T U N A

TUNnel Analysis Program

Version 7.05

COMTEC RESEARCH

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Contents

Introduction

1.1 Overview

TUNA is a fully automated computer program 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.

1.2 Features

- 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 Fibers of the Liner

1.3 Assumptions

- Liners and the surrounding medium are linear elastic.
- Liners are modeled by conventional beam element.
- 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 System Requirements

- ✓ Windows 32 bit operating system
- ✓ Intel Pentium 4 or AMD processors
- ✓ 4 GB Ram with 30 GB free space in Drive C
- ✓ SVGA monitor

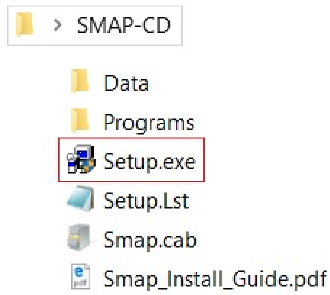
2.2 Installation Procedure

1. Uninstall if there are pre-existing SMAP programs.
   To uninstall SMAP programs, remove following program using Add/Remove in Control Panel:
   SMAP
   Delete following files if they are existing:
   C:\Program Files\Smap
   C:\Windows\Setup1.exe
   Rename or delete following folders if they are existing:
   C:\SMAP
   C:\SmapKey

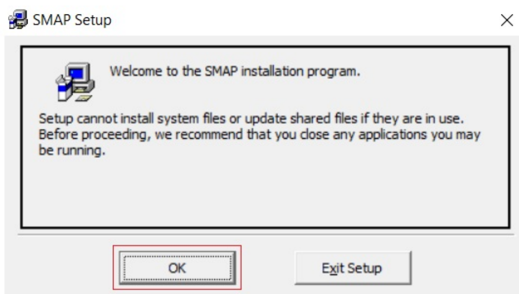
2. Download SMAP-CD.exe from the Download section of www.ComtecResearch.com

3. Run SMAP-CD.exe
   SMAP-CD folder will be created with SMAP installation programs

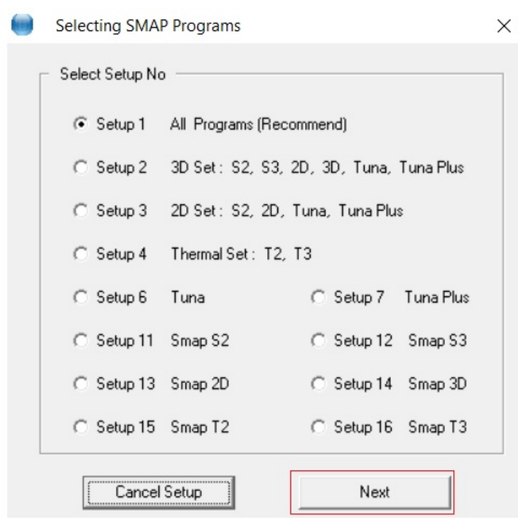
4. Double-click **Setup.exe**



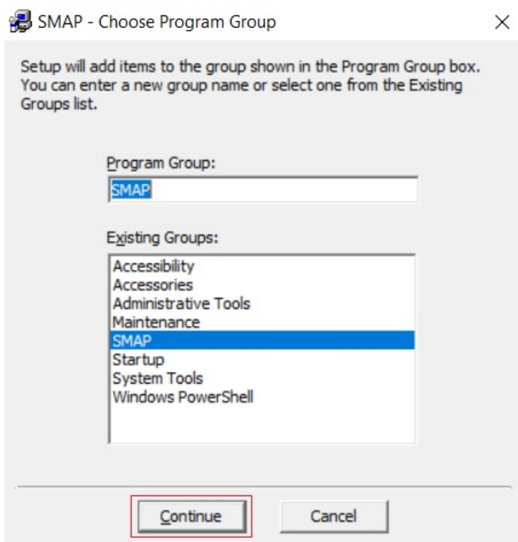
5. Click **OK**



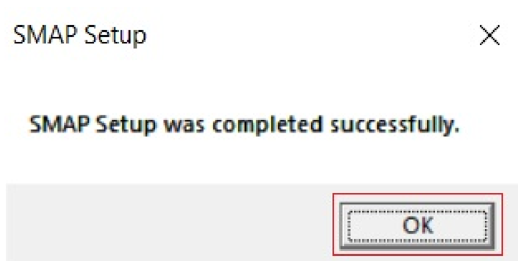
6. Click **Next**
   It will take few minutes.
   Wait until next step.



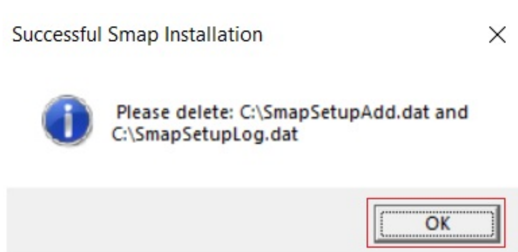
7. Click **Continue**



8. Click **OK**



9. Click **OK**



Note:

Following two log files will be generated once finished:
C:\SmapSetupAdd.dat
C:\SmapSetupLog.dat

If Smap Installation is successful, delete these two files.

If Smap Installation is not successful,
follow the instruction in SmapSetupAdd.dat.

If you still have problems with Smap Installation,
send these two files to info@ComtecResearch.com

Running Programs

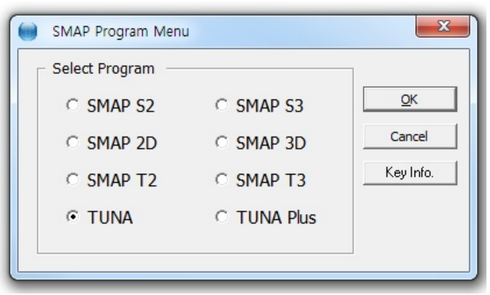
3.1 Introduction

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

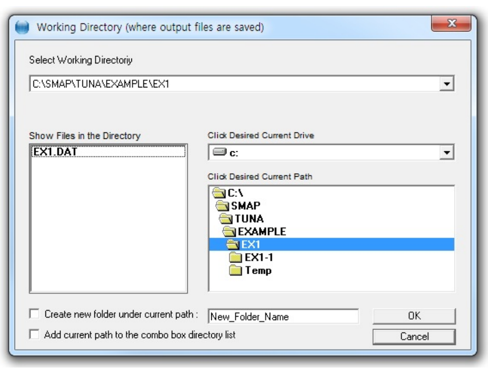
Accessing TUNA Program

1. When it is the first time, you copy Smap.exe in C:\Ct\Ctmenu and setup a Shortcut to SMAP Icon on your computer desktop. Then You simply double-click SMAP Shortcut.

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

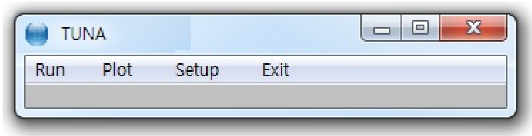


3. Next, you need to select **Working Directory**. Working Directory should be the existing directory where all the output files are saved. It is a good idea to have all your input files for the current project in this Working Directory. Click the disk drive, double-click the directory, and then **OK**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

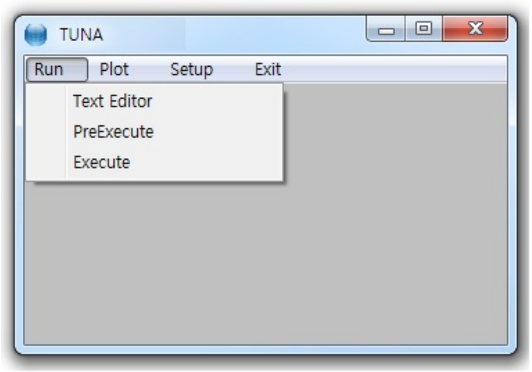


TUNA Menu

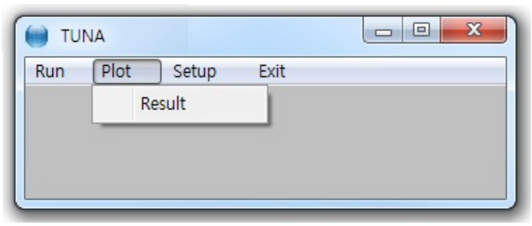
TUNA provides the following Main Menus; Run, Plot, Setup and Exit.



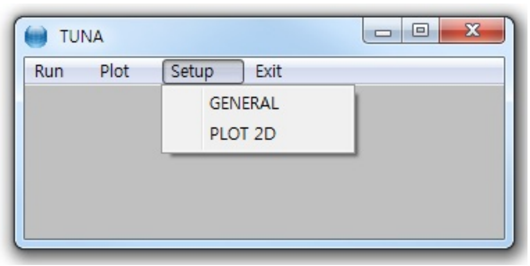
RUN executes main processing program and has following Sub Menus;
Text Editor,
Pre Execute and
Execute.



PLOT executes Result.
Result is associated with post-processing programs to show graphically the computed results.



SETUP is mainly used to set plotting control parameters for PLOT-2D and has the following Sub Menus;
General and PLOT-2D.

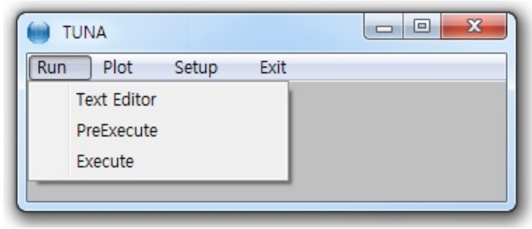


EXIT is used to end TUNA.

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.

RUN Menu has the following Sub Menus; Text Editor, Pre Execute, and Execute.



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

PRE EXECUTE is used either to check the input file or to generate plotting information files. **PRE EXECUTE** is especially useful when you want to check input data to see whether there is any input error. It is also useful when you have finished **EXECUTE** but you want to add or modify the Post File for plot. In this case, you edit the Post File as you want, run **PRE EXECUTE** and then run post-processing programs in **PLOT** menu.

EXECUTE executes TUNA main-processing program.

TUNA Output Files

Once you execute TUNA, generally you can obtain following output files:

CONTSS.DAT	Contains stresses/strains in continuum element
BEAMSF.DAT	Contains section forces in beam element
DISPLT.DAT	Contains nodal displacements

It should be noted that all of your output files are saved in the Working Directory that you specified at the beginning.

TUNA Graphical Output

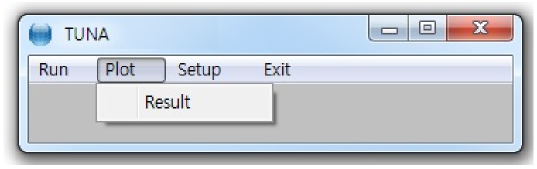
TUNA Post-processing program can generate the following graphical output:

- Finite element mesh
- Deformed shape
- Principal stress distribution
- Section forces in beam element
- Extreme fiber stresses/strains in beam elements
- Contours of stresses

Graphical output can be followed by running RESULT from PLOT Menu.

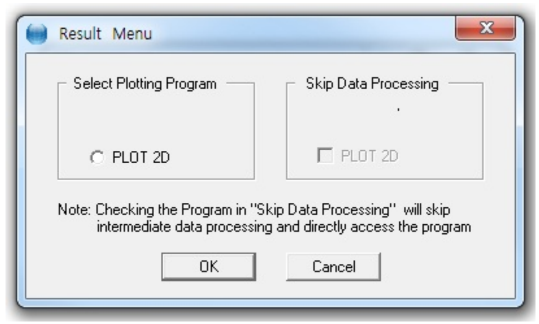
3.3 PLOT Menu

PLOT is to show graphically Computed Result.



Once you finished executing TUNA main-processing program, you need to run post-processing programs to show graphically numerical results.

PLOT Menu contains PLOT-2D.



PLOT-2D plots contours of continuum stresses, beam section forces, principal stress vectors, and deformed shapes. Refer to PLOT-2D Users?s Manual in Section 14 in SMAP-S2 Manual.

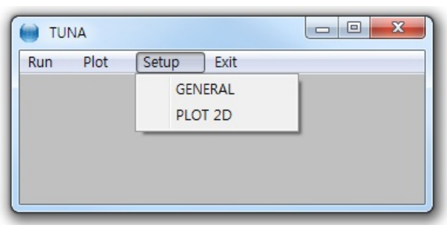
Note: When you first plot results, do not check the check box in Skip Data Processing. When you replot results, however, you can check the check box to skip intermediate data processing. This will save time and keep modified output data.

3.4 SETUP Menu

You need to run SETUP Menu

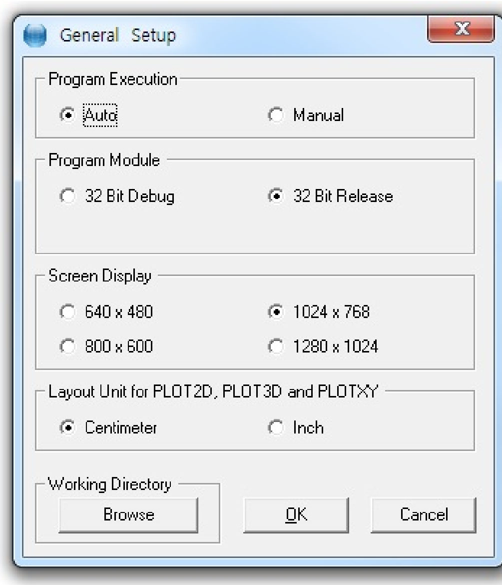
- To specify TUNA main-processing program module.
- To adjust scales of graphical outputs from PLOT-2D.

SETUP Menu has three Sub Menus; General and PLOT-2D



3.4.1 General Setup

General Setup has five different items; Program Execution, Program Module, Screen Display, Layout Unit, and Working Directory.



Program Execution has two options; Auto and Manual.
For Manual Execution, refer to Section 3.5 in User?s Manual.

Program Module has two options. 32 Bit Debug and 32 Bit Release. Debug program modules run slower but gives more detailed information when run time errors occur. For most cases, 32 Bit Release is recommended.

Screen Display has four options; 640x480, 800x600, 1024x768, and 1280x1024. This will affect the size of child window in PLOT-2D.

Layout Unit is used for PLOT-2D. You can select either Centimeter or Inch in specifying plot scales and dimensions.

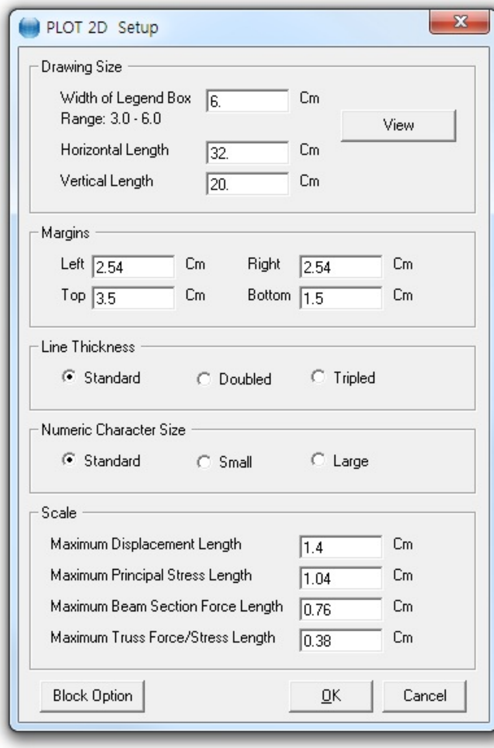
Working Directory is to change the current working directory. When you click the Browse button, Working Directory dialog will be shown so that you can select new directory.

3.4.2 PLOT-2D Setup

PLOT-2D Setup is mainly used to specify scales and dimensions of post processing program PLOT-2D. It has six different items; Drawing Size, Margins, Line Thickness, Numeric Character Size, Scale and Block Option. The first four items are much similar to those described in PLOT-XY Setup.

Scale specifies Maximum Displacement Length, Maximum Principal Stress Length, Maximum Beam Section Force Length, and Maximum Truss Force/Stress Length, which will be shown on PLOT-2D.

Block Option specifies options to generate either PRESMAP Output or Block Diagram. This option is not available for TUNA.



3.5 Manual Procedure to Run TUNA

Occasionally, you need to execute TUNA main-processing program manually to see what is going on each step, specially when terminated due to some errors.

Method 1

1. Select Setup -> General -> Manual in Program Execution
2. Select Run -> Execute
3. Select TUNA input file when displaying file open dialog
4. Now TUNA is running on Windows Command Line
5. Type Enter key to continue to next step or Control C to stop

Method 2

1. Select CMD and go to Working Directory
2. Change to Temp sub directory

   Create Temp sub directory if not existing.

   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. Type C:\Smap\Ct\Ctbat\TUNA.bat
4. Type ..\EX1.Dat to access input file in Working Directory, for example
5. Type Enter key to continue to next step or Control C to stop

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 "`Smap_S2.dat`" in the directory C:\Smap\Ct\Ctdata\Debug

```
     1,     11,       1,        1,       1,    100,         90
IDEBUG, NCLDEB, IOUTDEB, ICONVER, NELDEB, NO_MAX, NO_RESTART

   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. Refer to IOUTDEB.
               2 : Print debug information in each individual
                   files based on NO_MAX and NO_RESTART and
                   save in C:\SMAP\SMAPS2\DEBUG (NOT AVAILABLE)

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

   IOUTDEB =   0 : Debug information on screen.
               1 : Debug information on file,
                   Smap_S2.deb in Working Directory\Temp

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

   NELDEB   = -1 : Do not print element information in element
                   level operation.
            =  0 : Print current element number in element
                   level operation.
            >  0 : Print debug information for the element
                   number NELDEB in element level operation.

   NO_MAX        : Maximum number of individual files.
                   Used for IDEBUG = 2.

   NO_RESTART    : Restart number for individual file
                   once it reaches NO_MAX.
                   Used for IDEBUG = 2.
```

Description of Input Data

The input data is classified into seven different card groups.

The first card group includes general informations; job title (TITLE), unit selection (IUNIT), 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 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>
<tr><th>Card Group</th><th>Input Data and Definitions</th></tr>
<tr><td rowspan="4">1

General Information</td><td>1.1

TITLE

TITLE — Any title (Max = 60 characters)</td></tr>
<tr><td>1.2

IUNIT

<table>
<tr><th>IUNIT</th><th>Length</th><th>Force</th><th>Pressure</th><th>Unit Weight</th></tr>
<tr><td>1</td><td>in</td><td>lb</td><td>lb/in^2</td><td>lb/in^3</td></tr>
<tr><td>2</td><td>Cm</td><td>Kg</td><td>Kg/Cm^2</td><td>Kg/Cm^3</td></tr>
</table></td></tr>
<tr><td>1.3

NTALT

Unlined Tunnel
NTALT = 1 Excavation Load
= 2 Excavation and Live Load

Lined Tunnel
= 3 Excavation Load
= 4 Excavation and Live Load</td></tr>
<tr><td>1.4

HT, DGW

HT — Tunnel depth
DGW — Depth of water table from ground surface

See Figure 4.2 for minimum depth</td></tr>
</table>

<table>
<tr><th>Card Group</th><th colspan="2">Input Data and Definitions</th></tr>
<tr><td rowspan="3">2
Live Loads (If NTALT = 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>

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

Soil / Rock Material Property</td><td>3.1

NLAYER

NLAYER — Total number of layers. Max = 10</td></tr>
<tr><td>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</td></tr>
</table>

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 5, 6 and 7 are required for Lined Tunnels (NTALT = 3 and 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 = 15 > T_1, T_2, T_3, W_1, W_2, W_3 = 16 > T_1, T_2, T_3, W_1, W_2, W_3 D_1, A_{s1}, D_3, A_{s3} = 20 > T_b, T_t, W, A, I A: Cross section area I : Moment of inertia Liner types are shown in Figure 4.3

<table>
<tr><th>Card Group</th><th colspan="2">Input Data and Definitions</th></tr>
<tr><td rowspan="2">6
Liner Cross Section Data</td><td rowspan="2">6.2
Side Segment</td><td>6.2.1
LNTP, WL

LNTP Liner type. Select from Figure 4.3
WL Weight per unit length of liner</td></tr>
<tr><td>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
= 15 > T_1, T_2, T_3, W_1, W_2, W_3
= 16 > T_1, T_2, T_3, W_1, W_2, W_3
D_1, A_{s1}, D_3, A_{s3}

= 20 > T_b, T_t, W, A, I
A: Cross section area
I : Moment of inertia

Liner types are shown in Figure 4.3</td></tr>
</table>

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 = 15 > T_1, T_2, T_3, W_1, W_2, W_3 = 16 > T_1, T_2, T_3, W_1, W_2, W_3 D_1, A_{s1}, D_3, A_{s3} = 20 > T_b, T_t, W, A, I A: Cross section area I : Moment of inertia Liner types are shown in Figure 4.3

<table>
<tr><th>Card Group</th><th>Input Data and Definitions</th></tr>
<tr><td rowspan="2">7

Liner Moment Release Locations</td><td>7.1

NUMRELEASE

NUMRELEASE — Number of locations where liner moments are released</td></tr>
<tr><td>7.2

NUMRELEASE Cards:
X_1, Y_1
X_2, Y_2
- -
- -

X_i, Y_i — X and Y coordinates where liner moments are released

See Figure 4.4</td></tr>
</table>

Table 4.1 Work Sheet for TUNA Input Data

<table>
<tr><th colspan="2">Card Group</th><th colspan="2">Input Data</th></tr>
<tr><td rowspan="4">General Information</td><td>TITLE</td><td colspan="2"></td></tr>
<tr><td>IUNIT</td><td colspan="2"></td></tr>
<tr><td>NTALT</td><td colspan="2"></td></tr>
<tr><td>HT, DGW</td><td></td><td></td></tr>
<tr><td rowspan="17">Live Load</td><td rowspan="2">Distributed Load</td><td>P_s</td><td>X_s</td></tr>
<tr><td></td><td></td></tr>
<tr><td>NUMCON</td><td colspan="2"></td></tr>
<tr><td>Concentrated Load</td><td>F_i</td><td>X_i</td></tr>
<tr><td>Force 1</td><td></td><td></td></tr>
<tr><td>Force 2</td><td></td><td></td></tr>
<tr><td>Force 3</td><td></td><td></td></tr>
<tr><td>Force 4</td><td></td><td></td></tr>
<tr><td>Force 5</td><td></td><td></td></tr>
<tr><td>Force 6</td><td></td><td></td></tr>
<tr><td>Force 7</td><td></td><td></td></tr>
<tr><td>Force 8</td><td></td><td></td></tr>
<tr><td>Force 9</td><td></td><td></td></tr>
<tr><td>Force 10</td><td></td><td></td></tr>
<tr><td rowspan="2">Internal Pressure</td><td colspan="2">P_i</td></tr>
<tr><td colspan="2"></td></tr>
</table>

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		

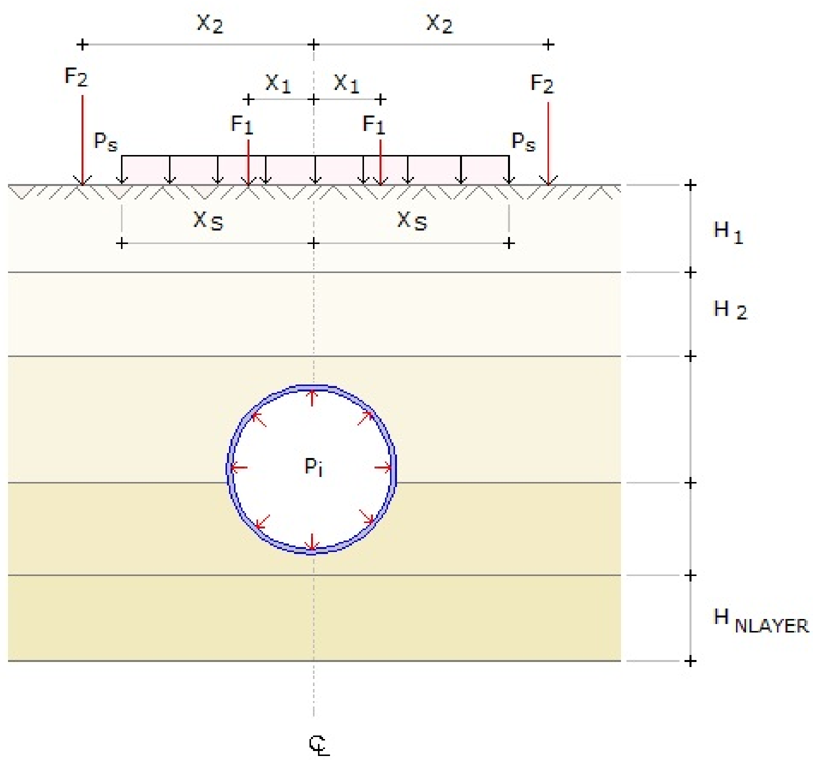
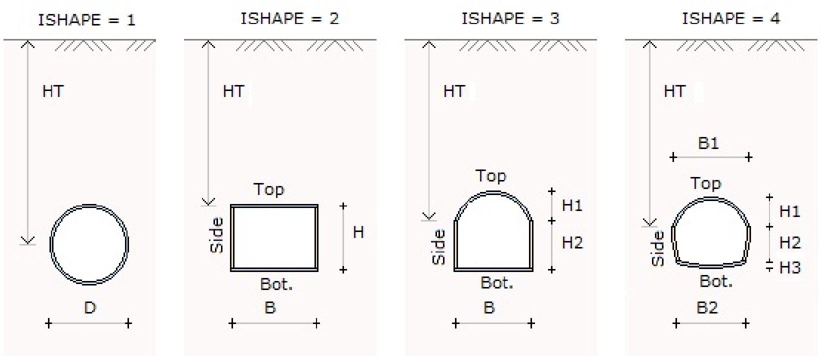


Figure 4.1 Schematic Tunnel Section View



ISHAPE = 1	ISHAPE = 2	ISHAPE = 3	ISHAPE = 4
HT $\geq$ 0.7 D	HT $\geq$ 0.1 B	HT $\geq$ 0.7B	HT $\geq$ 0.7 B1
	H $\geq$ 0.2 B	H1 $\leq$ 0.5 B	H1 $\leq$ 0.5 B1
	H $\leq$ 5 B	H2 $\geq$ 0.2 B	H2 $\geq$ 0.5 (B1-B2)
		H2 $\leq$ 5 B	H2 $\geq$ 0.1 B1
			H3 $\leq$ 0.5 B2
			B2 $\geq$ 0.1 B1
			B2 $\leq$ B1
			H1+H2+H3 $\geq$ B1/5
			H1+H2+H3 $\leq$ 5 B1

Figure 4.2 Tunnel Shapes and Dimensional Limits

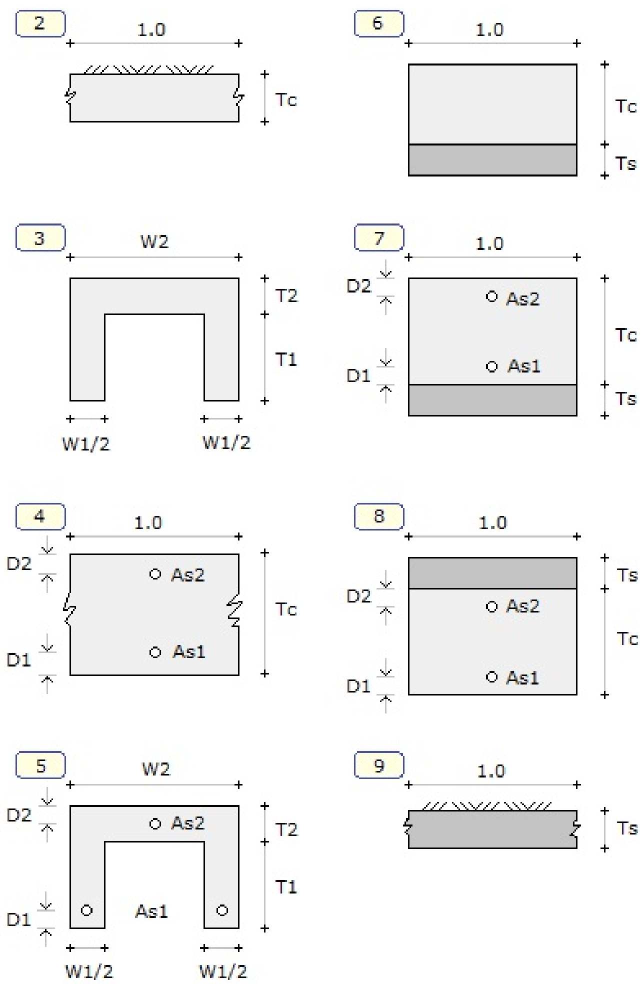


Figure 4.3 Liner Cross Sections

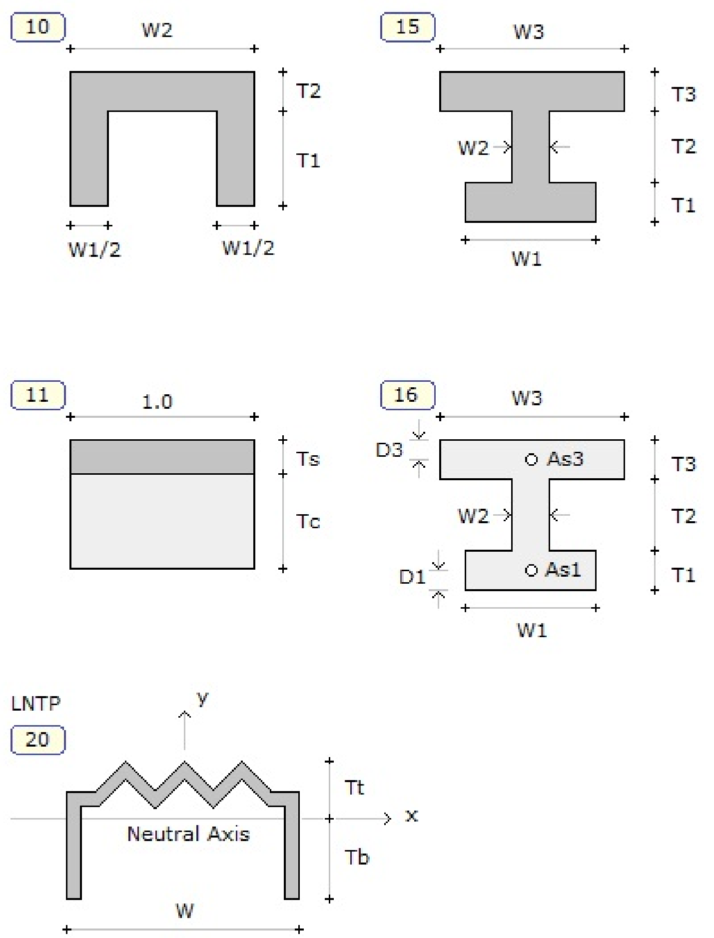


Figure 4.3 Liner Cross Sections (continued)

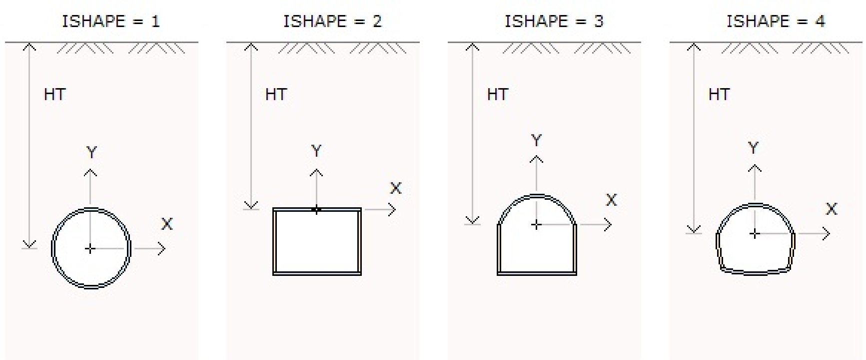


Figure 4.4 Reference origin for liner moment release

Description of Output Data

In general, there are 16 graphical outputs as summarized in Table 5.1. Figure 5.1 shows sign conventions and notations used for section forces and strains in the liner.

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	Shear in the Tunnel Liner
11	Inner Extreme Fiber Stress in the Tunnel Liner
12	Outer Extreme Fiber Stress in the Tunnel Liner
13	Inner Extreme Fiber Strain in the Tunnel Liner
14	Outer Extreme Fiber Strain in the Tunnel Liner
15	Inner Reinforcing Bar Stress in the Tunnel Liner
16	Outer Reinforcing Bar Stress in the Tunnel Liner

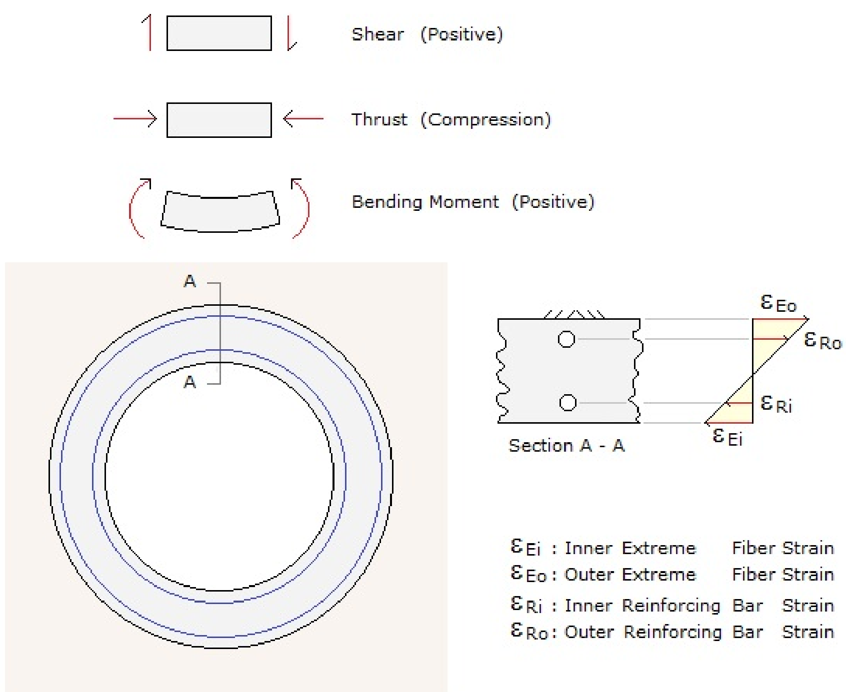


Figure 5.1 Sign conventions and notations used for section forces and strains in the liner

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.

Third example problem is the same as first example except that liner connections are moment-released.

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
3	EX3.DAT	0.02	Same as Example 1 except that liners are connected as hinge

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 surrounding media are listed in Figure 6.1. The tunnel is subjected to excavation load. Table 6.2 lists input file.

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 as in Example 3.

Results

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

Max. Tunnel Diameter Change:
0.19 in (0.16 % of tunnel diameter)

Max. Liner Compressive Stress:
14,250 psi (51 % of yield strength)

Table 6.2 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
* END
```

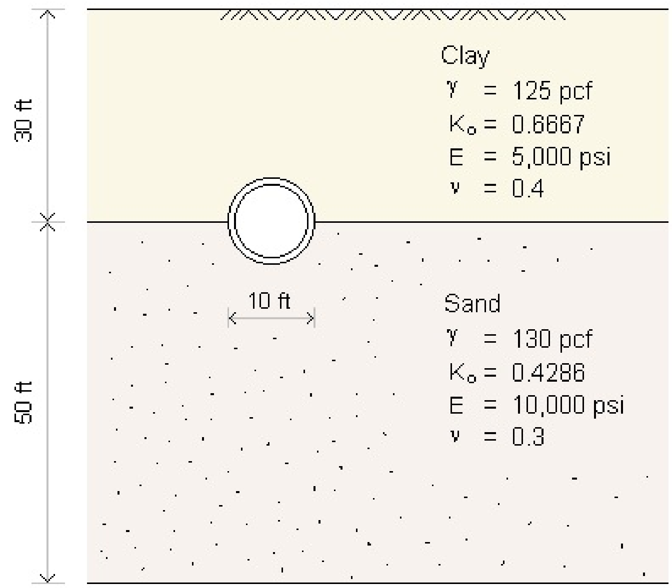
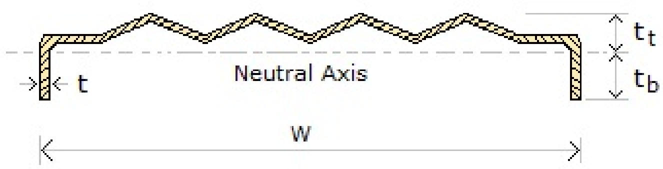


Figure 6.1 Schematic tunnel section



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 (Continued)

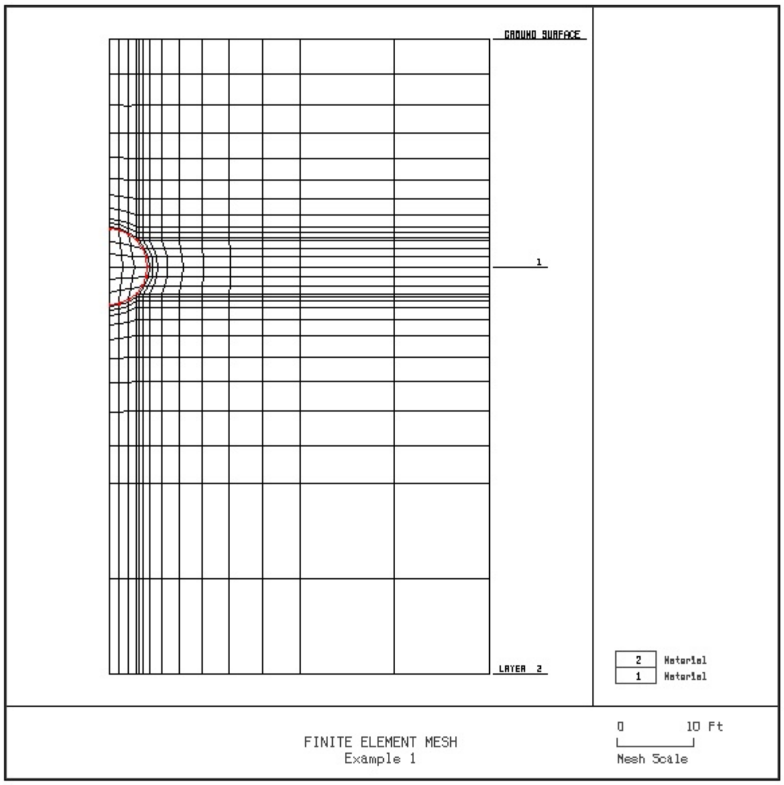


Figure 6.2 Finite element mesh

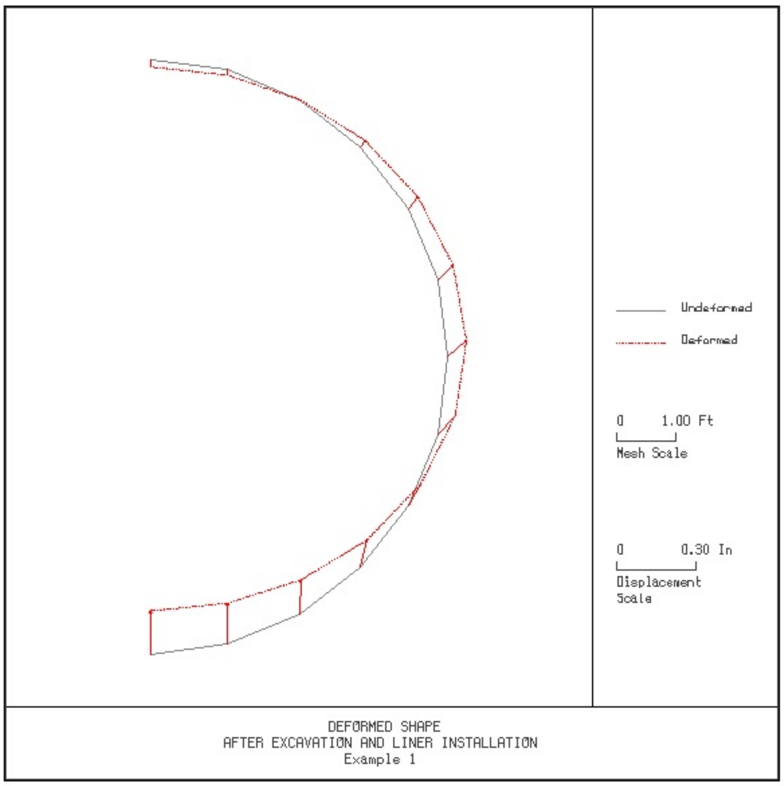
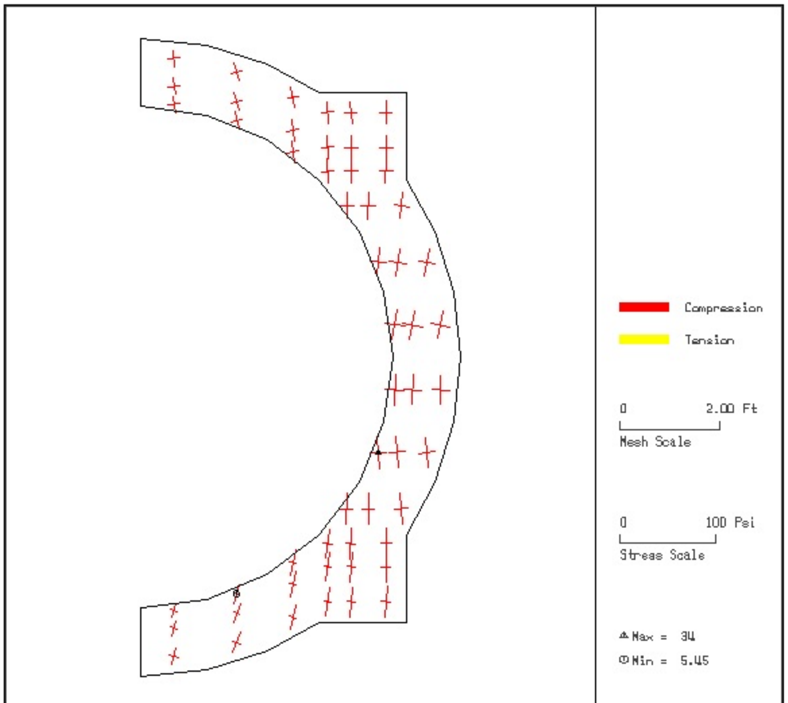


Figure 6.3 Tunnel deformed shape



PRINCIPAL STRESS DISTRIBUTION
AFTER EXCAVATION AND LINER INSTALLATION
Example 1

Figure 6.4 Principal stress (Adjacent to tunnel)

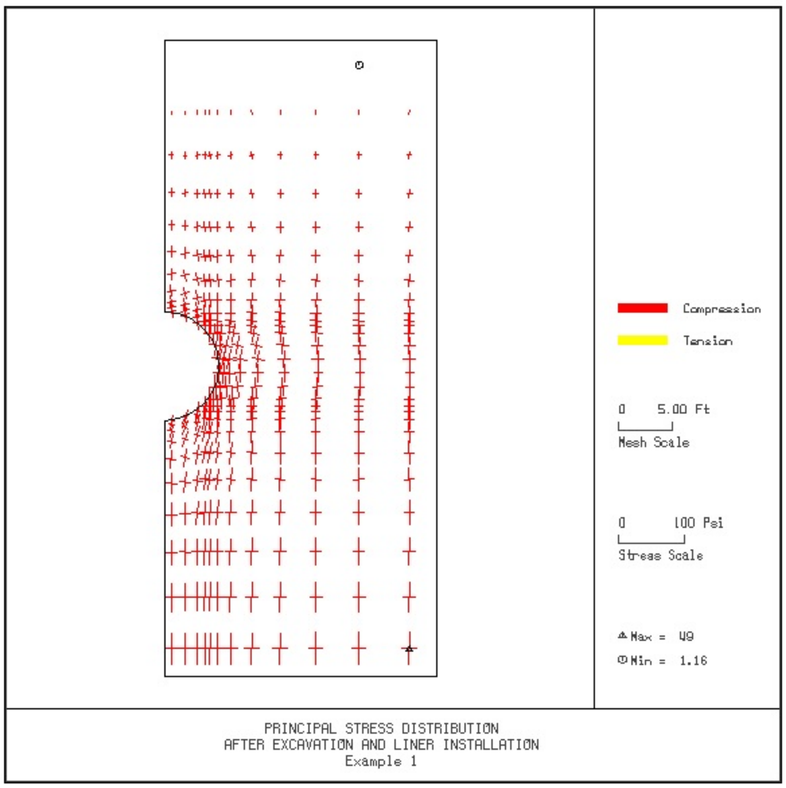


Figure 6.5 Principal stress (Overall)

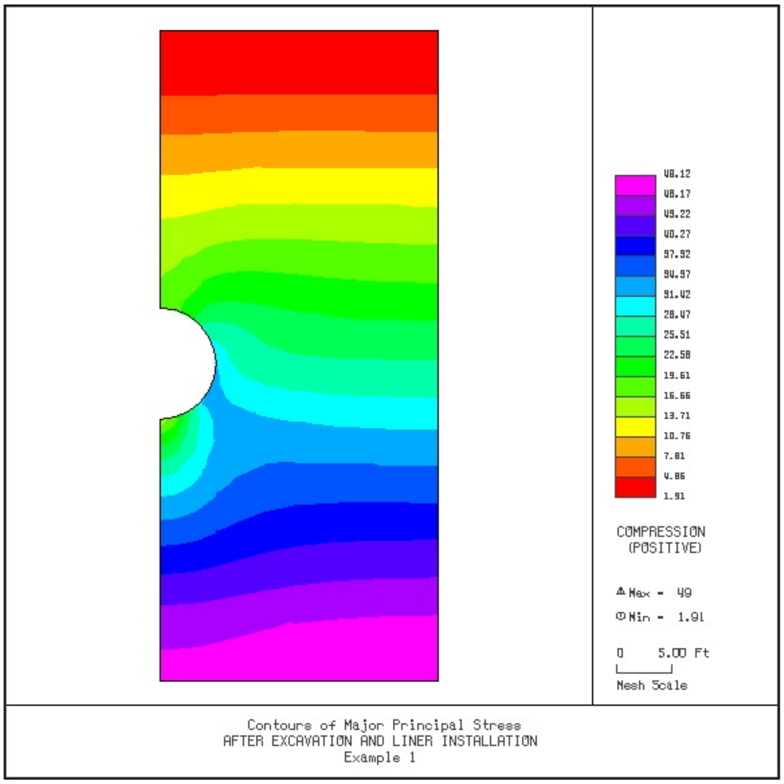


Figure 6.6 Major principal stress contour

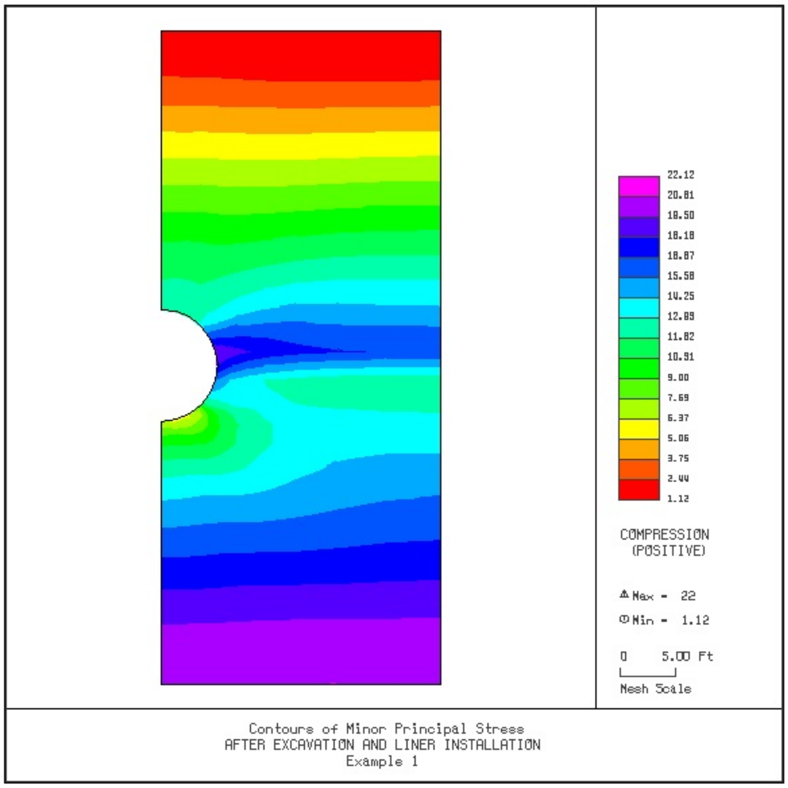


Figure 6.7 Minor principal stress contour

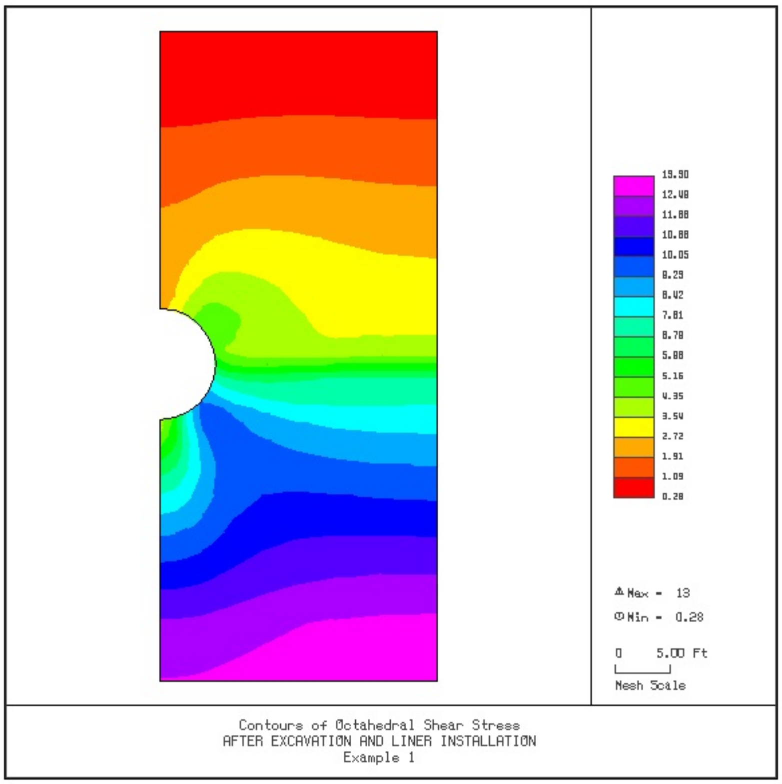


Figure 6.8 Octahedral shear stress contour

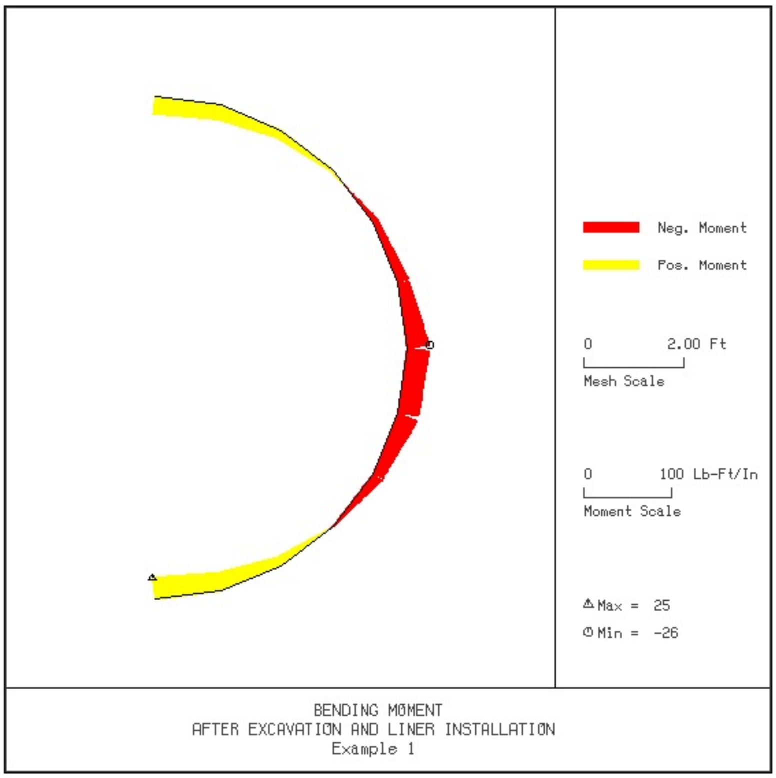


Figure 6.9 Bending moment in tunnel liner

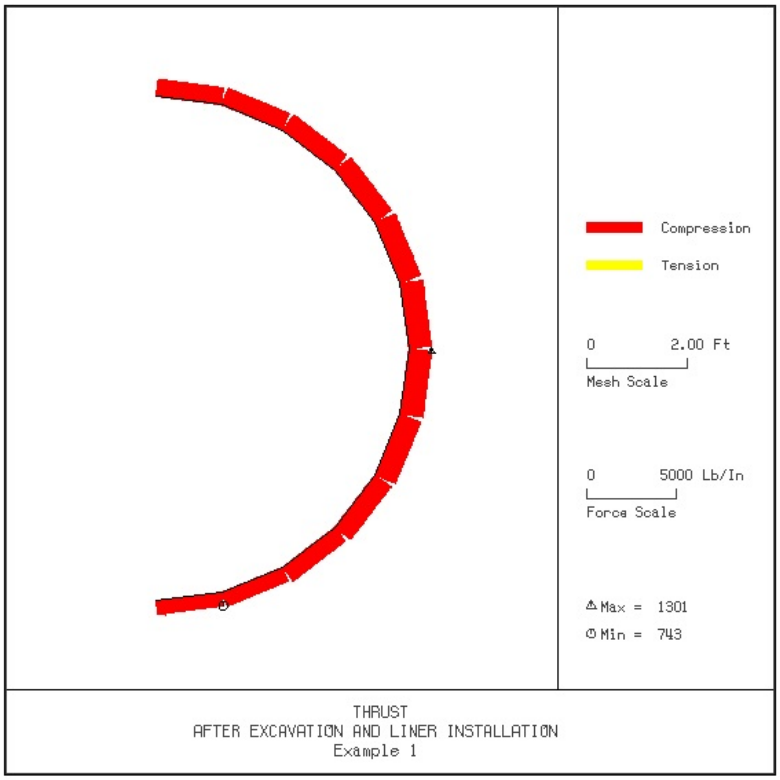


Figure 6.10 Thrust in tunnel liner

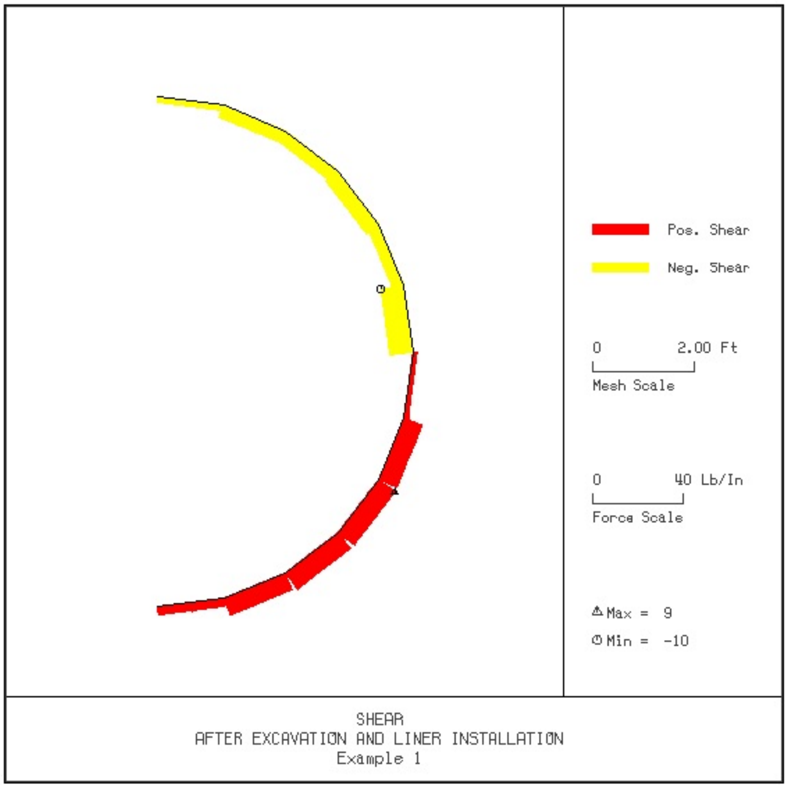


Figure 6.11 Shear in tunnel liner

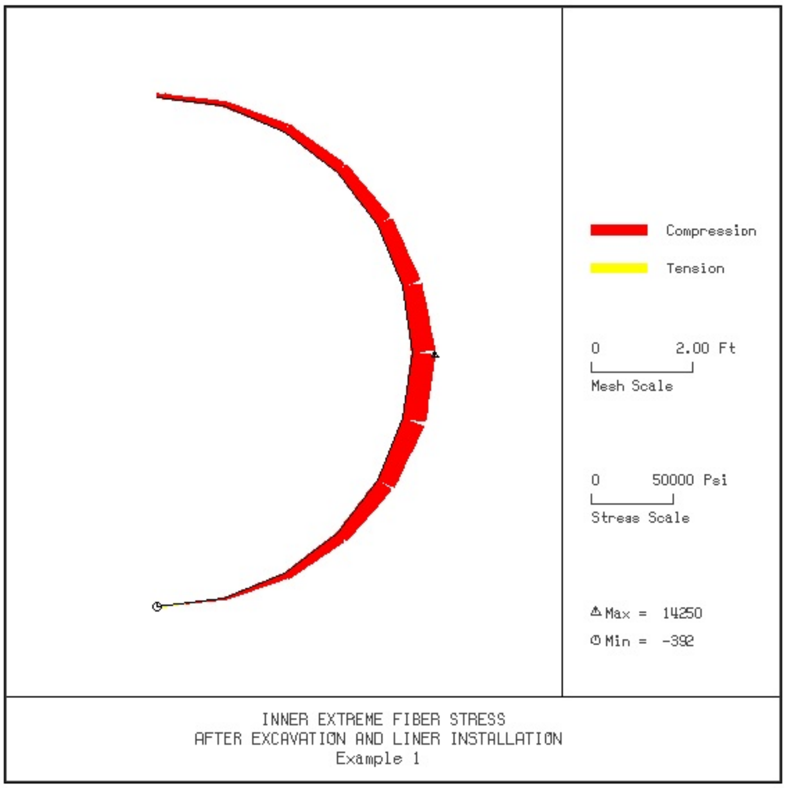


Figure 6.12 Inner extreme fiber stress in tunnel liner

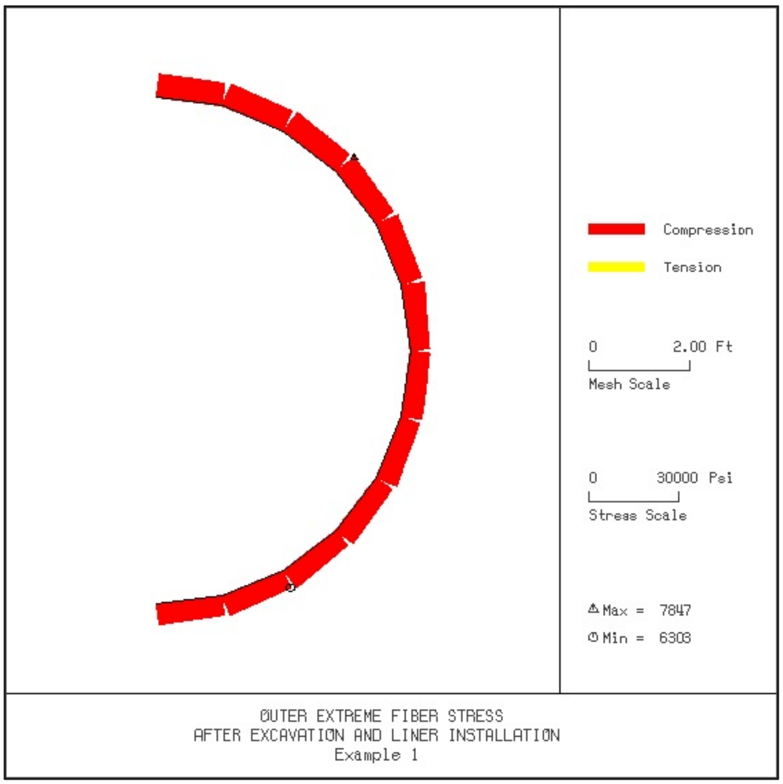


Figure 6.13 Outer extreme fiber stress in tunnel liner

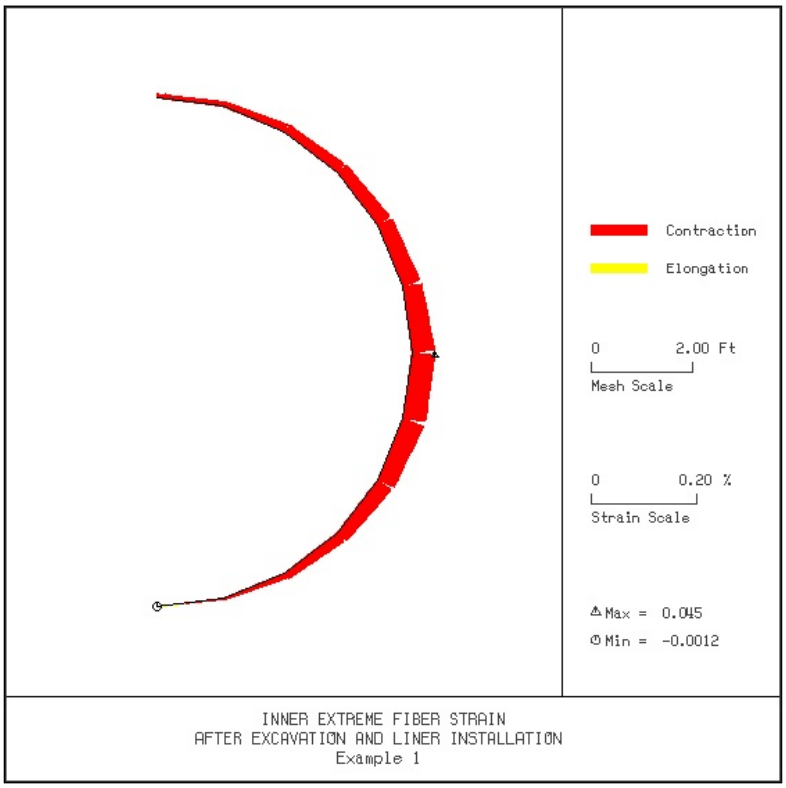


Figure 6.14 Inner extreme fiber Strain in tunnel liner

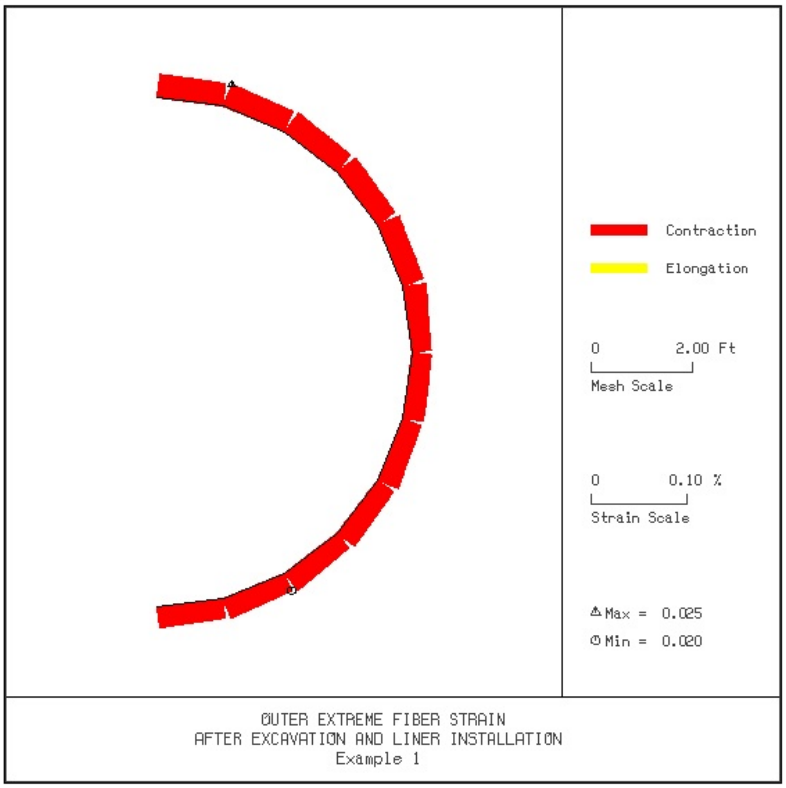


Figure 6.15 Outer extreme fiber Strain in tunnel liner

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 as schematically shown in Figure 6.16. Table 6.4 shows the listing of input file EX2.DAT. Figure 6.17 shows finite element mesh.

Results

Partial graphical outputs are shown in Figures 6.18 to 6.25.

Key results are summarized below:

Max. Liner hoop stress of 1,265 kg/Cm^2 takes place at the inner face of tunnel crown as shown in Figure 6.24. Assuming that the yield stress of steel liner is 2,530 kg/Cm^2, the safety factor is close to 2.

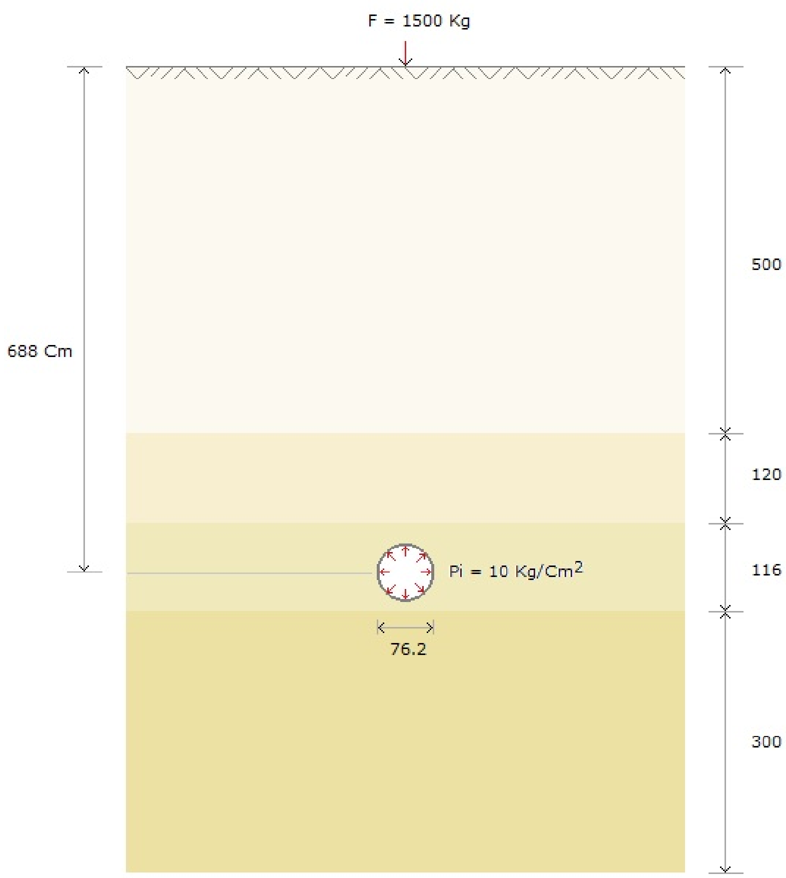


Figure 6.16 Schematic section view for buried gas pipe

Table 6.4 Listing of input file for Example 2

```
* CARD 1.1
* TITLE
: Example 2 [Buried Gas Pipeline]
* 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
* END
```

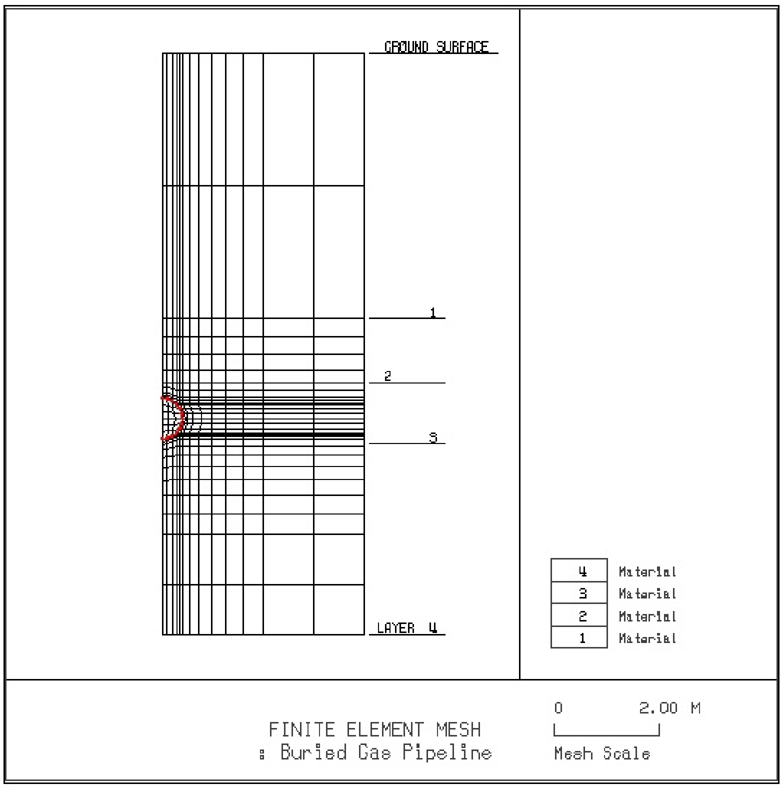


Figure 6.17 Finite element mesh

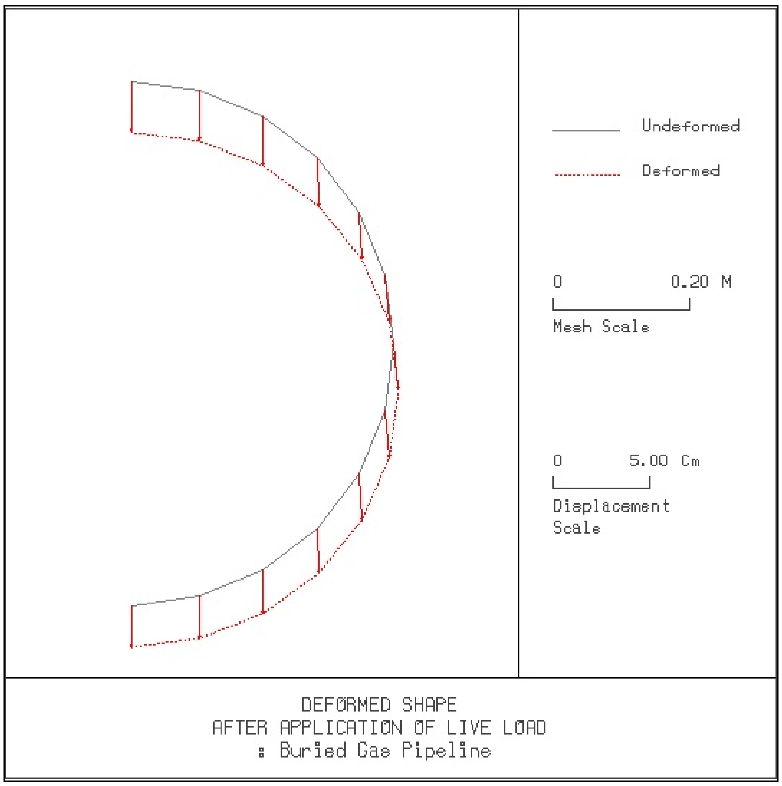


Figure 6.18 Deformed shape after live load

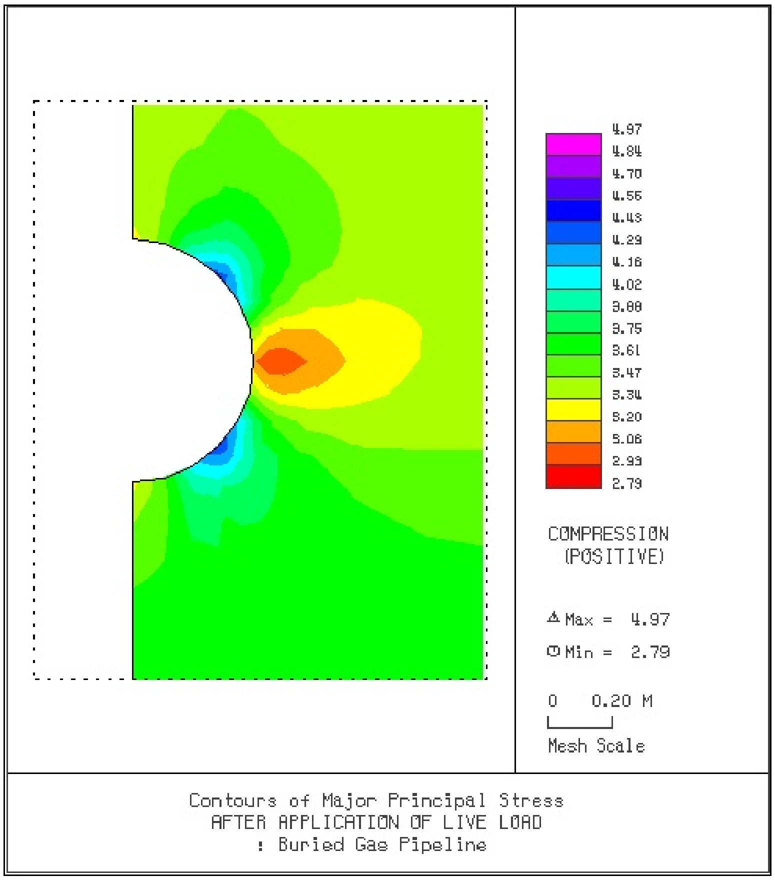


Figure 6.19 Major principal stress after live load

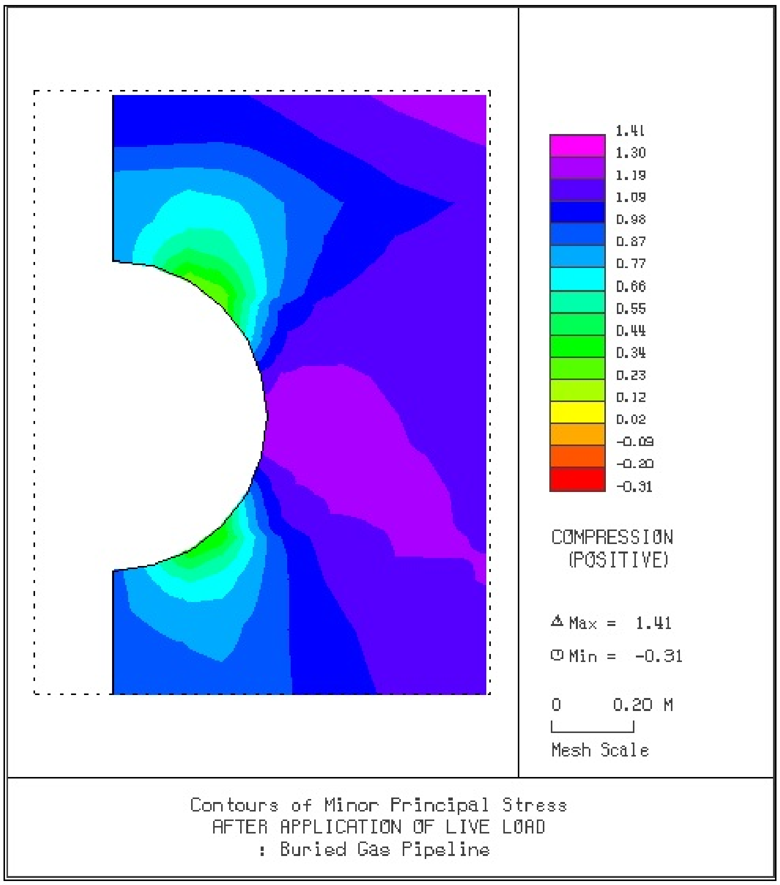


Figure 6.20 Minor principal stress after live load

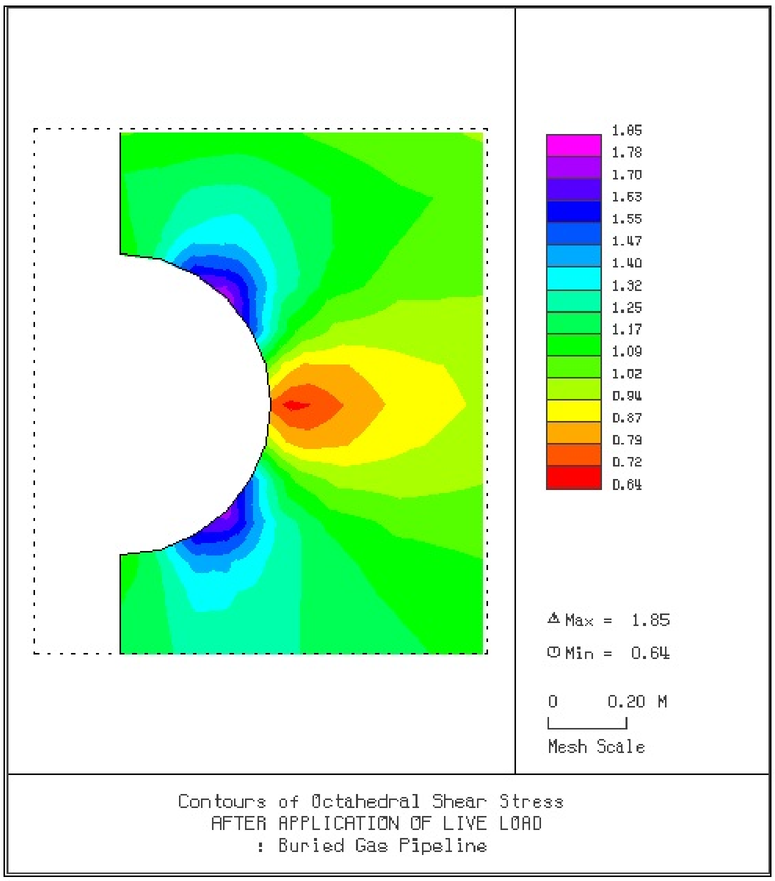


Figure 6.21 Octahedral shear stress after live load

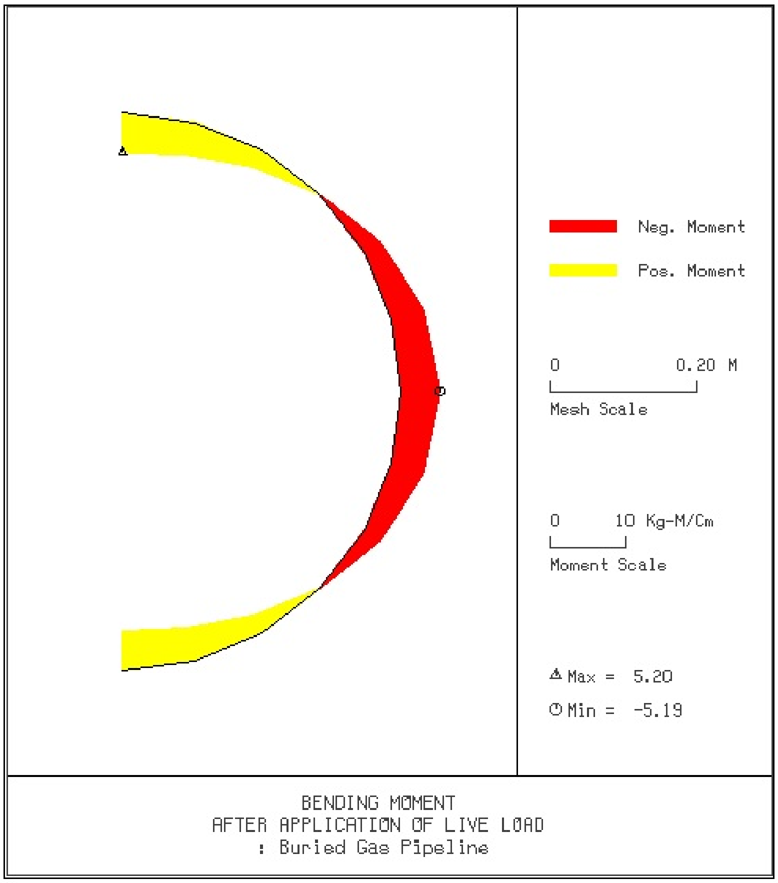


Figure 6.22 Bending moment after live load

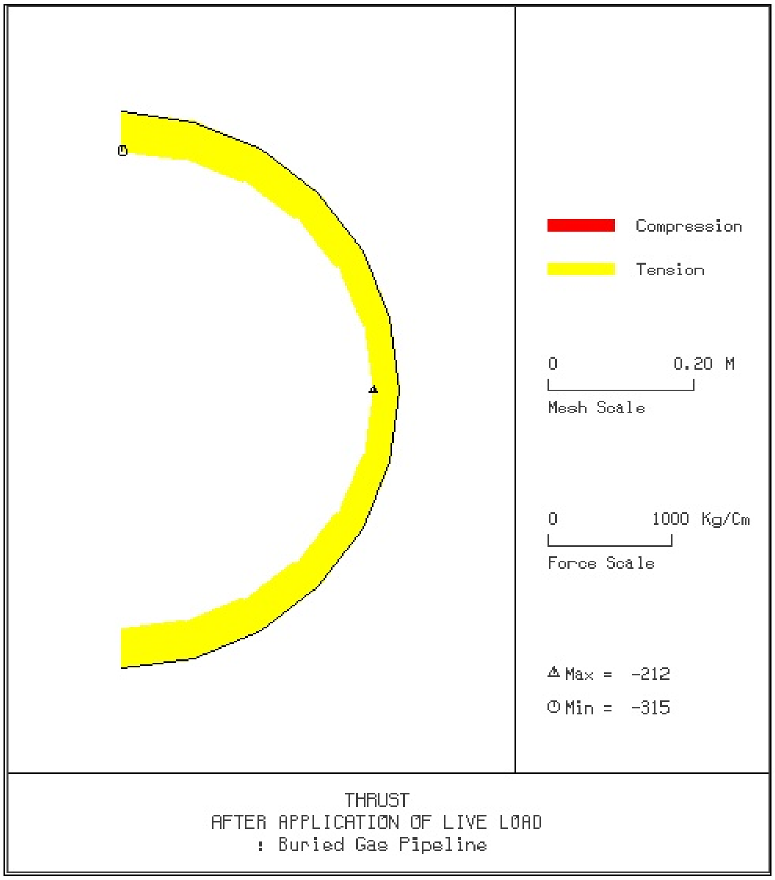


Figure 6.23 Thrust after live load

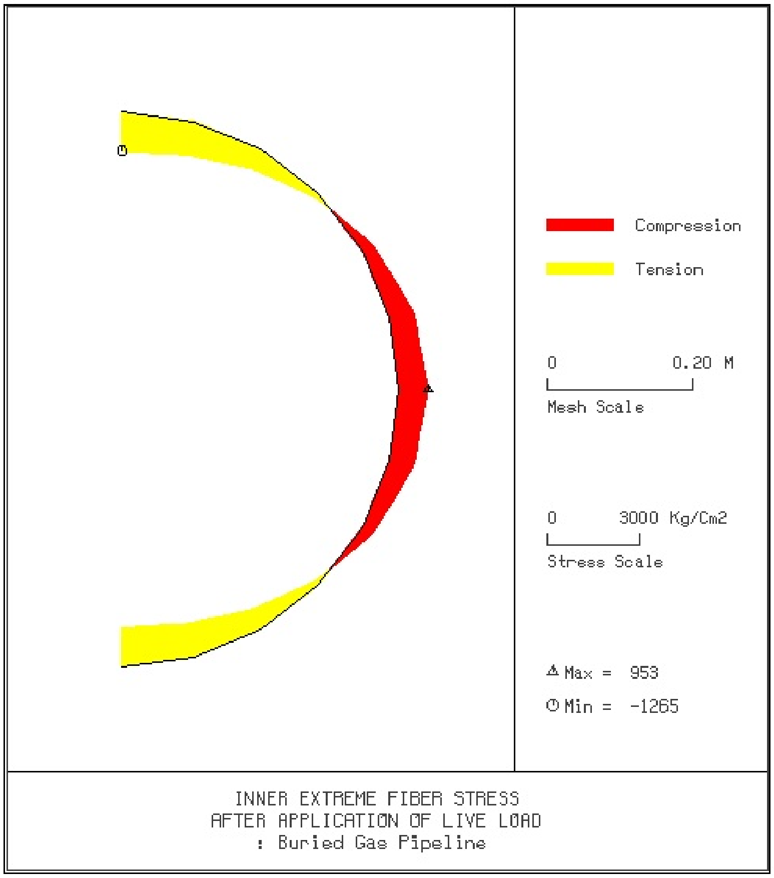


Figure 6.24 Inner extreme fiber stress after live load

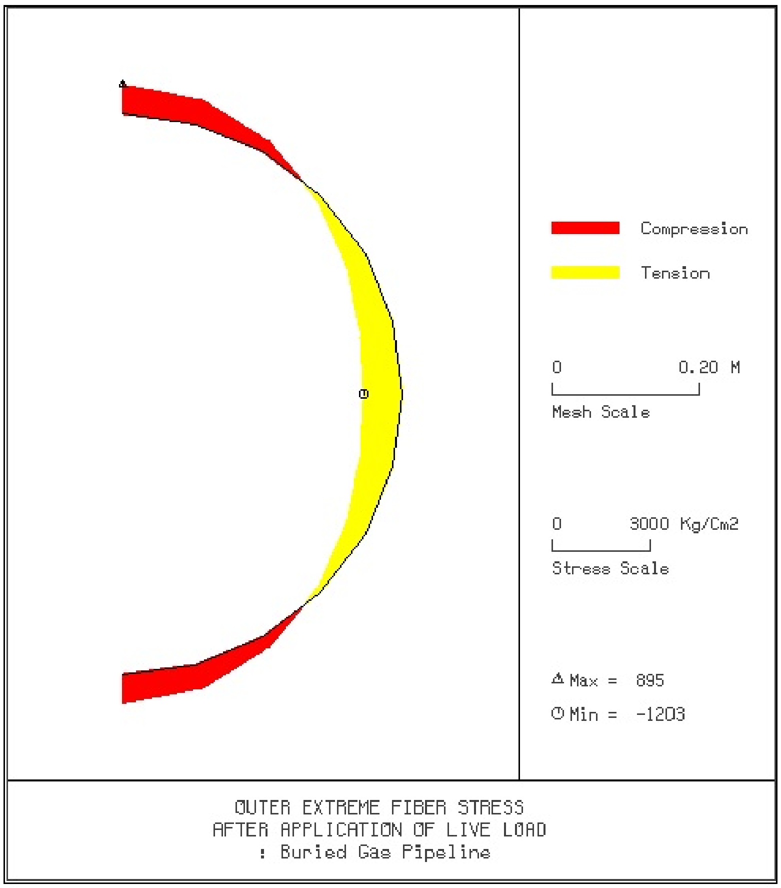


Figure 6.25 Outer extreme fiber stress after live load

6.3 Example 3

This example problem is the same as Example 1 except that tunnel liner consists of 4 segments that are connected as hinges. Locations of hinges are: center of crown, left and right springlines, and center of invert. Table 6.5 lists input file EX3.DAT.

Results

Partial graphical outputs are shown in Figures 6.26 to 6.30.

Key results are summarized below.

Max. Tunnel Diameter Change:
0.20 in (0.17 % of tunnel diameter)

Max. Liner Compressive Stress:
12,530 psi (45 % of yield strength)

Compared to Example 1, maximum liner compressive stress is decreased about 12 % while change of tunnel diameter is increased by 0.05 % which shows very little influence.

Table 6.5 Listing of Input File for Example 3

```
* CARD 1.1
* TITLE
: Example 3 [Moment Release]
* 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
  3
* CARD 7.2
* X1        Y1
  0.0       60.
  60.       0.0
  0.0      -60.
* END
```

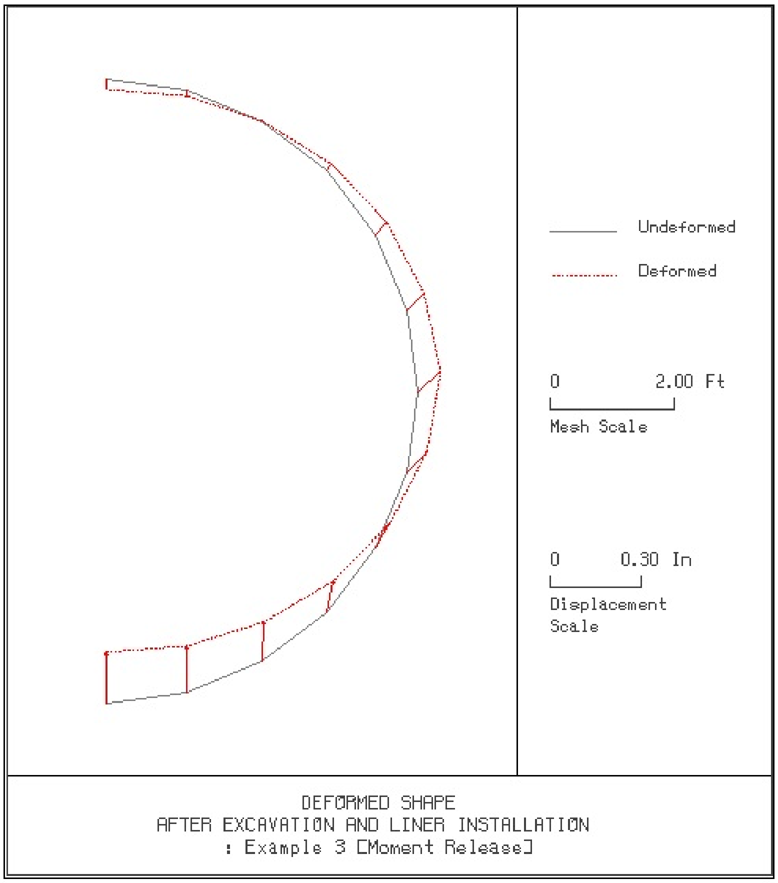


Figure 6.26 Tunnel deformed shape

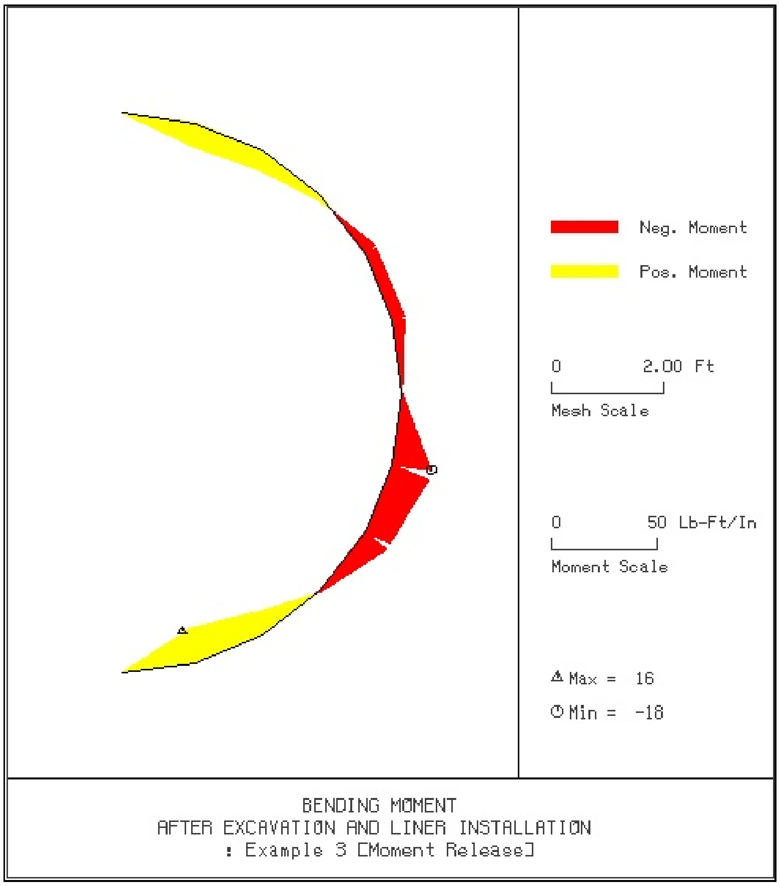


Figure 6.27 Bending moment in tunnel liner

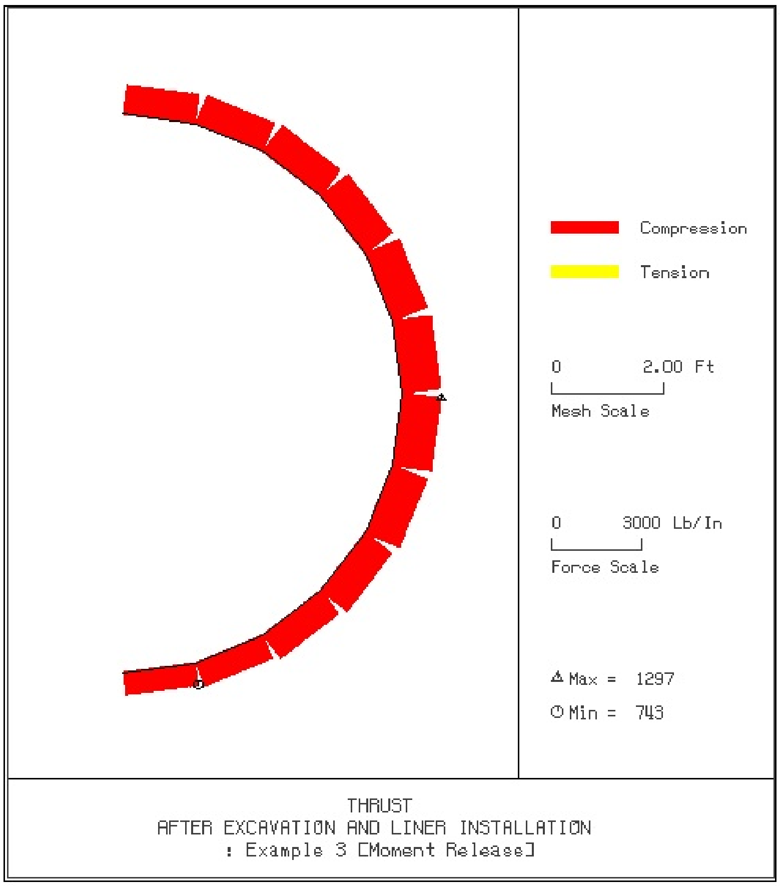


Figure 6.28 Thrust in tunnel liner

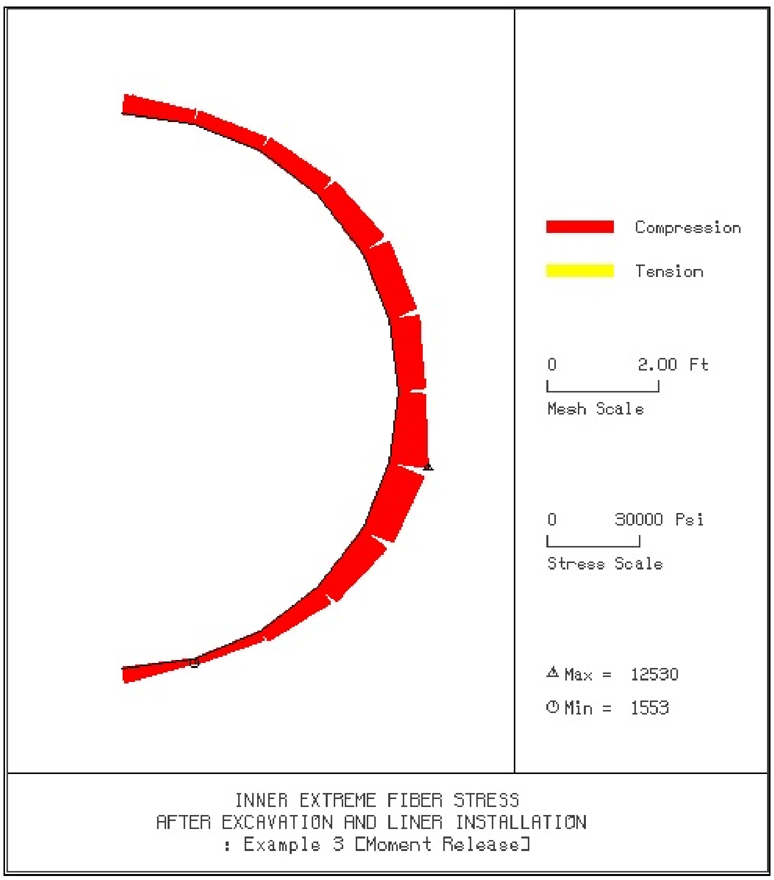


Figure 6.29 Inner extreme fiber stress in tunnel liner

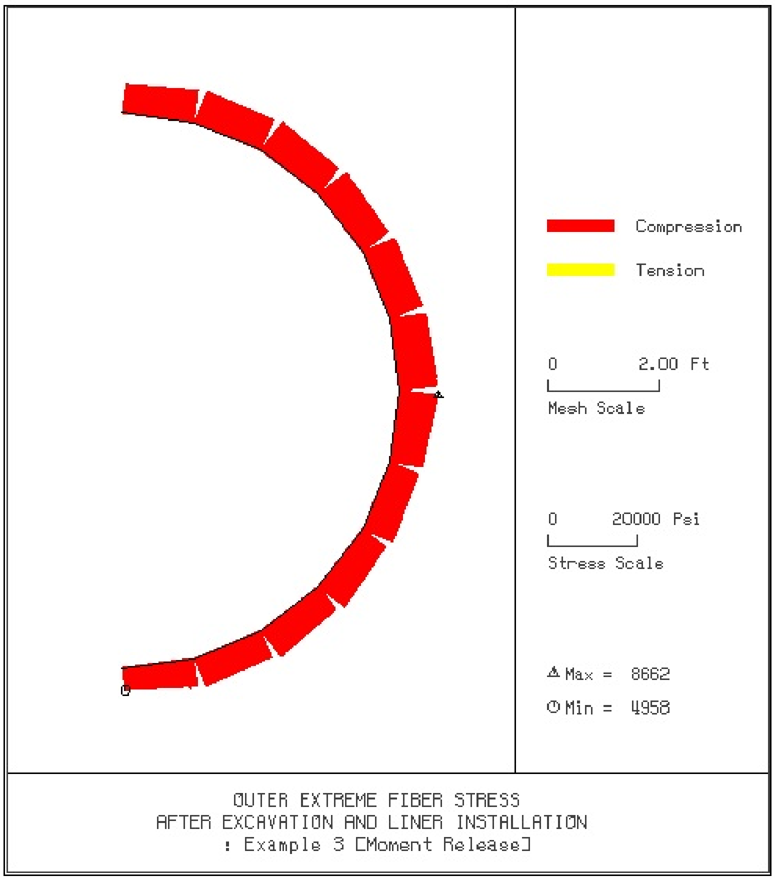


Figure 6.30 Outer extreme fiber stress in tunnel liner