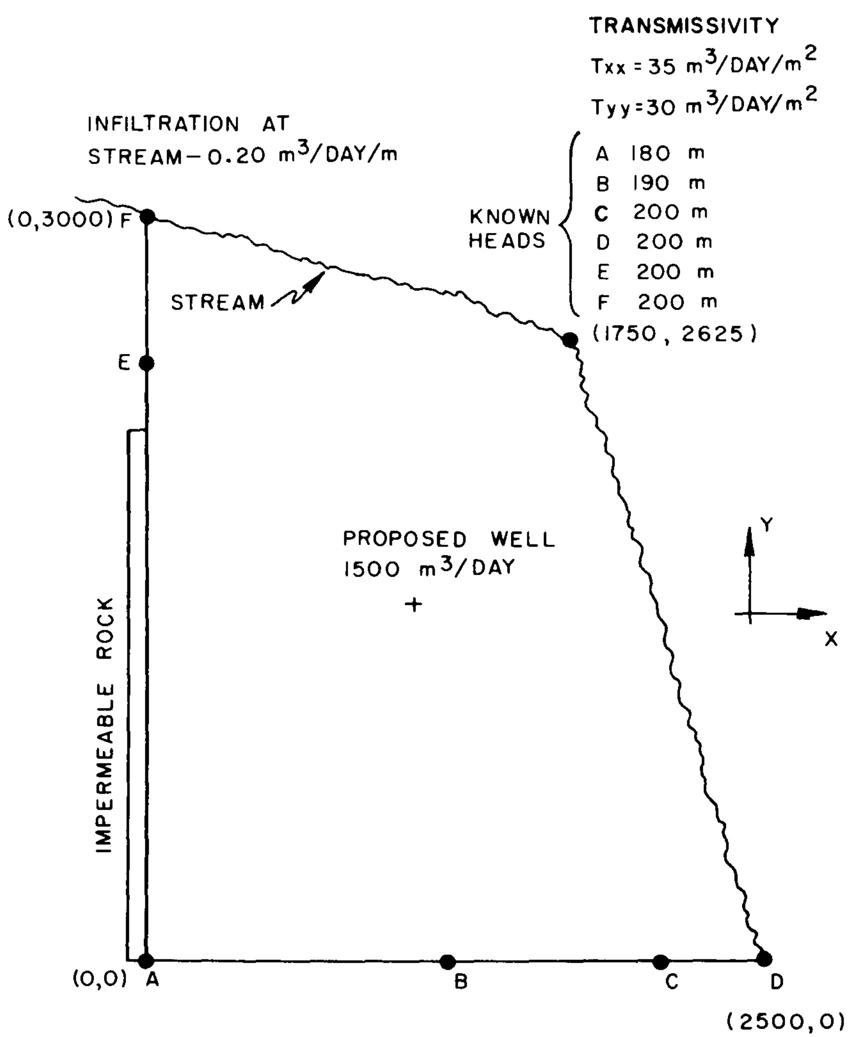


Fig. 3.3.2 Region for Grid Generation

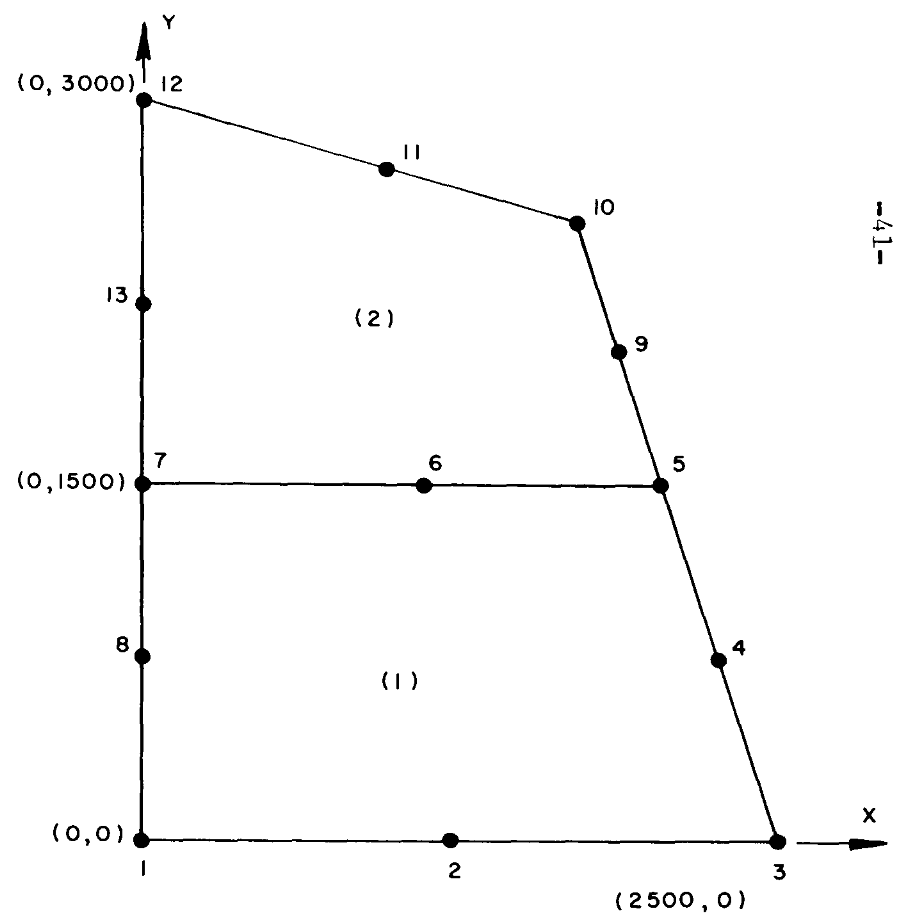


Fig. 3.3.3 Input for Groundwater Problem with Grid Generation

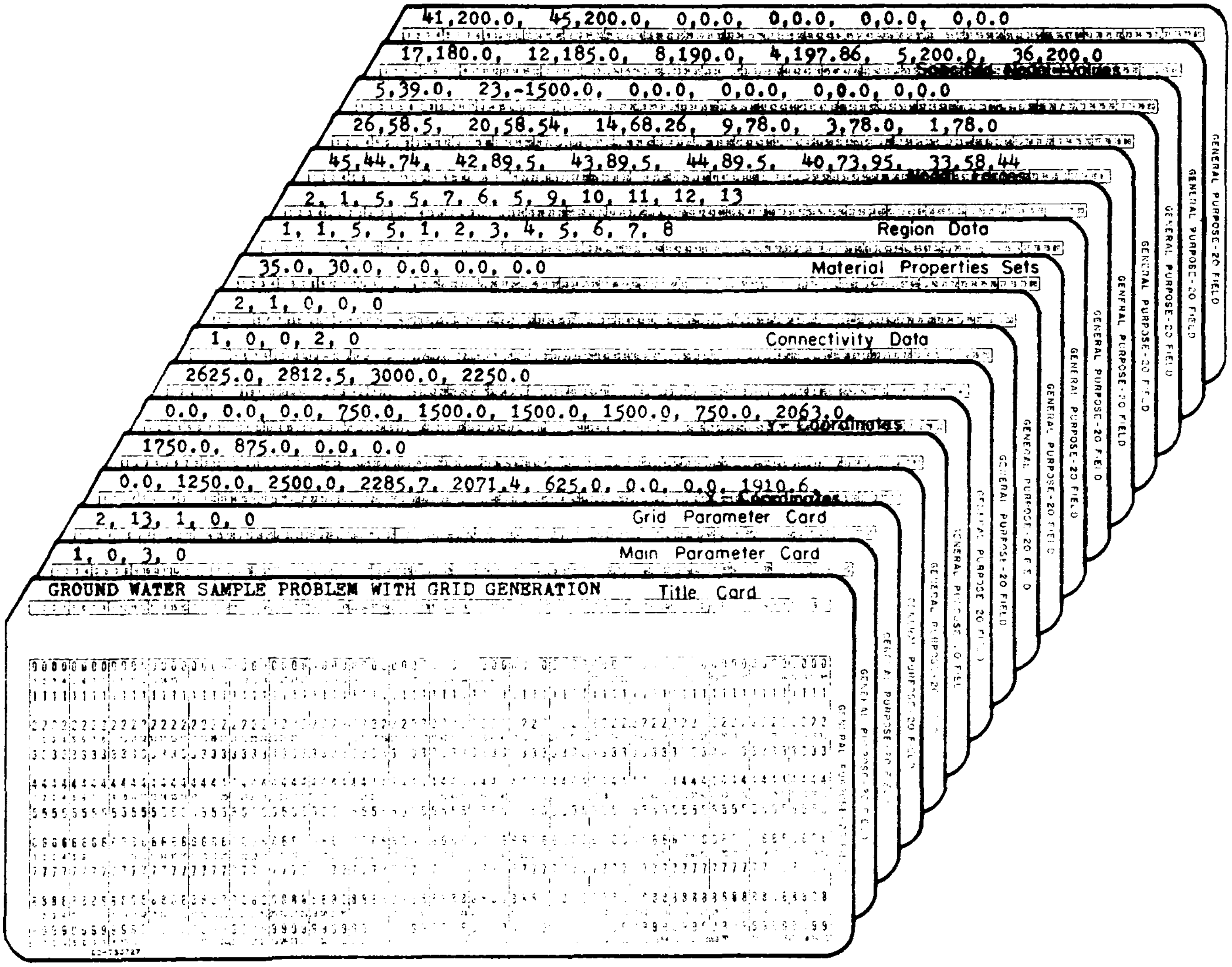


Fig. 3.3.4 Grid Generated Groundwater Example

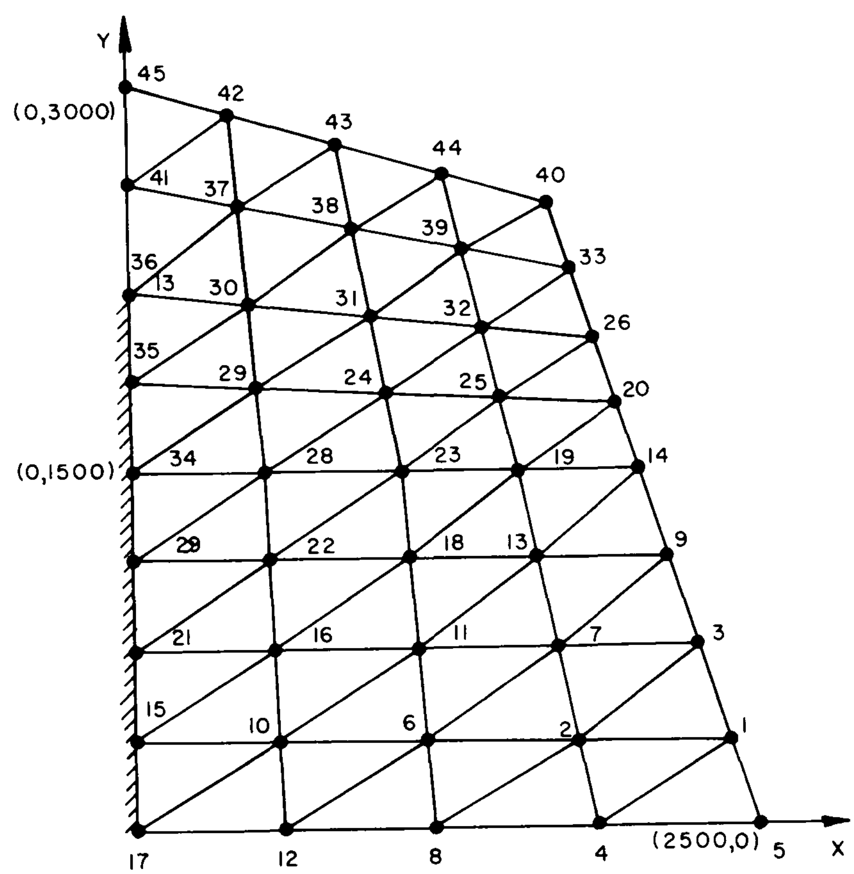


Fig. 3.3.5 Output for Groundwater Example

GROUND WATER SAMPLE PROBLEM WITH GRID GENERATION

THE GRID WILL BE AUTOMATICALLY GENERATED

APPLICATION PROGRAM GROUNDWATER FLOW WILL BE SOLVED

GLOBAL COORDINATES

NUMBER	X COORD	Y COORD
1	0	0
2	1250.00	0
3	2500.00	0
4	2285.70	750.00
5	2071.40	1500.00
6	625.00	1500.00
7	0	1500.00
8	0	750.00
9	1910.60	2063.00
10	1750.00	2625.00
11	875.00	2812.50
12	0	3000.00
13	0	2250.00

CONNECTIVITY DATA

	SIDE			
REGION	1	2	3	4
1	0	0	2	0
2	1	0	0	0

MATERIAL PROPERTIES

SET	MAT PROP 1	MAT PROP 2	MAT PROP 3	MAT PROP 4	MAT PROP 5
	TXX	TYY	N/A	N/A	N/A
1	.3500E+02	.3000E+02	0	0	0

REGION DATA

REGION	ROWS	COLS	MATERIAL SET	INPUT REGION NODE NO.							
1	5	5	1	1	2	3	4	5	6	7	8
2	5	5	1	7	6	5	9	10	11	12	13

NODE NUMBERS
OF SUBDIVIDED REGION

1

34	28	23	19	14
27	22	18	13	9
21	16	11	7	3
15	10	6	2	1
17	12	8	4	5

2

45	42	43	44	40
41	37	38	39	33
36	30	31	32	26
35	29	24	25	20
34	28	23	19	14

ELEMENT DATA, REGION 1 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
1	27	22	28	0	1125.0000	313.6188	1125.0000	209.8250	1500.0000
2	27	28	34	0	1125.0000	209.8250	1500.0000	0	1500.0000
3	22	18	23	313.6188	1125.0000	781.2500	1125.0000	625.0000	1500.0000
4	22	23	28	313.6188	1125.0000	625.0000	1500.0000	209.8250	1500.0000
5	18	13	19	781.2500	1125.0000	1402.8937	1125.0000	1245.5250	1500.0000
6	18	19	23	781.2500	1125.0000	1245.5250	1500.0000	625.0000	1500.0000
7	13	9	14	1402.8937	1125.0000	2178.5500	1125.0000	2071.4000	1500.0000
8	13	14	19	1402.8937	1125.0000	2071.4000	1500.0000	1245.5250	1500.0000
9	21	16	22	0	750.0000	417.4125	750.0000	313.6188	1125.0000
10	21	22	27	0	750.0000	313.6188	1125.0000	0	1125.0000
11	16	11	18	417.4125	750.0000	937.5000	750.0000	781.2500	1125.0000
12	16	18	22	417.4125	750.0000	781.2500	1125.0000	313.6188	1125.0000
13	11	7	13	937.5000	750.0000	1560.2625	750.0000	1402.8937	1125.0000
14	11	13	18	937.5000	750.0000	1402.8937	1125.0000	781.2500	1125.0000
15	7	3	9	1560.2625	750.0000	2285.7000	750.0000	2178.5500	1125.0000
16	7	9	13	1560.2625	750.0000	2178.5500	1125.0000	1402.8937	1125.0000
17	15	10	16	0	375.0000	521.2062	375.0000	417.4125	750.0000
18	15	16	21	0	375.0000	417.4125	750.0000	0	750.0000
19	10	6	11	521.2062	375.0000	1093.7500	375.0000	937.5000	750.0000
20	10	11	16	521.2062	375.0000	937.5000	750.0000	417.4125	750.0000
21	6	2	7	1093.7500	375.0000	1717.6312	375.0000	1560.2625	750.0000
22	6	7	11	1093.7500	375.0000	1560.2625	750.0000	937.5000	750.0000
23	2	1	3	1717.6312	375.0000	2392.8500	375.0000	2285.7000	750.0000
24	2	3	7	1717.6312	375.0000	2285.7000	750.0000	1560.2625	750.0000
25	17	12	10	0	0	625.0000	0	521.2062	375.0000
26	17	10	15	0	0	521.2062	375.0000	0	375.0000
27	12	8	6	625.0000	0	1250.0000	0	1093.7500	375.0000
28	12	6	10	625.0000	0	1093.7500	375.0000	521.2062	375.0000
29	8	4	2	1250.0000	0	1875.0000	0	1717.6312	375.0000
30	8	2	6	1250.0000	0	1717.6312	375.0000	1093.7500	375.0000
31	4	5	1	1875.0000	0	2500.0000	0	2392.8500	375.0000
32	4	1	2	1875.0000	0	2392.8500	375.0000	1717.6312	375.0000

ELEMENT DATA, REGION 2 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
33	41	37	42	0	2625.0000	380.5625	2554.7813	437.5000	2906.2500
34	41	42	45	0	2625.0000	437.5000	2906.2500	0	3000.0000
35	37	38	43	380.5625	2554.7813	812.4625	2484.5625	875.0000	2812.5000
36	37	43	42	380.5625	2554.7813	875.0000	2812.5000	437.5000	2906.2500
37	38	39	44	812.4625	2484.5625	1295.7000	2414.3438	1312.5000	2718.7500
38	38	44	43	812.4625	2484.5625	1312.5000	2718.7500	875.0000	2812.5000
39	39	33	40	1295.7000	2414.3438	1830.2750	2344.1250	1750.0000	2625.0000
40	39	40	44	1295.7000	2414.3438	1750.0000	2625.0000	1312.5000	2718.7500
41	36	30	37	0	2250.0000	323.6375	2203.2500	380.5625	2554.7813
42	36	37	41	0	2250.0000	380.5625	2554.7813	0	2625.0000
43	30	31	37	323.6375	2203.2500	749.9500	2156.5000	380.5625	2554.7813
44	31	38	37	749.9500	2156.5000	812.4625	2484.5625	380.5625	2554.7813
45	31	32	39	749.9500	2156.5000	1278.9375	2109.7500	1295.7000	2414.3438
46	31	39	38	749.9500	2156.5000	1295.7000	2414.3438	812.4625	2484.5625
47	32	26	33	1278.9375	2109.7500	1910.6000	2063.0000	1830.2750	2344.1250
48	32	33	39	1278.9375	2109.7500	1830.2750	2344.1250	1295.7000	2414.3438
49	35	29	30	0	1875.0000	266.7250	1851.6563	323.6375	2203.2500
50	35	30	36	0	1875.0000	323.6375	2203.2500	0	2250.0000
51	29	24	30	266.7250	1851.6563	687.4625	1828.3125	323.6375	2203.2500
52	24	31	30	687.4625	1828.3125	749.9500	2156.5000	323.6375	2203.2500
53	24	25	31	687.4625	1828.3125	1262.2125	1804.9688	749.9500	2156.5000
54	25	32	31	1262.2125	1804.9688	1278.9375	2109.7500	749.9500	2156.5000
55	25	20	26	1262.2125	1804.9688	1990.9750	1781.6250	1910.6000	2063.0000
56	25	26	32	1262.2125	1804.9688	1910.6000	2063.0000	1278.9375	2109.7500
57	34	28	35	0	1500.0000	209.8250	1500.0000	0	1875.0000
58	28	29	35	209.8250	1500.0000	266.7250	1851.6563	0	1875.0000
59	28	23	29	209.8250	1500.0000	625.0000	1500.0000	266.7250	1851.6563
60	23	24	29	625.0000	1500.0000	687.4625	1828.3125	266.7250	1851.6563
61	23	19	24	625.0000	1500.0000	1245.5250	1500.0000	687.4625	1828.3125
62	19	25	24	1245.5250	1500.0000	1262.2125	1804.9688	687.4625	1828.3125
63	19	14	20	1245.5250	1500.0000	2071.4000	1500.0000	1990.9750	1781.6250
64	19	20	25	1245.5250	1500.0000	1990.9750	1781.6250	1262.2125	1804.9688

NUMBER OF ELEMENTS = NE = 64

NUMBER OF NODES = NP = 45

BANDWIDTH = NBW = 9

BOUNDARY VALUES

NODAL FORCES

45	.44740E+02	42	.89500E+02	43	.89500E+02	44	.89500E+02	40	.73950E+02	33	.58440E+02
26	.58500E+02	20	.58540E+02	14	.68260E+02	9	.78000E+02	3	.78000E+02	1	.78000E+02
5	.39000E+02	23	-.15000E+04								

PRESCRIBED NODAL VALUES

17	.18000E+03	12	.18500E+03	8	.19000E+03	4	.19786E+03	5	.20000E+03	36	.20000E+03
41	.20000E+03	45	.20000E+03								

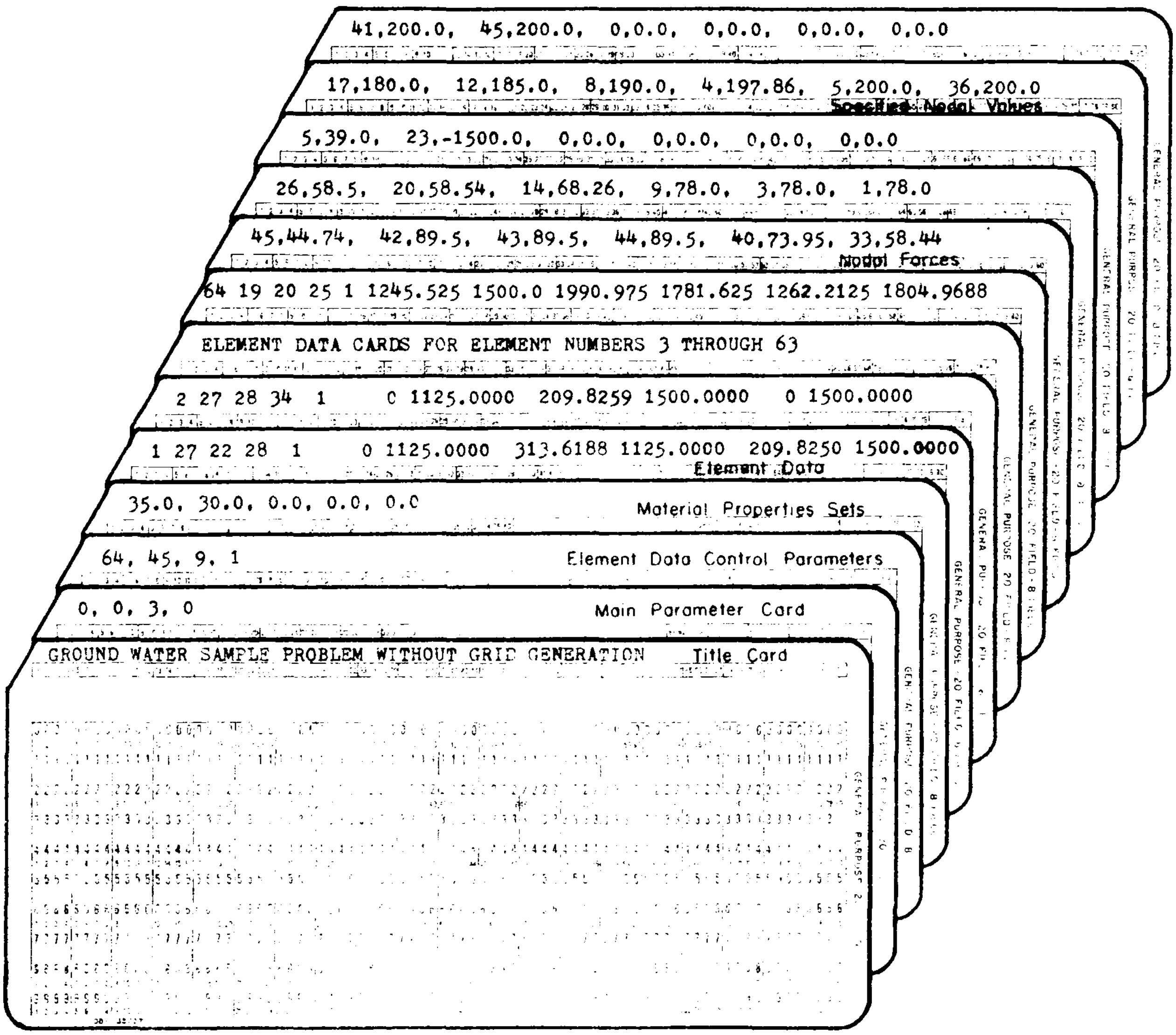
NODAL VALUES

1	.19860E+03	2	.19382E+03	3	.19654E+03	4	.19786E+03	5	.20000E+03	6	.18779E+03
7	.19086E+03	8	.19000E+03	9	.19485E+03	10	.18380E+03	11	.18488E+03	12	.18500E+03
13	.18831E+03	14	.19395E+03	15	.18179E+03	16	.18202E+03	17	.18000E+03	18	.18021E+03
19	.18643E+03	20	.19407E+03	21	.18134E+03	22	.17943E+03	23	.16957E+03	24	.18235E+03
25	.18875E+03	26	.19494E+03	27	.17985E+03	28	.17904E+03	29	.18538E+03	30	.19333E+03
31	.18989E+03	32	.19174E+03	33	.19629E+03	34	.17998E+03	35	.18713E+03	36	.20000E+03
37	.19685E+03	38	.19434E+03	39	.19454E+03	40	.19775E+03	41	.20000E+03	42	.19917E+03
43	.19716E+03	44	.19682E+03	45	.20000E+03						

ELEMENT VELOCITY COMPONENTS

ELEMENT	VEL(X)	VEL(Y)
1	.46946E-01	.42475E-01
2	.15711E+00	-.10358E-01
3	-.58564E-01	.83084E+00
4	.79857E+00	.22079E+00
5	-.45614E+00	-.13340E-01
6	-.95121E+00	.51203E+00
7	-.29485E+00	-.42912E-03
8	-.31874E+00	.36081E-01
9	-.56860E-01	.19381E+00
10	.46946E-01	.11940E+00
11	-.19203E+00	.30440E+00
12	-.58564E-01	.19340E+00
13	-.33629E+00	.82581E-01
14	-.45614E+00	.21007E+00
15	-.27416E+00	.68246E-01
16	-.29485E+00	.97486E-01
17	-.13464E+00	.10995E+00
18	-.56860E-01	.35734E-01
19	-.24404E+00	.14582E+00
20	-.19203E+00	.96334E-01
21	-.33838E+00	.11510E+00
22	-.33629E+00	.11288E+00
23	-.24764E+00	.10377E+00
24	-.27416E+00	.13820E+00
25	-.28000E+00	.29929E-01
26	-.13464E+00	-.14324E+00
27	-.28000E+00	.76988E-01
28	-.24404E+00	.38460E-01
29	-.44016E+00	.16493E+00
30	-.33838E+00	.56140E-01
31	-.11984E+00	.82916E-01
32	-.24764E+00	.23418E+00
33	.24017E+00	-.23125E+00
34	.66731E-01	0
35	.14941E+00	-.28199E+00
36	.10734E+00	-.21281E+00
37	-.51751E-01	-.22221E+00
38	-.35611E-01	-.25175E+00
39	-.14416E+00	-.19099E+00
40	-.12926E+00	-.21854E+00
41	.65583E+00	-.39159E+00
42	.28995E+00	0
43	.23932E+00	-.33378E+00
44	.12187E+00	-.42714E+00
45	-.14992E+00	-.26878E+00
46	-.80879E-01	-.39403E+00
47	-.19405E+00	-.19184E+00
48	-.15604E+00	-.26849E+00
49	.15756E+00	-.69939E+00
50	.54831E+00	-.10296E+01
51	.20703E+00	-.70625E+00
52	.18983E+00	-.72056E+00
53	-.41948E+00	-.62112E+00
54	-.15177E+00	-.28673E+00
55	-.26121E+00	-.15693E+00
56	-.20204E+00	-.28437E+00
57	.15711E+00	-.57193E+00
58	.17127E+00	-.56514E+00
59	.79857E+00	-.65214E+00
60	.17531E+00	-.11964E+01
61	-.95121E+00	-.10127E+01
62	-.39998E+00	-.20958E+00
63	-.31874E+00	-.90455E-01
64	-.26342E+00	-.21598E+00

Fig. 3.3.6 Input for Groundwater Example Without Grid Generation



3.4 TORSION OF NON-CIRCULAR SHAFT

3.4.1 Introduction

This program calculates the shear stresses in a non-circular shaft for a specified torque. The program is based on using a stress function, ϕ, which has a zero value on the surface of the body and for which

$$\frac{\partial\phi}{\partial y} = \tau_{zx} \text{ and } \frac{\partial\phi}{\partial x} = \tau_{xy}. \quad 1/$$

Therefore all nodal values on the surface of the body must be specified as zero. The program uses simple linear triangular elements only. Automatic grid generation can be used with the program.

3.4.2 Material Properties Description

The material Property sets for this program include, in the following order

G - the shear modulus (N/cm^2)
SL - the length of the shaft (cm)
TORQUE - the applied torque (N-cm)
PCT - twice the number of axes of symmetry. PCT is 1.0 when no symmetry exists
Dummy Variable 1 - = 0.0

Units shown are only sample units. Any compatible sets of units English or metric may be used. Up to 20 sets may be input.

3.4.3 Torque Input Card

The value of the torque applied to the shaft for which stresses are to be calculated is input in units compatible with those used for material properties. Torque value is input on a card. For example, if the torque value is 2.5 ft-lb, the torque input card appears as [215.0] .

3.4.4 Boundary Values

Boundary conditions are input in two sections. First, the nodal forces which for the torsion are nonexistent. Second, specified nodal values which would be specifying zero values for the stress function at the free surface nodal locations.

Nodal values are input by node numbers and associated value with six sets per card. 2/ Each card must have six sets of node number and value. If a complete card is not needed, the remaining set should be specified with zero values. If an even multiple of 6 sets occurs or no values are to be input, a card with 6 sets of zeros (12 zeros) must follow to terminate that section of data input.

For the torsion problem, one card with 6 sets of zero values (12 zeros) would be input for nodal forces.

1/ For more detailed discussion of this approach see Segerlind, Applied Finite Element Analysis, 1976, Wiley.

2/ A preliminary run of auto-grid generation may be necessary to determine nodes for boundary conditions.

If nodes 3, 5, 7, and 9 are the surface nodes, the specified nodal values would be input as

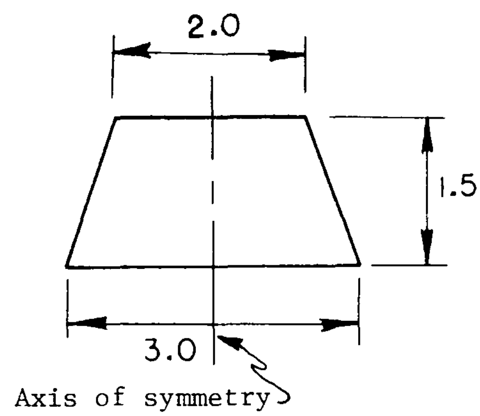
```
3,  0.0,  5,  0.0,  7,  0.0,  9,  0.0,  0,  0.0,  0,  0.0
```

3.4.5 Input Description

Table 3.4.1 shows the inputs required for the two possible cases using TORSION. The first case, auto-grid case, assumes the use of the automatic grid generation program. The second case, non-auto-grid case, assumes the user will input the element data from cards.

3.4.6 Sample problem

Consider the problem of torsion of a trapeqoidal shaft as shown below. Note the shaft has one axis of symmetry, therefore, it is only necessary to consider one-half of the body.



Material Properties

G = 8000000.
SL = 100.
TORQUE = 196.6
PCT = 2

Regions for grid input

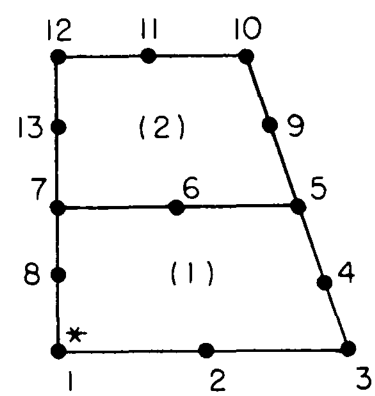


Figure 3.4.1 shows the input using grid generation for the sample problem. Figure 3.4.2 shows the grid generation by the program. Figure 3.4.3 shows the output of the program.

Figure 3.4.4 shows the input for the same grid as shown in Figure 3.4.2 but not using automatic grid generation.

Table 3.4.1 Program Input for Torsion

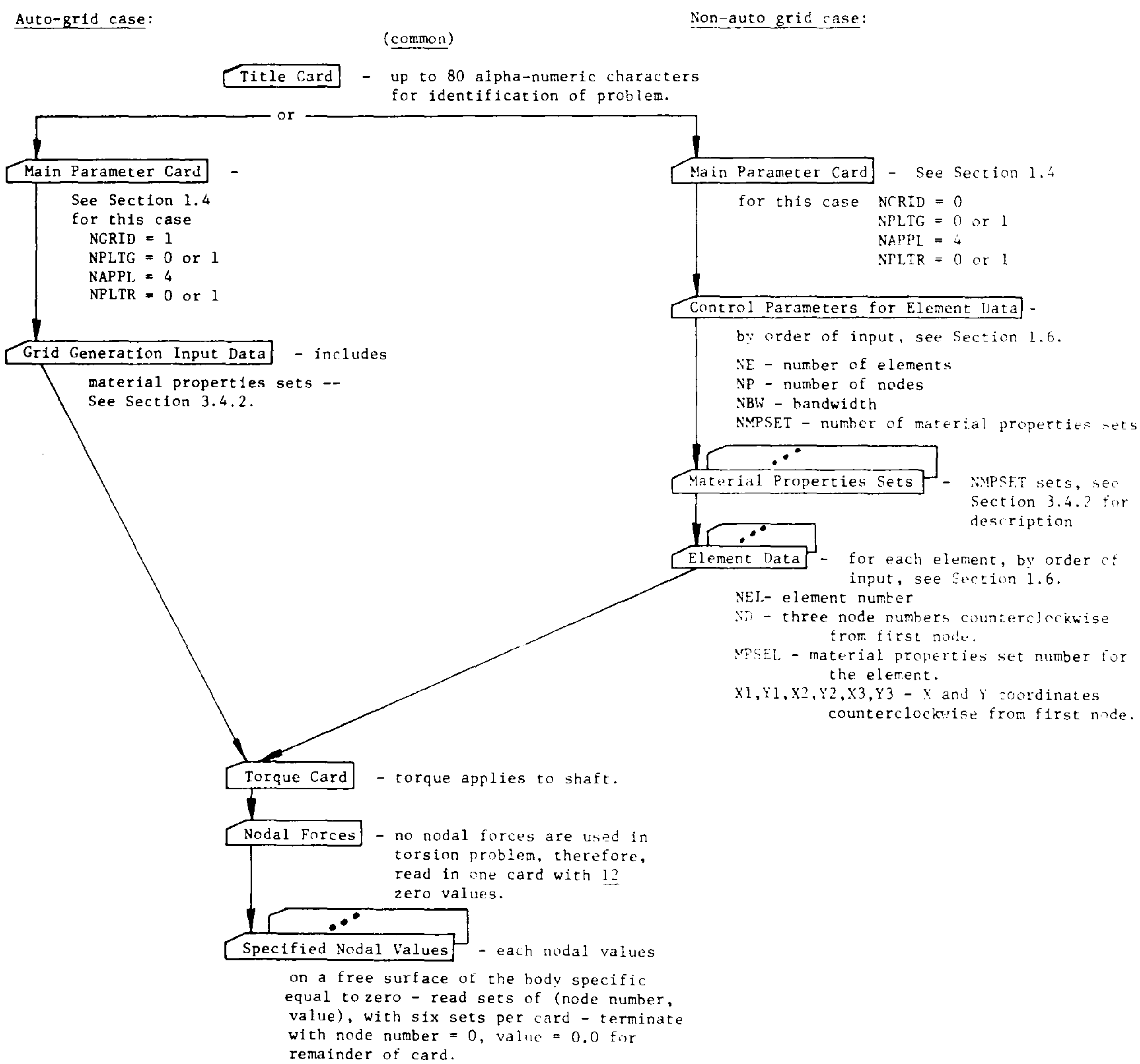


Fig. 3.4.1 Input for Torsion Problem with Grid Generation

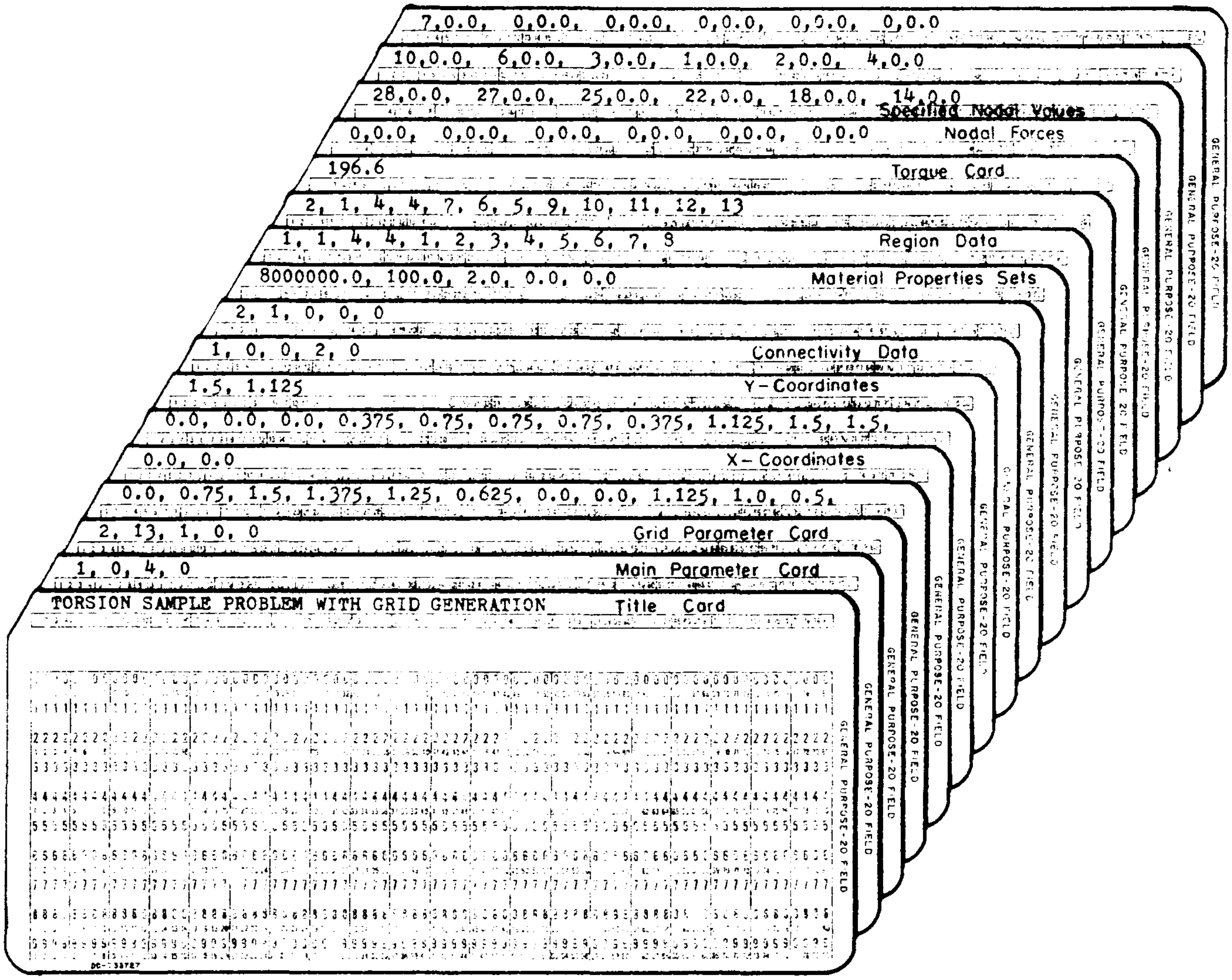


Fig. 3.4.2 Grid Generated for Torsion Example

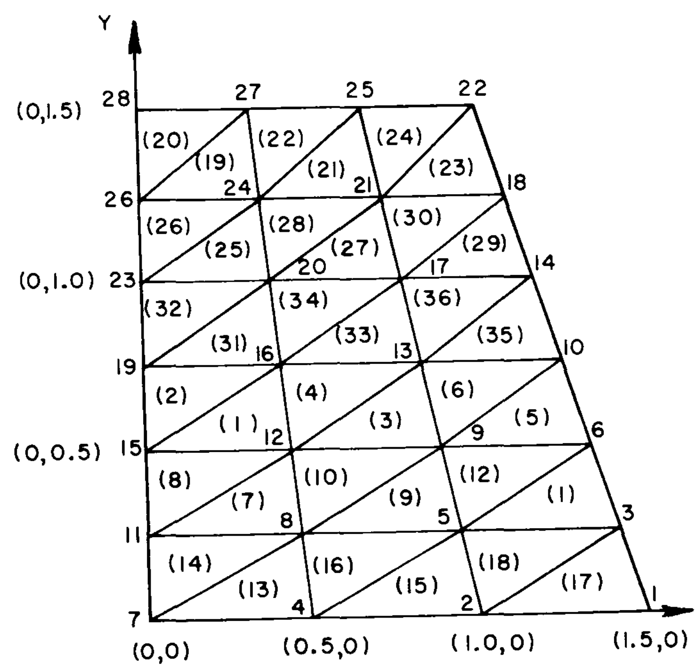


Fig. 3.4.3 Output for Torsion Example with Grid Generation

TORSION SAMPLE PROBLEM WITH GRID GENERATION

THE GRID WILL BE AUTOMATICALLY GENERATED

APPLICATION PROGRAM TORSION(1) WILL BE SOLVED

GLOBAL COORDINATES

NUMBER	X COORD	Y COORD
1	0	0
2	.75	0
3	1.50	0
4	1.38	.38
5	1.25	.75
6	.63	.75
7	0	.75
8	0	.38
9	1.13	1.13
10	1.00	1.50
11	.50	1.50
12	0	1.50
13	0	1.13

CONNECTIVITY DATA

	SIDE			
REGION	1	2	3	4
1	0	0	2	0
2	1	0	0	0

MATERIAL PROPERTIES

SET	MAT PROP 1	MAT PROP 2	MAT PROP 3	MAT PROP 4	MAT PROP 5
	G	SL	PCT	N/A	N/A
1	.8000E+07	.1000E+03	.2000E+01	0	0

REGION DATA

REGION	ROWS	COLS	MATERIAL SET	INPUT REGION NODE NO.							
1	4	4	1	1	2	3	4	5	6	7	8
2	4	4	1	7	6	5	9	10	11	12	13

NODE NUMBERS
OF SUBDIVIDED REGION

1

19	16	13	10
15	12	9	6
11	8	5	3
7	4	2	1

2

28	27	25	22
26	24	21	18
23	20	17	14
19	16	13	10

ELEMENT DATA, REGION 1 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
1	15	12	16	0	.5000	.4444	.5000	.4167	.7500
2	15	16	19	0	.5000	.4167	.7500	0	.7500
3	12	9	13	.4444	.5000	.8889	.5000	.8333	.7500
4	12	13	16	.4444	.5000	.8333	.7500	.4167	.7500
5	9	6	10	.8889	.5000	1.3333	.5000	1.2500	.7500
6	9	10	13	.8889	.5000	1.2500	.7500	.8333	.7500
7	11	8	12	0	.2500	.4722	.2500	.4444	.5000
8	11	12	15	0	.2500	.4444	.5000	0	.5000
9	8	5	9	.4722	.2500	.9444	.2500	.8889	.5000
10	8	9	12	.4722	.2500	.8889	.5000	.4444	.5000
11	5	3	6	.9444	.2500	1.4167	.2500	1.3333	.5000
12	5	6	9	.9444	.2500	1.3333	.5000	.8889	.5000
13	7	4	8	0	0	.5000	0	.4722	.2500
14	7	8	11	0	0	.4722	.2500	0	.2500
15	4	2	5	.5000	0	1.0000	0	.9444	.2500
16	4	5	8	.5000	0	.9444	.2500	.4722	.2500
17	2	1	3	1.0000	0	1.5000	0	1.4167	.2500
18	2	3	5	1.0000	0	1.4167	.2500	.9444	.2500

ELEMENT DATA, REGION 2 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
19	26	24	27	0	1.2500	.3611	1.2500	.3333	1.5000
20	26	27	28	0	1.2500	.3333	1.5000	0	1.5000
21	24	21	25	.3611	1.2500	.7222	1.2500	.6667	1.5000
22	24	25	27	.3611	1.2500	.6667	1.5000	.3333	1.5000
23	21	18	22	.7222	1.2500	1.0833	1.2500	1.0000	1.5000
24	21	22	25	.7222	1.2500	1.0000	1.5000	.6667	1.5000
25	23	20	24	0	1.0000	.3889	1.0000	.3611	1.2500
26	23	24	26	0	1.0000	.3611	1.2500	0	1.2500
27	20	17	21	.3889	1.0000	.7778	1.0000	.7222	1.2500
28	20	21	24	.3889	1.0000	.7222	1.2500	.3611	1.2500
29	17	14	18	.7778	1.0000	1.1667	1.0000	1.0833	1.2500
30	17	18	21	.7778	1.0000	1.0833	1.2500	.7222	1.2500
31	19	16	20	0	.7500	.4167	.7500	.3889	1.0000
32	19	20	23	0	.7500	.3889	1.0000	0	1.0000
33	16	13	17	.4167	.7500	.8333	.7500	.7778	1.0000
34	16	17	20	.4167	.7500	.7778	1.0000	.3889	1.0000
35	13	10	14	.8333	.7500	1.2500	.7500	1.1667	1.0000
36	13	14	17	.8333	.7500	1.1667	1.0000	.7778	1.0000

NUMBER OF ELEMENTS = NE = 36

NUMBER OF NODES = NP = 28

BANDWIDTH = NBW = 5

APPLIED TORQUE EQUALS 196.6000

BOUNDARY VALUES

NODAL FORCES

PRESCRIBED NODAL VALUES

28	0	27	0	25	0	22	0	18	0	14	0
10	0	6	0	3	0	1	0	2	0	4	0
7	0										

NODAL VALUES

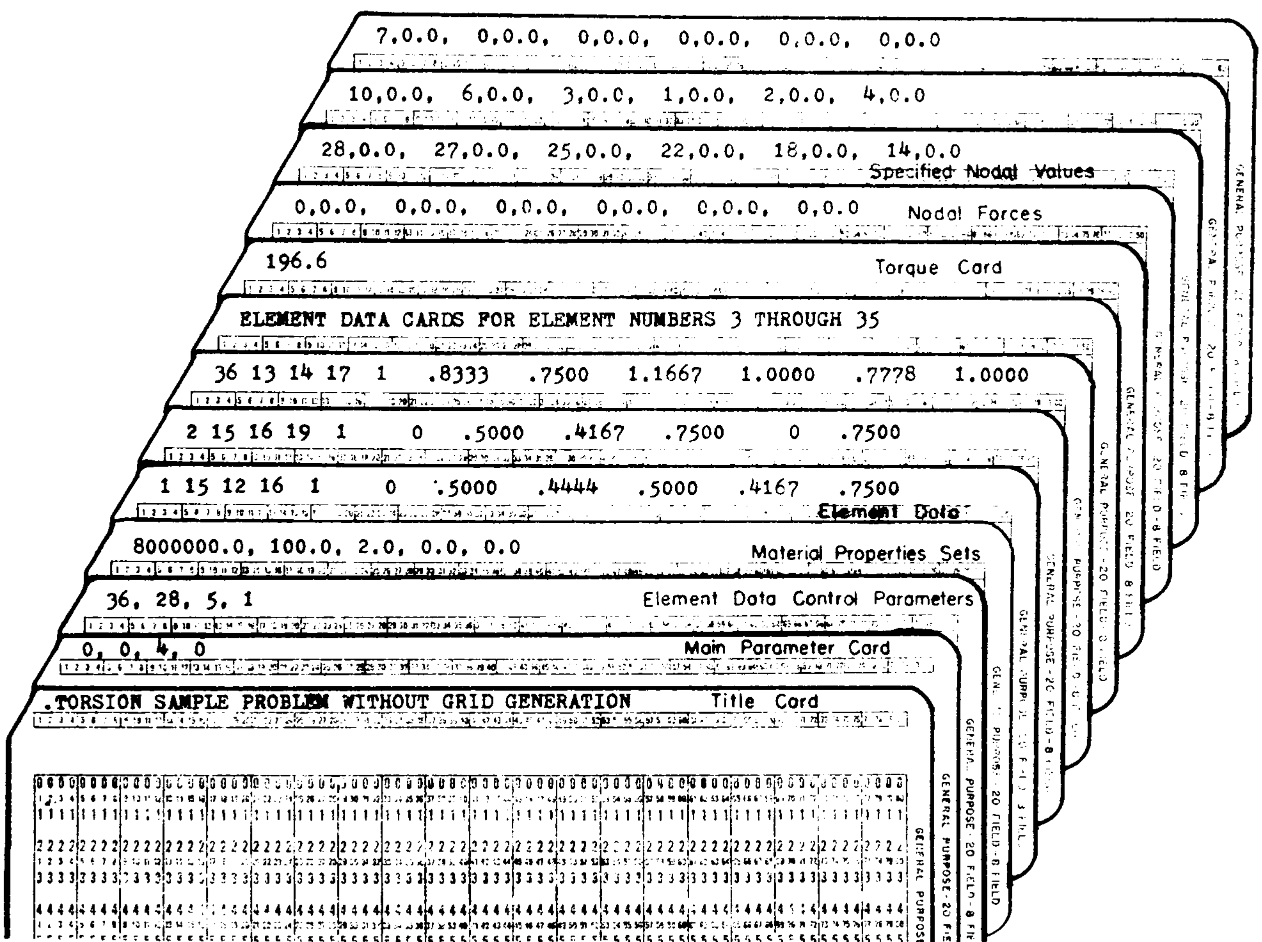
1	0	2	0	3	0	4	0	5	.21259E+02
6	0	7	0	8	.30494E+02	9	.33319E+02	10	0
11	.32788E+02	12	.48001E+02	13	.37604E+02	14	0	15	.51702E+02
16	.53745E+02	17	.34615E+02	18	0	19	.57761E+02	20	.48225E+02
21	.23463E+02	22	0	23	.51468E+02	24	.30911E+02	25	0
26	.32574E+02	27	0	28	0				

ELEMENT STRESSES

ELEMENT	TAUZX	TAUZY	TAUMAX
1	.22048E+02	.83269E+01	.23568E+02
2	.24235E+02	.96394E+01	.26082E+02
3	.97980E+01	.33034E+02	.34456E+02
4	.18669E+02	.38737E+02	.43001E+02
5	-.24990E+02	.74969E+02	.79024E+02
6	-.29167E+01	.90250E+02	.90297E+02
7	.69490E+02	.48583E+01	.69660E+02
8	.75657E+02	.83269E+01	.76114E+02
9	.43896E+02	.19556E+02	.48055E+02
10	.66360E+02	.33034E+02	.74127E+02
11	-.15006E+02	.45019E+02	.47454E+02
12	.31582E+02	.74969E+02	.81349E+02
13	.12198E+03	0	.12198E+03
14	.13115E+03	.48583E+01	.13124E+03
15	.85036E+02	0	.85036E+02
16	.11980E+03	.19556E+02	.12139E+03
17	0	0	0
18	.75032E+02	.45019E+02	.87502E+02
19	-.12416E+03	.46054E+01	.12424E+03
20	-.13030E+03	0	.13030E+03
21	-.98435E+02	.20626E+02	.10057E+03
22	-.12364E+03	0	.12364E+03
23	-.21658E+02	.64974E+02	.68489E+02
24	-.93852E+02	0	.93852E+02
25	-.70181E+02	.83398E+01	.70675E+02
26	-.75575E+02	.46054E+01	.75715E+02
27	-.52386E+02	.34997E+02	.63000E+02
28	-.71546E+02	.20626E+02	.74460E+02
29	-.29670E+02	.89010E+02	.93825E+02
30	-.59047E+02	.64974E+02	.87797E+02
31	-.23150E+02	.96394E+01	.25077E+02
32	-.25172E+02	.83398E+01	.26517E+02
33	-.20565E+02	.38737E+02	.43857E+02
34	-.25967E+02	.34997E+02	.43578E+02
35	-.30083E+02	.90250E+02	.95132E+02
36	-.31737E+02	.89010E+02	.94499E+02

ANGLE OF TWIST FOR THE APPLIED TORQUE IS .09 DEGREES
MAXIMUM SHEAR STRESS FOR THE APPLIED TORQUE IS 131.2
MAXIMUM SHEAR STRESS IS LOCATED IN ELEMENT 14

Fig. 3.4.4 Input for Torsion Problem Without Grid Generation



3.5 TWO-DIMENSIONAL TRANSIENT HEAT TRANSFER

3.5.1 Introduction

This program can be used to analyze two dimensional problems involving transient heat transfer with either prescribed boundary temperatures or surface convections. The body may have internal heat generation. The user must specify the initial temperature of each node. The time step, number of time steps, and frequency of printing of nodal temperatures can be controlled by the user. This program uses a finite element procedure for temperature distribution at any time step and a forward difference technique in time for solution of the transient problem.

The program uses only simple linear triangular elements. Automatic grid generation can be used with this program.

3.5.2 Material Properties Description

The material properties sets for this program include, in the following order

KXX - Conductivity in X-direction
KYY - Conductivity in Y-direction
H - Surface convection coefficient
TINF - Fluid temperature at a distance from convection surface.
CRHO - Product of specific heat and density

Any compatible set of units may be used. Up to twenty material properties sets may be input.

3.5.3 Control Parameters for Two-Dimensional Transient Heat Transfer

Control parameters read in during the application program section are

1) NIT - Number of iterations or time steps

2) IWTR - Control for output of calculated nodal temperatures. Temperatures are printed every IWTR iterations. If IWTR = 4 temperature are printed every fourth iteration.

3) IPCH - Control for punched output of final nodal temperatures. 0 for no punch and 1 to punch. (These cards may be used for thermal stress analysis by 2-D elasticity.)

4) DT - Time increment or time step

Sample Application Control Parameter Card

NIT, No. of Iterations	IWTR Print Output Control	IPCH, Punch Output Control	DT, time step
10,	5,	0,	0.1

This example specifies 10 iterations with printing every 5 iterations, no punched output and a time step of 0.1 units.

3.5.4 Input of Convection and Internal Heat Generation.

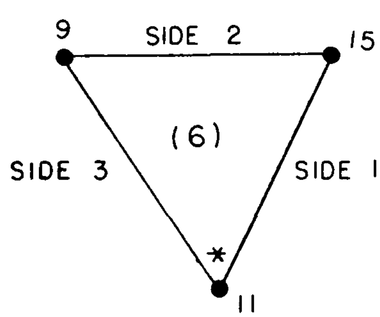
Data establishing sides of elements that are surfaces with convection and elements with internal heat generation must be input. The element number, the number of the side or sides having convection, and the internal heat generation per unit volume must be input for each element having convection and/or internal heat generation. Sides are numbered 1, 2, and 3 counterclockwise from the first input node for the element. Heat added to the body is considered positive.

A maximum of two sides may have convection, therefore, the data input as:

NELC - element no.,	ISIDE (1) - 1st side, for convection	ISIDE (2) - 2nd side, for convection	QG - internal heat generation per unit volume

If only one side has convection, a zero value is entered in the second side for convection location.

Assuming that element (6) shown below has surface convection on sides 2 and 3, and no internal heat generation,



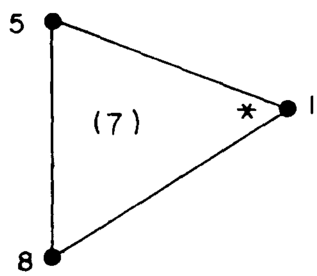
*designates first input node

the convection and heat generation data appears as

6,	2,	3,	0.0

.

Assuming element (7) shown below has convection on side 2 only and an internal heat generation of 10.5 units/unit volume,



*designates first input node

the convection and heat generation data appears as | 7, 2, 0, 10.5 | .

This data set must be terminated with a card with element number, side number, and heat generation all equal to zero, i.e. | 0, 0, 0, 0 | .

IF NO CONVECTION OR INTERNAL HEAT GENERATION OCCURS for the problem, a card with zero values | 0, 0, 0, 0 | , must be input for the convection and internal heat generation data.

This data must be ordered by element numbers with one card per element.

3.5.5 Initial Nodal Temperatures

Input of the initial temperature value for each node must be ordered by node numbers. For example, if a body had 52 nodes, fifty-two values for initial temperature must be input.

3.5.6 Fixed Nodal Values

Nodal numbers for those nodes which are to remain at their initially prescribed values must be input. Node numbers are input in sets of ten per card. If a full set of ten is not required, zero values should be used to complete the set of 10. For example, if nodes 12, 14, 18, 19, 23, and 26 are to be held at the initial temperature, the Fixed Nodal Values would read

| 12, 14, 18, 19, 23, 26, 0, 0, 0, 0 | .

If an even multiple of ten values occurs or if no nodal values are to be fixed, a card with ten zero values must be input to terminate that section of data input.

Table 3.5.1 Program Input for 2-D Transient Heat Transfer

(common)

Title Card - up to 80 alpha-numeric characters for identification of problem

or

Auto-grid case:

Main Parameter Card - see Section 1.3.

for this case NGRID = 1
NPLTG = 0 or 1
NAPPL = 5
NPLTR = 0 or 1

Grid Generation Input Data - includes material properties sets

Non-auto-grid case:

Main Parameter Card - see Section 1.3

for this case NGRID = 0
NPLTG = 0 or 1
NAPPL = 5
NPLTR = 0 or 1

Control Parameters for Element Data - by order of input, see Section 1.6

NE - number of elements
NP - number of nodes
NBW - bandwidth
NMPSET - number of material properties sets

Material Properties Sets - NMPSET sets, see Section 3.5.2 for description

Element Data - for each element by order of input, see Section 1.6

NEL- element number
ND - three node numbers counterclockwise from first node
MPSEL - material properties set number for the element
X1,Y1,X2,Y2,X3,Y3 - X and Y coordinates counterclockwise from first node

Control Parameters for Application - see Section 3.5.3

NIT - number of iterations
IWTR - print control
IPCH - punch control IPCH=0 no punch,
IPCH=1, punch final temperatures
DT - time increment

Convection and Heat Generation Data - element no., sides for convection, heat generated. Terminate with [0, 0, 0, 0]. See Section 3.5.5.

Initial Nodal Temperature - temperature for each node ordered by node number, see Section 3.5.5

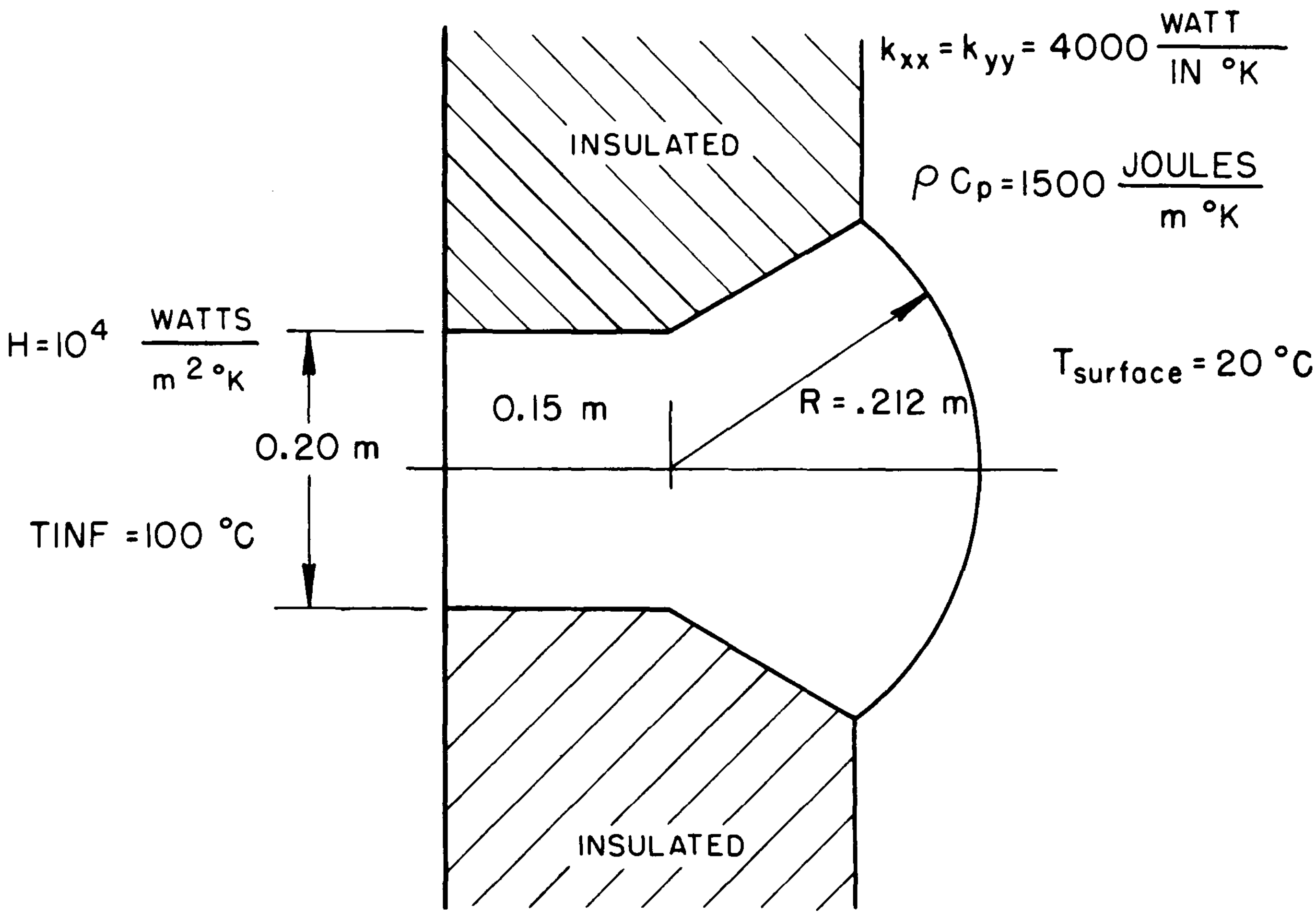
Fixed Nodal Values - node numbers for nodes at fixed temperature, see Section 3.5.6

3.5.7 Input Description

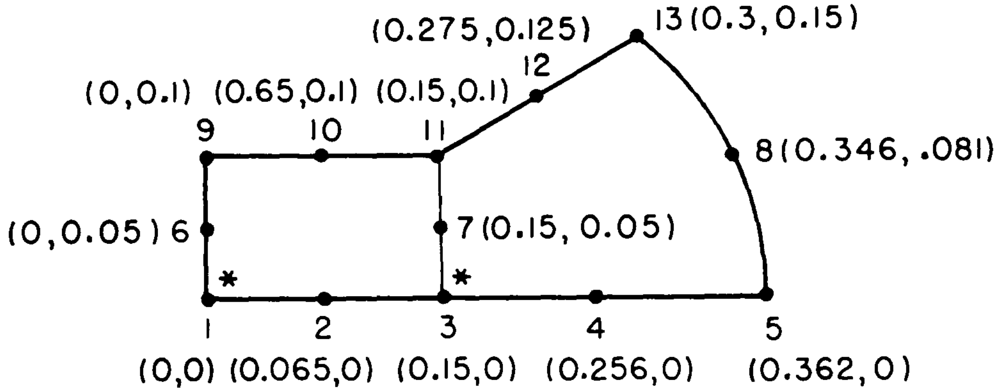
Table 3.5.1 shows the inputs and order of input required for the two possible cases using 2-D transient heat transfer. The first case, auto-grid case, assumes use of the automatic grid generation program. The second case, non-auto-grid case, assumes the users will input the element data from cards. The element data must be ordered by element number for this program.

3.5.8 Sample Problem

Assume the body shown below is inserted through an insulated wall. The body was at an initial temperature of 20°C. Assume at time t=0 the left side is subjected to conversion as shown and that the right side stays at 20°C. Determine temperature change in the body with time.



Regions for Grid Generation



Assume Time Step = 0.001 hr = DT
Number of iterations = 20 = NIT
Print every 5 iterations, 5 = IWTR

Figure 3.5.1 Input for Transient Heat Transfer with Grid Generation

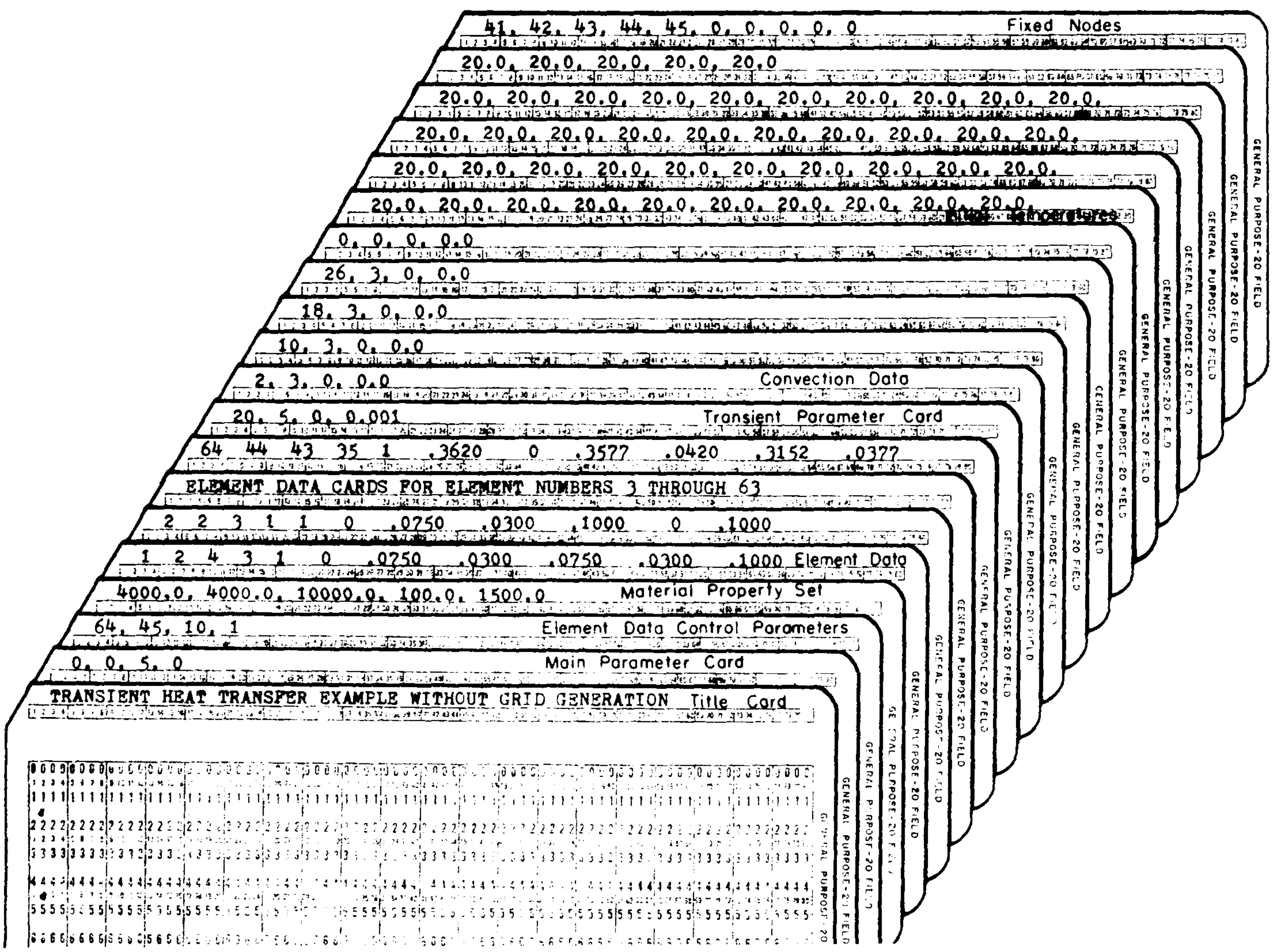


Figure 3.5.2 Output for Sample Transient Heat Transfer

TRANSIENT HEAT TRANSFER EXAMPLE WITH GRID GENERATION

THE GRID WILL BE AUTOMATICALLY GENERATED

APPLICATION PROGRAM TRANSIENT HEAT TRANSFER WILL BE SOLVED

GLOBAL COORDINATES

NUMBER	X COORD	Y COORD
1	0	0
2	.07	0
3	.15	0
4	.26	0
5	.36	0
6	0	.05
7	.15	.05
8	.35	.08
9	0	.10
10	.07	.10
11	.15	.10
12	.28	.13
13	.30	.15

CONNECTIVITY DATA

REGION	SIDE 1	2	3	4
1	0	2	0	0
2	0	0	0	1

MATERIAL PROPERTIES

SET	MAT PROP 1	MAT PROP 2	MAT PROP 3	MAT PROP 4	MAT PROP 5
	KXX	KYY	H	TINF	CRHO
1	.4000E+04	.4000E+04	.1000E+05	.1000E+03	.1500E+04

REGION DATA

REGION	ROWS	COLS	MATERIAL SET	INPUT REGION NODE NO.							
1	5	5	1	1	2	3	7	11	10	9	6
2	5	5	1	3	4	5	8	13	12	11	7

NODE NUMBERS
OF SUBDIVIDED REGION

1

1	3	6	10	15
2	4	7	11	16
5	8	12	17	22
9	13	18	24	29
14	19	25	32	37

2

15	21	28	36	45
16	20	26	33	41
22	23	27	34	42
29	30	31	35	43
37	38	39	40	44

ELEMENT DATA, REGION 1 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
1	2	4	3	0	.0750	.0300	.0750	.0300	.1000
2	2	3	1	0	.0750	.0300	.1000	0	.1000
3	4	7	6	.0300	.0750	.0650	.0750	.0650	.1000
4	4	6	3	.0300	.0750	.0650	.1000	.0300	.1000
5	7	11	10	.0650	.0750	.1050	.0750	.1050	.1000
6	7	10	6	.0650	.0750	.1050	.1000	.0650	.1000
7	11	16	15	.1050	.0750	.1500	.0750	.1500	.1000
8	11	15	10	.1050	.0750	.1500	.1000	.1050	.1000
9	5	8	4	0	.0500	.0300	.0500	.0300	.0750
10	5	4	2	0	.0500	.0300	.0750	0	.0750
11	8	12	7	.0300	.0500	.0650	.0500	.0650	.0750
12	8	7	4	.0300	.0500	.0650	.0750	.0300	.0750
13	12	17	11	.0650	.0500	.1050	.0500	.1050	.0750
14	12	11	7	.0650	.0500	.1050	.0750	.0650	.0750
15	17	22	16	.1050	.0500	.1500	.0500	.1500	.0750
16	17	16	11	.1050	.0500	.1500	.0750	.1050	.0750
17	9	13	8	0	.0250	.0300	.0250	.0300	.0500
18	9	8	5	0	.0250	.0300	.0500	0	.0500
19	13	18	12	.0300	.0250	.0650	.0250	.0650	.0500
20	13	12	8	.0300	.0250	.0650	.0500	.0300	.0500
21	18	24	17	.0650	.0250	.1050	.0250	.1050	.0500
22	18	17	12	.0650	.0250	.1050	.0500	.0650	.0500
23	24	29	22	.1050	.0250	.1500	.0250	.1500	.0500
24	24	22	17	.1050	.0250	.1500	.0500	.1050	.0500
25	14	19	13	0	0	.0300	0	.0300	.0250
26	14	13	9	0	0	.0300	.0250	0	.0250
27	19	25	18	.0300	0	.0650	0	.0650	.0250
28	19	18	13	.0300	0	.0650	.0250	.0300	.0250
29	25	32	24	.0650	0	.1050	0	.1050	.0250
30	25	24	18	.0650	0	.1050	.0250	.0650	.0250
31	32	37	29	.1050	0	.1500	0	.1500	.0250
32	32	29	24	.1050	0	.1500	.0250	.1050	.0250

ELEMENT DATA, REGION 2 MAT. PROP. SET = 1

NEL	NODE NUMBERS			X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)
33	16	20	15	.1500	.0750	.2223	.0855	.1500	.1000
34	20	21	15	.2223	.0855	.2250	.1125	.1500	.1000
35	20	26	21	.2223	.0855	.2759	.0960	.2250	.1125
36	26	28	21	.2759	.0960	.2750	.1250	.2250	.1125
37	26	33	28	.2759	.0960	.3107	.1065	.2750	.1250
38	33	36	28	.3107	.1065	.3000	.1375	.2750	.1250
39	33	41	36	.3107	.1065	.3268	.1170	.3000	.1375
40	41	45	36	.3268	.1170	.3000	.1500	.3000	.1375
41	22	23	16	.1500	.0500	.2178	.0577	.1500	.0750
42	23	20	16	.2178	.0577	.2223	.0855	.1500	.0750
43	23	27	20	.2178	.0577	.2730	.0655	.2223	.0855
44	27	26	20	.2730	.0655	.2759	.0960	.2223	.0855
45	27	34	26	.2730	.0655	.3157	.0732	.2759	.0960
46	34	33	26	.3157	.0732	.3107	.1065	.2759	.0960
47	34	42	33	.3157	.0732	.3460	.0810	.3107	.1065
48	42	41	33	.3460	.0810	.3268	.1170	.3107	.1065
49	29	30	22	.1500	.0250	.2113	.0292	.1500	.0500
50	30	23	22	.2113	.0292	.2178	.0577	.1500	.0500
51	30	31	23	.2113	.0292	.2664	.0335	.2178	.0577
52	31	27	23	.2664	.0335	.2730	.0655	.2178	.0577
53	31	35	27	.2664	.0335	.3152	.0377	.2730	.0655
54	35	34	27	.3152	.0377	.3157	.0732	.2730	.0655
55	35	43	42	.3152	.0377	.3577	.0420	.3460	.0810
56	35	42	34	.3152	.0377	.3460	.0810	.3157	.0732
57	37	38	29	.1500	0	.2030	0	.1500	.0250
58	38	30	29	.2030	0	.2113	.0292	.1500	.0250
59	38	39	30	.2030	0	.2560	0	.2113	.0292
60	39	31	30	.2560	0	.2664	.0335	.2113	.0292
61	39	40	31	.2560	0	.3090	0	.2664	.0335
62	40	35	31	.3090	0	.3152	.0377	.2664	.0335
63	40	44	35	.3090	0	.3620	0	.3152	.0377
64	44	43	35	.3620	0	.3577	.0420	.3152	.0377

NUMBER OF ELEMENTS = NE = 64

NUMBER OF NODES = NP = 45

BANDWIDTH = NBW = 10

CONVECTION FROM SIDE 3 OF ELEMENT 2
CONVECTION FROM SIDE 3 OF ELEMENT 10
CONVECTION FROM SIDE 3 OF ELEMENT 18
CONVECTION FROM SIDE 3 OF ELEMENT 26

TRANSIENT ANALYSIS

NO. ITERATION 20 TIME INCREMENT .00100

TIME = 0

1	.200000E+02	2	.200000E+02	3	.200000E+02	4	.200000E+02
5	.200000E+02	6	.200000E+02	7	.200000E+02	8	.200000E+02
9	.200000E+02	10	.200000E+02	11	.200000E+02	12	.200000E+02
13	.200000E+02	14	.200000E+02	15	.200000E+02	16	.200000E+02
17	.200000E+02	18	.200000E+02	19	.200000E+02	20	.200000E+02
21	.200000E+02	22	.200000E+02	23	.200000E+02	24	.200000E+02
25	.200000E+02	26	.200000E+02	27	.200000E+02	28	.200000E+02
29	.200000E+02	30	.200000E+02	31	.200000E+02	32	.200000E+02
33	.200000E+02	34	.200000E+02	35	.200000E+02	36	.200000E+02
37	.200000E+02	38	.200000E+02	39	.200000E+02	40	.200000E+02
41	.200000E+02	42	.200000E+02	43	.200000E+02	44	.200000E+02
45	.200000E+02						

TIME = .0045

1	.313277E+02	2	.313008E+02	3	.289232E+02	4	.289143E+02
5	.312846E+02	6	.266307E+02	7	.266295E+02	8	.289055E+02
9	.312683E+02	10	.246362E+02	11	.246424E+02	12	.266281E+02
13	.288966E+02	14	.312412E+02	15	.230622E+02	16	.231062E+02
17	.246495E+02	18	.266266E+02	19	.288837E+02	20	.220904E+02
21	.221332E+02	22	.231294E+02	23	.220522E+02	24	.246558E+02
25	.266251E+02	26	.223542E+02	27	.219102E+02	28	.230153E+02
29	.231486E+02	30	.220703E+02	31	.216957E+02	32	.246601E+02
33	.226511E+02	34	.218410E+02	35	.214433E+02	36	.252889E+02
37	.231743E+02	38	.221630E+02	39	.216868E+02	40	.213727E+02
41	.200000E+02	42	.200000E+02	43	.200000E+02	44	.200000E+02
45	.200000E+02						

TIME = .0095

1	.357253E+02	2	.357073E+02	3	.334254E+02	4	.334201E+02
5	.356974E+02	6	.310812E+02	7	.310806E+02	8	.334146E+02
9	.356870E+02	10	.288301E+02	11	.288361E+02	12	.310309E+02
13	.334091E+02	14	.356694E+02	15	.267759E+02	16	.268411E+02
17	.288484E+02	18	.310809E+02	19	.334037E+02	20	.249598E+02
21	.249283E+02	22	.268770E+02	23	.249980E+02	24	.288566E+02
25	.310797E+02	26	.246685E+02	27	.242424E+02	28	.253297E+02
29	.269017E+02	30	.251035E+02	31	.240594E+02	32	.288604E+02
33	.246771E+02	34	.237456E+02	35	.232768E+02	36	.275552E+02
37	.269262E+02	38	.252987E+02	39	.241981E+02	40	.232689E+02
41	.200000E+02	42	.200000E+02	43	.200000E+02	44	.200000E+02
45	.200000E+02						

TIME = .0145

1	.389134E+02	2	.389002E+02	3	.367065E+02	4	.367027E+02
5	.388927E+02	6	.343897E+02	7	.343899E+02	8	.366991E+02
9	.388851E+02	10	.320681E+02	11	.320776E+02	12	.343914E+02
13	.366953E+02	14	.388718E+02	15	.298112E+02	16	.298867E+02
17	.320899E+02	18	.343925E+02	19	.366913E+02	20	.275093E+02
21	.274285E+02	22	.299287E+02	23	.275971E+02	24	.320992E+02
25	.343919E+02	26	.268050E+02	27	.263963E+02	28	.274593E+02
29	.299553E+02	30	.277580E+02	31	.262023E+02	32	.321031E+02
33	.265588E+02	34	.255308E+02	35	.250044E+02	36	.290112E+02
37	.299772E+02	38	.280157E+02	39	.264910E+02	40	.250553E+02
41	.200000E+02	42	.200000E+02	43	.200000E+02	44	.200000E+02
45	.200000E+02						

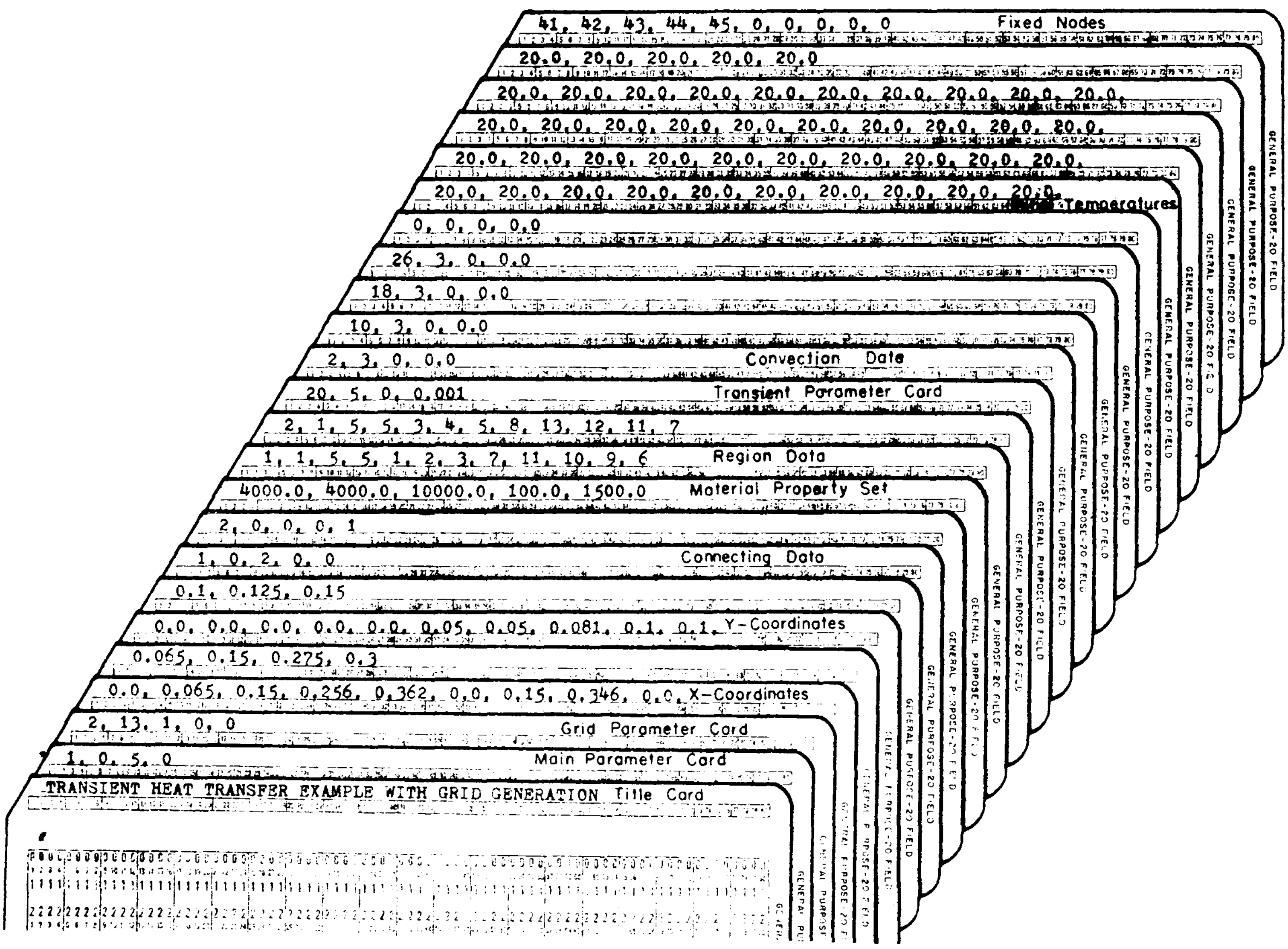
TIME = .0195

1	.414057E+02	2	.413953E+02	3	.392746E+02	4	.392717E+02
5	.413897E+02	6	.369918E+02	7	.369926E+02	8	.392693E+02
9	.413840E+02	10	.346391E+02	11	.346497E+02	12	.369950E+02
13	.392668E+02	14	.413736E+02	15	.322571E+02	16	.323394E+02
17	.346632E+02	18	.369969E+02	19	.392633E+02	20	.296130E+02
21	.294959E+02	22	.323352E+02	23	.297370E+02	24	.346733E+02
25	.369968E+02	26	.268000E+02	27	.231050E+02	28	.292380E+02
29	.324127E+02	30	.292220E+02	31	.281293E+02	32	.343772E+02
33	.281353E+02	34	.270295E+02	35	.264561E+02	36	.313243E+02
37	.324323E+02	38	.302405E+02	39	.283980E+02	40	.265559E+02
41	.200000E+02	42	.200000E+02	43	.200000E+02	44	.200000E+02
45	.200000E+02						

ELEMENT RESULTANTS

ELEMENT	GRAD(X)	GRAD(Y)	AVE TEMP
1	-.70737E+02	.11297E+00	.39981E+02
2	-.71037E+02	.41281E+00	.40692E+02
3	-.65118E+02	-.30587E-01	.37752E+02
4	-.65221E+02	.11297E+00	.38512E+02
5	-.58574E+02	-.42246E+00	.35427E+02
6	-.58819E+02	-.30587E-01	.36208E+02
7	-.51339E+02	-.32913E+01	.33092E+02
8	-.52933E+02	-.42246E+00	.33849E+02
9	-.70679E+02	.96380E-01	.39977E+02
10	-.70787E+02	.22541E+00	.40686E+02
11	-.64980E+02	-.97248E-01	.37752E+02
12	-.65118E+02	.96380E-01	.38511E+02
13	-.58297E+02	-.54070E+00	.35436E+02
14	-.58574E+02	-.97248E-01	.36212E+02
15	-.50621E+02	-.18325E+01	.33129E+02
16	-.51339E+02	-.54070E+00	.33884E+02
17	-.70574E+02	.10144E+00	.39973E+02
18	-.70679E+02	.22777E+00	.40681E+02
19	-.64855E+02	-.72918E-01	.37753E+02
20	-.64980E+02	.10144E+00	.38510E+02
21	-.58090E+02	-.40287E+00	.35444E+02
22	-.58297E+02	-.72918E-01	.36213E+02
23	-.50234E+02	-.11006E+01	.33157E+02
24	-.50621E+02	-.40287E+00	.33907E+02
25	-.70327E+02	.11915E+00	.39968E+02
26	-.70574E+02	.41617E+00	.40675E+02
27	-.64773E+02	.44551E-02	.37752E+02
28	-.64855E+02	.11915E+00	.38509E+02
29	-.57988E+02	-.15994E+00	.35449E+02
30	-.58090E+02	.44551E-02	.36222E+02
31	-.49888E+02	-.78259E+00	.33174E+02
32	-.50234E+02	-.15994E+00	.33921E+02
33	-.37225E+02	-.32913E+01	.31403E+02
34	-.36702E+02	-.63404E+00	.30455E+02
35	-.18614E+02	-.24845E+01	.29233E+02
36	-.10664E+02	.22025E+02	.29108E+02
37	-.19621E+02	.21755E+02	.28654E+02
38	.27308E+02	.11228E+03	.29566E+02
39	-.46321E+03	-.59550E+02	.26407E+02
40	-.11176E+04	-.90594E+03	.23775E+02
41	-.38878E+02	-.18325E+01	.31487E+02
42	-.37960E+02	.17726E+01	.30563E+02
43	-.27927E+02	.12309E+00	.29182E+02
44	-.22046E+02	.15027E+02	.28799E+02
45	-.30125E+02	.15789E+02	.27938E+02
46	-.22076E+02	.29896E+02	.27918E+02
47	-.23186E+03	-.20442E+01	.25055E+02
48	-.37530E+03	-.20068E+03	.22712E+02
49	-.40287E+02	-.11006E+01	.31579E+02
50	-.39296E+02	.18266E+01	.30687E+02
51	-.32877E+02	.37662E+00	.29268E+02
52	-.29042E+02	.80673E+01	.28687E+02
53	-.35083E+02	.93192E+01	.27593E+02
54	-.30278E+02	.16633E+02	.27227E+02
55	-.14726E+03	-.44365E+02	.22152E+02
56	-.23748E+03	.19916E+02	.24495E+02
57	-.41354E+02	-.78259E+00	.31695E+02
58	-.40443E+02	.11491E+01	.30864E+02
59	-.34765E+02	-.46455E+00	.29525E+02
60	-.33018E+02	.22041E+01	.28822E+02
61	-.34756E+02	.27423E+01	.27694E+02
62	-.34540E+02	.30173E+01	.27047E+02
63	-.12370E+03	.17631E+02	.24337E+02
64	-.15017E+03	-.15196E+02	.22152E+02

Figure 3.5.3 Input for Transient Heat Transfer without Grid Generation



3.6 TRUSS

3.6.1 Introduction

This program calculates the nodal displacements and member stresses for statistically determinate and indeterminate plane trusses. Temperature increase from the steady state conditions may be included. Material properties may be varied from member to member. The program uses only simple, one-dimensional elements (2 nodes/element). Automatic grid generation and grid plottings are not available for this program. Element data control parameters and the element data must be input by the user.

3.6.2 Material Properties Description

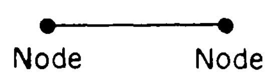
The material properties sets for this program include, in the following order

EM - Elastic modulus
ALPHA - Coefficient of thermal expansion
AREA - Cross-section area
Dummy Variable 1 - = 0.0
Dummy Variable 2 - = 0.0

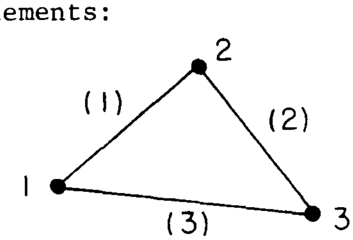
Any compatible set of units may be used. Up to twenty sets of material properties may be input.

3.6.3 Simple Linear Element

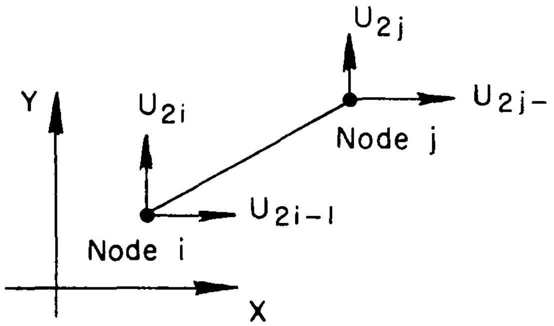
The element type used in this program consists of a 2 node linear element

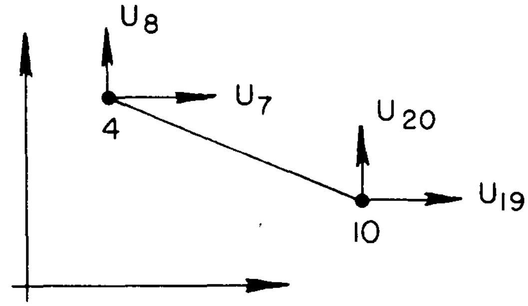


Each node and each element must be numbered. The example below shows an assemblage of three elements:



Truss problems are complicated by having a vector unknown, displacement of nodes. The displacement is expressed as the sum of the components in the X and Y coordinate directions. The figures below demonstrate how the components at each node are expressed. At each node two degrees of freedom (global degrees of freedom) are used. They are two times the node number for the Y-component and two times the node number minus one for the X-component.





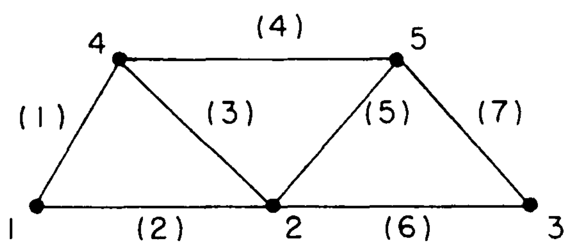
Input of force values and known nodal displacements are also input in vector components keyed to the global degree of freedom.

3.6.4 Element Data Control Parameters

Element data control parameters establish the size of the problem and the number of material properties sets to be used. Element data control parameters for Truss include, in order of input

NE - number of elements
NP - number of nodes
NBW - bandwidth = (maximum difference in node numbers of any element + 1) *2
NMPSET - number of material properties sets to be input.

Sample bandwidth determination



Bandwidth = ((4-1) + 1) *2 = 8

3.6.5 Element Data

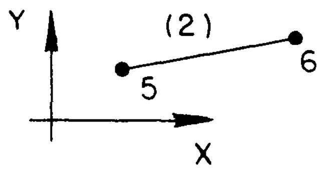
The element data establish the element numbers, node numbers for the elements, number of the material properties set for each element, the change in temperature for each element, and the X and Y coordinates of the nodes for the truss under study.

Element data for each element are input in the following order

NEL - element number
ND - node numbers
MPSEL - material properties set number for the element
DT - increase in temperature of the element from the steady state
X1,Y1,X2,Y2 - X and Y coordinates for element nodes in same order as node numbers were input.

Element data must be input with one element per card.

Sample element data card



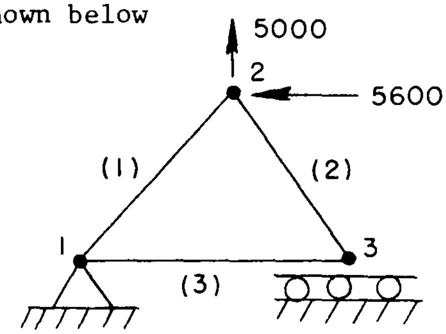
Change in temp. = 10.0
Matl. Set No. = 3

NEL	ND		MPSEL	DT	X1	Y1	X2	Y2
2,	5,	6,	3,	10.0,	10.0,	5.0,	15.0,	10.0

3.6.6. Boundary Values

Boundary values are input in two sections. The first is nodal forces. The second is known displacements. Both are input by the global degrees of freedom at each node and the value of the vector component parallel to the direction of that degree of freedom. Each card must have six sets consisting of global degree of freedom and associated value. If a complete card is not needed, the remaining sets should be specified with zero values. If an even multiple of 6 sets occurs or no values are to be input, a card with 6 sets of zeros (12 zeros) must follow to terminate that section of data input.

For the simple truss shown below



the nodal forces would be input as

3,	-5600.0,	4,	5000.0,	0,	0.0,	0,	0.0,	0,	0.0,	0,	0.0

and the known nodal values (displacements)

1,	0.0,	2,	0.0,	6,	0.0,	0,	0.0,	0,	0.0,	0,	0.0

Note sign convention has been established such that forces and displacements in the positive coordinate direction are assumed positive. Those in the oposite direction are assumed negative.

3.6.7 Input description

Table 3.6.1 shows the inputs required for the truss program.

Table 3.6.1 Program Input for Truss

Title Card - up to 80 alpha-numeric characters for identification of problem.

Main Parameter Card - See Section 1.4 for this case NGRID = 0
NPLTG = 0
NAPPL = 6
NPLTR = 0

Control Parameters for Elements Data - by order of input, see Section 3.6.4.

NE - number of elements
NP - number of nodes
NBW - bandwidth
MNPSET - number of material properties sets.

Material Properties Sets - NMPSET sets, see Section 3.6.2 for description.

Element Data - for each element, by order of input, see Section 3.6.5..

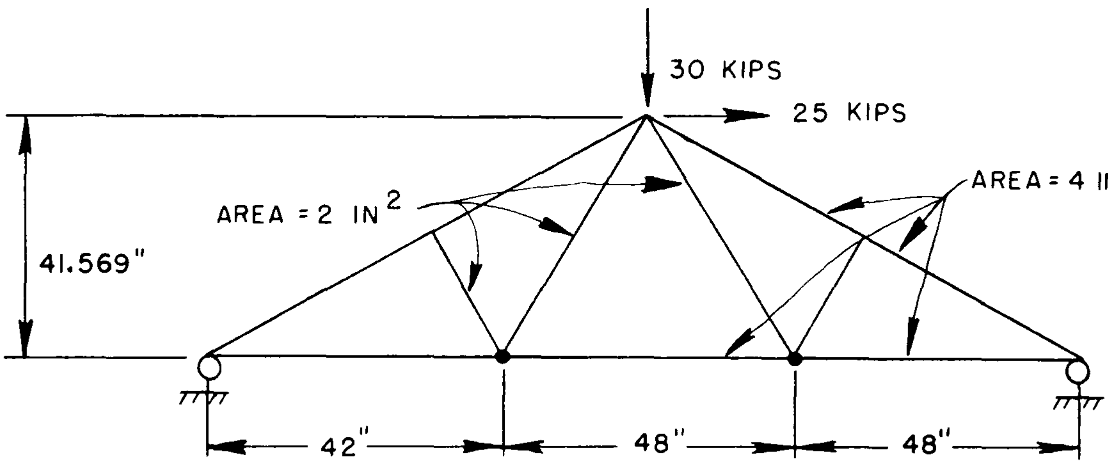
NEL - element number
ND - node numbers
MPSEL - material properties set number for the element
DT - increase in temperature of element
X1,Y1,X2,Y2 - X and Y coordinates for element nodes in same order as node numbers were input.

Nodal Forces - read sets of global degree of freedom associated with force and value, with 6 sets per card - terminate with global d.o.f. = 0, value = 0.0 for remainder of card. See Section 3.6.6.

Specified Nodal Values - read sets of global degree of freedom associated with displacement and value of displacement with 6 sets per card - terminate with global d.o.f. = 0, value = 0.0 for remainder of card.

3.6.8 Sample Problem

Consider the truss problem diagrammed below. The truss is assumed to be fixed at both ends.



The following figure shows the truss with elements and nodes labeled for input.

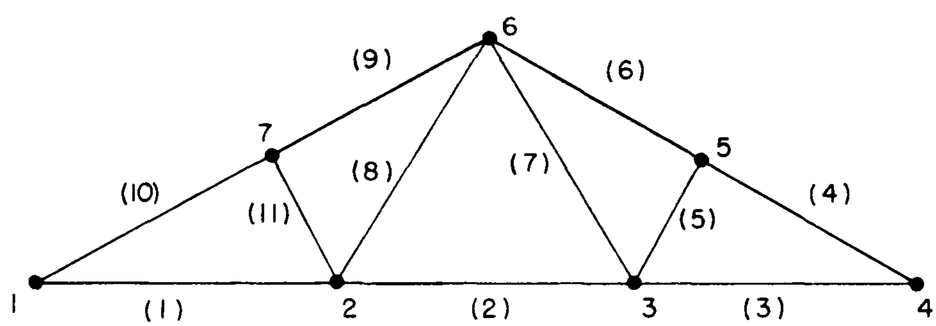


Figure 3.6.1 shows the input for this problem. Note that units must be consistent (i.e., if material properties are in inches, nodal distance must be in inches).

Figure 3.6.2 shows the output of the truss program for this problem.

Figure 3.6.1 Input for Truss Example Problem

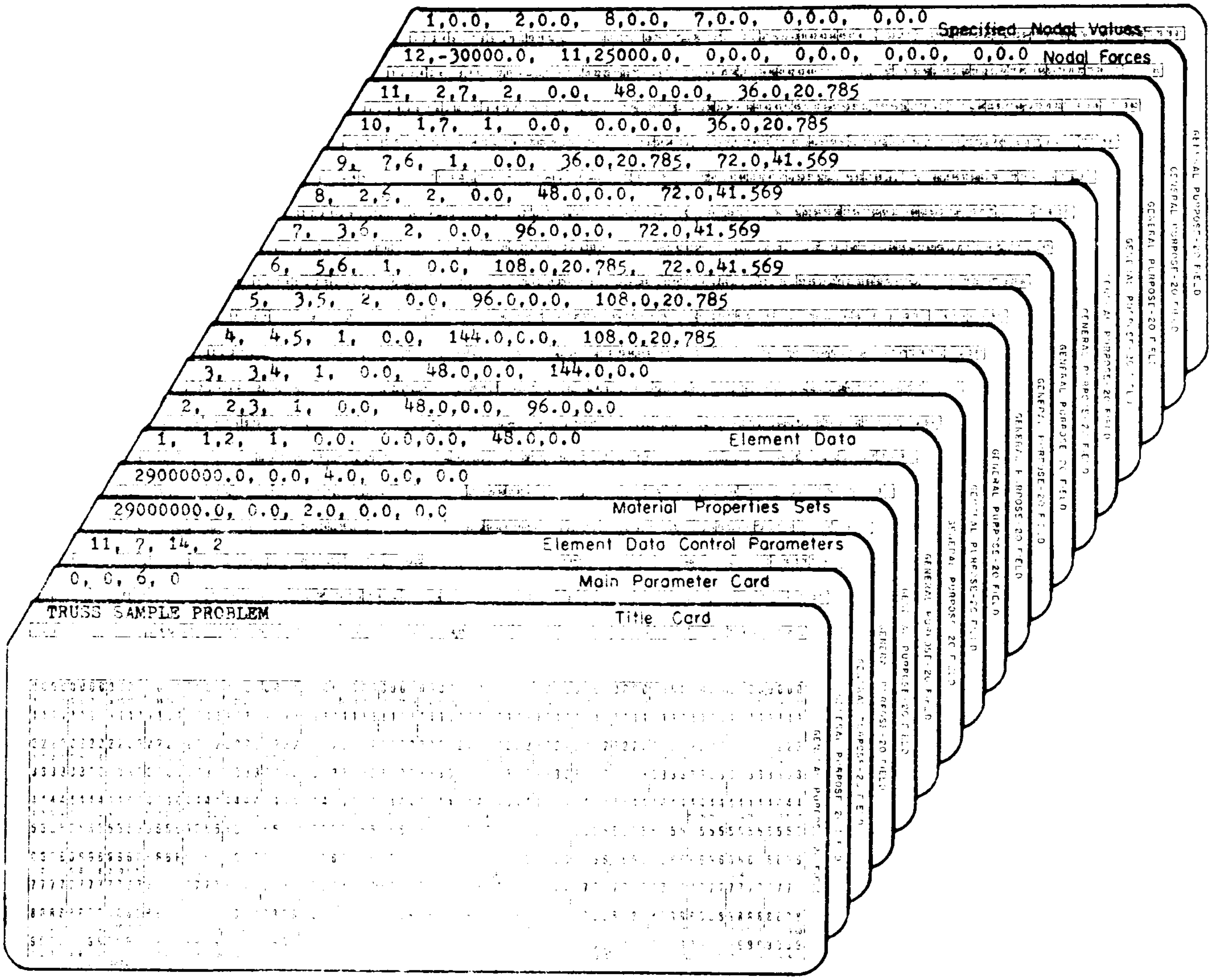


Figure 3.6.2 Output for Truss Example Problem

BOUNDARY VALUES

NODAL FORCES

45	.44740E+02	42	.89500E+02	43	.89500E+02	44	.89500E+02	40	.73950E+02	33	.58440E+02
26	.58500E+02	20	.58540E+02	14	.68260E+02	9	.78000E+02	3	.78000E+02	1	.78000E+02
5	.39000E+02	23	-.15000E+04								

PRESCRIBED NODAL VALUES

17	.18000E+03	12	.18500E+03	8	.19000E+03	4	.19786E+03	5	.20000E+03	36	.20000E+03
41	.20000E+03	45	.20000E+03								

NODAL VALUES

1	.19860E+03	2	.19382E+03	3	.19654E+03	4	.19786E+03	5	.20000E+03	6	.18779E+03
7	.19086E+03	8	.19000E+03	9	.19485E+03	10	.18380E+03	11	.18488E+03	12	.18500E+03
13	.18831E+03	14	.19395E+03	15	.18179E+03	16	.18202E+03	17	.18000E+03	18	.18021E+03
19	.18643E+03	20	.19407E+03	21	.18134E+03	22	.17943E+03	23	.16957E+03	24	.18235E+03
25	.18875E+03	26	.19494E+03	27	.17985E+03	28	.17904E+03	29	.18538E+03	30	.19333E+03
31	.18989E+03	32	.19174E+03	33	.19629E+03	34	.17998E+03	35	.18713E+03	36	.20000E+03
37	.19685E+03	38	.19434E+03	39	.19454E+03	40	.19775E+03	41	.20000E+03	42	.19917E+03
43	.19716E+03	44	.19682E+03	45	.20000E+03						

ELEMENT VELOCITY COMPONENTS

ELEMENT	VEL(X)	VEL(Y)
1	.46946E-01	.42475E-01
2	.15711E+00	-.10358E-01
3	-.58564E-01	.83084E+00
4	.79857E+00	.22079E+00
5	-.45614E+00	-.13340E-01
6	-.95121E+00	.51203E+00
7	-.29485E+00	-.42912E-03
8	-.31874E+00	.36081E-01
9	-.56860E-01	.19381E+00
10	.46946E-01	.11940E+00
11	-.19203E+00	.30440E+00
12	-.58564E-01	.19340E+00
13	-.33629E+00	.82581E-01
14	-.45614E+00	.21007E+00
15	-.27416E+00	.68246E-01
16	-.29485E+00	.97486E-01
17	-.13464E+00	.10995E+00
18	-.56860E-01	.35734E-01
19	-.24404E+00	.14582E+00
20	-.19203E+00	.96334E-01
21	-.33838E+00	.11510E+00
22	-.33629E+00	.11288E+00
23	-.24764E+00	.10377E+00
24	-.27416E+00	.13820E+00
25	-.28000E+00	.29929E-01
26	-.13464E+00	-.14324E+00
27	-.28000E+00	.76988E-01
28	-.24404E+00	.38460E-01
29	-.44016E+00	.16493E+00
30	-.33838E+00	.56140E-01
31	-.11984E+00	.82916E-01
32	-.24764E+00	.23418E+00
33	.24017E+00	-.23125E+00
34	.66731E-01	0
35	.14941E+00	-.28199E+00
36	.10734E+00	-.21281E+00
37	-.51751E-01	-.22221E+00
38	-.35611E-01	-.25175E+00
39	-.14416E+00	-.19099E+00
40	-.12926E+00	-.21854E+00
41	.65583E+00	-.39159E+00
42	.28995E+00	0
43	.23932E+00	-.33378E+00
44	.12187E+00	-.42714E+00
45	-.14992E+00	-.26878E+00
46	-.80879E-01	-.39403E+00
47	-.19405E+00	-.19184E+00
48	-.15604E+00	-.26849E+00
49	.15756E+00	-.69939E+00
50	.54831E+00	-.10296E+01
51	.20703E+00	-.70625E+00
52	.18983E+00	-.72056E+00
53	-.41948E+00	-.62112E+00
54	-.15177E+00	-.28673E+00
55	-.26121E+00	-.15693E+00
56	-.20204E+00	-.28437E+00
57	.15711E+00	-.57193E+00
58	.17127E+00	-.56514E+00
59	.79857E+00	-.65214E+00
60	.17531E+00	-.11964E+01
61	-.95121E+00	-.10127E+01
62	-.39998E+00	-.20958E+00
63	-.31874E+00	-.90455E-01
64	-.26342E+00	-.21598E+00

4. GRID PLOTTING

Grid plotting is intended to aid the user in visualization of the grid developed and in development of boundary condition inputs for application programs using the three-node linear triangular element. The user needs only specify the parameter NPLTG = 1 on the main control parameter card to obtain a grid plot. No additional input is required. Automatic grid generation is not required for use of the grid plotting program.

The program automatically produces a ten-inch square plot with an asterisk (*) at each nodal location. The plot scale is determined by the element data and is printed at the top of each plot. The same scale is used in both the X and Y directions.

Figure 4.1 shows a sample plot. Figure 4.2 shows how the user, with the help of the element data printed out prior to the grid plot, might develop the plot to assist in determination of nodal values for boundary conditions.

Figure 4.1 Example Grid Plot

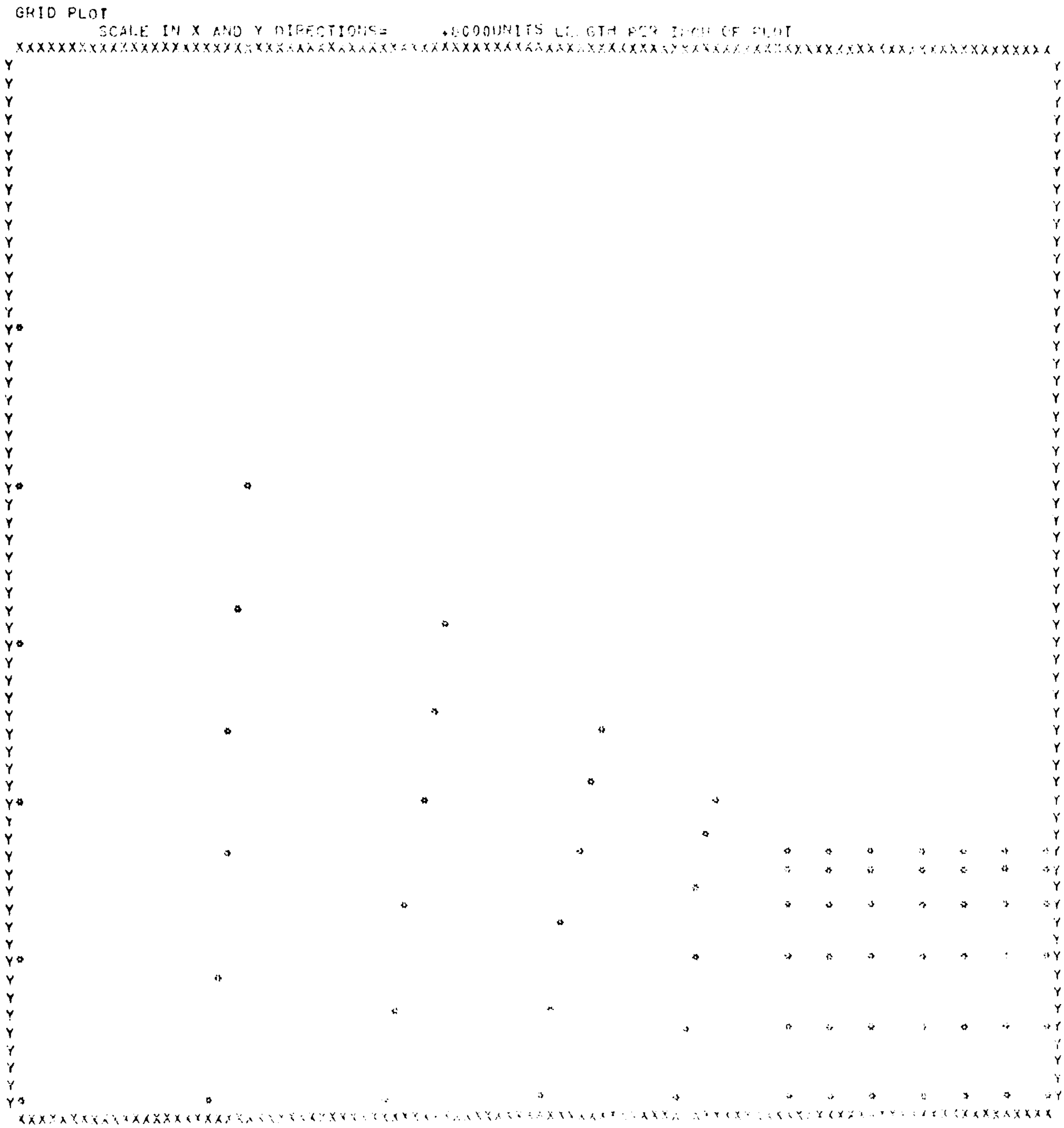
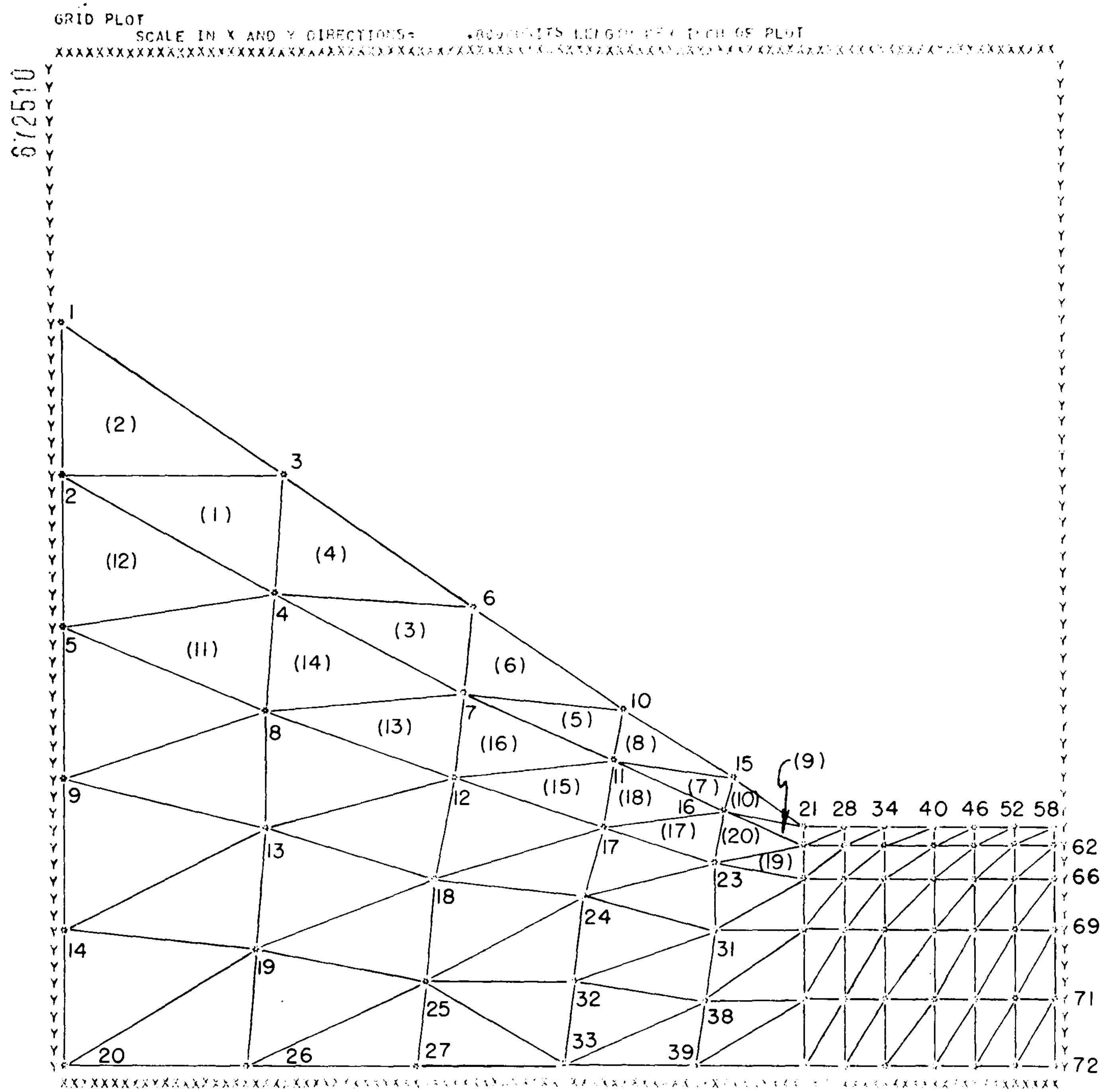


Figure 4.2 Grid Plot Developed for Boundary Condition Determination



5. RESULT PLOTTING

5.1 PURPOSE

Interpretation and use of the large amount of data which can be produced by a finite element program is often tedious and difficult. The purpose of the result plotting program is to assist in interpretation of pertinent output variables. The program produces line-printer plots of the same scale and size as those produced by the grid plotting program (ten inch square plot).

5.2 REQUIREMENT FOR USE

The user need only specify the parameter NPLTR = 1 on the main control parameter card to obtain result plots. No additional input is required. Table 5.1 below shows the results which will be plotted for each application program.

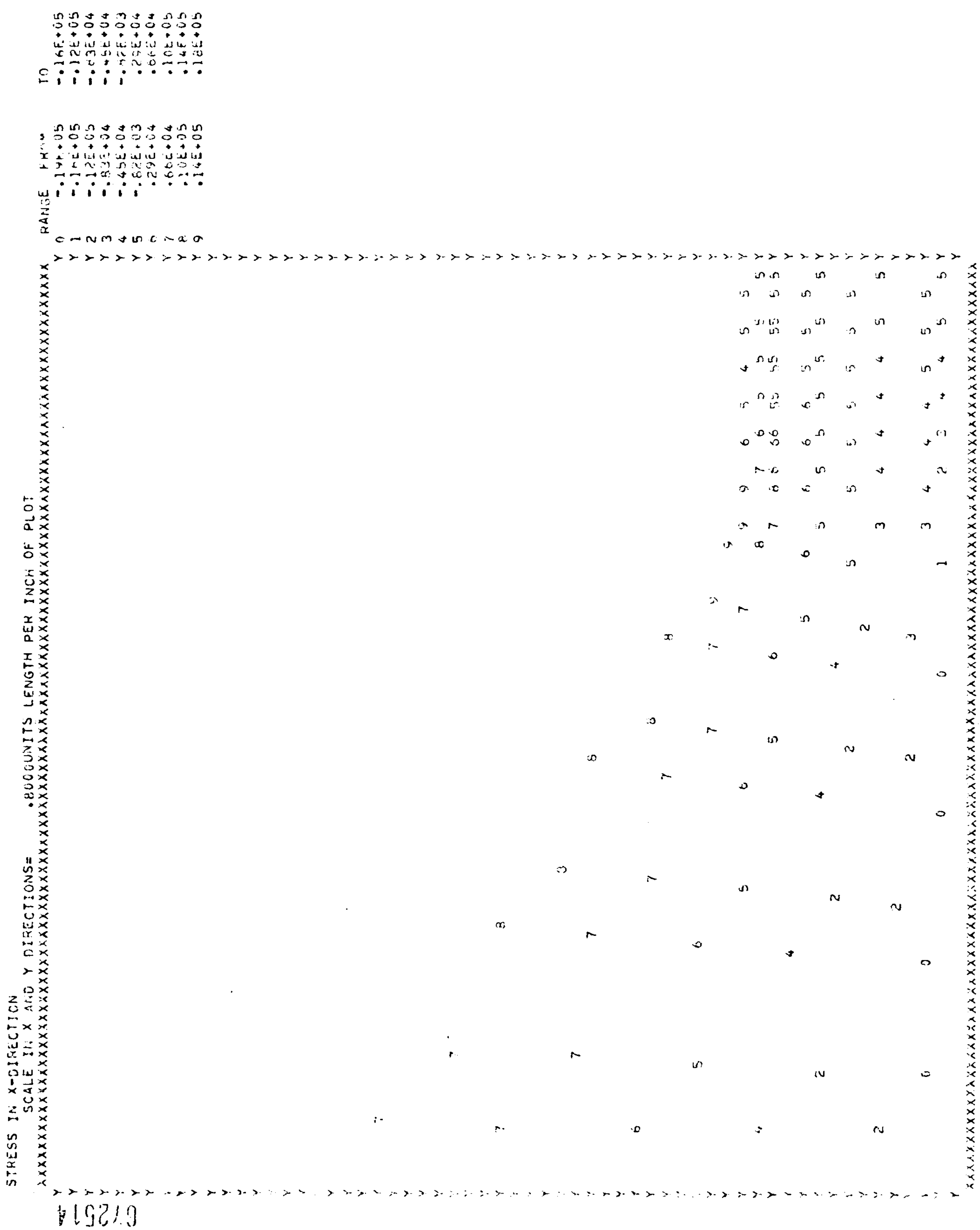
Table 5.1 Result Plotting

Application Program	NAPPL	Variables Plotted	Nodal or Element Values
2-D Elasticity	1	Stress X-direction	Element
		Stress Y-direction	Element
		Shear Stress	Element
		Maximum Principal Stress	Element
		Minimum Principal Stress	Element
		Principal Shear Stress	Element
2-D Heat Transfer	2	Temperatures	Nodal
2-D Groundwater	3	Potentials	Nodal
		Velocity X-direction	Element
		Velocity Y-direction	Element
Torsion	4	Shear Stress ZX	Element
		Shear Stress ZY	Element
		Maximum Shear Stress	Element
2-D Transient Heat Transfer	5	Temperatures - each time step at which values are printed.	Nodal
Truss	6	Result plotting not available.	

5.3 PLOTTING PROCEDURE AND SAMPLE PLOT

This program divides the range of the variable to be plotted into ten equal subranges which are labelled 0 through 9.
Subrange values are printed at the right of each plot. Appropriate subrange labels are then plotted at nodal or element centriodal locations. Figure 5.1 shows a sample result plot.

Figure 5.1 Sample Result Plot



Appendix 1. Sample Time and Core Memory Requirements

The table below gives execution time and core memory requirements for sample moderate size problems.

Application Program	Number of Elements	Bandwidth	Time (sec) w/Grid Generation w/All Plots	Time (sec) w/Grid Generation w/o Plot	Time (sec) w/o Grid Generation w/o Plots
2-D Elasticity	96	6	7.9	2.7*	2.0
2-D Heat Transfer	96	7	5.9	2.1*	1.4
2-D Groundwater	96	6	5.9	2.0*	1.3
Torsion	96	6	4.5	2.1*	1.4
2-D Transient Heat Transfer -100 iterations	108	9	14.1	6.1	5.4
Truss	23	10	---	---	0.4**

*Minimum Core Memory = 46000

**Minimum Core Memory = 21000

Appendix 2 - Control Cards for Using FEMPAC

The following control cards are necessary to obtain and execute this package. Details on those cards not listed completely can be obtained from appropriate University Computer Center Documentation or the KRONOS manual.

```
JOB card
ACCOUNT card
FETCH,FEMPAC.
FEMPAC.
△ (7-8-9 card)
     FEMPAC input cards.
        .
        .
        .
□ (6-7-8 card)
```