TUNA Version 6.50 Update Note

November 5, 2005

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November 5, 2005

1. SMAP-S2 / TUNA can consider hydrostatic ground water pressures below water table.
   Refer to updated manual and example problem.
   TUNA: User's Manual (Page 4-3)
   Example EX1-1.DAT in C:\SMAP\TUNA\EXAMPLE\EX1\EX1-1

2. SMAP automatically creates a sub directory **Temp** under current working directory.
   All intermediate scratch files are saved in this sub directory. Consequently, to run SMAP programs manually, you need to move to this **Temp** directory.
   Refer to updated manual.
   TUNA: User's Manual (Pages 3-2 and 3-15)

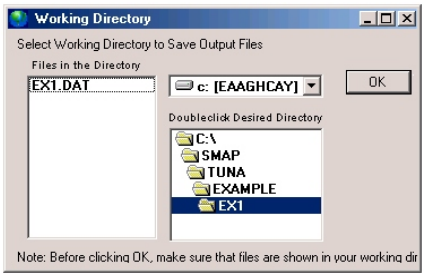
3. SMAP provides debug information during execution of main-processing program (solver). This information is useful for tracing run time errors, extracting convergence status, and checking elapsed time.
   Refer to updated manual.
   TUNA: User's Manual (Page 3-16)

TINA User's Manual

Update Version 6.50

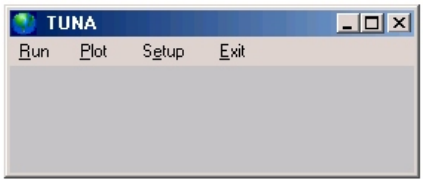
November 5, 2005

3. Next, you need to select **Working Directory**. Working Directory should be the existing directory where all the output files are saved. It is a good idea to have all your input files for the current project in this Working Directory. Click the disk drive, double-click the directory, and then **OK** button.

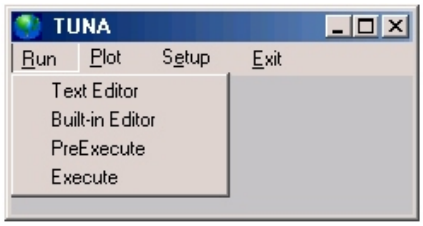


Note that when you select **Working Directory**, a sub directory **Temp** is created automatically. All intermediate scratch files are saved in this **Temp** directory.

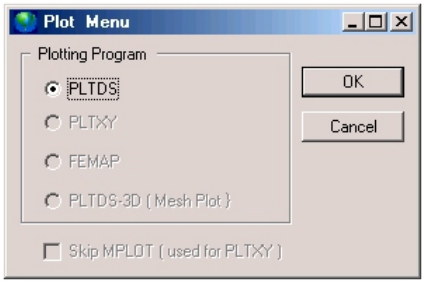
TUNA Menu



TUNA provides the following Main Menus; RUN, PLOT, SETUP and EXIT.



RUN executes TUNA main processing programs and has the following Sub Menus; TEXT EDITOR, BUILT-IN EDITOR (not available), PRE EXECUTE and EXECUTE.



PLOT executes post-processing programs to show graphically the computed results and has the following one program; PLTDS.

3.5 Manual Procedure to Run TUNA

Occasionally, you need to execute programs manually to see what is going on each step.

Executing TUNA Programs Step by Step

1. Select MS-DOS mode or Command Prompt.
2. Go to Working Directory where you want to save your output files.

   Create temporary sub directory.

   type MD Temp

   Then change to this sub directory.

   type CD Temp

   Now, the files in the Working Directory can be accessed by prefixing "..\" to the file name.
3. To run TUNA main-processing program,

   type C:\SMAP\CT\CTBAT\TUNA
4. To plot PLOT-2D output,

   type \SMAP\CT\CTBAT\PLTDS

3.6 Debugging TUNA Main-Processing Program

Debug information would be helpful in the following cases:

- **Having run time errors**
- **Extracting convergence**
- **Checking elapsed time**

In order to get debug information, you need to modify the file "DEBUG.DAT" in the directory C:\SMAP\CT\CTDATA.

```
     0,      2,       1        1
IDEBUG, NCLDEB, IOUTDEB, ICONVER

Note: This "DEBUG.DAT" file allows listing of status with
      elapsed time information while running main process
      of SMAP programs.   This is the very useful
      features to see where it spends most time and where
      it stops.

      IDEBUG  = 0 :    Do not print debug information.
                1 :    Print debug information.

      NCLDEB      :    Ending cycle number.
                       No printing debug information
                       after NCLDEB.

     IOUTDEB =  0 :    Debug information on screen.
                1 :    Debug information on file,
                       c:\smap\ct\ctdata\DEBUG.OUT

     ICONVER =  0 :    Do not print convergence
                       information.
                1 :    Print the ratio of displacement
                       increment to current displacement
                       (DU/U)
```

Card Group	Input Data and Definitions
1 General Information	1.1 TITLE TITLE Any title of up to 60 characters
	1.2 IUNIT IUNIT / Length / Force / Pressure / Unit Weight 1 / in / lb / lb/in^2 / lb/in^3 2 / Cm / Kg / Kg/Cm^2 / Kg/Cm^3
	1.3 NTALT NTALT =1 Unlined Tunnel subjected to Excavation Load =2 Unlined Tunnel subjected to Excavation and Live Load. =3 Lined Tunnel subjected to Excavation Load =4 Lined Tunnel subjected to Excavation and Live Load.
	1.4 HT, DGW HT Tunnel depth DGW Depth of water table from ground surface See Figure 4.2 for minimum depth.

Table 4.1 Work Sheet for TUNA Input Data

Card Group		Input Data	
General Information	TITLE		
	IUNIT		
	NTALT		
	HT, DGW		
Live Load	Distributed Load	P_s	X_s
	NUMCON		
	Concentrated Load	F_i	X_i
	Force 1		
	Force 2		
	Force 3		
	Force 4		
	Force 5		
	Force 6		
	Force 7		
	Force 8		
	Force 9		
	Force 10		
	Internal Load	P_i	

T U N A

TUNnel Analysis Program

Version 6.0

COMTEC RESEARCH

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Contents

Introduction

1.1 Overview

TUNA is a fully automated computer program developed for TUNnel Analysis. TUNA employs a static, two-dimensional, linear elastic finite element method. Pre- and post-processors of TUNA are built-in so that only the physical geometries and material properties associated with a proposed tunnel are required as input and graphical outputs can be obtained directly through printers.

1.2 Features

Features of TUNA include:

- Liner-Medium Interaction
- English and Metric Units
- Shallow and Deep Buried Tunnels
- Multi-Layered Geological Medium
- Circular, Rectangular and Horseshoe Shape Tunnels
- Plain Concrete, Steel Plate, Reinforced Concrete and Composite integral Liners.
- Moment Release Option for the Connections between Segmented Liners.
- Excavation and Live Loads including Internal Pressure

- Lined and Unlined Tunnels
- Graphical Outputs
  - Tunnel Deformed Shape
  - Principal Stresses in the Medium
  - Octahedral Shear Stress in the Medium
  - Bending Moment and Thrust in the Liner
  - Stresses in the Reinforcing Bars
  - Stresses and Strains in the Extreme Fiber of the Liner

1.3 Assumptions

TUNA assumes:

- Liners and the surrounding medium are linear elastic
- Liners are modeled by conventional beam
- Plane strain condition in the longitudinal tunnel direction
- No slippage along the interface between the liner and the surrounding medium.
- Excavation load is defined as tunnel deformations due to the excavation of tunnel. Excavation of tunnel and installation of liner occur instantaneously and simultaneously so that there is no displacement in the surrounding medium prior to the excavation. So the liner interacts with the surrounding medium immediately after excavation and must resist full displacement of tunnel.
- Surface loads are the externally applied concentrated or distributed loads on the ground surface such as traffic loads on the highway.
- Internal pressure loads are the hydrostatic pressures acting on the tunnel liner such as gas or water pressures.
- Liners and the surrounding medium are planar symmetry about the vertical axis passing through the tunnel center line. Soil/rock layers are horizontal (i.e., perpendicular to the gravitational direction)

Installing TUNA

2.1 Minimum Hardware Requirement

- ✓ Pentium with 128 Mb RAM and 580 Kb free memory.
- ✓ Windows 95/98/me/2000/XP system.
- ✓ SVGA monitor.

2.2 Installation Procedure

1. Uninstall if there are pre-existing SMAP programs. To uninstall SMAP programs, remove following two programs using Add/Remove in Control Panel:

   SMAP

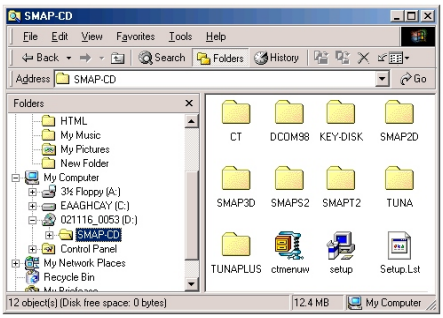
   Sentinel System Drives

   And then rename or delete following folders if they are existing:

   C:\Program Files\Smap

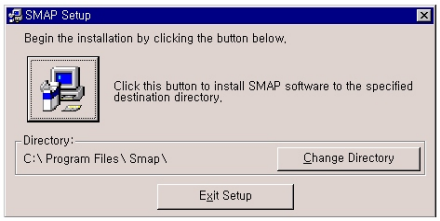
   C:\SMAP

2. Insert SMAP distribution CD, go to **SMAP-CD** directory and double-click **Setup**.

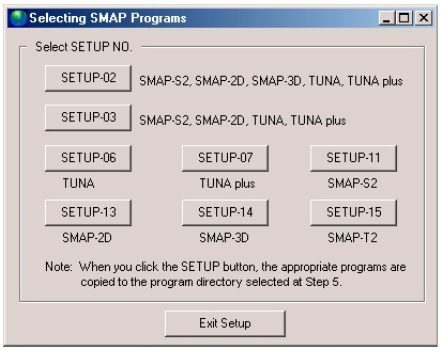


3. Click **OK** button to continue installation.

4. Click **Computer Logo** button to continue installation.



5. *Selecting SMAP Programs* window will be shown. Click the button showing the appropriate **Setup Number.** The last two digits in the SMAP key serial number represent the Setup Number. For example, if the key serial number is 0148-600-02, click **SETUP-02** button.



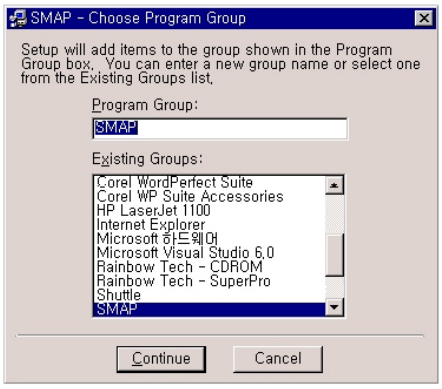
6. *Sentinel System Drivers -Install Shield Wizard window* will be shown. This System Driver is required for the SMAP Key to work properly. Click the **Next** button.

7. Select **Complete** and click **Next** button.

8. Click **Install** button.

9. Click **Finish** button. Do not reboot the system when the Sentinel Driver installation is finished.

10. Choose Program Group and click **Continue**.



11. Click **OK** button to finish installation.

12. If you have 3.5 inch SMAP key setup disk, insert the disk and run INSTALL.EXE. If you do not have 3.5 inch setup disk, go to SMAP-CD-->KEY-DISK--> SMAP-0XXX directory and run INSTALL. Where XXX represents the Serial Number which is the first three digits in SMAP key. For Demo Version, you do not need key setup.

13. Turn off the system.
    Attach SMAP key to the parallel port LPT1.
    Turn on the system.

14. If you have FEMAP program, modify the file FemapDir.dat in C:\SMAP\CT\CTDATA directory so that it contains correct path.

15. For Windows 2000/XP operating systems, set the maximum size of virtual memory to 4000 MB thru Control Panel ->System->Advanced-> Performance Option->Change.

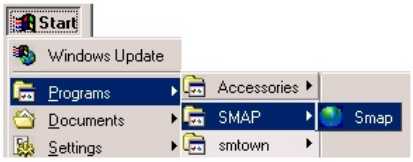
Running Programs

3.1 Introduction

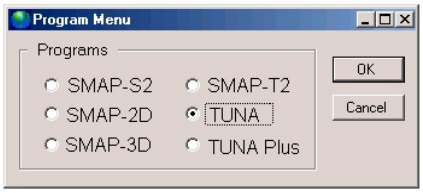
Once you prepared the input file as described in Section 4, running TUNA programs are straightforward since finite element meshes and graphical instruction files are automatically generated.

Accessing TUNA Programs

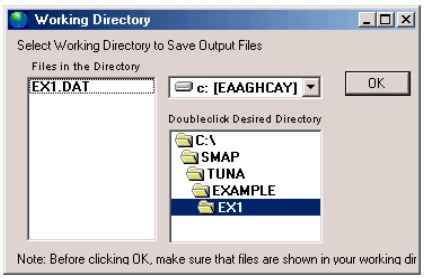
1. When you setup a Shortcut to SMAP Icon, you simply double-click SMAP Shortcut. Otherwise, click **Start** button, point to **Programs**, and then click the **SMAP**.



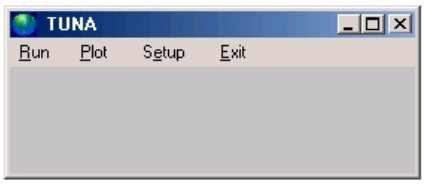
2. Select **TUNA** radio button and then click **OK** button.



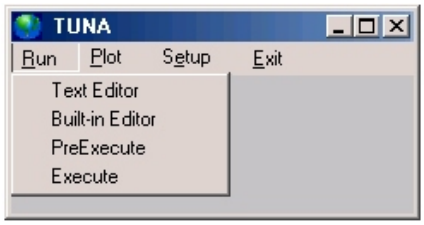
3. Next, you need to select **Working Directory**. Working Directory should be the existing directory where all the output files are saved. It is a good idea to have all your input files for the current project in this Working Directory. Click the disk drive, double-click the directory, and then **OK** button.



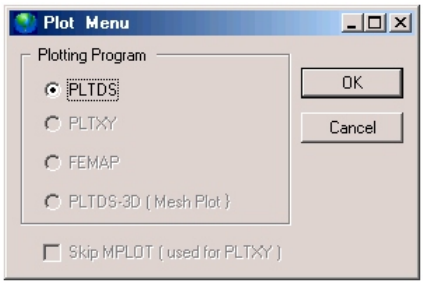
TUNA Menu



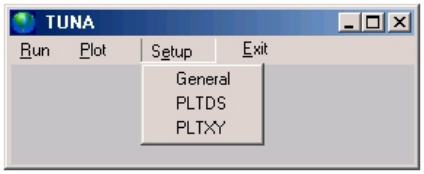
TUNA provides the following Main Menus; RUN, PLOT, SETUP and EXIT.



RUN executes TUNA main processing programs and has the following Sub Menus; TEXT EDITOR, BUILT-IN EDITOR (not available), PRE EXECUTE and EXECUTE.



PLOT executes post-processing programs to show graphically the computed results and has the following one program; PLTDS.

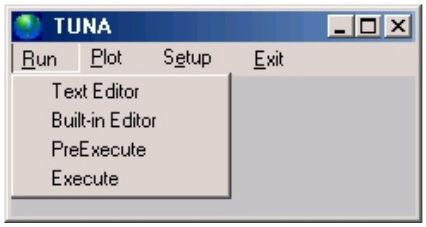


SETUP is used to set plotting control parameters for PLTDS and PLTXY. It has the following Sub Menus; General, PLTDS and PLTXY (not available).

EXIT is used to end TUNA.

3.2 RUN Menu

Once you have prepared the input file according to Section 4, you are ready to execute TUNA main-processing program by selecting EXECUTE Menu.



RUN Menu has the following Sub Menu; TEXT EDITOR, BUILT-IN EDITOR (not available), PRE EXECUTE and EXECUTE.

TEXT EDITOR is used to create or modify the input file using Wordpad.

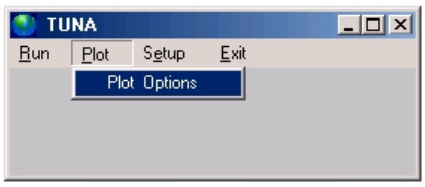
BUILT-IN EDITOR (not available) is used to create or modify the input file using the specially designed editor which allows much easier input preparation.

PRE EXECUTE is used either to check the input file or to generate plotting information files.

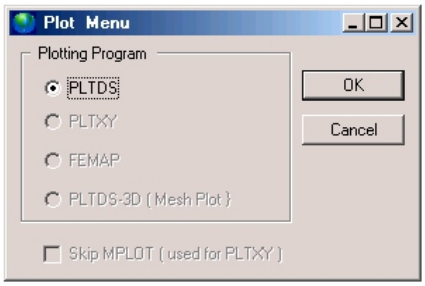
EXECUTE executes TUNA main-processing program. You are asked to open your input file.

3.3 PLOT Menu

Once you finished executing TUNA main-processing program, you need to run post-processing programs to show graphically the numerical results. Plot Menu is mainly used to execute post-processing programs; PLTDS and PLTXY. To access PLOT Menu, click **Plot → Plot Options**.



Plot Menu contains PLTDS.



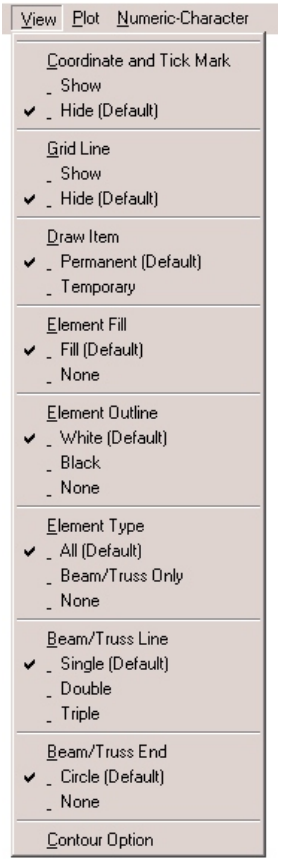
3.3.1 PLTDS

PLTDS is used to plot the following output:

- Finite element mesh
- Principal stress distribution
- Deformed shape
- Lining section force/extreme fiber stress
- Rock bolt axial stress
- Contours of principal stresses and octahedral shear stress

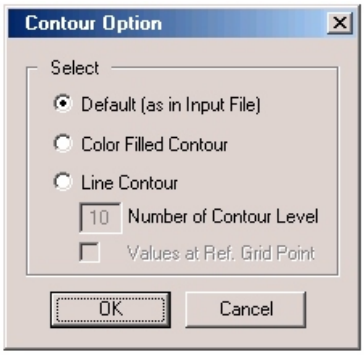
PLTDS has 12 menus; File, Edit, View, Plot, Numeric-Character, Draw, Draw-Style, Node, Element, Child-Window, Window, and Help.

For description of File, Edit and Window menus, refer to the contents in Help menu.

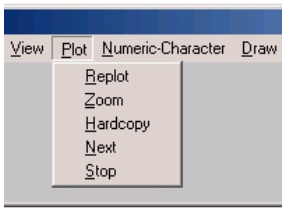


View is provided to show different appearance of finite element meshes and draw items. Currently there are 8 different check items and 1 contour option. Click different options if you want other than default. Check mark will be moved to the clicked item. Default options are used as initial check. **Coordinate and Tick Mark** and **Grid Line** can be applied to all types of plots. **Draw Item** is for drawing in **Draw** menu to be either permanent or temporary. **Element Fill**, **Element Outline**, **Element Type**, **Beam/Truss Line** and **Beam/Truss End** influence only the appearance of finite element mesh plot.

Contour Option is provided to switch from line contour to color filled contour or viceversa.

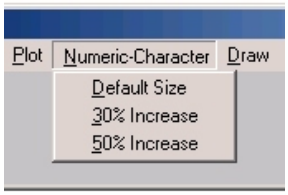


Plot has the following five menus;



Replot	Replot the currently focused child window.
Zoom	Zoom the currently focused child window. It zooms only mesh. Once this sub menu is selected, you can specify the rectangular zoom area by left-mouse-button-down at the left top corner and then left-mouse-button-up at the right bottom corner.
Hardcopy	Print the currently focused child window.
Next	Plot the next graph.
Stop	Stop plotting.

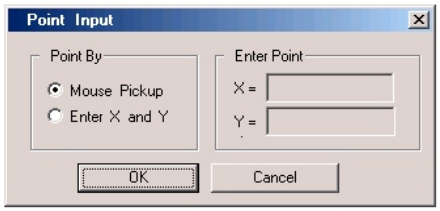
Numeric-Character has 3 sub menus;
Default size, 30% Increase and 50% Increase.



Default Size	Use numeric character size set in PLTDS Setup window.
30% Increase	Increase the current size by 30%.
50% Increase	Increase the current size by 50%.

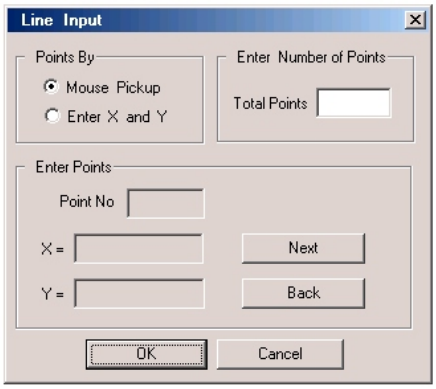
Draw has 5 sub menus: Point, Line, Arc, Text and Grid. You can add these drawing items on the current plot. Drawing is influenced by sub menu *Draw-Style*.

Point is to draw point. When you select *Mouse Pickup* and click **OK**, the point will be marked at the position where the left mouse button is down. As you move the mouse, the current mouse location is shown on the status bar at the bottom of PLTDS window. When you select *Enter X and Y,* the point will be marked at the position where you specified on the *Point Input* window.

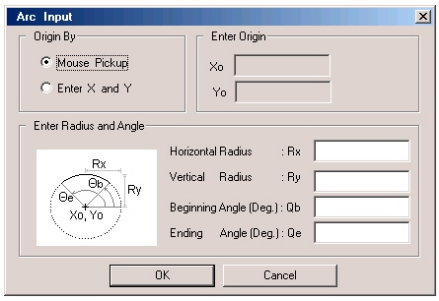


Point is influenced by Color, Mark Type, and Mark Size in the *Draw-style* menu.

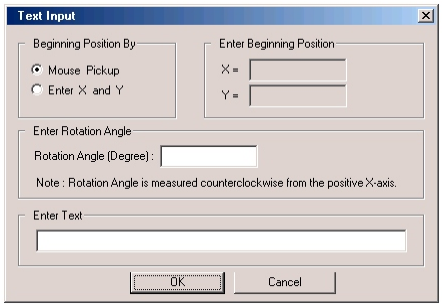
Line is to draw straight lines. As for point, the coordinates of line can be specified by either *Mouse Pickup* or *Enter X and Y*. Line is influenced by Color, Mark Type, Mark Size, Line Style, and Line Type.



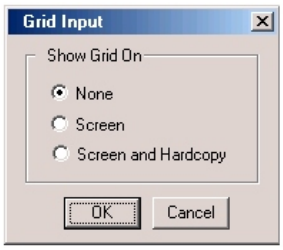
Arc is to draw elliptical arc. You need to specify Horizontal Radius, Vertical Radius, Beginning and Ending Angles. The origin of Arc can be specified by either *Mouse Pickup* or *Enter X and Y*. Arc is influenced by Color and Line Type.



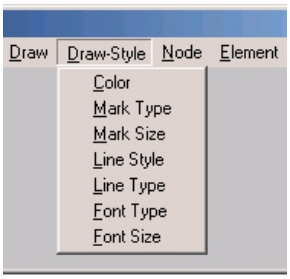
Text is to draw text. You need to specify Rotation Angle and Text. Beginning Position can be specified by either *Mouse Pickup* or *Enter X and Y*. Text is influenced by Color, Font Type, and Font Size.



Grid is to draw grid lines. When you select *Screen and Hardcopy,* the selected plot file is modified to include grid lines. Grid is influenced by Color and Line Type.

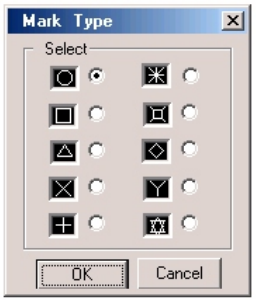


Draw-Style has 7 sub menus; Color, Mark Type, Mark Size, Line Style, Line Type, Font Type, and Font Size. Draw-Style influences drawing items in Draw menu.

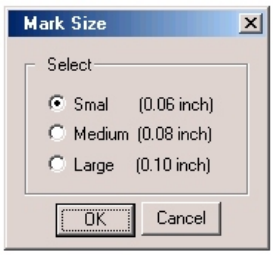


Color shows color palette having 16 different colors. Select the current color to be used. Color influences all the drawing items in the Draw menu.

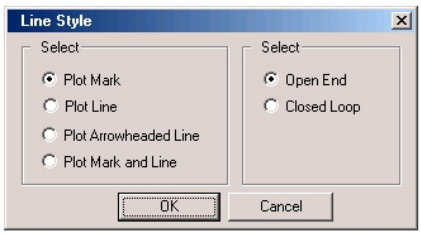
Mark Type shows 10 different mark types. Mark Type influences point and Line drawing.



Mark Size includes 3 options; Small (0.06 inch), Medium (0.08 inch), and Large (0.10 inch). Mark Size influences Point and Line drawing.

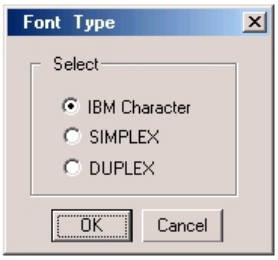


Line Style is used to select Mark, Line, Arrowheaded Line, or Mark and Line to plot line. The other selection is applicable for the case when the total number of points is greater than 2. When you select Closed Loop, the first and the last points can be connected to make a polygon. It influences only Line.

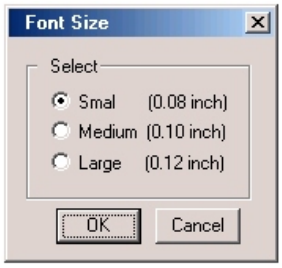


Line Type includes Solid Line, Long Dashes, and Short Dashes as selection. It influences Line, Arc and Grid.

Font Type includes IBM Character, SIMPLEX and DUPLEX to draw Text.



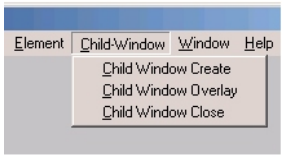
Font Size includes 3 options; Small (0.08 inch), Medium (0.10 inch), and Large (0.12 inch) to draw Text.



Node is used to find the node number. You can find the node number which is close to the position where you press down the left mouse button. Node number close to the mouse position will be listed on *Message List and Keyboard Input Window*.

Element is used to find the element number. You can find the element number which is close to the position where you press down the left mouse button. Element number close to the mouse position will be listed on *Message List and Keyboard Input Window*.

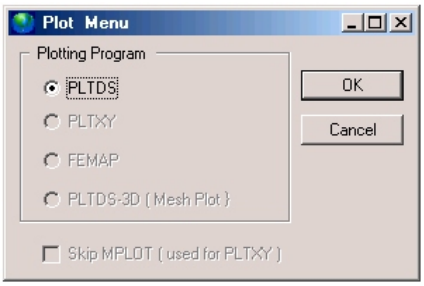
Child-Window has three sub menus; Child Window Create, Child Window Overlay and Child Window Close.



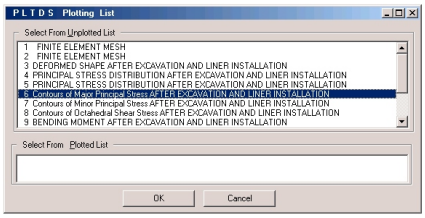
Child Window Create	New child window will be created. A maximum of 40 child windows can be opened.
Child Window Overlay	New child window will be overlaid on the current child window.
Child Window Close	Currently focused child window will be closed.

Running PLTDS

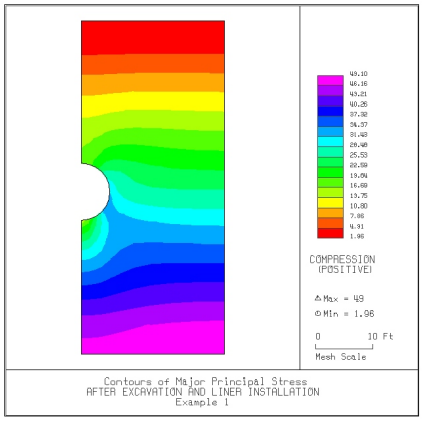
1. Select **PLTDS** and click **OK** button.



2. A list of plot items is shown in the *Select From Unplotted List* window. **Double-click** any one item in the list.



3. The selected plot item will be shown on the screen.



3.4 SETUP Menu

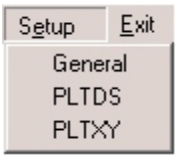
You need to run SETUP menu

To specify TUNA main-processing program module.

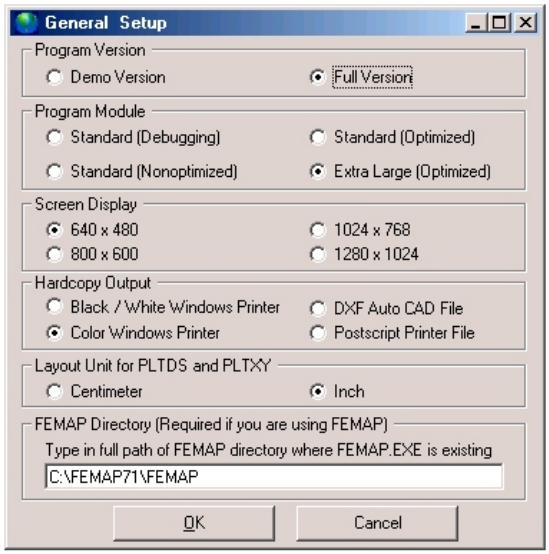
To adjust scales of graphical outputs from PLTDS.

To specify FEMAP directory (not applicable for TUNA).

SETUP menu has three sub menus; General, PLTDS, and PLTXY (not available).



3.4.1 General Setup



General Setup has six different items; Program Version, Program Module, Screen Display, Hardcopy Output, Layout Unit, and FEMAP Directory.

Program Version has two options; Demo and Full Version. Demo Version does not require SMAP key but it has the following maximum limits:

Number of Nodes	= 300
Number of Continuum Elements	= 100
Number of Beam Elements	= 50
Number of Truss Elements	= 50

Full Version requires SMAP Key attached on the parallel port of your computer.

Program Module contains four options. Standard (Debugging) uses TUNA main-processing program having debugging. This program module runs slow but gives more detailed information when run time errors occur. Standard (Nonoptimized) is the same as Standard (Debugging) except it does not include debugging information. Standard (Optimized) runs fast but it does not include debugging information. For most cases, Standard (Optimized) is recommended. Extra Large (Optimized) is designed to run large problems.

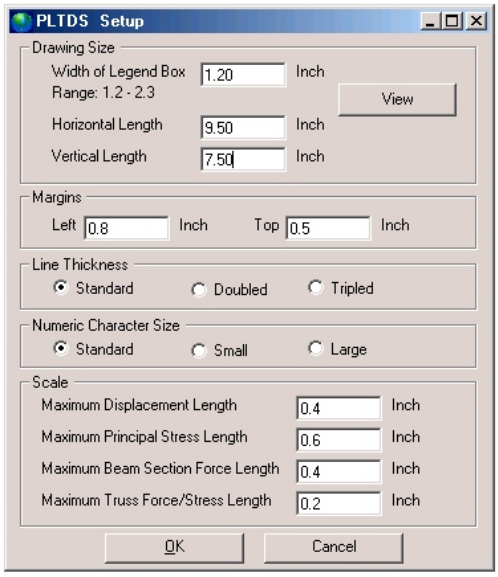
Screen Display has four options: 640x480, 800x600, 1024x768, and 1280x1024.

Hardcopy Output is used for post-processing program PLTDS and PLTXY. You can select Black/White Windows Printer, Color Windows Printer, DXF Auto CAD File, or Postscript Printer File as hardcopy output.

Layout Unit is used for PLTDS and PLTXY. You can select either Centimeter or Inch in specifying plot scales and dimensions.

FEMAP Directory is required if you are using FEMAP. You need to type in full path of FEMAP directory where FEMAP.EXE is existing.

3.4.2 PLTDS Setup



PLTDS Setup is mainly used to specify scales and dimensions of post-processing program PLTDS and mesh plotting program PLTDS-3D (not available for TUNA). It has five different items; Drawing Size, Margins, Line Thickness, Numeric Character Size, and Scale.

Drawing Size controls the size of output. Once you specify Legend Box Width, Horizontal and Vertical Length, you can click **View** button to see the scaled layout.

Margins is used to shift the drawing area. *Left* margin is the distance from the left edge of printer page to the left frame line. *Top* margin is the distance from the top edge of printer page to the top frame line.

Line Thickness specifies the thickness of contour lines. It has three options; Standard, Doubled, and Tripled.

Numeric Character Size specifies the size of numeric characters such as node and element numbers. It has 3 options; Standard, Small, and Large.

Scale specifies Maximum Displacement Length, Maximum Principal Stress Length, Maximum Beam Section Force Length, and Maximum Truss Force/Stress Length.

3.5 Manual Procedure to Run TUNA

Occasionally, you need to execute programs manually to see what is going on each step.

Executing TUNA Programs Step by Step

1. Select MS-DOS mode or Command Prompt.
2. Go to Working Directory where you want to save your output files.
3. To run TUNA main-processing program,
   type C:\SMAP\CT\CTBAT\TUNA
4. To plot PLTDS output,
   type C:\SMAP\CT\CTBAT\PLTDS

Description of Input Data

The input data is classified into seven different card groups.

The first card group includes general informations; job title (TITLE), selection of unit (IUNIT), tunnel analysis type (NTALT) and tunnel depth (HT).

The second card group specifies live loads. Live loads as schematically shown in Figure 4.1 include concentrated/distributed surface loads and internal pressure load acting on the liner.

The third card group specifies soil/rock material property for each layer. Soil/rock Layers are schematically shown in Figure 4.1.

The fourth card group specifies tunnel dimensions. Currently there are four tunnel shapes available; circular, rectangular, vertical walls with arch roof and general horseshoe shapes. Tunnel shapes and dimensional limits are shown in Figure 4.2.

The fifth card group specifies liner elastic material properties for the concrete, steel plate and reinforcing bars.

The sixth card group contains liner cross section data. For the non-circular tunnel shapes, tunnels are composed of three segments (top, side and bottom) as marked in Figure 4.2. A different liner type (LNTP) can be

applied to each segment of liner. Figure 4.3 shows the liner cross sections.

The last card group specifies locations where moments are released along the tunnel liner.

Table 4.1 is the work sheet designed for easy preparation of input data. You can save this original work sheet and copy it as you need.

Card Group	Input Data and Definitions
1 General Information	1.1 TITLE TITLE Any title of up to 60 characters
	1.2 IUNIT IUNIT / Length / Force / Pressure / Unit Weight 1 / in / lb / lb/in^2 / lb/in^3 2 / Cm / Kg / Kg/Cm^2 / Kg/Cm^3
	1.3 NTALT NTALT =1 Unlined Tunnel subjected to Excavation Load =2 Unlined Tunnel subjected to Excavation and Live Load. =3 Lined Tunnel subjected to Excavation Load =4 Lined Tunnel subjected to Excavation and Live Load.
	1.4 HT HT Tunnel depth See Figure 4.2 for minimum depth.

<table>
<tr><th>Card Group</th><th colspan="2">Input Data and Definitions</th></tr>
<tr><td rowspan="3">2

Live Loads (If NTATL=1 or NTALT=3, skip this card)</td><td rowspan="2">Surface Load</td><td>2.1

(Distributed Surface Load)
P_s, X_s
P_s Load intensity in terms of pressure unit
X_s Distance from center line to edge of load</td></tr>
<tr><td>2.2

(Concentrated Surface Load)
NUMCON

NUMCON Cards

F_1, X_1
F_2, X_2
- -
- -

NUMCON Number of concentrated loads. By symmetry, consider only right half of loads.
F_i, X_i Force F_i at the distance X_i from the center line.</td></tr>
<tr><td>Internal Load</td><td>2.3

(Internal Pressure Load)
P_i
P_i Internal hydrostatic pressure acting on the liner.</td></tr>
</table>

Card Group	Input Data and Definitions
3 Soil / Rock Material Property	3.1 NLAYER NLAYER Total number of layers (maximum 10)
	3.2 NLAYER Cards: H_1, $GAMA_1$, RKO_1, E_1, V_1 / H_2, $GAMA_2$, RKO_2, E_2, V_2 / - - - - - / - - - - - H Layer thickness GAMA Unit weight RKO Coefficient of earth pressure at rest E Young's modulus V Poisson's ratio See Figure 4.1

Card Group	Input Data and Definitions
4 Tunnel Dimension	4.1 ISHAPE
	4.2 ISHAPE = 1 > D = 2 > B, H = 3 > B, H1, H2 = 4 > B1, B2, H1, H2, H3 See Figure 4.2

Card Group 5,6 and 7 are required for lined tunnels (NTALT=3 or 4)

Card Group	Input Data and Definitions
5 Liner Property	5.1 (Concrete Property) E_C, V_C E_C Young's modulus of concrete V_C Poisson's ratio of concrete
	5.2 (Steel Plate Property) E_S, V_S E_S Young's modulus of steel plate V_S Poisson's ratio of steel plate
	5.3 (Reinforcing Bar Property) E_R, V_R E_R Young's modulus of reinforcing bar V_R Poisson's ratio of reinforcing bar

Card Group	Input Data and Definitions	
6 Liner Cross Section Data	6.1 Top Segment or Circular Tunnel (ISHAPE = 1)	6.1.1 LNTP, WL LNTP Liner type (Select from Figure 4.3) WL Weight per unit length of liner
		6.1.2 LNTP = 1 > No data, skip this Card = 2 > T_C = 3 > T_1, T_2, W_1, W_2 = 4 > T_C, D_1, A_{S1}, D_2, A_{S2} = 5 > T_1, T_2, W_1, W_2, D_1, A_{S1}, D_2, A_{S2} = 6 > T_C, T_S = 7 > T_C, D_1, A_{S1}, D_2, A_{S2}, T_S = 8 > T_C, D_1, A_{S1}, D_2, A_{S2}, T_S = 9 > T_S = 10 > T_1, T_2, W_1, W_2 = 11 > T_C, T_S = 20 > T_b, T_t, W, A, I

Card Group	Input Data and Definitions	
6 Liner Cross Section Data	6.2 Side Segment	6.2.1 LNTP, WL LNTP — Liner type (Select from Figure 4.3) WL — Weight per unit length of liner
		6.2.2 LNTP = 1 > No data, skip this Card = 2 > T_C = 3 > T_1, T_2, W_1, W_2 = 4 > T_C, D_1, A_{S1}, D_2, A_{S2} = 5 > T_1, T_2, W_1, W_2, D_1, A_{S1}, D_2, A_{S2} = 6 > T_C, T_S = 7 > T_C, D_1, A_{S1}, D_2, A_{S2}, T_S = 8 > T_C, D_1, A_{S1}, D_2, A_{S2}, T_S = 9 > T_S = 10 > T_1, T_2, W_1, W_2 = 11 > T_C, T_S = 20 > T_b, T_t, W, A, I

Card Group		Input Data and Definitions
6 Liner Cross Section Data	6.3 Bottom Segment	6.3.1 LNTP, WL LNTP Liner type (Select from Figure 4.3) WL Weight per unit length of liner
		6.3.2 LNTP = 1 > No data, skip this Card = 2 > T_C = 3 > T_1, T_2, W_1, W_2 = 4 > T_C, D_1, A_{S1}, D_2, A_{S2} = 5 > T_1, T_2, W_1, W_2, D_1, A_{S1}, D_2, A_{S2} = 6 > T_C, T_S = 7 > T_C, D_1, A_{S1}, D_2, A_{S2}, T_S = 8 > T_C, D_1, A_{S1}, D_2, A_{S2}, T_S = 9 > T_S =10 > T_1, T_2, W_1, W_2 =11 > T_C, T_S =20 > T_b, T_t, W, A, I

Card Group	Input Data and Definitions
7 Liner Moment Release Locations	7.1 NUMRELEASE NUMRELEASE — Number of locations where liner moments are released.
	7.2 NUMRELEASE Cards $\begin{bmatrix} X_1, & Y_1 \\ X_2, & Y_2 \\ - & - \\ - & - \end{bmatrix}$ X_i, Y_i — X and Y coordinates where liner moments are released. See Figure 4.4.

Table 4.1 Work Sheet for TUNA Input Data

Card Group		Input Data	
General Information	TITLE		
	IUNIT		
	NTALT		
	HT		
Live Load	Distributed Load	P_s	X_s
	NUMCON		
	Concentrated Load	F_i	X_i
	Force 1		
	Force 2		
	Force 3		
	Force 4		
	Force 5		
	Force 6		
	Force 7		
	Force 8		
	Force 9		
	Force 10		
	Internal Load	P_i	

Table 4.1 Work Sheet for TUNA Input Data (Continued)

Card Group		Input Data				
Soil/Rock Material Property	NLAYER					
		H	GAMA	RKO	E	V
	LAYER = 1					
	LAYER = 2					
	LAYER = 3					
	LAYER = 4					
	LAYER = 5					
	LAYER = 6					
	LAYER = 7					
	LAYER = 8					
	LAYER = 9					
	LAYER = 10					
Tunnel Dimension	ISHAPE					
	ISHAPE = 1					
	ISHAPE = 2					
	ISHAPE = 3					
	ISHAPE = 4					

Table 4.1 Work Sheet for TUNA Input Data (Continued)

Card Group		Input Data							
Liner Material Property	Concrete	E_c				V_c			
	Steel Plate	E_s				V_s			
	Reinf. Bar	E_r				V_r			
Liner Section Data	Top Segment Circular Tunnel	LNTP				WL			
	Side Segment	LNTP				WL			
	Bottom Segment	LNTP				WL			

Table 4.1 Work Sheet for TUNA Input Data (Continued)

Card Group		Input Data	
Moment Release Locations	NUMRELEASE		
		X_i	Y_i
	Location 1		
	Location 2		
	Location 3		
	Location 4		
	Location 5		

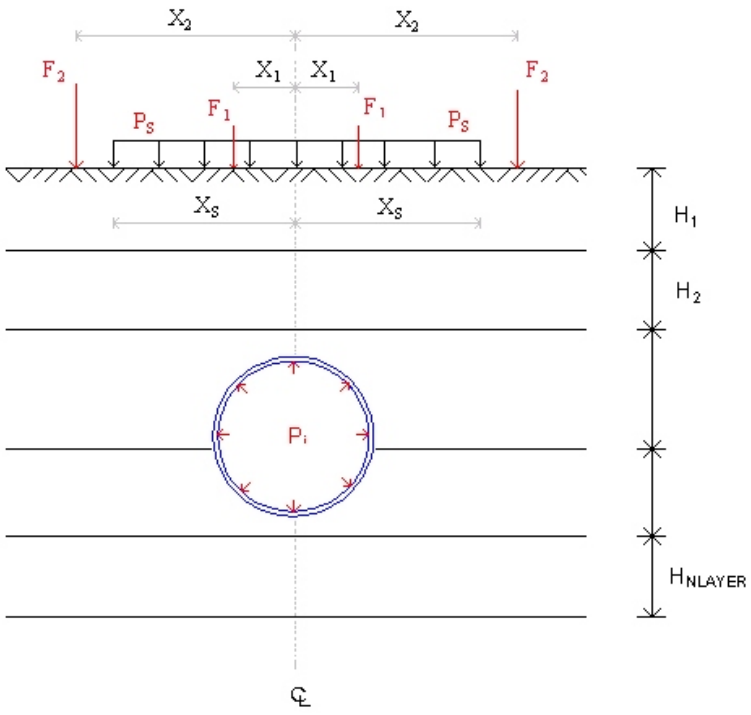
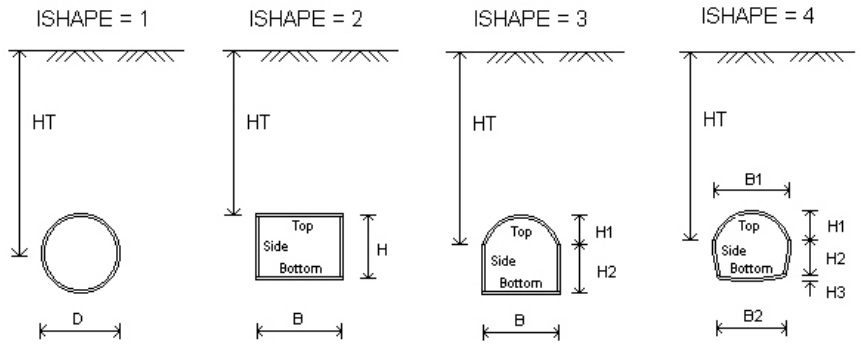


Figure 4.1 Schematic Tunnel Section in the Layered Medium

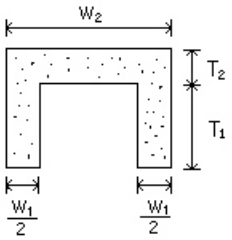


ISHAPE = 1	ISHAPE = 2	ISHAPE = 3	ISHAPE = 4
HT ≥ 0.7 D	HT ≥ 0.1 B	HT ≥ 0.7B	HT ≥ 0.7 B1
	H ≥ 0.2 B	H1 ≤ 0.5 B	
H1 ≤ 0.5 B1			
	H ≤ 5 B	H2 ≥ 0.2 B	H2 ≥ 0.5 (B1-B2)
		H3 ≤ 5 B	H2 ≥ 0.1 B1
			H3 ≤ 0.5 B2
			B2 ≥ 0.1 B1
			B2 ≤ B1
			H1+H2+H3 ≥ 0.2 B1
			H1+H2+H3 ≤ 5 B1

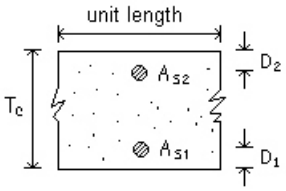
Figure 4.2 Tunnel Shapes and Dimensional Limits

LNTP = 2

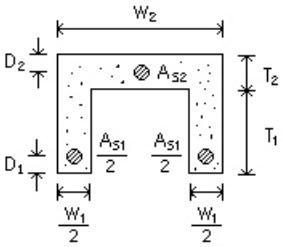
LNTP= 3



LNTP= 4



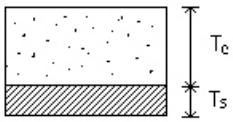
LNTP= 5



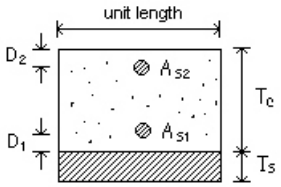
	Concreted section
	Steel section
	Reinforcing bar section
LNTP	Liner type

Figure 4.3 Liner Cross Sections

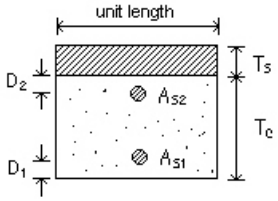
LNTP= 6



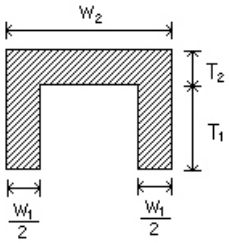
LNTP= 7



LNTP= 8



LNTP= 10



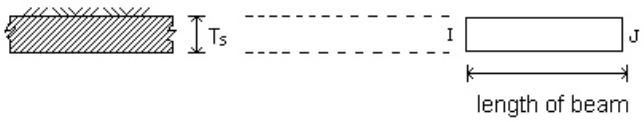

Concreted section


Steel section

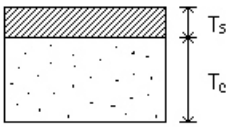

Reinforcing bar section

Figure 4.3 Liner Cross Sections (continued)

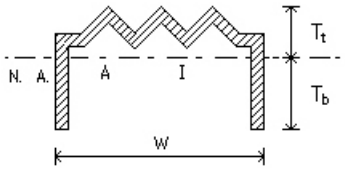
LNTP= 9



LNTP= 11



LNTP= 20



A: Cross section area
I: Moment of inertia

Concrete section

Steel section

Reinforcing bar section

Figure 4.3 Liner Cross Sections (continued)

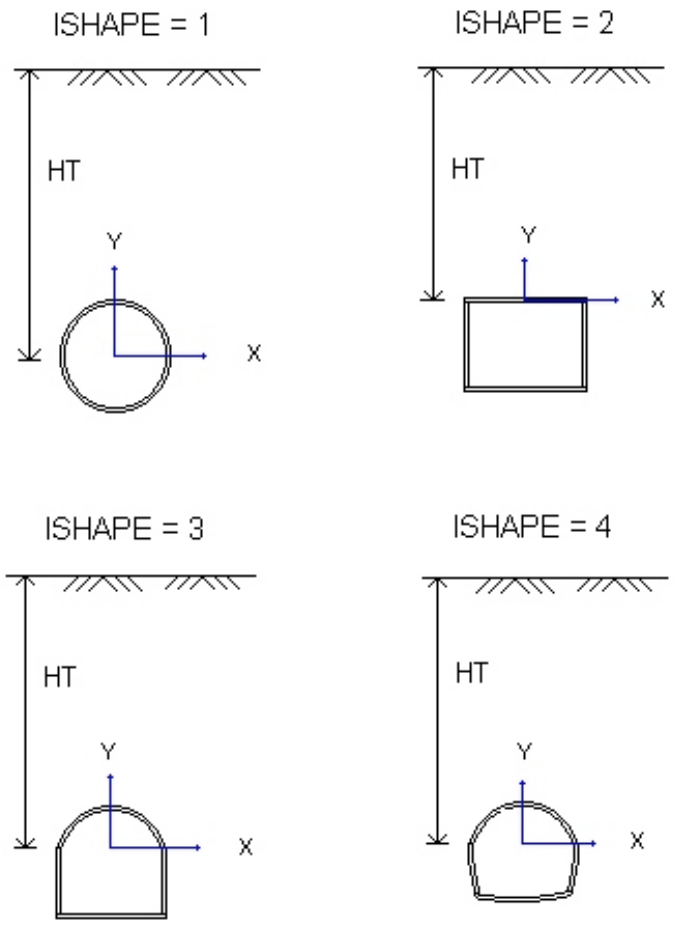


Figure 4.4 X and Y coordinates to specify locations of liner moment release.

Description of Output Data

In general, there are 15 graphical outputs as summarized in Table 5.1. Sign conventions and notations used for section forces and strains in the liner are shown in Figure 5.1.

Table 5.1 Summary of TUNA Output Data

Plot Type	Descriptions
1	Finite Element Mesh
2	Tunnel Deformed Shape
3	Principal Stress Distribution in Surrounding Medium (Adjacent to the Tunnel Surface)
4	Principal Stress Distribution in Surrounding Medium (Overall)
5	Contours of Major Principal Stress
6	Contours of Minor Principal Stress
7	Contours of Octahedral Shear Stress
8	Bending Moment in the Tunnel Liner
9	Thrust in the Tunnel Liner
10	Inner Extreme Fiber Stress in the Tunnel Liner
11	Outer Extreme Fiber Stress in the Tunnel Liner
12	Inner Extreme Fiber Strain in the Tunnel Liner
13	Outer Extreme Fiber Strain in the Tunnel Liner
14	Inner Reinforcing Bar Stress in the Tunnel Liner
15	Outer Reinforcing Bar Stress in the Tunnel Liner

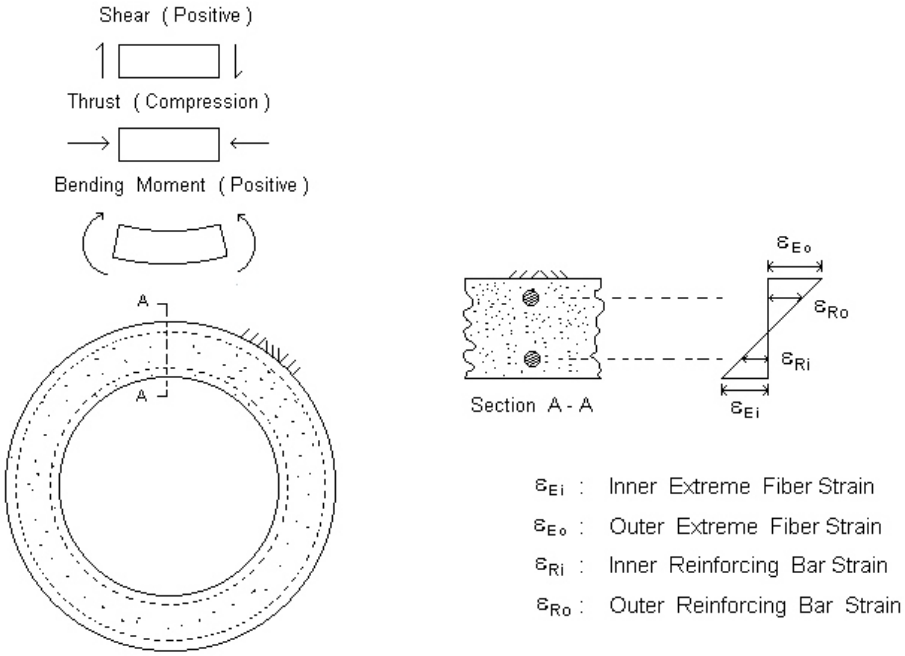


Figure 5.1 Sign conventions and notations used for section forces and strains in the liner.

Example Problems

This section is to illustrate how TUNA can be applied for the analysis of tunnel problems. Main features of example problems are summarized in Table 6.1. First example problem is for the analysis of segmented liner due to the excavation associated with shield tunneling. Second example problem is for the analysis of steel pipe subjected to both surface loads and internal gas pressure. For each example problem, brief problem descriptions, listing of input files, and graphical outputs are presented.

Table 6.1 List of example problems

Problem Number	File Name	Run Time (min) PIII 850 MHZ	Description
1	EX1.DAT	0.02	Segmented shield tunnel liner subjected to excavation load
2	EX2.DAT	0.03	Steel pipeline subjected to surface loads and internal gas pressure

6.1 Example 1

A 10 feet diameter circular tunnel is buried along the interface between the clay and sand layers as shown in Figure 6.1. An assembly of 16" width four-flange steel plates is used as tunnel liner. Material properties of the liner and the surrounding media are listed in Figure 6.1. The tunnel is subjected to excavation load.

It should be noted that in this analysis, the connections between the liner segments are assumed to carry the full moments. You can also analyze this example problem by assuming that connections are moment-released using the Card group 7.

As an illustration for input preparation, a work sheet is provided in Table 6.2. And the actual input file is listed in Table 6.3.

Results

Figures 6.2 to 6.14 show the graphical outputs from TUNA. Key results are summarized below.

Max. Tunnel Diameter Change	=	0.2 in (0.17 % of tunnel diameter)
Max. Liner Compressive Stress	=	14,000 psi (50 % of yield strength)

Table 6.2 Work Sheet for Example 1

Card Group		Input Data	
General Information	TITLE	Example 1	
	IUNIT	1	
	NTALT	3	
	HT	360	
Live Load	Distributed Load	P_s	X_s
	NUMCON		
	Concentrated Load	F_i	X_i
	Force 1		
	Force 2		
	Force 3		
	Force 4		
	Force 5		
	Force 6		
	Force 7		
	Force 8		
	Force 9		
	Force 10		
	Internal Load	P_i	

Table 6.2 Work Sheet for Example 1 (Continued)

Card Group		Input Data				
Soil/Rock Material Property	NLAYER	2				
		H	GAMA	RKO	E	V
	LAYER = 1	360	0.0723	0.6667	5000	0.4
	LAYER = 2	600	0.0752	0.4286	10000	0.3
	LAYER = 3					
	LAYER = 4					
	LAYER = 5					
	LAYER = 6					
	LAYER = 7					
	LAYER = 8					
	LAYER = 9					
	LAYER = 10					
Tunnel Dimension	ISHAPE	1				
	ISHAPE = 1	120				
	ISHAPE = 2					
	ISHAPE = 3					
	ISHAPE = 4					

Table 6.2 Work Sheet for Example 1 (Continued)

Card Group		Input Data							
Liner Material Property	Concrete	E_c				V_c			
		0.0				0.0			
	Steel Plate	E_s				V_s			
		29.E+06				0.3			
	Reinf. Bar	E_r				V_r			
		0.0				0.0			
Liner Section Data	Top Segment Circular Tunnel	LNTP				WL			
		20				0.0			
		T_b	T_t	W	A	I			
		2.094	0.718	16.	2.396	1.915			
	Side Segment	LNTP				WL			
	Bottom Segment	LNTP				WL			

Table 6.2 Work Sheet for Example 1 (Continued)

Card Group		Input Data	
Moment Release Locations	NUMRELEASE	0	
		X_i	Y_i
	Location 1		
	Location 2		
	Location 3		
	Location 4		
	Location 5		

Table 6.3 Listing of Input File for Example 1

```
* CARD 1.1
* TITLE
: Example 1
* CARD 1.2
* IUNIT
   1
* CARD 1.3
* NTALT
   3
* CARD 1.4
* HT
  360.
* CARD 2.1
* Ps     Xs
* CARD 2.2
* NUMCON
* Fi     Xi
* CARD 2.3
* Pi
* CARD 2.1
* NLAYER
   2
* CARD 2.2
* H      GAMA     RKO      E        V
  360.   0.0723   0.6667   5000.    0.4
  600.   0.0752   0.4286   10000.   0.3
* CARD 3.1
* ISHAPE
   1
* CARD 3.2
* D
  120.
* CARD 4.1
* EC        VC
  0.0       0.0
* CARD 4.2
* ES        VS
  29.E+06   0.3
* CARD 4.3
* ER        VR
  0.0       0.0
* CARD 5.1.1
* LNTP    WL
  20      0.0
```

```
* CARD 5.1.2
* Tb      Tt      W       A       I
  2.094   0.718   16.     2.396   1.915
* CARD 7.1
* NUMRELEASE
   0
* CARD 7.2
* Xi      Yi
* END
```

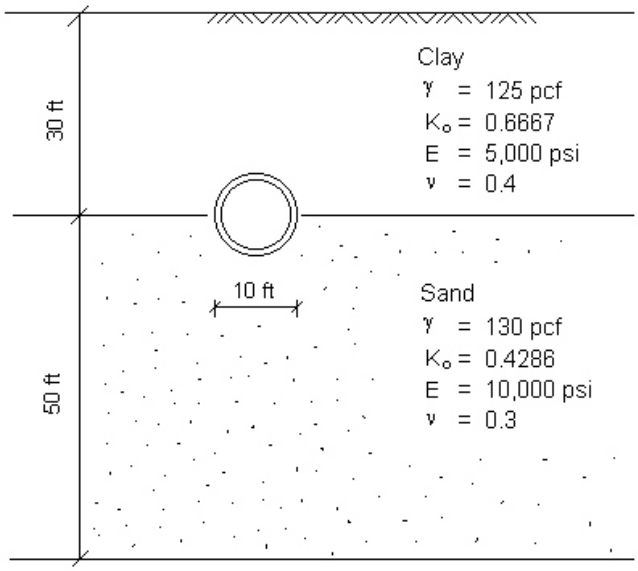
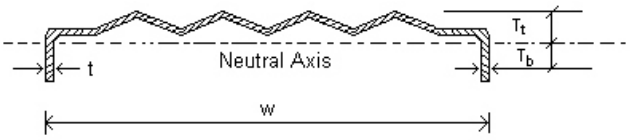


Figure 6.1 Schematic tunnel section view for example 1



Liner Cross Section Property (16" width four-flange steel plate)

W = 16 in
A = 2.396 in^2
I = 1.915 in^4
t = 0.239 in
T_b = 2.094 in
T_t = 0.718 in
E = 29. x 10^6 psi
v = 0.3
Min. Tensile Strength = 42,000 psi
Min. Yield Strength = 28,000 psi

Figure 6.1 Schematic tunnel section view for example 1 (Continued)

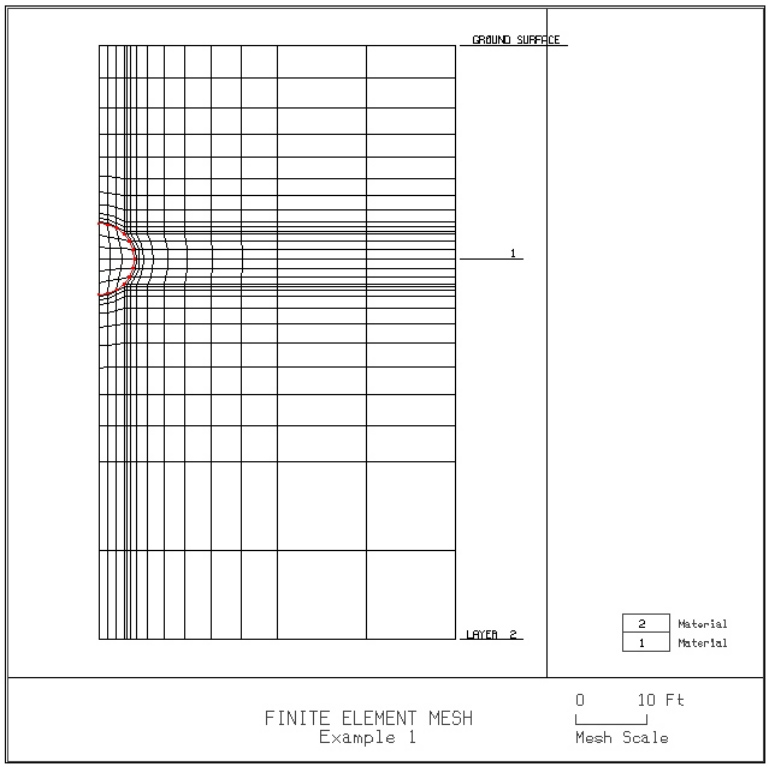

GROUND SURFACE
1
LAYER 2
2 Material
1 Material
FINITE ELEMENT MESH
Example 1
0 10 Ft
Mesh Scale

Figure 6.2

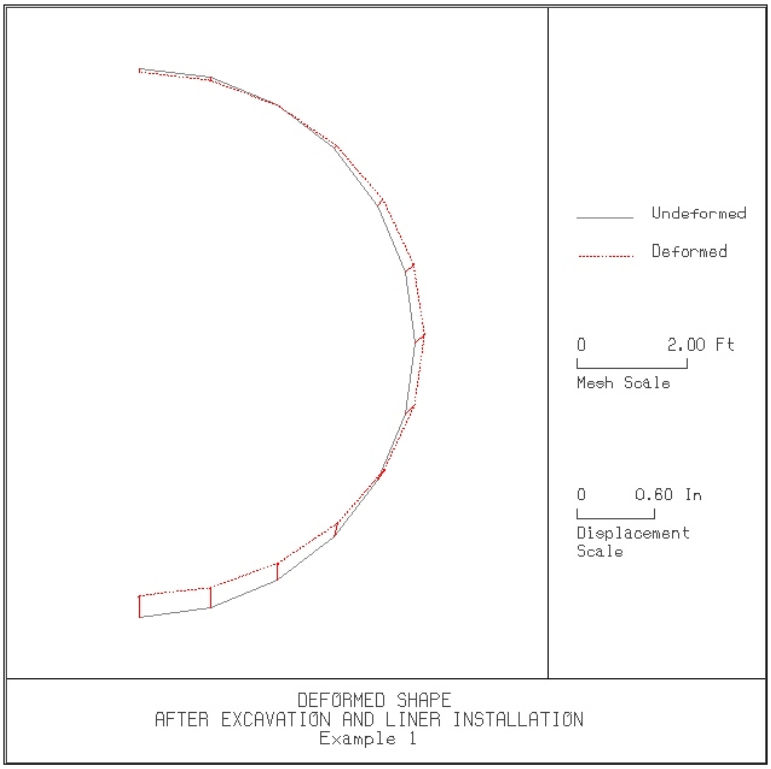

Undeformed
Deformed
0 2.00 Ft
Mesh Scale
0 0.60 In
Displacement
Scale
DEFORMED SHAPE
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.3

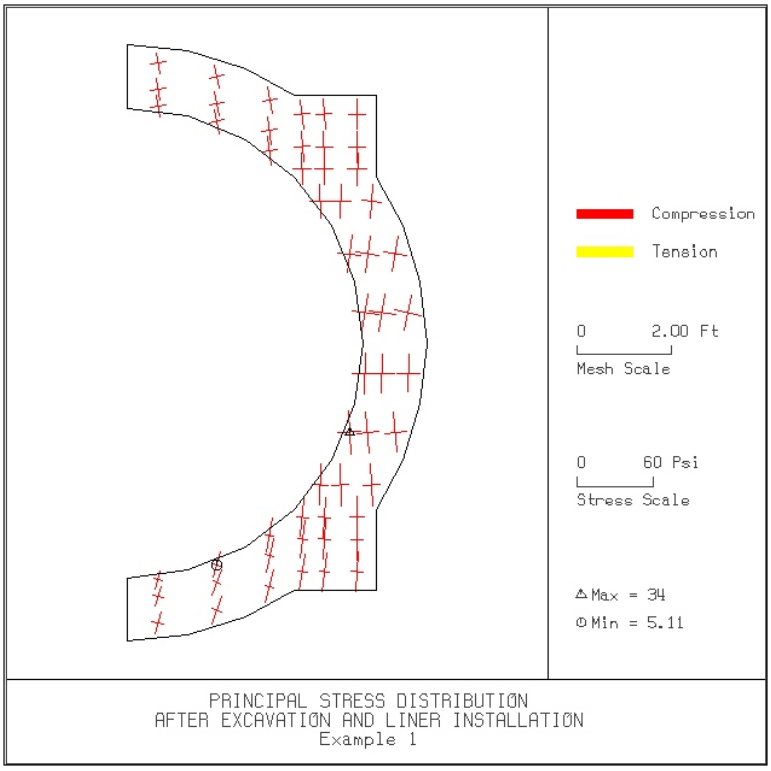

Compression
Tension
0 2.00 Ft
Mesh Scale
0 60 Psi
Stress Scale
Max = 34
Min = 5.11
PRINCIPAL STRESS DISTRIBUTION
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.4

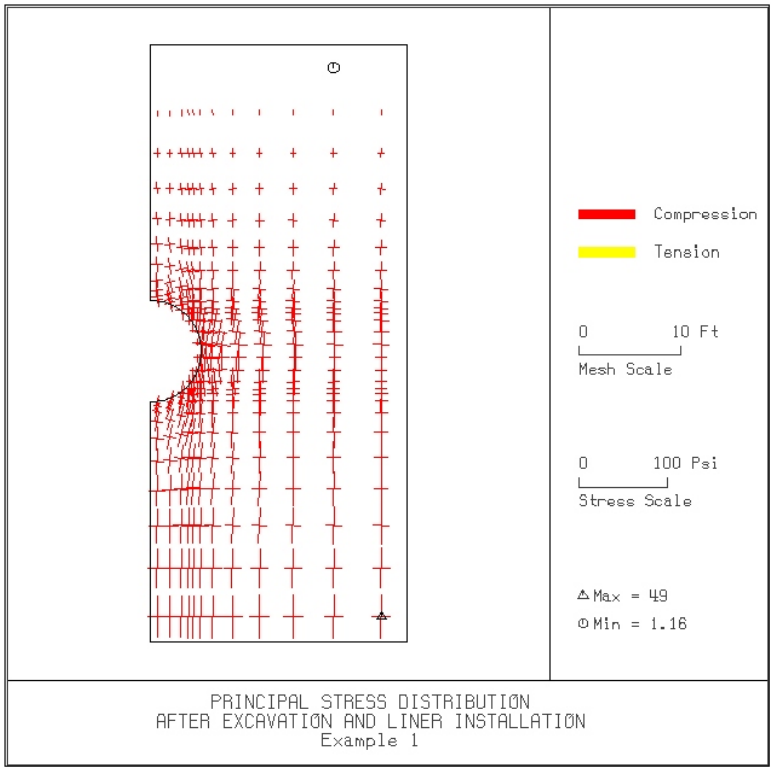

Compression
Tension
0 10 Ft
Mesh Scale
0 100 Psi
Stress Scale
Max = 49
Min = 1.16
PRINCIPAL STRESS DISTRIBUTION
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.5

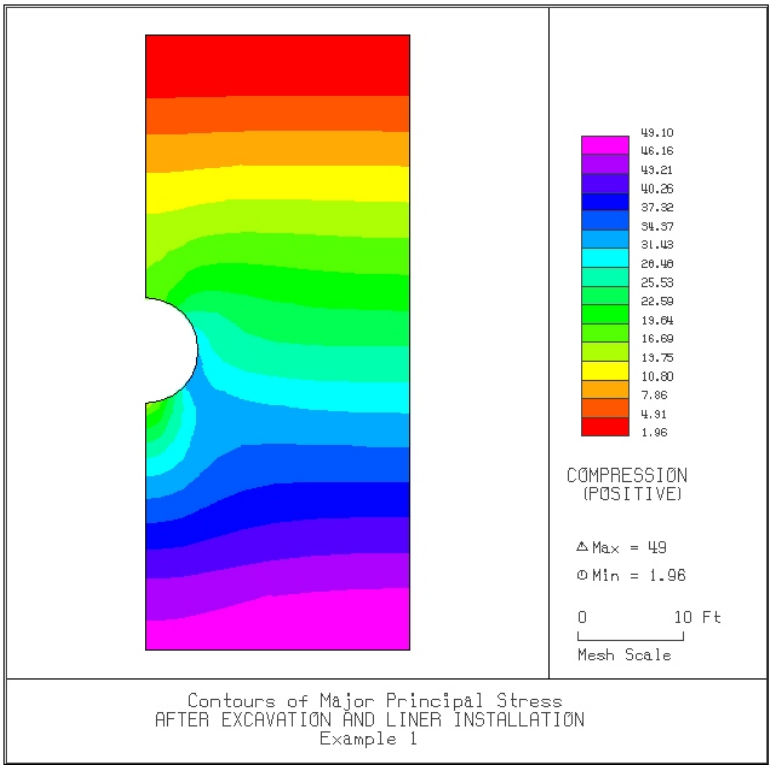

49.10
46.16
43.21
40.26
37.32
34.37
31.43
28.48
25.53
22.59
19.64
16.69
13.75
10.80
7.86
4.91
1.96
COMPRESSION
(POSITIVE)
Max = 49
Min = 1.96
0
10 Ft
Mesh Scale
Contours of Major Principal Stress
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.6

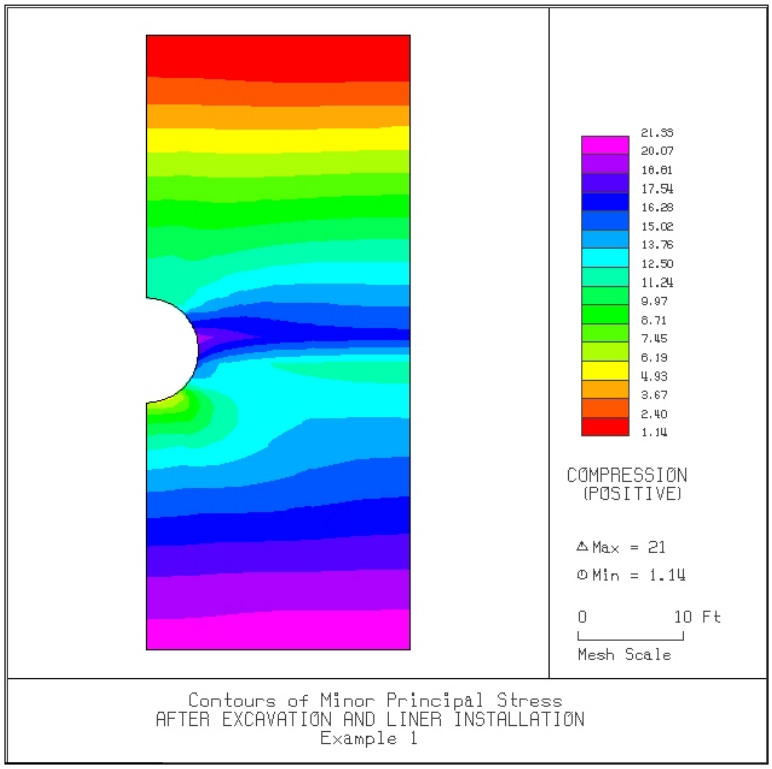

21.33
20.07
18.81
17.54
16.28
15.02
13.76
12.50
11.24
9.97
8.71
7.45
6.19
4.93
3.67
2.40
1.14
COMPRESSION
(POSITIVE)
Max = 21
Min = 1.14
0
10 Ft
Mesh Scale
Contours of Minor Principal Stress
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.7

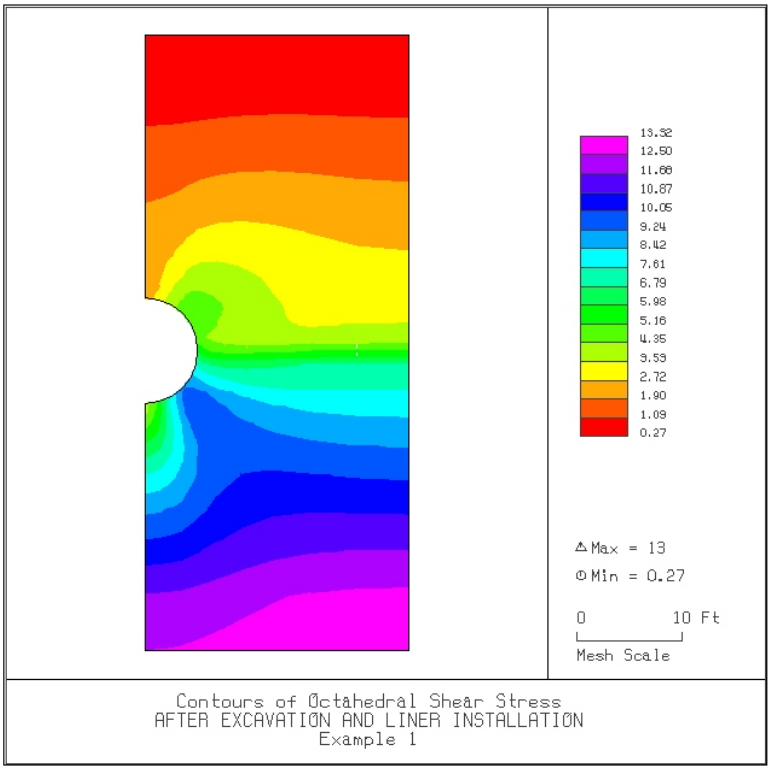

13.32
12.50
11.68
10.87
10.05
9.24
8.42
7.61
6.79
5.98
5.16
4.35
3.53
2.72
1.90
1.09
0.27
Max = 13
Min = 0.27
0
10 Ft
Mesh Scale
Contours of Octahedral Shear Stress
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.8

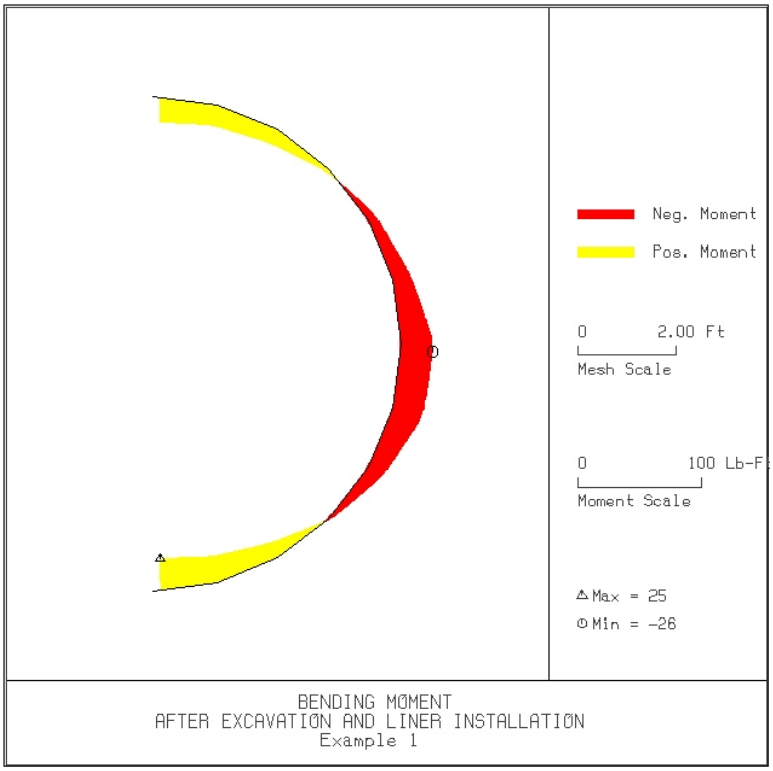

Neg. Moment
Pos. Moment
0 2.00 Ft
Mesh Scale
0 100 Lb-F
Moment Scale
Max = 25
Min = -26
BENDING MOMENT
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.9

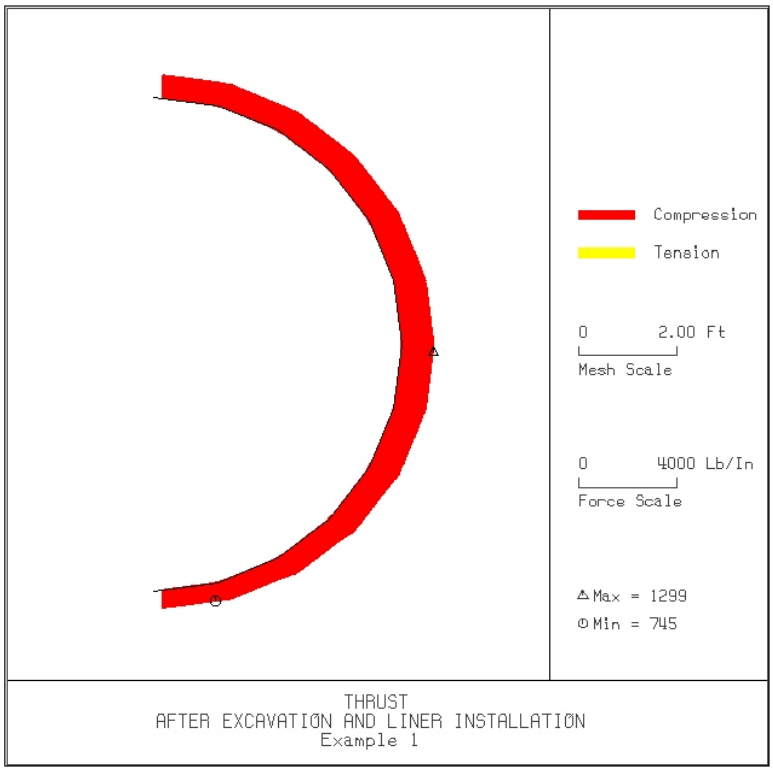

Compression
Tension
0 2.00 Ft
Mesh Scale
0 4000 Lb/In
Force Scale
Max = 1299
Min = 745
THRUST
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.10

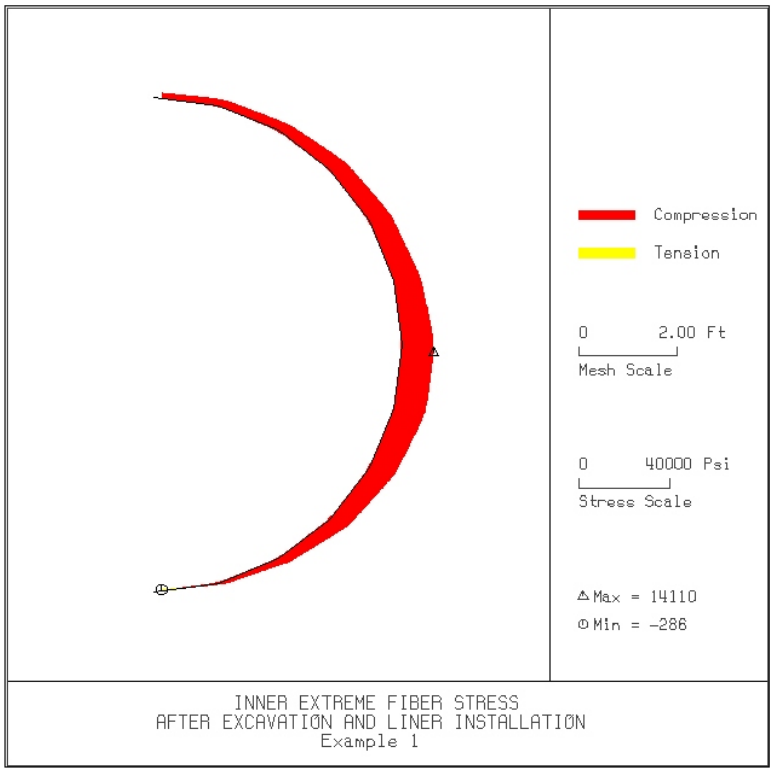

Compression
Tension
0 2.00 Ft
Mesh Scale
0 40000 Psi
Stress Scale
Max = 14110
Min = -286
INNER EXTREME FIBER STRESS
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.11

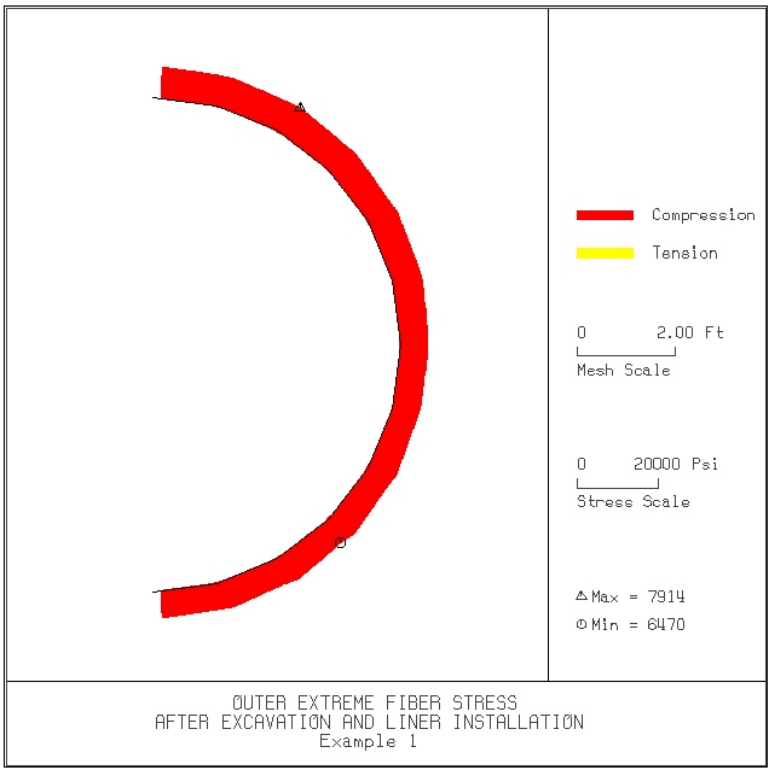

Compression
Tension
0 2.00 Ft
Mesh Scale
0 20000 Psi
Stress Scale
Max = 7914
Min = 6470
OUTER EXTREME FIBER STRESS
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.12

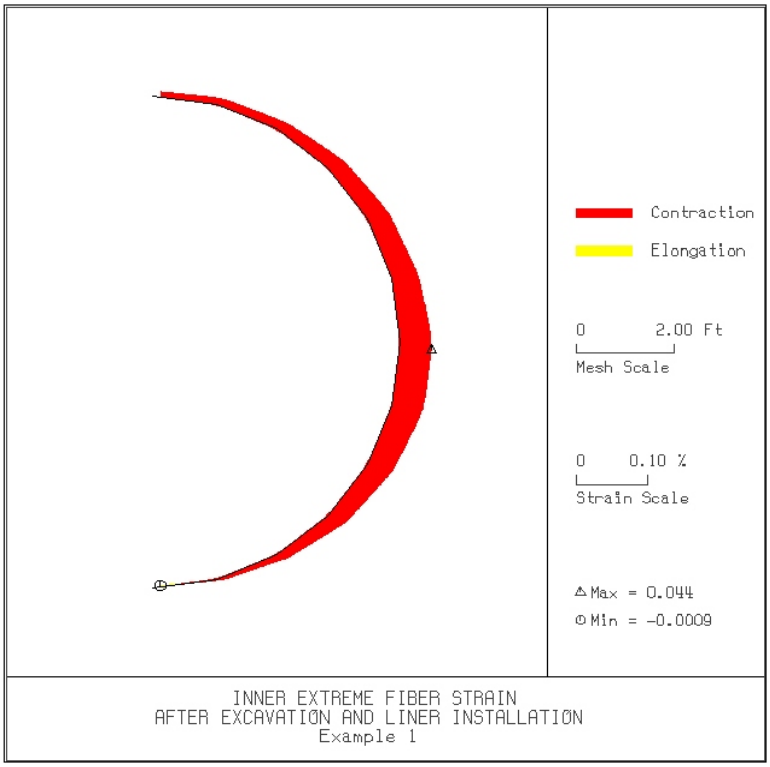

Contraction
Elongation
0 2.00 Ft
Mesh Scale
0 0.10 %
Strain Scale
Max = 0.044
Min = -0.0009
INNER EXTREME FIBER STRAIN
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.13

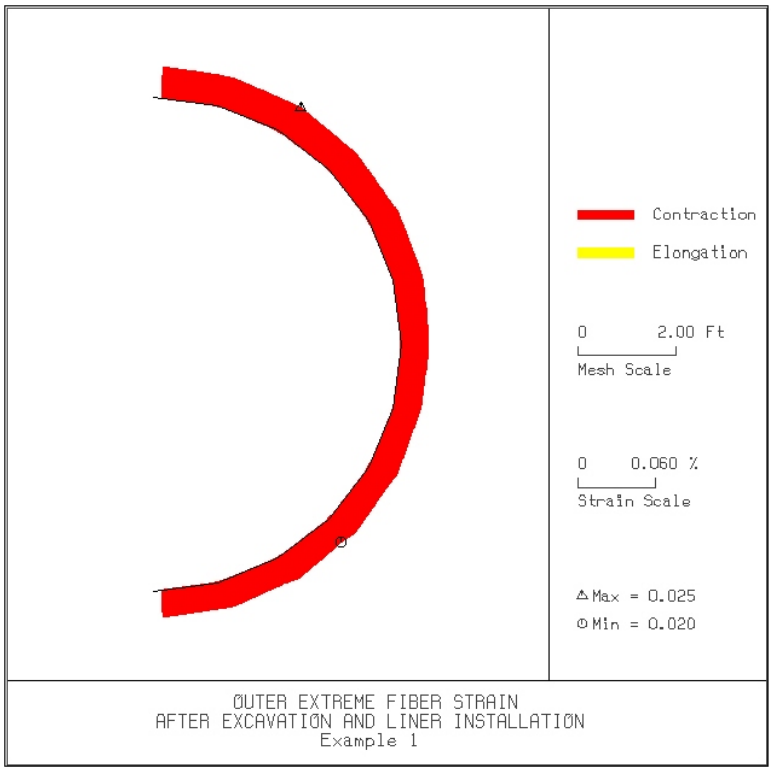

Contraction
Elongation
0 2.00 Ft
Mesh Scale
0 0.060 %
Strain Scale
Max = 0.025
Min = 0.020
OUTER EXTREME FIBER STRAIN
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.14

6.2 Example 2

Example 2 represents steel gas pipeline subjected to concentrated and distributed loads applied on the ground surface as well as the uniformly distributed internal gas pressure acting on the pipe wall. Table 6.4 shows the listing of input file EX2.DAT. Figure 6.15 shows finite element meshes along with soil layers.

Results

Partial graphical outputs are shown in Figures 6.16 to 6.23.

Key results are summarized below:

Max. Liner hoop stress of 1,276 kg/Cm^2 takes place at the inner face of tunnel crown as shown in Figure 6.22. Assuming that the yield stress of steel liner is 2,530 kg/Cm^2, the safety factor is close to 2.

Table 6.4 Listing of input file for Example 2

```
* CARD 1.1
* TITLE
: Buried Gas Pipeline For Example 2
* CARD 1.2
* IUNIT
   2
* CARD 1.3
* NTALT
   4
* CARD 1.4
* HT
  688.
* CARD 2.1
* Ps      Xs
  10.     5.0
* CARD 2.2
* NUMCON
   2
* Fi      Xi
   250.   0.0
   500.   2.0
* CARD 2.3
* Pi
  10.
* CARD 2.1
* NLAYER
   4
* CARD 2.2
* H       GAMA      RKO       E         V
  500.    0.002     0.4       230.      0.3
  120.    0.002     0.4       230.      0.3
  116.    0.0022    0.33      250.      0.25
  300.    0.0023    0.31      300.      0.25
* CARD 3.1
* ISHAPE
   1
* CARD 3.2
* D
  76.2
* CARD 4.1
* EC          VC
  0.0         0.0
* CARD 4.2
* ES          VS
  2.11E+06    0.3
```

```
* CARD 4.3
* ER         VR
  0.0        0.0
* CARD 5.1.1
* LNTP       WL
  9          0.0
* CARD 5.1.2
* Ts
  1.7
* CARD 7.1
* NUMRELEASE
   0
* CARD 7.2
* Xi      Yi
* END
```

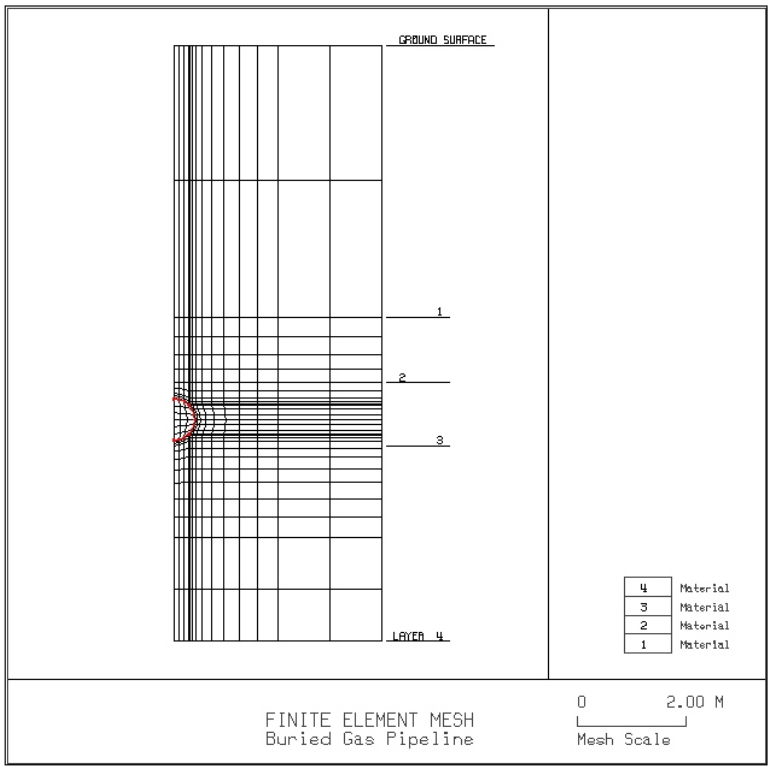

GROUND SURFACE
1
2
3
LAYER 4
4 Material
3 Material
2 Material
1 Material
FINITE ELEMENT MESH
Buried Gas Pipeline
0 2.00 M
Mesh Scale

Figure 6.15

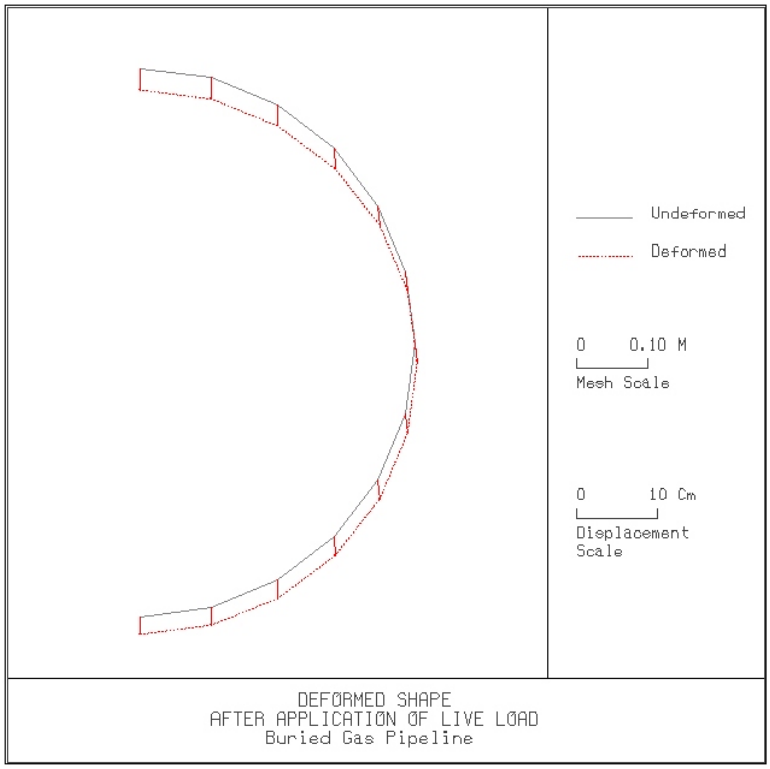

Undeformed
Deformed
0 0.10 M
Mesh Scale
0 10 Cm
Displacement
Scale
DEFORMED SHAPE
AFTER APPLICATION OF LIVE LOAD
Buried Gas Pipeline

Figure 6.16

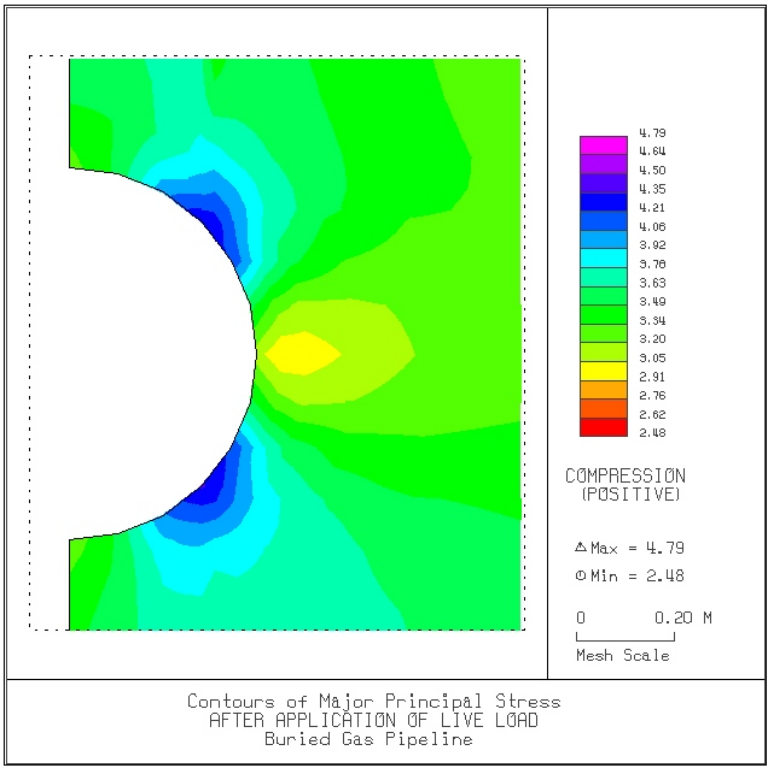

4.79
4.64
4.50
4.35
4.21
4.06
3.92
3.76
3.63
3.49
3.34
3.20
3.05
2.91
2.76
2.62
2.48
COMPRESSION
(POSITIVE)
Max = 4.79
Min = 2.48
0 0.20 M
Mesh Scale
Contours of Major Principal Stress
AFTER APPLICATION OF LIVE LOAD
Buried Gas Pipeline

Figure 6.17

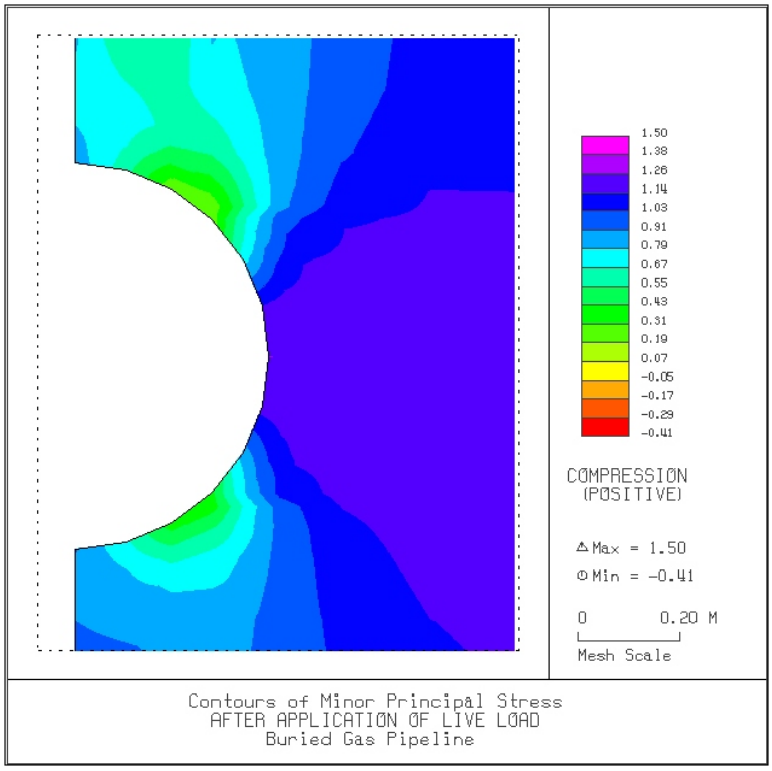

1.50
1.38
1.26
1.14
1.03
0.91
0.79
0.67
0.55
0.43
0.31
0.19
0.07
-0.05
-0.17
-0.29
-0.41
COMPRESSION
(POSITIVE)
Max = 1.50
Min = -0.41
0
0.20 M
Mesh Scale
Contours of Minor Principal Stress
AFTER APPLICATION OF LIVE LOAD
Buried Gas Pipeline

Figure 6.18

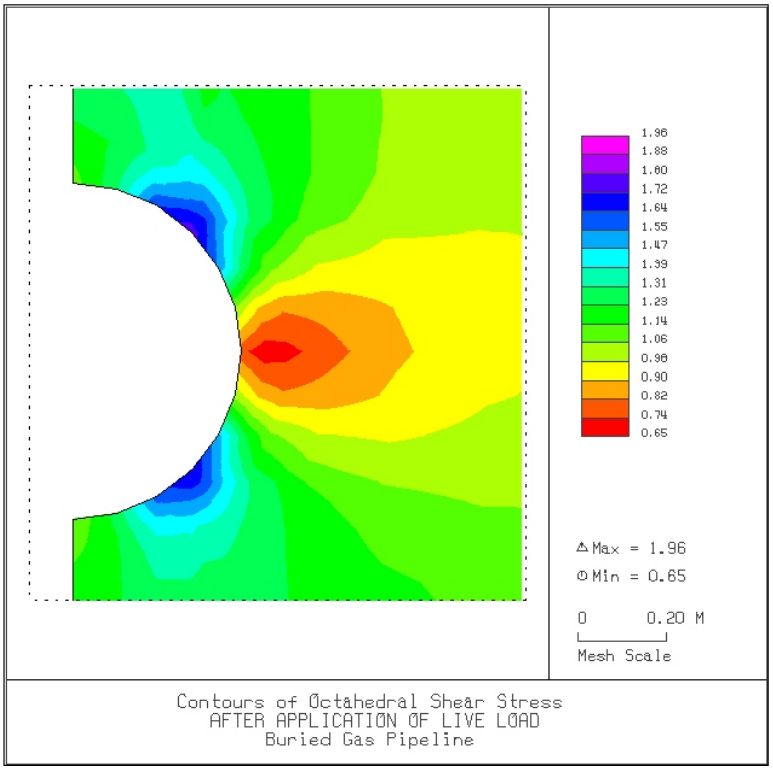

1.96
1.88
1.80
1.72
1.64
1.55
1.47
1.39
1.31
1.23
1.14
1.06
0.98
0.90
0.82
0.74
0.65
Max = 1.96
Min = 0.65
0
0.20 M
Mesh Scale
Contours of Octahedral Shear Stress
AFTER APPLICATION OF LIVE LOAD
Buried Gas Pipeline

Figure 6.19

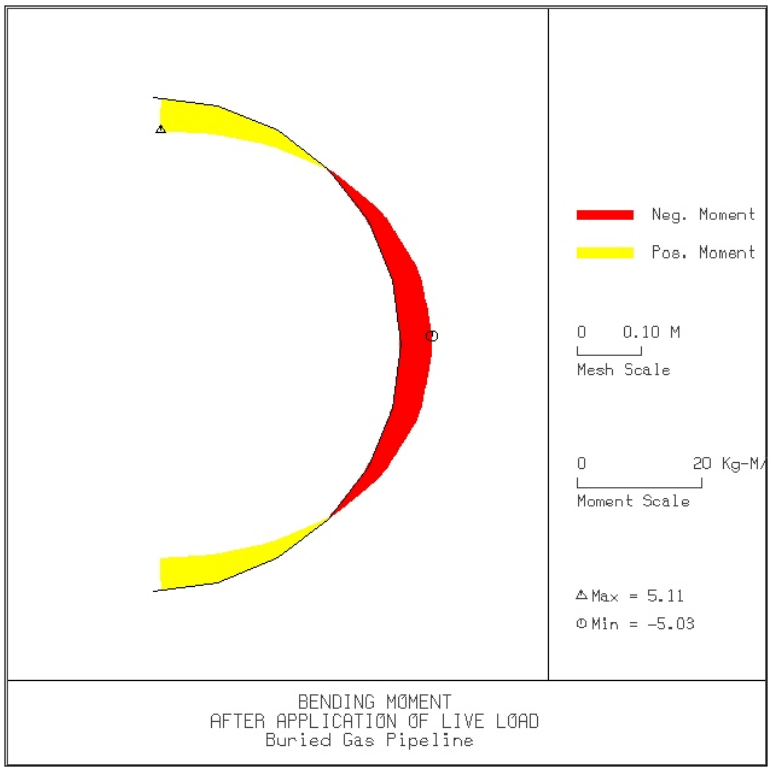

Neg. Moment
Pos. Moment
0 0.10 M
Mesh Scale
0 20 Kg-M
Moment Scale
Max = 5.11
Min = -5.03
BENDING MOMENT
AFTER APPLICATION OF LIVE LOAD
Buried Gas Pipeline

Figure 6.20

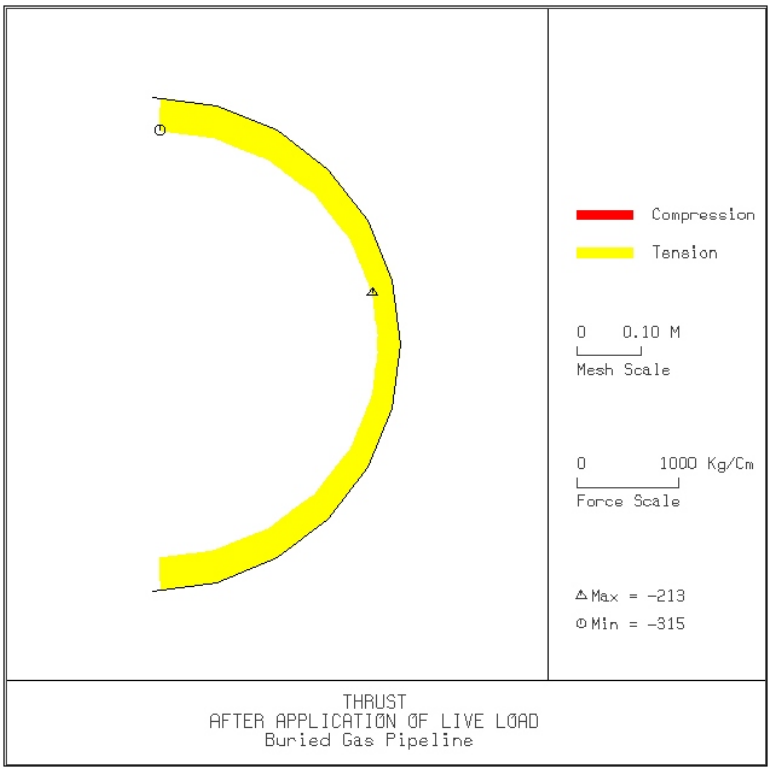

Compression
Tension
0 0.10 M
Mesh Scale
0 1000 Kg/Cm
Force Scale
Max = -213
Min = -315
THRUST
AFTER APPLICATION OF LIVE LOAD
Buried Gas Pipeline

Figure 6.21

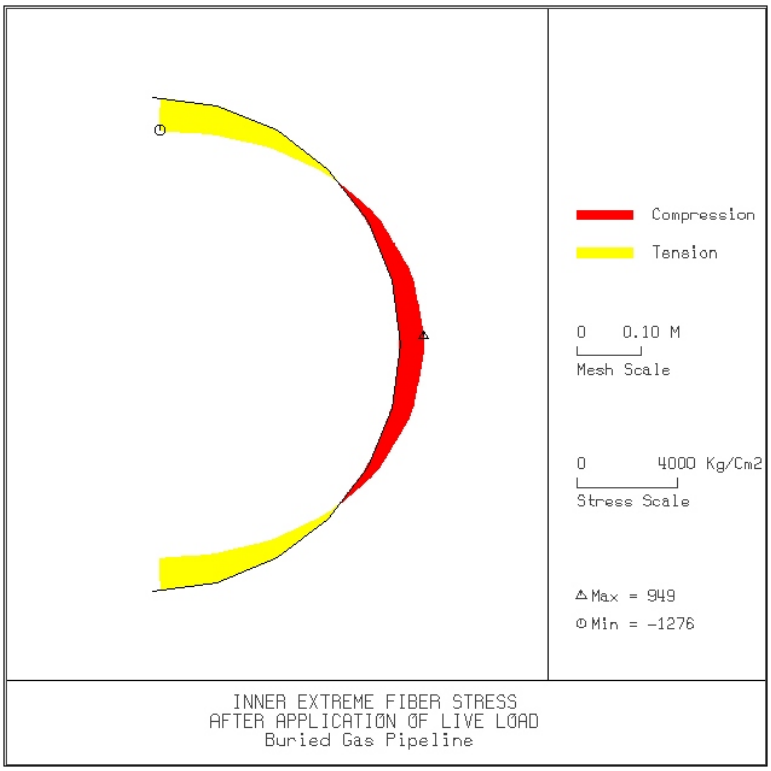

Compression
Tension
0 0.10 M
Mesh Scale
0 4000 Kg/Cm2
Stress Scale
Max = 949
Min = -1276
INNER EXTREME FIBER STRESS
AFTER APPLICATION OF LIVE LOAD
Buried Gas Pipeline

Figure 6.22

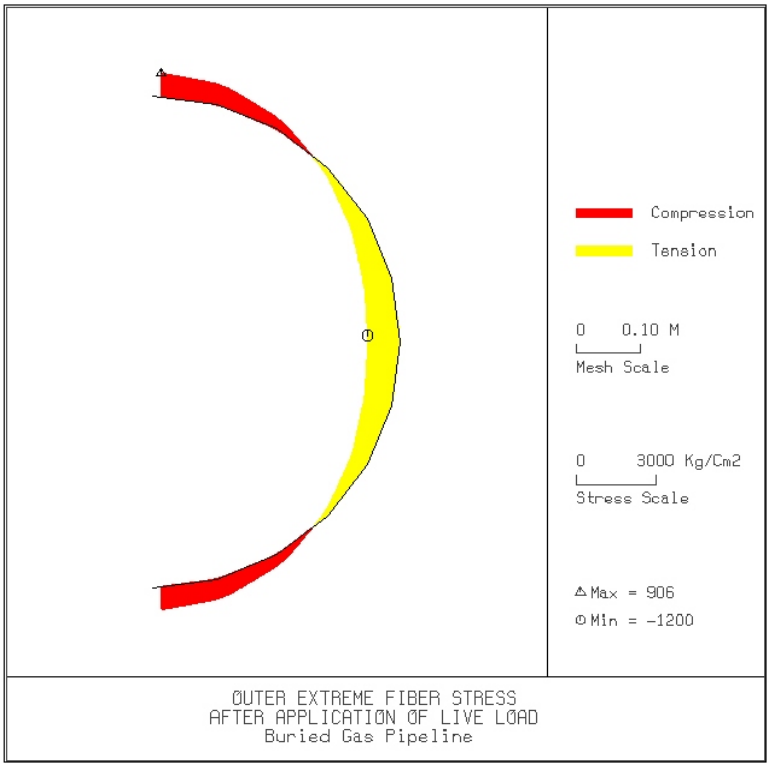

Compression
Tension
0 0.10 M
Mesh Scale
0 3000 Kg/Cm2
Stress Scale
Max = 906
Min = -1200
OUTER EXTREME FIBER STRESS
AFTER APPLICATION OF LIVE LOAD
Buried Gas Pipeline

Figure 6.23