SMAP[®] - 3D

Structure Medium Analysis Program

3-D Static, Consolidation and Dynamic Analysis for Dry, Saturated and Partially Saturated Soils and Rock Mass

Example Problems

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Introduction **1-1**

Introduction

Example Problems are mainly provided:

- To give you some guide in preparing input data.
- To demonstrate the validity of SMAP programs.

Section 2 describes methods of preparing Mesh Files which represent the geometry of structures to be analyzed.

Section 3 describes two different methods of running main- and post-processing programs.

Section 4 illustrates SMAP-3D main example problems as summarized in Table 1.1. First 9 problems are presented to demonstrate the accuracy and validity of SMAP-3D main- processing program.

Section 5 illustrates Group Mesh examples. Group Mesh Generator is a two dimensional CAD program specially designed to build group mesh which can be used to generate finite element mesh with the aid of program ADDRGN-2D.

Section 6 illustrates Block Mesh examples. Block Mesh Generator is a three dimensional CAD program specially designed to build block mesh which can be used to generate finite element mesh with the aid of program PRESMAP-GP.

Section 7 illustrates PRESMAP examples which are used to generate two and three dimensional Mesh Files.

Section 8 illustrates ADDRGN examples which are used to combine or modify existing Mesh Files. ADDGRN-2D has a powerful mesh generation feature as demonstrated in sub section 8.1.3.

Section 9 illustrates SUPPLEMENT examples which are useful to prepare input data for pre- and main-processing programs.

Section 10 illustrates LOAD examples which are used to generate external nodal loads in two and three dimensional coordinate systems.

Section 11 illustrates XY Graph examples. XY Graph is a two dimensional graph consisting of lines connecting each pair of data points, which can be plotted by PLOT-XY or Excel.

Introduction 1-3

Problem Number	Project File Name	Run Time Pent. III 850	Description
1	VP1.dat	0.01 min.	Undrained uniaxial strain compression. Check: • Static • Fully coupled two-phase medium
2	VP2.dat	0.03	Terzaghi's linear consolidation Check: • Consolidation • Gravity load
	VP2-1.dat	0.10	Using linear wedge element
3	VP3.dat	0.37	Planar compression wave propagatic Check: • Dynamic two-phase response
	VP3-1.dat	0.13	Using transmitting boundary
4	VP4.dat	0.35	Circular tunnel in Drucker-Prager medium Check: • 3-D elasto-plastic matrix of Generalized Hoek and Brown Model
	VP4-1.dat		Using element surface load
	VP4-2.dat		Using linear wedge element
5	VP5.dat	0.15	Laminated beam with slip interface Check: • Joint element • Joint model
	VP5-1.dat	0.98	Thin layer joint element, NM=4 Joint thickness by CARD 5.3.2.4.11

5 1 1			2
Problem Number	Project File Name	Run Time Pent. III 850	Description
6	VP6.dat	0.02 min.	Gibson's construction pore pressure Check: • Consolidation • Variable time step • Moving boundary
	VP6-1.dat		Using linear wedge element
7	VP7.dat	0.01	Drained triaxial compression test Check: • Modified Cam Clay Model • Drained triaxial compression path
8	VP8.dat	0.01	Undrained plane strain comp. test. Check: • Modified Cam Clay Model • Undrained plane compression path
9	VP9.dat	0.01	Volumetric creep in isotropic undrained test. Check: • Modified Cam Clay Model • Volumetric creep
10	VP10.dat	0.01	Space truss analysis
11	VP11.dat	0.01	Fixed end beam analysis
12	VP12.dat	0.01	Beam dynamic analysis
13	VP13.dat	0.85	William's toggled beam analysis
14	VP14.dat	0.02	Plane strain tunnel analysis
15	VP15.dat	0.01	Hemispherical shell
	VP15-1.dat		Using triangular shell element
16	VP16.dat	0.02	Simply supported plate analysis

Introduction 1-5

Problem Number	Project File Name	Run Time Pent. III 850	Description
	VP17.dat	0.01 min.	Heated beam modeled by shell
17	VP17-1.dat		Heated beam modeled by beam
	VP17-2.dat		Heated beam modeled by continuum
18	VP18.dat	0.01	Thin pipe subjected to internal pressure
	VP18-1.dat		Single precision with FACBD = 1×10^6
19	VP19.dat	24.12	Preload consolidation & excavation
20	VP20.dat	16.93	Seismic tunnel analysis
21	VP21.dat	0.01	Frames with hinge connection Modeled by beam element
	VP21-1.dat		Modeled by shell element
22	VP22.dat		Embedded rebars with slip
23	VP23.dat		Pseudo dynamic embankment fill
24	VP24.dat		Plane strain tunnel in jointed continuur
25	VP25.dat		Spring analysis
26	VP26.dat		Nonlinear truss analysis
27	VP27.dat		SDOF System To Ground Acceleration
28	VP28.dat		Frames with Rotational Spring Connection
29	VP29.dat		Reinforced Concrete Beam
30	VP30.dat		Reinforced Concrete Cylinder
31	VP31.dat		Plate Modal Analysis
32	VP32.dat		Seismic Response Analysis
33	VP33.dat		Silo Lining Analysis
34	VP34.dat		Liquefaction Analysis with PM4Sand

Pre-Processing Programs Pre-Processing programs are mainly used to generate Mesh File described in Section 4.3 of SMAP-3D User's Manual. The Mesh File represents the geometry of the structure to be analyzed. This file contains information about nodal coordinates, element indexes, material property numbers, and boundary codes. In SMAP-3D, you may generate such Mesh Files using the following methods: Method 1 First, generate 2D Mesh File representing a typical two dimensional section using Group Mesh Generator, Block Mesh Generator, or 2D PRESMAP. Modify this 2D Mesh File using ADDRGN-2D if you need to do it. And then extend the 2D mesh into 3D mesh using GEN-3D. 1. Generate 2D Mesh File GROUP MESH GENERATOR BLOCK MESH GENERATOR PRESMAP-2D NATM-2D CIRCLE-2D PRESMAP-GP Modify 2D Mesh File 2. ADDRGN-2D 3. Extend into 3D Mesh File GEN-3D

Method 2

Generate 3D Mesh Files using Block Mesh Generator or 3D PRESMAP. Then combine or modify these 3D Mesh Files using ADDRGN-3D if you need to do it.

1. Generate 3D Mesh File

BLOCK MESH GENERATOR PRESMAP-3D CROSS-3D PRESMAP-GP

2. Combine or modify 3D Mesh File

ADDRGN-3D

Above two methods can be combined to make a final 3D Mesh File representing the structure to be analyzed.

To view the Mesh Files, you can use PLOT-3D by selecting following order: Plot \rightarrow Mesh \rightarrow F. E. Mesh \rightarrow Open

Boundary codes can affect analysis result significantly so that it is strongly recommended for you to double check those codes to avoid solving wrong problems.

Main- and Post-Processing Programs

Main-Processing program reads Mesh and Main Files as input and performs static, consolidation, or dynamic analysis. Post-Processing programs read Post File along with analysis results from Main-Processing program and then produce graphical output.

Mesh Files can be generated using Pre-Processing programs as outlined in the previous Section 2. Main and Post Files can be created according to Section 4.4 and 4.5, respectively, in SMAP-3D User's Manual. Normally, they can copy existing Main or Post Files which are similar to the problem to be analyzed and modify those files using Text Editor.

Main- and Post-Processing programs can be executed using the following methods:

Method 1

Prepare Mesh, Main, and Post Files. Run EXECUTE menu to get analysis results. And run PLOT menu to view graphical output of analysis results.

1. Prepare All Input Files

Mesh, Main and Post Files

2. Get Analysis Results

 $\mathsf{RUN} \to \mathsf{SMAP} \to \mathsf{EXECUTE}$

3. View Graphical Output

 $\mathsf{PLOT} \rightarrow \mathsf{RESULT} \rightarrow \mathsf{PLOT}\text{-}\mathsf{XY}, \, \mathsf{PLOT}\text{-}\mathsf{2D}, \, \mathsf{PLOT}\text{-}\mathsf{3D}$



Post-Processing programs are mainly used to show graphical output of the analysis results.

PLOT-XY reads Card Group 12 in Post File and plots time histories of stresses, strains, and displacements. Once you run PLOT-XY, you will obtain intermediate plotting information file (PLOTXY.Lin). PLOTXY.Lin file can be modified as it will be described in Section 11 of SMAP Examples.

PLOT-2D reads Card Group 11 in Post File and plots two dimensional snap shots. Once you run PLOT-2D in PLOT menu, you will obtain intermediate plotting information file (PLOT2D.DAT).

PLOT-3D does not need any Post File.

This program plots following three dimensional snapshots:

- Finite element mesh
- Deformed shape
- Principal stress distribution
- Section forces in beam element
- Extreme fiber stresses/strains in beam elements (2D)
- Axial force/stress/strain in truss element
- Contours of stresses, strains and factor of safety
- 3D iso surface of stresses and strains

SMAP-3D Example Problem

SMAP-3D is the main-processing program which computes static, consolidation and dynamic response of three-dimensional problems. Input parameters of SMAP-3D are described in detail in Section 4 of SMAP-3D User's Manual.

Running SMAP-3D is described in Section 3.2.1 of User's Manual and can be selected in the following order:

 $RUN \rightarrow SMAP \rightarrow EXECUTE$

Manual procedure to run SMAP-3D is outlined in Section 3.5 of User's Manual. Once you finished execution of SMAP-3D, you can obtain graphical outputs by selecting:

PLOT \rightarrow RESULT \rightarrow PLOT-XY, PLOT-2D, or PLOT-3D

PLOT Menu is described in Section 3.3 of SMAP-3D User's Manual.

Table 1.1 in Section 1 shows the summary of SMAP-3D example problems. First nine example problems are the verification problems. The main objective of these verification problems is to demonstrate the accuracy and validity of SMAP-3D.

You can access all input files of example problems in the directory:

C:\Smap\Smap3D\Example\Smap

For each example problem, brief problem descriptions and partial graphical outputs will be presented in this section.

4.1 Undrained Uniaxial Strain Compression

The problem concerns fully coupled undrained uniaxial strain response of saturated porous linear elastic medium as shown in Figure 4.1.

Finite element mesh in Figure 4.2 is generated by Block Mesh Generator as explained in detail in Section 6.1 in SMAP-3D Example Problem.

The exact solution for the undrained stress response is given by Blouin and Kim, 1984.

$$\pi_{o} = \sigma_{v} \frac{1}{1 + \beta_{m}}$$
(4.1)

$$\beta_{m} = \frac{K_{g}^{2} M_{s} + K_{m} K_{s}^{2} - M_{s} K_{m} K_{s} - K_{g} K_{m} K_{s}}{K_{m} K_{g} (K_{g} - K_{s})}$$
(4.2)

Where

- σ_v Applied total vertical stress
- π_{o} Pore water pressure
- K_s Bulk modulus of skeleton
- G_s Shear modulus of skeleton
- M_s Constrained modulus of skeleton ($M_s = K_s + 4G_s/3$)
- n Porosity
- K_q Bulk modulus of grain
- K_w Bulk modulus of water
- $K_{m} \qquad \text{Mixture modulus} \quad K_{m} = K_{g} \ K_{w} / \ \{K_{w} + n \ [K_{g} K_{w}]\}$

The following material properties are used for computing undrained uniaxial strain response:

 $\begin{array}{rcl} {\sf K}_{\sf g} & = & 3.5210 \ x \ 10^6 \ t/m^2 \\ {\sf K}_{\sf w} & = & 0.2042 \ x \ 10^6 \ t/m^2 \\ {\sf E} & = & 0.7042 \ x \ 10^6 \ t/m^2 \\ {\sf v} & = & 0 \\ {\sf n} & = & 0.3 \\ {\sf G}_{\sf s} & = & 2.674 \\ \\ {\sf K}_{\sf s} & = & 0.2347 \ x \ 10^6 \ t/m^2 \\ {\sf G}_{\sf s} & = & 0.3521 \ x \ 10^6 \ t/m^2 \end{array}$

The exact ratio of pore water pressure (π_o) to applied total vertical stress $(\sigma_{_v})$ is obtained from equations 4.1 and 4.2

$$\pi_{o} / \sigma_{v} = 0.4592$$

and the exact ratio of effective vertical stress $(\sigma_{_{\!v}}{}')\,$ to applied total vertical stress $(\sigma_{_{\!v}})$ is given by

$$\sigma'_v / \sigma_v = 0.5408$$

Figure 4.3 shows predicted undrained uniaxial stress response compared with an exact solution. As shown in Figure 4.3, the predicted response by program SMAP-3D is identical to the exact solution.









4.2 Terzaghi's Linear Consolidation

The problem concerns Terzaghi's linear consolidation with initial triangular distribution of excess pore water pressures. As initial conditions, it is assumed that soil is liquefied and pore water takes all the weight. The exact solution for the excess pore water pressure (π_e) is given by

$$\pi_{e} = \sum_{m=1,3}^{\infty} \left(\frac{8 \gamma' H}{m^2 \pi^2} \right) \left(\sin \frac{m \pi}{2} \right) \left(\sin \frac{m \pi}{2 H} y \right) e^{-\frac{m^2 \pi^2}{4} T}$$
(4.3)

where

H Thickness of soil deposit.

- Top is free surface, bottom is rigid impermeable base.
- y Distance from the free surface.
- $\gamma' ~=~ \gamma \gamma_w$

 $\gamma~$ is the total unit weight and

 γ_{w} is the unit weight of pore water.

And the time factor (T) is given by

$$T = \frac{k M t}{\gamma_w H^2}$$

where

t Time

k Coefficient of permeability

M Constrained modulus

To simulate numerically, following material parameters are assumed:

$$E = 1,000 \text{ t/m}^2$$

$$v = 0.3$$

$$M = (1-v) E / ((1+v)(1-2v)) = 1,346 \text{ t/m}^2$$

$$k = 0.001 \text{ m/day}$$

$$H = 10 \text{ m}$$

Figure 4.4 shows finite element mesh consisting of 20 elements used for this example problem.

Figure 4.5 shows profiles of pore water pressures at T = 0.05 and 0.5. And Figure 4.6 shows profiles of effective vertical stresses at T = 0.05 and 0.5. SMAP-3D calculations are very close to the exact solution.









4.3 Planar Compression Wave Propagation

The problem is to check overall two-phase dynamic equations implemented in the program SMAP-3D. A vertically propagating planar compression wave through idealized saturated soil is considered. The input loading, as shown in Figure 4.8, is a short rise time triangular pulse with a peak stress of $3,521 \text{ t/m}^2$ and a positive phase duration of 10 msec. The loading pulse is applied to the saturated sand having the properties listed in Figure 4.8. The load is applied to an impermeable boundary at the ground surface.

Figure 4.7 shows finite element mesh consisting of 200 elements.

Computed profiles of pore water pressure and effective vertical stress at 20 msec are shown in Figures 4.9 and 4.10, respectively. The closed-form solution for this problem is not available. So, the same problem has been solved by the existing two-dimensional version of TPDAP-II for direct comparison. These TPDAP-II results are not shown in Figures 4.9 and 4.10, but they are identical to the SMAP-3D results.



Figure 4.7 Finite element mesh



4-11







4.4 Circular Tunnel in Drucker-Prager Medium

The problem is to check the implementation of the 3-dimensional formulation of elasto-plastic matrix derived for the Generalized Hoek and Brown Model. In this problem, the plane strain response of a tunnel subjected to axisymmetric loading as calculated using SMAP-3D is compared to a semi-analytical solution developed by Piepenburg, Kim and Davister (1986).

Figure 4.11 shows a schematic section view of 3.05m (10 feet) diameter circular tunnel subjected to a hydrostatic loading of 1972 t/m² (2800 psi). The surrounding rock is assumed to be linear elastic beneath the failure surface and to follow the Drucker-Prager plasticity model upon reaching the failure surface. The elastic and strength properties of the rock are listed in Figure 4.11.

By symmetry, only a quadrant of tunnel cross section is modeled as shown in Figure 4.12. Along the axis of tunnel (in z-direction), three elements (sections) are used so that the internal section can have unconstrained full 3 degrees of freedom per each node. This is to check the uniform response of the integrated three dimensional grids though problem is essentially one dimensional axisymmetric.

Figure 4.13 shows tunnel displacement contour. Figure 4.14 shows stresses along the 4.5° from the X-axis in Section 2. And Figure 4.15 shows stresses along the 85.5° from the X-axis in Section 2. As we see, both deformations and stresses are uniform along the tunnel tangential direction. The computed tunnel radial displacement (0.896 Cm) is very close to the semi-analytical solution (0.89 Cm). The computed stress profiles agree well with the semi-analytical solution in both the plastic and elastic zones of deformation surrounding tunnel.

It should be noted that the stresses plotted in Figures 4.14 and 4.15 are in X, Y and Z coordinates so that for exact comparison, these stresses should have transformed to radial and tangential coordinate system.








4-17







4.5 Laminated Beam with Slip Interface

The problem is to check the joint element and the nonlinear joint model described in Section 3.6 in theory. Figure 4.16 shows the schematic view of a laminated simply supported beam subjected to uniform and concentrated transverse loads along with the material properties of the beam and the interface.

By symmetry, only the right half of the beam is modeled by 60 continuum elements and 10 joint elements as shown in Figures 4.17 and 18. Element numbers from 61 to 70 are joint elements which represent the slip interface. Joint face is designated along the line from nodes 4 to 144. Thus, nodal coordinates along the other side of joint face are used mainly for visual presentation of joint elements. That is, program SMAP-3D resets internally the nodal coordinates of nodes from 157 to 176 equal to the nodal coordinates of the joint face (nodes from 4 to 144). Then joint thickness (t=0.00254 cm) is specified through the material properties of the joint model.

In Figure 4.19, the midspan deflections by SMAP-3D are compared to the closed-form solution derived from beam theory (Agbabian Associates, 1981). Overall, SMAP-3D results show good agreement with the closed-form solution, especially when the sliding occurs along the interface. It should be noted that there are some differences between the beam and continuum theories, to which slight overestimation by SMAP-3D may be attributed.



4-22 SMAP-3D Example Problem











Table 4.1 Variable time steps applied for each lift

Sequence	$\Delta t/(\Delta h/m)$
Beginning	0.001
	0.106
	0.106
Intermediate	0.160
	0.160
	0.234
End	0.234

where $\Delta t~$ is time step and Δh thickness of current top layer.

Following input parameters are used to compute profiles of pore pressure.

```
\begin{array}{rcl} E &=& 1000 \ t/m^2 \\ \nu &=& 0.3 \\ G_s &=& 2.7 \\ \gamma_w &=& 1.0 \ t/m^3 \\ n &=& 0.6 \\ k &=& 0.001 \ m/day \\ h &=& 18 \ m \\ t &=& 60.03 \ days \\ \end{array}
\begin{array}{rcl} T &=& 4 \\ m &=& 0.3 \ m/day \\ M_s &=& 1346.15 \ t/m^2 \\ C_\nu &=& 1.3462 \ m^2/day \\ \gamma' &=& 0.68 \ t/m^3 \end{array}
```













4.7 Drained Triaxial Compression Test

The problem is to check the implemented algorithm of the Modified Cam Clay Model in drained triaxial compression mode. The problem is to model the experimental test used by Karshenas and Ghaboussi.

The sample is modeled by a single cubic element with unit length as shown in Figure 4.23. The sample is artificial soil which is composed of 90% CO_3C_a and 10% kaolinite. The material parameters tabulated in Figure 4.24 are those determined by Karshenas and Ghaboussi.

Both computed and measured values are plotted as a function of axial strain in Figure 4.25 for deviatoric stresses and in Figure 4.26 for volumetric strains. As you see, the SMAP-3D results reflect well the overall behavior of test results for the normally consolidated clay.





4-31







4.8 Undrained Plane Strain Compression Test

The problem is to check the implemented algorithms of Modified Cam Clay Model in undrained plane strain compression stress path. The following analytical solution for this problem has been presented by Kim (1982).

Three components of the effective principal stresses are directly obtained from the specified value of axial strain increment.

$$d\sigma'_{x} = g_{x} d\epsilon_{x} \qquad d\sigma'_{y} = g_{y} d\epsilon_{y} \qquad d\sigma'_{z} = g_{z} d\epsilon_{z} \qquad (4.5)$$

$$\sigma'_{x} = \int d\sigma'_{x} \qquad \sigma'_{y} = \int d\sigma'_{y} \qquad \sigma'_{z} = \int d\sigma'_{z} \qquad (4.6)$$

where

$$g_{x} = (b-a) - f [3a_{o}b + (a-b) a_{x}]$$

$$g_{y} = (a-b) - f [3a_{o}b + (a-b) a_{y}]$$

$$g_{z} = - f [3a_{o}b + (a-b) a_{z}]$$

$$f = \frac{(a - b) (a_{y} - a_{x})}{(a - b) (a_{x}^{2} + a_{y}^{2} + a_{z}^{2}) + q a_{0}^{2} b + \beta M^{2}P' P'_{o} (2P' - P'_{o})}$$

$$a = \frac{6.9 (1 + e_{o}) (1 - v)}{C_{r} (1 + v)} P' \qquad b = \frac{6.9 (1 + e_{o}) v}{C_{r} (1 + v)} P'$$

$$a'_{x} = a_{o} + 3(\sigma'_{x} - P') \qquad a'_{y} = a_{o} + 3(\sigma'_{y} - P') \qquad a'_{z} = a_{o} + 3(\sigma'_{z} - P')$$

$$\beta = \frac{2.3 (1 + e_{o})}{(C_{c} - C_{r})} \qquad a_{o} = \frac{2}{3} M^{2} (P' - \frac{1}{2}P'_{o})$$

$$P'_{o} = P'_{c} \exp (\beta \epsilon_{y}^{P})$$

Note that the initial stress conditions in Equation 4.6 should be imposed on the basis of the stress-strain state at the end of $K_{\rm o}-$ consolidated condition.

To perform numerical and analytical solutions, following $K_{\!\scriptscriptstyle o}$ initial stresses and material parameters are assumed:

Initial stresses:

 $\sigma_x' = 0.764 \text{ t/m}^2$ $\sigma_y' = 1.472 \text{ t/m}^2$ $\sigma_z' = 0.764 \text{ t/m}^2$

Material Parameters:

 $e_{o} = 1.339$ $C_{c} = 0.508$ $C_{r} = 0.254$ M = 1.1137 v = 0.4

The sample is modeled by a single cubic element with unit length as shown in Figure 4.27.

Figure 4.28 shows effective stresses normalized by preconsolidation pressure and plotted as a function of axial strain. It seems that the SMAP-3D results are very close to the analytical solution. It is interesting to note that the effective stress (σ_x') in x direction where total stress remains constant is decreasing while other effective stresses (σ_{v}' and σ_{z}') change very little.



Figure 4.27 Finite element mesh



4.9 Volumetric Creep in Isotropically Undrained Test

The problem is to check volumetric creep behavior in isotropically undrained test. The closed-form solution for this problem has been presented by Borja (1992).

$$P' = P_o \left[1 + \frac{C_c}{C_r} \left(\frac{t}{t_o} - 1 \right) \right]^{-\frac{C_r}{C_o}} \qquad \pi = P_o - P' \qquad (4.7)$$

Note that effective mean pressure (P') was P_o at initial time (t_o) but decreases with time (t) while total mean pressure (P_o) remains constant during the volumetric creep. Consequently, the excess pore pressure (π) increases with time.

The sample is modeled by a single cubic element with unit length as shown in Figure 4.29.



To conduct numerical calculation, the following initial conditions and material parameters are assumed:

Figure 4.30 shows variation of effective mean pressure and excess pore pressure as a function of time while total mean pressure remains constant. SMAP-3D results are almost identical to the closed-form solution.



Figure 4.30 Volumetric creep in isotropically undrained test

4.10 Space Truss Analysis

This example problem is to solve the static response of space truss as shown in Figure 4.31. Block mesh example 5 illustrates how to generate this mesh. This space structure is subjected to a horizontal load along the negative z direction.

Graphical outputs are shown in Figure 4.32 for member axial forces and in Figure 4.33 for deformed shape of the structure. Note that the computed member forces are exact compared to the closed form solution.



Figure 4.31 Schematic section view of space truss







4.11 Fixed End Beam Analysis

This example problem is to solve fixed end beam subjected to a concentrated load at mid span as schematically shown in Figure 4.34.

The exact solution for this beam is given below

 $\delta_{max} = \frac{PL^{3}}{192 EI} = 0.01046 m \qquad M_{max} = \frac{PL}{8} = 12.5 t-m$ $E = 21 \times 10^{6} t/m^{2} \quad v = 0.3 \qquad L = 10 m$ $A = 0.008412 m^{2} \qquad I = 2.37 \times 10^{-4} m^{4}$ $\delta_{max} = Maximum deflection at mid span$ $M_{max} = Maximum bending moment at mid span$

The problem has been modeled by 20 beam elements as shown in Figure 4.35. Graphical outputs are plotted in Figures 4.36 and 4.37 for deformed shape and bending moment diagram, respectively. Both computed mid span deflection and maximum bending moment are the same as those of the exact solution.



Figure 4.34 Fixed end beam subjected to concentrated load

SMAP-3D Example Problem 4-43















Figure 4.41 Time history of deflection at mid span

4.13 William's Toggled Beam Analysis

This classic problem of a rigidly jointed toggle is selected to verify the geometric nonlinear behavior of the continuum element.

For the toggle shown in Figure 4.42 the closed form solution as well as experimental results was obtained by Williams (Williams, F.W., An Approach to the Nonlinear Behavior of the Members of a Rigidly Jointed Plane Framework with Finite Deflections, Quarterly Journal of Mechanics and Applied Mathematics, Vol. 17, London, UK, 1964, pp. 451-469)

This toggled structure is modeled by 400 continuum finite elements: 100 elements along the beam axis, 4 elements across the depth, and only 1 element through the thickness.

Figures 4.43 and 4.44 show the load-deflection response at mid span and deformed shape at applied load of 16 kg, respectively. SMAP-3D results are very close to the Williams' closed form solution.



Figure 4.42 William's toggled beam (Not Scaled)






4.14 Plane Strain Tunnel Analysis

The objective of this problem is to verify generation of in situ stresses and interaction of a tunnel liner with the surrounding soils. This example problem has been presented in SMAP-S2. Figure 4.45 shows schematic tunnel section view and material properties of soil and steel liner.

Figure 4.46 shows Finite element mesh. By symmetry, only the right half of the tunnel is modeled. Tunnel liner is modeled by shell elements as shown in Figure 4.47. Block mesh example 4 illustrates how to generate this mesh.

The first two load steps were used to generate in situ stresses. Tunnel excavation and liner installation were simulated by deactivating soil elements within the tunnel and activating liner elements at the third load step.

Graphical results are presented in the following order:

- Figure 4.48 Tunnel deformed shape
- Figure 4.49 Tunnel liner bending moment
- Figure 4.50 Tunnel liner axial stress
- Figure 4.51 Principal stress vector
- Figure 4.52 Major principal stress distribution
- Figure 4.53 Minor principal stress distribution

SMAP-3D results are almost identical to SMAP-S2 results







SMAP-3D Example Problem 4





















4.15 Hemispherical Shell

This classic problem of a hemispherical shell with 18° hole is selected to verify accuracy of the membrane and bending performance of shell element.

The theoretical solution for this problem was presented by R. H. MacNeal and R. L. Harder (<u>A proposed standard set of problems to</u> <u>test finite element accuracy</u>, Finite Element Anal. Des., 1, 3-20, 1985).

Figure 4.54 shows finite element mesh, material properties, loading and boundary conditions. By symmetry, only a quadrant of the shell is modeled. Block mesh example 3 illustrates how to generate this mesh.

Graphical results are presented in the following order: Figure 4.55 Deformed shape Figure 4.56 Maximum bending moment

SMAP-3D result gives excellent results for the displacement at the point of load in the direction of load as compared below:

Theoretical solution = 0.094SMAP-3D result = 0.0944 SMAP-3D Example Problem







SMAP-3D Example Problem



4.16 Simply Supported Plate Analysis

A simply supported rectangular plate, shown in Figure 4.57, is selected to verify the dynamic response of shell element. By symmetry, only a quarter of the plate is modeled. The plate is subjected to a concentrated step load at center.

The computed displacement time history at plate center is shown in Figure 4.58 along with static results. SMAP-3D solution shows good results with such a relatively coarse mesh:

Static vertical displacement at plate center

Kirhhoff theory = 0.925 cm SMAP-3D result = 0.942 cm

Period of the first mode Kirhhoff theory = 0.2366 sec SMAP-3D result = 0.237 sec (Estimated from Figure 4.58)





Figure 4.58 Vertical displacement time history at plate center

4.17 Heated Beam Analysis

A Simply supported plain concrete beam, shown schematically in Figure 4.59, is subjected to linear temperature increase through depth.

The temperature of the top surface of the beam is increased from -30° C to 50° C while temperature of the bottom surface remains constant at -30° C. Consequently, it is expected that the top surface expands relative to the bottom surface and the beam deflects upwards.





4-72 SMAP-3D Example Problem





4.18 Thin Pipe Subjected To Internal Pressure

A very thin steel pipe, with radius of 20 cm and thickness of 0.003 cm, is subjected to the internal pressure of 0.2 kg/cm². The pipe is assumed to be in plain strain condition in the axial direction. Theoretically, the pipe is radially expanding due to the in-plane (membrane) deformations.

A total of 32 Shell elements is used to model the circular pipe as shown in Figure 4.62. A constant internal pressure is regarded as the hydrostatic pressure acting on the inner surface of Shell element.

Since the bending stiffness of the pipe is proportional to the third power of the pipe thickness while the in-plane stiffness is linearly proportional to the pipe thickness, the bending stiffness in such a very thin pipe would be much smaller than in-plane stiffness.

Thus, even a very small force associated with the bending degrees of freedoms may induce unrealistically large displacement. To improve the accuracy of displacement result, bending stiffness is multiplied by a factor of 100000.

The theoretical elastic solution gives the following radial displacement (u_r) and the hoop stress (σ_{θ}) :

$$u_r = \frac{P \cdot r^2}{E \cdot t} (1 - v^2) \qquad \sigma_{\theta} = \frac{P \cdot r}{t}$$

where

Е	Young's modulus	V	Poisson's ratio			
t	Thickness of pipe	r	Radius of pipe			
р	Internal pressure					
Numerical parameters are assumed as:						

 $E = 2.0 \times 10^{6} \text{ kg/cm}^{2} \quad v = 0.3$ t = 0.003 cm r = 20 cm

 $p = 0.2 \text{ kg/cm}^2$







4.19 Preload Consolidation and Excavation

This example problem is to illustrate the analysis of the slope to be constructed under sea water. The in situ soil consists of about 40 meters of soft clay layer overlying hard soil layers.

Figure 4.65 shows schematically four stages of preloading embankment construction followed by excavation up to 17.6 meters below sea level.

Before preloading embankment, material zones 4, 5, 7, 8, 12 and 13 shown in Figure 4.66 are to be improved by drain methods (sand drain and PDB). In situ and improved soil properties are listed in Table 4.1.

The rate of embankment construction and excavation is shown schematically in Figure 4.67 along with computational steps used for SMAP-3D analysis.

Finite element meshes used for the analysis are shown:

Figure 4.68 Finite element mesh

Figure 4.69 Finite element mesh around preload

Figure 4.70 Finite element mesh at completion

Figure 4.71 Finite element mesh around slope

A total of 2330 elements is used to model a sequence of embankment construction and excavation.

Computed results at 152 days after completion of excavation are plotted by PLOT-3D in the following order:

Figure 4.72 Deformed shape around slope

Figure 4.73 Horizontal displacement distribution

Figure 4.74 Pore pressure distribution

Figure 4.75 Effective mean pressure distribution

Figure 4.76 Deviatoric stress distribution

The horizontal contour lines of the hydrostatic water pressure in Figure 4.74 indicates that there will be no further consolidation settlement at 152 days after completion of excavation. Figure 4.76 shows that deviatoric stresses are concentrated around the base of the slope. Looking at both effective mean pressure (p') and deviatoric stress (q), the value of stress ratio (q/p') is less than one at locations approximately 3 meters away from the surface of slope.

Figure 4.77 shows the location of selected elements where time histories of stresses and stress path are plotted. These selected elements are located within 10 meters from the surface of slope.

Computed results of time history of stresses are plotted by PLOT-XY in the following order:

Figure 4.78 Stress time history at element 120 Figure 4.79 Stress path at element 120

It should be noted that first 2000 days are used to generate in situ k_0 stresses. During embankment construction, excess pore water pressures develop mostly immediately after placement and then dissipate with time while effective stresses develop gradually. During excavation, effective stresses undergo unloading stress paths which will end up with higher horizontal stresses in over consolidated soil condition and pore water pressures drop rapidly and then get gradually back to the hydrostatic water pressure level as the dissipation length is shorter.

It is worth noting that the effective mean pressures decrease slightly while deviatoric stresses increase during the short period of placement of preloading fills. This is due to the fact that the compressive plastic volumetric strains develop while the total volumetric strains remain nearly constant since very little excess pore pressure dissipations are expected in such a short period.

Examining all the stress path plots, elements 120, 299, 477, 655 and 833 lie on the failure surface and elements 300 and 478 are slightly below the failure surface. Noting that elements 120, 299, 477, 655 and 833 are located within 2 meters from the surface of slope and elements 300 and 478 are located within 4 meters from the surface of slope, it is expected that soil failure would occur around the slope base within approximately 3 meters from the surface of slope. It may require redesign of the slope or accompany engineered structures for the slope to stay in safe.

Table 4.1 Material model parameters

Material Number	Porosity (%)	Specific Gravity	k (m/day)	E (t/m ²)	v	Remark
1	42	2.7	0.0864	600	0.33	Dry
2	42	2.7	0.0864	600	0.33	Dry
3	42	2.7	0.0864	600	0.33	Saturated
6	44	2.7	0.0864	1400	0.33	Saturated
14	99.9	2.7	10.0	10.0	0.2	Water

Elastic Model Parameters

Modified Cam-Clay Model Parameters

Material Number	Porosity (%)	Specific Gravity	k (m/day)	e _o	C _c	C _r	Μ
4	59.1	2.72	* 0.0274	1.49	0.55	0.077	1.2
5	61.0	2.72	* 0.0274	1.57	0.70	0.098	1.2
7	59.1	2.72	* 0.0274	1.49	0.55	0.077	1.2
8	61.0	2.72	* 0.0274	1.57	0.70	0.098	1.2
9	59.1	2.72	4.32x10 ⁻⁵	1.49	0.55	0.077	1.2
10	61.0	2.72	4.32x10 ⁻⁵	1.57	0.70	0.098	1.2
11	61.0	2.72	4.32x10 ⁻⁵	1.62	0.80	0.112	1.2
12	61.0	2.72	* 0.0274	1.62	0.80	0.112	1.2
13	61.0	2.72	* 0.0274	1.62	0.80	0.112	1.2

(*) Soil permeability improved by sand drain or PDB

SMAP-3D Example Problem 4-81



Figure 4.65 Construction sequence

4-82 SMAP-3D Example Problem



Figure 4.65 Construction sequence (Continued)

SMAP-3D Example Problem 4-


















SMAP-3D Example Problem













SMAP-3D Example Problem 4





SMAP-3D Example Problem





4-95



4.20 Seismic Tunnel Analysis

This example problem is to analyze a typical NATM tunnel subjected to earthquake loading. The tunnel is located about 22 meters below ground surface as shown in Figure 4.80. Figure 4.81 shows detailed tunnel cross section. Material properties are listed in Table 4.2.

This example problem consists of static and dynamic analyses for the typical horseshoe tunnel constructed by NATM method.

The static part (Steps 1 thru 9) of the analyses as shown in Figure 4.82 is the same as the example problem 2 in TUNA Plus User's Manual except the followings:

- Top core excavation followed by lower core excavation.
- Lining modeled by Shell element with plain concrete.

The dynamic part starting from Step 10 as in Figure 4.83 is performed by applying following boundary conditions and base acceleration:

- Left and right sides of boundary are horizontal roller and bottom of mesh is fixed.
- As horizontal base acceleration, N-S component of the El Centro earthquake is applied with scaled maximum acceleration of 0.2g.

Figure 4.84 shows key location selected for displacement time history plot. Numbers shown in the figure represent node numbers. Figure 4.85 thru 4.87 show finite element meshes used for the analysis.

Figure 4.88 shows tunnel deformed shape at 5 seconds after the onset of earthquake loading. Figures 4.89 and 4.90 show top and bottom surface extreme fiber stresses at 5 seconds after onset of earthquake loading.

The graphical outputs of inner (bottom) and outer (top) extreme fiber stresses of the lining show the maximum compressive stress of 119.9 t/m^2 and the maximum tensile stress of 31.88 t/m^2 at 5 seconds after onset of earthquake loading. Such maximum extreme fiber stresses are far below the strength of the typical plain concrete.

Figure 4.91 shows ground surface horizontal displacement time histories at selected locations: Nodes 609, 837, and 2020. As it can be seen, horizontal ground surface displacements are influenced very little due to the presence of the tunnel.

Figures 4.92 and 4.93 show springline horizontal displacement time histories at the right and left sides of the tunnel, respectively. Each figure shows two adjacent nodes: inner and outer nodes which are separated by interface element as shown in Figures 4.84 and 4.87.

Compared with ground surface, displacements at tunnel springlines are much less amplified. Overall, tunnel lining is moving with the surrounding rock mass but the outgoing lining displacements are limited to the adjacent rock mass displacements. In other words, at those locations where lining is in contact with the adjacent rock mass, the outgoing lining displacements do not exceed the rock mass displacements.

Material Type	γ (t/m³)	K _o	E (t/m²)	v	φ deg.	C (t/m²)	T (t/m²)
Weathered Soil	1.90	0.50	2.00x10 ³	0.33	30	3	20
Weathered Rock	1.90	0.43	5.000x10 ³	0.30	35	30	30
Soft Rock	2.40	0.33	2.00x10 ⁴	0.25	40	70	40
Hard Rock	2.55	0.25	2.00x10⁵	0.20	45	100	50
Shotcrete (Soft)	2.40		0.50x10 ⁶	0.20	30	500	100
Shotcrete (Hard)	2.40		1.50x10 ⁶	0.20	30	500	100
Rock Bolt			2.10x10 ⁷				
Reinforced Concrete Lining	2.50		2.10x10 ⁶	0.20	30	500	300
Reinforcing Bar			2.10x10 ⁷	0.20			
Interface Joint			2.00x10⁵		5	0.001	0.02

Table 4.2 Material property





4-102 SMAP-3D Example Problem

Step	Construction State	Descriptions		
1,2		In Situ K $_{\circ}$ State		
3		50 % Stress Relief		
4	75 % Stress Relief Soft Shotcrete Rock Bolt		Upper Core Excavation	
5		100 % Stress Relief Hard Shotcrete Rock Bolt		

Figure 4.82 Construction sequence, static part

SMAP-3D Example Problem 4-103

Step	Construction State	Descriptions		
6		50% Stress Relief		
7		75% Stress Relief Soft Shotcrete	Lower Core Excavation	
8		100% Stress Relief Hard Shotcrete		
9		Lining Subjected to: V	Veight	

Figure 4.82 Construction sequence, static part (Continued)



















SMAP-3D Example Problem 4-113





4.21 Frames with Hinge Connection This example problem is to solve symmetric plane frame members subjected to a vertical concentrated load at the hinge connecting both frames as shown is Figure 4.94. The exact solutions for this frame structures without shear deformation are given below: $\delta = \frac{P}{EA/L + 3EI/L^3} \qquad M_{max} = \frac{PL/\sqrt{2}}{1 + AL^2/3I}$ where Maximum deflection at the center δ M_{max} Maximum moment at fixed end Two SMAP-3D calculations are performed using the geometrical and material parameters listed in Figure 4.94. Frames modeled by 10 beam elements: Figure 4.95 Beam element with material number Figure 4.96 Beam deformed shape Figure 4.97 Beam bending moment diagram Frames modeled by 40 shell elements: Figure 4.98 Shell element with material number Figure 4.99 Shell deformed shape Figure 4.100 Shell bending moment diagram SMAP-3D results show good agreement with the exact solutions. Maximum deflection at the center (δ) Exact solution = 0.01768 cm SMAP-3D (Beam) = 0.01767 cm SMAP-3D (Shell) = 0.01767 cm Maximum moment at fixed end (M_{max}) Exact solution = 0.1000 t-m SMAP-3D (Beam) = 0.1000 t-m SMAP-3D (Shell) = 0.1003 t-m















4.22 Embedded Rebars with Slip

This example problem is to verify the implementation of the embedded reinforcing bars (rebars) with interface shear (slip) between rebars and surrounding concrete. Figure 4.101 shows a simply supported reinforced concrete beam subjected to a concentrated load at midspan. To simplify the problem, it was assumed that both reinforcing bars and concrete are linearly elastic while the interface shear is elastic - perfectly plastic with a limiting constant cohesion.

The exact beam solution without shear deformation is given below:

Maximum deflection at the center without rebars,

$$\delta = \frac{P \cdot L^3}{48 E_c \cdot I_c} = 1.190 \text{ Cm}$$

Maximum deflection at the center with rebars,

$$\delta = \frac{P \cdot L^3}{48 E_c \cdot I_t} = 1.040 \text{ Cm}$$

By symmetry, only left half of the beam is modeled using 60 continuum elements for concrete and 2 embedded truss elements for reinforcing bars as shown in Figure 4.102. It should be noted that the end points of embedded truss elements do not belong to the corner nodes of continuum elements.

The computed center deflections are compared with the exact beam solution as shown in Table 4.3. SMAP-3D results approach to the upper bound beam solution at lower cohesion and the lower bound beam solution at higher cohesion. At the intermediate cohesion, however, the computed deflection is in between upper and lower bound beam solutions, indicating some resistance from slip strength.

Figures 4.103 and 4.104 show the deformed shape and the axial stress distribution, respectively, from SMAP-3D result at the intermediate cohesion of 5 t/m².

Table 4.3	Computed center deflections

Cmax (t/m ²)	SMAP-3D Result	Exact Beam Solution
0.1	1.1746 Cm	1.190 Cm (without rebar)
5.0	1.0990 Cm	
280	1.0379 Cm	1.040 Cm (with rebar)

Cmax : Interface Cohesion








4.23 Pseudo-Dynamic Embankment Fill Analysis

This example problem is to solve the response of an embankment fill subjected to pseudo-dynamic earthquake load as schematically shown in Figure 4.105.

As listed in Table 4.4, the sequence of construction consists of 5 steps. The first two steps are used to compute in situ Ko state with water table at GL-25. At step 3, water table is raised up to GL-5. At step 4, embankment fill is completed. At final step 5, pseudo-dynamic earthquake load is applied to the embankment fill.

Material properties are listed in Table 4.5.

The change of water table is modeled by adding Intensity times Distribution Factor to the Y component of unit gravity load (FRY). Intensity history number and distribution factor are specified in Card Group 9.1.2.

The pseudo-dynamic earthquake load is modeled by adding Intensity times Distribution Factor to the X component of unit gravity load (FRX).

Figure 4.106 shows the finite element mesh used for the analysis. Figures 4.107 and 108 show deformed shape and vertical stress distribution, respectively, at final step 5 where pseudo-dynamic earthquake load is applied to the embankment fill.

Computed vertical stress at GL-23 is reduced by 18 t/m^2 due to the water table at GL-5. The reduction of vertical stress is associated with the water head of 18 m at GL-23.

Horizontal displacement of 1.16 Cm is obtained at the top surface of embankment fill due to the pseudo dynamic load. Exact solution for this problem is not available. However, SMAP-S2 and SMAP-2D analyses show the same results.

4-130 SMAP-3D Example Problem



Table 4.4 Construction sequence

Step	Description
1, 2	In Situ Ko state with water table at GL-25
3	In Situ Ko state with water table at GL-5
4	Completion of embankment fill
5	Embankment fill subjected to pseudo-dynamic load

Table 4.5 Material property

Material Type	γ (t/m³)	K _o	E (t/m²)	V	φ deg.	C (t/m²)	T (t/m²)
Weathered Soil	1.90	0.50	2.0 x10 ³	0.33	30	3	20
Weathered Rock	1.90	0.43	5.0 x10 ³	0.30	35	30	30
Soft Rock	2.40	0.33	2.0 x10 ⁴	0.25	40	70	40
Embankment Fill	2.00	0.50	3.0 x10 ³	0.33	30	3	20

4-132 SMAP-3D Example Problem







4.24 Plane Strain Tunnel in Jointed Continuum

This example problem is to verify the jointed continuum mesh generated by JOINT-3D pre-processing program. Jointed continuum analysis is similar to the discrete element analysis. For the jointed continuum analysis, each continuum finite element is surrounded by joint elements.

The main advantages of using such joint elements are to allow slippage along the joint when reaching shear strength and debonding normal to joint face when exceeding tensile strength.

This example is identical to the Example Problem 14 except that the tunnel is located in the jointed continuum. The jointed continuum mesh is generated by JOINT-3D program with the input file Joint.inp. Refer to JOINT-3D User's Manual.

Figure 4.109 shows the finite element mesh consisting of the jointed continuum around tunnel.

To compare with continuum model (Example Problem 14), two analyses are performed with Elastic and Plastic Joint Models. The Elastic Joint Model assumes strong joint properties so that it essentially represents continuum model. The Plastic Joint Model assumes lower shear and tensile strengths so that it allows slippage and debonding along the joints.

Results are listed in the following order:

Figure 4.110 Deformed shape for Elastic Joint

Figure 4.111 Principal stress vector for Elastic Joint

Figure 4.112 Bending moment for Elastic Joint

Figure 4.113 Deformed shape for Plastic Joint

Figure 4.114 Principal stress vector for Plastic Joint

Figure 4.115 Bending moment for Plastic Joint

In general, rersults of the Elastic Joint Model are close to those of conventional continuum analysis in Example Problem 14.

On the other hand, Plastic Joint Model shows considerable amount of slippage below bottom corner of tunnel as in Figures 4.113 and 4.114. Stress distributions are quite different from Elastic Joint Model.

4-136 SMAP-3D Example Problem







SMAP-3D Example Problem 4-139









4.25 Spring Analysis

This example problem is to show how to model springs using special features in beam element in Card 6.4.1 of SMAP-3D User's Manual.

The example is composed of two truss members connected by horizontal and vertical springs as shown in Figure 4.116. The structure is subjected to external horizontal and vertical nodal forces.

Figure 4.117 shows the finite element mesh consisting of two beam elements and two truss elements. Beam element 1 and 2 are used to model vertical and horizontal spring, respectively. When you specify MR = 11 or -11 in Card 6.4.1, beam axial stiffness (E A/L) represents axial spring constant (Ks).

For the material properties, dimensions and loads in Figure 4.116, the exact solution gives following displacements and truss axial forces:

HorizontalDisplacement = 0.04VerticalDisplacement = 0.02HorizontalTrussAxialForce = 40 (Compression)VerticalTrussAxialForce = 20 (Tension)

SMAP-3D results show exact as shown in Figures 4.118, and 4.119 for displacements and truss axial forces, respectively.



Figure 4.116 Truss members connected by springs







4.26 Nonlinear Truss Analysis

Truss elements in SMAP can consider nonlinear behavior such as yielding and post buckling as schematically illustrated in Figure 4.121. Following examples are to show how to use such material parameters in truss element in Card 7.4.3 of SMAP-3D User's Manual.

Figure 4.120 shows a horizontal truss element subjected to axial force. A typical I-section $(400 \times 150 @720 \text{kN/m})$ is assumed for truss member with material and cross section properties as listed in the figure.

Six different cases are performed:

- 1. Buckling and Tension Yielding (Figure 4.122)
- 2. Compression and Tension Yielding (Figure 4.123)
- 3. Tension Yielding for No Compression Member (Figure 4.124)
- 4. Compression Yielding for No Tension Member (Figure 4.125)
- 5. Buckling for No Tension Member (Figure 4.126)
- 6. Initial Stress (See Case 6 at the end of example)

Compression resistance is not allowed for No Compression Member such as cable and tension resistance is not allowed for No Tension Member such as strut. A linear elastic truss element is added to prevent the structure from being unstable when plastic yielding. Both compression and tension yield strengths are increased more than 12 times in order to make an exaggerated graphical presentation associated with load and unload.



I-Section (400x150@720 kN/m)

Figure 4.120 Truss member subjected to axial force



4-149 SMAP-3D Example Problem







SMAP-3D Example Problem



4-151



4-152 SMAP-3D Example Problem

SMAP-3D Example Problem 4-153



Case 6 Initial Stress

For this example, following parameters are used: L = 400 Cm $E_1 = 21000 \text{ kN/Cm}^2$ $E_2 = 1000 \text{ kN/Cm}^2$ To check Initial Stress, Member 1 is assumed to have initial compressive stress ($\sigma_i = -10 \text{ kN/Cm}^2$) with the corresponding initial strain ($\epsilon_i = \sigma_i / E_1 = -0.00047619$). Thus the original length of Member 1 at stress free $Lo = L / (1 + \epsilon_i) = 400 / (1 - 0.00047619) = 400.19057 Cm$ Now, when Members 1 and 2 are connected, $\sigma_1 \cdot A + \sigma_2 \cdot A = P = 0$ i.e. $\sigma_2 = -\sigma_1$ (1) $\sigma_2 = E_2 \cdot \varepsilon_2$ (2) $\epsilon_1 = ((L + \Delta L) - Lo) / Lo$ = ((L + $\varepsilon_2 \cdot$ L) - Lo) / Lo = $(L / Lo) \cdot (1 + \varepsilon_2) - 1$ (3) $\sigma_1 = E_1 \cdot \varepsilon_1$

$$= (\mathsf{E}_1 \cdot \mathsf{L} / \mathsf{Lo}) \cdot (1 + \varepsilon_2) - \mathsf{E}_1$$
(4)

Substituting (2) and (4) into (1),

$$\epsilon_{2} = E_{1} (1 - L / Lo) / (E_{2} + E_{1} \cdot L / Lo)$$
(5)
= 0.00045475

From (3) $\epsilon_1 = -0.000021654$

And from (2) and (1) $\sigma_1 = -0.45475 \text{ kN/Cm}^2$ (Compression) $\sigma_2 = 0.45475 \text{ kN/Cm}^2$ (Tension)

SMAP results show exact solution.

4.27 SDOF System To Ground Acceleration

A single Truss element is used to model axial spring subjected to sinusoidal ground acceleration as schematically shown in Figure 4.127. Mass is lumped at the node in the right side of truss member.

 $\begin{array}{ll} \mbox{Following parameters are assumed:} \\ \mbox{L} &= 120 \mbox{ inch } & \mbox{A} = 1 \mbox{ in}^2 & \mbox{E} = 30 \mbox{10}^6 \mbox{ psi} \\ \mbox{ρ} &= (1/1.2) \mbox{ lb-s}^2/\mbox{in}^4 & \mbox{a} = 200 \mbox{ in}/\mbox{s}^2 & \mbox{ω} = 40 \mbox{ rad/s} \\ \mbox{c} &= 500 \mbox{ lb-s/in} \\ \end{array}$

Lumped mass at right node: $m = \rho \mbox{ A } L = (1/1.2) \mbox{ (1) } (120) = 100 \mbox{ lb-s}^2/in$

Equivalent spring constant: $k = E A / L = (30x10^{6}) (1) / (120) = 250,000 \text{ lb/in}$

Natural frequency: $\omega_n = (k \ / \ m)^{1/2} = (250,000 \ / \ 100)^{1/2} = 50 \ rad/s$

Critical damping ratio: $\xi = c / (2 m \omega_n) = 0.05$

Damped natural frequency : $\omega_d = \omega_n \sqrt{1-\xi^2}$

Frequency ratio: $\beta = \omega / \omega_n = 40 / 50 = 0.8$

For systems with viscously damped single degree of freedom, the relative displacement is given by

$$\overline{x}(t) = e^{-\xi \omega_n t} (A \cos \omega_d t + B \sin \omega_d t) + C \sin \omega t + D \cos \omega t$$

The constants C and D are given by

$$C = \frac{ma}{k} \frac{1 - \beta^2}{(1 - \beta^2)^2 + (2\xi\beta)^2} \qquad D = \frac{ma}{k} \frac{-2\xi\beta}{(1 - \beta^2)^2 + (2\xi\beta)^2}$$

Assuming initial conditions at rest, constants A and B are given by

A = -D B =
$$-(\frac{\omega}{\omega_d})$$
 C - $\xi(\frac{\omega_n}{\omega_d})$ D



4.28 Frames with Rotational Spring Connection

This example is the same as Example problem 21 except that it is connected by rotational spring and subjected to both moment and horizontal force at the connection as shown in Figure 4.129.

The rotational spring is modeled by the simple Joint Spring Element which can consider axial, shear, torsional and flexural resistances. For this example, the Joint Spring properties are assumed very rigid in all deformation modes except the rotation about z-axis.

Five analyses are performed to see the influence of connection:

- 1. Rigid connection
- 2. Hinge connection
- 3. Rotational spring connection, rigid $Kr = 1 \times 10^6 \text{ t-m/rad}$
- 4. Rotational spring connection, very flexible $Kr = 1x10^{-3} t-m/rad$
- 5. Rotational spring connection, somewhat rigid $Kr = 1 \times 10^4 \text{ t-m/rad}$

Computed results are summarized in detail in Joint_Spring_3D.pdf. It approaches to rigid connection when the rotational spring is rigid and hinge connection when the spring constant is very flexible.

Figures 4.130 to 4.134 show finite element mesh, deformed shape, thrust, shear and bending moment distributions, respectively, for the rotational spring connection with $Kr = 1 \times 10^4$ t-m/rad.



Fig 4.129 Frames with rotational spring connection

4-158 SMAP-3D Example Problem





4-160 SMAP-3D Example Problem




4-162 SMAP-3D Example Problem



4.29 Reinforced Concrete Beam

This example problem is to verify the implementation of reinforcing bars (rebars) into quadrilateral shell element. This example is the same as Example problem 22 except that it is modeled by reinforced shell element. Figure 4.135 shows a simply supported reinforced concrete beam subjected to a concentrated load at midspan. To simplify the problem, it was assumed that both reinforcing bars and concrete are linearly elastic.

The exact beam solution without shear deformation is given below:

Maximum deflection at the center without rebars,

$$\delta = \frac{P \cdot L^3}{48 E_c \cdot I_c} = 1.190 \text{ Cm}$$

Maximum deflection at the center with rebars,

$$\delta = \frac{P \cdot L^3}{48 E_c \cdot I_t} = 1.040 \text{ Cm}$$

By symmetry, only left half of the beam is modeled using 10 reinforced shell elements.

The computed center deflections are compared with the exact beam solution as shown in Table 4.6. SMAP-3D results are very close to the exact beam solutions.

Computed results are shown in the following order:

Figure 4.136	Deformed shape
Figure 4.137	Bending moment
Figure 4.138, 4.139	Top and bottom surface axial stress
Figure 4.140, 4.141	Top and bottom reinforing bar axial stress

4-164 SMAP-3D Example Problem

Table 4.6 Computed center deflections			
Reinforcement	SMAP-3D Shell Element	Exact Beam Solution	
Plain Concrete	1.1812 Cm	1.190 Cm (without rebar)	
Reinforced Concrete	1.0329 Cm	1.040 Cm (with rebar)	







4-168 SMAP-3D Example Problem





4-169

4-170 SMAP-3D Example Problem





4.30 Reinforced Concrete Cylinder

This example is to check the reinforced concrete cylinder subjected to uniformly distributed radial line loads as shown in Figure 4.142. This example is an axially symmetric problem since both the structure and the external load are axially symmetric.

The exact solution for unreinforced cylinder can be obtained from the reference: Timoshenko and Woinowsky-Krieger, Theory of Plates and Shells, 2nd Edition, McGraw-Hill International Series, 28th Printing 1989.

This exact solution is further modified here such that it includes both axial (meridian) and hoop (circumferential) reinforcements as listed in the file Reinforced_Cylinder_3D.pdf.

Four cases are performed with different reinforcements:

- 1. Concrete without reinforcements
- 2. Concrete with hoop reinforcements
- 3. Concrete with axial & hoop reinforcements, Vc = 0.15
- 4. Concrete with axial & hoop reinforcements, Vc = 0.0
- Note that the analytical solutions represent exact solutions

except the case 3 where it is an approximate closed-form solution.

As in Figure 4.143, the structure is modeled by quadrilateral shell elements which have capability of modeling two way reinforcements.

Overall, SMAP-3D results are very close to the exact solutions. Refer to the following two files for detailed graphical outputs: Reinforced_Cylinder_3D.pdf and Smap-3D_Vp30.pdf.

SMAP-3D results for case 3 are compared with closed-form solutions:Figure 4.144 Radial displacement profileFigure 4.145 Meridian bending moment profile





SMAP-3D Example Problem 4-175





4.31 Plate Modal Analysis

A simply supported rectangular plate, shown in Figure 4.146, is selected to verify the Modal Superposition method for the dynamic response. By symmetry, only a quarter of the plate is modeled. The plate is subjected to a concentrated step load at center. This problem is identical to the Verification Problem 4.16 which was solved by Direct Integration method.

The closed form solution of natural frequencies of simply supported rectangular plate is given by Kirchhoff plate theory:

 $\omega_{mn} = \sqrt{\frac{D}{\rho h}} \left[\left(\frac{m \pi}{a} \right)^2 + \left(\frac{n \pi}{b} \right)^2 \right] \qquad D = \frac{E h^3}{12 (1 - v^2)}$ $\rho = 0.0003 \text{ lb-s}^2 / \text{ in}^4 \qquad v = 0.25 \qquad h = 1 \text{ in}$ $E = 3 \times 10^4 \text{ lb} / \text{ in}^2 \qquad a = 60 \text{ in} \qquad b = 40 \text{ in}$

Table 4.7 summarizes the computed natural frequencies along with closed form solution. Both shell and continuum modal analyses predict pretty well natural frequencies of the simply supported rectangular plate.

Figure 4.147 shows the contours of the first three modes solved by shell modal analysis.

Figure 4.148 shows deflection time history at plate center as predicted by modal superposition method using only first 6 mode shapes. To verify the computed response of the modal superposition method, step-by-step solution by direction integration with the same shell element mesh which was used in shell modal superposition is included. SMAP-3D modal superposition solutions predict very closely the direct integration solution.

Table 4.7 Computed natural frequencies (rad/s)

Mode No	Kirchhoff Plate Theory	Shell 4 Node Quad 16x24 Mesh	Continuum 8 Node Hexa* 8x12 Mesh
1	26.565	26.544	26.412
2	91.955	91.729	91.356
3	173.693	172.992	173.411

Notes:

- 1. Computed frequencies represent natural frequencies associated with symmetric boundary conditions. $\omega_1 = \omega_{11}, \quad \omega_2 = \omega_{31}, \quad \omega_3 = \omega_{13}$
- 2. All modal analyses used Subspace Iteration method with lumped mass to compute natural frequencies.
- Shell modal analysis used 16x24 mesh consisting of 4 node quadrilateral shell elements.
- Continuum modal analysis used 8x12 mesh consisting of 8 node hexahedral continuum elements with 3 incompatible extra degrees of freedom* (IEDOF =1).





SMAP-3D Example Problem 4-181



4.32 Seismic Response Analysis

This example is to solve the free-field seismic response of the linearly viscous elastic soil profile, shown in Figure 4.149 along with material properties, subjected to earthquake excitations from the bedrock.

This problem is the same as the sample problem in SHAKE91 (Idriss and Sun, 1992). A 45.72 m (150 ft) soil profile is subjected to Diamond Heights earthquake in 1989 as outcrop to the elastic half space. The earthquake is scaled to peak acceleration of 0.1g. Scaled earthquake time history and its spectral acceleration are shown in Figures 4.150 and 4.151, respectively. The predominant period of the earthquake is about 0.4 second as shown in the response spectrum.

To mitigate frequency dependency, Rayleigh mass and stiffness proportional damping constants (a, b) are computed in the equation:

 $a = 2 \beta \omega_1 \omega_i / (\omega_1 + \omega_i)$ $b = 2 \beta / (\omega_1 + \omega_i)$

where $\omega_{\scriptscriptstyle 1}$ represents for fundamental natural circular frequency of soil profile, $\omega_{\scriptscriptstyle i}$ for predominant circular frequency of the input earthquake motion and β for critical damping ratio in an element.

Figure 4.152 shows computed acceleration time histories on the ground surface and Figure 4.153 shows the same accelerations between 10 and 12 seconds where strong motions occur. SMAP-3D solutions predict very closely the closed-form frequency domain SHAKE91 solution.

Figure 4.154 shows spectral accelerations with 5% structural damping on the ground surface and Figure 4.155 shows the same accelerations between 0.1 and 1 seconds. SMAP-3D solutions are very close to SHAKE91 solution.

It should be noted that both base shear and base acceleration options for earthquake load produce exactly the same results as presented in the reference (S. H. Kim and K. J. Kim, 2024).



Figure 4.149 Finite element meshes and material properties



Figure 4.151 Spectral acceleration for input earthquake

Period (S)

10

0.1

Absolute Acceleration

0.3

0.2

0.1

0





Figure 4.154 Spectral accelerations on ground surface



4.33 Silo Lining Analysis

This example is to solve the lining stresses developed in underground silo subjected to residual water pressure. This silo structure in Gyeongju, South Korea, was constructed to store the low-andintermediate-level radioactive waste.

Figures 4.156 and 4.157 show finite element meshes and close-up view around silo, respectively. This 3 dimensional model consists of 65,598 continuum, 792 joint, 1,584 shell elements and 71,867 nodes. Program used thin shell elements to model reinforced concrete lining.

Table 4.8 lists material properties and Figure 4.158 shows schematic view of detailed silo lining structure. Table 4.9 lists lining thickness and reinforcement. Figure 4.159 shows silo lining material numbers. Table 4.10 shows schematically the sequence of silo construction including residual water pressure applied at step 5. Figure 4.160 shows key locations along the silo lining.

The following is a partial listing of graphical outputs at load step 5 when lining is subjected to residual water pressure head of 17.47m:

Figure 4.101	Deformed shape of sho mining
Figure 4.162	Dome deflection along A-B
Figure 4.163	Storage wall radial displacement along C-D
Figure 4.164	Dome lining inner hoop stress along A-B
Figure 4.165	Dome outer rebar meridian stress along A-B
Figure 4.166	Storage wall lining inner hoop stress along C-D
Figure 4.167	Storage wall outer rebar meridian stress along C-D

SMAP-3D results are compared with SMAP-2D results to verify the validity of the solution. As shown, SMAP-3D results are very close to SMAP-2D results. It seems that the reinforced concrete lining is in safe condition under the applied residual water pressure head of 17.47m.

Note: It takes about 5 hours of run time in the following computer: 64 Bit Windows 11, 8 Core i7-11700F CPU, 16 GB of DDR4 Ram.



Table 4.8 Material properties				
Ground Layer	Unit weight (KN/m ³)	Young's modulus (MPa)	Poisson's ratio	Internal Friction Angle
Soil Layer	18.56	0.124×10^{4}	0.33	30°
Weathering Rock	20.52	0.342×10 ⁴	0.30	38°
Rock	26.28	8.260×10^4	0.27	43°
Shotcrete	23.0	24,500	0.167	-
Concrete	23.5	29,500	0.167	-
Rebar	-	210,000	0.25	-





Figure 4.158 Schematic view of detailed silo lining structure

4-189

Table 4.9 Silo lining thickness and reinforcement				
Material	Thickness	Steel Ratio (%)		
Number	(Meter)	Ноор	Meridian	Location
1	1.211	0.85	0.85	Dome Crown
4	1.246	0.83	0.83	Dome Crown
5	1.279	0.81	0.81	Dome Crown
6	1.328	0.78	0.78	Dome Crown
7	1.398	0.74	0.74	Dome Crown
8	1.475	0.70	0.70	Dome Crown
9	1.547	0.67	0.67	Dome Crown
10	1.594	0.65	0.65	Dome Crown
11	1.600	0.65	0.65	Dome Wall
12	1.200	0.86	0.86	Dome Bottom
13	0.800	1.29	1.29	Storage Wall
14	1.200	0.86	0.86	Storage Bottom
15	1.200	0.86	0.86	Storage Bottom







Figure 4.160 Key locations along silo lining

Storage Bottom E-D

E

ðр

SMAP-3D Example Problem 4-193












4.34 Liquefaction Analysis with PM4Sand

It should be noted that PM4Sand in SMAP-3D works only for plane strain condition. It does not work for general 3 dimensional condition.

The main objective of this example is to verify PM4Sand model implemented in SMAP-3D finite element program. The PM4Sand model (Boulanger and Ziotopoulou, 2017) is the effective stress material model which is calibrated in the finite difference program FLAC 8.0 (Itasca 2016) for the plane strain condition.

As first step, several different stress paths for a single element are considered to verify implementation; including drained and undrained conditions, monotonic and cyclic loadings, and isotropic and K_o initial conditions. Figure 4.168 shows isotropic consolidated drained cyclic direct simple shear test. All other results are summarized in the file; Single Element Stress-Strain Response of PM4Sand Model.pdf

This analysis is to solve the free-field seismic response of the soil profile, shown in Figure 4.169 along with material properties, subjected to earthquake excitation from the bedrock.

This problem is the same as the problem in the report (Chen and Arduino, 2021). A 6 m soil profile is subjected to Loma Prieta earthquake in 1989 (RSN766) as outcrop to the elastic half space. Earthquake time history with peak acceleration 0.37g and its spectral acceleration are shown in Figures 4.170 and 4.171, respectively.

Figures 4.172 and 4.173 show computed profiles of peak ground accelerations and maximum shear strains, respectively, compared with SHAKE 91 and DEEP SOIL. Note that this linear elastic analysis is performed to check the initial stresses and boundary conditions prior to liquefaction analysis by scaling down peak acceleration to 0.02g.

Results of liquefaction analysis are presented in the following:

- Figure 4.174 Maximum acceleration profile (PGA)
- Figure 4.175 Maximum displacement profile
- Figure 4.176 Maximum shear strain profile
- Figure 4.177 Maximum r_u profile

 r_{μ} = Excess Pore Pressure / Initial Effective Ver. Stress

Overall, PM4Sand in SMAP-3D is performing very well in predicting the stress-strain responses compared to the calibrated FLAC results.

4-199 SMAP-3D Example Problem























4-208 SMAP-3D Example Problem





5.1 Arch Tunnel

The main objective of this first example is to show the step by step procedure to create and modify group meshes.

This example has the following three parts:

Part 1 : Creating Arch Tunnel (Figure 5.1)

- Create group mesh
- Set built-in base mesh
- Draw arch tunnel
- Plot finite element mesh

Part 2 : Adding Rock Bolts (Figure 5.2)

- Open the group mesh file in part 1
- Add three rock bolts
- Plot finite element mesh

Part 3 : Adding Utility Tunnel (Figure 5.3)

- Open the group mesh file in part 2
- Remove the first rock bolt
- Change the second rock bolt length
- Replace the third rock bolt by utility tunnel
- Plot finite element mesh

Table 5.1 shows the construction sequence.





5-4 Group Mesh Example



Group Mesh Example 5-5

5.1.1 Part 1: Creating Arch Tunnel

Part 1 consists of the following main actions:

- Create group mesh
- Set built-in base mesh
- Draw arch tunnel
- Plot finite element mesh

Step 1: Group Mesh Generator (New)

Access Group Mesh Generator by selecting the following menu items in SMAP (Figure 5.4):

Run →	Mesh	Generator →	Group	Mesh	→ New
-------	------	-------------	-------	------	-------

Run Plot Setup	Exi	t		
Smap	-			
Mesh Generator	+	Group Mesh	•	New
Load Generator	×	Block Mesh	•	Open
	_	PreSmap	· · ·	
		AddRgn		
		Supplement		
		File Conversion		

Figure 5.4 Accessing group mesh generator (New)

Step 2: Group Input (New)

Select Built-in Base Mesh in Figure 5.5. Click OK.

Built-in Base Mesh Existing Finite Element Mesh Browse OK Cancel	Built-in Base Mesh C Existing Finite Element Mesh Browse DK Cancel	Base Mesh	1
C Existing Finite Element Mesh Browse	C Existing Finite Element Mesh Browse	Built-in Base Mesh	
0K Cancel	OK Cancel	C Existing Finite Element Mesh Browse	
		0K Cancel	

File Edit View Plot	Entity Mouse-Snap Gro	up Child-Window State	Window
	Figure 5.6 Gro	oup menu	
dialog in Figure 5	.7 is displayed w	ith initial default	values.
Group			2
Group No 1 <>	Title Group No = 1		Add Group
MTYPE and Material Paramete	ər		Show Number
1: Generate lines & remove	elements within closed loop		
MATNO 1 KF	1.00 MATold 3	MTYPE	cut
		Description	
LTPi 2 LMATi	1 Line Option	s	Update
LTPo 2 LMATO	2 Color	Type Thickness	Save
Coordinate Constraint			
 Generated coordinates are 	movable C Generated coord	nates are not movable	Base Mesh
Element Activity	PLOT-2D Plot	Geometry will be marked	Replot
	Principal Stress	by distance Dx and Dy	Group Editor
	Deformed Shape Beam	in x and Y direction	Segment Editor
LMAT 0 0	Truss	Dx 0.00	Close
	Reference Line	Dy 0.00	Exit



Step 5: MTYPE Click MTYPE button in Group dialog. Select MTYPE=3 in MTYPE dialog in Figure 5.10. Click OK. Select MTYPE Select MTYPE Image in Figure 5.10. Click OK.	
Image: State of the state	
Fill in input fields for Group dialog as shown in Figure 5.11.	
Group Group Identity Group No I MTYPE and Material Parameter 3. Assign new material number within closed loop MATNO KF MATNO KF ITP 2 LTP	
Figure 5.11 Group dialog with MTYPE = 3	

Step 6: Mouse Snap Click Mouse-Snap menu in PLOT-2D. Select Snap to Grid in Figure 5.12. Click OK. Figure 5.12 Mouse snap dialog Mouse snap dialog

Step 7: Add Group

Click Add Group button in Group dialog.

Table 5.2 summarizes group parameters used for arch tunnel.

					Element	Activity
No	MIYPE	Description	Element Type	Mat. Np.	NAC	NDAC
		Core	Cont.	MATNO=2	0	3
1	3	Lining	Beam (LPT=2)	LMAT=1	3	999

			Line Se	egment	:			Arc Se	gment			
Group No	Seg. No	Begir Po	nning int	Enc Po	ling int	Ori	gin	Ra	idius ar	nd Angl	e	IEND
		Х	Y	Х	Y	X _o	Y _o	R _x	R _y	$\Theta_{\rm b}$	$\Theta_{\rm e}$	
1	1	10	5	20	5							2
	2					15	5	5	5	0	1 8 0	2

Table 5.2 Group parameters for arch tunnel

	Line Segment
	Segment No: 1 Group No: 1 Arch Tunnel Points By C. Exter X and X
	Beginning Point Ending Point X = X = Y = Y = Divisions and Inclusions Include beginning & ending point 2. Include beginning & ending point Image: Conceler
Click the mouse ne ends as she	Figure 5.13 Line segment dialog where the line begins and then click the mouse where the vn in Figure 5.14.
lick the mouse ne ends as sh	Figure 5.13 Line segment dialog where the line begins and then click the mouse where the vn in Figure 5.14.
lick the mouse ne ends as sh	Figure 5.13 Line segment dialog where the line begins and then click the mouse where the vn in Figure 5.14.
lick the mouse ne ends as she	Figure 5.13 Line segment dialog where the line begins and then click the mouse where the vn in Figure 5.14.
lick the mouse ne ends as she	Figure 5.13 Line segment dialog where the line begins and then click the mouse where the vn in Figure 5.14.





Once finished, finite element mesh file is generated as Group.Mes in the directory Plot_Mesh as shown in Figure 5.20 along with finite element mesh plot in Figure 5.21.

# Message List & Keyboard Input Window	
PLOT NO : 1	
PLOT NO : 1	
File is saved as C:\SMAP\SMAP3D\EXAMPLE\Group_Mesh\EX1\TEST\Group.Me	g
Finite Element Mesh File is Generated as Group.Mes in the Directory Plot_Mesh	
٠ 🔲	ti ∢

Figure 5.20 Message for finite element mesh file



Step 12	: Exit
lick <mark>Exit</mark> b	outton in Group dialog.
lick <mark>OK</mark> in	Exit dialog as shown in Figure 5.22.
ſ	Exit
	Total Number of Groups = 1
	Enter Output File
	C:\SMAP\SMAP3D\EXAMPLE\Group_Mesh\EX1\TEST\Group.Meg
	Note: This "Output File" will be the input file to program ADDRGN-2D. When you execute ADDRGN-2D, following files will be generated:
	Group.Mes contains coordinates and index for mesh file. Group.Man contains element activity data for main file.
	Group.Pos contains graphical input data for post file.
	OK Cancel Exit without Saving
l	

5.1.2 Part 2: Adding Rock Bolts

Part 2 consists of the following main actions:

- Open the group mesh file in part 1
- Add three rock bolts
- Plot finite element mesh

Step 13: Group Mesh Generator (Open)

Access Group Mesh Generator by selecting the following menu items in SMAP (Figure 5.4):

 $\mathsf{Run} \to \mathsf{Mesh} \; \mathsf{Generator} \to \mathsf{Group} \; \mathsf{Mesh} \to \mathsf{Open}$

Step 14: Group Input (Open)

File open dialog will be displayed as in Figure 5.23. Select group mesh file Group.Meg in Part 1 and click Open.



Figure 5.23 File open dialog

Step 15: Group Menu and Dialog

Click Group menu in PLOT-2D as shown in Figure 5.6. Group dialog for Group No 2 is displayed with initial default values.

Step 16: MTYPE

Click MTYPE button in Group dialog. Select MTYPE=2 in MTYPE dialog in Figure 5.10. Click OK.

Step 17: Group No 2 for Rock Bolt 1

Table 5.3 summarizes group parameters for rock bolts. Rock bolt is modeled by a straight radial line in Arc Segment.

Group	Bolt No	MTYPE	Elem. Type	Mat. No	Ele Act	ment :ivity	Ra	adius a	nd Ang	gle	IEND
No			(LTP)	(LMAT)	NAC	NDAC	R _x	R _Y	$\Theta_{\rm b}$	$\Theta_{\rm e}$	
2	Bolt-1	2	Truss (3)	1	4	999	5	10	60	60	-2
3	Bolt-2	2	Truss (3)	1	4	999	5	10	90	90	-2
4	Bolt-3	2	Truss (3)	1	4	999	5	10	120	120	-2

Table 5.3Group parameters for rock bolts

Group No 2 represents Rock Bolt 1 with a length of 5m at 60 degrees. Fill in input fields for Group dialog as shown in Figure 5.24.

MTYPE and Material Parameter	Show Number
2: Generate lines	-
MATNO 1 KF 1.00 MATold 3 MTYPE MATNOI 0 KFi 1.00 THICI 0.10 Description	
LTPI 2 LMATI 1 Add new mesh Hide LTPI 2 LMATI 1 Line Options LTPo 2 LMATo 2 Color Type Thickness	Update Save
Coordinate Constraint Generated coordinates are movable Generated coordinates are not movable Element Aution Torontology Element Aution Element Aution Torontology Element Aution Torontology Element Aution Element Aution Torontology Element Aution Torontology Element Aution Element	Base Mesh
Definition NAC NAC Mesh Geometry will be move 0 0 0 Principal Stress by distance Dr and Dy 0 0 0 Deformed Shape in X and Y direction LMAT 4 939 Truss Dx 0.00	d Group Editor Segment Editor F.E. Mesh Plot
0 0 FReference Line	Exit

Group Mesh Example 5-17

Step 18: Mouse Snap

Click Mouse-Snap menu in PLOT-2D. Select Snap to Grid in Figure 5.12. Click OK.

Step 19: Add Group

Click Add Group button in Group dialog.

Step 20: Arc Segment

Click Arc Segment button in Line Segment dialog. Fill in input fields for Arc Segment as shown in Figure 5.25. Click Draw.

Enter Origin Xo Yo Finer X and T Enter Radius and Angle Enter Radius and Angle Ry Horizontal Radius : Rx 5 Vertical Radius : Ry 10 Beginning Angle (Deg.) : Qb 60
Rx Finite Product Ry Ry Ry Ry Ry Ry Ry Ry Ry Ry Ry Ry Ry Ry Ry Ry
Enter Radius and Angle Rx Horizontal Radius : Rx F Vertical Radius : Ry Horizontal Radius : Ry H
Rx Horizontal Radius : Rx 5 OB Ry Vertical Radius : Ry 10 OB Ry Beginning Angle (Deg.): Qb 60
Ob Ry Vertical Radius : Ry 10 Oe Pair No Beginning Angle (Deg.) : Qb 60
Beginning Angle (Deg.) : Qb 60
X0,Y0 /
Ending Angle (Deg.) : Qe 60
Note: When Qb = Qe, a straight radial line is drawn from R = Rx to R = Ry. That is, Rx and Ry represent radial distances at angle Q = Qb = Qe.
Divisions and Inclusions
Divisions Inclusions
0 -2: Include beginning & ending point but no splitting
Draw Line Segment Finish Cano





5.1.3 Part 3: Adding Utility Tunnel

Part 3 consists of the following main actions:

- Open the group mesh file in part 2
- Remove the first rock bolt
- Change the second rock bolt length
- Replace the third rock bolt by utility tunnel
- Plot finite element mesh

Step 24: Open Group Mesh File in Part 2

Follow Steps 13 through 15 to open Group dialog for Group No 2.

Step 25: Remove Rock Bolt 1

Select Group No 2 in Group dialog. Click MTYPE button in Group dialog. Select MTYPE=0 in MTYPE dialog in Figure 5.10. Click OK.

Click Update and then Replot buttons in Group dialog. A new plot with the Group No 2 missing is displayed in Figure 5.29



Figure 5.29 Rock Bolt 1 removed on drawing board



5-22 Group Mesh Example



Click OK	TYPE=1 in MTYPE dialog in Figure 5.10.	
ill in inr	aut fields for Group dialog as shown in Figure 5.33	
lick <mark>Edi</mark>	t Group.	•
ſ	Group	
	Group Identity Group No 4 <> Title Utility Tunnel	Edit Group
	MTYPE and Material Parameter	Show Number
	1: Generate lines & remove elements within closed loop	
	MATNO 1 KF 1.00 MATOId 3 MTYPE	cut
	LTP 2 LMAT 2 Add new meth	
	LTPi 2 LMATI 1 Line Options	Update
	LTPo 2 LMATo 2 Color Type Thickness	Save
	Coordinate Constraint	Base Mesh
	Element Activity PI 0T-20 Plot Translation	
	NAC NDAC Mesh Geometry will be moved	Replot
	0 0 I Principal Stress by distance Ux and Dy 0 0 I Deformed Shape in X and Y direction	Segment Editor
	0 0 Beam Dx 0.00	F.E. Mesh Plot
	Contour 0 0 Contour Dy 0.00 -	Close
		Exit

Select Replace All Segments in Edit Segment dialog in Figure 5.34 Click Edit.
Edit Segment Group No: 4 Utility Tunnel Enter Segment Number and Doubleclick Edit Button Modify Segment Modify Segment Edit Finish Cancel
Warning message is displayed as shown in Figure 5.35. Click OK.
You are about to delete geometry data of Current Group and create new geometry !!! OK Cancel
Figure 5.35 Warning message


5-25



Click OK in Exit dialog as in Figure 5.22.

5.2 NATM Tunnel

This example illustrates how to build group meshes for typical NATM (New Austrian Tunneling Method) tunnel.

5.2.1 Overview

The cross section of NATM tunnel consists of rock bolts, shotcrete, reinforced concrete liner, and core as schematically shown in Figure 5.39.



Figure 5.39 Tunnel cross section





5-30 Group Mesh Example

Group	Name	MTYPE	NAC	NDAC	MATNO / LTP / LMAT / IEND
1	Top Soil	3			1 / 0 / 0 / 2
2	Weathered Rock	3			2 / 0 / 0 / 2
3	Soft Rock	3			3 / 0 / 0 / 2
4	Hard Rock	3			4 / 0 / 0 / 2
5	Rock Bolt-1	2	4	999	0 / 3 / 1 / -2
6	Rock Bolt-2	2	4	999	0 / 3 / 1 / -2
7	Rock Bolt-3	2	4	999	0 / 3 / 1 / -2
8	Rock Bolt-4	2	4	999	0 / 3 / 1 / -2
9	Rock Bolt-5	2	4	999	0 / 3 / 1 / -2
10	Rock Bolt-6	2	4	999	0 / 3 / 1 / -2
11	Rock Bolt-7	2	4	999	0 / 3 / 1 / -2
12	Rock Bolt-8	2	4	999	0 / 3 / 1 / -2
13	Rock Bolt-9	2	4	999	0 / 3 / 1 / -2
14	Rock Bolt-10	2	4	999	0 / 3 / 1 / -2
15	Rock Bolt-11	2	4	999	0 / 3 / 1 / -2
16	Tunneling Lining	-2	9	999	MATNOj = 7, LTPi = 0, LTPo = LMATo = 2, IEND = 2
17	Shotcrete Right Lower	2	7	999	0 / 2 / 1 / 3
18	Shotcrete Upper	2	4	999	0/2/1/3
19	Shotcrete Left Lower	2	7	999	0 / 2 / 1 / 3
20	Upper Core	3	0	5	5/0/0/3
21	Lower Core	3	0	8	6/0/0/3

Table 5.5 Group key parameters



5.2.3 Groups

Group meshes are divided into five parts:

- Geological profile
- Rock bolt
- Lining
- Shotcrete
- Core

Final finite element meshes are most influenced by group order and IEND.

5.2.3.1 Geological Profile

In situ geological profile consists of four layers: top soil, weathered rock, soft rock, and hard rock. Table 5.6 lists key parameters of these groups.

6			-			Beginn	ing Point	Endin	g Point	TEND
Group	Profile	MIYPE	Elem.	MATNO	Seg.	х	Y	х	Y	IEND
					1	0	17.24	60	17.24	2
1	Top Soil	3	Cont	1	2	60	17.24	60	21.44	2
					3	60	21.44	0	21.44	2
					4	0	21.44	0	17.24	2
					1	0	12.94	60	12.94	2
2	Weathered	3	Cont	2	2	60	12.94	60	17.24	2
	Rock				3	60	17.24	0	17.24	2
					4	0	17.24	0	12.94	2
					1	0	9.44	60	9.44	2
3	3 Soft Rock	3	Cont	3	2	60	9.44	60	12.94	2
				3	60	12.94	0	12.94	2	
					4	0	12.94	0	9.44	2
					1	0	-30	60	-30	2
4	Hard Rock	3	Cont	4	2	60	-30	60	9.44	2
					3	60	9.44	0	9.44	2
					4	0	9.44	0	-30	2

Table 5.6 Key parameters for geological profile

Group Group Identity Group No 1 <> Title Top Soil MTYPE and Material Parameter Show Number
3: Assign new material number within closed loop MATND KF 1.00 MATOId MTYPE Description LTP LMAT Add new mesh Hide Line Options LTPo LMATo Z Color Type Thickness Save
Coordinate Constraint Generated coordinates are not movable Base Mesh Element Activity PLOT-2D Plot Translation NAC NDAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction MATNO 0 0 Deformed Shape Beam LMAT 0 0 Truss Dx 0.00 0 0 Reference Line Dy 0.00 Exit
Figure 5.43 Group dialog for top soil layer

5-33

5.2.3.2 Rock Bolt

There are eleven rock bolts above the tunnel crown as schematically shown in Figure 5.44. Table 5.7 lists key parameters of these groups.



Figure 5.44 Rock bolt layout

			Orig	in		Radius a	& Angle		
Group	Name	NAC/NDAC	X _o	Y _o	R _x	R _Y	Θ_{b}	Θ _e	MTYPE/LTP/LMAT/IEND
5	Bolt-1	4 / 999	30.866	0.5	4.24	7.24	15	15	2 / 3 / 1 / -2
6	Bolt-2	4 / 999	30	0	5.24	8.24	30	30	2 / 3 / 1 / -2
7	Bolt-3	4 / 999	30	0	5.24	8.24	45	45	2 / 3 / 1 / -2
8	Bolt-4	4 / 999	30	0	5.24	8.24	60	60	2 / 3 / 1 / -2
9	Bolt-5	4 / 999	30	0	5.24	8.24	75	75	2 / 3 / 1 / -2
10	Bolt-6	4 / 999	30	0	5.24	8.24	90	90	2 / 3 / 1 / -2
11	Bolt-7	4 / 999	30	0	5.24	8.24	105	105	2 / 3 / 1 / -2
12	Bolt-8	4 / 999	30	0	5.24	8.24	120	120	2 / 3 / 1 / -2
13	Bolt-9	4 / 999	30	0	5.24	8.24	135	135	2 / 3 / 1 / -2
14	Bolt-10	4 / 999	30	0	5.24	8.24	150	150	2 / 3 / 1 / -2
15	Bolt-11	4 / 999	29.134	0.5	4.24	7.24	165	165	2 / 3 / 1 / -2

Table 5.7 Key parameters for rock bolt

Group No 5 Itle Rock Bolk - 1 Edit Group MTYPE and Material Parameter Show Num 2 Generate lines Image: Constraint MATNO 1 KF 1.00 MATold Image: Constraint Image: Color IP 2 IMAT 1 Add new mesh Hide Update IP 2 IMAT 1 Add new mesh Hide Update IP 2 IMAT 1 Image: Color Type Thickness Save Coordinate Constraint Color Type Thickness Save Coordinate Constraint Generated coordinates are not movable Base Mee IP Plot-2D Plot Translation Replot IMAT 0 0 Plot-2D Plot Translation Replot IMAT 0 0 Defearm Dx 0.00 E.Math IMAT 999 0 Dx 0.00 E.Math Dx 0.00 E.wit IMAT 0 0 D Translation E.wit E.	Group No 5 > Title Rock Bolt - 1 Edit Group MTYPE and Material Parameter 2 Generate lines Show Nu 2: Generate lines Image: Constraint Image: Constraint Image: Coordinate Constraint Image: Coordinates are movable Description LTP 2 LMAT 1 Add new mesh Hide Update LTP 2 LMAT 1 Color Type Thickness Save Coordinate Constraint Generated coordinates are movable Generated coordinates are not movable Base M Element Activity PLOT-2D Plot Translation Replay 0 0 Principal Stress Deformed Shape Beam LMAT 939 0 O Deformed Shape Dx 0.00 LMAT 4 939 0 O Exit Exit Figure 5.45 Group dialog for rock bolt at 15 degreese Exit				
MTYPE and Material Parameter Show Num 2. Generate lines Image: Constraint MATNO1 KF MATNO1 KF LTP LMAT 1 Add new mesh LTP LMAT 2 LMAT 1 Add new mesh LTP LMAT 2 LMAT 1 Add new mesh Hide Update Save Coordinate Constraint Generated coordinates are not movable Base Mee Element Activity PL0T-2D Plot Math Mesh Principal Stress Geometry will be moved by distance Dx and Dy in X and Y direction D D 0 0 LMAT 9393 0 Contour Dx 0.00 Dy 0.00 Exit Exit	MTYPE and Material Parameter Show Nu 2: Generate lines Image: Constraint MATNO1 KFi MATNO1 KFi LTP LMAT 1 Add new mesh LTP LMAT 2 LMAT 1 Add new mesh LTP LMAT 2 LMATO2 Coordinate Constraint Generated coordinates are not movable Base M Element Activity PLOT-2D Plot NAC NDAC 0 0 0 0 0 0 0 0 Regize Geometry will be moved by distance Dx and Dy Regize 0 0 Freese 0 0 Freese </td <td>Group No 5 < ></td> <td>Title Rock Bolt</td> <td>- 1</td> <td>Edit Grou</td>	Group No 5 < >	Title Rock Bolt	- 1	Edit Grou
2 Generate lines MATNO 1 KF 1.00 MATold 3 MTYPE MATNO 1 KF 1.00 THICi 0.10 Description LTP 3 LMAT 1 Add new mesh Hide Update LTP 2 LMAT 1 Add new mesh Hide Update LTP 2 LMATo 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are not movable Base Me Base Me Coordinate Constraint © Generated coordinates are not movable Base Me Element Activity PLOT-2D Plot Translation Replot Deformed Shape Principal Stress Dx 0.00 Segment E LMAT 999 0 Entrus Dx 0.00 Exit LMAT 4 999 0 Entrus Dx 0.00 Exit Figure 5.45 Group dialog for rock bolt at 15 degrees Exit	2: Generate lines MATNO 1 KF 1.00 MATold 3 MTYPE MATNO; 0 KF; 1.00 THIC; 0.10 Description LTP 3 LMAT 1 Add new mesh Hide Update LTP 2 LMAT; 1 Line Options Type Thickness Save Coordinate Constraint © Color Type Thickness Save © Generated coordinates are movable Base M Base M Element Activity PLOT-2D Plot Translation Replot 0 0 0 Plot-2D Plot Translation Replot MAT 0 0 0 Element Activity Replot Segment LMAT 4 939 0 Contour D D Segment LMAT 4 939 Contour D D D Esit Figure 5.45 Group dialog for rock bolt at 15 degrees Esit	MTYPE and Material Parameter	2		Show Num
MATNO 1 KF 1.00 MATold 3 MTYPE MATNO 0 KFi 1.00 THICI 0.10 Description LTP 3 LMAT 1 Add new mesh Hide Update LTP 2 LMAT 1 Add new mesh Hide Update LTP 2 LMATo 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are movable Generated coordinates are movable Base Me Element Activity PLOT-2D Plot Translation Replot Group Edi MAT 0 0 Deformed Shape Datomet Shape Dx 0.00 LMAT 999 0 Entropy Truss Confour Dy 0.00 Exit Confour 0 0 Reference Line Dx 0.00 Exit Figure 5.45 Group dialog for rock bolt at 15 degrees Exit	MATNO 1 KF 1.00 MATOId 3 MTYPE MATNO 0 KFi 1.00 THICI 0.10 Description LTP 3 LMAT 1 Add new mesh Hide Update LTP 3 LMAT 1 Add new mesh Hide Update LTP 2 LMATo 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are not would and the save Base M Base M Element Activity PLOT-2D Plot Translation Repla 0 0 0 Deformed Shape Base M Base M LMAT 4 939 Translation Repla Group E 0 0 0 Exit Deformed Shape Exit UMAT 4 939 0 0 O O Deformed Shape Deformed Shape E	2: Generate lines		•	
LTP 3 LMAT 1 Add new mesh Hide Update LTP 2 LMATi 1 Line Options Update LTPo 2 LMATo 2 Coordinate Save Coordinate Constraint © Generated coordinates are not movable Base Mer Coordinate Constraint © Generated coordinates are not movable Base Mer Element Activity PLOT-2D Plot Translation Replot O O O Deformed Shape Base LMAT 4 939 O Principal Stress Dx 0.00 LMAT 4 939 O Principal Stress Dx 0.00 E.E. Mesh Dx 0.00 Principal Stress Dx 0.00 E.E. Mesh Dy 0.00 P.E. Mesh Dy 0.00 E.X.	LTP 3 LMAT 1 Add new mesh Hide Update LTPi 2 LMATi 1 Line Options Update Update Save Coordinate Constraint Coordinate Constraint Coordinates are movable Base M Base M Coordinate Constraint © Generated coordinates are not movable Base M Element Activity PLOT-2D Plot Translation Replet 0 0 0 Deformed Shape Beam Dx 0.00 Esem Dx 0.00 LMAT 939 0 Entropy of the entropy o	MATNO 1 KF MATNOI 0 KFi	1.00 MATold 3	MTYPE Description	
LTPi 2 LMATi 1 Line Options Update LIPo 2 LMATo 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are not movable Base Me Base Me © Generated coordinates are movable © Generated coordinates are not movable Base Me Element Activity PLOT-2D Plot Translation Replot O O O Deformed Shape Deformed Shape Dx 0.00 LMAT 4 939 O Truss Contour Dy 0.00 E.Mesh UMAT 0 0 O Reference Line Dx 0.00 E.Xit Figure 5.45 Group dialog for rock bolt at 15 degrees Figures Segment E Exit	LTPi 2 LMATi 1 Line Options Update LTPo 2 LMATo 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are not movable Base M Element Activity PLOT-2D Plot Translation Replace NAC NDAC Mesh Geometry will be moved by lottance Dx and Dy in X and Y direction Replace LMAT 4 939 O Deformed Shape Dx 0.00 Exit LMAT 4 939 O O Deformed Shape Dx 0.00 Exit Contour Reference Line Dy 0.00 Exit Exit	LTP 3 LMAT	1 Add nev	v mesh THide	<u> </u>
Clove 2 Coold Type Interteess Save Coordinate Constraint	Close Type Thickness Save Coordinate Constraint © Generated coordinates are movable Base M Element Activity PLOT-2D Plot Translation Replation Max 0 0 Principal Stress Geometry will be moved by distance Dx and Dy in X and Y direction Replation LMAT 0 0 Perioripal Stress Dx 0.00 Estimate Deformed Shape Beam Truss Coordinates Estimate Estimate Max 0.00 0 Estimate Dy 0.00 Estimate F.E. Mest Dy 0.00 Estimate Estimate Estimate Figure 5.45 Group dialog for rock bolt at 15 degrees Estimate	LTPi 2 LMATi	1 Line Opti	ions	Update
Coordinate Constraint Generated coordinates are movable Base Mei Element Activity PLOT-2D Plot Translation Geometry will be moved by distance Dx and Dy in X and Y direction Deformed Shape Deformed Shape Dx 0.00 Dx 0.00 Exit F.E. Mesh Dy 0.00 Exit 	Coordinate Constraint Generated coordinates are not movable Base M Element Activity PLOT-2D Plot Mesh Principal Stress Deformed Shape Detorned Shape Dx 0.00 F.E. Mest Contour Dy 0.00 Figure 5.45 Group dialog for rock bolt at 15 degrees				Save
Element Activity PLOT-2D Plot Translation Replot 0 0 Mesh Geometry will be moved by distance Dx and Dy in X and Y direction Segment E LMAT 939 0 Truss Dx 0.00 F.E. Mesh 0 0 0 Reference Line Dx 0.00 Exit	Element Activity PL07-2D Plot Geometry will be moved by distance Dx and Dy in X and Y direction 0 0 Deformed Shape Deformed Shape LMAT 4 999 0 Deformed Shape 0 0 0 Deformed Shape Dx 0.00 0 0 0 Deformed Shape Dx 0.00 Esem 0 0 0 0 Deformed Shape Dx 0.00 Esem 0 0 0 0 Dx 0.00 Dy 0.00 Eset 0 0 0 0 Dy 0.00 Eset Eset Figure 5.45 Group dialog for rock bolt at 15 degrees Group dialog for rock bolt at 15 degrees	 Coordinate Constraint Generated coordinates are r 	novable C Generated coo	ordinates are not movable	Base Mes
NAC NDAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction 0 0 0 Deformed Shape Dx 0.00 0 0 0 Truss Dx 0.00 F.E. Mesh 0 0 0 Reference Line Dx 0.00 Exit	NAC NAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction 0 0 Deformed Shape Deformed Shape Dx 0.00 LMAT 4 939 Contour Dx 0.00 F.E. Mest Contour Reference Line Dy 0.00 Exit	Element Activity	PLOT-2D Plot	Translation	Benlot
Image: Definition of the second state of the second sta	Image: Definition of the second state of the second sta	NAC NDAC	☐ Mesh ☐ Principal Stress	Geometry will be moved by distance Dx and Dy	Group Edit
LMAT 0	LMAT 0		Deformed Shape	in X and Y direction	Segment Ec
Figure 5.45 Group dialog for rock bolt at 15 degrees	Figure 5.45 Group dialog for rock bolt at 15 degrees	LMAT 4 999	Truss	Dx 0.00	F.E. Mesh F
Figure 5.45 Group dialog for rock bolt at 15 degrees	Figure 5.45 Group dialog for rock bolt at 15 degrees			Dy 0.00	Exit
Figure 5.45 Group dialog for rock bolt at 15 degrees	Figure 5.45 Group dialog for rock bolt at 15 degrees				
Figure 5.45 Group dialog for rock bolt at 15 degrees	Figure 5.45 Group dialog for rock bolt at 15 degrees				
		Figure 5.45	Group dialog fo	or rock bolt at 15 (degrees

5.2.3.3 Lining

Lining is the reinforced concrete liner which is modeled by beam elements. Seven segments are used to model lining as shown in Figure 5.46. The interface between lining and shotcrete is modeled by joint element as shown in Figure 5.47. It should be noted that MTYPE = -2 in this group includes both lining and joint elements.



Table 5.8 lists key parameters of this group.

	Element Type	Material No	Element	Activity
		- Action at the	NAC	NDAC
Interface	Joint	MATNOj = 7	9	999
Lining	Beam (LTPo = 2)	LMATo = 2	9	999

				Ori	gin		Radius	& Angle		
Group	Name	MTYPE	Seg.	X _o	Y _o	R _X	R _Y	Θ_{b}	Θ _e	IEND
			1	30	20.59	23.86	23.86	270	280.94	2
			2	25.25	0.5	9.86	9.86	-19.78	0	2
16	Tunnel Lining	-2	3	30.866	0.5	4.24	4.24	0	30	2
			4	30	0	5.24	5.24	30	150	2
			5	29.134	0.5	4.24	4.24	150	180	2
			6	34.75	0.5	9.86	9.86	-180	-160.22	2
			7	30	20.59	23.86	23.86	259.06	270	2

Table 5.8 Key parameters for lining and joint elements

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Group No 16 Title Tunnel Lining Edit Group MTYPE and Material Parameter Show Number Show Number -2: Generate slip lines with joint elements Image: Show Number Image: Show Number MATNO 1 KF 1.00 MATold 3 MTYPE MATNO 1 KF 1.00 MATold 3 MTYPE MATNO 7 KFi 1.00 THICi 0.10 Description LTP 2 LMAT 1 Add new mesh Hide Update LTPo 2 LMATo 2 Color Type Thickness Save Coordinate Constraint Generated coordinates are not movable Base Mesh Base Mesh Element Activity PLOT-2D Plot Translation Description Description
MTYPE and Material Parameter -2: Generate slip lines with joint elements MATNO 1 KF 1.00 MATold 3 MTYPE MATNO 1 KF 1.00 MATold 3 MTYPE MATNO 7 KFi 1.00 THICi 0.10 Description LTP 2 LMAT 1 Add new mesh Hide Update LTPo 2 LMATo 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are not movable Base Mesh Base Mesh Element Activity PLOT-2D Plot Translation Detail Detail
LTPi 0 LMATi 1 Line Options Update LTPo 2 LMATo 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are movable © Generated coordinates are not movable Base Mesh
Coordinate Constraint Generated coordinates are movable C Generated coordinates are not movable Base Mesh Element Activity PLOT-2D Plot Translation
Element Activity PLOT-2D Plot
NAC NDAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction Heplot 0 0 Principal Stress by distance Dx and Dy in X and Y direction Group Editor MATNOI 9 999 Beam Dx 0.00 0 0 Truss Dx 0.00 F.E. Mesh Plot LMATi 0 0 Contour Dy 0.00 LMATo 9 999 Reference Line Exit

5.2.3.4 Shotcrete

Shotcrete is applied to upper tunnel wall right after excavation of upper core and lower tunnel walls right after excavation of lower core as shown in Figure 5.49. But shotcrete is not applied at tunnel invert. Table 5.9 lists key parameters of these groups.

Figure 5.49 Shotcrete cross section



	Troup Name				Element	Activity
Group	Name	MIYPE	LIP	LMAT	NAC	NDAC
17	Shotcrete: Right Lower	2	2	1	7	999
18	Shotcrete: Upper	2	2	1	4	999
19	Shotcrete: Left Lower	2	2	1	7	999

				Origi	n		Radius	& Angle		
Group	oup Name		Seg	X _o	Yo	R _x	R _Y	Θ_{b}	Θ _e	IEND
17	Shotcrete Right Lower	2	1	25.25	0.5	9.86	9.86	-19.78	0	3
			1	30.866	0.5	4.24	4.24	0	30	3
18	Shotcrete Upper	2	2	30	0	5.24	5.24	30	150	3
			3	29.134	0.5	4.24	4.24	150	180	3
19	Shotcrete Left Lower	2	1	34.75	0.5	9.86	9.86	-180	-160.22	3

Table 5.9 Key parameters for shotcrete elements

5-40 Group Mesh Example

Group Identity Group Identity Edit Group MTYPE and Material Parameter Image: Show Numeric Parameter Image: Show Numeric Parameter 2: Generate lines Image: Show Numeric Parameter Image: Show Numeric Parameter Image: No 1 KF 1.00 MATold 3 Image: Material Parameter Image: No 1 KF 1.00 MATold 3 Image: Material Parameter Image: No 1 KF 1.00 MATold 3 Image: Material Parameter Image: No 1 KF 1.00 MATold 3 Image: Material Parameter Image: No 1 KF 1.00 MATold 3 Image: Material Parameter Image: No 1 KF 1.00 MATold 3 Image: Material Parameter Update Image: Image: No 2 Image:	Group No 18 ∑ Title Shotcrete Upper Edit Group MTYPE and Material Parameter ∑ Show Num Show Num 2: Generate lines ▼ ▼ Image: Show Num Show Num MATNO 1 KF 1.00 MATod 3 MTYPE Show Num LTP Z LMAT 1 Add new mesh Hide Update LTP Z LMAT 1 Add new mesh Hide Update LTP Z LMAT 1 Color Type Thickness Save Coordinate Constraint © Generated coordinates are moreable Base Mest Base Mest Element Activity PLOT-20 Plot Translation Replat Group Edit LMAT 4 939 Deformed Shape Deformed Shape Dx 0.00 Est LMAT 4 939 Control Reference Line Dx 0.00 Est Figure 5.50 Group dialog for upper shotcrete Est Est	Group Identity Group No 18 Title Shocknete Upper Edk Group MTYPE and Material Parameter Image: Shocknete Upper Shock Num 2 Generate lines Image: Shocknete Upper Shock Num MATNO 1 KF 1.00 MATods 3 MTYPE MATNO 0 KF 1.00 MATods 3 MTYPE LTP 2 LMAT 1 Add new mesh Hide Update LTP 2 LMAT 1 Add new mesh Hide Update LTP 2 LMAT 0 2 Color Type Thickness Save Coordinate Constraint Generated coordinates are movable Base Mesh Base Mesh Base Mesh LMAT 0 0 Phot-20 Plot Translation Replat Deformed Shape Deformed Shape Dx 0.00 Segment Eigend LMAT 4 939 Comour Reference Line Dx 0.00 Eigend FE Mesh 0 0 Comour Reference Line Eigend Eigend Fi	Group Identity Group No 18 Trite Shotcrete Upper Edit Group MTYPE and Material Parameter 2 Generate lines Image: Constraint of the co	Group	
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Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete	0 0 Eeam Dx 0.00	F.E. Mesh F
Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete		Close
Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete		Exit
Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete	Figure 5.50 Group dialog for upper shotcrete	0 0 □ □ Contour Dy 0.00	Clos
				Figure 5.50 Group dialog for upper shot	crete

5.2.3.5 Core

Core is divided into upper and lower parts as in Figure 5.46 considering the order of excavation. Table 5.10 lists key parameters of these groups.

			_		Element	Activity
Group	Name	MTYPE	Element	ΜΑΤΝΟ	NAC	NDAC
20	Upper Core	3	Cont.	5	0	5
21	Lower Core	3	Cont.	6	0	8

			Line Se	egment				Arc S	Segmen	t		
Group	Seg	Beginnii	ng Pt.	Ending	g Pt.	Orig	jin		Radiu	s & Angle	e	IEND
		х	Y	х	Y	X _o	Yo	R _X	R _Y	Θ_{b}	Θ _e	
	1	24.894	0.5	35.106	0.5							3
20	2					30.866	0.5	4.24	4.24	0	30	3
	3					30	0	5.24	5.24	30	150	3
	4					29.134	0.5	4.24	4.24	150	180	3
	1					30	20.59	23.86	23.86	259.06	280.94	3
21	2					25.25	0.5	9.86	9.86	-19.78	0	3
	3	35.106	0.5	24.894	0.5							3
	4					34.75	0.5	9.86	9.86	-180	-160.22	3

Table 5.10 Key parameters for core elements

5-42 Group Mesh Example

Group No 20 Title Upper Core Edit Group MTYPE and Material Parameter Show Number Show Number MATNO 5 KF 1.00 MATod THC Description I -> 2 MATNO 6 KF 1.00 MATod Image: Color Type Thickness Save MATNO 6 KF 1.00 MATod Image: Color Type Thickness Save Coordinate Constraint Color Type Thickness Save Coordinate Constraint Generated coordinates are not movable Base Mesh Element Activity PLOT-2D Plot Translation Replot MATNO 0 5 Deformed Shape Deformed Shape Deformed Shape LMAT 0 0 Eleference Line Dx 0.00 Exit Figure 5.51 Group dialog for upper core Exit	Group		
MTYPE and Material Parameter Show Number 3. Assign new material number within closed loop Image: Coordinate Constraint MATNO KFF 1.00 TP LMAT O Add new mesh Hide Update Save Coordinate Constraint Color Generated coordinates are movable Generated coordinates are not movable NAC NDAC NAC NDAC NAC NDAC NATNO O Segment Edite Beam Truss Deformed Shape Beam Dx 0.00 Truss Contour Reference Line Dy 0.00 Exit	Group No 20 <> Title	Upper Core	Edit Group
3 Assign new material number within closed loop MATNO 5 KF 1.00 MATold 3 MTYPE MATNO 5 KF 1.00 THICI 0.10 Description LTP 0 LMAT 0 Add new mesh Hide Update LTP 2 LMAT 1 Line Options Type Thickness Save Coordinate Constraint © Generated coordinates are not movable Base Mesh Element Activity PLOT-2D Plot Translation Replot MATNO 0 5 Deformed Shape Deformed Shape MATNO 0 0 Element Constraint Element Constraint MATNO 0 0 Deformed Shape Deformed Shape Deformed Shape MATNO 0 0 Element Constraint Element Constraint Element Constraint Element Activity Element Activity Replot MATNO 0 0 0 Element Activity PLOT-2D Plot Translation Replot Deformed Shape Deformed Shape Deformed Shape	MTYPE and Material Parameter		Show Numbe
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LTN 0 Add new mesh Hide LTPi 2 LMATi 1 Line Options LTPo 2 LMATo 2 Color Type Coordinate Constraint © Generated coordinates are not movable Base Mesh Element Activity PLOT-2D Plot Translation Replot MATNO 0 5 Deformed Shape Base LMAT 0 0 Truss Dx 0.00 LMAT 0 0 Element Cline Element Cline Element Cline	MATNO 5 KF 1.00 MATO MATNO; 0 KF; 1.00 THIC LTP 0 LMAT 0	old 3	MTYPE escription 1-> 2
LTP0 2 LMAT0 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are movable Base Mesh © Generated coordinates are movable PLOT-2D Plot Base Mesh NAC NAC NAC PLOT-2D Plot Geometry will be moved by distance Dx and Dy in X and Y direction Replot MATND 0 0 0 Deformed Shape Dx 0.00 Segment Editor LMAT 0 0 0 Reference Line Dx 0.00 Exit	LTPi 2 LMATi 1	Add new mesh	fide Update
Coordinate Constraint Generated coordinates are movable Element Activity NAC NAT NAT<!--</td--><td>LTPO 2 LMATO 2</td><td>Color Type T</td><td>hickness</td>	LTPO 2 LMATO 2	Color Type T	hickness
Generated coordinates are movable C Generated coordinates are not movable Deformed Shape NAT NO 0 0 0 LMAT 0 0 0 Figure 5.51 Group dialog for upper core	Coordinate Constraint		Rase Mesh
Element Activity PLU1-2D Plot Instation Replot MATNO 0 0 Geometry will be moved by distance Dx and Dy in X and Y direction Segment Edit MATNO 0 0 0 Deformed Shape Dx 0.00 LMAT 0 0 0 Contour Dx 0.00 Exit Contour Reference Line Dy 0.00 Exit Exit	Generated coordinates are movable C	Generated coordinates are not mov	able Dase mesti
MATND 0 0 0 by distance Dx and Dy in X and Y direction by distance Dx and Dy in X and Y direction LMAT 0 0 0 0 0 F.E. Mesh Pk Dx 0.00 0 0 0 0 Close Dy 0.00 0 Exit Exit	NAC NDAC Mesh	Plot I ranslation Geometry wil	be moved Replot
LMAT 0 0 0 F.E. Mesh Pk 0 0 0 0 0 F.E. Mesh Pk Close Contour Dy 0.00 Exit Figure 5.51 Group dialog for upper core	0 0 Princip MATNO 0 5 Deforr	bal Stress by distance [med Shape in X and Y di	vx and Dy Group Editor rection Segment Editor
Figure 5.51 Group dialog for upper core		Dx 0.00	F.E. Mesh Plo
Figure 5.51 Group dialog for upper core		ur Dy 0.00	Close
Figure 5.51 Group dialog for upper core			Exit
	Figure 5.51 C	Group dialog for up	oper core



5.3 Excavation

This example illustrates how to build group meshes for typical multi-step excavations performed near the existing box structure.

5.3.1 Overview

The cross section of this excavation problem consists of box structure, SCE-wall, anchors, and excavation zones as shown in Figure 5.54.

Cross section near the box structure is shown in detail in Figure 5.55.







Table 5.12 summarizes key parameters of groups.

Group	Name	MTYPE	NAC	NDAC	MATNO / LTP / LMAT / IEND
1	Fill	3	0	0	1/0/0/2
2	Silty-Sand	3	0	0	2 / 0 / 0 / 2
3	Sand-Gravel	3	0	0	3 / 0 / 0 / 2
4	Box Frame	2	3	999	0 / 2 / 2 / 2
5	Box Column	2	3	999	0 / 2 / 3 / 2
6	Box Excavation	3	0	3	0/0/0/3
7	SCE-Wall	2	4	999	0 / 2 / 1 / 2
8	Excavation-1	3	0	4	0/0/0/2
9	Excavation-2	3	0	6	0/0/0/2
10	Excavation-3	3	0	8	0/0/0/2
11	Excavation-4	3	0	10	0/0/0/2
12	Anchor-1 Free	2	5	999	0/3/1/0
13	Anchor-1 Fixed	2	5	999	0 / 3 / 2 / -2
14	Anchor-2 Free	2	7	999	0 / 3 / 3 / 0
15	Anchor-2 Fixed	2	7	999	0 / 3 / 4 / -2
16	Anchor-3 Free	2	9	999	0/3/5/0
17	Anchor-3 Fixed	2	9	999	0/3/6/-2

Table 5.12 Group key parameters



5.3.3 Groups

Group meshes are divided into five parts:

- Geological profile
- Box structure
- SCE-Wall
- Excavation
- Anchor

It should be noted that the final finite element meshes are most influenced by group order and IEND.

5.3.3.1 Geological Profile

In situ geological profile consists of three layers: fill, silty-sand, and sandgravel. Table 5.13 lists key parameters of these groups

				ΜΑΤΝΟ	_	Beginn	ing Point	Endin	g Point	
Group	Profile	MTYPE	Elem.	MATNO	Seg.	х	Y	х	Y	IEND
					1	-45	9.3	40	9.3	2
1	Fill	3	Cont	1	2	40	9.3	40	12.5	2
					3	40	12.5	-45	12.5	2
					4	-40	12.5	-45	9.3	2
					1	-45	1	40	1	2
2	Silty-Sand	3	Cont	2	2	40	1	40	9.3	2
					3	40	9.3	-45	9.3	2
					4	-45	9.3	-45	1	2
					1	-45	-20	40	-20	2
3	Sand-Gravel	3	Cont	3	2	40	-20	40	1	2
					3	40	1	-45	1	2
					4	-45	1	-45	-20	2

Table 5.13 Key parameters for geological profile

Image: Strategy of the strategy	MTYPE and Material Parameter Sho 3. Assign new material number within closed loop Image: Constraint of the second sec
MIYPE and Material Parameter 3: Assign new material number within closed loop MATNO KF MATNO KF IP LMAT Coordinate Constraint Generated coordinates are movable Carrier Generated coordinates are movable Base Me MATNO PLOT-2D Plot Image: Principal Stress Replot Generated coordinates are movable Base Me MATNO O MATNO O MATNO O MATNO O NAC NAC NAC NAC NAC O MATNO O Deformed Shape Dx Beam Dx Dy 0.00 D O D O D O D	M1YPE_and Material Parameter 3: Assign new material number within closed loop MATN0 1 KF 1.00 MATold 3 MTYPE MATN0 0 KFi 1.00 THICi 0.10 Description 1 LTP 0 LMAT 0 Add new mesh Hide L LTP 2 LMATi 1 Line Options L LTPo 2 LMATo 2 Color Type Thickness Coordinate Constraint © Generated coordinates are movable © Ba Element Activity PLOT-2D Plot Translation Gro MATNO 0 0 Principal Stress Deformed Shape Dx 0.00 F.E. LMAT 0 0 0 Reference Line Dx 0.00 F.E.
MATNO 1 KF 1.00 MATod 3 MTYPE MATNO 0 KFi 1.00 THICI 0.10 Description LTP 0 LMAT 0 Add new mesh Hide Update LTP 0 LMAT 0 Add new mesh Hide Update LTP 2 LMATo 2 Coordinate Color Type Thickness Save Coordinate Constraint 0 0 Generated coordinates are not would be Base Me Element Activity PLOT-2D Plot Translation Replot Group Ed MATNO 0 0 Deformed Shape Deformed Shape Data Odd Segment E LMAT 0 0 0 Truss Dy 0.00 Exit FE.Mesh D odd Reference Line Dx 0.00 Exit Figure 5.59 Group dialog for top fill Exit	MATNO 1 KF 1.00 MATold 3 MTYPE MATNO 0 KFi 1.00 THICi 0.10 Description 1 LTP 0 LMAT 0 Add new mesh Hide L LTP 0 LMAT 0 Add new mesh Hide L LTP 2 LMATo 2 Color Type Thickness Coordinate Constraint © Generated coordinates are not movable Ba Celement Activity PLOT-2D Plot Translation Image: Segee MATNO 0 0 Deformed Shape Dx 0.00 Segee LMAT 0 0 Element Constraint Dx 0.00 F.E. Data 0 0 Element Shape Dx 0.00 F.E. Data 0 0 Element Charle Dx 0.00 F.E. Dy 0.00 Element Charle Dy 0.00 F.E.
MATNO; 0 KFi 1.00 THIG: 0.10 Description LTP 0 LMAT 0 Add new mesh Hide Update LTP: 2 LMAT 1 Line Options Update LTP: 2 LMAT 2 Color Type Thickness Coordinate Constraint © Generated coordinates are movable Base Me Coordinate Constraint © Generated coordinates are not movable Base Me MATNO 0 0 PhOT-2D Plot Translation Replot MATNO 0 0 Principal Stress Deformed Shape Dx 0.00 Eff. Mesh LMAT 0 0 0 Truss Dy 0.00 Eff. Mesh Corrour Reference Line Dx 0.00 Exit	MATNOI 0 KFi 1.00 THICI 0.10 Description LTP 0 LMAT 0 Add new mesh Hide LTP 2 LMAT 1 Line Options Line LTPo 2 LMATo 2 Color Type Thickness Coordinate Constraint © Generated coordinates are not movable Ba Coordinate Constraint © Generated coordinates are not movable Ba Element Activity PLOT-2D Plot Translation Image: Coordinate Shape Image: Contour Image: Contour Image: Contour Image: Contour LMAT 0 0 Image: Contour Dx 0.00 F.E. Dy 0.00 Image: Contour
LTP 0 LMAT 0 Add new mesh Hide Update LTPi 2 LMATi 1 Line Options Update LTPo 2 LMATo 2 Color Type Thickness Coordinate Constraint © Color Type Thickness Save Coordinate Constraint © Generated coordinates are movable Base Me Element Activity PLOT-2D Plot Translation Replot MATND 0 0 Deformed Shape Beam Bream LMAT 0 0 Element Activity Dx 0.00 Esegment E LMAT 0 0 Deformed Shape Dx 0.00 Esem LMAT 0 0 Contour Dy 0.00 Exit Close Exit Exit Exit Figure 5.59 Group dialog for top fill Exit	LTP 0 LMAT 0 Add new mesh Hide LTPi 2 LMATi 1 Line Options Line Options LTPo 2 LMATo 2 Color Type Thickness Coordinate Constraint © Generated coordinates are movable Ba Element Activity PLOT-2D Plot Translation I MATND 0 0 Principal Stress Dx distance Dx and Dy in X and Y direction Segr LMAT 0 0 Truss Dy 0.00 F.E. Dy 0.00 Segr
LTPi 2 LMATi 1 Line Options Update LTPo 2 LMATo 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are not movable Base Me Element Activity PLOT-2D Plot Translation Replot MATNO 0 0 Principal Stress Deformed Shape Dx 0.00 LMAT 0 0 Element Contour Dx 0.00 Exit FE. Mesh Contour Reference Line Dx 0.00 Exit	LTPi 2 LMATi 1 Line Options LTPo 2 LMATo 2 Color Type Thickness Coordinate Constraint © Generated coordinates are movable © Ba Coordinate Constraint © Generated coordinates are not movable Ba Element Activity PLOT-2D Plot Translation MATND 0 0 Principal Stress Geometry will be moved by distance Dx and Dy in X and Y direction MATND 0 0 Truss Dx 0.00 F.E. LMAT 0 0 © Truss Dy 0.00 F.E. Dy 0.00 0 © Reference Line Dy 0.00 E.E.
Coordinate Constraint Generated coordinates are movable Base Me © Generated coordinates are movable PLOT-2D Plot Translation Replot MATND 0 0 Principal Stress Deformed Shape Beam Tx and Y direction Replot LMAT 0 0 0 Contour Dx 0.00 Exit Figure 5.59 Group dialog for top fill Group fill	Coordinate Constraint Coordinates Constraint • Generated coordinates are movable • Generated coordinates are not movable Element Activity PLOT-2D Plot Translation MATND 0 0 Det Det Det Det Det Det Det
Coordinate Constraint Generated coordinates are not movable Base Me Element Activity PL0T-2D Plot Translation Replot MATNO 0 0 Principal Stress Geometry will be moved by distance Dx and Dy in X and Y direction Replot LMAT 0 0 0 Deformed Shape Dx 0.00 F.E. Mesh Contour Contour Reference Line Dy 0.00 Exit Figure 5.59 Group dialog for top fill Figure 5.59 Group dialog for top fill	Coordinate Constraint
Element Activity PLOT-2D Plot Translation Replot MAT NO 0 0 Frincipal Stress Deformed Shape Deformed Shape Dx 0.00 FE. Mesh LMAT 0 0 0 Frincipal Stress Dx 0.00 EF. Mesh Contour Contour Contour Reference Line Dx 0.00 Exit	Element Activity PLOT-2D Plot Image: Second se
Image: Principal Stress Principal Stress Principal Stress Beam LMAT 0 0 Fransadon Beam Contour Contour Data Deformed Shape Dx 0.00 Deformed Shape Deformed Shape Dx 0.00 E.M.Adv direction Dx 0.00 Deformed Shape Deformed Shape Dx 0.00 Dx 0.00 E.M.Adv direction Data Contour Contour Dy 0.00 E.xit Discourd Figure 5.59 Group dialog for top fill Group fill	NAC NDAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction MATNO 0 0 Deformed Shape LMAT 0 0 Truss 0 0 Truss Dx 0 0 F.E. 0 0 Reference Line
MATNO 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0 Frincipal Stress by distance Dx and Dy in X and Y direction Group MATNO 0 0 Deformed Shape in X and Y direction Segr MATNO 0 0 Truss Dx 0.00 F.E. UMAT 0 0 Contour Dy 0.00 F.E. 0 0 Reference Line Dy 0.00 Image: Contour Dy Dy
LMAT 0	Image: Construction of the state o
LMAT 0 0 0 Truss Dy 0.00 Close 0 0 0 Feference Line Dy 0.00 Exit Figure 5.59 Group dialog for top fill	LMAT 0 0 □ Truss 0 0 □
Figure 5.59 Group dialog for top fill	0 0 Reference Line
Figure 5.59 Group dialog for top fill	
Figure 5.59 Group dialog for top fill	
Figure 5.59 Group dialog for top fill	
	Figure 5.59 Group dialog for top fill

5.3.3.2 Box Structure

Box structure consists of frame, column, and excavation as schematically shown in Figure 5.56. Table 5.14 lists key parameters of these groups.

Group	Name	МТҮРЕ	LTP	LMAT	Element Activity		Seg	Begir Po	nning int	Enc Po	ling int	IEND
					NAC	NDAC		x	Y	х	Y	
							1	4.26	8.12	11.56	8.12	2
							2	11.56	8.12	11.56	11	2
4	Frame	2	2	2	3	999	3	11.56	11	6.06	11	2
							4	6.06	11	6.06	12.5	2
							5	6.06	12.5	4.26	12.5	2
							6	4.26	12.5	4.26	8.12	2
5	Column	2	2	3	3	999	1	8.26	11	8.26	8.12	2

Group	Name	MTYPE	Elem	MATNO	Ele Act	ment tivity	Seg	Begir Po	nning int	End Po	ling int	IEND
					NAC	NDAC		х	Y	х	Y	
							1	4.26	8.12	11.56	8.12	2
							2	11.56	8.12	11.56	11	2
6	Excavation	3	Cont	0	0	3	3	11.56	11	6.06	11	2
							4	6.06	11	6.06	12.5	2
							5	6.06	12.5	4.26	12.5	2
							6	4.26	12.5	4.26	8.12	2

Table 5.14 Key parameters for box structure

Group No 4 Ittle Box Frame Edit C MTYPE and Material Parameter Show N 2. Generate lines Ittle MATold MTYPE MATNO 1 KF 1.00 MATold MTYPE MATNO 1 KF 1.00 MATold MTYPE MATNO 0 KFi 1.00 MATold MTYPE MATNO 0 KFi 1.00 MATold MTYPE LTP 2 LMAT 2 Add new mesh Hide Upd LTP 2 LMAT 2 Color Type Thickness Sar Coordinate Constraint © Generated coordinates are movable Base I Element Activity PLOT-2D Plot Translation Ber NAC NAC NAC Photopal Stress Group in X-and Y direction Screener 0 0 0 0 D Deformed Shape Screener
MTYPE and Material Parameter Show N 2: Generate lines Image: Constraint for the constrain
2: Generate lines Image: Constraint MATNO 1 KF 1:00 KFi 1:00 ITP 2 Image: Constraint Image: Coordinate Constraint Image: Coordinates are movable Image: Coordinates are not movable Element Activity PLOT-2D Plot Translation Rep Image: Coordinate Constraint Image: Coordinates are not movable Rep Image: Coordinate Constraint Image: Coordinates are not movable Rep Image: Coordinate Constraint Image: Coordinates are not movable Rep Image: Coordinate Constraint Image: Coordinates are not movable Rep Image: Coordinate Constraint Image: Coordinates are not movable Rep Image: Coordinate Constraint Image: Coordinates are not movable Rep Image: Coordinate Constraint Image: Coordinates are not movable Rep Image: Coordinate Constraint Image: Coordinates are not movable Rep Image: Coordinate Constraint Image: Coordinates are not movable Rep Image: Coordinate Constraint Image: Coordinates are not movable Rep Image: Coordinate Coordinates are not movable Image: Coordinates are n
LTPo 2 LMATo 2 Color Type Thickness Sa Coordinate Constraint Image: Coordinate Constraint Image: Coordinates are not movable Image: Coordinates
Coordinate Constraint Basel Image: Coordinates are movable C Generated coordinates are not movable Element Activity PL0T-2D Plot Image: NAC NDAC Image: Optimized Stress Geometry will be moved Image: Optimized Stress Image: Optimized Stress
Element Activity PLOT-2D Plot Translation Reg NAC NDAC Mesh Geometry will be moved Broup 0 0 Principal Stress by distance Dx and Dy Group 0 0 Deformed Share in X and Y direction Searce
LMAT 3 999 Truss Dx 0.00 F.E. Me 0 0 0 Contour Dy 0.00 Es

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Group Identity Group No 6 ≥ Title Box Excavation Edit Group MTYPE and Material Parameter 3. Assign new material number within closed loop Image: Close of the second s	Group	
MTYPE and Material Parameter Show Number 3. Assign new material number within closed loop Image: Coordinate within closed loop MATNO KF 1.00 MATNO Cordinate constraint Update Save Save Save Coordinate Constraint Generated coordinates are movable Base Mesh NAC NDAC PloT-2D Plot Translation NAT NO 0 0 Perioreal Stress Deformed Shape Beam Contour NX 0.00 F.E. Mesh Plot Dy UMAT 0 0 Contour Reference Line Dx 0.00 Exit Figure 5.61 Group dialog for box excavation Exit	Group Identity Group No 6 <> Title Box Excavation	Edit Group
3 Assign new material number within closed loop MATNO KF 1.00 MATodd 3 MTYPE MATNO KF 1.00 MATodd 3 MTYPE LTP UMAT Add new mesh Hide Update LTP UMAT Add new mesh Hide Update LTP UMAT Coordinate Constraint Coordinate Constraint Save Coordinate Constraint Generated coordinates are movable Generated coordinates are movable Base Mesh MATNO 0 0 Frincipal Stress Deformed Shape Beam MATNO 0 0 Contour Dx 0.00 F.E. Mesh Plad LMAT 0 0 Contour Reference Line Dy 0.00 Eskt	MTYPE and Material Parameter	Show Number
MATNO 0 KF 1.00 MATodd 3 MTYPE MATNO 0 KF 1.00 THICI 0.10 Description 1->2 LTP 0 LMAT 0 Add new mesh Hide Update LTP 2 LMATO 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are not movable Base Mesh Base Mesh Element Activity PLOT-2D Plot Translation Replot Group Editor MATNO 0 0 0 Deformed Shape Dx 0.00 F.E. Mesh Plot MATNO 0 0 0 Principal Stress Dx 0.00 F.E. Mesh Plot Segment Editor MATNO 0 0 0 Reference Line Dx 0.00 E.sit LMAT 0 0 0 Exit Exit Exit Figure 5.61 Group dialog for box excavation Exit Exit	3: Assign new material number within closed loop	
LTP UMAT Image: Constraint for the constraint for the constraint for Generated coordinates are movable Update Coordinate Constraint for Generated coordinates are movable Generated coordinates are movable Base Mesh Matro 0 0 0 Floor 2 Plot Floor 2 Plot Element Activity PLOT-2D Plot Geometry will be moved by distance Dx and Dy in X and Y direction Replot MATND 0 0 0 Deformed Shape Dx 0.00 E.E. Mesh Plot LMAT 0 0 0 Contour Dy 0.00 E.E. Mesh Plot LMAT 0 0 0 E.E. Mesh Plot Dy 0.00 E.E. Mesh Plot LMAT 0 0 0 E.E. Mesh Plot Dy 0.00 E.E. Mesh Plot Dy 0.00 0 E.E. Mesh Plot Dy 0.00 E.E. Mesh Plot Dy 0.00 0 E.E. Mesh Plot Dy 0.00 E.W. Mesh E.E. Mesh Plot D.M. MAT D.M. Mesh Dy D.M. Mesh E.W. Mesh Dy 0.00 D.M. Mesh D.M. Mesh D.M.	MATNO 0 KF 1.00 MATold 3 MTYPE MATNOI 0 KFI 1.00 THICI 0.10 Description	1-> 2
LTPi 2 LMATi 1 Line Options Update LTPo 2 LMATo 2 Color Type Thickness Save Coordinate Constraint Generated coordinates are not movable Base Mesh Base Mesh Element Activity PLOT-2D Plot Translation Replot MATNO 0 0 Beam Deformed Shape Beam Dx 0.00 F.E. Mesh Plot LMAT 0 0 Element Constraint Reference Line Dx 0.00 F.E. Mesh Plot LMAT 0 0 Element Constraint Element Constra	LTP 0 LMAT 0 Add new mesh Hide	
Coordinate Constraint © Generated coordinates are movable Element Activity NAC NDAC MATNO 0 3 LMAT 0 0 0 0 FE. Mesh Deformed Shape Beam Truss Contour Reference Line Figure 5.61 Group dialog for box excavation	LTPi 2 LMATi 1 Line Options	Update
Coordinate Constraint		Save
Element Activity PLOT-2D Plot Translation Replot MATND 0 0 0 Group Editor MATND 0 0 0 Beam Dx 0.00 F.E. Mesh Plot LMAT 0 0 0 Ference Line Dx 0.00 F.E. Mesh Plot Dy 0.00 0 Exit Exit Exit	Coordinate Constraint Generated coordinates are movable Generated coordinates are not movable	Base Mesh
NAC NAC NAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction MATNO 0 0 0 Deformed Shape Dx 0.00 E.E. Mesh Ploi LMAT 0 0 0 Contour Dy 0.00 E.E. Mesh Ploi Dx 0.00 E.E. Mesh Ploi Dy 0.00 0 0 0 Exit Exit	Element Activity PLOT-2D Plot Translation	Replot
MATNO 0 3 Deformed Shape In X and Y direction Segment Edito LMAT 0	NAL Mesh Geometry will be moved 0 0 Principal Stress by distance D and Dy	Group Editor
LMAT 0	MATNO 0 3 Deformed Shape in∧ and Fourection	Segment Editor
Figure 5.61 Group dialog for box excavation	LMAT 0 0 Truss Dy 0.00	Close
Figure 5.61 Group dialog for box excavation	0 0 Reference Line	Exit
Figure 5.61 Group dialog for box excavation		
	Figure 5.61 Group dialog for box excavat	ion

5.3.3.3 SCE-Wall SCE-Wall is the structure to prevent ground movement due to excavations and is supported by anchors as schematically shown in Figure 5.56. Table 5.15 lists key parameters of this group. Element Beginning Ending Group Name MTYPE LTP LMAT Activity Seg Point Point IEND NAC NDAC Х Υ Y Х 7 SCE-Wall 2 2 1 4 999 1 0 12.5 0 -4 2 Table 5.15 Key parameters for SCE-wall Figure 5.62 shows Group dialog for SCE-wall. Group Group Identity-Group No 7 < > Edit Group Title SCE - Wall Show Number MTYPE and Material Parameter 2: Generate lines • MATNO 1 KF 1.00 MATold 3 MTYPE MATNOj 0 THICI 0.10 1.00 Description LTP 2 LMAT 1 🗌 Add new mesh ☐ Hide LMATi 1 Update 2 Line Options LMATo 2 Color Type Thickness 2 Save Coordinate Constraint Base Mesh Generated coordinates are movable Generated coordinates are not movable Element Activity PLOT-2D Plot Translation Replot Mesh NAC NDAC Geometry will be moved Group Editor 0 🔲 Principal Stress by distance Dx and Dy 0 in X and Y direction 0 🔲 Deformed Shape 0 Segment Editor Beam Г 0 0 F.E. Mesh Plot Dx 0.00 Truss LMAT 4 999 Close Contour Reference Line 0 0 Dy 0.00 0 0 Exit Figure 5.62 Group dialog for SCE-wall

5.3.3.4 Excavation

Excavations are conducted through four stages as schematically shown in Figure 5.56. Table 5.16 lists key parameters of these groups.

Group	Name	MTYPE	Elem	MATNO	Seg.	Begi Po	nning bint	Ene Po	ding bint	IEND
				/ NAC / NDAC		х	Y	х	Y	
					1	-45	8.4	0.0	8.4	2
8	Excavation-1	3	Cont	0/0/4	2	0	8.4	0	12.5	2
					3	0	12.5	-45	12.5	2
					4	-45	12.5	-45	8.4	2
					1	-45	5	0	5	2
9	Excavation-2	3	Cont	0/0/6	2	0	5	0	8.4	2
					3	0	8.4	-45	8.4	2
					4	-45	8.4	-45	5	2
	10 Excavation-3 3 Cont			1	-45	2.3	0	2.3	2	
10		Cont	0/0/8	2	0	2.3	0	5	2	
					3	0	5	-45	5	2
					4	-45	5	-45	2.3	2
					1	-45	0	0	0	2
11	Excavation-4	3	Cont	0/0/10	2	0	0	0	2.3	2
					3	0	2.3	-45	2.3	2
					4	-45	2.3	-45	0	2

Table 5.16 Key parameters for excavation

Figure 5.63 shows Group dialog for the first excavation. Group dialogs for the other excavations are very similar t	to this group 8.
Group	
Group Identity Group No 8 < > Title Excavation - 1	Edit Group
MTYPE and Material Parameter	Show Number
3: Assign new material number within closed loop	
MATNO 0 KF 1.00 MATold 3 MTYPE MATNOj 0 KFi 1.00 THICi 0.10 Description	1→2
LIP 0 LMAI 0 Add new mesh Hide	Update
LTPo 2 LMATO 2 Color Type Thickness	Save
Coordinate Constraint Generated coordinates are movable C Generated coordinates are not movable	Base Mesh
Element Activity PL0T-2D Plot Translation NAC Mesh Geometry will be moved 0 0 Principal Stress by distance Dx and Dy	Replot Group Editor
MATNO 0 4 Deformed Shape in X and Y direction	Segment Editor
LMAT 0 0 Truss Dx 0.00	F.E. Mesh Plot
0 0 Contour Dy 0.00	Close
Figure 5.63 Group dialog for the first exca	vation

5.3.3.5 Anchor

Three anchors are used to support SCE-wall as schematically shown in Figure 5.56. Each anchor consists of two parts: free and fixed length. Table 5.17 lists key parameters of these groups.

Group	Name	MTYPE / LTP / LMAT	Seg.	Begir Poi	ining int	End Poi	ling int	NDIV	IEND
		/ NAC / NDAC		х	Y	х	Y		
12	Anchor-1 Free	2/3/1/5/999	1	0	8.9	9.46	1.51	1	0
13	Anchor-1 Fixed	2/3/2/5/999	1	9.46	1.51	15.68	-3.35	0	-2
14	Anchor-2 Free	2/3/3/7/999	1	0	5.5	6.63	1.03	1	0
15	Anchor-2 Fixed	2/3/4/7/999	1	6.63	1.03	11.52	-2.27	0	-2
16	Anchor-3 Free	2/3/5/9/999	1	0	2.8	3.9	0.55	1	0
17	Anchor-3 Fixed	2/3/6/9/999	1	3.9	0.55	10.74	-3.4	0	-2

Table 5.17 Key parameters for anchor

	Group Group Identity Group No 12 Edit Group Mary PE Edit Group MATNO 12 Edit Group MATNO KF 1.00 MATNO Edit Group MATNO KF Edit Group MATNO Edit Group MATNO KF Show Number MATNO KF 1.00 MATNO KF MATNO MATNO MATNO KF MATNO KF Idit Group Show Number Show Number Show Number Show Number Idit Colspan="2"Show Number <th colspan="2" show<="" th=""></th>		
l	Figure 5.64 Group dialog for the first anchor (free part)		

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5.3.4 Finite Element Mesh Plot

Figure 5.65 shows finite element meshes generated from group meshes. Finite element meshes near box structure are shown in Figure 5.66.



5.4 Buried Pipe

This example illustrates how to build group meshes for typical pipe buried in the trench followed by multi-step embankment lifts.

5.4.1 Overview

The cross section of this buried pipe consists of natural soil, bedding, steel pipe, backfill, and lifts as shown in Figure 5.67.



5-60 Group Mesh Example

Step	Construction Sequence	Description	Element Activity
1,2	~	In situ K _o state	Active elements: Natural soil within trench
3		Excavate trench	Deactive elements: Natural soil within trench
4		Place bedding	Active elements: Compacted sand for bedding
5		Place steel pipe Fill the backfill	Active elements: Steel pipe Compacted sand for backfill
6	TO/	Place first lift of embankment fill	Active elements: First lift of embankment fill
7		Place second lift of embankment fill	Active elements: Second lift of embankment fill
8		Place third lift of embankment fill	Active elements: Third lift of embankment fill
9		Place fourth lift of sand done	Active elements: Fourth lift of sand done


5-62 Group Mesh Example

Table 5.19 summarizes key parameters of groups.

Group	Name	MTYPE	NAC	NDAC	MATNO / LTP / LMAT / IEND
1	Natural Soil	3	0	0	1 / 0 / 0 / 2
2	Excavation	3	0	3	1 / 0 / 0 / 2
3	Bedding	3	4	999	2 / 0 / 0 / 2
4	Steel Pipe	2	5	999	0 / 2 / 1 / 2
5	Backfill	3	5	999	3 / 0 / 0 / 2
6	Lift-1	3	6	999	4 / 0 / 0 / 2
7	Lift-2	3	7	999	5 / 0 / 0 / 2
8	Lift-3	3	8	999	6 / 0 / 0 / 2
9	Lift-4	3	9	999	7 / 0 / 0 / 2

Table 5.19 Group key parameters

5.4.2 Base Mesh

Built-in Base Mesh dialog is shown in Figure 5.69 with input data for blocks and boundary condition. Element size is more refined at the block in trench considering relatively high stress change here due to pipe construction. Figure 5.70 shows base mesh plot on drawing board.

Horiz	ontal Block				Vertic	al Block		
	Horizontal bl	ocks are defined fr	om left to rig	pht.		Vertical block	s are defined from	top to bottom.
	Number of b	locks in X directio	n: 3			Number of blo	ocks in Y directio	m: 6
No.	Width (₩)	Element Size (DX)	Normali Midpoin	zed it (AX)	No.	Height (H) (H)	Element Size (DY)	Normalized Midpoint (A'Y
1	3.0000	0.10000	0.3	•	1	1.0000	0.30000	0.5
2	4.0000	0.10000	0.5	•	2	2.0000	0.30000	0.5
3	3.0000	0.10000	0.3	•	3	2.0000	0.30000	0.5
4				-	4	1.0000	0.20000	0.5
5				~	5	2.0000	0.10000	0.5 -
6				~	6	2.5000	0.10000	0.3 -
16				-	16			
Origin Xo Wate For t	r Table otal stress ana /water lower th	Yo lysis, an Yo Ywate	-3.5000		- Bour	Left	Top 0 Free V Bottom 1 Roller V	Right 1 Roller <mark>▼</mark>
	Base	Mesh Layout Desi	ription			OK		Cancel

Figure 5.69 Built-in base mesh dialog



Figure 5.70 Base mesh plot on drawing board

5.4.3 Groups

Group meshes are divided into three parts:

- Natural soil and excavation
- Pipe construction
- Lift

It should be noted that the final finite element meshes are most influenced by group order and IEND.

5.4.3.1 Natural Soil and Excavation

Excavation is performed in natural soil to make trench. Table 5.20 lists key parameters of these groups

Group	Name	MTYPE	Elem	MATNO	Seg.	Begi Po	nning pint	En Po	ding pint	IEND
				/ NAC / NDAC		х	Y	х	Y	
					1	-5	-3.5	5	-3.5	2
1	Natural Soil	3	Cont	1/0/0	2	5	-3.5	5	1	2
					3	5	1	-5	1	2
					4	-5	1	-5	-3.5	2
					1	-1	-1	1	-1	2
2	Excavation	3	Cont	1/0/3	2	1	-1	2	1	2
					3	2	1	-2	1	2
					4	-2	1	-1	-1	2

Table 5.20 Key parameters for natural soil and excavation

Group Mesh Example 5

Group Identity Group No Image: Constraint of the second seco	Group Identity	
MTYPE and Material Parameter Show N 3 Assign new material number within closed loop Image: Constraint of the state of	Group No 1 < > Title Natural Soil	Edit Group
3: Assign new material number within closed loop MATNO MATNO I KF I MATNO KF I Coordinate Constraint Coordinate Constraint Coordinate Constraint Coordinate Constraint Generated coordinates are movable Base N NAC D </td <td>MTYPE and Material Parameter</td> <td>Show Numb</td>	MTYPE and Material Parameter	Show Numb
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LTPo 2 LMATo 2 Color Type Thickness Sax Coordinate Constraint © Generated coordinates are movable © Base M © Generated coordinates are movable © Constraint © Base M Element Activity PLOT-2D Plot Translation Rep MATND 0 0 Principal Stress Dy distance Dx and Dy Segment LMAT 0 0 Franse Dx 0.00 F.E. Met 0 0 France Dy 0.00 Contour 0 0 F.E. Met Dy 0.00 Contour	LTPi 2 LMATI 1 Line Options	Update
Coordinate Constraint Base M • Generated coordinates are movable • PLOT-2D Plot Translation • NAC • NDAC • Mesh Geometry will be moved by distance Dx and Dy Rep • MATNO • O • Deformed Shape Dx 0.00 LMAT 0 0 Contour Dy 0.00	LTPo 2 LMATo 2 Color Type Thickness	Save
Generated coordinates are movable Generated coordinates are not movable Base M Base M Base M Base M Base M Geometry will be moved Geometry will be moved Geometry will be moved Google Deformed Shape Dx 0.00 D	Coordinate Constraint	_
Element Activity PLOT-2D Plot Translation Rep NAC NDAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction Group II MATNO 0 0 Deformed Shape In X and Y direction Segment LMAT 0 0 Truss Dx 0.00 F.E. Mest 0 0 Contour Dy 0.00 F.E. Mest	Generated coordinates are movable Generated coordinates are not movable	Base Mes
NAL NDAL I Mesh Geometry will be moved 0 0 I Principal Stress by distance Dx and Dy Group MATNO 0 0 I Deformed Shape in X and Y direction Segment LMAT 0 0 I Truss Dx 0.00 F.E. Mest 0 0 I Contour Dy 0.00 Image: Contour Contour Dy 0.00	Element Activity PLOT-2D Plot Translation	Replot
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0 0 Contour Dy 0.00 Clos	0 0 1 Beam LMAT 0 0 Truss Dx 0.00	F.E. Mesh P
Hererence Line	0 0 Contour Dy 0.00	Close
		Exit
Figure 5.71 Group dialog for natural soil	Figure 5.71 Group dialog for natural	soil

5-65

5-66 Group Mesh Example

Group No Itile Excavation Group No Itile Excavation MTYPE and Material Parameter Show Number 3: Assign new material number within closed loop Itile MATNO KF 1.00 MATNO KF 1.00 MATNO KF 1.00 ITP LMAT Itile LTP LMAT Itile Coordinate Constraint Color Type Generated coordinates are movable Generated coordinates are not movable Base Mesi Element Activity PLOT-2D Plot Itranslation Replot MATNO 0 0 Deformed Shape Dx 0.00 MATNO 0 0 Deformed Shape Dx 0.00 Exit MATNO 0 0 Contour Dy 0.00 Exit	Group No 2 Itle Excavation Edit Group MTYPE and Material Parameter 3. Assign new material number within closed loop Image: Show Number MATNO 1 KF 1.00 MATold Image: Show Number MATNO 1 KF 1.00 MATold Image: Show Number MATNO 1 KF 1.00 MATold Image: Show Number MATNO 0 KF 1.00 MATold Image: Show Number ITP 0 LMAT 0 Image: Show Number Image: Show Number LIP 0 LMAT 0 Add new mesh Hide Image: Show Number LIP 0 LMAT 0 Color Type Thickness Save Coordinate Constraint 0 Color Type Thickness Save Element Activity PLOT-2D Plot Translation Replot Group Edit MATND 0 0 0 Translation Replot Segment Edit MATND 0 0 0 Translation Replot Segm	Group No 2 2 Title Excavation Edit Group MTYPE and Material Parameter 3. Assign new material number within closed loop Image: Show Number within closed loop Image: Show Number within closed loop Image: Show Number within closed loop MATNO 1 KF 1.00 MATold Image: Show Number within closed loop Image: Show Number within closed loop MATNO 0 KF 1.00 THIC 0.10 Description LTP 0 LMAT 0 Add new mesh Hide Update LTP 2 LMAT 1 Color Type Thickness Coordinate Constraint 6 Generated coordinates are movable Base Mest Element Activity PLOT-2D Plot Translation Replot MATNO 0 0 Fincipal Stress Dx 0.00 Edit Group LMAT 0 0 0 Translation Replot Group Edity LMAT 0 0 0 Translation Replot Edit Group UP dift 0 0 Difterence Line Dx	Group No 2 < Title Excavation Edit Group MTYPE and Material Parameter Show Numt Show Numt 3 Assign new material number within closed loop MATNO KF 1.00 MATold 3 MTYPE LTP UMATO KF 1.00 THIC 0.10 Description LTP UMATO Add new mesh Hide Update Update Update LTP UMATO Color Type Thickness Save Coordinate Constraint © Generated coordinates are not movable Base Mesi Element Activity PLOT-2D Plot Translation Replot MATNO 0 0 Deformed Shape Dx and Y direction LMAT 0 0 Enternee Line Dx 0.00 Exit FE. Mesh Principal Stress Dy 0.00 Exit Exit MATNO 0 0 Contour Reference Line Dx 0.00 Exit FE. Mesh Plotonur Reference Line Exit </th <th>Group No 2 State Excavation Edit Group MTYPE and Material Parameter Show Numini Show Numini Show Numini 3. Assign new material number within closed loop Image: Show Numini Image: Show Numini Image: Show Numini MATNO 1 KF 1.00 MATold Image: Show Numini Image: Show Numini MATNO 1 KF 1.00 MATold Image: Show Numini Image: Show Numini MATNO 1 KF 1.00 MATold Image: Show Numini Image: Show Numini MATNO 0 KFF 1.00 MATold Image: Show Numini Image: Show Numini LTP 0 LMAT 0 Add new mesh Hide Update LTP 2 LMATO Color Type Thickness Save Coordinate Constraint 2 Coordinate sare movable Generated coordinates are movable Base Mes Element Activity PLOT-2D Plot Translation Reptot Group Edit MATNO 0 0 0 Deformed Shape Dx 0.00</th> <th>Group</th> <th></th> <th></th> <th></th>	Group No 2 State Excavation Edit Group MTYPE and Material Parameter Show Numini Show Numini Show Numini 3. Assign new material number within closed loop Image: Show Numini Image: Show Numini Image: Show Numini MATNO 1 KF 1.00 MATold Image: Show Numini Image: Show Numini MATNO 1 KF 1.00 MATold Image: Show Numini Image: Show Numini MATNO 1 KF 1.00 MATold Image: Show Numini Image: Show Numini MATNO 0 KFF 1.00 MATold Image: Show Numini Image: Show Numini LTP 0 LMAT 0 Add new mesh Hide Update LTP 2 LMATO Color Type Thickness Save Coordinate Constraint 2 Coordinate sare movable Generated coordinates are movable Base Mes Element Activity PLOT-2D Plot Translation Reptot Group Edit MATNO 0 0 0 Deformed Shape Dx 0.00	Group			
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Clipo 2 Color Type Thickness Save Coordinate Constraint Generated coordinates are movable Base Mesi Base Mesi PloT-2D Plot PloT-2D Plot Principal Stress Deformed Shape Beam Truss Contour Reference Line NAC NAC Replot Group Edite Segment Edite Segmen	Coordinate Constraint Coordinate Constraint Base Mesi • Generated coordinates are movable • Base Mesi • Lement Activity • PLOT-2D Plot • Translation • NAC NAC • PLOT-2D Plot • Generated coordinates are not movable • Replot • MATND • 0 • Plincipal Stress • Geometry will be moved by distance Dx and Dy • Replot • MATND • 0 • Deformed Shape Dx • 0.00 F.E. Mesh • MAT • 0 • 0 • 0 • Close Exit • MAT • 0 • 0 • 0 • Close Exit • Figure 5.72 • Group dialog for excavation	Image: Coordinate Constraint Save Coordinate Constraint Base Mesi • Generated coordinates are movable Base Mesi Element Activity PLOT-2D Plot Translation MATND 0 0 MATND 0 0 LMAT 0 0 Contour Deformed Shape Dx 0.00 Deformed Shape Beam Dx 0.00 Data Contour Deformed Line Dx 0.00 Data Contour Data Data Exit	Coordinate Constraint Coordinate Constraint Condinate Constraint Condinate Constraint Condinate Constraint Condinate Constraint Condinate Constraint Condinate Constraint Condinate Constraint Contour Contour Contour Contour Reference Line Contour Close Exit Figure 5.72 Group dialog for excavation	Coordinate Constraint Coordinate Constraint Coordinate Constraint Coordinate Constraint Coordinates are movable Control Plot - 2 Plot Plot - 2 Plot Principal Stress Deformed Shape Beam Truss Contour Reference Line Contour Reference Line Figure 5.72 Group dialog for excavation	LTP 0 LMAT	0 Add new n 1 Line Option	nesh THide	Update
Coordinate Constraint Base Mesi Generated coordinates are movable Base Mesi Element Activity PLOT-2D Plot MATND O O O MATND O O O LMAT O O O Element Activity PLOT-2D Plot Principal Stress Geometry will be moved by distance Dx and Dy Group Edit Deformed Shape Dx Deformed Shape Dx O O Contour Dy O O Reference Line Dy Figure 5.72 Group dialog for excavation	Coordinate Constraint Generated coordinates are movable Element Activity NAC NDAC MATND 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Coordinate Constraint • Generated coordinates are not movable Element Activity NAC NDAC 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Coordinate Constraint © Generated coordinates are not movable Element Activity NAC NDAC 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Coordinate Constraint © Generated coordinates are not movable Element Activity NAC NDAC 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	LTPo 2 LMATC	2 Color	Type Thickness	Save
(* Generated coordinates are movable Education Element Activity PLOT-2D Plot MATNO 0 0 0 LMAT 0 0 0 <td>(* Generated coordinates are not movable Education Element Activity PL0T-2D Plot Geometry will be moved MATNO 0 0 0 0 0 LMAT 0 0 0 0 0</td> <td>• Generated coordinates are not movable Element Activity PL0T-2D Plot Replot MAT NO 0 0 0 LMAT 0 0 0 0 0 0 0 0 0 0 Element Activity PloT-2D Plot Geometry will be moved by distance Dx and Dy in X and Y direction Replot MAT NO 0 0 0 Deformed Shape Dx 0.00 E.E. Mesh P Data Truss Contour Reference Line Dy 0.00 Exit Figure 5.72 Group dialog for excavation</td> <td>(* Generated coordinates are not movable Education Element Activity PLOT-2D Plot Geometry will be moved MATNO 0 0 0 0 0 LMAT 0 0 0 0 0</td> <td>(* Generated coordinates are not movable Education Element Activity PLOT-2D Plot Translation Replot MATND 0 0 0 Group Edit MATND 0 0 0 Group Edit LMAT 0 0 0 F.E. Mesh F Deformed Shape Dx 0.00 F.E. Mesh F Dy 0.00 Close Exit</td> <td>Coordinate Constraint</td> <td></td> <td></td> <td>Base Mes</td>	(* Generated coordinates are not movable Education Element Activity PL0T-2D Plot Geometry will be moved MATNO 0 0 0 0 0 LMAT 0 0 0 0 0	• Generated coordinates are not movable Element Activity PL0T-2D Plot Replot MAT NO 0 0 0 LMAT 0 0 0 0 0 0 0 0 0 0 Element Activity PloT-2D Plot Geometry will be moved by distance Dx and Dy in X and Y direction Replot MAT NO 0 0 0 Deformed Shape Dx 0.00 E.E. Mesh P Data Truss Contour Reference Line Dy 0.00 Exit Figure 5.72 Group dialog for excavation	(* Generated coordinates are not movable Education Element Activity PLOT-2D Plot Geometry will be moved MATNO 0 0 0 0 0 LMAT 0 0 0 0 0	(* Generated coordinates are not movable Education Element Activity PLOT-2D Plot Translation Replot MATND 0 0 0 Group Edit MATND 0 0 0 Group Edit LMAT 0 0 0 F.E. Mesh F Deformed Shape Dx 0.00 F.E. Mesh F Dy 0.00 Close Exit	Coordinate Constraint			Base Mes
Element Activity PL01-2D Plot Geometry will be moved NAC NDAC Hesh Geometry will be moved MATND 0 3 Deformed Shape Beam LMAT 0 0 F.E. Mesh Dy inX and Y direction Contour Contour Dy 0.00 Exit	Element Activity PL01-2D Plot Geometry will be moved NAC NDAC Hesh Geometry will be moved MATNO 0 0 Geometry will be moved Group Edit MATNO 0 0 Deformed Shape Deformed Shape Beam Truss Do Dx 0.00 LMAT 0 0 Contour Dy 0.00 Reference Line Dy 0.00 Exit	Element Activity PL07-2D Plot Geometry will be moved MATND 0 0 Geometry will be moved MATND 0 0 Geometry will be moved Group Edit LMAT 0 0 Geometry will be moved Geometry will be moved Geometry will be moved LMAT 0 0 Geometry will be moved Geometry will be moved Geometry will be moved LMAT 0 0 Geometry will be moved Geometry will be moved Geometry will be moved Deformed Shape Beam Truss Dv 0.00 F.E. Mesh F Close Dy 0.00 Dv 0.00 Exit Segment Edit Dy 0.00 Exit Close Dy 0.00 Exit Exit Figure 5.72 Group dialog for excavation Geometry will be moved	Element Activity PL01-2D Plot Geometry will be moved NAC NDAC Principal Stress Geometry will be moved MATND 0 3 Deformed Shape Beam LMAT 0 0 0 Deformed Shape Dx 0.00 LMAT 0 0 0 Contour Dy 0.00 E.Mesh Contour Reference Line Dy 0.00 E.xit	Element Activity PL01-2D Plot Geometry will be moved MATND 0 0 Geometry will be moved MATND 0 0 Geometry will be moved Group Edit LMAT 0 0 Geometry will be moved Geometry will be moved Geometry will be moved LMAT 0 0 Geometry will be moved Geometry will be moved Geometry will be moved LMAT 0 0 Geometry will be moved Geometry will be moved Geometry will be moved LMAT 0 0 Geometry will be moved Geometry will be moved Geometry will be moved LMAT 0 0 Geometry will be moved Geometry will be moved Geometry will be moved Dy 0.00 Geometry will be moved Dy Dy Good Dy 0.00 Geometry will be moved Dy Dy Dy Dy 0.00 Geometry will be moved Dy Exit Dy 0.00 Geometry will be moved Dy Exit Figure 5.72 Group dialog for excavation Geometry will be moved Exit	 Generated coordinates are 	movable C Generated coord	inates are not movable	Dase mes
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Figure 5.72 Group dialog for excavation	Figure 5.72 Group dialog for excavation	Figure 5.72 Group dialog for excavation	Figure 5.72 Group dialog for excavation	Figure 5.72 Group dialog for excavation	LMAT 0 0 0 0	☐ Beam ☐ Truss ☐ Contour ☐ Reference Line	Dx 0.00 Dy 0.00	F.E. Mesh F Close
Figure 5.72 Group dialog for excavation	Figure 5.72 Group dialog for excavation	Figure 5.72 Group dialog for excavation	Figure 5.72 Group dialog for excavation	Figure 5.72 Group dialog for excavation				
					Figure	5.72 Group dia	log for excavatio	n

5.4.3.2 Pipe Construction

Pipe construction consists of bedding, steel pipe, and backfill as shown in Figure 5.67. Table 5.21 lists key parameters of these groups

						Eleme	nt Activity
Group	Name	MTYPE	Add New Mesh	Element	MATNO / LMAT	NAC	NDAC
3	Bedding	3	Checked	Cont.	2 / 0	4	999
4	Steel Pipe	2		Beam	0/1	5	999
5	Backfill	3	Checked	Cont.	3 / 0	5	999

			Line Se	egment				Arc S	egme	nt		
Group	Seg	Beginnir	ng Point	Ending	g Point	Ori	gin		Radius	s & Ang	le	IEND
		х	Y	х	Y	Xo	Yo	R _x	R _Y	Θ_{b}	Θ _e	
	1	-1	-1	1	-1							2
3	2	1	-1	1.353	-0.294							2
	3	1.353	-0.294	0.4045	-0.294							2
	4					0	0	0.5	0.5	-36	-144	2
	5	-0.4045	-0.294	-1.353	-0.294							2
	6	-1.353	-0.294	-1	-1							2
4	1					0	0	0.5	0.5	0	360	2
	1	2	1	-2	1							2
5	2	-2	1	-1.353	-0.294							2
	3	-1.353	-0.294	-0.4045	-0.294							2
	4					0	0	0.5	0.5	216	-36	2
	5	0.4045	-0.294	1.353	-0.294							2
	6	1.353	-0.294	2	1							2

Table 5.21 Key parameters for pipe construction

5-68 Group Mesh Example

Figure 5.73 shows Group dialog for bedding. Group dialog for backfill is very similar to this group 3.	
Group	
Group Identity Group No 3 > Title Bedding (Compacted Sand) MTYPE and Material Parameter 3. Assign new material number within closed loop • MATNO 2 KF 1.00 MATold 3 MTYPE MATNOI 0 KFi 1.00 THICi 0.10 Description LTP 0 LMAT 0 Image: Add new mesh Hide LTPo 2 LMATo 2 Color Type Thickness	Edit Group Show Number 1-> 2 Update Save
Coordinate Constraint Generated coordinates are movable C Generated coordinates are not movable	Base Mesh
Element Activity PLOT-2D Plot Translation NAC NDAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction MAT NO 999 Deformed Shape Dx 0.00 LMAT 0 0 Truss Dx 0.00 0 0 Contour Dy 0.00 Dy 0.00	Replot Group Editor Segment Editor F.E. Mesh Plot Close Exit
Figure 5.73 Group dialog for bedding	

Group Mesh Example 5-69

Group Identity Group No 4 2 Title Steel Pipe MTYPE and Material Parameter 2 Generate lines MATNO 1 KF 1.00 MATold 3 MTYPE MATNO 0 KF 1.00 THIC 0.10 Description LTP 2 LMAT 1 Add new mesh Hide Update LTP 2 LMAT 1 Color Type Thickness Save Coordinate Constraint © Generated coordinates are movable © Generated coordinates are not movable Element Activity NAC NDAC 0 0 0 PLOT-2D Plot Principal Stress Deformed Shape Beam Translation Replot Do 0 0 0 0 Element Ed Do 0 0 0 0 Element Activity NAC NDAC 0 0 0 0 0 Element Stress Deformed Shape Beam Truss Contour Reference Line Figure 5.74 Group dialog for steel pipe	Group Identity Group No Ittle Steel Pipe Edit Group Show Numb MTYPE and Material Parameter Show Numb Show Numb 2 Generate lines Image: Steel Pipe Show Numb MATNO Image: Steel Pipe Image: Steel Pipe Show Numb MATNO Image: Steel Pipe Image: Steel Pipe Show Numb MATNO Image: Steel Pipe Image: Steel Pipe Image: Steel Pipe MATNO Image: Steel Pipe Image: Steel Pipe Image: Steel Pipe MATNO Image: Steel Pipe Image: Steel Pipe Image: Steel Pipe Coordinate Constraint Image: Steel Pipe Image: Steel Pipe Image: Steel Pipe Image: Steel Pipe Image: Steel Pipe Image: Steel Pipe Image: Steel Pipe Image: Image: Steel Pipe Image: Steel Pipe Image: Steel Pipe Image: Steel Pipe Image: Imag	Group Identity Group No 4 S Title Steel Pipe Edit Group MTYPE and Material Parameter 2 Generate lines MATNO 1 KF 1.00 MATOI 3 MTYPE Show Numb ITP 2 LMAT 1 Add new mesh Hide Update TP 2 LMAT 1 Add new mesh Hide Update Color Type Thickness Save Coordinate Constraint Coordinate Constraint Contour Constraint Contour Constraint	Group Identity Group No Image: Steel Pipe Edit Group MTYFE and Material Parameter 2 Generate lines Show Numb MATNO 1 KF 1.00 MATOId 3 MTYFE LIP 2 LMAT 1 Add new mesh Hide Update LTP 2 LMAT 2 Color Type Thickness Save Coordinate Constraint Generated coordinates are movable Generated coordinates are movable Base Mesh Element Activity NAC NDAC 0 0 Replot Deformed Shape Dx 0.00 Exit LMAT 5 9393 0 Contou	Group No Ittle Steel Pipe Edit Group MTYPE and Material Parameter Show Numit Show Numit 2: Generate lines Ittle 0.00 Ittle MATNO 1 KF 1.00 MATOId MTYPE IP 2 LMAT 1 Add new mesh Hide LTP 2 LMAT 1 Color Update LTP 2 LMAT 1 Color Type Thickness Coordinate Constraint Coordinates are movable Generated coordinates are not movable Base Mesi Element Activity PLOT-2D Plot Translation Replot O 0 Principal Stress Deformed Shape Dx 0.00 F.E. Mesh P LMAT 5 939 O O Dy 0.00 Elsext Figure 5.74 Group dialog for steel pipe Exit	Group Identity- Group No Image: Steel Pipe Edit Group MTYPE and Material Parameter Show Numing 2: Generate lines Image: Show Numing MATNO KF 1.00 MATNO; KF 1.00 LTP LMAT Image: Show Numing LTP LMAT Image: Show Numing Coordinate Constraint Coordinate Constraint Generated coordinates are not movable Base Mes Coordinate Constraint Generated coordinates are not movable Base Mes PLOT-2D Plot Translation NAC NDAC PLOT-2D Plot Group Edit MAT 0 0 Principal Stress Deformed Shape LMAT 5 939 0 Contour Dividiance Dx and Dy Image: Contour Reference Line Dx 0.00 Ess th FE. Mesh Contour Reference Line Dividiance Dx and Dy Est th D 0 0 0 Ess th Est th Segment Ec Contour Reference Line Est th Est th	Group Identity- Group No Image: Steel Pipe Edit Group MTYPE and Material Parameter Show Numini 2 Generate lines Image: Show Numini MATNO KF 1.00 MATNO KF 1.00 LIP LMAT Image: Add new mesh LIP LMAT Image: Add new mesh LIP LMAT Image: Color Coordinate Constraint Coordinates are movable Generated coordinates are not movable Element Activity PLOT-2D Plot Translation NAC NDAC Plot-2D Plot Group Edit NAT 5 9393 Deformed Shape Dx 0.00 Deformed Shape Reference Line Dx 0.00 Exit Figure 5.74 Group dialog for steel pipe Figure 5.74 Group dialog for steel pipe	Group No Image: Steel Pipe Edit Group MTYPE and Material Parameter Show Num 2 Generate lines Image: Show Num MATNO KFI 1.00 MATNO KFI 1.00 LTP LMAT Image: Show Num LTP LMAT Image: Show Num Coordinate Constraint Image: Show Num Image: Show Num Coordinate Constraint Coordinate coordinates are movable Base Mes Element Activity PLOT-2D Plot Translation Reptot MAT 0 0 Plot-2D Plot Base Mes ILMAT 5 939 Deformed Shape Deformed Shape LMAT 5 939 O Deformed Line Dx 0.00 Junc 0 0 Confour Reference Line Exit Exit Figure 5.74 Group dialog for steel pipe	Group				
MTYPE and Material Parameter Show Number 2 Generate lines Image: Show Number MATNO KF 1.00 MATNO KF 1.00 ITP LMAT Add new mesh ITP LMAT Image: Show Number ITP LMAT Image: Show Number Coordinate Constraint Color Description Generated coordinates are movable Generated coordinates are not movable Base Mesh NAC NAC NAC PLOT-2D Plot Geometry will be moved by distance Dx and Dy in X and Y direction Segment Ed IMAT 5 939 Deformed Shape Dx 0.00 F.E. Mesh Data Truss Dy 0.00 Exit Segment Ed MAT 5 939 Ontour Dy 0.00 Exit Figure 5.74 Group dialog for steel pipe Exit	MTYPE and Material Parameter Show Numb 2 Generate lines Image: Constraint MATNO 1 KF MATNO 1 KF LTP 2 LMAT 1 Add new mesh Hide LTP 2 LMAT 2 LMAT 1 Add new mesh Hide Update Save Coordinate Constraint Generated coordinates are not movable Base Mesh Plot - 2D Plot Plot - 2D Plot Plot - 2D Plot Principal Stress Geometry will be moved by distance Dx and Dy Segment Edit NAC NAC 0 0 0 0 0 0 0 0 0 0 Deformed Shape Dx 0 Deformed Shape 0 Dy 0.00 0 Contour Dy 0 0 Exit	MTYPE and Material Parameter Show Numb 2 Generate lines Image: Constraint MATNO KF LTP LMAT 2 LMAT Add new mesh LTP LMAT 2 LMAT Add new mesh LTP LMAT 2 LMAT Color TPo LMAT 2 LMATo Color TPo LMATO Coordinate Constraint Generated coordinates are not movable Base Mesh Plot-2D Plot Plot-2D Plot Geometry will be moved by distance Dx and Dy NAC NAC NAC 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	MTYPE and Material Parameter Show Numb 2 Generate lines Image: Show Numb MATNO 1 KF 1.00 MATNO 1 KF 1.00 MATOId Image: Matrix MATNO 0 KF 1.00 MATOId Image: Matrix <	MTYPE and Material Parameter Show Nume 2 Generate lines Image: Show Nume MATNO 1 KF MATNO 1 KF LIP 2 LMAT 2 LMAT 1 Add new mesh Hide LIP 2 LMAT 2 LMAT 1 Add new mesh Hide Update Save Coordinate Constraint Generated coordinates are not movable Base Mest PloT-2D Plot 1 Mesh 1 NAC 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	MTYPE and Material Parameter Show Numing 2 Generate lines Image: Show Numing MATNO 1 KF 1.00 MATold Image: Show Numing MATNO 0 KF 1.00 Hilde Image: Show Numing MATNO 1 KF 1.00 MATold Image: Show Numing LTP 2 LMAT 1 Add new mesh Hide Update LTP 2 LMAT 2 Color Type Thickness Save Coordinate Constraint Generated coordinates are not movable Base Mesh Principal Stress Deformed Shape Dx 0.00 Dx 0.00 Est LMAT 5 939 0 0 Dx 0.00 Dy 0.00 Est LMAT 5 939 0 0 Dx	MTYPE and Material Parameter Show Numi 2 Generate lines Image: Constraint MATNO 1 KF MATNO 1 KF LIP LMAT 2 LMAT 1 Add new mesh Hide LIP LMAT 1 2 LMAT 1 Coordinate Constraint Color • Generated coordinates are movable Generated coordinates are not movable Element Activity PLOT-2D Plot 0 0 </td <td>MTYPE and Material Parameter Show Num 2 Generate lines Image: Constraint MATNO1 KF MATNO1 KF LTP LMAT 2 LMAT Add new mesh Hide Update LTP LMAT 2 LMAT Line Options LTP LMAT 2 Generated coordinates are movable Generated coordinates are not movable Base Mes Coordinate Constraint Generated coordinates are movable Coordinate Coordinates are movable Generated coordinates are not movable Element Activity PLOT-2D Plot 0 PLOT-2D Plot PLOT-2D Plot Genometry will be moved 0 Deformed Shape Beam Truss Contour Dx 0.00 Reference Line Dx 0.00 Exit Figure 5.74 Group dialog for steel pipe</td> <td>Group Identity Group No 4</td> <td>< > Title</td> <td>Steel Pipe</td> <td></td> <td>Edit Grou</td>	MTYPE and Material Parameter Show Num 2 Generate lines Image: Constraint MATNO1 KF MATNO1 KF LTP LMAT 2 LMAT Add new mesh Hide Update LTP LMAT 2 LMAT Line Options LTP LMAT 2 Generated coordinates are movable Generated coordinates are not movable Base Mes Coordinate Constraint Generated coordinates are movable Coordinate Coordinates are movable Generated coordinates are not movable Element Activity PLOT-2D Plot 0 PLOT-2D Plot PLOT-2D Plot Genometry will be moved 0 Deformed Shape Beam Truss Contour Dx 0.00 Reference Line Dx 0.00 Exit Figure 5.74 Group dialog for steel pipe	Group Identity Group No 4	< > Title	Steel Pipe		Edit Grou
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ⓒ Generated coordinates are movable ○ Bease Mest Element Activity PLOT-2D Plot ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ □ ○ ○ ○ □ ○ ○ ○ □ ○ ○ ○ □ □ ○ ○ □ □ ○ ○ □ □ ○ ○ □ □ ○ ○ □ □ ○ ○ □ □ ○ ○ □ □ ○ ○ □ □ ○ ○ □ □ ○ ○ □ □ ○ □ □ □ ○ □ □ □ ○ □ □ □ ○ □ □ □ ○ □ □ □ ○ □ □ □ ○ □ □ □ ○ □ □ □ ○ □ □ □ ○ □ □ □ □ ○ □ □ □ □ ○ □ □ □ □ ○ □ □ □ □ ○ □ □ □ □ ○	Image: Generated coordinates are movable Base Mest Element Activity PLOT-2D Plot NAC NDAC 0 0 0 0 0 0 0 0 Deformed Shape Deformed Shape Deformed Shape Dx and Y direction Dx 0.00 E.MAT 0 0 0 Principal Stress Deformed Shape Beam Dx 0.00 Close Exit Contour Reference Line Dy 0.00 Exit	Image: Generated coordinates are movable Base Mest Image: Generated coordinates are not movable Replot Image: Generated coordinates are not movable Replot Image: Generated coordinates are not movable Replot Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable Image: Generate Coordinates are not movable <td>Image: Generated coordinates are movable Base Mest Element Activity PLOT-2D Plot Translation Replot Image: NAC Image: Open content of the stress open content of the stress open content open cont</td> <td>Generated coordinates are movable Generated coordinates are not movable Base Mesi Generated coordinates are not movable Generated coordinates are not movable Figure 5.74 Group dialog for steel pipe Generated coordinates are not movable Generated coordinates are not movable Translation Geometry will be moved by distance Dx and Dy in X and Y direction Dx 00 0</td> <td>© Generated coordinates are movable © Generated coordinates are not movable Element Activity NAC NDAC ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○</td> <td>Generated coordinates are movable Generated coordinates are not movable Generate will be moved by distance Dx and Dy in X and Y direction Dx 0.00 Dx 0.00 Dx 0.00 Close Exit F.E. Mesh Close Exit Figure 5.74 Group dialog for steel pipe</td> <td>ⓒ Generated coordinates are movable ⓒ Generated coordinates are not movable Base Mest Element Activity NAC NDAC ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○</td> <td>Coordinate Constra</td> <td>aint</td> <td></td> <td></td> <td></td>	Image: Generated coordinates are movable Base Mest Element Activity PLOT-2D Plot Translation Replot Image: NAC Image: Open content of the stress open content of the stress open content open cont	Generated coordinates are movable Generated coordinates are not movable Base Mesi Generated coordinates are not movable Generated coordinates are not movable Figure 5.74 Group dialog for steel pipe Generated coordinates are not movable Generated coordinates are not movable Translation Geometry will be moved by distance Dx and Dy in X and Y direction Dx 00 0	© Generated coordinates are movable © Generated coordinates are not movable Element Activity NAC NDAC ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○	Generated coordinates are movable Generated coordinates are not movable Generate will be moved by distance Dx and Dy in X and Y direction Dx 0.00 Dx 0.00 Dx 0.00 Close Exit F.E. Mesh Close Exit Figure 5.74 Group dialog for steel pipe	ⓒ Generated coordinates are movable ⓒ Generated coordinates are not movable Base Mest Element Activity NAC NDAC ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○	Coordinate Constra	aint			
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LMAT 0 0 0 F.E. Mesh P 0 0 0 0 0 0 0 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe 6 6	LMAT 0 0 0 F.E. Mesh P 0 0 0 0 0 0 0 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe	LMAT 0 0 0 Beam Dx 0.00 F.E. Mesh P 0 <td>LMAT 0 0 0 Beam Dx 0.00 F.E. Mesh P 0<td>LMAT 0 0 0 F.E. Mesh F 0 0 0 0 0 0 Provide 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe Figure 5.74 Figure 5.74</td><td>LMAT 0 0 F.E. Mesh F 0 0 0 0 0 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe</td><td>LMAT 0 0 0 F.E. Mesh F 0 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe</td><td>LMAT 0 0 F.E. Mesh f 0 0 0 0 0 Contour Dy 0.00 Exit Figure 5.74 Group dialog for steel pipe</td><td>Element Activity –</td><td>NDAC PLOT-2 NDAC Mes 0 Prin 0 Def</td><td>2D Plot h cipal Stress ormed Shape</td><td>Translation Geometry will be m by distance Dx and in X and Y directior</td><td>Dived Dy Group Ed Segment E</td></td>	LMAT 0 0 0 Beam Dx 0.00 F.E. Mesh P 0 <td>LMAT 0 0 0 F.E. Mesh F 0 0 0 0 0 0 Provide 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe Figure 5.74 Figure 5.74</td> <td>LMAT 0 0 F.E. Mesh F 0 0 0 0 0 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe</td> <td>LMAT 0 0 0 F.E. Mesh F 0 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe</td> <td>LMAT 0 0 F.E. Mesh f 0 0 0 0 0 Contour Dy 0.00 Exit Figure 5.74 Group dialog for steel pipe</td> <td>Element Activity –</td> <td>NDAC PLOT-2 NDAC Mes 0 Prin 0 Def</td> <td>2D Plot h cipal Stress ormed Shape</td> <td>Translation Geometry will be m by distance Dx and in X and Y directior</td> <td>Dived Dy Group Ed Segment E</td>	LMAT 0 0 0 F.E. Mesh F 0 0 0 0 0 0 Provide 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe Figure 5.74 Figure 5.74	LMAT 0 0 F.E. Mesh F 0 0 0 0 0 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe	LMAT 0 0 0 F.E. Mesh F 0 0 0 0 0 0 Figure 5.74 Group dialog for steel pipe	LMAT 0 0 F.E. Mesh f 0 0 0 0 0 Contour Dy 0.00 Exit Figure 5.74 Group dialog for steel pipe	Element Activity –	NDAC PLOT-2 NDAC Mes 0 Prin 0 Def	2D Plot h cipal Stress ormed Shape	Translation Geometry will be m by distance Dx and in X and Y directior	Dived Dy Group Ed Segment E
Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	LMAT 0 0 0	0 ☐ Bea 999 ☐ Trus 0 ☐ Con 0 ☐ Ref	m ss tour erence Line	Dx 0.00 Dy 0.00	F.E. Mesh Close Exit
Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe	Figure 5.74 Group dialog for steel pipe					
								F	Figure 5.74	Group dia	log for steel	pipe

5.4.3.3 Lift

Embankment lifts are placed through four steps as shown in Figure 5.67. Table 5.22 lists key parameters of these groups

Group	Name	MTYPE	Element	MATNO	Seg.	Begi Po	nning Þint	En Po	ding bint	IEND
				/ NAC / NDAC		х	Y	х	Y	
					1	-5	1	5	1	2
6	Lift-1	3	Cont	4 / 6 / 999	2	5	1	5	2	2
					3	5	2	-5	2	2
					4	-5	2	-5	1	2
					1	-5	2	5	2	2
7	Lift-2	3	Cont	5 / 7 / 999	2	5	2	5	4	2
					3	5	4	-5	4	2
					4	-5	4	-5	2	2
					1	-5	4	5	4	2
8	Lift-3	3	Cont	6 / 8 / 999	2	5	4	5	6	2
					3	5	6	-5	6	2
					4	-5	6	-5	4	2
					1	-5	6	5	6	2
9	Lift-4	3	Cont	7 / 9 / 999	2	5	6	5	7	2
					3	5	7	-5	7	2
					4	-5	7	-5	6	2

Table 5.22 Key parameters for lift

Group Mesh Example

Group No Group No Edit Group Group No Title Lift 1 MTYPE and Material Parameter Show Numb MATNO KF 100 MATNO MATO Add new mesh Hide Line Options Type Coordinate Constraint Generated coordinates are not movable Base Mest Pitoripal Stress Deformed Shape Feam MATNO O O O Dx LMAT O O O Dy 0.00 D O	Group No Image: Second sec	Group No 6 <> Title Lift 1	
MTYPE and Material Parameter Show Numb 3. Assign new material number within closed loop Image: Close cl	MTYPE and Material Parameter Show Num 3. Assign new material number within closed loop Image: Coordinate Constraint MATNO1 KFi 1.00 MATO1 KFi 1.00 MATNO2 Line Options Update LTP LMAT Image: Color Type TP0 LMAT Image: Color Type Coordinate Constraint Generated coordinates are movable Base Mest Element Activity PLOT-2D Plot Translation Replot MATNO 0 0 Base Base Mest MATNO 0 0 Image: Color Type Thickness MATNO 0 0 Image: Color Type Thickness Save Element Activity PLOT-2D Plot Translation Replot Group Edit Group Edit Group Edit Group Edit Segment Edit Segment Edit Segment Edit F.E. Mesh F Dx 0.00 Exit Segment Edit Segment Edit Exit	MTYPE and Material Darameter	Edit Group
3: Assign new material number within closed loop MATNO 4 KF 1.00 MATold 3 MTYPE MATNO 0 KF 1.00 THIC 0.10 Description LTP 0 LMAT 0 Add new mesh Hide Update LTP 2 LMAT 1 Line Options Type Thickness Save Coordinate Constraint © Generated coordinates are movable © Base Mesh © Generated coordinates are movable PLOT-2D Plot Translation Replot MATNO 6 939 Deformed Shape Dx 0.00 Etement Activity LMAT 0 0 0 Etement Currence Line Dx 0.00 Etement Edit MATNO 6 939 Etement Currence Line Dx 0.00 Etement Edit MATNO 0 0 0 Etement Activity Etement Edit Etement Edit MATNO 0 0 0 Etement Activity Etement Edit Etement Edit Deformed Shape Etemen	3: Assign new material number within closed loop MATNO MATNO 4 KF 100 THICI 0 KFi 110 THICI 0 KFi 11 Line Options LTP LMAT 12 LMAT 14 Color 179 LMATO 2 LMATO 2 LMATO 2 LMATO 2 LMATO 2 LMATO 2 Coordinate Constraint • Generated coordinates are movable Base Mest NAC NDAC PLOT-2D Plot Translation Replot Geometry will be moved by distance Dx and Dy in X and Y direction D 0 D Deformed Shape Beam Dx 0.00 D 0 D Contour D 0 D Deformed Shape Beam Dx 0.00 D 0 D Contour D 0 D D	MITTE and Matchai Falailletoi	Show Numb
MATNO 4 KF 1.00 MATod 3 MTYPE MATNO; 0 KFi 1.00 THC; 0.10 Description LTP 0 LMAT 0 Add new mesh Hide Update LTP 2 LMAT 1 Line Options Update LTP 2 LMATo 2 Color Type Thickness Coordinate Constraint © Generated coordinates are movable Base Mesh Base Mesh Element Activity PLOT-2D Plot Translation Replot Group Edity MATNO 6 939 Deformed Shape Dx 0.00 Segment Ed MATNO 0 0 0 Contour Dy 0.00 Exit LMAT 0 0 0 Contour Reference Line Dx 0.00 Exit Figure 5.75 Group dialog for first lift Exit Exit Exit Exit	MATNO 4 KF 1.00 MATold 3 MTYPE MATNO 0 KF 1.00 THICI 0.10 Description LTP 0 LMAT 0 Add new mesh Hide Update LTP 2 LMATi 1 Line Options Update Save Coordinate Constraint Color Type Thickness Save Coordinate Constraint © Generated coordinates are not movable Base Mes Element Activity PLOT-2D Plot Translation Replot MATNO 6 939 Deformed Shape Dx 0.00 MATNO 0 0 Contour Dy 0.00 Exit LMAT 0 0 0 Exit Exit Exit	3: Assign new material number within closed loop	
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ITPi 2 LMATi 1 Line Options Update ITPo 2 LMATo 2 Color Type Thickness Save Coordinate Constraint © 6 Generated coordinates are movable Base Mest Element Activity PL07-2D Plot Translation Replot Geometry will be moved by distance Dx and Dy in X and Y direction Segment Ed MATNO 6 939 Deformed Shape Dx 0.00 E.MATO LMAT 0 0 0 Truss Dx 0.00 E.MATO IMATNO 0 0 0 E.MATO E.MATO E.MATO E.MATO UMAT 0 0 0 E.MATO E.MATO E.MATO E.MATO D 0 0 0 E.MATO E	Image: Picture of the system	LTP 0 LMAT 0 Add new mesh Hide	
LIPO 2 LMATO 2 Color Type Thickness Save Coordinate Constraint • Generated coordinates are not movable Base Mest Element Activity PLOT-2D Plot Translation Geometry will be moved by distance Dx and Dy in X and Y direction Beam Beam Element Activity Beam Dx 0.00 Close Etermine Element Activity Beam Dx 0.00 Close Etermine Etermine Dx 0.00 Close Exit Exit MATN 0 0 0 0 Dx 0.00 Dy 0.00 Close Exit Exit Deformed Shape Dy 0.00 Dy 0.00 Element Activity Element Activity Element Activity	Clippe 2 LMATO 2 Color Type Thickness Save Coordinate Constraint • Generated coordinates are movable • Generated coordinates are not movable • Generated coordinates are not movable • Generated coordinates are not movable • Principal Stress • Deformed Shape • Deformed Shape • Deformed Shape • Truss • Contour • Reference Line • O Dx 0.00 • F.E. Mesh F • Close • Exit Figure 5.75 Group dialog for first lift Figure 5.75 Group dialog for first lift Figure 5.75 Group dialog for first lift Figure 5.75 Group dialog for first lift	LTPi 2 LMATi 1 Line Options	Update
Coordinate Constraint Generated coordinates are not movable Base Mest Element Activity PLOT-2D Plot Translation Replot MATNO 0 0 0 Replot Replot LMAT 0 0 0 Contour Dx 0.00 E.xit Figure 5.75 Group dialog for first lift	Coordinate Constraint Base Mest • Generated coordinates are movable Base Mest Element Activity PL07-2D Plot Translation Replot MATNO O O Deformed Shape Translation Replot MATNO O O O Deformed Shape Dx O.00 Segment Ed LMAT O O Contour Dx O.00 E.wit Contour O O O E.wit Contour O O E.wit Figure 5.75 Group dialog for first lift	LIPo 2 LMATO 2 Color Type Thickness	Save
Element Activity PLOT-2D Plot Geometry will be moved by distance Dx and Dy in X and Y direction Replot MATN0 0 0 0 Frincipal Stress Deformed Shape Dx 0.00 Egement Ed LMAT 0 0 0 Frincipal Stress Dx 0.00 Egement Ed Contour Truss Contour Dx 0.00 Exit Figure 5.75 Group dialog for first lift	Element Activity PLOT-2D Plot Translation Replot MATNO 0 0 0 Geometry will be moved by distance Dx and Dy in X and Y direction Segment Edition LMAT 0 0 0 Deformed Shape Dx 0.00 F.E. Mesh F LMAT 0 0 0 Contour Dy 0.00 Close Exit	Coordinate Constraint Generated coordinates are not movable Generated coordinates are not movable	Base Mesh
NAC NDAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction MATNO 6 939 Deformed Shape Dx 0.00 LMAT 0 0 Truss Dx 0.00 E.E. Mesh Contour 0 0 Exit Exit	NAC NDAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction MAT NO 0 0 0 0 LMAT 0 0 0 0 0 0 0 0 0 FE. Mesh Deformed Shape Dx 0.00 0 0 0 Contour Dy 0.00 0 0 0 Efference Line Dx 0.00 Figure 5.75 Group dialog for first lift	Element Activity PLOT-2D Plot Translation	B 1.
MATNO 6 999 Image: Stepse status Image: Stepse	MATNO 6 993 Deformed Shape in X and Y direction Segment Ed LMAT 0 0 Truss Dx 0.00 F.E. Mesh f Contour 0 0 Environment Exit Exit	NAC NDAC Mesh Geometry will be moved	Group Edito
LMAT 0 0 0 F.E. Mesh P 0 0 0 0 0 0 0 0 0 0 0 0 Reference Line Dy 0.00 Exit Figure 5.75 Group dialog for first lift	LMAT 0	MATNO 6 999 Deformed Shape in X and Y direction	Segment Edi
Figure 5.75 Group dialog for first lift	Image: Contour median Dy 0.00 Close median Image: Dy 0.00 Image: Dy 0.00 Exit Figure 5.75 Group dialog for first lift	0 0 Beam Dx 0.00	F.E. Mesh Pl
Figure 5.75 Group dialog for first lift	Figure 5.75 Group dialog for first lift	0 0 Contour Dy 0.00	Close
Figure 5.75 Group dialog for first lift	Figure 5.75 Group dialog for first lift		Exit
Figure 5.75 Group dialog for first lift	Figure 5.75 Group dialog for first lift		
		Figure 5.75 Group dialog for first lift	

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Figure 5.76 shows finite element meshes generated from group meshes. Finite element meshes near buried pipe are shown in Figure 5.77.



5.5 Arch Warehouse

This example illustrates how to build group meshes for typical arch warehouse structure.

5.5.1 Overview

The cross section of this arch warehouse consists of soil layer, foundations, and arch frame as shown in Figure 5.78.

Construction sequence is listed in Table 5.23.



Figure 5.78 Schematic section of arch warehouse

Step	Description
1,2	In situ stress
3	Excavate trench & place foundation
4	Construct steel arch frame

Table 5.23 Construction sequence

5-74 Group Mesh Example

A total of 5 groups are used to model this arch warehouse as schematically shown in Figure 5.79: 1 for soil layer, 1 for above ground, 2 for foundations, and 1 for arch frame. Table 5.24 summarizes key parameters of groups.





Group	Name		MTYPE	NAC / NDAC	MAT _{OLD} / MATNO / LTP / LMAT / IEND
1	Soil Layer		3	0 / 0	1/0/0/2
2	Above Ground		1	0 / 0	0/0/0/0/0
3	Left	MAT _{OLD}		0/3	
	Foundation	MATNO	4	3 / 999	2 / 3 / 0 / 0 / 2
4	Right	MAT _{OLD}		0/3	
	Foundation	MATNO	4	3 / 999	2 / 3 / 0 / 0 / 2
5	Arch Frame		2	4 / 999	0 / 0 / 2 / 1 / 2 (Checked Add new mesh)

Table 5.24 Group key parameters

Group Mesh Example 5-75



5.5.3 Groups

Group meshes are divided into three parts:

- Soil layer and above ground
- Foundation
- Arch frame

It should be noted that the final finite element meshes are most influenced by group order and IEND.

5.5.3.1 Soil Layer and Above Ground

Above Ground represents upper block of base mesh which will vanish. Table 5.25 lists key parameters of these groups

Group	Name	MTYPE	Elem	MATNO	Seg.	Begir Poi	ning int	End Poi	ing int	IEND
				/ NAC / NDAC		х	Y	х	Y	
					1	0	0	40	0	2
					2	40	0	40	10	2
1	Soil Layer	3	Cont	1/0/0	3	40	10	0	10	2
					4	0	10	0	0	2
					1	0	10	40	10	2
					2	40	10	40	25	2
2	Above Ground	1	Cont	0/0/0	3	40	25	0	25	2
					4	0	25	0	10	2

Table 5.25 Key parameters for soil layer and above ground

Group Mesh Example 5-77

Group Identity Group No 1		Title Soil Laver		Edit Group
MTYPE and M	aterial Parameter			Show Numb
3 Assign ne	w material number w	within closed loop	•	
MATNO 1 MATNOi 0	KF 1.	.00 MATold 3 .00 THIC 0.10	MTYPE Description	1-> 2
LTP 0	LMAT 0	Add new	mesh 🗆 Hide	
LTPi 2	LMATi 1	Line Opti	Oris	Update
LIF6 [2	LINNIO Z	Color	Type Inconess	Save
Coordinate Co	straint coordinates are mov	rable C Generated noo	rdinates are not movable	Base Mest
Element Activ	ly	PLOT-2D Plot	Translation	
NA	NDAC	E Mesh	Geometry will be moved	Group Edito
MATNO	0	Principal Stress Deformed Shape	by distance Dx and Dy in X and Y direction	Segment Ed
		E Beam	0* 000	F.E. Mesh P
LMAT 0	0	E Contour	DX 0.00	Close
E E	0	Reference Line	by J add	Exit
	0	Contour Reference Line	Dy 0.00	Close Exit

5-78 Group Mesh Example

Group	
Group No 2 <> Title Above Ground	Edit Group
MTYPE and Material Parameter	Show Number
1: Generate lines & remove elements within closed loop	
MATNO 1 KF 1.00 MATold 3 MTYPE MATNO; 0 KFi 1.00 THIC; 0.10 Description	cut inside
LTPi 2 LMATi 1 Add new mesh Hide	Update
LTPO 2 LMATO 2 Color Type Thickness	Save
Coordinate Constraint	
Generated coordinates are movable C Generated coordinates are not movable	Base Mesh
Element Activity PLOT-2D Plot Translation NAC NDAC Mesh Geometry will be moved by distance Dx and Dy in X and Y direction 0 0 Beam Dx 0 0 Trunce Dx	Replot Group Editor Segment Editor F.E. Mesh Plot
Differ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 Dy 0.00	Close Exit
Figure 5.83 Group dialog for above grou	nd

5.5.3.2 Foundation

Each foundation group includes both in situ soils and concrete block such that in situ soils are replaced by concrete block when foundation is built. Table 5.26 lists key parameters of these groups.

Group	Na	me	NAC / NDAC	MTYPE	Seg.	Begir Po	nning int	End Poi	ing int	IEND
				Elem		х	Y	х	Y	
					1	8	8	12	8	2
3	Left	MAI _{OLD} =2	0/3	4	2	12	8	12	10	2
	Foundation			Cont	3	12	10	8	10	2
		MATNO=3	3 / 999		4	8	10	8	8	2
					1	28	8	32	8	2
4	Right	MAI _{OLD} =2	0/3	4	2	32	8	32	10	2
	Foundation			Cont	3	32	10	28	10	2
		MATNO=3	3 / 999		4	28	10	28	8	2

Table 5.26 Key parameters for foundation

5-80 Group Mesh Example

Group Identity Group No Title Left Foundation Edit Group Show Nu MTYPE and Material Parameter Image: Show Nu (4: Same as MTYPE = 3 but keep old & add new materials Image: Show Nu MATNO KF 1.00 MATold 2 Image: MTYPE MATNO KF 1.00 MATold 2 Image: MTYPE LTP LMAT O Add new mesh Hide Updat LTP LMATO Add new mesh Hide Updat Coordinate Constraint Generated coordinates are movable Base Mr Coordinate Constraint Generated coordinates are not movable Base Mr MAT NO 3 939 PLOT-2D Plot Translation Replot MAT NO 3 939 Deformed Shape Dx and Y direction Segment R LMAT 0 0 O Deformed Shape Dx and Y direction Exit MATNO 0 0 O Deformed Shape Dx and Y direction Exit MATNO 0 0 O Deformed Shape Dx and Y direction Exit Difference Line Differe	Group Identity Group No Image: Table Left Foundation Edit Graphic School Schol School School School School School School Schol Sch	Group			
MTYPE and Material Parameter Show Nu 4: Same as MTYPE = 3 but keep old & add new materials Image: Constraint MATNO KF 1.00 MATNO MATO Add new mesh LTPo LMATO Color Type Thickness Save Coordinate Constraint Generated coordinates are not movable Base Me MATNO Base Mesh PloT-2D Plot Translation Replo MATNO Base Mesh Dx 0.00 Segment M MATNO Beam Translation Replo Segment M LMAT O O O Deformed Shape Dx 0.00 Dy 0.00 Exit Exit Corotour Reference Line <td< td=""><td>MTYPE and Material Parameter Show Nu 4: Same as MTYPE = 3 but keep old & add new materials Image: Constraint MATNO 3 KF 1.00 MATNO 0 KF 1.00 MAT 0 Add new mesh Hide UTP 0 LMAT 0 Add new mesh Coordinate Constraint Color Type © Generated coordinates are movable Base M PLOT-20 Plot Translation Replay MATNO 3 3939 Deformed Shape Dx 0.00 MAT 0 0 0 0 Dx 0.00 Esem Truss Contour Reference Line Dx 0.00 Eset Figure 5.84 Group dialog for left foundation Eset</td><td>Group Identity Group No 3</td><td>Title Left Foundation</td><td></td><td>Edit Gro</td></td<>	MTYPE and Material Parameter Show Nu 4: Same as MTYPE = 3 but keep old & add new materials Image: Constraint MATNO 3 KF 1.00 MATNO 0 KF 1.00 MAT 0 Add new mesh Hide UTP 0 LMAT 0 Add new mesh Coordinate Constraint Color Type © Generated coordinates are movable Base M PLOT-20 Plot Translation Replay MATNO 3 3939 Deformed Shape Dx 0.00 MAT 0 0 0 0 Dx 0.00 Esem Truss Contour Reference Line Dx 0.00 Eset Figure 5.84 Group dialog for left foundation Eset	Group Identity Group No 3	Title Left Foundation		Edit Gro
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LTP: 2 LMATi 1 Line Options Update LTP: 2 LMATo 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are not worable Base Me Element Activity PLOT-2D Plot Translation Replo MAT 00 3 939 Deformed Shape Base Me LMAT 0 0 Deformed Shape Dx 0.00 LMAT 0 0 Element Contour Reference Line Dx 0.00 FE. Mest Dy 0.00 Exit Exit	LTP 2 LMATO 1 Line Options Update LTPO 2 LMATO 2 Color Type Thickness Save Coordinate Constraint © Generated coordinates are not movable Base M Element Activity PLOT-2D Plot Translation Replay MATO 0 3 939 Deformed Shape Beam LMAT 0 0 Element Constraint Segment F.E. Mesi LMAT 0 0 Element Constraint Segment F.E. Mesi Deformed Shape Deformed Shape Dato Dato Segment E.E. Mesi Director Director Director Director Director E.E. Mesi Director Director Director Director Exit Segment Director Director Director Exit Director Director Director Director Exit Director Director Director Director Exit Figure 5.84 Group dialog for left foundation Sit	LTP 0 LMAT	0 🗖 Add nev	w mesh 🗖 Hide	
Coordinate Constraint Generated coordinates are movable Element Activity MAT old O MAT old O Coordinates are movable PLOT-2D Plot Principal Stress Deformed Shape Deformed Shape Contour Reference Line Figure 5.84 Group dialog for left foundation	Coordinate Constraint Generated coordinates are not movable Base M Element Activity PLOT-2D Plot Translation Replation MAT old 0 0 Mesh Principal Stress Deformed Shape LMAT 0 0 0 Beam Dx 0.00 Segment LMAT 0 0 0 Reference Line Dx 0.00 Exit	LTPi 2 LMATi LTPo 2 LMATo	1 Line Opt	r Type Thickness	Update
Image: Second coordinates are movable Base Mail Image: Second coordinates are movable Base Mail Image: Second coordinates are movable PLOT-2D Plot Image: Second coordinates are movable PLOT-2D Plot Image: Second coordinates are movable Replot Image: Second coordinates are movable Replot Image: Second coordinates are movable PLOT-2D Plot Image: Second coordinates are movable Replot Image: Second coordinates are movable Image: Second coordinates are movable Image: Second coordinates are movable Image: Second coordinates are movable Image: Second coordinates are movable Image: Second coordinates are movable Image: Second coordinates are movable Image: Second coordinates are movable Image: Second coordinates are movable Image: Second coordinates ar	Image: Second late weak of the second late sec	Coordinate Constraint			
Element Activity PLOT-2D Plot Geometry will be moved by distance Dx and Dy in X and Y direction Replot Group Edition MATNO 3 939 Deformed Shape Dx 0.00 F.E. Mesh LMAT 0 0 0 Deformed Shape Dx 0.00 Edition F.E. Mesh DMAT 0 0 D Reference Line Dx 0.00 Exit	Element Activity PLOT-2D Plot Translation Replay MAT old 0 3 999 Deformed Shape by distance Dx and Dy in X and Y direction Segment LMAT 0 0 0 Element Contour Dy 0.00 Exit Figure 5.84 Group dialog for left foundation	 Generated coordinates are manual 	ovable C Generated cod	ordinates are not movable	Base Me
MAL NUAL Mesh Geometry will be moved by distance Dx and Dy in X and Y direction Group Ed Segment I MATNO 3 939 Deformed Shape Dx 0.00 F.E. Mesh LMAT 0 0 Truss Dy 0.00 Exit Figure 5.84 Group dialog for left foundation	MAL NAL NAL Mesh Geometry will be moved by distance Dx and Dy in X and Y direction MATNO 3 999 Deformed Shape Dx 0.00 F.E. Mest LMAT 0 0 0 Contour Dx 0.00 Exit Dy 0.00 0 Contour Dy 0.00 Exit Figure 5.84 Group dialog for left foundation	Element Activity	PLOT-2D Plot	Translation	Replo
MATNO 3 999 Deformed Shape in X and Y direction Segment If LMAT 0	MATNO 3 999 Deformed Shape in X and Y direction Segment LMAT 0 0 0 Truss Dx 0.00 F.E. Mest 0 0 0 0 Ference Line Dx 0.00 Exit Figure 5.84 Group dialog for left foundation	MATold 0 3	Principal Stress	by distance Dx and Dy	Group Ec
LMAT 0 0 0 Truss Dx 0.00 Truss Dy 0.00 Close 0 0 0 0 Feference Line Dy 0.00 Exit Figure 5.84 Group dialog for left foundation	Imate of the second	MATNO 3 999	Deformed Shape	in X and Y direction	Segment i
Figure 5.84 Group dialog for left foundation	Figure 5.84 Group dialog for left foundation	LMAT 0 0	Truss	Dx 0.00	Close
Figure 5.84 Group dialog for left foundation	Figure 5.84 Group dialog for left foundation	0 0	Reference Line	by 0.00	Exit
Figure 5.84 Group dialog for left foundation	Figure 5.84 Group dialog for left foundation				
		Figure 5.8	4 Group dial	og for left foundat	tion
		rigure sie		og for fere foundu	

5.5.3.3 Arch Frame

Arch Frame is the only structure in the upper block of base mesh since the Above Ground group generates void space. Table 5.27 lists key parameters of this group.

					Elemen	t Activity
Group	Name	MIYPE	Element	LIP / LMAI	NAC	NDAC
5	Arch Frame	2	Beam	2 / 1	4	999

			Line Se	egment				Arc Se	egment				
Group	Seg	Begir	n. Pt.	Endir	ng Pt.	Orig	jin		Radius a	& Angle		NDIV	IEND
		х	Y	х	Y	Xo	Yo	R _x	R _Y	Θ_{b}	Θ _e		
	1	30	10	30	15							5	2
5	2					20	15	10	5	0	180	20	2
	3	10	15	10	10							5	2

Table 5.27Key parameters for arch frame

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Group Identity- Group No 5 > THe Atch Frame Edit Gr MTYPE and Material Parameter 2 Generate Ines Show Ni 2 Generate Ines Matrial 3 MTYPE MATND 1 KF 1.00 Matrial 3 MTYPE MATND 0 KFi 1.00 Matrial 3 MTYPE LTP 2 LMAT 1 IV Add new mesh Hide Upda LTPi 2 LMATi 1 IV Add new mesh Hide Upda Coordinate Constraint Color Type Thickness Saw
MTYPE and Material Parameter 2 Generate lines Image: Constraint MATND 1 KF 1.00 MATold Image: Constraint MATND 1 KF 1.00 MATold Image: Constraint Image: Constraint MATND 1 KF 1.00 THIC; 0.10 Description LTP 2 LMAT Image: Color Type Thickness Save Coordinate Constraint Image: Constraint Image: Constraint Image: Constraint Base M
2. Generate lines Image: Constraint MATND 1 KF 1.00 MATold 3 MTYPE MATND 0 KFi 1.00 THICi 0.10 Description LTP 2 LMAT Image: Color Type Thickness Sav LTPo 2 LMATo 2 Color Type Thickness Sav Coordinate Constraint Generated coordinates are movable C Generated coordinates are not movable Base M
Coordinate Constraint Generated coordinates are movable Generated coordinates are not movable Base M
Uenerated coordinates are movable Uenerated coordinates are not movable
Element Activity PLOT-2D Plot Translation Repl NAC NDAC Mesh Geometry will be moved by distance Dx and Dy inX and Y direction Geometry will be moved by distance Dx and Dy inX and Y direction Repl LMAT 0 0 Functional Stress Dx 0.00 F.E. Mess 0 0 Functional Stress Dx 0.00 F.E. Mess 0 0 Formed Dy 0.00 F.E. Mess 0 0 Formed Dy 0.00 Exist



5.6 Finite Element Mesh Modification

This example illustrates how to modify existing finite element meshes using Mesh Generator.

5.6.1 Overview

When you open input file, Mesh Generator reads the extension of the input file name and it assumes that the input file is the finite element mesh file if the extension is .Mes.

Editing finite element meshes has three parts: Nodal Boundary, Nodal Coordinate and Element Material. These editing modes can be accessed from Mesh menu in PLOT-2D as shown in Figure 5.87.



Figure 5.87 Menu for editing finite element mesh

It should be noted that once you edited the finite element meshes, modified finite element mesh is saved as MeshFile.Mes in the current working directory. The original input mesh file is not changed.

Figure 5.88 shows existing finite element mesh with six layers of natural soils. The top layer of this existing mesh is to be replaced by sand embankment with reduced width as schematically shown in Figure 5.89.

This modification involves following three works:

- Change top surface nodal coordinates
- Change top surface nodal boundaries
- Change top layer element materials

Group Mesh Example 5



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5.6.2 Change Top Surface Nodal Coordinates Click Nodal Coordinate from the Mesh menu, then Edit Coordinate dialog in Figure 5.90 is displayed.
Select Coordinate Method and Click Select Node Coordinate By Image: Mouse Pickup Image: Mouse P
Figure 5.90 Edit coordinate dialog For this example, Snap to Half of Grid in Figure 5.91 is the most convenient method for Mouse Pickup.
Mouse Snap Method C Screen Resolution C Whole Number (0000) C Snap to Node C 1 after Decimal Pt. (0000.0) C Snap to Grid C 2 after Decimal Pt. (0000.00) Image: Snap to Half of Grid C 3 after Decimal Pt. (0000.000) Image: Snap to Half of Grid C 4 after Decimal Pt. (0000.0000) Image: Snap to Entity Line End Point / Arc Origin C Snap to Entity Line / Arc Face Image: DK Cancel
Figure 5.91 Mouse snap method

Group Mesh Example



5-87

5-88 Group Mesh Example



Group Mesh Example 5-89





Change the boundary codes as in Figure 5.100 so that the top left node can be free to move in both horizontal and vertical directions and then click Apply Code button. Figure 5.100 Select Node By Mouse Right Click Modified boundary code Node Number By Enter Node Nofor top left node € Mouse Pickup C Enter Node No 1 New Boundary Code-= 0 Free to move in specified direction. = 1 Fixed in specified direction. Apply Code Cancel In the same way, select the top right node, modify boundary codes, and click Apply Code. Since all boundary codes are modified, click Finish button in Figure 5.101. Figure 5.101 Select Node By Mouse Right Click Modified boundary code Node Number By-----Enter Node Nofor top right node Mouse Pickup C Enter Node No 43 New Boundary Code-
 ISX
 ISY
 IFX
 IFY
 IRZ
 IEX
 IEY

 0
 0
 1
 1
 1
 1
 1
 1
 = 0 Free to move in specified direction. = 1 Fixed in specified direction. Undo Finish Cancel

Click General View from the View menu. Select Skeleton Boundary Code in General View Options dialog as shown in Figure 5.102 and then click OK button. Modified skeleton boundary codes are shown in Figure 5.103.

Figure 5.102

General view for skeleton boundary code



Figure 5.103 Modified skeleton boundary code plot





Figure 5.106 Modified material number for element 1	Select Element By Mouse Right Click Element Number By Element No Mouse Pickup 1 Enter Element No 1 New Material Parameter 1 MATNo KF TBJWL 2 0 1 0.00000 KS e0:Solid, > 0:Joint Face No, -1:Detonation KF = 0:Fluid, TBJWL: Det. Time for KS=-1 Apply Cancel
Repeat the same procedure for th Once finished, click Finish button i	e other elements on the top layer. in Figure 5.107.
	Select Element By Mourse Pight Click




6.1 Single Element

The main objective of this first example is to show the step by step procedure to create block mesh.

This example is to build single cube element in Figure 6.1 by using block mesh generator. This single element is subjected to undrained uniaxial strain loading.

This example involves following seven main steps:

- 1. Access block mesh generator
- 2. Set work plane
- 3. Build cube entity
- 4. Build hexahedron block
- 5. Edit block boundary code
- 6. View skeleton boundary code
- 7. Plot finite element mesh



Figure 6.1 Single element in uniaxial strain condition



Figure 6.2 Accessing block mesh generator

Step 2: Set Work Plane

Prebuilt Work Plane is displayed on drawing board along with Work Plane Editor dialog. Modify NDx and Wx in Figure 6.3 and click Update.

Mana				
Name	Plane (X :	YJ		
Reset Initia	al Global Coord	linate Layout —		
	y L x	z 🚽	× z	z×x
🖲 None	C Front	C Side	C Plan	C Isometric
Reset Bas	e Work Plane	Local Coordinal	te	
🖲 None	$\mathbf{C}_{(\mathbf{x},\mathbf{y})}$	$\mathbf{C}_{(z,y)} = \mathbf{C}$	(z, x) C Mar	nual Specify
Translate /	Rotate Work	Plane		
Translate	×	- y'	z'	
Botate: De	р. а. Го.	10.	- IO.	- New
Rotate: Orr	er 1	2	3	
Grid Dimer	isions and Divi	isions		-
NQ	NDx 2	NDy 2	Wx	- Wy 2.
-	<u> </u>	J=.	1-	
	List	Hide Plane	Descr	iption Uptio
odate	Entity	Add Plane	Delete	Plane Exit

Step 3: Build Cube Entity1. Click Entity button in Figure 6.3.2. Entity Editor dialog is displayed as in Figure 6.4.
Entities on Work Plane 1 Entity Number 1 (Line Entity) Name Line Entity) Name Line Segment Line Thickness Line Type C Thin C Thick Image: Solid C Dash C Show Image: Solid C Dash C Show Image: Hide Line Color Image: Solid C Dash C Green Image: Blue C Red C Grey C Black Reference Coordinate Image: Solid C Dash Image: Line Color Image: Solid C Dash Reset To Global Image: Solid C Dash Reset To Global Image: Solid C Dash Exit
Figure 6.4 Entity editor 3. Click Add button in Figure 6.4. 4. Select Cube entity and click OK button in Figure 6.5.
Add Entity 3 Select Entity Type C Line C Arc C Cube C Ellipsoid C Cylinder C Copy Existing Entity Entity No : 1 OK Cancel
Figure 6.5 Entity type selection

Entity 3 on Work Plane 1
1. Select Reference 3. Enter Drigin Local $xo' = [0,, yo' = 0]$ 2. Select Method $xo' = [0,, yo' = 0]$ \bigcirc Mouse Pickup $zo' = [0,, zo' = 0]$ \bigcirc Enter xo', yo', zo' \square New Drawing 4. Enter Dimensions $ x = 1 $ \bigvee \downarrow \bigvee \downarrow
5. Draw Cube Entity Finish Cancel Local coordinates depend on current work plane. Click Finish button once you finished an entity.
Figure 6.6 Cube entity





12. Click F 13. Click F 14. Select 15. Click R	inish in Figure 6.7. inish in Figure 6.6. Global for Reference Coordinate in Figure 6.11. Reset To Global and then Exit buttons in Figure 6.11.
-	Entities on Work Plane 1
	Name Cube Entity (New) Line Thickness Line Type Image: Thin Control Thick Image: Solid Control Thick
	Line Color
	Update Edit Add Delete Exit
	Figure 6.11 Entity editor





Block Mesh Example



6-11

6-12 Block Mesh Example



Block	Mesh	Example	6-13
-------	------	---------	------



6-14 Block Mesh Example

	BIOCK	Editor	
Title Single Elemen	k l		
Block No 1 [Hexahe	edron Block]		2
Name Hexahedron B	Nock		Hide Block
- Interpolation Coordinate	System (ICOORD)		
I. Rectangular	C 2. Spherical	C 3. Cylindrical	
- Coordinate Modification	(IMODE)	an an an ann an an an an an an an an an	Ur.
🗭 0. Donot modify	C 1. Modify coord	inate using node M28 as o	rign
 Interpolation Scheme (II 	AG) — C 1. Lagrangian		
0 (M28) Origin 0 (M29) Defin	Negative value means	arc shape over 180 degre 9 0 0th	es in sphere or cylinder er cylinder axis M28-M31
- Material and Element G	NDV NDZ	KS KE	e.
1 1	1 1		
Mid Node AlphaX Reset 0.	Alpha Y Alpha Z	Nt1 Mat1 Nt2 Mat2	Nt3 Mat3 Nt4 Mata
	Chau Index	Show F. E. Mesh	Edit Boundary
< > List	Show moex		

Step 5: Edit Block Boundary Code

- 1. Click Edit Boundary in Figure 6.22.
- 2. Set the boundary codes as shown in Figure 6.23.
- 3. Click IBTYPE button to see description of boundary type in Fig. 6.24.
- 4. Click Update and then OK buttons.

			Bo	undary	Code			-	x
Boundary C	Codes for	Block I	No 1 -						_
IBTYPE	Skelet ISX	on DOF ISY	ISZ	Pore I IFX	Fluid DC IFY)F IFZ			
1	1	1	1	1	1	1			
IBTYPE	ISX	ISY	ISZ	IFX	IFY	IFZ			
Note: Fre Default c	1 ee to mov codes IS	1 /e in sp X=ISY=	1 ecified di ISZ=0	1 irection fr FX=IFY=I	1 or DOF = IFZ=1	1 = 0, Fixed RX=IRY=	for DOF = IRZ=1	1	
Update		Add	Del	ete			OK	Cancel	

Figure 6.23 Boundary code editor



General View Options	
Legend Number Format	Numbers & Current Mesh File -
C Exponential (e) Cecimal Floating (r)	C None
Continuum Element Outline	C Element Number
C White C Blue C Red C Grey @ Black	C Node and Element Number
Beam Element Outline	Skeleton Boundary Code
C Green C Blue (* Red C Grey C Black	C Botation Boundary Code
Truss Element Outline	C Slip Boundary Code
In Green ○ Blue ○ Red ○ Grey ○ Black	C Material Number
Joint Element Outline	C Material and Node Number
C White C Blue C Red C Grey @ Black	C Y Coordinate
Shell Element Outline	C Z Coordinate
○ White ● Blue ○ Red ○ Grey ○ Black	C Current Mesh File Name
Node No	Element Number Range
⊂ Green ⊂ Blue ⊂ Red ⊂ Grey ④ Black	Minimum Maximum
Boundary Code	11 [100000
⊂ Green IF Blue ⊂ Red ⊂ Grey ⊂ Black	Node Number Range
Element No / Material No	Minimum Maximum
⊂ Green ⊂ Blue @ Red ⊂ Grey ⊂ Black	1 100000
- Index No	Mark Nodal Points
C Green C Blue @ Red C Grev C Black	it shell it been it has
Color on Cin Plane	Min and Max Values
	Add XYZ axes
Show At Binkt Meuro Putter Fish	- Reset Al View Onlines
	C Yes @ No
- Show Unreferenced Nadex: Net Connected to Elemente	
Show Unreferenced Nodes: Not Connected to Elements	





6.2 Cube Foundation

This example illustrates how to build block mesh for cube foundation. Cube foundation has the dimensions of $100 \times 100 \times 100$ units with all roller boundaries except free on top surface.

This example has the following two parts:

Part 1: Creating Cube Foundation (Figure 6.30)

- Access block mesh generator (New)
- Set work plane
- Build hexahedron block
- Edit block boundary
- Set global boundary
- View skeleton boundary code
- Plot finite element mesh

Part 2: Modifying Cube Foundation (Figure 6.31)

- Access block mesh generator (Open)
- Modify element generation parameters
- Plot finite element mesh

6-20 Block Mesh Example



6.2.1 Part 1: Creating Cube Foundation

Part 1 consists of the following seven main steps:

- 1. Access block mesh generator (New)
- 2. Set work plane
- 3. Build hexahedron block
- 4. Edit block boundary
- 5. Set global boundary
- 6. View skeleton boundary code
- 7. Plot finite element mesh

Step 1: Access Block Mesh Generator (New)

Access Block Mesh Generator by selecting the following menu items in SMAP (Figure 6.2):

 $\mathsf{Run} \to \mathsf{Mesh} \; \mathsf{Generator} \to \mathsf{Block} \; \mathsf{Mesh} \to \mathsf{New}$

Step 2: Set Work Plane

Prebuilt Work Plane is displayed on drawing board along with Work Plane Editor dialog. Modify NDx and Wx in Figure 6.32 and click Update button.

Name T	ana DC:Y	1		
- Reset Initial Gio	bal Coordin	da Layout -		
	ť	Ì	£.	1.
@ Nove C	Front	C Sete	C Plan	C horate
Renet Base We	R Plane Lo	cal Coordinate		
@ Now C	ical C	EN CI	C. Mars	of Specify
Translate / Rot	sie Work PS	ana		
	/	4		
Translate [10	10.	Dian
Rolate Dep		0	0.	Origin
Rulate Order		2	3	-
- Grid Dimensions	and Distric			
NO N	Da	NDy	We	W
0 2		2	200.	200.
-	-		-	-

Figure 6.32 Work plane editor

Step 3: Build Hexahedron Block

Follow the same procedure as in Step 4 in the first example.

- 1. Click Axis toolbar as shown in Figure 6.9.
- 2. Click Block Editor toolbar in Figure 6.12.
- 3. Select Hexa for block type and click OK in Figure 6.13.
- 4. Click Draw Index Number in Figure 6.14.
- 5. Coordinates on Work Plane dialog is displayed as in Figure 6.15.

Index Numbers on Front Surface

- 6. Translate work plane as in Figure 6.33 and click Update button.
- 7. Click the points for index numbers on front surface as in Fig. 6.34.

Index Numbers on Back Surface

8. Translate work plane as in Figure 6.35 and click Update button.

9. Click the points for index numbers on back surface as in Figure 6.36.

Now, the geometry of hexahedron block is completed.

- 10. Click Finish in Figure 6.20.
- 11. Click Finish in Figure 6.14.
- 12. Modify Title and Material & Element Generation Parameters in Block Editor dialog as shown in Figure 6.37.

Block Mesh Example 6-23





lesh Exa	ample	6-25
	lesh Exa	esh Example

	Block Editor		
Title Cube Foundation			
Block No 1 [Hexahedron B	lement]		
Name Hexahedron Block			Hide Block
Interpolation Coordinate Syste	m (ICOORD)		
 1. Rectangular 	2. Spherical C 3. C	ylindrical	
Coordinate Modification (IMOE	E)		
 O. Do not modify 	 Modify coordinate using no 	de M28 as orign	
Interpolation Scheme (ILAG) - O Serendinitu	1 Lagrangian		
Deferred No. 1. N. 1			
Meterence Node Numbers —	ative value means arc shape ov	er 180 dearees in sr	bere or culinder
0 (M29) Defining cyl	nder axis M28-M29	(M30) Other cylind	ler axis M28-M3
Material and Element Generat	on Parameters		
MATNO NDX ND'	NDZ KS	KF	
Mid Node Alpha× Alph	a Y Alpha Z Nt1 Mat1	Nt2 Mat2 Nt3 M	/lat3 Nt4 Mat
	0. 0		0 0 0
Reset U. U.			
Reset U. U.	Show Index Show F	E Mesh E	dit Boundary
Reset U. U.	Show Index Show F.	E. Mesh E	dit Boundary



Figure 6.39 Boundary type for hexa block





Figure 6.42 Skeleton boundary codes on drawing board





ep 9 Click E Iodify Click F Click S	Modify Element Generation Parameters Block Editor toolbar in Figure 6.12. Alpha X, Alpha Y, Alpha Z as in Figure 6.46. Reset. Gave.
	Block Editor
	Title Cube Foundation Block No 1 [Hexahedron Element]
	Name Hexahedron Block Hide Block
	Interpolation Coordinate System (ICOORD)
	Coordinate Modification (IMODE) Coordinate Modify Coordinate based on rectangular grid
	Interpolation Scheme (ILAG) Interpolation Scheme (ILAG) Image: Constraint of the second se
	Reference Node Numbers 0 (M28) Origin. Negative value means arc shape over 180 degrees in sphere or cylinder 0 (M29) Defining cylinder axis M28-M29 0 (M30) Other cylinder axis M28-M30
	Material and Element Generation Parameters
	MATNO NDX NDY NDZ KS KF 1. 6 6 6 0 1
	Mid Node Alpha X Alpha Y Alpha Z Nt1 Nt2 Mat2 Nt3 Mt4 Mat4 Reset 0.3 0.3 0.3 0.0 0
	List Show Index Show F. E. Mesh Edit Boundary Edit Coordinate Add Block Delete Block Save Exit
	Figure 6.46 Block editor

6-32 Block Mesh Example



- 6. Click Axis toolbar in Figure 6.9.
- 7. Block mesh is shown in Figure 6.47.



Figure 6.47 Block mesh on drawing board





Step 1: Access Block Mesh Generator (New)

Access Block Mesh Generator by selecting the following menu items in SMAP (Figure 6.2):

 $\mathsf{Run} \to \mathsf{Mesh}\;\mathsf{Generator} \to \mathsf{Block}\;\mathsf{Mesh} \to \mathsf{New}$

Step 2: Set Work Plane

1. Select Work Plane No 4 and set parameters for Grid Dimension and Division as shown in Figure 6.50.

Name	Plane (X:	Ŋ		
- Reset Initia	I Global Coord	inate Layout –		
	Ý L.x	z 🚽	y x	z
None	C Front	C Side	C Plan	C Isometric
- Reset Base	Work Plane	Local Coordina	te	
None	C (x, y)	C (z, y) C	(z, x) C Mar	nual Specify
- Translate /	Rotate Work	Plane		
Translate	× 0.	y 0.	Z	Draw
Rotate: Deg	0.	0.	0.	- New Origin
Rotate: Ord	er 1	2	3	•
- Grid Dimen	sions and Divi	sions		
NQ	NDx	NDy	Wx	Wy
0	10	10	10.	10.
	List	Hide Plane	Descr	iption Option
Update E	Entity	Add Plane	Delete	Plane Exit




 Type in dimensions of arc entity as shown in Figure 6.55. Click Draw Arc Entity.
Entity 3 on Work Plane 4
1. Select Reference3. Enter Origin $Local$ $xo' = 0$ $yo' = 0$ $yo' = 0$ c Mouse Pickup $v' = 0$ c Enter xo', yo', zo' w New Drawing4. Enter Dimensions $Rx = 10$ $Py = 10$ $Qb = 18$ $Qe = 90$ $Qe = 90$ For $Qb = Qe$, straight line from $R = Rx$ to $R = Ry$ Rx and Ry represent radial distance at $Q = Qb$.5. Draw Arc EntityFinishCancelLocal coordinates depend on current work plane.Click Finish button once you finished an entity.
Figure 6.55 Arc entity 6. Figure 6.56 shows Coordinates on Work Plane dialog.
Coordinates on Work Plane Point Number 1 Drawing Mode x' = 0.0000e+00 Image: Single Point y' = 0.0000e+00 Image: Single Point z' = 0.0000e+00 Info Finish Elick Point Snap Image: Half Grid Full Grid Tenth Grid Image: Half Grid Full Grid Tenth Grid Image: Ent. Point Ent. Face Block Node
Figure 6.56 Coordinates on work plane

Block Mesh Example 6



6-40 Block Mesh Example

9. C 10. C 11. C 12. C	lick Finish in Figure 6.56. lick Finish in Figure 6.55. lick Global for Reference Coordinate in Figure 6.59. lick Reset To Global.
	Entities on Work Plane 4 Entity Number 3 (Arc Entity) Name Arc Entity (on YZ) Line Thickness Line Type Line Thickness Line Type C Thin C Thick © Solid C Dash © Green O Blue O Red O Grey O Black C Local © Global C > List Show Entity No Reset To Global Update Edit Add Delete
	Figure 6.59 Entity editor

Arc Entity on XZ plane

Follow the same procedure as for Arc Entity on YZ plane.

- 1. Click Add in Entity Editor dialog in Figure 6.59.
- 2. Select Arc in Entity Type Selection dialog in Figure 6.54.
- 3. Click OK.
- 4. Type in dimensions of arc entity as shown in Figure 6.60.
- 5. Click Draw Arc Entity.
- 6. Coordinates on Work Plane dialog in Figure 6.56 is shown.

1. Select Reference Local 2. Select Method C Mouse Pickup C Enter xo', yo', zo' 4. Enter Dimensions Rx OB Ry	3. Enter Origin xo' = 0. yo' = 0. zo' = 0. New Drawing Rx = 10 Ry = 10 Ry = 10
For Qb = Qe, straight line fro Rx and Ry represent radial 5. Draw Arc Entity	Qb = 0 $Qe = 72$ $m R = Rx to R = Ry$ distance at Q = Qb. Finish Cancel
Click Finish button once y	our finished an entity.

6-42 Block Mesh Example



9. 10. 11. 12.	Click Click Click Click	Finish in Figure 6.56. Finish in Figure 6.60. Global for Reference Coordinate in Figure 6.63. Reset To Global and then Exit buttons in Figure 6.63.
		Entities on Work Plane 4 Entity Number 4 (Arc Entity) Name Arc Entity (on X2) Line Thickness Line Thickness Line Thick Solid Dash Entity Color Green Blue Reference Coordinate Local List Show Entity No Reset To Global Update Edit Add Delete
		Figure 6.63 Entity editor







6-46 Block Mesh Example



Block Mesh Example 6-47



6-48 Block Mesh Example



Block Editor
Title Hemispherical Shell
Block No 1 [Quad Block]
Name Quad Block Hide Block
└ Interpolation Coordinate System (ICOORD)
C 1. Rectangular • 2. Spherical C 3. Cylindrical
Coordinate Modification (IMODE)
Interpolation Scheme (ILAG) O O. Serendipity C 1. Lagrangian C 2. Surface Sector Define Sector
Reference Node Numbers 5 (M10) Origin. Negative value means arc shape over 180 degrees in sphere or cylinder 0 (M11) Defining cylinder axis M10-M11 0 (M12) Other cylinder axis M10-M12
Material and Element Generation Parameters MATND NDX NDY 1 8 8 Mid Node Alpha X Alpha Y Nt1 Mat1 Nt2 Mat2 Nt3 Mat3 Nt4 Mat4
Reset 0. 0. 0 0 0 0 0 0 0
List Show Index Show F. E. Mesh Edit Boundary

Step 5: Edit Block Boundary Code

- 1. Click Edit Boundary in Figure 6.73.
- 2. Set the boundary codes as shown in Figure 6.74.
- 3. Click IBTYPE button to see description of boundary type in Fig. 6.75.
- 4. Click Update and then OK buttons.
- 5. Click Save in Figure 6.73 and type in file name as EX3.

loundary (Sedes to	r Block	No 1			
	Skele	ton DOR	-	Rotat	ional D C	IF
UTYPE	151	1\$Y	152	IFDC	IRY'	RZ
1	0	0	0	0	0	0
2	0	1	D	1	0	1
4	1	0	D	a	1	1
IBTYPE	ISX	ISY	ISZ	IRK	IBY	IRZ
Note: Fit Default of	ee to nic	we in op DoetSho	eoiled direction for 1 d52-0 100-074-02	DOF = 0. Fired for DOF 5-1 IFD04FFY-4Fi2-0	-1	

Figure 6.74 Boundary code editor





6-52 Block Mesh Example





- 4. Follow the same procedure to plot boundary codes as in Step 6.
- 5. Skeleton and rotation boundary codes are shown in Figures 6.80 and 6.81, respectively.



Figure 6.80 Skeleton boundary codes



6.4 Horseshoe Tunnel

This example illustrates how to build block mesh for horseshoe tunnel with reinforced concrete lining as schematically shown in Figure 6.82.

This example involves following eight main steps:

- 1. Access block mesh generator
- 2. Set work plane
- 3. Build entities
- 4. Add work plane
- 5. Build blocks
- 6. Set global boundary
- 7. View selected material
- 8. Plot finite element mesh



Step 1: Access Block Mesh Generator (New)

Access Block Mesh Generator by selecting the following menu items in SMAP (Figure 6.2):

 $\mathsf{Run} \to \mathsf{Mesh} \; \mathsf{Generator} \to \mathsf{Block} \; \mathsf{Mesh} \to \mathsf{New}$

Step 2: Set Work Plane

- 1. Select Work Plane No 4 as shown in Figure 6.83.
- 2. Select Isometric for Reset Initial Global Coordinate Layout.
- 3. Set parameters for Grid Dimensions and Divisions.
- 4. Click Description to see layout of NQ = 8 in Figure 6.84.
- 5. Click Update.
- 6. Figure 6.85 shows isometric view of work plane.

Name	Plane (X:	YI		-
Repet Initial	Global Coord	inate Layout -		
	¥ •×	z +	ž	z ×
C None	C Fronk	C Side	C Plan	@ Isometric
Translate Rotate: Deg	x' 0.	0.	2" 0.	Draw New Drain
Translate Rotate: Dec	0.	0.	0.	Diam New
Rotate: Orde	H 1	2	3	•
Grid Dimens NQ 8	ions and Divi NDx 10	NDy 10	Wx 500	Wy [500
pdate E	List	Hide Plane Add Plane	Descrip	Nion Opti Plane Exi





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6-57
```

Step 3: Build Entities

Following five entities are used to make it easier to build blocks

- Cylinder entity for Upper Core
- Cube entity for Lower Core
- Cylinder entity for Around Upper Core
- Cube entity for Around Lower Core
- Cube entity for Outer Boundary

Upper Core by Cylinder Entity

- 1. Click Entity in Figure 6.83.
- 2. Click Add in Entity Editor dialog in Figure 6.88.
- 3. Click Cylinder in Figure 6.86 and click OK.
- 4. Set the geometric parameters as in Figure 6.87.
- 5. Click Draw Cylinder Entity and then click Finish.
- 6. Set option parameters as in Figure 6.88 and click Reset To Global.
- 7. Cylinder entity for upper core is shown in Figure 6.89.



Figure 6.86 Entity type selection

Other Entities

8. Follow the same procedure as for upper core.

Figures 6.90 - 6.92
Figures 6.93 - 6.95
Figures 6.96 - 6.98
Figures 6.99 - 6.101

Block Mesh Example 6-59	lock Mesl	n Example	6-59
-------------------------	-----------	-----------	------

	Entity 3 on Work Plane 4
	1. Select Reference 3. Enter Origin 2. Select Method wo' = 0. \bigcirc Mouse Pickup vo' = 0. \bigcirc Enter xo'. yo'. zo' New Drawing 4. Enter Dimensions Nex = 36 \bigvee z' Rx \bigvee z' Rx = 136 $x = 100$ Ns = 1. Ns < 0: Rx and Ry are scaled by factor INsI at z = Lz
l	Click Finish button once you finished an entity.
Figur	e 6.87 Cylinder entity for upper core
	Entities on Work Plane 4



lock Mesh Example 🛛 🤇

Entity 4 on Work	Plane 4
 1. Select Reference Local 2. Select Method Mouse Pickup Enter xo', yo', zo' 4. Enter Dimensions V U U U Ly x At z = Lz, Lx and Ly are so 5. Draw Cube Entity Local coordinates deper Click Finish button once	3. Enter Drigin xo' = $[0.$ yo' = $[-36]$ zo' = $[0.$ New Drawing Lx = $[36]$ Ly = $[36]$ Lz = $[100]$ r = $[1.$ aled by factor r Finish Cancel nd on current work plane. you finished an entity.
ıre 6.90 Cube e	entity for lower co
Entities on Work Entities on Work Cube Entity Name Cube 1 (Lower Core) Line Thickness C Thin C Thick C Solid Line Color G Green C Blue C Red C Grey List Show E	Plane 4

Figure 6.91 Entity editor





Block Mesh	Example	6
------------	---------	---

Figure	Entity 5 on Work Plane 4 1. Select Reference Local 2. Select Method C Mouse Pickup • Enter xo', yo', zo' • New Drawing 4. Enter Dimensions V V Py Ns < 0. Rx and Ry are scaled by factor [Ns] at z = Lz Ns < 0. Rx and Ry are scaled by factor [Ns] at z = Lz Ns = 0. All 1:1st Quadrant 51:L 52:R 53:T 54:B 5. Draw Cylinder Entity Finish Local coordinates depend on current work plane. Click Finish button once you finished an entity.
	Entities on Work Plane 4
	Figure 6.94 Entity editor



Block Mesh	Example 🛛
------------	-----------

Image: Select ReferenceImage: Select	Entity 6 on Work Plane 4 1. Select Reference Local 2. Select Method (Mouse Pickup (Enter Dimensions L Enter Dimensions L Enter Dimensions L = 100 L
Entities on Work Plane 4 Finite Solution Ine Thickness Line Thickness	Entities on Work Plane 4



Block	Mesh	Example	6
-------	------	---------	---

1. Select Reference 3. Enter Drigin 2. Select Method 90 = 1500 8. Enter xo', yo', zo' New Drawing 4. Enter Dimensions 1 = 500 1. Enter Dimensions 1 = 100 1. Enter Dimensions Enter Diverse 1. Enter Dimensions Enter Diverse 1. Enter Dimensions Enter Diverse 1. Enter Diverse Enter Diverse
Local coordinates depend on current work plane. Click Finish button once you finished an entity. Figure 6.99 Cube entity for outer boundary
Entitles on Work Plane 4 Entity Number 7 (Cube Entity) Name Cube 3 (Duter Boundary) Line Thickness Line Type G Thin C Thick © Solid C Dash Core Blue C Red C Grey Black C Global
Update Edit Add Delete Exit





Step 4: Add Work Plane

At Step 2, we set Work Plane No 4 which represents back surface. At Step 3, we built 5 entities on this Work Plane No 4.

Here, we want to add new Work Plane No 5 in the following way:

- Copy Work Plane No 4 along with entities on it.
- Add this copied one as new Work Plane No 5.
- Modify such that it represents front surface.

Once we have this new Work Plane No 5, it will be much easier to build blocks since front and back surfaces of work planes can be accessed simply by one click of Back or Next button on Coordinates on Work Plane dialog in Figure 6.103.

Perform the following four steps:

- 1. Select Work Plane No 4 in Work Plane Editor dialog in Figure 6.83
- 2. Click Add Plane button in Figure 6.83
- 3. Modify Name and Translation as in Figure 6.104
- 4. Click Update in Figure 6.104

Index Number 1	Drawing Mode
x'= 3.7500e+02	C Single Point
y'= 1.0000e+02	Continuous
z' = 0.0000e+00	Info Finish
Click Point Snap	
C Half Grid C Full G	rid 🛛 🔿 Tenth Grid
● Ent. Point C Ent. F	ace 🔿 Block Node
	/ N List

Figure 6.103 Coordinates on work plane

		Work Hone Le		
│ ^{Work Plane}	No 5			
Name	Plane (X:)	Y) Front Surface		
Reset Initia	al Global Coordi	nate Layout —		
	y t x	z 🚽	z ×	z×x
None	C Front	C Side	C Plan	C Isometric
Reset Bas	e Work Plane L	.ocal Coordinate		
None	C (x, y) (○ (z, y) ○ (z,	x) O Manu	al Specify
Translate / Translate Rotate: De Rotate: Oro	2 Rotate Work F x' 0. 9 0. der 1	Plane y' 0. 0. 2	z' 100. 0. 3	Draw New Origin
Grid Dimer NQ 8	isions and Divis NDx 10	ions NDy 10	₩x 500.	Wy 500.
	List	Show Plane	Descrip	tion Option
Update	Entity	Add Plane	Delete F	'lane Exit

Step 5: Build Blocks

Fourteen blocks are used to model the geometry of horseshoe tunnel as shown in Figures 6.105 and 6.106.

- 8 blocks for surrounding medium
- 2 blocks for tunnel core
- 4 blocks for tunnel lining as shell elements



Figure 6.105 Block numbers for surrounding medium
















 Now, the geometry of the first hexahedron block is completed. 14. Click Finish in Figure 6.103 and then click Finish in Figure 6.112. 15. Modify Title, Block Name and Material & Element Generation Parameters in Block Editor as shown in Figure 6.115. 16. Click Reset button.
Block Editor
Title Horseshoe Tunnel
Block No 1 [Hexahedron Block]
Name Top-1 Hide Block
Interpolation Coordinate System (ICOORD)
C 1. Rectangular C 2. Spherical @ 3. Cylindrical
Coordinate Modification (IMODE)
Interpolation Scheme (ILAG)
Beference Node Numbers 9 (M28) Origin. Negative value means arc shape over 180 degrees in sphere or cylinder 10 (M29) Defining cylinder axis M28-M29 11 (M30) Other cylinder axis M28-M30
Material and Element Generation Parameters
MATNO NDX NDY NDZ KS KF
Image:
List Show Index Show F. E. Mesh Edit Boundary Edit Coordinate Add Block Delete Block Save Exit
Figure 6.115 Block No 1







Building Other Blocks

18. Follow the same procedure as for Block No 1.

Block No 2	(Side-1):	Figures 6.117 - 6.118
Block No 3	(Side-2):	Figures 6.119 - 6.120
Block No 4	(Bottom-1):	Figures 6.121 - 6.122
Block No 5	(Top-2):	Figures 6.123 - 6.124
Block No 6	(Side-3):	Figures 6.125 - 6.126
Block No 7	(Side-4):	Figures 6.127 - 6.128
Block No 8	(Bottom-2):	Figures 6.129 - 6.130
Block No 9	(Core-1):	Figures 6.131 - 6.132
Block No 10	(Core-2):	Figures 6.133 - 6.134
Block No 11	(Liner-1):	Figures 6.135 - 6.136
Block No 12	(Liner-2):	Figures 6.137 - 6.138
Block No 13	(Liner-3):	Figures 6.139 - 6.140
Block No 14	(Liner-4):	Figures 6.141 - 6.142





	Block E	ditor	
Tide Horseshoe To	unnel		
Block No 2 [Hexahe	dron Block.]		
Name Side-1			Hide Block
Interpolation Coordinate	System (ICOORD)		
C 1. Rectangular	C 2. Spherical	④ 3. Cylindrical	
Coordinate Modification	(IMODE)		
0. Do not modify	C 1. Modify coorde	nate based on rectangui	ar grid
Interpolation Scheme (IL	AG) C. 1. Lagrangian		
a. a standarda			
Reference Node Numbe	Nacativa value maeor	era shene over 190 dea	men in sphere or culinder
36 (M29) Defini	ng cylinder axis M28-M29	37 (M30) 0	ther cylinder axis M28-M30
Material and Element Ge	eneration Parameters		
MATNO NDX	NDY NDZ	KS KF	
1. 5	1- 1-		2 NI3 Mat3 NI4 Mate
1. 5 Mid Node AlphaX	Alpha Y Alpha Z	Nt1 Mat1 Nt2 Mat	a recombando recordio
1. 5 Mid Node Alpha X Reset 0.	Alpha Y Alpha Z 0.4 0.	Nt1 Mat1 Nt2 Mat	
1. 5 Mid Node AlphaX Reset 0.	Alpha Y Alpha Z 0.4 0.	Nt1 Mat1 Nt2 Mat	0 0 0 0
1. 5 Mid Node Alpha X Reset 0. < > List Edit Coordinate	Alpha Y Alpha Z 0.4 0.	Nt1 Mat1 Nt2 Mat 0 0 0 0 0 Show F. E. Mesh Delete Block	0 0 0 0





Title Horseshoe Tunnel	
Block No 3 [Hexahedron Block]	
Name Side-2 Hide Blo	ck
Interpolation Coordinate System (ICDORD)	
I. Rectangular C 2. Spherical C 3. Cylindrical	
Coordinate Modification (IMODE)	
O. Do not modify 1. Modify coordinate using node M28 as orign	
Interpolation Scheme (ILAG)	
(M29) Defining cylinder axis M28-M29 [0 (M30) Other cylinder axis M2	8-M30
Material and Element Generation Parameters	
MATNO NDX NDY NDZ KS KF 1. 5 9 3 0 1	
Mid Node Alpha X Alpha Y Alpha Z Nt1 Mat1 Nt2 Mat2 Nt3 Mt4 Reset 0. 0.4 0. 0	Mat4
	ary
List Show Index Show F. E. Mesh Edit Bounds	





Title Horseshoe Tunnel	
Block No 4 [Hexahedron Block]	
Name Bottom-1 Hide Blo	xck
Interpolation Coordinate System (ICOORD)	
I. Rectangular C 2. Spherical C 3. Cylindrical	
Coordinate Modification (IMODE)	
Interpolation Scheme (ILAG) © 0. Serendipity C 1. Lagrangian	
Image: Reference Node Numbers Image: M28) Origin. Negative value means arc shape over 180 degrees in sphere or cy Image: Image: M29) Defining cylinder axis M28-M29 Image: Imag	ylinder 28-M30
Material and Element Generation Parameters	
MATNO NDX NDY NDZ KS KF 1. 5 9 3 0 1	
Mid Node AlphaX AlphaY AlphaZ Nt1 Mat1 Nt2 Mat2 Nt3 Mat3 Nt4 Reset 0. 0.4 0. 0	4 Mat4
	dary
< > List Show Index Show F. E. Mesh Edit Bound	





Didek Editor	
Title Horseshoe Tunnel	
Block No 5 [Hexahedron Block]	
Name Top-2	Hide Block
Interpolation Coordinate System (ICOORD)	
1. Rectangular C 2. Spherical C 3. Cylindrical	
Coordinate Modification (IMODE)	
O. Serendipity O. 1. Lagrangian Reference Node Numbers M281 Dripin. Negative value means are shape over 190 decrease in an	ohere or cvinder
O. Serendipity O. Lagrangian Reference Node Numbers [0 [M28] Origin. Negative value means arc shape over 180 degrees in sp [0 [M29] Defining cylinder axis M28-M29 [0 [M30] Other cylind Material and Element Generation Parameters	phere or cylinder der axis M28-M30
O. Serendipity O. Lagrangian Reference Node Numbers O (M28) Drigin. Negative value means arc shape over 180 degrees in sp (M29) Defining cylinder axis M28-M29 O (M30) Other cylind Material and Element Generation Parameters MATNO NDX NDY NDZ KS KF 1	phere or cylinder der axis M28-M30
Image: Constraint of the second system of	phere or cylinder der axis M28-M30 Mat3 Nt4 Mate
	phere or cylinder der axis M29-M30 Mat3 Nt4 Mate 0 0 0 0 0

6-89



	Block I	Editor			
Title Horseshoe T	unnel				
Block No 6 [Hexah	edron Block]				
Name Side-3				Hide	Block
Interpolation Coordinate	e System (ICOORD)				
I. Rectangular	C 2. Spherical	CBD	lindrical		
Coordinate Modification	(IMODE)				
0. Do not modify	C 1. Modify coord	inate using not	de M28 as or	ign	
Reference Node Numb	ers n. Negative value means ning cylinder axis M28-M25	arc shape ove 9 0	er 180 degre (M30) Oth	es in sphere o er cylinder axis	r cylinder M28-M30
Material and Element G	eneration Parameters		1000		
MATNO NDX 1. 5	NDY NDZ	KS 0	KF 1		
Mid Node Alpha X Reset 0.	AlphaY AlphaZ	Nt1 Mat1	Nt2 Mat2	Nt3 Mat3	Nt4 Mat4
< > List	Show Index	Show F.	E. Mesh	Edit Bo	undary
E D C L . L	Add Block	Delete	Block	Save	Exit





6-92 Block Mesh Example

			Block I	Editor			
Title F	forseshoe T	unnel					
Block No	7 [Hexahe	dron Block]				
Name S	ide-4					Hide	Block
Interpolation	n Coordinate	System (ICC	ORD)				
1. Rec	tangular	C 2 5	Spherical	C 3. C	ylindrical		
Coordinate	Modification	(IMODE) -					
(* 0. Do	not modify	(* 1.)	Modify coord	nate using no	de M28 as o	ngn	
Interpolation	n Scheme (IL rendipity	.AG)	agrangian				
Reference	Node Numb	ers					
0	(M28) Drigin	Negative	value means	arc shape ov	er 180 degre	es in sphere	or cylinde
10	(M23) Denn	ng cylinder a	3NS M20442;	5 JO	(MOU) UU	er cylinder ak	S M204M3
Material and	d Element Gr	eneration Pa	rameters				
MATNO	NDX	NDY	NDZ	KS	KF		
1.	5	8	3	0	1	NI-0 14-10	
Reset	Alpha X	Alpha Y	Alpha Z				
		Char	u lodeu	Show F	E. Mesh	Edit Bo	undary
<>	List	Show	4 Index	01101111			





	Block	Editor			
Title Horseshoe T	unnel				
Block No 8 [Hexah	edron Block]				
Name Bottom-2				Hide	Block
Interpolation Coordinate	System (ICOORD)				
1. Rectangular	C 2. Spherical	C 3 C	ylindrical		
Coordinate Modification	(IMODE)				
O. Do not modify	C 1. Modify coord	dinate using no	de M28 as o	ign	
Interpolation Scheme (I	LAG)				
0. Serendipity	C 1. Lagrangian				
Reference Node Numb 0 (M28) Origin 0 (M29) Defin	ers Negative value mean: ing cylinder axis M28-M2	s arc shape ov 19 0	er 180 degre (M30) Oth	es in sphere c er cylinder axis	r cylinder M28-M30
Material and Flowert G	eneration Paramatara				
MATNO NDX	NDY NDZ	KS	KF		
1. 5	8 3	0	1		
Mid Node AlphaX	Alpha Y Alpha Z	Nt1 Mat1	Nt2 Mat2	Nt3 Mat3	Nt4 Mat4
[note:] to	Jan Jan	1- 1-	1- 1-	1- 1-	1- 1-
< > List	Show Index	Show F	E. Mesh	Edit Box	undary
Edt Coordinate	Add Block	Delete	Block	Save	Exit





	Block Editor
Title	Horseshoe Tunnel
Block N	o 9 [Hexahedron Block]
Name	Core-1 Hide Block
Interpola	ition Coordinate System (ICOORD)
● 1. F	Rectangular C 2. Spherical C 3. Cylindrical
Coordina	ate Modification (IMODE)
● 0.	Do not modify O 1. Modify coordinate using node M28 as orign
C 0. Referen	Serendipity • 1. Lagrangian ce Node Numbers (M28) Origin. Negative value means arc shape over 180 degrees in sphere or cylinder (M29) Defining cylinder axis M28-M29 <u>0</u> (M30) Other cylinder axis M28-M30
Material	and Element Generation Parameters
MATNO 2) NDX NDY NDZ KS KF
Mid Nor Reset	de Alpha X Alpha Y Alpha Z Nt1 Mat1 Nt2 Mat2 Nt3 Mat3 Nt4 Mat4
	List Show Index Show F. E. Mesh Edit Boundary





6-98 Block Mesh Example

	DIOCK	ditor	
Title Horseshoe	Tunnel		
Block No 10 [Hex	ahedron Block]		
Name Core-2			Hide Block
- Interpolation Coordina	ate System (ICOORD)		
1. Rectangular	C 2. Spherical	C 3. Cylindrical	
 Coordinate Modificati 0. Do not modifi 	on (IMUDE) — O 1. Modify coordi	nate using node M28 as o	rign
Reference Node Nur 0 (M28) Ori 0 (M29) De	nbers gin. Negative value means fining cylinder axis M28-M29	arc shape over 180 degre 3 0 (M30) Oth	es in sphere or cylinder er cylinder axis M28-M30
MATNO NDX	NDY NDZ	KS KF	
2. 5	5 3		
Reset 0.	Alpha Y Alpha Z		
< > List	Show Index	Show F. E. Mesh	Edit Boundary Save Exit
Edit Coordinate	Add Block	Delete Block	





	BIOCK E	ditor	
Title Horseshoe Tunnel			
Block No 11 [Quad Block]			
Name Liner-1			Hide Block
Interpolation Coordinate System	(ICOORD)		
I. Rectangular	2. Spherical	C 3. Cylindrical	
- Coordinate Modification (IMODE)		
O. Do not modify	1. Modify coordin	nate using node M10 as or	ign
Interpolation Scheme (ILAG) —			
O. Serendipity O C	1. Lagrangian	C 2. Surface Secto	Define Sector
0 (M10) Origin. Negat 0 (M11) Defining cylind	ive value means a der axis M10-M11	arc shape over 180 degree	es in sphere or cylinder er cylinder axis M10-M13
Material and Element Generation	Parameters —		
MATNO NDX NDY			
Mid Node Aloba X Aloba	Y	NH MaH NH2 M∋P2	NI3 Mat3 NI4 Mate
Reset 0. 0.			
< > List S	how Index	Show F. E. Mesh	Edit Boundary
< > List S	how Index	Show F. E. Mesh	Edit Boundary





6-101

Block	k Editor
Title Horseshoe Tunnel	
Block No 12 [Quad Block]	
Name Liner-2	Hide Block
Interpolation Coordinate System (ICOORD)	
I. Rectangular C 2. Spherical	C 3. Cylindrical
Coordinate Modification (IMODE)	
O. Do not modify O. 1. Modify coo O	rdinate using node M10 as orign
Interpolation Scheme (ILAG) O. Serendipity O. Lagrangian	C 2. Surface Sector Define Sector
Reference Node Numbers 0 (M10) Origin. Negative value mean 0 (M11) Defining cylinder axis M10-M	ns arc shape over 180 degrees in sphere or cylinde 111 0 (M12) Other cylinder axis M10-M1
Material and Element Generation Parameters -	
MATNO NDX NDY	
ja jo ja Mid Node Albha X Albha X	NH Mait NR Mai2 NR Mai3 MM Mai
Reset 0. 0.	
C > List Show Index	Show F. E. Mesh Edit Boundary
Edit Coordinate Add Block	Delete Block Save Exit





6-103

Bloc	k Editor
Title Horseshoe Tunnel	
Block No 13 [Quad Block]	5203.00
Name Liner-3	Hide Block
Interpolation Coordinate System (ICOORD) -	
I. Rectangular C 2. Spherical	C 3. Cylindrical
Coordinate Modification (IMODE)	
O. Do not modify O. 1. Modify cod O	rdinate using node M10 as orign
Interpolation Scheme (ILAG)	n C 2. Surface Sector Define Sector
Pleference Node Numbers (M10) Origin. Negative value mea (M11) Defining cylinder axis M104	ns arc shape over 180 degrees in sphere or cylinder 111 0 (M12) Other cylinder axis M10-M1
Material and Element Generation Parameters	
3. 5 3	
Reset 0. 0.	0 0 0 0 0 0 0 0 0
< > List Show Index	Show F. E. Mesh Edit Boundary
Edt Coordoate Add Black	Delete Block Save Exit



6-105

Title Horseshoe Tunnel Block No 14 [Quad Block] Neme Liner-4 Hide Blo	
Block No 14 [Quad Block] Hide Block	
Name Liner-4 Hide Blo	
	ick.
Interpolation Coordinate System (ICOORD)	
Coordinate Modification (IMODE)	
O. Do not modify C 1. Modify coordinate using node M10 as orign 1	
Interpolation Scheme (ILAG)	
O. Serendipity C 1. Lagrangian C 2. Surface Sector Define Sector	ector
[0 (M10) Origin. Negative value means arc shape over 180 degrees in sphere or c, [0 (M11) Defining cylinder axis M10-M11 [0 (M12) Other cylinder axis M [0 Material and Element Generation Parameters	ylind: 10-M
MATNO NDX NDY	
Microsofe Appra A Appra A Nitr Mail Nitr Nitr Nitr Mail <td>ч ма 0</td>	ч ма 0
List Show Index Show F.E. Mesh Edit Bound	larv

19. All blocks are listed as shown in Figure 6.143 by clicking List			
20. Click OK.	og.		
Existing Blocks			
Block Information			
Existing Blocks			
Block No 1 : Hexa	Visible Top-1		
Block No 2 : Hexa	Visible Side-1		
Block No 3 : Hexa	Visible Bottom-1		
Block No 5 : Hexa	Visible Ton-2		
Block No 6 : Hexa	Visible Side-3		
Block No 7 : Hexa	Visible Side-4		
Block No 8 : Hexa	Visible Bottom-2		
Block No 9 : Hexa	Visible Core-1		
Block No 10 : Hexa	Visible Core-2		
Block No 11 : Quad	Visible Liner-1		
Block No 12 : Quad	Visible Liner-2		
Block No 13 : Quad	Visible Liner-3		
BLOCK NO 14 : Quad	Visible Liner-4		
1			
Selected Block			
Block No 1 : Hexa	Visible Top-1		
Show All Blocks Hide All	Blocks OK Cancel		
]		
Figure 6.143 Listi	ng of all of the blocks		






Step 7: View Select 1. Select View → Mesh in F 2. Select Only Selected On 3. Click Number 3 in Availa 4. Click OK.	ted Material PLOT-3D menu. le for Material Select able list.	tion in Figure 6.147.
Element Type Continuum 80 Element 0 Element 0 F Beam 0 F Truss 0 F Joint 0 F Shell 16 Total Nodes 155 Material Color Sequential Repeating Boundary Outline Finite Element Mesh Show Only On Clip Plane Show Continuum data only on clip plane	Material Selection All Materials All Except Selected One Only Selected One All Except Selected One All Except Selected One All Except Selected One All Except Selected One Only Selected One Only Selected One Selected Elements From To Image: Only Selected One Selected Elements From To Image: Only Selected One Image: Only	Continuum/Joint/Shell Color Available Selected 1. 2. 3. Click to select
Figure 6	.147 Mesh options	







Figure 6.150 Finite element mesh representing tunnel lining





6-116 Block Mesh Example



Step 3: Build Cube Entity1. Click Entity in Figure 6.153.2. Click Add in Entity Editor dialog in Figure 6.155.					
Entities on Work Plane 4					
Thin Thick Solid Dash Show Hide Line Color Energian Reference Coordinate Local Global Green Blue Red Grey Black Elocal Global					
Image: Second					
 Select Cube in Entity Type Selection dialog in Figure 6.156. Click OK. 					
Add Entity 3 Select Entity Type C Line C Arc C Cube C Ellipsoid C Cylinder C Copy Existing Entity Entity No : 1					
Figure 6.156 Entity type selection					

 Set geometric parameters of cube entity as shown in Figure 6.157 Click Draw Cube Entity. Click Finish. 			
Entity 3 on Work Plane 4			
1. Select Reference Local 2. Select Method C< Mouse Pickup			
$ \begin{array}{c} -4. \text{ Enter Dimension} \\ \hline \\ \hline \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $			
At z = Lz, Lx and Ly are scaled by factor r			
The Description of the Land			
Local coordinates: depend on current work plane.			
Click Finish button once you finished an entity.			
Figure 6.157 Cube entity			
 8. Set parameters of cube entity as shown in Figure 6.158. 9. Click Reset To Global and then click Exit. 			
Entities on Work Plane 4			
Entity Number 3 (Cube Entity) Name Cube Entity for Space Truss			
Line Thickness Line Type Line Visibility			
Thin C Thick Solid C Dash Show C Hide			
C Green C Blue C Red C Grey C Black C Local C Global			
< > List Show Entity No Reset To Global			
Update Edit Add Delete Exit			
Figure 6.158 Entity editor			





Step 4: Add Work Plane

At Step 2, we set Work Plane No 4 which represents bottom surface. At Step 3, we built cube entity on this Work Plane No 4.

Here, we want to add new Work Plane No 5 in the following way:

- Copy Work Plane No 4 along with cube entity on it.
- Add this copied one as new Work Plane No 5.
- Modify such that it represents top surface.

Once we have this new Work Plane No 5, it will be much easier to build blocks since top and bottom surfaces of work planes can be accessed simply by one click of Back or Next button on Coordinates on Work Plane dialog in Figure 6.160.

Perform the following four steps:

- 1. Select Work Plane No 4 in Work Plane Editor dialog in Figure 6.153
- 2. Click Add Plane button in Figure 6.153
- 3. Modify Name and Translation as in Figure 6.161
- 4. Click Update in Figure 6.161

Index Number 1	Drawing Mode -	
x'= 3.7500e+02	C Single Point	
y'= 1.0000e+02	 Continuous 	
z' = 0.0000e+00	Info Finisł	
Click Point Snap		
C Half Grid C Full G	rid 🛛 🔿 Tenth Grid	
● Ent. Point C Ent. F	ace 🔿 Block Nod	
Select Work Plane	Z D List	

Figure 6.160 Coordinates on work plane

***	rk Plane Edito	or 🙂	
Vork Plane No 5		9	
Name Plane (X:Y) T	op Surface		
Reset Initial Global Coordinate	Layout		
y x	z 🚽	x z	z×x
None C Front C	Side (© Plan	C Isometric
Reset Base Work Plane Local • None C (x, y) C (z	l Coordinate — z, y) (z, x)	C Manual	Specify
Translate / Rotate Work Plane	e	z'	
Translate 0.	0.	5	Draw
Rotate: Deg. 0.	0.	0.	Origin
Rotate: Order 1	2	3 💌	
Grid Dimensions and Divisions			200200
NQ NDx	NDy 6	Wx 6.	Wy 6.
List Hide	e Plane	Description	n Op
pdate Entity Add	l Plane	Delete Plar	ne E





6-124 Block Mesh Example









Build Element 3

17. Get Popup menu in Figure 6.169 by Shift + Right click.18. Click Add menu.

Draw Index Numbers For Element 3

19. Repeat steps 2 through 11 for Element 3 with MatNo = 3.20. Figure 6.171 shows index numbers for Element 3.









 6. Set the boundary codes for Node 2 as shown in Figure 6.181. 7. Click Update button. 						
Boundary Code Boundary Codes for Node No 2 Skeleton DOF Pore Fluid DOF Rotational DOF Node No ISX ISY ISZ 2 1 1 1 1 Note: Free to move in specified direction for DOF = 0, Fixed for DOF = 1 Default codes ISX=ISY=ISZ=0 Default codes ISX=ISY=ISZ=0 IFX=IFY=IFZ=1 IRX=IRY=IRZ=1 Once modified, click Update: Update OK Cancel						
Figure 6.181 Boundary codes for Node 2						
 Repeat steps 6 and 7 for Nodes 3, 4, 5 and 6. Click OK button. Click Save toolbar in Figure 6.174. 						

