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16. Abstract

Computer program FRAME51 performs a nonlinear analysis of statically loaded plane frames using a discrete element model. Enhancements are made to an existing FORTRAN code using currently available hardware and software. The original code runs on a minicomputer with alphanumeric terminals, while the enhanced version runs on a microcomputer with an improved user interface that includes panel-oriented input and extensive use of graphics. Low level assembly language routines are written to provide functions for manipulating screens, and calls to a commercial software package provide functions for graphical capabilities. The existing code is integrated with the new program as subroutines, but no other modifications are made to facilitate avoidance of new error sources. Panel-oriented input eases the user's burden of creating and editing problems. Graphical representation of input data allows error-checking before execution of the code. In addition to the conventional numerical presentation, output data from analysis is also displayed graphically. A menu structure controls access to various capabilities of the software package. FORTRAN 77 is used as the primary language for new code development.

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Graphically-Oriented Nonlinear Analysis of Statically Loaded Plane Frames on Microcomputers

by

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Research Report 1183-2

on

User-Oriented Analysis Packages for Bridges
Research Study No. 2-5-88/9-1183

Sponsored by

Texas State Department of Highways and Public Transportation

in cooperation with

The United States Department of Transportation
Federal Highway Administration

May, 1989

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3136

METRIC (SI*) CONVERSION FACTORS

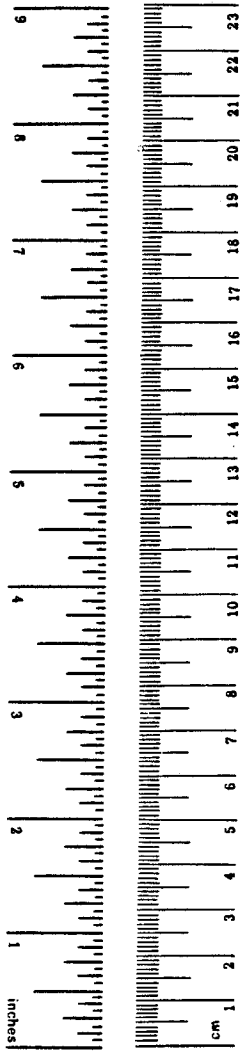
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
AREA				
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
MASS (weight)				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
VOLUME				
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

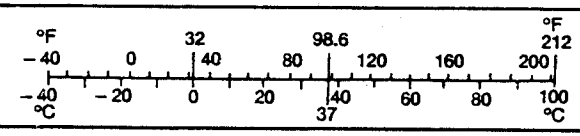


APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
AREA				
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
MASS (weight)				
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

ABSTRACT

Computer program FRAME51 performs a nonlinear analysis of statically loaded plane frames using a discrete element model. Enhancements are made to an existing FORTRAN code using currently available hardware and software. The original code runs on a minicomputer with alphanumeric terminals, while the enhanced version runs on a microcomputer with an improved user interface that includes panel-oriented input and extensive use of graphics. Low level assembly language routines are written to provide functions for manipulating screens, and calls to a commercial software package provide functions for graphical capabilities. The existing code is integrated with the new program as subroutines, but no other modifications are made to facilitate avoidance of new error sources. Panel-oriented input eases the user's burden of creating and editing problems. Graphical representation of input data allows error-checking before execution of the code. In addition to the conventional numerical presentation, output data from analysis is also displayed graphically. A menu structure controls access to various capabilities of the software package. FORTRAN 77 is used as the primary language for new code development.

DISCLAIMER

KEY WORDS
Nonlinear, Frames, Computers, Finite-element, Software, Graphics, Microcomputers

ACKNOWLEDGMENTS

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IMPLEMENTATION STATEMENT

Results of this study are available for immediate implementation by the Texas State Department of Highways and Public Transportation. Other states may want to realize benefits from this study.

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I. BACKGROUND AND SIGNIFICANCE OF WORK

Substantial advancements in hardware and software have been made since the time when many of the current bridge analysis codes in use by the State Department of Highways and Public Transportation were written. Both minicomputer and microcomputer equipment with large memory and graphics capabilities have been installed for use by bridge engineers. Faster compilers and graphics routines are available for software modification.

In view of these changes, the purpose of this research is to use currently available hardware and software to enhance existing analysis programs toward optimum usefulness for design engineers. As a general method of approach, languages and routines which are within the mainstream of engineering and scientific computation are employed. In light of SDHPT maintenance requests, FORTRAN 77 is used as the primary language for new code development, and it remains the mainstay of numerical calculations. Special purpose, low level routines are written in assembly language. They are isolated for facile identification should future hardware dependent changes require maintenance of these portions of the code. This report describes enhancements to an analysis code, FRAME51, which performs a nonlinear analysis of statically loaded plane frames using a discrete element model.

This is the second in a series of reports that document enhancements to four existing analysis codes used by SDHPT. This report describes modifications to analysis code FRAME51.

II. INTRODUCTION

Computer program FRAME51 performs a discrete element analysis which considers geometric, material, and support nonlinearities of statically loaded plane frames [1]. While the original code performs its intended analytical functions, it is written without programming enhancements, such as color graphics, which can simplify data input at the preprocessing stage and graphically summarize output. Engineers currently must sift through large quantities of numerical data in order to interpret results. Other than painstakingly "checking" by hand, no facile means of verifying geometry, material, and support locations is available to an analyst before execution of the code.

The current analysis code has been enhanced towards optimum usefulness for design engineers. The analysis portion of the code is left unmodified to avoid introduction of new error sources. The capability to directly manipulate screens has been included to provide a highly interactive system which is easy

to use. Panel-oriented input provides a simplified way of entering data. Graphical capabilities complement panel-oriented alphanumeric input by providing a quick, visual verification of data. Output from analysis is available in both alphanumeric or graphical form. Comprehensive error trapping is also provided.

These additions to the FRAME51 code provide the user with a program that is not only executable at the engineer's own desk (saving numerous trips to remote terminal locations), but also through panel-oriented input and graphics capabilities, allows error-checking before the analysis code is executed. Graphical output also provides rapid access to important design parameters, without having to interpret large quantities of numerical data.

In what follows, salient features of the new, complete FRAME51 code are described by means of narrative and photographs taken from a microcomputer screen. A sample session guides the first time user in execution of a typical problem. Finally, an installation procedure is described which transfers the program from diskette media to an executable location on a microcomputer.

III. DESCRIPTION OF PROGRAM

The new software package for FRAME51 utilizes a menu structure for accessing and controlling execution of the program. Various capabilities of the software are divided into the following six (6) modules:

1. FILE INFORMATION
2. EDIT/INPUT DATA
3. PREVIEW GRAPHICS
4. RUN ANALYSIS
5. ALPHANUMERIC RESULTS
6. GRAPHICAL RESULTS

These major subdivisions of the program are integrated together under a master menu structure which allows the user easy access to various capabilities of the program. Pertinent file information (current input file, current output file, and problem number) is also displayed on the main menu (Fig. 1). The original FRAME51 analysis code is integrated into the menu structure by means of the module RUN ANALYSIS.

These six modules and their subdivisions are described in the following sections.

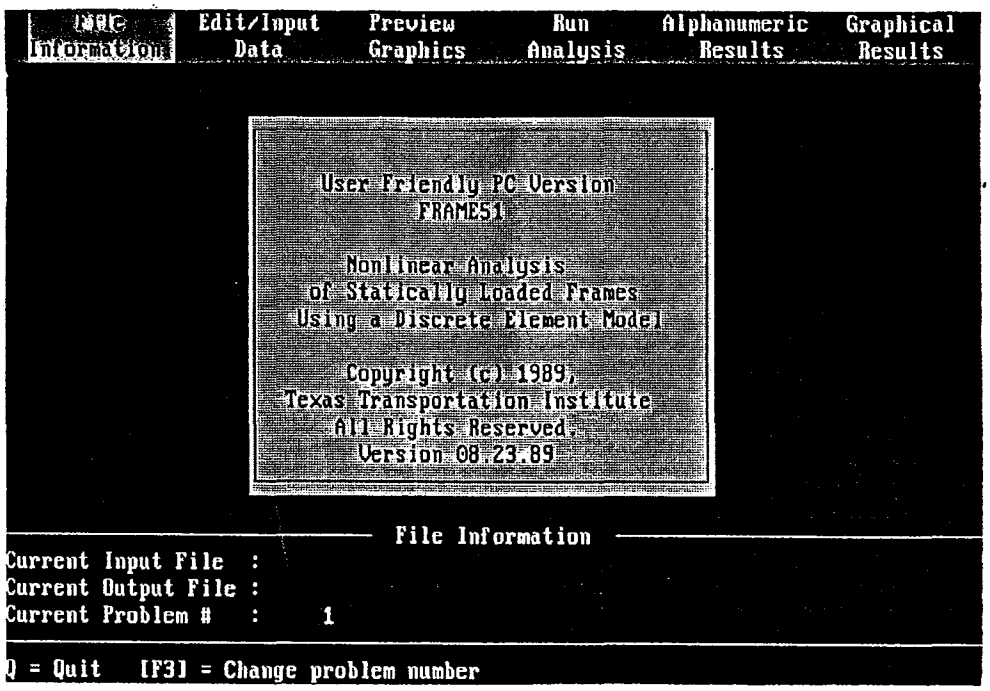


Fig. 1 Main Menu and Screen Layout

1. FILE INFORMATION

In order to execute FRAME51, an input file which describes geometry, material, loading, etc. must be prepared. Names for these files must follow naming conventions specified by the Disk Operating System (DOS). After execution, results of the analysis are placed in an output file for subsequent review, printing, or plotting.

The FILE INFORMATION module aids the user in preparation and manipulation of input and output files. Five selections are available to the user from within this module's menu (Fig. 2):

a) **Change Input File** - The user specifies which input file is to be used by entering a filename by means of the keyboard. The default filename for this case is left blank, until the user assigns a specific filename.

b) **Change Output File** - The name of the current output file is specified by selecting this option. The default filename for this case is left blank, until the user assigns a specific filename.

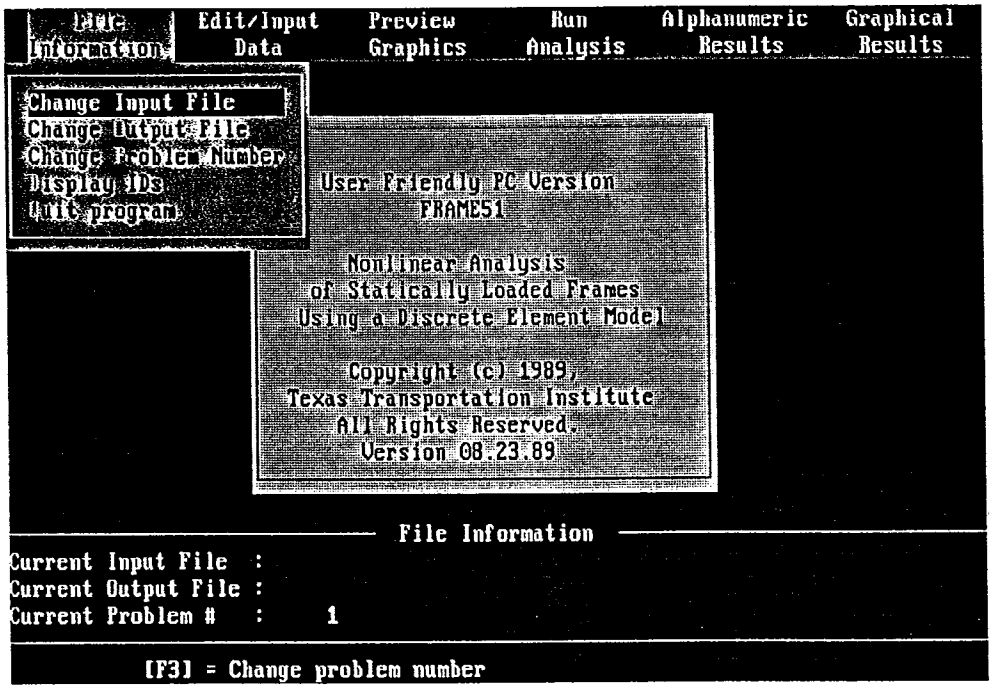


Fig. 2 Submenu "File Information" Module

c) **Change Problem Number** - This option allows the user to assign problem numbers within the input file (see Reference 1 which refers to the unlimited number of problems allowed). Because this option is used so often, a keyboard function key ([F3]) is programmed so that its use allows for changing problem numbers from within any menu module. The default problem number is one (1).

d) **Display Problem ID** - This option displays problem identification numbers in the current input file along with each problem number's description (Fig. 3).

e) **Quit** - Program execution can be terminated using this option. Pressing the letter "Q" from within the main menu also performs the same function.

It should be noted that for the first three options, all changes in file information are immediately updated on screen and internally within the code. For this reason, file information displayed on the main menu is always up-to-date.

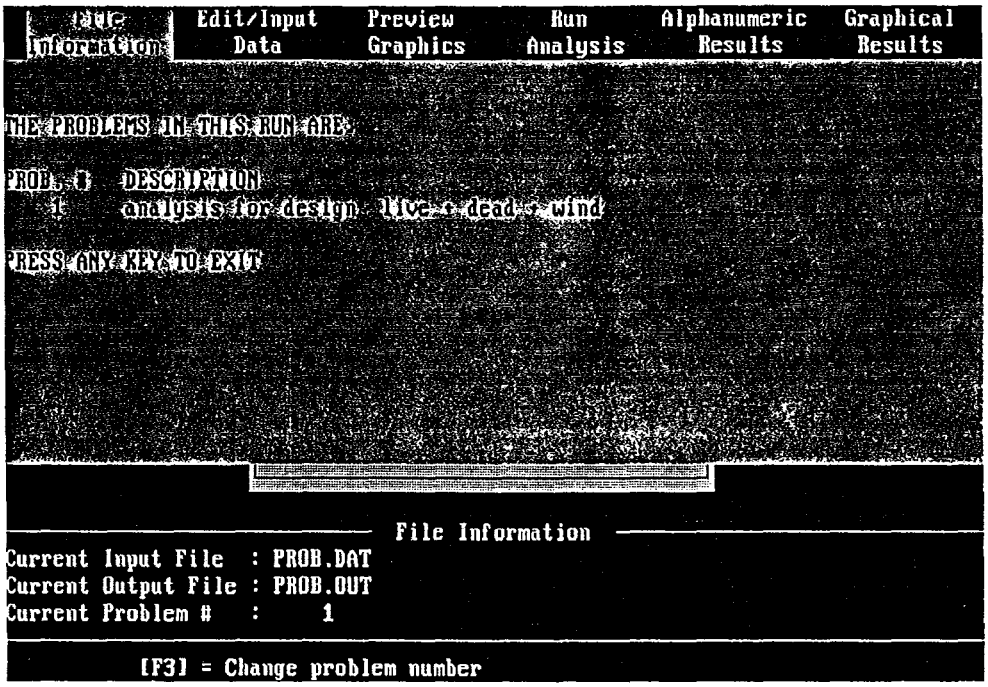


Fig. 3 Problem Id Display

2. EDIT/INPUT DATA

This module provides for creation of new input data files and modification of existing data files. The first twelve entries in this submenu allow the user to view and/or edit data for the twelve input tables referred to in Ref. 1 (Fig. 4). Examples of these tables are shown in Section IV, Sample Session.

When any one of the tables is selected, data from that table for the current problem number is displayed. The user can easily move between fields on any screen by using the up, down, left, and right cursor keys. The current field is highlighted. If the user begins typing a new value for the current field, it is written to a buffer which is simultaneously displayed at the top left of the screen. When the user presses the enter key, the value in the buffer is written to the current field. If the user presses any of the cursor keys, the value displayed in the buffer is written to the current field and the highlight is moved from the current field to a new field, depending on which direction was previously indicated by the cursor key. If at any time while the user is typing data into the buffer, the [Esc] key is pressed, the buffer is cleared and no changes are made to the data on the screen.

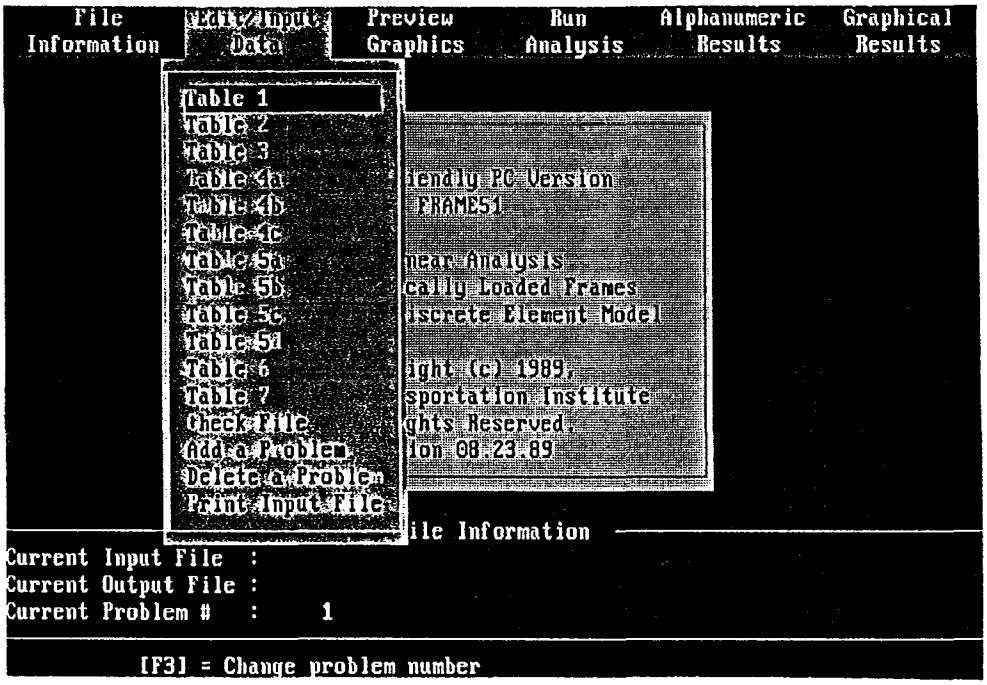


Fig. 4 Submenu "Edit/Input Data" Module

Another way to modify data on the screen is to press the [F2] function key. This transfers data in the current field to a buffer which is displayed at the top left of the screen where it can be edited. Once data has been transferred to the buffer, left and right cursor keys can be used to move within the buffer. The [Delete] key erases the character above the cursor, while the [Backspace] key erases the character immediately to the left of the cursor. Numbers or letters typed will be inserted at the current cursor position. As before, if the [Enter] key is pressed, data in the buffer is transferred back to the current field. If the [Esc] key is pressed, the buffer is cleared and the original data remains unchanged.

An input file can contain more than one problem, as described in Ref. 1. Problems can be added or deleted from the input file by means of this submenu. When the user selects **"Add a Problem"**, the program prompts the user for the problem number to add, and then adds this problem to the input file (Fig. 5). When the user selects **"Delete a Problem"**, the program prompts the user for the problem number to delete and then removes the specified problem from the input file.

The input file can be sent to a printer from within FRAME51 by selecting the last option on this submenu, **"Print Input File"**. Options LPT1, LPT2, COM1,

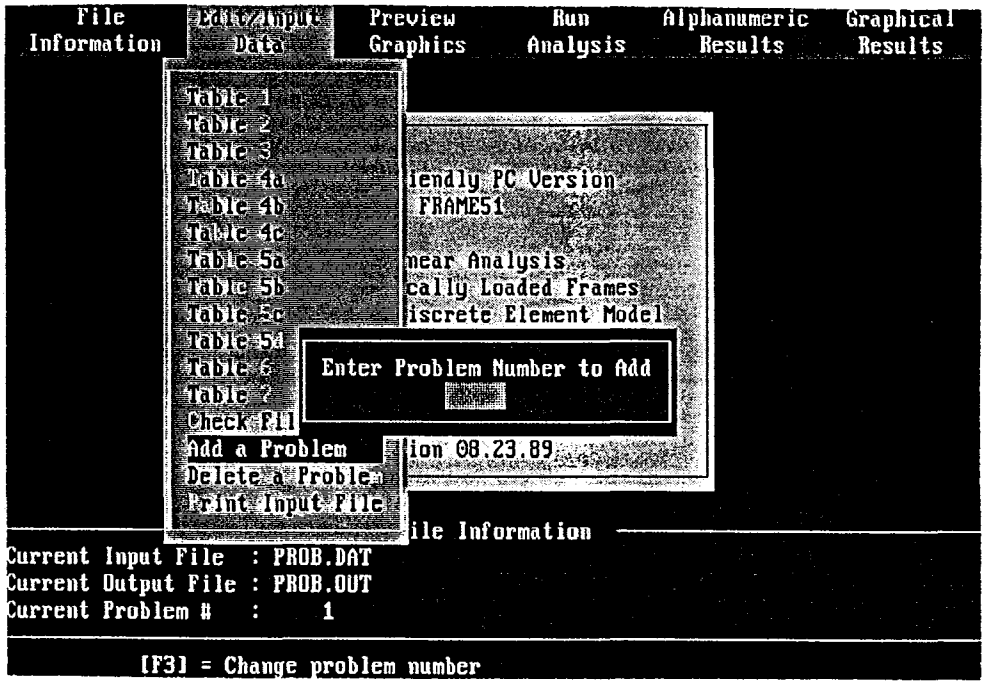


Fig. 5 Addition of Problem to Input File

and COM2 in the submenu (Fig. 6) refer to the communications port assigned to the printer connector from within DOS.

3. PREVIEW GRAPHICS

This module reads the current input file and reports important input data in graphical form. It provides the user with a quick visual check of the input data so that simple errors can be detected before execution of the analysis code. No logic is provided in this module to check errors for input as required by the FRAME51 analysis code. The input file is read and the data is simply displayed. The module has one subdivision which is as follows (Fig. 7):

Frame Geometry & Loadings - Selection of this option allows the user to view the geometry of the frame. Support conditions at the joint are displayed along with joint loadings. Three toggle switches are provided for viewing the joint numbers, load types, and stiffness types on this screen. The [F5], [F6], and [F7] keys, respectively, are assigned for this purpose.

4. RUN ANALYSIS

Selection of this option triggers execution of the analysis code with the specified input data file. In this implementation, the original FRAME51 analysis code is a subroutine which runs at the command of this menu selection

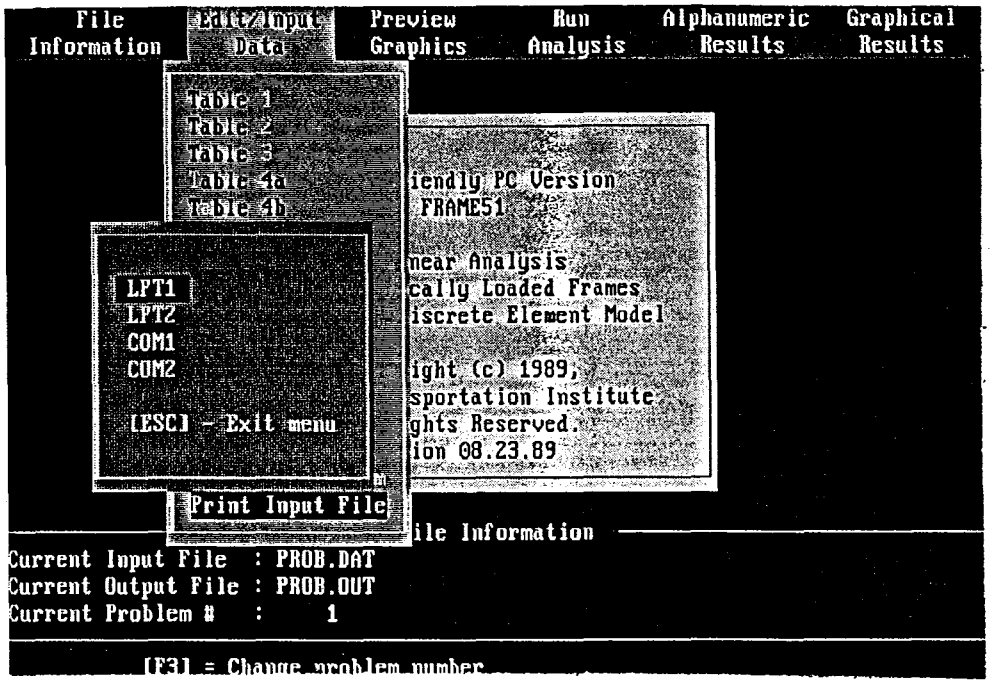


Fig. 6 Port Selection Screen

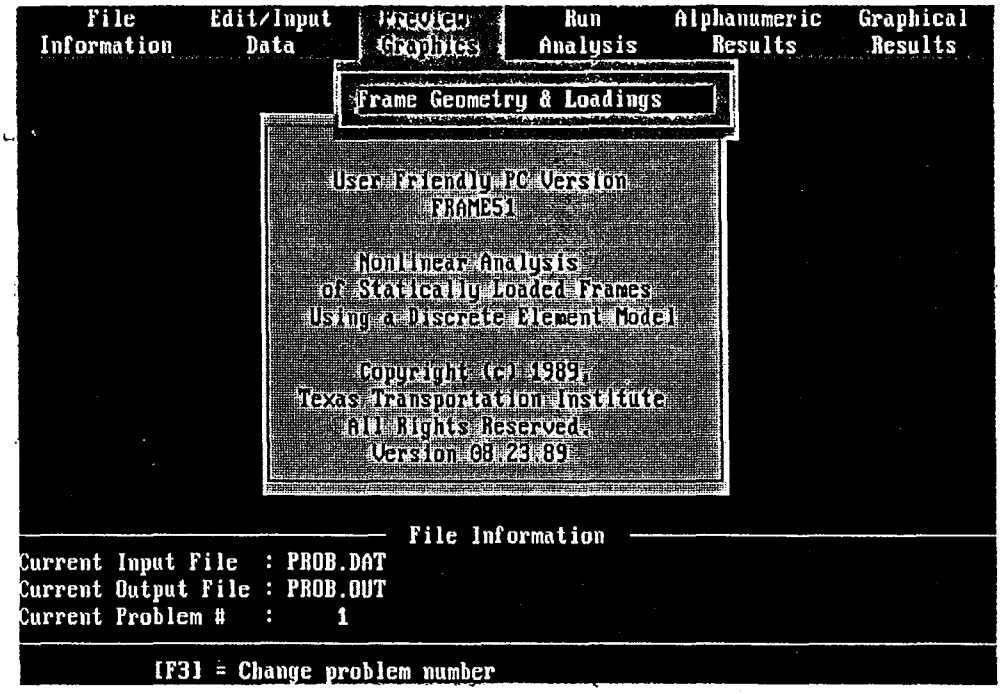


Fig. 7 Submenu "Preview Graphics" Module

and calls its own subroutines. Although modification to FRAME51 is minimal, the READ and WRITE statements have been changed to allow reading and writing to the specified input and output files, respectively. If input and output files have not been specified, they can be input at this stage.

A message is overlaid on the display screen to keep the user informed as to the problem number currently being solved. Error messages check the validity of the input and output files specified by the user. No other changes have been made to the code itself in order to avoid introduction of new error sources.

Execution time varies, depending on the number of problems in the run as well as the size and complexity of these problems. Typical runs such as the Sample Session analysis require from several to many minutes on an IBM PS/2 Model 80 running at 16 megahertz.

5. ALPHANUMERIC RESULTS

This module allows the user to view alphanumeric results output by the analysis part of the code. Alphanumeric results are useful if the user needs to determine the exact value of a result at a particular point, while graphical results are more useful for visualizing overall behavior of forces or deflections over the entire length of the beam.

Results of FRAME51 are divided into three (3) tables, whose numbering follows that of Ref. 1. Table 8 gives displacements and reactions for all frame joints [1]. Table 9 gives member-end-forces or detailed output for each member, as requested in Table 5A [1]. Table 10 gives the equilibrium errors at each joint from the final solution of a problem [1].

The user can select an individual table for viewing from the menu (Fig. 8). Each table is presented on a separate screen and allows the user to scroll through data using up and down arrow keys, and [Page Up] and [Page Down] keys. Each table also shows the problem number. A printout of the specified output file can be obtained by selecting the **"Print Output File"** option in this module. Printing is set up for a 132-column printer. After printing is complete, the user has the option to either keep or delete the output file.

6. GRAPHICAL RESULTS

Graphical output from results of the analysis is presented under this option. Two fundamental kinds of graphs are provided: 1) a diagram of the displaced frame, and 2) member results. The submenu for this module is displayed in Fig. 9. Graphs include problem identification and number, and appropriate scales.

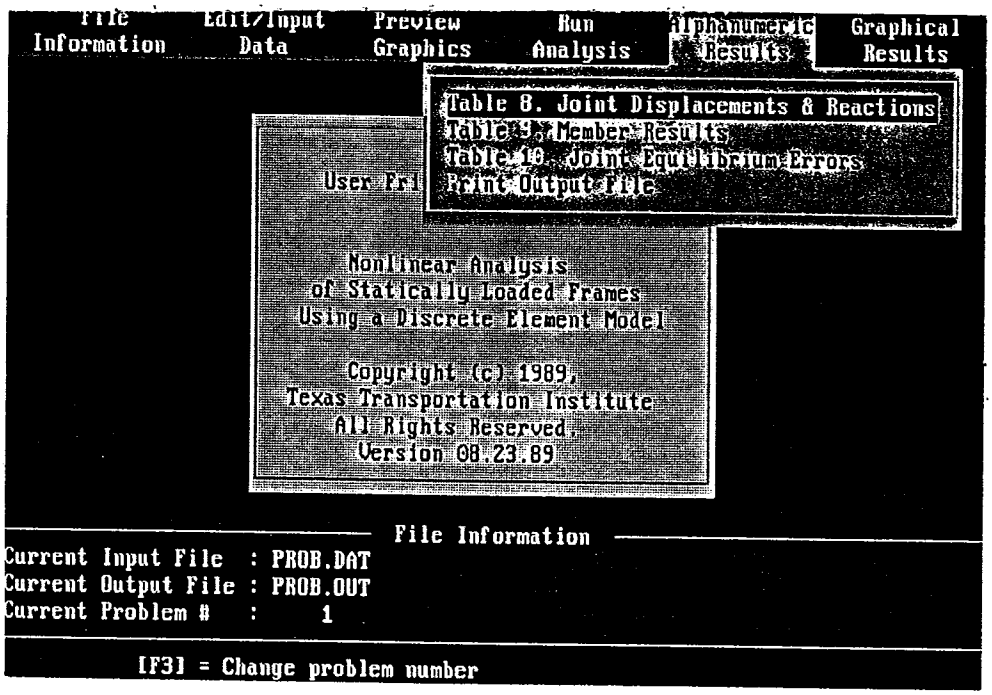


Fig. 8 Submenu "Alphanumeric Results" Module

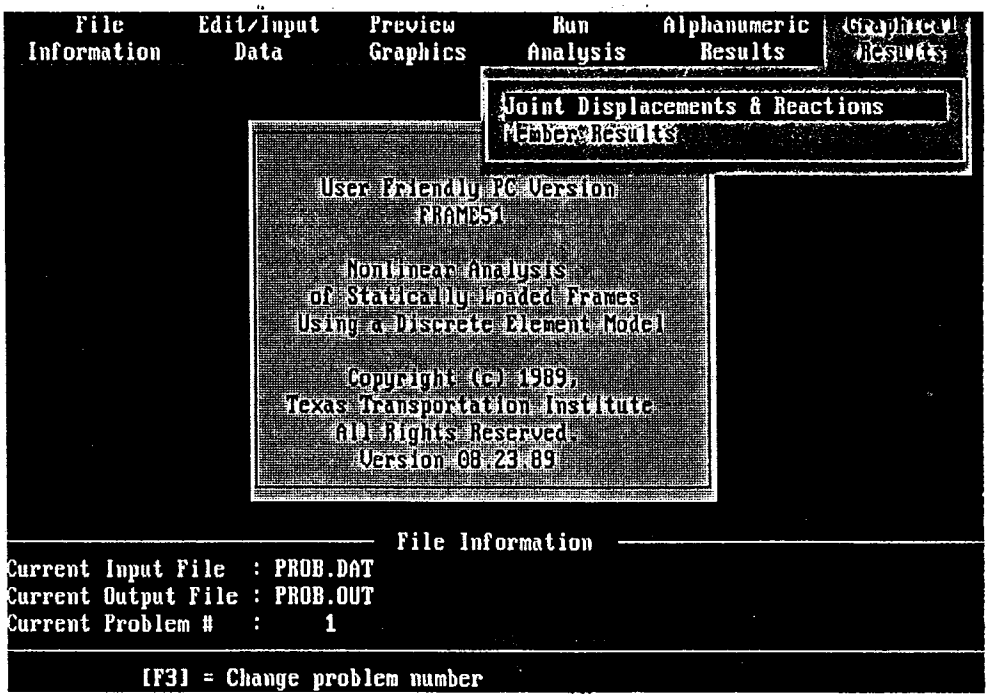


Fig. 9 Submenu "Graphical Results" Module

a) **Joint Displacements and Reactions** - This option allows the user to view the deflected shape of the frame. The displaced frame is superimposed on the original undisplaced shape. Reactions at the joints are also shown graphically. All reactions and displacements are scaled to allow viewing of the entire graph on the screen. Also available for display via the [F5] key are scales for X and Y displacements.

b) **Member Results** - This option allows the user to view pertinent member information in graphical form. This option is available only for members for which detailed output is requested in Table 5A. Six (6) graphs are provided for each member (Fig. 10). They are:

1. Axial Displacement
2. Lateral Displacement
3. Rotational Displacement
4. Axial Force
5. Shear Force
6. Moment

These functions are plotted against the length of the member selected. Vertical and horizontal axes are displayed on the graph along with maximum and minimum values plotted for quick reference.

c) **Plotting options** - After a graph is displayed on the screen, a hardcopy plot can be obtained by accessing the plot options. Three options are available for obtaining hardcopy plots:

1. **Screen Dump** - Plots can be dumped from a screen to a printer by using this option. Printers supported are Epson, IBM, Okidata, HP LaserJet, and those fully compatible with one of the above types (Fig. 11). Hardcopy obtained is in black and white and takes from several to many minutes to complete.
2. **Plotter** - All plotters that support the Hewlett-Packard Graphics Language (HPGL) are supported. Various parameters displayed on the graphs are assigned default pen numbers and pen speeds (cm/sec), which may be changed if desired by means of an additional submenu (Fig. 12). Areas between curves and axes are not filled with color for hardcopy output.
3. **Copy to File** - This option can be used to copy a graph to a file. This file can be copied to an output device at a later time to obtain the hardcopy completely independent from the enhanced FRAME51 software package. Plotter defaults can also be changed by means of a special submenu.

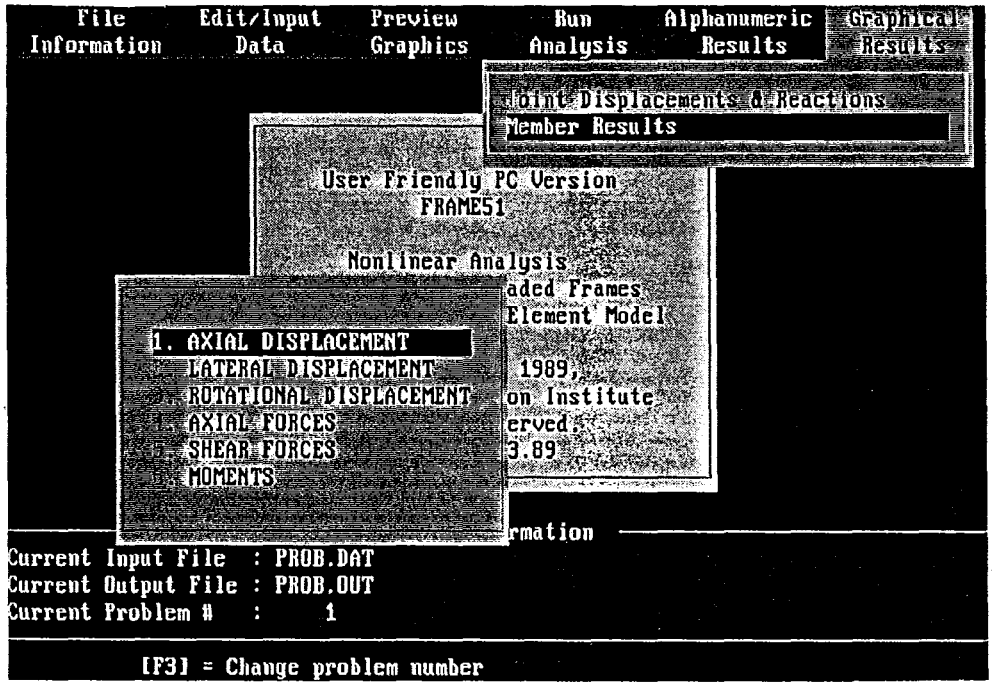


Fig. 10 Graph Selection Screen - "Graphical Results"

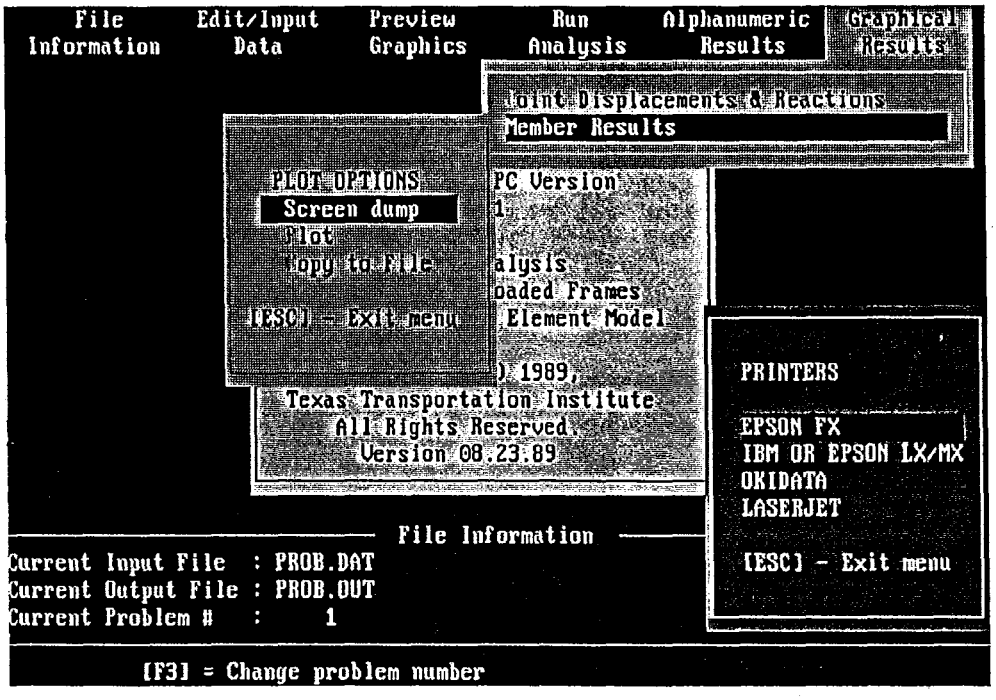


Fig. 11 Screen Dump - Printer Selection Screen

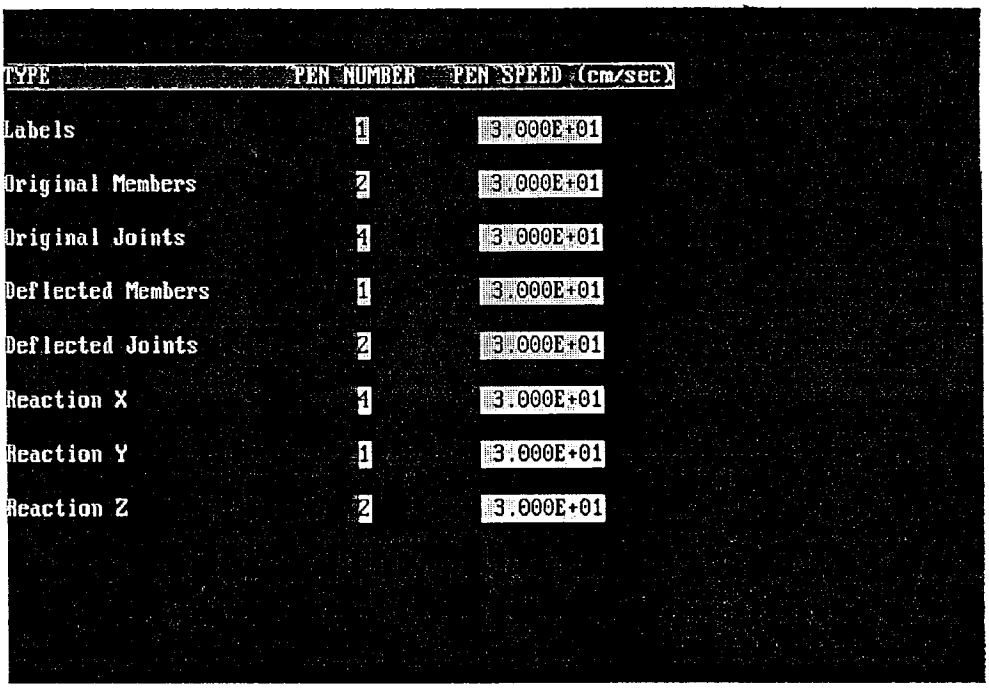


Fig. 12 Plot Parameter Selection Screen

IV. SAMPLE SESSION

This sample session is a description of the steps required to create and execute a typical frame problem. The run contains one problem which is described in detail below [1].

The frame shown in Fig. 13 is chosen to illustrate important features of the enhanced FRAME51 program. All of the input tables except Table 5D are used in forming the input file.

Before creating and executing this problem, the general scheme for using menus is described below.

MENU SCHEME

An option can be selected from the main menu by either using the direction arrow keys to highlight a desired option, or by pressing the highlighted letter of the option desired. Once the option selected is highlighted, the [Enter] key can be pressed to invoke the submenu within that option. Procedures for selecting an option from a pull-down menu are the same as for the main menu except that the [Up] and [Down] arrow keys are used to move from one option to another. Using the [Left] and [Right] arrow keys within a pull-down menu allows movement from one pull-down menu to the next. The option highlighted within

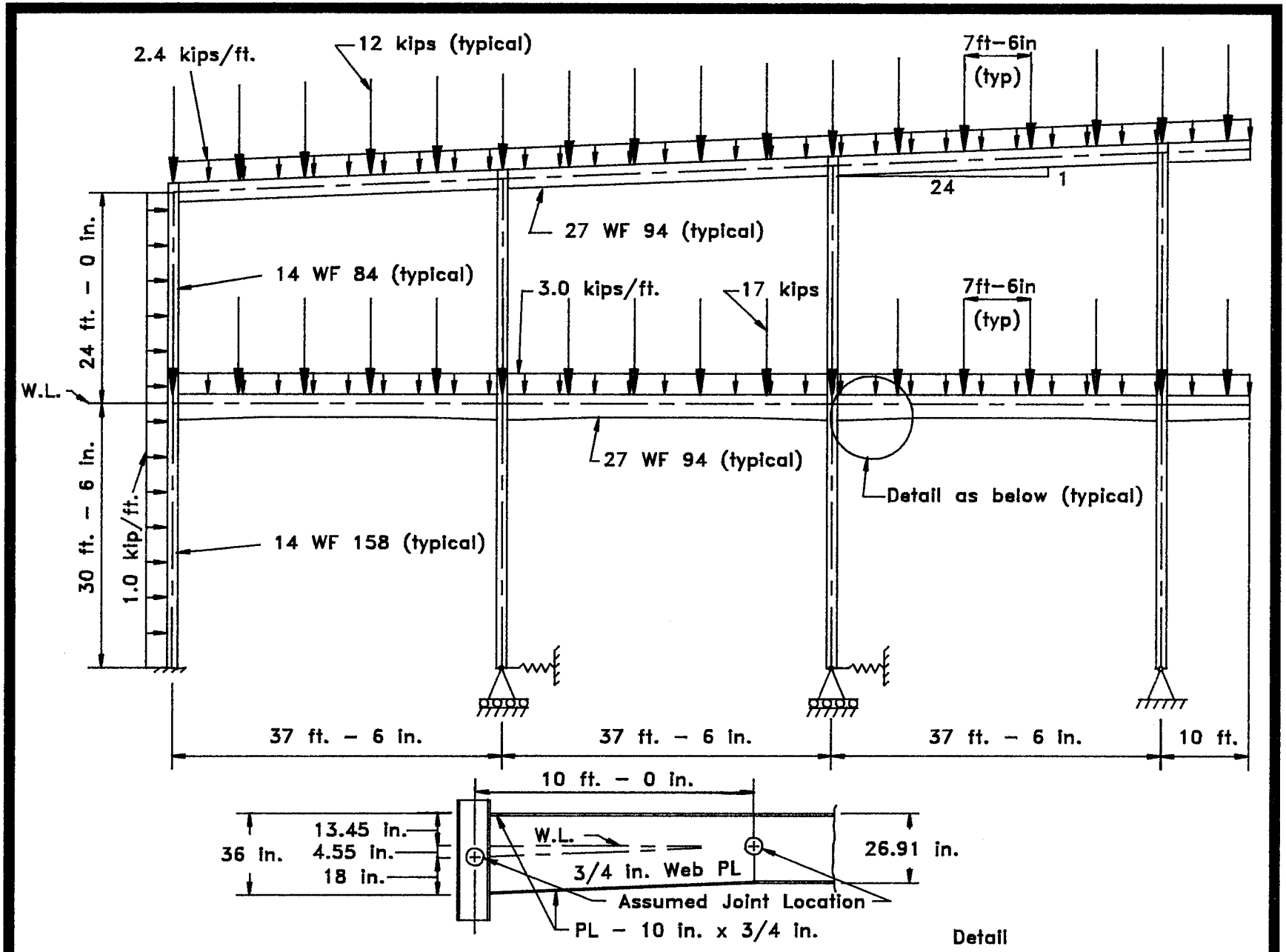


Fig. 13 Sample Problem – Geometry and Loading

this new pull-down menu is the most recently selected option in that menu. The [Esc] key can be used from within a submenu to return to the main menu.

In the description that follows, selection of an option will imply use of this scheme without specific mention.

STEP 1 - FILE INFORMATION

Default filenames for input and output files are left as blanks, respectively. Let the new file containing this problem be called PROB.DAT and the output file PROB.OUT (user should make sure these files do not exist in the current directory). To change filenames, select **FILE INFORMATION** and invoke the submenu within this option. Select **"Change Input File"** and enter PROB.DAT, using the keyboard when the program prompts for the filename (Fig. 14). Similarly, to change the name of the output file, select **"Change Output File"** and enter PROB.OUT.

STEP 2 - EDIT/INPUT FILE

Once the filenames and problem number have been selected, the data can be entered into the appropriate tables. For this example the following data is entered:

TABLE 1 Program Control Data - Since there are no previous problems, fields specifying data to be held should be left blank. For the number of cards for Tables 2 through 7 enter 15, 21, 12, 2, 2, 18, 20, 2, 0, 25, 2, respectively. Enter 1 in the field for Problem Type. Leave all other fields blank. The table is shown in Fig. 15.

TABLE 2 Frame Geometry Data - Enter the following data for the first card of Table 2 (Fig. 16):

Number of Joints	20
Reference Joint	1
X-coordinate	0.0
Y-coordinate	0.0
Joint Location Tolerance	0.3

After completing this information, press [Esc] key to access the table containing the 2nd and succeeding cards for Table 2. Enter the following data in this table (Fig. 17):

From Joint	X-offset	Y-offset	To Joint	To Joint	To Joint	To Joint	To Joint	To Joint	To Joint
1	450.0		6	11	16				
1		355.45	2						
2		292.55	3						
2	450.0		7	12	17				

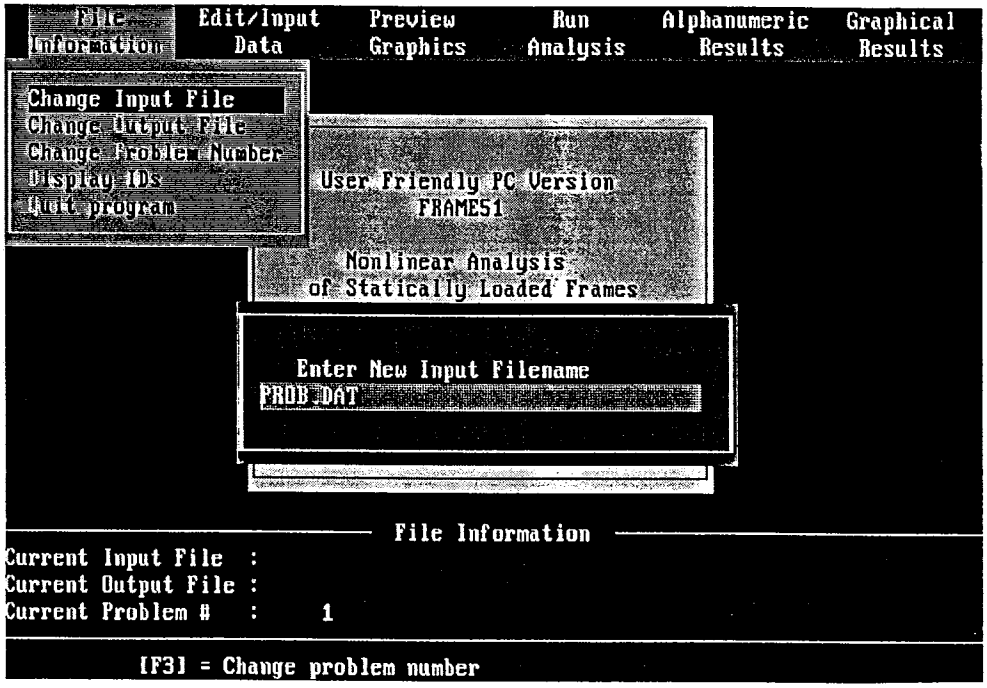


Fig. 14 Specification of Input File

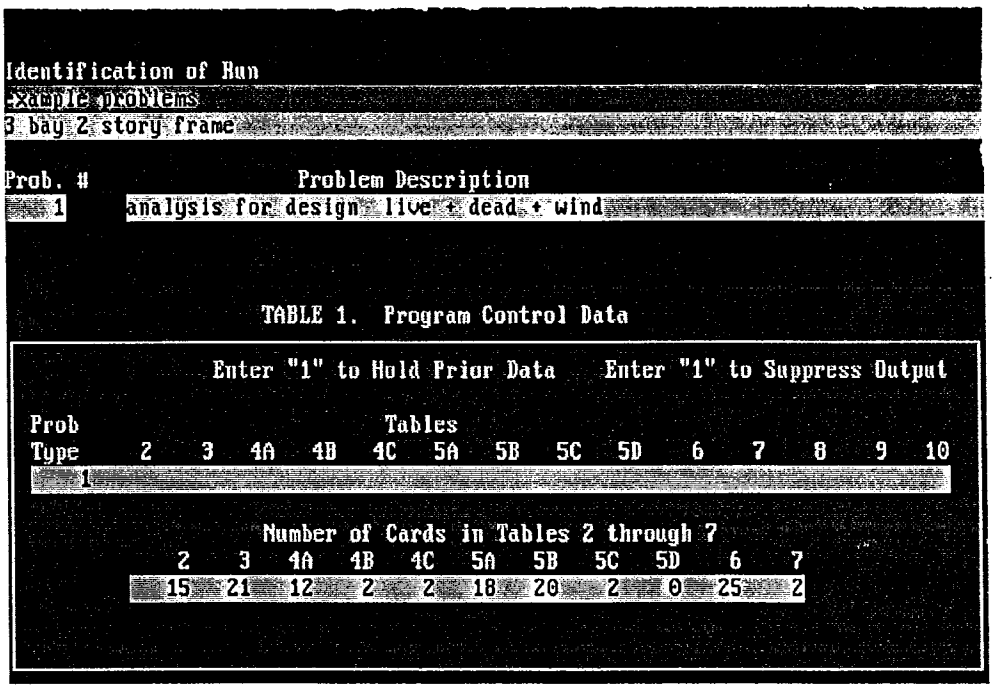


Fig. 15 Table 1 - Input File

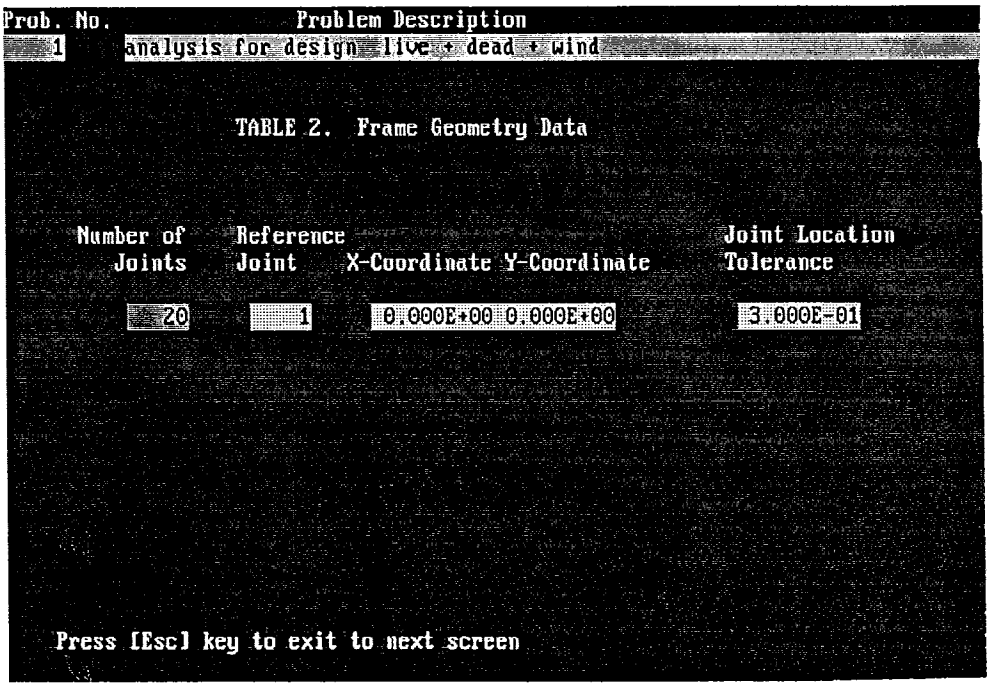
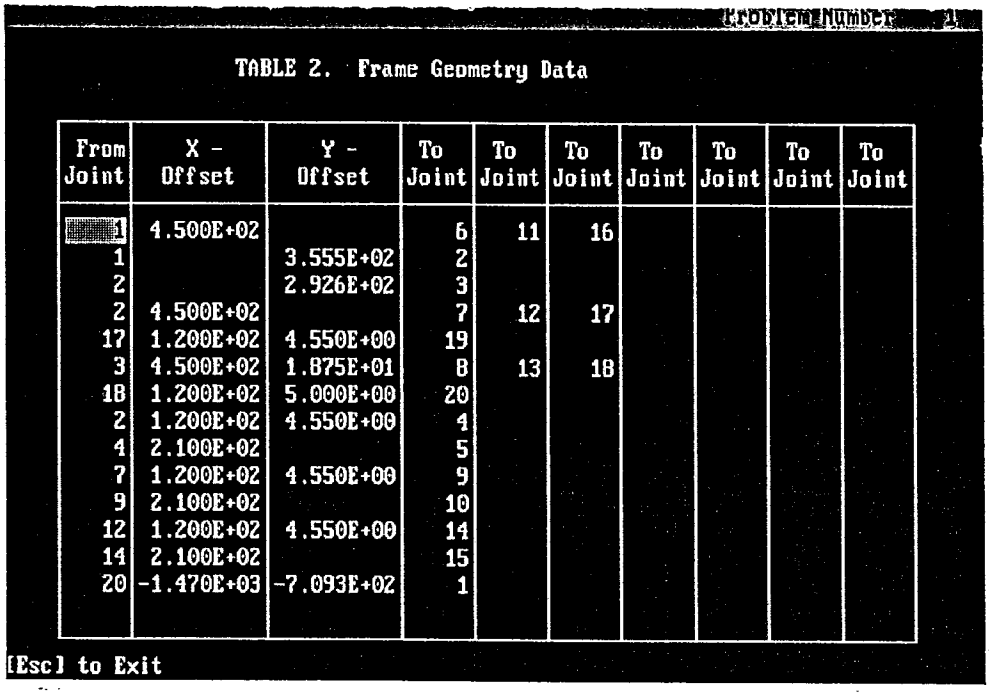


Fig. 16 Table 2 - Input File, First Card



From Joint	X - Offset	Y - Offset	To Joint	To Joint	To Joint	To Joint	To Joint	To Joint	To Joint
1	4.500E+02		6	11	16				
1		3.555E+02	2						
2		2.926E+02	3						
2	4.500E+02		7	12	17				
17	1.200E+02	4.550E+00	19						
3	4.500E+02	1.875E+01	8	13	18				
18	1.200E+02	5.000E+00	20						
2	1.200E+02	4.550E+00	4						
4	2.100E+02		5						
7	1.200E+02	4.550E+00	9						
9	2.100E+02		10						
12	1.200E+02	4.550E+00	14						
14	2.100E+02		15						
20	-1.470E+03	-7.093E+02	1						

Fig. 17 Table 2 - Input File, 2nd and Succeeding Cards

17	120.0	4.55	19		
3	450.0	18.75	8	13	18
18	120.0	5.00	20		
2	120.0	4.55	4		
4	210.0		5		
7	120.0	4.55	9		
9	210.0		10		
12	120.0	4.55	14		
14	210.0		15		
20	-1470.0	-709.30	1		

TABLE 3 Member Type Location - Enter the following data for the first card of Table 3 (Fig. 18):

Number of Stiffness Types 10
Number of Load Types 11
Number of Elements per Member 20

After completing this information, press [Esc] key to access the table containing the 2nd and succeeding cards for Table 3. Enter the following data in this table (Fig. 19):

From Joint	Stiffness Type	Load Type	To Joint	To Joint	To Joint	To Joint	To Joint	To Joint	To Joint
1	1	1	2						
6	1	2	7						
11	1	2	12						
16	1	2	17						
2	2	3	3						
7	3	4	8						
12	4	5	13						
17	5	6	18						
3	6	7	8	13	18				
18	7	8	20						
2	8	9	4						
4	9	10	5						
5	10	11	7						
7	8	9	9						
9	9	10	10						
10	10	11	12						
12	8	9	14						
14	9	10	15						
15	10	11	17						
17	8	9	19						

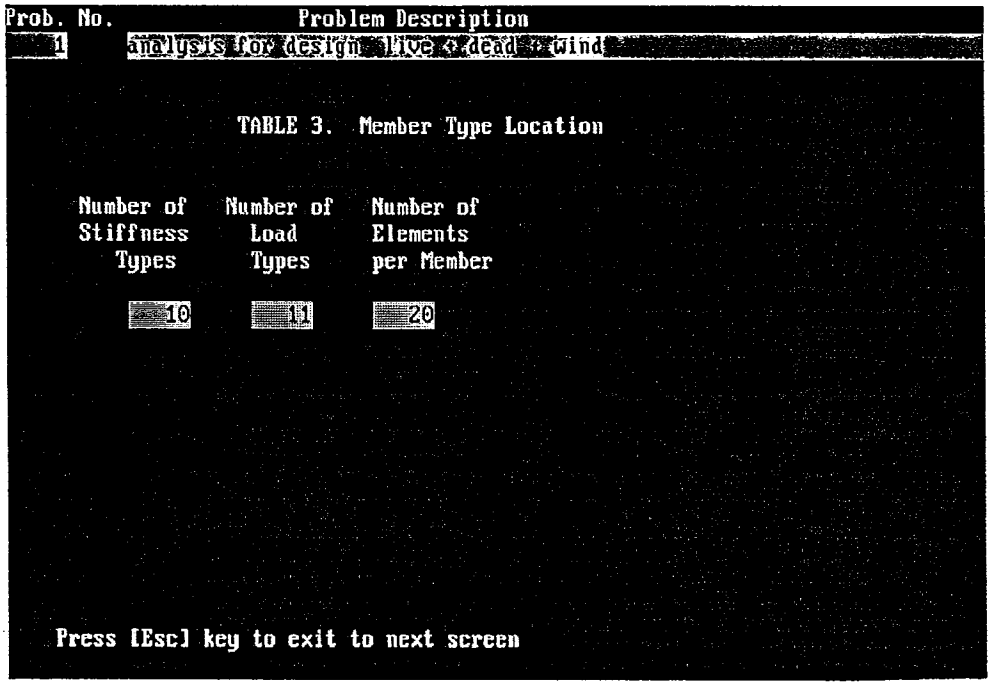


Fig. 18 Table 3 - Input File, First Card

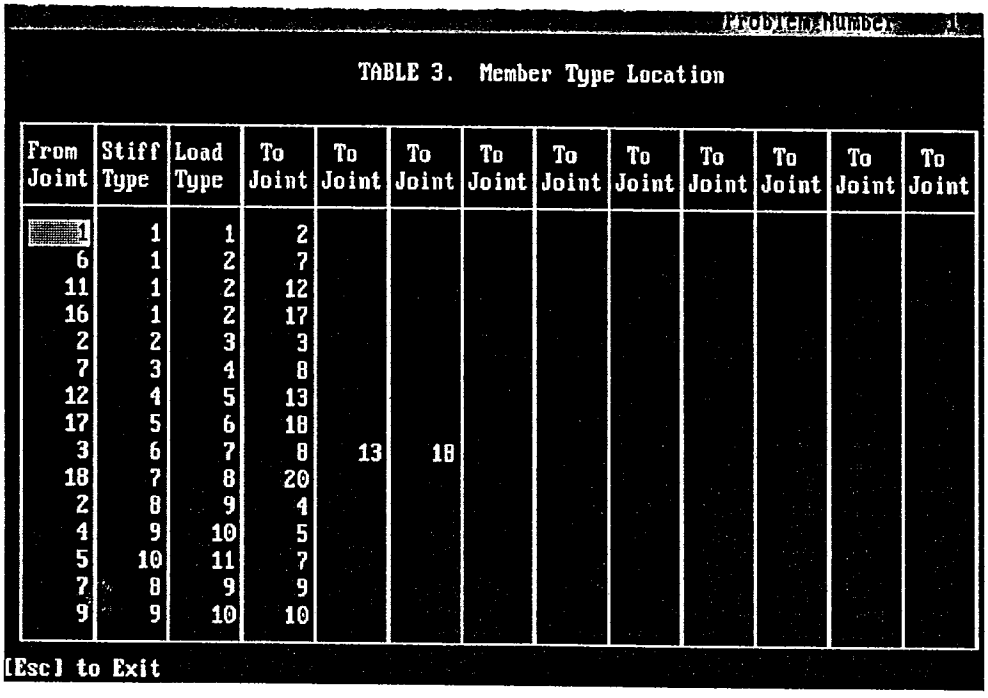


Fig. 19 Table 3 - Input File, 2nd and Succeeding Cards

TABLE 4A Joint Loads and Supports (Linear Restraints) - Enter the following data for Table 4A (Fig. 20):

Joint	Load // to x	Load // to y	Moment about z	Restraint // to x	Restraint // to y	Rotational Restraint about z
2	-17.0					
7	-17.0					
12	-17.0					
17	-17.0					
3	-12.0					
8	-12.0					
13	-12.0					
18	-12.0					
1				1.0E+20	1.0E+20	1.0E+20
6					1.0E+20	
11					1.0E+20	
16				1.0E+20	1.0E+20	1.0E+20

TABLE 4B Nonlinear Joint Supports - Enter the following data for Table 4B (Fig. 21):

Joint	Q-Mult	W-Mult	// to x	// to about y	// to z	// to x"	Stiff y"Type
6	1.0	0.01					
11	1.0	0.01					

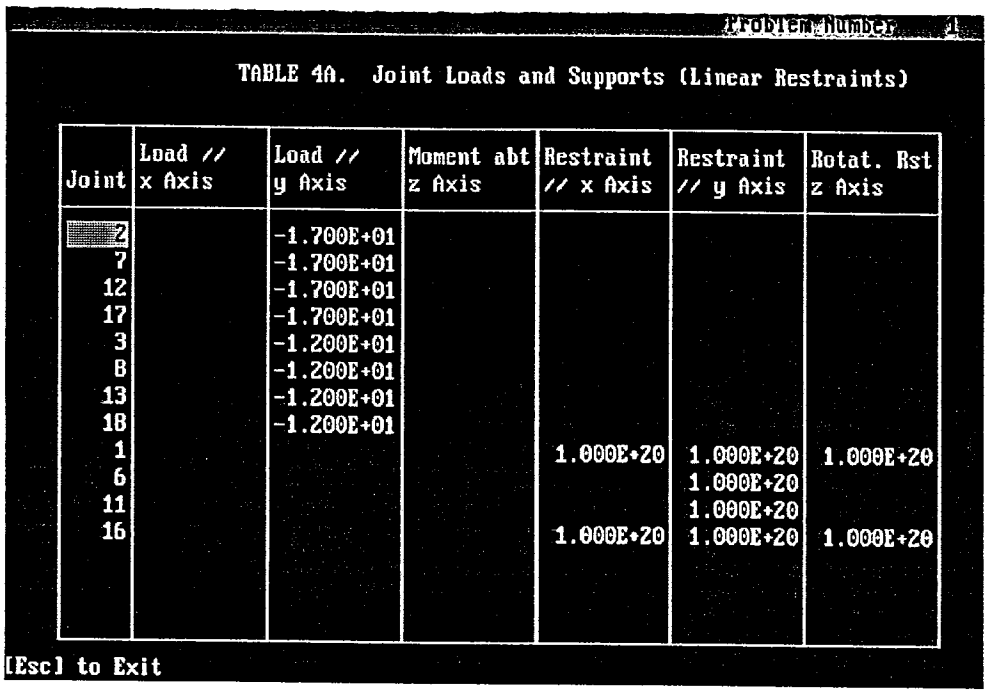
TABLE 4C Nonlinear Support Curves - This table is divided into two parts. The first screen is used for Q-values (Fig. 22) and the second screen for W-values (Fig. 23). For the first screen enter the following data:

Curve Number	Number of Points	Symmetry Option	Q-Values				
1	5	1	0	-5	-10	-15	-15

Once this information is completed, access the second part of Table 4C by pressing [Esc] key and enter the following data:

W-Values				
0	25	100	300	1000

TABLE 5A Member Stiffness Types - This table is divided into three subtables. The first screen is used to enter the first card of each data set in Table 5A. The second screen is used for the 2nd and succeeding cards of each set if the nonlinear option is left blank in the first card of the set. The third screen is for the 2nd and succeeding cards of each set if the nonlinear option is specified to be one (1) in the first card of the set.



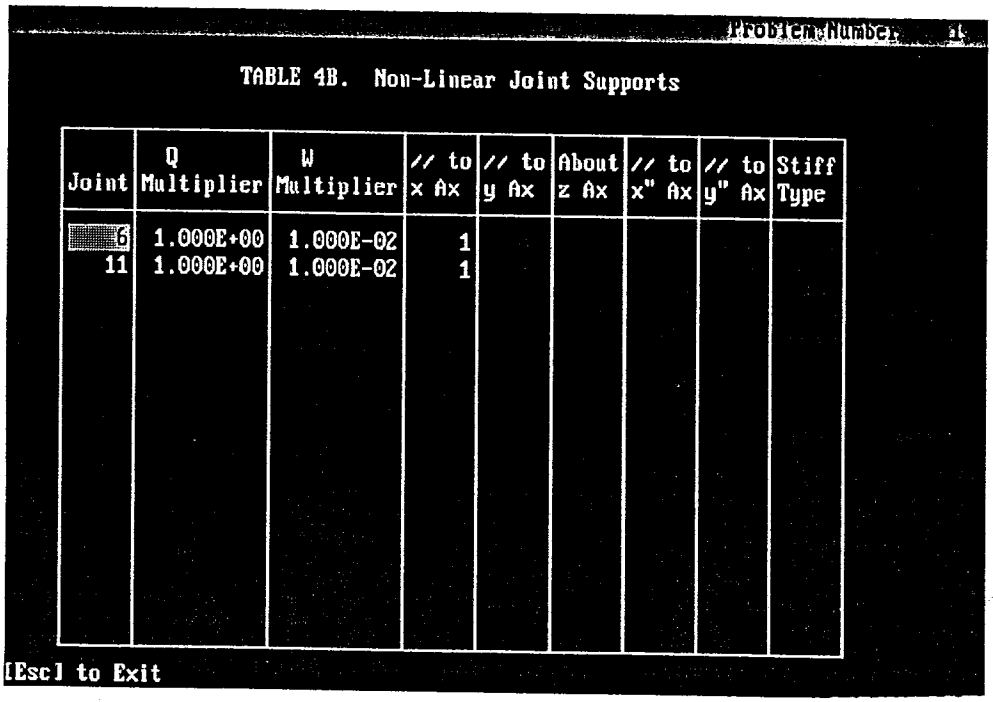
Problem Number 1

TABLE 4A. Joint Loads and Supports (Linear Restraints)

Joint	Load // x Axis	Load // y Axis	Moment abt z Axis	Restraint // x Axis	Restraint // y Axis	Rotat. Rst z Axis
2		-1.700E+01				
7		-1.700E+01				
12		-1.700E+01				
17		-1.700E+01				
3		-1.200E+01				
8		-1.200E+01				
13		-1.200E+01				
18		-1.200E+01				
1				1.000E+20	1.000E+20	1.000E+20
6					1.000E+20	
11					1.000E+20	
16				1.000E+20	1.000E+20	1.000E+20

[Esc] to Exit

Fig. 20 Table 4A - Input File



Problem Number 1

TABLE 4B. Non-Linear Joint Supports

Joint	Q Multiplier	W Multiplier	// to x Ax	// to y Ax	About z Ax	// to x" Ax	// to y" Ax	Stiff Type
6	1.000E+00	1.000E-02	1					
11	1.000E+00	1.000E-02	1					

[Esc] to Exit

Fig. 21 Table 4B - Input File

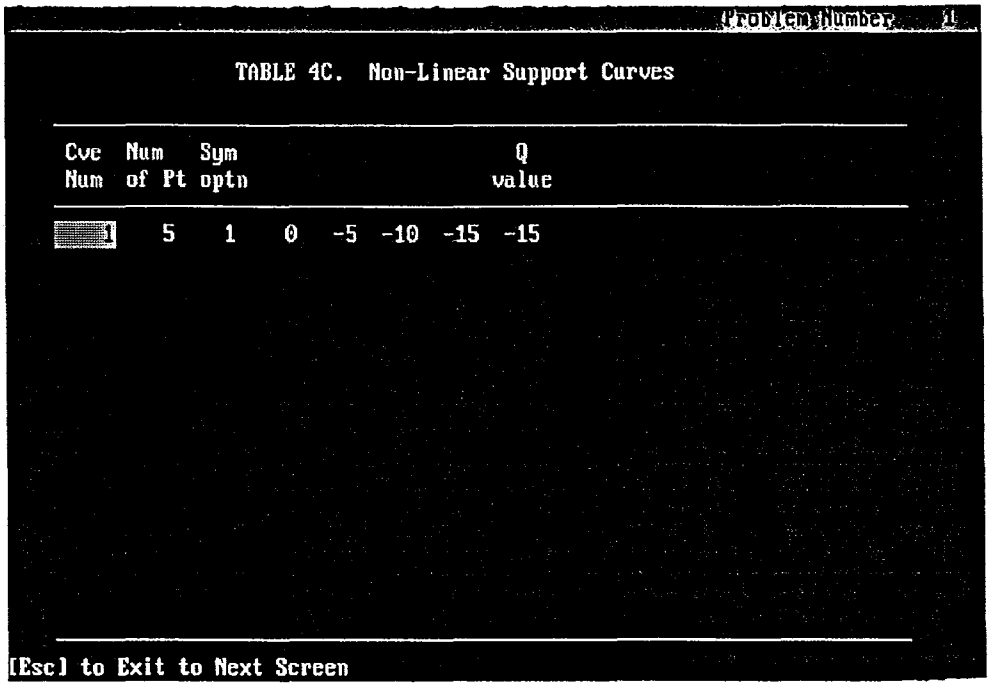


Fig. 22 Table 4C - Input File, Q Values

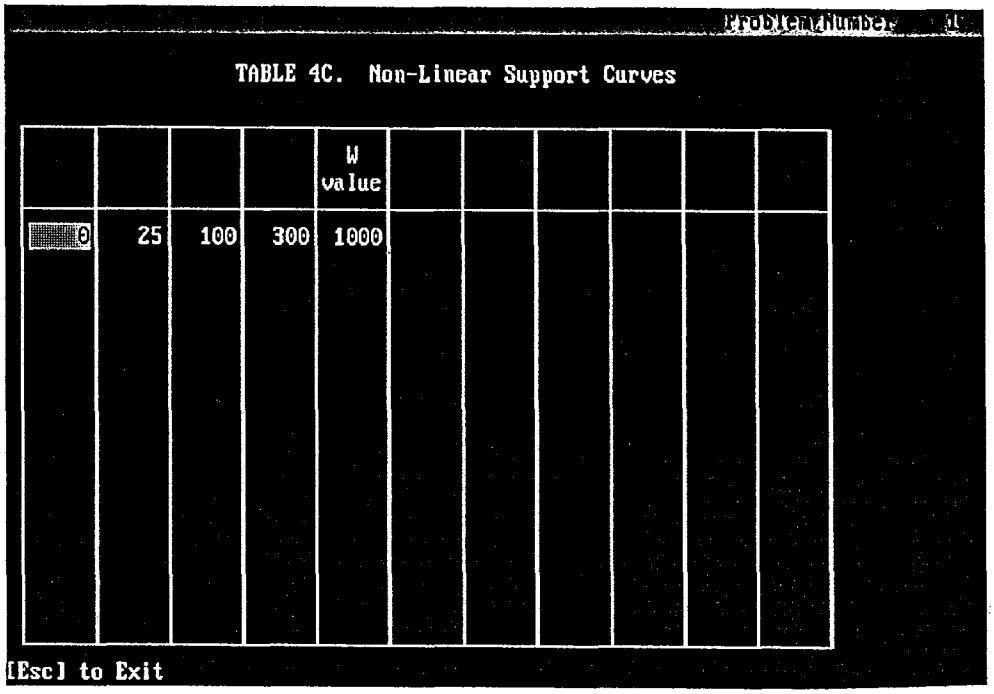


Fig. 23 Table 4C - Input File, W Values

If Table 5A is selected, the user is prompted for choice of a subtable (Fig. 24). Select one (1) to enter the first cards of each set and enter the following data (Fig. 25):

Stiffness Type	Modulus of Elasticity	Prismatic Moment of Inertia	Prismatic Area	Nonlinear Option	Num cards follow	Axis Optn	Output Optn	From Jnt	To Jnt
1				1	1	1			
2				1	1	1			
3				1	1	1	1		
4				1	1	1	1		
5				1	1	1	1		
6	3.00E+4	3266.7	27.65	0	0	1			
7	3.00E+4	3266.7	27.65	0	0	1			
8				1	1	1			
9				1	1	1			
10				1	1	1			

After completing this screen, press [Esc] key to return to the Edit/Input submenu. Select Table 5A again and at the subtable prompt screen enter three (3) (there is no data for subtable 2 because the number of succeeding cards were specified to be zero for all members with the nonlinear option left blank). Enter the following data in this subtable (Fig. 26):

Cross Section Number	q-w Curve Numbers x", x y", y z"	Cross Section Number	q-w Curve Numbers x", x y", y z"	q-mult	w-mult
1		1			
2		2			
2		2			
2		2			
2		2			
4		5			
3		3			
5		4			

TABLE 5B Cross Section Properties - This table is also divided into two parts. Part one is used for the first card of each data set and the second part for the 2nd and succeeding cards of these data sets. Invoke Table 5B and select one (1) at the subtable prompt screen. Enter the following data at the first screen (Fig. 27):

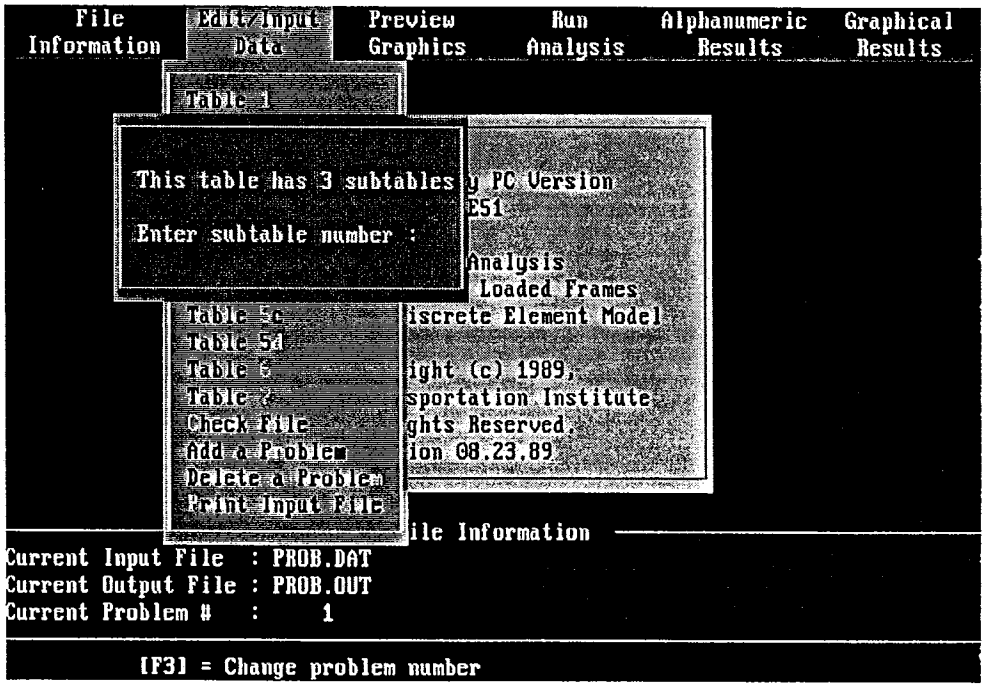
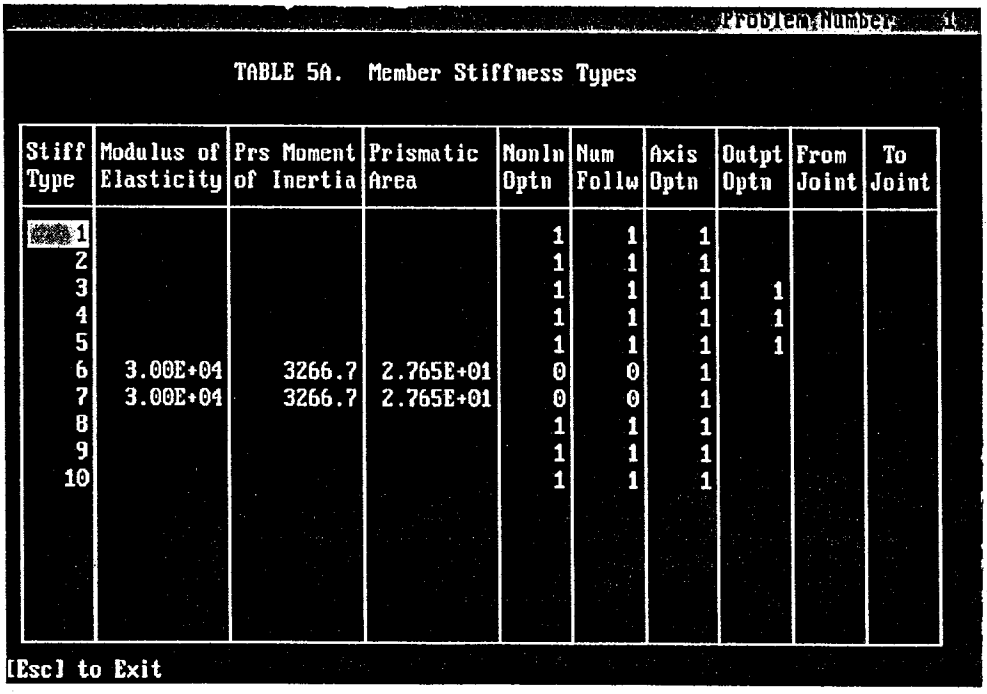


Fig. 24 Subtable Selection Screen



Stiff Type	Modulus of Elasticity	Prs Moment of Inertia	Prismatic Area	Nonln Optn	Num Follw	Axis Optn	Outpt Optn	From Joint	To Joint
1				1	1	1			
2				1	1	1			
3				1	1	1	1		
4				1	1	1	1		
5				1	1	1	1		
6	3.00E+04	3266.7	2.765E+01	0	0	1			
7	3.00E+04	3266.7	2.765E+01	0	0	1			
8				1	1	1			
9				1	1	1			
10				1	1	1			

Fig. 25 Table 5A - Input File, First Card of Each Set

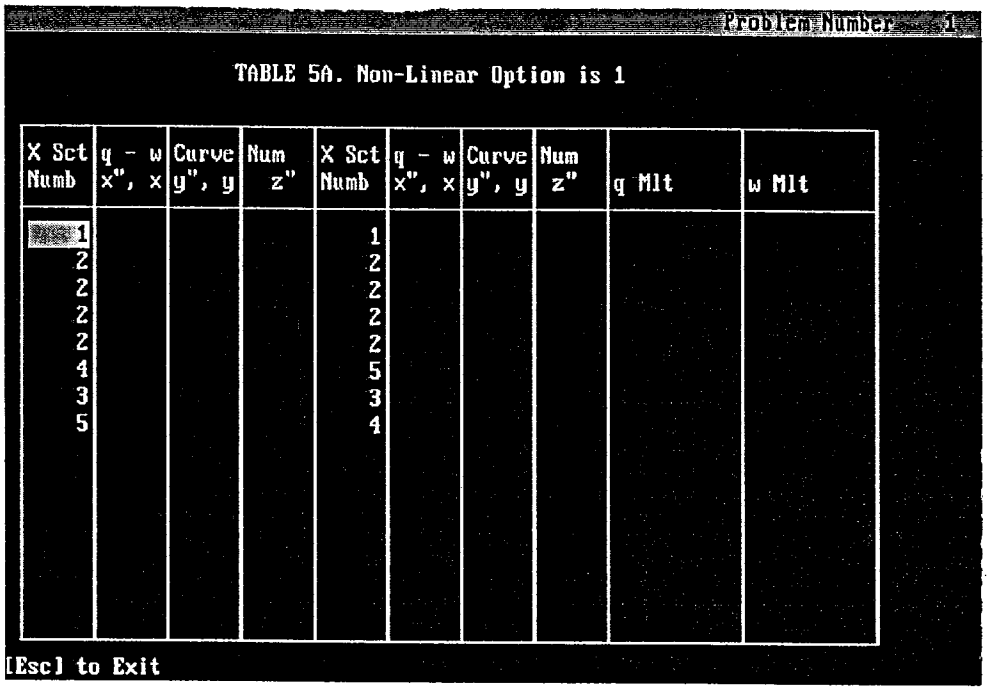


Fig. 26 Table 5A - Input File, Nonlinear Option is 1

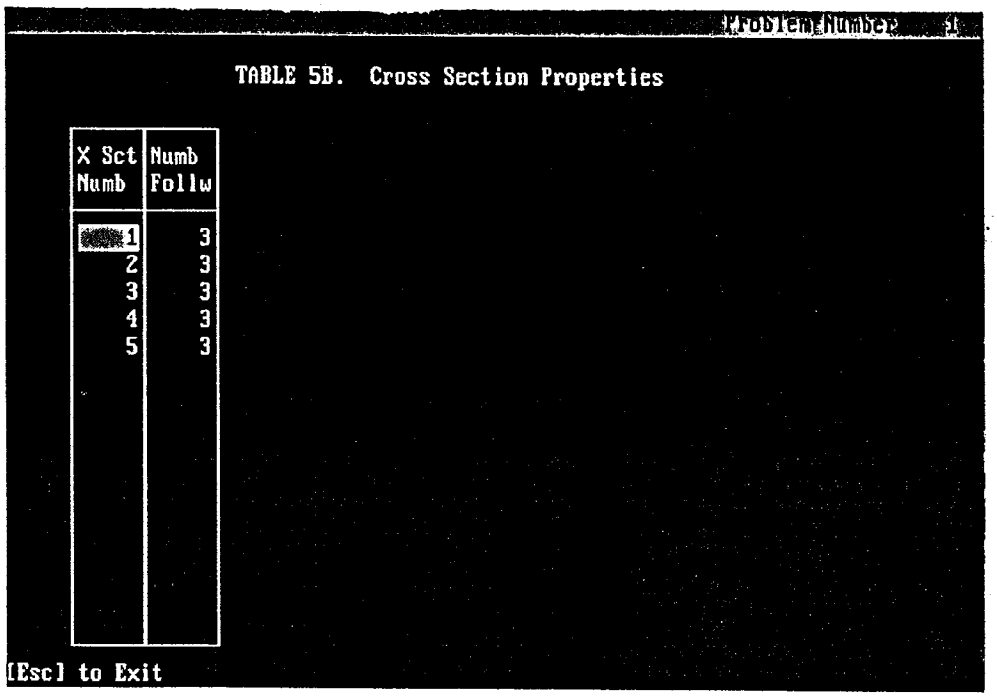


Fig. 27 Table 5B - Input File, First Card of Each Set

Cross Section Number	Number Cards Follow
1	3
2	3
3	3
4	3
5	3

After completing this screen, press [Esc] key to return to Edit/Input submenu. Invoke Table 5B and select two (2) at the subtable prompt screen. Enter the following data (Fig. 28):

Width or Outside Diameter	Depth or Thickness	Centroidal Distance	Area Optn	Curve Number	Stress Mult	Strn Mult
15.55	1.188	6.906		1	1.0	1.0E04
15.55	1.188	-6.906		1	1.0	1.0E04
.730	12.62			1	1.0	1.0E04
12.02	.778	6.700		1	1.0	1.0E04
12.02	.778	-6.700		1	1.0	1.0E04
.451	12.62			1	1.0	1.0E04
9.99	.747	13.08		1	1.0	1.0E04
9.99	.747	-13.08		1	1.0	1.0E04
.49	25.42			1	1.0	1.0E04
10.00	.75	17.625		1	1.0	1.0E04
10.00	.75	-17.625		1	1.0	1.0E04
.75	34.50			1	1.0	1.0E04
10.00	.75	13.08		1	1.0	1.0E04
10.00	.75	-13.08		1	1.0	1.0E04

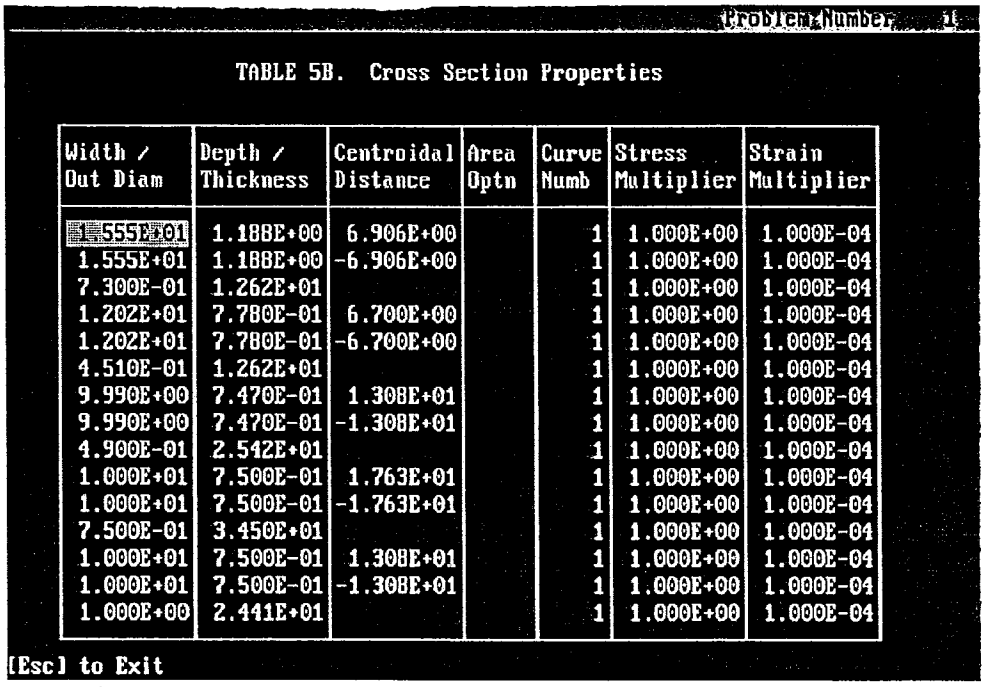
TABLE 5C Stress-Strain Curves - This table is divided into two parts. The first screen is used for stress values (Fig. 29) and the second screen for strain values (Fig. 30). For the first screen enter the following data:

Curve Number	Number of Points	Symmetry Option	Stress Values	
1	2	1	0	24

Once this information is completed, access the second part of Table 4C by pressing [Esc] key and enter the following data:

Strain Values	
0	8

TABLE 6 Member Load Data - This table is divided into four subtables. The first screen is used for entering the first card of each data set in Table 6. The



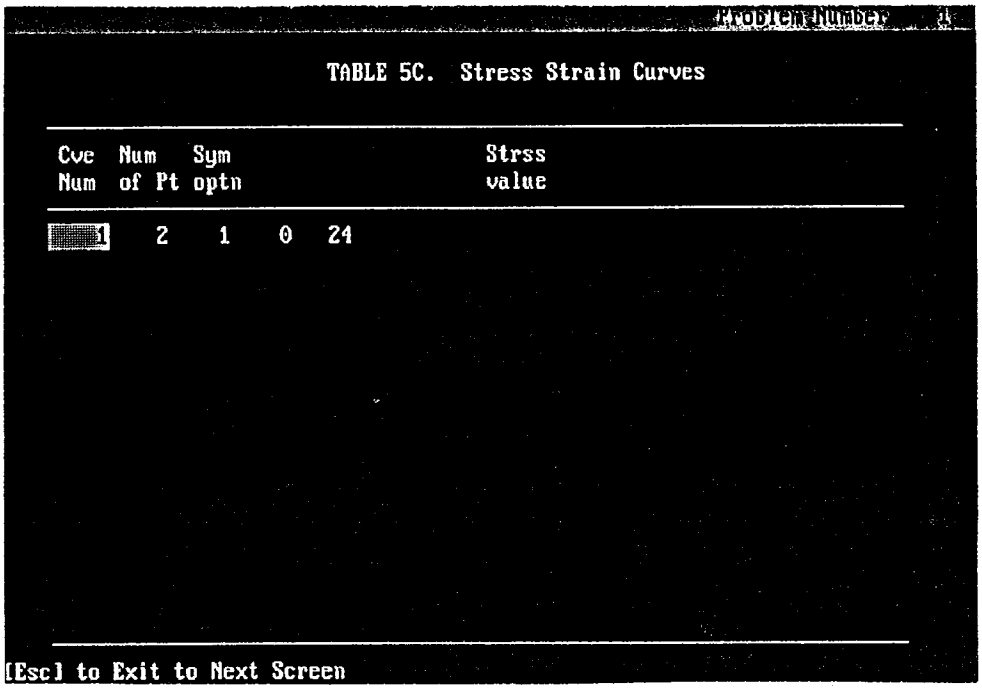
Problem Number 1

TABLE 5B. Cross Section Properties

Width / Out Diam	Depth / Thickness	Centroidal Distance	Area Optn	Curve Numb	Stress Multiplier	Strain Multiplier
1.555E+01	1.188E+00	6.906E+00		1	1.000E+00	1.000E-04
1.555E+01	1.188E+00	-6.906E+00		1	1.000E+00	1.000E-04
7.300E-01	1.262E+01			1	1.000E+00	1.000E-04
1.202E+01	7.780E-01	6.700E+00		1	1.000E+00	1.000E-04
1.202E+01	7.780E-01	-6.700E+00		1	1.000E+00	1.000E-04
4.510E-01	1.262E+01			1	1.000E+00	1.000E-04
9.990E+00	7.470E-01	1.308E+01		1	1.000E+00	1.000E-04
9.990E+00	7.470E-01	-1.308E+01		1	1.000E+00	1.000E-04
4.900E-01	2.542E+01			1	1.000E+00	1.000E-04
1.000E+01	7.500E-01	1.763E+01		1	1.000E+00	1.000E-04
1.000E+01	7.500E-01	-1.763E+01		1	1.000E+00	1.000E-04
7.500E-01	3.450E+01			1	1.000E+00	1.000E-04
1.000E+01	7.500E-01	1.308E+01		1	1.000E+00	1.000E-04
1.000E+01	7.500E-01	-1.308E+01		1	1.000E+00	1.000E-04
1.000E+00	2.441E+01			1	1.000E+00	1.000E-04

[Esc] to Exit

Fig. 28 Table 5B - Input File, 2nd and Succeeding Cards



Problem Number 1

TABLE 5C. Stress Strain Curves

Cve Num	Num of Pt	Sym optn			Strss value
1	2	1	0	24	

[Esc] to Exit to Next Screen

Fig. 29 Table 5C - Input File, Stress Values

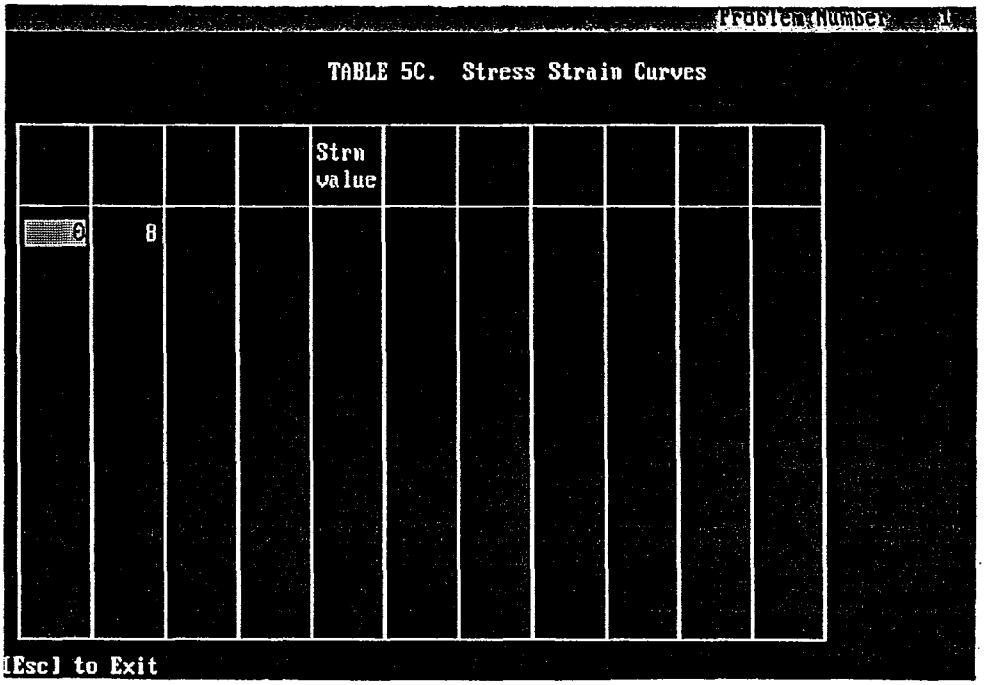


Fig. 30 Table 5C, Strain Values

second screen is used for the 2nd and succeeding cards of each set if the axis option has been specified as one (1) in the first card of the set. The third screen is used for the 2nd and succeeding cards of each set if the axis option has been specified as two (2) in the first card of the set. The fourth screen is used for the 2nd and succeeding cards of each set if the axis option has been specified as three (1) in the first card of the set.

If Table 6 is selected, the user is prompted for choice of a subtable. Select one (1) to enter the first cards of each set and enter the following data (Fig. 31):

Load Type	% increase in Load	Uniform Load // to x"	Uniform Load // to y"	Number Cards Follow	Axis Optn
1		-0.013	-0.0833	0	1
2		-0.013		0	1
3		-0.007	-0.0833	0	1
4		-0.007		0	1
5		-0.007		0	1
6		-0.007		0	1
7				5	2
8				2	2
9				2	3
10				3	3
11				2	3

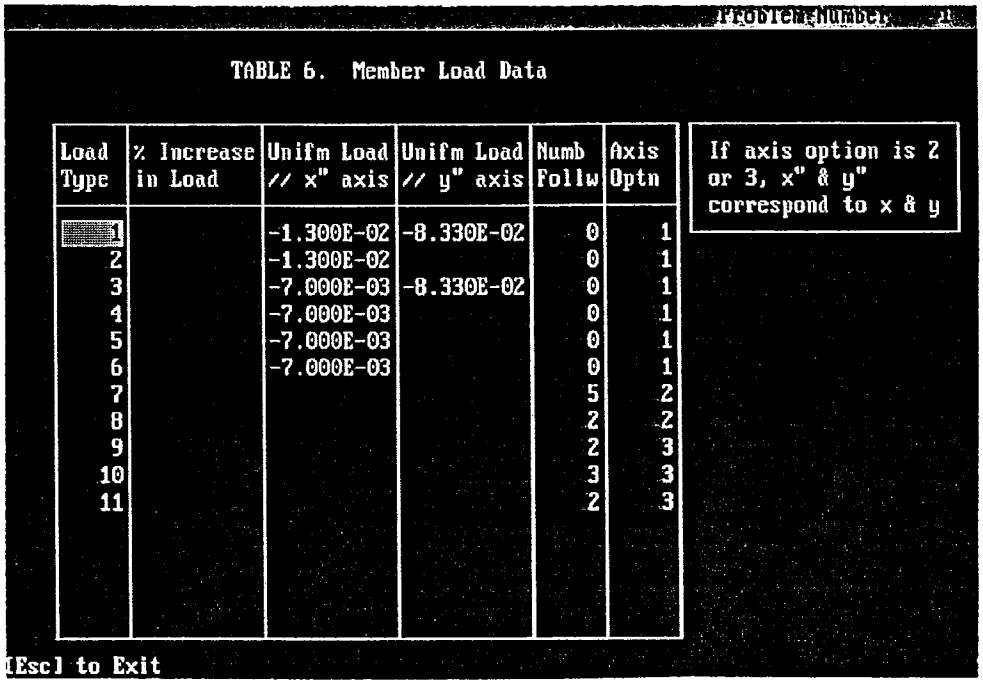


Fig. 31 Table 6 - Input File, First Card of Each Set

After completing this table, press [Esc] key to return to submenu. Select Table 6 again and enter three (3) at the subtable selection screen. Enter the following data (Fig. 32):

From (Distance along member)	To (Distance along member)	Load // x" Axis	Load // y" Axis	Moment about z" Axis
90.07	90.07		-12.0	
180.10	180.10		-12.0	
270.2	270.2		-12.0	
360.3	360.3		-12.0	
0.0	450.4		-0.2	
90.07	90.07		-12.0	
0.0	120.10		-0.2	

After completing this screen, access the fourth subtable in the manner previously described and enter the following data (Fig. 33):

Problem Number 1

Table 6. Axis Option 2

From (Dist along mem)	To (Dist along mem)	Load // to x axis	Load // to y axis	Moment abt z" axis
9.007E+01	9.007E+01		-1.200E+01	
1.801E+02	1.801E+02		-1.200E+01	
2.702E+02	2.702E+02		-1.200E+01	
3.603E+02	3.603E+02		-1.200E+01	
0.000E+00	4.504E+02		-2.000E-01	
9.007E+01	9.007E+01		-1.200E+01	
0.000E+00	1.200E+02		-2.000E-01	

[Esc] to Exit

Fig. 32 Table 6 - Input File, Axis Option is 2

Problem Number 1

Table 6. Axis Option 3

From (Dist along mem)	To (Dist along mem)	Load // to x axis	Load // to y axis	Moment abt z" axis
9.000E+01	9.000E+01		-1.700E+01	
0.000E+00	1.200E+02		-2.500E-01	
6.000E+01	6.000E+01		-1.700E+01	
1.500E+02	1.500E+02		-1.700E+01	
0.000E+00	2.100E+02		-2.500E-01	
3.000E+01	3.000E+01		-1.700E+01	
0.000E+00	1.200E+02		-2.500E-01	

[Esc] to Exit

Fig. 33 Table 6 - Input File, Axis Option is 3

From (Distance along structure)	To (Distance along structure)	Load // x Axis	Load // y Axis	Moment about z" Axis
90.00	90.00		-17.0	
0.00	120.00		-.25	
60.00	60.00		-17.0	
150.00	150.00		-17.0	
0.0	210.00		-.25	
30.00	30.00		-15.0	
0.0	120.00		-.25	

TABLE 7 Iteration Control - Enter the following data in this table (Fig. 34):

Frame Solutions					
Maximum Number of Iterations	10				
Force Error	.02				
Moment Error	10.0				
Monitor Joint Numbers	1	2	3	6	11
Member Solutions					
Maximum Number of Iterations	10				
Force Error	.002				
Moment Error	1.0				
Monitor Member Numbers	1	4	9		

STEP 3 - PREVIEW GRAPHICS

After the problem has been created, it can be visually checked for mistakes by accessing the **PREVIEW GRAPHICS** option. This option provides the user with a rapid check of the problem before the time-consuming execution process. Invoke this submenu and select the option provided.

Frame Geometry and Loadings - The graph displayed on the screen is shown in (Fig. 35). Use the [Esc] key to return to the pull-down menu.

Return control to the main menu by using the [Esc] key or [Left] and [Right] arrow keys from within the submenu as described before.

STEP 4 - RUN ANALYSIS

Select this option and execute the input file to obtain the alphanumeric output file. The current problem number being analyzed is displayed on the screen (Fig. 36). Upon completion of the run, this message is erased.

Return control to the main menu by using the [Esc] key or [Left] and [Right] arrow keys from within the submenu as described before.

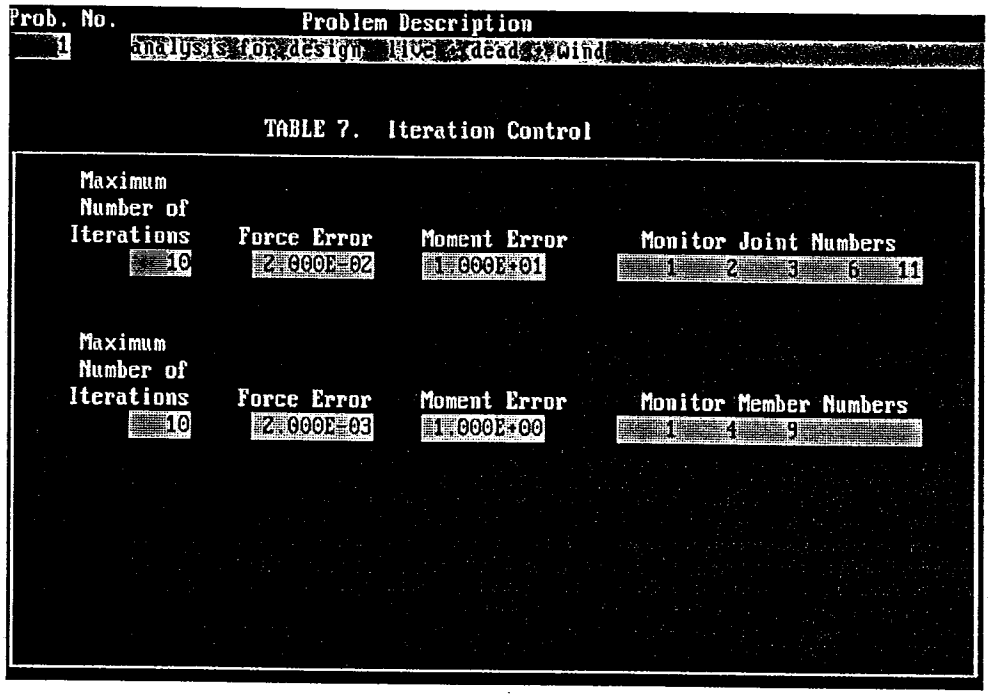


Fig. 34 Table 7 - Input File

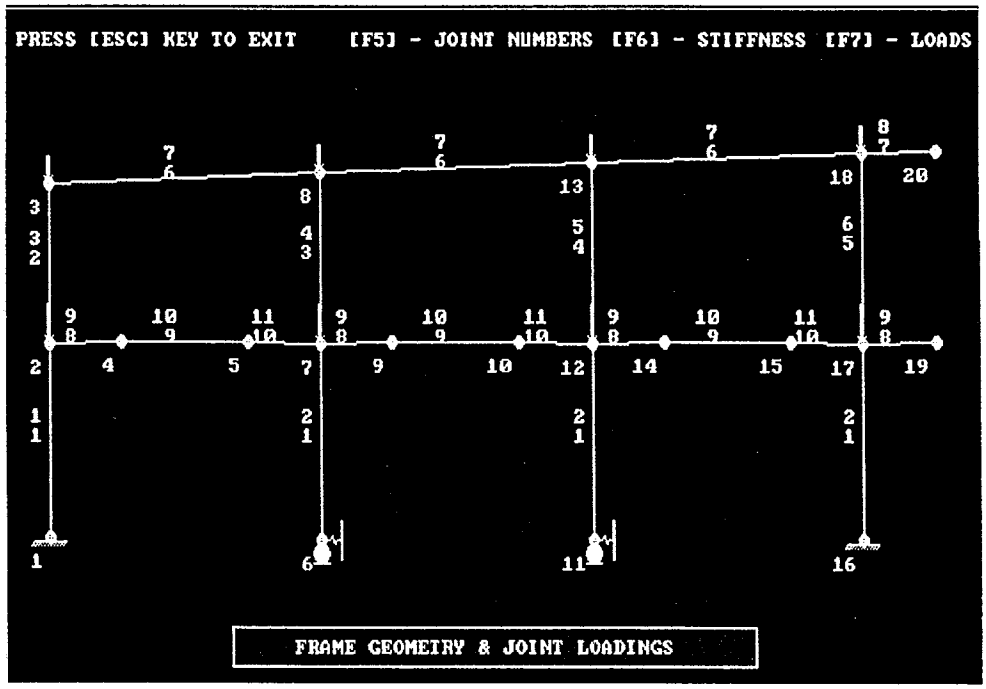


Fig. 35 Frame Geometry and Loadings

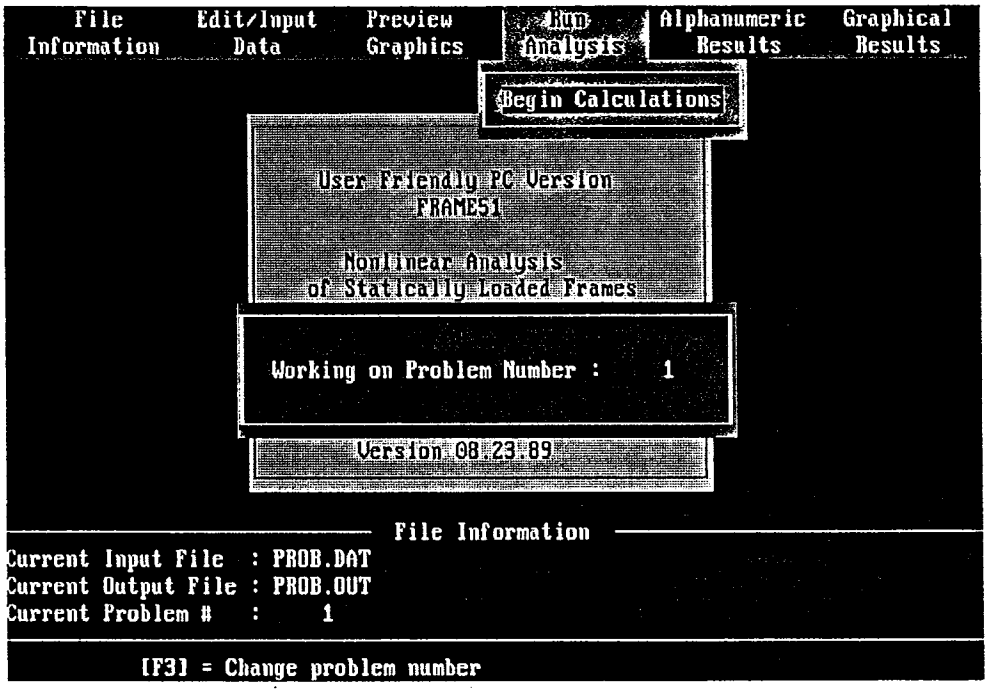


Fig. 36 Screen Display "Run Analysis"

STEP 5 - ALPHANUMERIC RESULTS

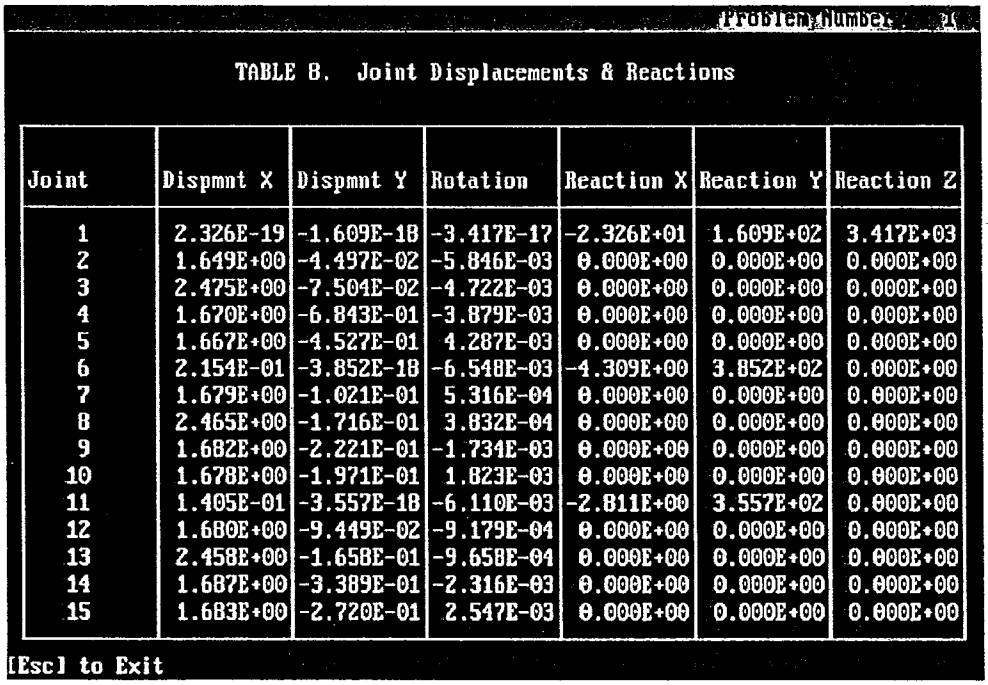
This option presents the output data from analysis in numerical form. After invoking this option, select one of the following submenu options:

Table 8 Joint Displacements & Reactions - This table is shown in Fig. 37. Use the direction arrow keys to move within this table. Pressing the [Home] key positions the screen on the first line of the table, while the [End] key positions the screen on the last line. [Page Up] and [Page Down] keys can be used to move through the table one page at a time. The [Esc] key is used to return to the previous pull-down menu.

Table 9 Member Results - Upon selecting this table, the user is prompted for the specific member whose results are desired (Fig. 38). Select member 1 at this screen. The initial table is shown in Fig. 39. Press [Esc] key and complete member results are presented (Fig. 40). If a member is selected for which complete results are not computed, only the initial screen is displayed.

Table 10 Joint Equilibrium Errors - This table is shown in Fig. 41. The same keys are used to move within this table as previously described.

Print Output File - This option is used to obtain a printout of numerical results from analysis. After this option is selected, the program displays a menu of communication ports. Select the port to which the printer is connected to obtain a printout.



Problem Number 1

TABLE 8. Joint Displacements & Reactions

Joint	Dispmnt X	Dispmnt Y	Rotation	Reaction X	Reaction Y	Reaction Z
1	2.326E-19	-1.609E-18	-3.417E-17	-2.326E+01	1.609E+02	3.417E+03
2	1.649E+00	-4.497E-02	-5.846E-03	0.000E+00	0.000E+00	0.000E+00
3	2.475E+00	-7.504E-02	-4.722E-03	0.000E+00	0.000E+00	0.000E+00
4	1.670E+00	-6.843E-01	-3.879E-03	0.000E+00	0.000E+00	0.000E+00
5	1.667E+00	-4.527E-01	4.287E-03	0.000E+00	0.000E+00	0.000E+00
6	2.154E-01	-3.852E-18	-6.548E-03	-4.309E+00	3.852E+02	0.000E+00
7	1.679E+00	-1.021E-01	5.316E-04	0.000E+00	0.000E+00	0.000E+00
8	2.465E+00	-1.716E-01	3.832E-04	0.000E+00	0.000E+00	0.000E+00
9	1.682E+00	-2.221E-01	-1.734E-03	0.000E+00	0.000E+00	0.000E+00
10	1.678E+00	-1.971E-01	1.823E-03	0.000E+00	0.000E+00	0.000E+00
11	1.405E-01	-3.557E-18	-6.110E-03	-2.811E+00	3.557E+02	0.000E+00
12	1.680E+00	-9.449E-02	-9.179E-04	0.000E+00	0.000E+00	0.000E+00
13	2.458E+00	-1.658E-01	-9.658E-04	0.000E+00	0.000E+00	0.000E+00
14	1.687E+00	-3.389E-01	-2.316E-03	0.000E+00	0.000E+00	0.000E+00
15	1.683E+00	-2.720E-01	2.547E-03	0.000E+00	0.000E+00	0.000E+00

[Esc] to Exit

Fig. 37 Table 8 - Joint Displacements and Reactions

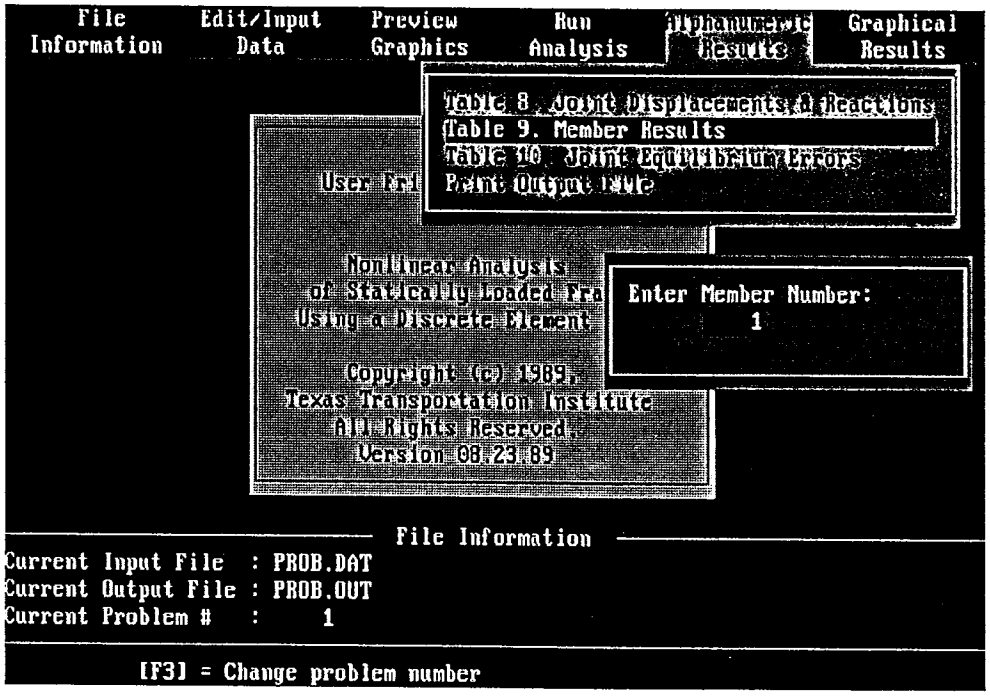


Fig. 38 Table 9 - Member Selection Screen

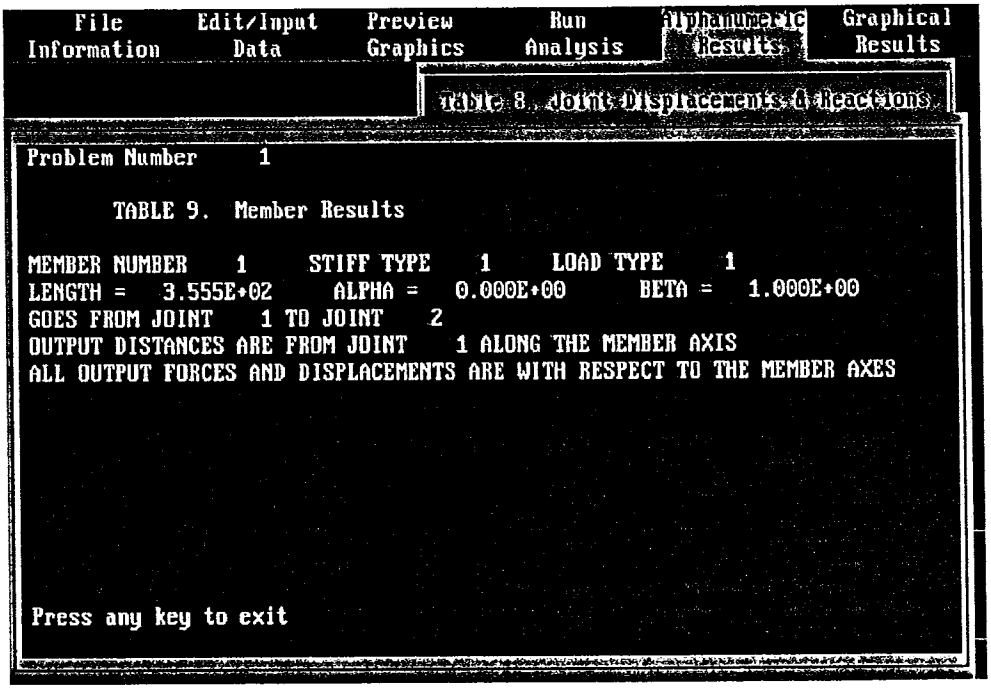
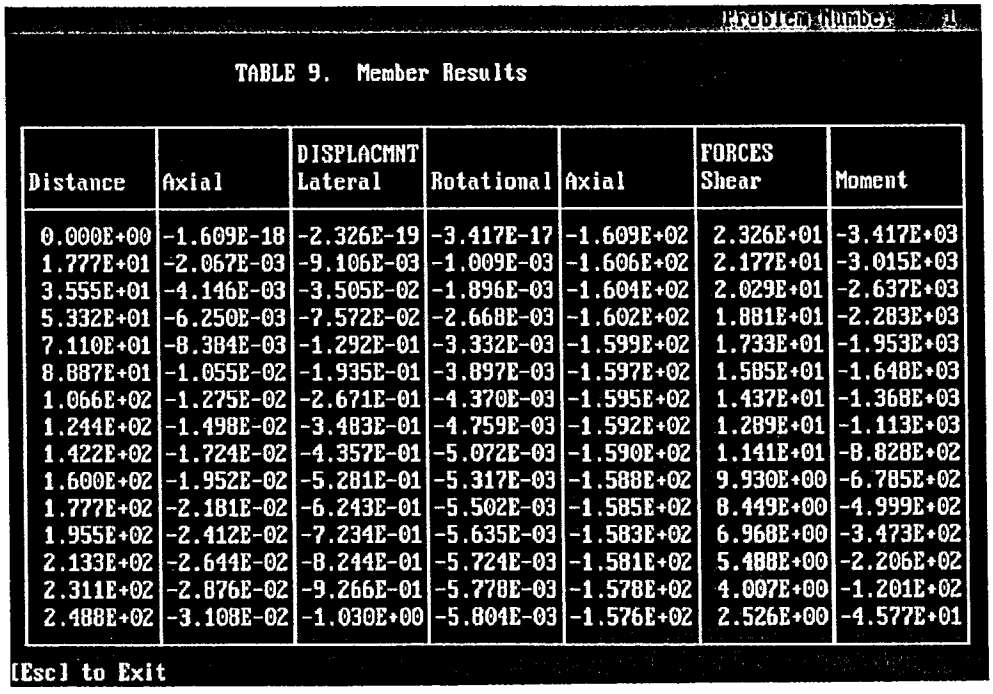


Fig. 39 Table 9 - End Results



Problem Number 1

TABLE 9. Member Results

Distance	Axial	DISPLACMNT Lateral	Rotational	Axial	FORCES Shear	Moment
0.000E+00	-1.609E-18	-2.326E-19	-3.417E-17	-1.609E+02	2.326E+01	-3.417E+03
1.777E+01	-2.067E-03	-9.106E-03	-1.009E-03	-1.606E+02	2.177E+01	-3.015E+03
3.555E+01	-4.146E-03	-3.505E-02	-1.896E-03	-1.604E+02	2.029E+01	-2.637E+03
5.332E+01	-6.250E-03	-7.572E-02	-2.668E-03	-1.602E+02	1.881E+01	-2.283E+03
7.110E+01	-8.384E-03	-1.292E-01	-3.332E-03	-1.599E+02	1.733E+01	-1.953E+03
8.887E+01	-1.055E-02	-1.935E-01	-3.897E-03	-1.597E+02	1.585E+01	-1.648E+03
1.066E+02	-1.275E-02	-2.671E-01	-4.370E-03	-1.595E+02	1.437E+01	-1.368E+03
1.244E+02	-1.498E-02	-3.483E-01	-4.759E-03	-1.592E+02	1.289E+01	-1.113E+03
1.422E+02	-1.724E-02	-4.357E-01	-5.072E-03	-1.590E+02	1.141E+01	-8.828E+02
1.600E+02	-1.952E-02	-5.281E-01	-5.317E-03	-1.588E+02	9.930E+00	-6.785E+02
1.777E+02	-2.181E-02	-6.243E-01	-5.502E-03	-1.585E+02	8.449E+00	-4.999E+02
1.955E+02	-2.412E-02	-7.234E-01	-5.635E-03	-1.583E+02	6.968E+00	-3.473E+02
2.133E+02	-2.644E-02	-8.244E-01	-5.724E-03	-1.581E+02	5.488E+00	-2.206E+02
2.311E+02	-2.876E-02	-9.266E-01	-5.778E-03	-1.578E+02	4.007E+00	-1.201E+02
2.488E+02	-3.108E-02	-1.030E+00	-5.804E-03	-1.576E+02	2.526E+00	-4.577E+01

[Esc] to Exit

Fig. 40 Table 9 - Complete Results

Problem Number 1

TABLE 10. Joint Equilibrium Errors

Joint	Error (X) Force	Error (Y) Force	Error (Z) Moment
1	-3.928E-06	2.161E-04	1.503E-04
2	-1.275E-05	-1.510E-04	-8.541E-05
3	-3.102E-06	-7.844E-06	6.827E-06
4	-6.631E-05	8.830E-06	-9.807E-05
5	1.439E-04	1.817E-05	1.185E-04
6	9.754E-05	-1.118E-02	2.997E-03
7	-1.984E-04	-1.401E-02	-7.682E-03
8	-8.398E-07	-2.402E-05	-8.341E-06
9	-1.224E-04	1.425E-05	-9.252E-05
10	1.158E-05	1.924E-05	1.360E-04
11	-1.074E-05	-1.354E-04	2.788E-05
12	-3.622E-05	-1.903E-04	3.202E-04
13	-5.023E-07	-2.082E-06	1.207E-06
14	-5.903E-06	-1.334E-06	-2.794E-06
15	1.916E-07	-2.130E-06	-1.970E-05

[Esc] to Exit

Fig. 41 Table 10 - Joint Equilibrium Errors

STEP 6 - GRAPHICAL RESULTS

Invoke the submenu to begin this option. Choose the graph desired from the options provided.

Joint Displacements & Reactions

Select this option. The graph displayed on the screen is shown in Fig. 42.

Member Results

Select this option. The program will again prompt the user for the number of the member desired, as described in the alphanumeric results option. If complete results are not computed for the member selected, the program will display a message to this effect.

Select member 1. A graph selection menu is displayed.

1. **Axial Displacements** - The graph displayed on the screen is shown in Fig. 43.
2. **Lateral Displacements** - The graph displayed on the screen is shown in Fig. 44.
3. **Rotational Displacements** - The graph displayed on the screen is shown in Fig. 45.

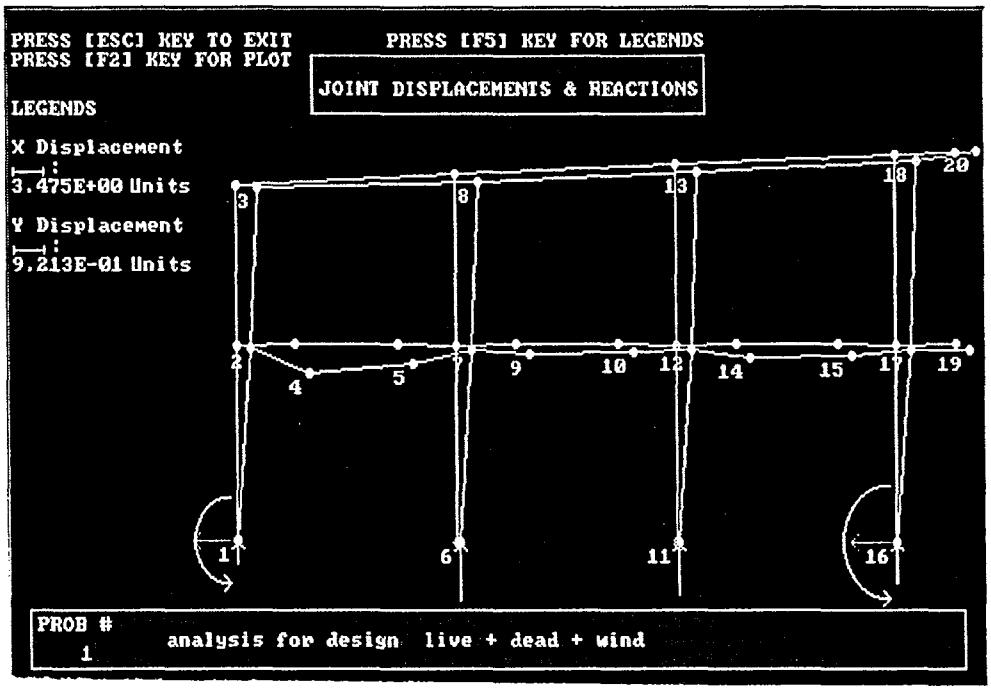


Fig. 42 Joint Displacements and Reactions

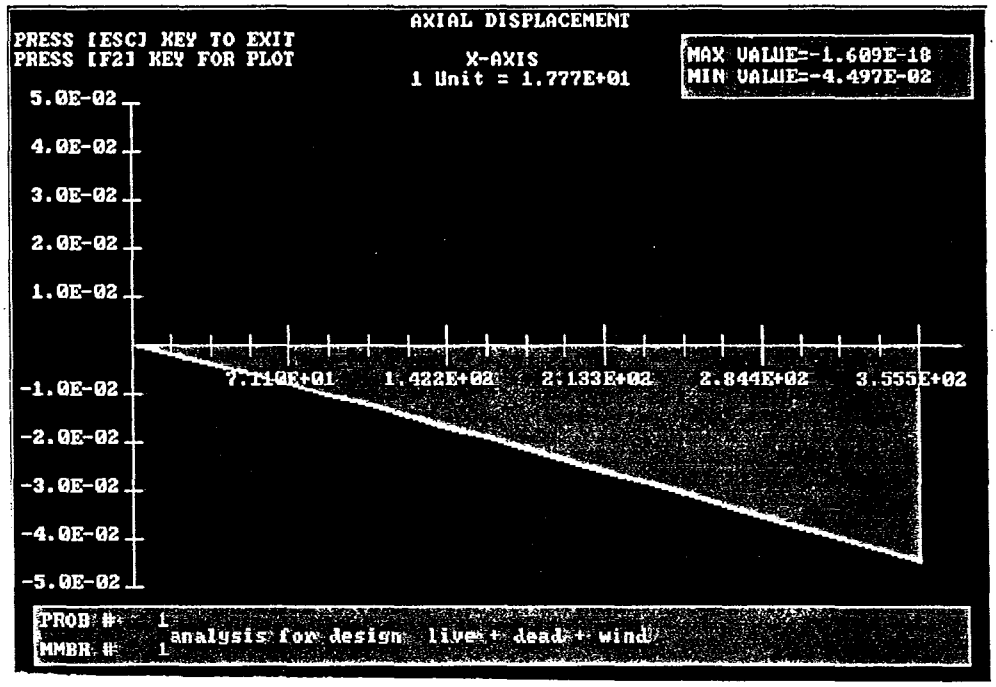


Fig. 43 Member Results - Axial Displacements

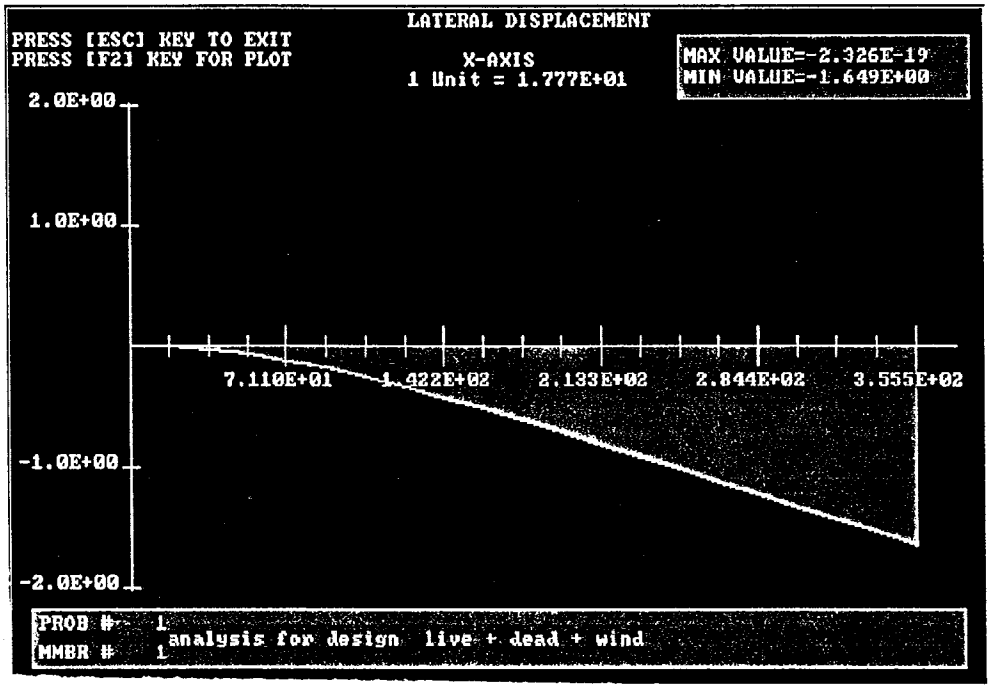


Fig. 44 Member Results - Lateral Displacements

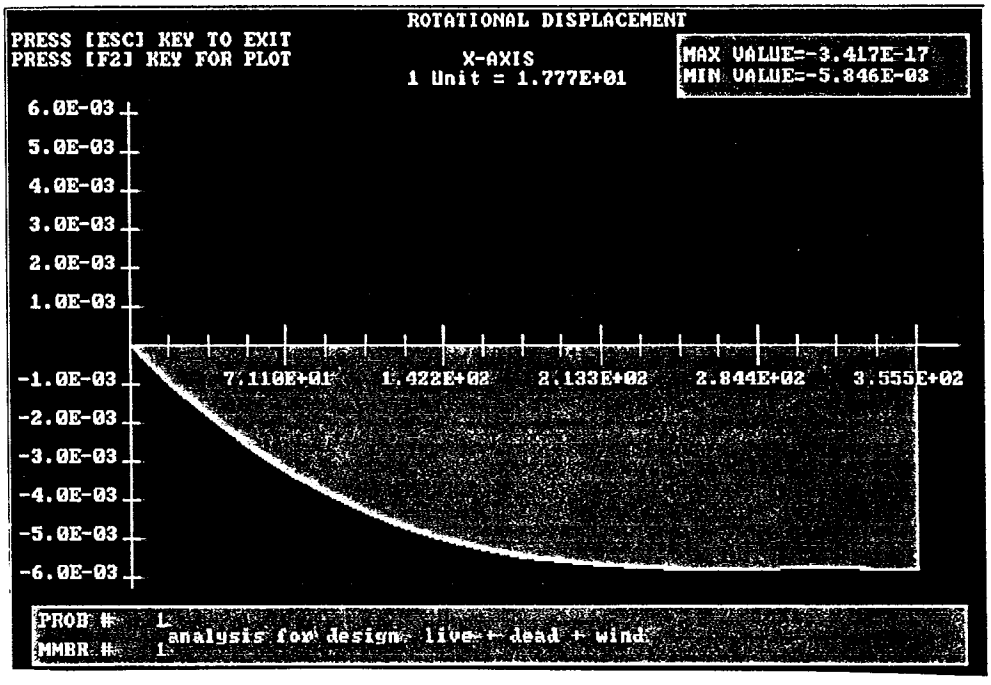


Fig. 45 Member Results - Rotational Displacements

4. **Axial Forces** - The graph displayed on the screen is shown in Fig. 46.
5. **Shear Forces** - The graph displayed on the screen is shown in Fig. 47.
6. **Moments** - The graph displayed on the screen is shown in Fig. 48.

HARDCOPY PLOTS

Hardcopy plots can be obtained once a graph is displayed on the screen. The procedure will be outlined for the Joint Displacements and Reactions graph. The same procedure applies to all types of graphs.

Select this option. The graph will be displayed on the screen as before. Press [F2] key to select plotting options. The graph on the screen will be replaced by a plotting options menu. Three choices are available as to the kind of hardcopy desired. Select one of these options according to the following:

Screen Dump - Once this option is selected, a second menu will appear specifying printer names supported by the software. Select the type of printer connected to the computer. The graph is displayed on the screen as it will appear on the hardcopy. Once the hardcopy has been completed, the display on the screen will return to the original colored graph.

Plot - Selection of this option leads the program to prompt the user for plot option changes. Press [Y] at this prompt to change or view the defaults. The plot options screen will be displayed at this point. Editing of the default pen numbers and speeds is performed in the same manner as in the editing of input tables (refer to **EDIT/INPUT DATA**). If there is an error in the pen number or speed selected (for example, specifying a pen number greater than 6), the program will select the most recent pen number and the default pen speed of the plotter being used. After editing or viewing this screen, press the [Esc] key. The program will prompt the user to connect the plotter to the computer. Press any key other than the [Esc] key (this key will cause a return to the original graph) to invoke the plotter. Once the hardcopy has been completed, the display on the screen will return to the original colored graph.

Copy to File - The program prompts the user for plot option changes. Edit the plot options as described before. Once the main option has been selected, the program will prompt the user for the name of a file to write the plot to. Enter the name desired (for this example, name the file "PLOT.DAT"). The plot will be written to this file and upon completion, the display on the screen will return to the original colored graph.

This plot file is independent from the FRAME51 program. A hardcopy can be obtained by issuing a "copy" command at the DOS prompt. For example, if the plotter is connected to COM1 and the default drive is C, this command will take the form:

```
C:\> COPY   PLOT.DAT   COM1
```

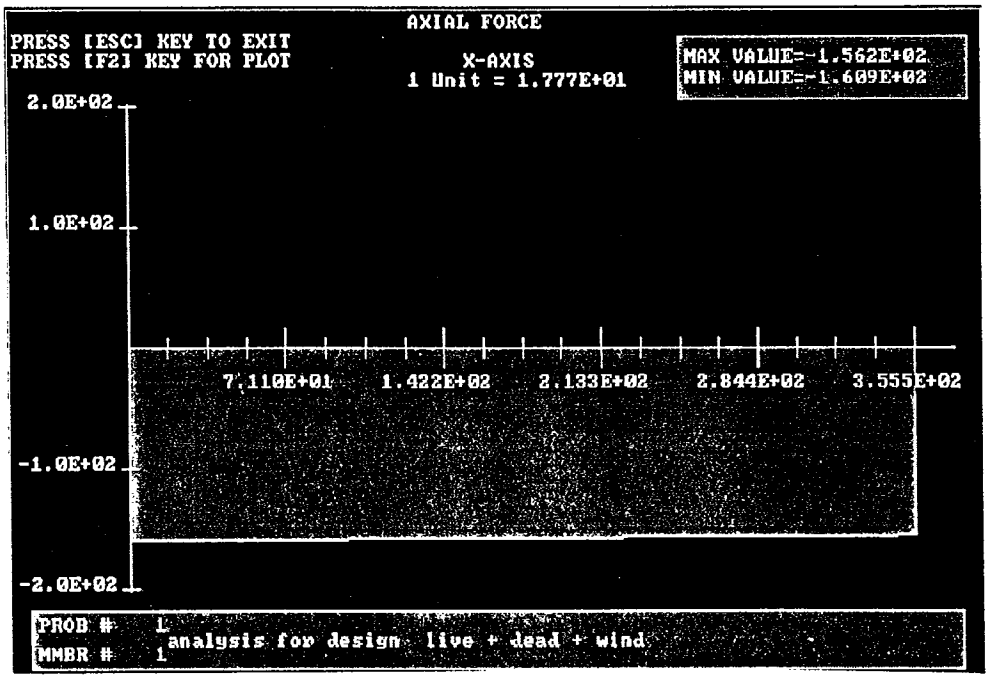


Fig. 46 Member Results - Axial Forces

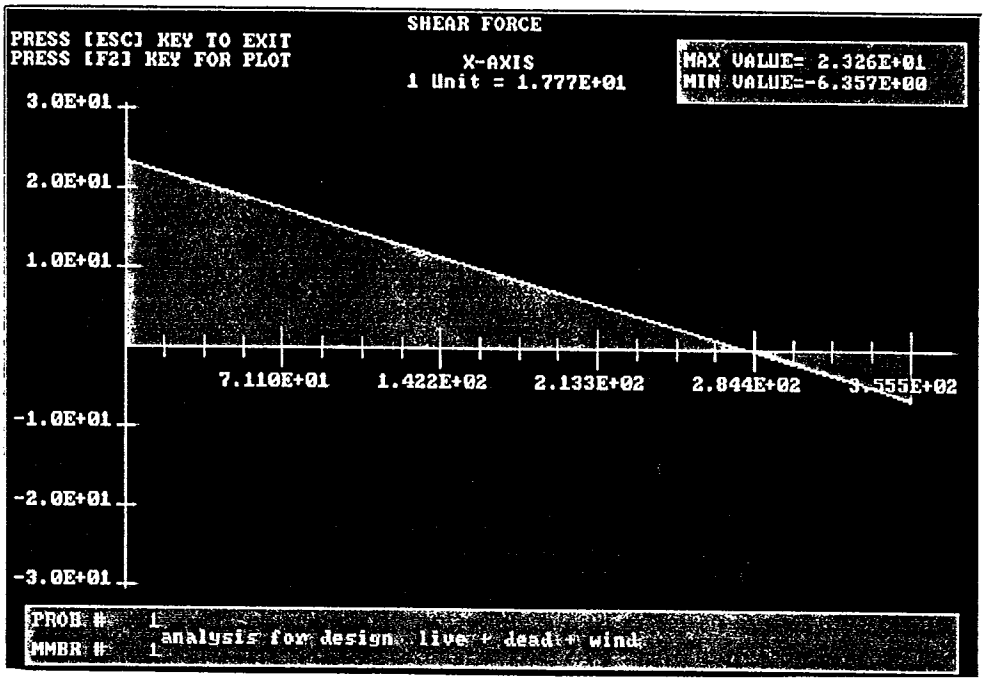


Fig. 47 Member Results - Shear Forces

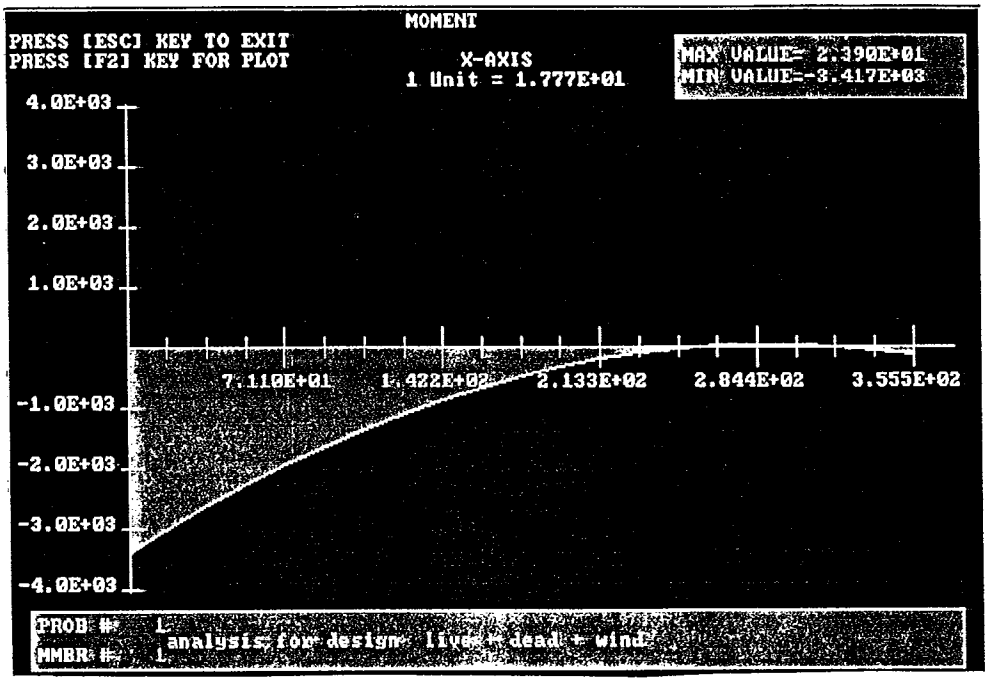


Fig. 48 Member Results - Moments

V. WORK FILES

The program uses temporary files called work files for all manipulations. The input file specified by the user is copied to a new temporary file with the same name and a .WKF extension. This is the file used as the input file by the program. All edits are made to this .WKF file, while the original file specified by the user is left unchanged. If "Quit" or "Change Input File" option is selected, the program prompts the user as to whether the work file is to be saved or not. If the user presses [Y], the program prompts for a filename under which the filename is to be saved. Any valid DOS name can be used including the original filename specified. In this case, the original file is over-written by the work file. If the user presses [N], the .WKF file is deleted without being copied to another file. The original file, however, is saved.

In specifying an input file, the user should **NOT** use a .WKF extension because this file is used by the program.

Work files are invoked only if the specified input file already exists. If this is not the case, the program creates the file specified by the user. The user is not provided with the option of deleting this file and it is saved under the specified name.

VI. GENERAL DOCUMENTATION AND INSTALLATION PROCEDURE

HARDWARE REQUIREMENTS

The program **FRAME51.EXE** requires certain minimum hardware in order to run.

CPU

This program will run on any IBM PC or 100% compatible.

Memory

640K of memory must be installed on the machine. The program requires a minimum of 450K of free memory in order to run.

Graphics Card

The program requires either an EGA card connected to an EGA monitor, or a VGA card connected to a color VGA monitor.

Disk Drives

The program can be run from a machine with only one floppy disk drive, but a hard disk is strongly recommended.

Math Coprocessor

The program requires a math coprocessor (8087, 80287, or 80387) to be installed in the machine used.

INSTALLATION PROCEDURE

Insure that the computer is equipped with the hardware required to run the program (see hardware requirements above). The program can run on a computer from a floppy disk, but it is advisable to install and execute the program from a hard drive. To install FRAME51 on a computer with a hard drive, use the DOS COPY command to transfer the executable file from a floppy disk onto a hard drive. For example, to copy the program from a floppy disk in drive A to hard drive C, issue the following command;

```
> COPY  A:FRAME51.EXE  C:
```

REFERENCES

1. Matlock, Hudson, and Hays, Clifford O., "A Nonlinear Analysis of Statically Loaded Plane Frames Using a Discrete Element Model," *Research Report 56-23*, Project 3-5-63-56, Center for Highway Research, Austin, Texas, May, 1972.

2. "Microsoft FORTRAN Optimizing Compiler for the MS-DOS Operating System; User's Guide, Version 4.1," Microsoft Corporation, Redmond, WA, 1987.

3. "Microsoft FORTRAN Optimizing Compiler for the MS-DOS Operating System; Language Reference, Version 4.1," Microsoft Corporation, Redmond, WA, 1987.

4. "Microsoft Macro Assembler; Programmer's Guide, Version 5.0," Microsoft Corporation, Redmond, WA, 1987.

5. "Essential Graphics User Guide, Version 1.5," Essential Software Inc., Maplewood, NJ, 1986.