Workshop on Numerical Modelling
Timmins, Ontario
April 25-27,1989

EXAMPLE PROBLEMS
PCEPFE Software Package

CANMET/MRL/CMTL
Ottawa, Ontario

EXAMPLE PROBLEMS

Several examples were devised to illustrate the use of the PCEPFE computer package and to demonstrate how to achieve the loading correctly.

Underground Opening

The first example is a hypothetical underground opening, horse-shoe in shape, approximately 10m high and 6m wide, is located at a depth of about 340m below the ground surface. Figure 1 shows the cross sectioanl view of the location of the opening. The region of interest for simulation is shown in dashed-lines. Beacuse of symmetry, only one half of will be considered for simulation. Figure 2 shows the schematic diagram of the opening with boundary constraints. A traction is applied along the top boundary to simulate the 'over-burden' stresses. Note that a postive traction represents compression. The horse-shoe opening, its zone diagram and its associated key diagram for mesh-generation are shown in Fig. 3. Figure 4 shows the corresponding finite element mesh.

The input data required by MSHGEN to generate part of the input for PCEPFE is shown in Fig. 5. Additional input data required by EPFEC, as shown in Fig. 6, is then merged with MSHGEN output data ('genout.dat') to produce an input file which is acceptable to PCEPFE.

The Initial Stresses are assumed to be varying linearly with depth and are in the form of:

$$\sigma_{xx} = a_{xx} + b_{xx} \times Y$$
$$\sigma_{yy} = a_{yy} + b_{yy} \times Y$$
$$\sigma_{zz} = a_{zz} + b_{zz} \times Y$$
$$\sigma_{xy} = a_{xy} + b_{xy} \times Y$$

where σ_{xx}, σ_{yy} are the horizontal and vertical stresses respectively. σ_{zz} is the stress perpendicular to the plane and σ_{xy} is the shearing stress in the XY plane. a_{xx}, b_{xx}, a_{yy} ...... are the coefficients relating the stress components with depth. Y is the depth at which the stresses are evaluated. The definition of axes is shown in Figs. 2 and 3.

Under Gravitational Loading and under plane strain conditions, the loading for evaluating the resultant stresses from the finite element model can either be achieved by applying appropriate tractions along the boundary of a model or by placing appropriate constraints along the sides of the model.

Case 1 - No Initial Stresses:

In this case the loading is assumed to be gravational only. The loading can be generated through appropriate boundary constraints as shohwn in Fig. 2.

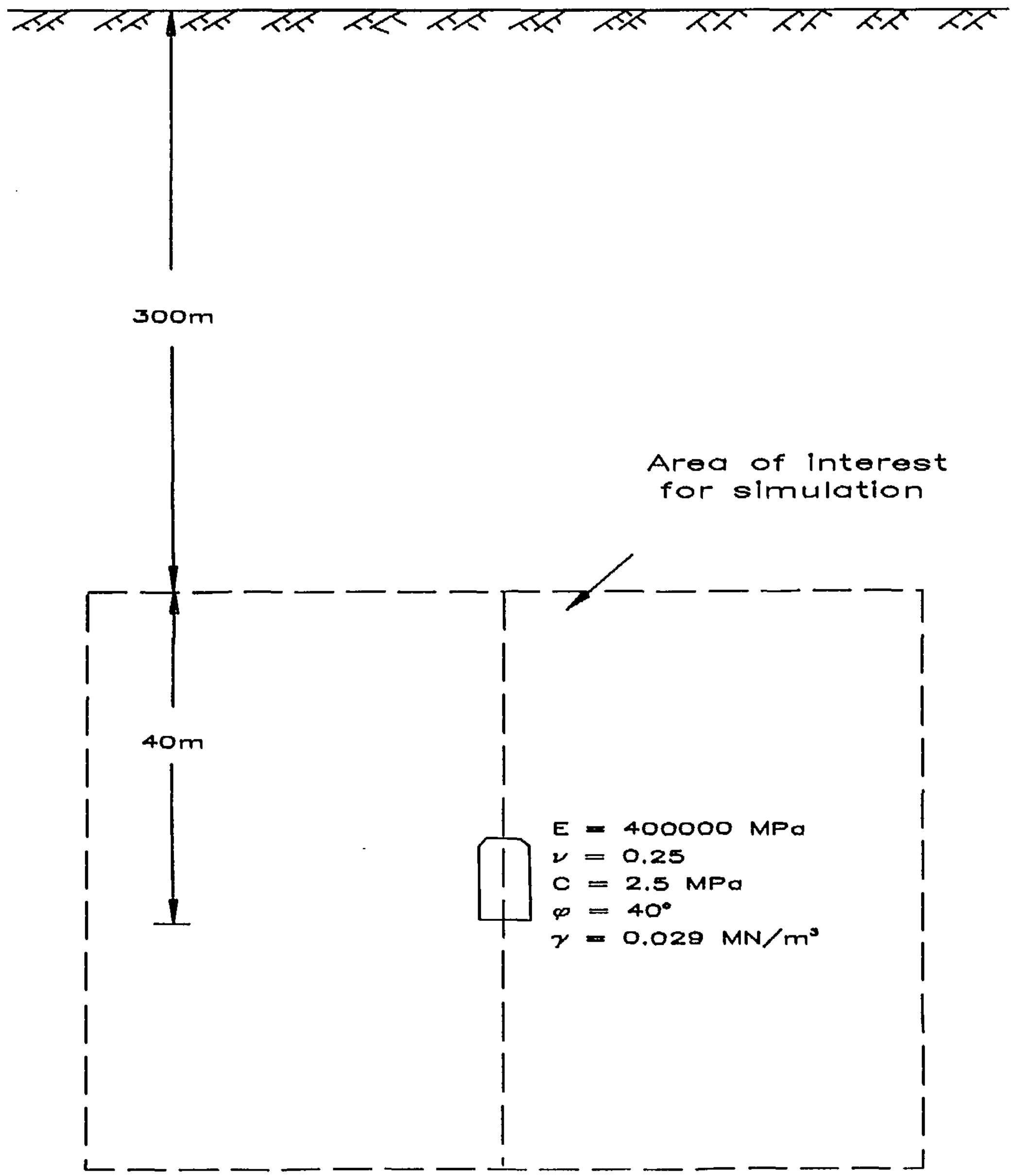


Fig. 1 A hypothetical underground opening - a sectional view

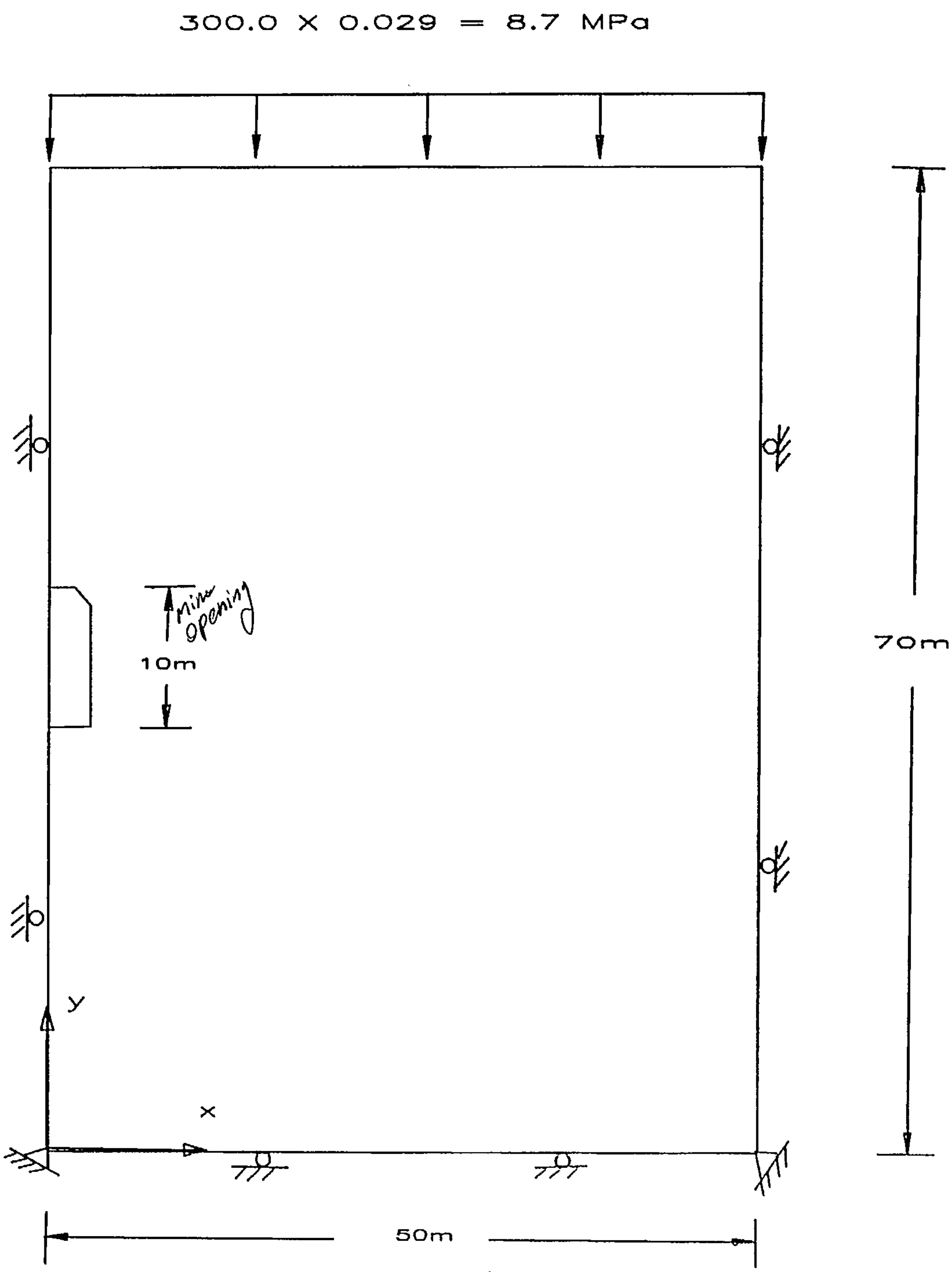


Fig. 2 An underground opening with fictious boundaries and constraints

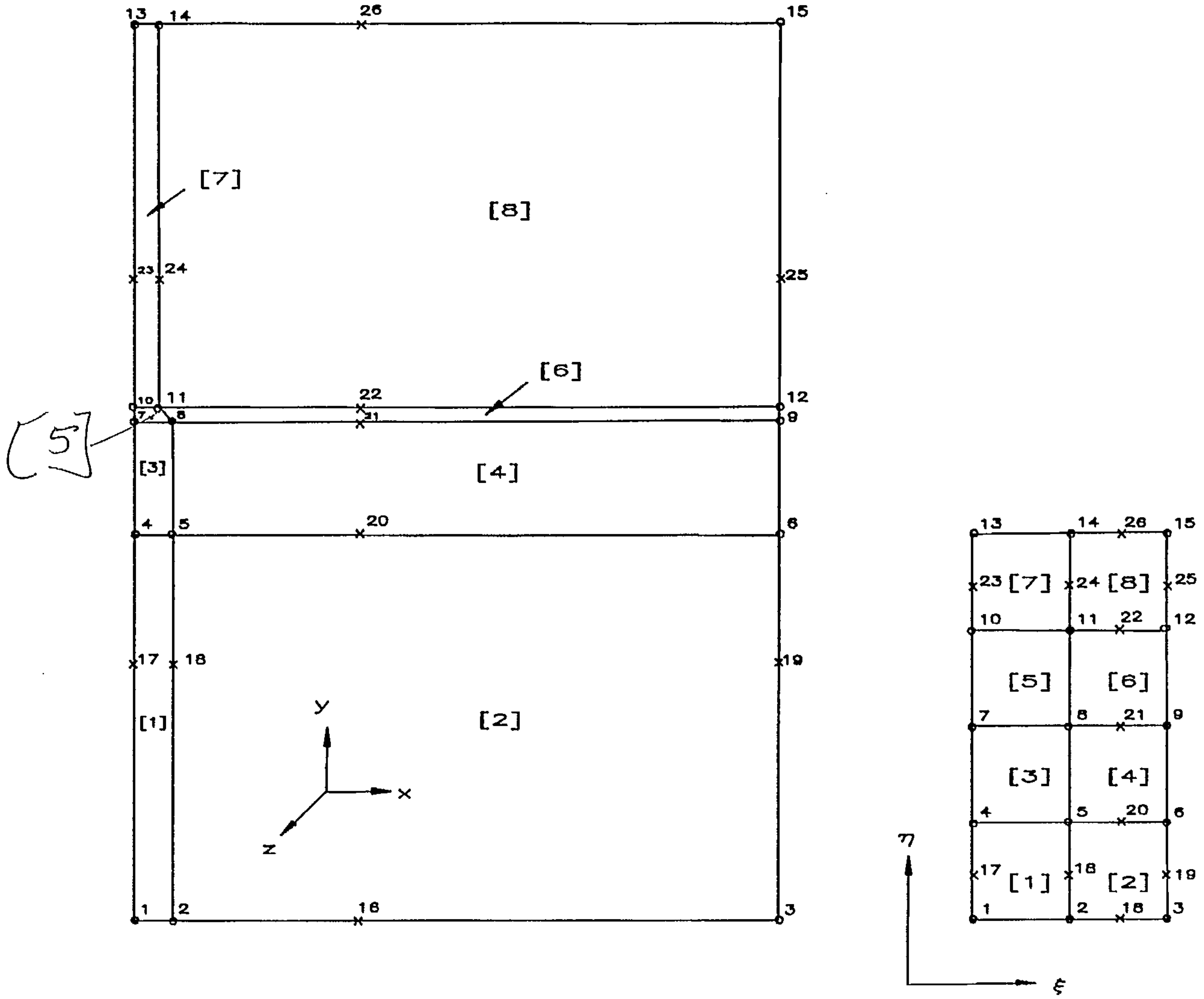


Fig. 3 A zone diagram (numbers are specified nodes and numbers in brackets are zones) and its associated key diagram

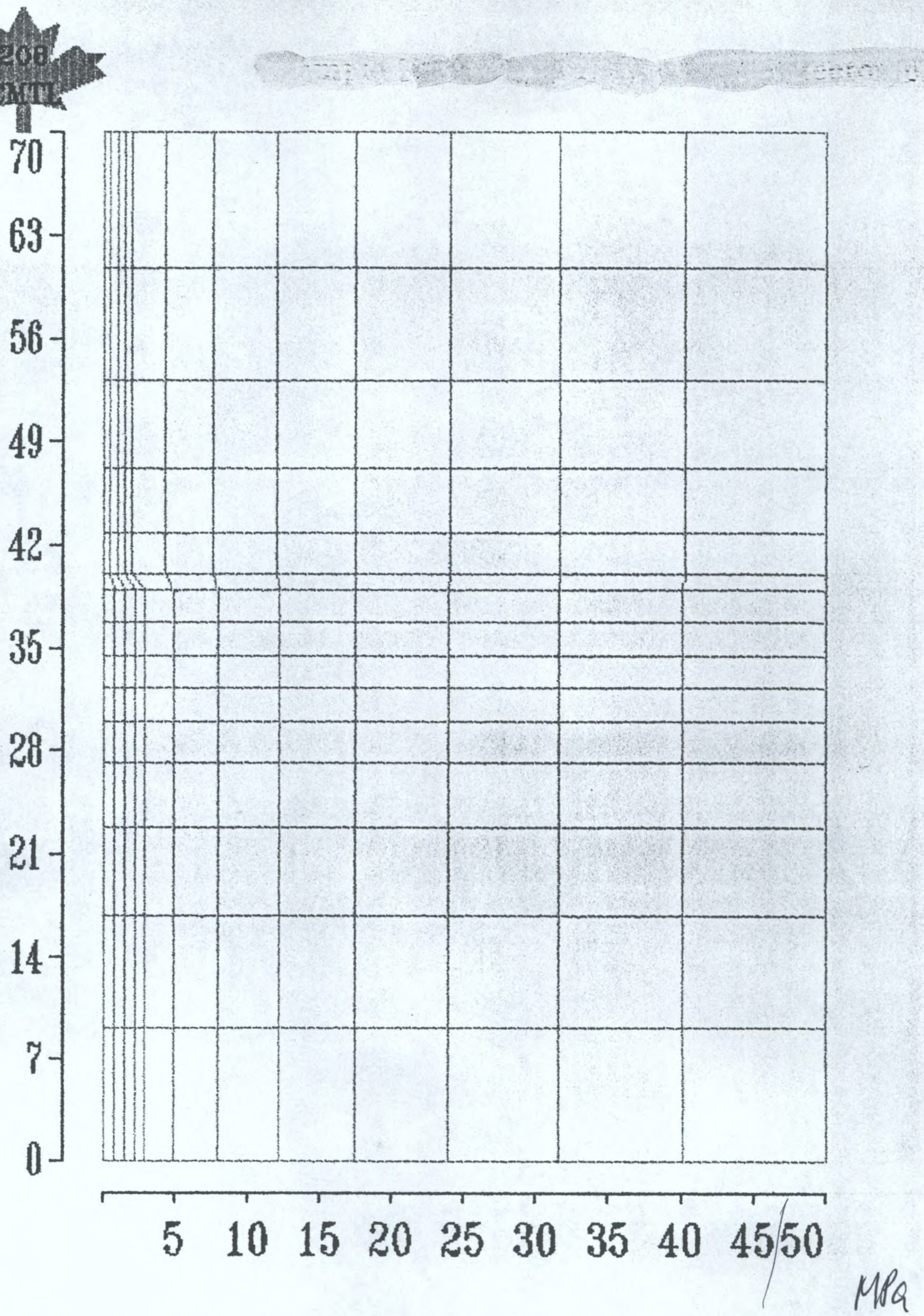


Fig. 4 Finite element mesh

```
'Example 1A - gravity with no initial stress'
  26    8    2    4    2    0
   4   10
   6    4    1    6
   1    3        0.00    0.00
   2    2        3.00    0.00
   3    3       50.00    0.00
   4    1        0.00   30.00
   5    0        3.00   30.00
   6    1       50.00   30.00
   7    1        0.00   39.00
   8    0        3.00   39.00
   9    1       50.00   39.00
  10    1        0.00   40.00
  11    0        2.00   40.00
  12    1       50.00   40.00
  13    1        0.00   70.00
  14    0        2.00   70.00
  15    1       50.00   70.00
  16    0       17.50    0.00
  17    0        0.00   20.00
  18    0        3.00   20.00
  19    0       50.00   20.00
  20    0       17.50   30.00
  21    0       17.50   39.00
  22    0       17.50   40.00
  23    0        0.00   50.00
  24    0        2.00   50.00
  25    0       50.00   50.00
  26    0       17.50   70.00
   1    1    2    5    4    0   18    0   17    1    0    0
   2    2    3    6    5   16   19   20   18    1    0    0
   3    4    5    8    7    0    0    0    0    1    2    0
   4    5    6    9    8   20    0   21    0    1    0    0
   5    7    8   11   10    0    0    0    0    1    2    0
   6    8    9   12   11   21    0   22    0    1    0    0
   7   10   11   14   13    0   24    0   23    1    0    1
   3      8.70      8.70
   8   11   12   15   14   22   25   26   24    1    0    1
   3      8.70      8.70
```

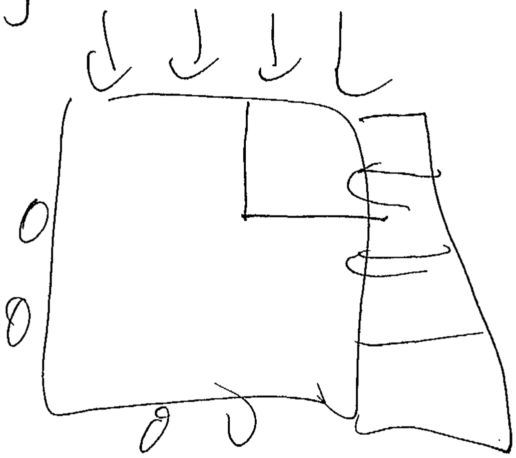
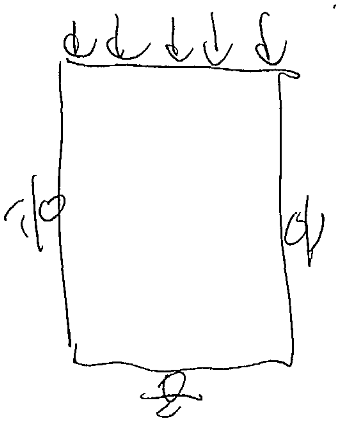
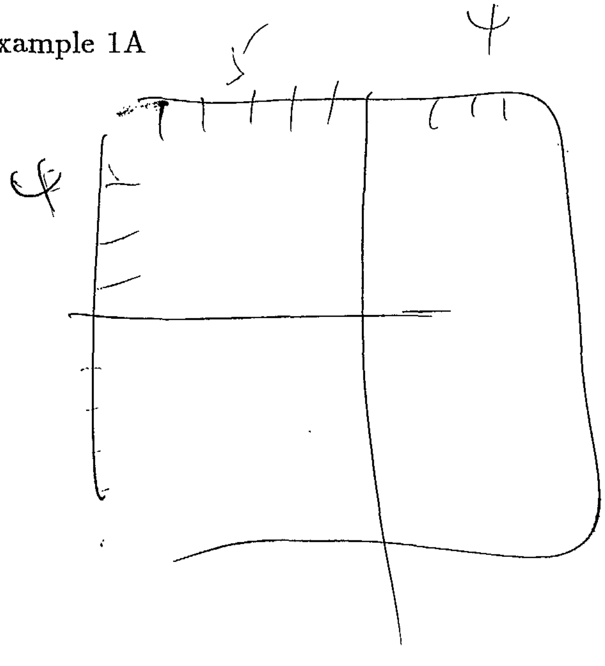


Fig. 5 MSHGEN input data - Example 1A





```
 50   20    1    2        0.0        -1.0        1.0
  0
  1    0.029
 4.0E+05       0.25        2.50       40.0        0.0
  2    0.000
     0.0       0.00        0.0        0.0        0.0
  0
****** Evaluating the state of initial stresses ******
  1
****** Excavating the underground opening ******
  2
```

Fig. 6 EPFEC input data with no initial stresses - Example 1A

If displacements are of no concern, then it is not required to enter the initial stresses. The input of initial stresses will not affect, in any way, the resultant stresses resulting from any excavation, but it will have an effect on the displacements.

In other words, a model, consisting of no excavation, is loaded with boundary tractions together with the input of initial stresses which are compatible with the applied tractions, then, the displacements everywhere within the model should be zero. This establishes the reference point for evaluating displacements in the subsequent subproblems.

First, let's examine the model under gravitational loading which is achieved through the boundary constriants but without the input of initial stresses. A traction is applied at the top of the model to simulate the 'overburden stresses'.

The input data for MSHGEN and EPFEC, genin.dat and epfecin.dat, is given in Fig. 5 and Fig. 6 respectively.

<u>Case 2 - with initial stresses</u>

Under gravitational loading, the initial shearing stress $\sigma_{xy} = 0$, therefore, the coefficients $a_{xy} = b_{xy} = 0$. The vertical stress σ_{yy} is due to gravity only and the horizonal stresses, σ_{xx} and σ_{zz}, are due to Poisson's effect. If we assume that γ, the average unit weight of rock mass, is 0.029 MPa/m, and the Poisson's ratio is 0.25, then, the stresses are given:

$$\sigma_{yy} = \gamma \times h'$$
$$\sigma_{xx} = \frac{\nu}{1-\nu}\sigma_{yy}$$
$$\sigma_{zz} = \nu(\sigma_{xx} + \sigma_{yy})$$

Where h' is the depth below the ground surface.

The coordinates system adopted for this model is shown in Fig. 3. At the top of the model, $Y = 70$m, and it is 300m below the ground surface ($h' = h = 300$).

We have:

$$\begin{aligned}\sigma_{yy} &= 0.029 \times (-300) \\ &= a_{yy} + b_{yy} \times Y \qquad (1)\end{aligned}$$

Note that a negative sign is added here so that the sign convention used in the PCEPFE program is maintained (please refer to users manual for detail).

At the bottom of the model, where $Y = 0.0$m and $h' = 300 + 70$, we have:

We have:

$$
\begin{aligned}
\sigma_{yy} &= 0.029 \times (-300 - 70) \\
&= a_{yy} + b_{yy} \times Y
\end{aligned}
\tag{2}
$$

From Eq. 1 and Eq. 2, we have: $a_{yy} = -10.73$
$b_{yy} = +0.029$

The following two equations also hold:

$$
a_{xx} + b_{xx} \times Y = \frac{0.25}{1 - 0.25}(a_{yy} + b_{yy} \times Y) \tag{3}
$$

$$
\begin{aligned}
a_{zz} + b_{zz} \times Y &= 0.25 \times \{(a_{xx} + b_{xx} \times Y) + (a_{yy} + b_{yy} \times Y)\} \\
&= \{0.25 \times (a_{xx} + a_{yy}) + 0.25 \times (b_{xx} + b_{yy}) \times Y\}
\end{aligned}
\tag{4}
$$

From Eq. 3 and Eq. 4, we obtain:

$$
\begin{aligned}
a_{xx} &= -3.57667 \\
b_{xx} &= +0.009667 \\
a_{zz} &= -3.57667 \\
b_{xx} &= +0.009667
\end{aligned}
$$

Summarizing, we have:

$$
\begin{aligned}
a_{xx} &= -3.576667 \\
b_{xx} &= +0.009667 \\
a_{yy} &= -10.7300 \\
b_{yy} &= +0.02900 \\
a_{zz} &= -3.576667 \\
b_{zz} &= +0.009667 \\
a_{xy} &= 0.0 \\
b_{xy} &= 0.0
\end{aligned}
$$

The input data for MSHGEN (genin.dat) is same as that shown in Fig. 5. However, the input for EPFEC (epfecin.dat) with the initial stresses is different and is shown in Fig. 7.

Assignment No.1:

1. Run both cases (Case 1 and Case 2) and examine the deformed mesh before and after the horse-shoe shaped excavation was made.
2. Print (if you have a 132-column printer) your output file: epfeprt.dat and examine the resultant stresses and displacements for both cases. What are the differences?

```
50   20    0    2       0.0       -1.0       1.0
 0
 1     0.029
4.0E+05     0.25        2.50      40.0       0.0
 2     0.000
     0.0        0.00        0.0       0.0        0.0
 0
 -3.576667, 0.009667
-10.730000, 0.029000
 -3.576667, 0.009667
  0.0,       0.0
****** Evaluating the state of initial stresses ******
 1
****** Excavating the underground opening ******
 2
```

Fig. 7 EPFEC input data with initial stresses - Example 1B

Case 3 - Uniform Tectonic Stresses:

In the Canadian Shield, it is known that horizontal stresses are greater than vertical stresses. In this case the conditions simulating the in-situ stress field must be achieved by applying appropriate tractions along the boundary of the mine model. Let's suppose that the vertical stress σ_{yy} is due to gravity only. The horizonal stresses, σ_{xx} and σ_{zz}, are consisting of two components, one of which is the tectonic stress uniformly distributed across the depth, say 3 MPa in x-direction and 2 MPa in z-direction, and the other part is due to the Poisson's effect, i.e., $\frac{\nu}{1-\nu}\sigma_{yy}$. Also we assume that the vertical stress is one of the principal stresses. Then the initial shearing stress $\sigma_{xy} = 0$, and therefore, the coefficients $a_{xy} = b_{xy} = 0$.

Now we assume that γ, the average unit weight of rock mass, is 0.029 MPa/m, and the Poisson's ratio is 0.25, then, the stresses are given:

$$\sigma_{yy} = a_{yy} + b_{yy} \times Y \tag{5}$$

$$\sigma_{xx} = \sigma'_{xx} + \sigma''_{xx} \tag{6}$$

$$\sigma_{zz} = \sigma'_{zz} + \sigma''_{zz} \tag{7}$$

where a_{yy} and b_{yy} are the same as we calculated before. σ'_{xx} and σ'_{zz} are the tectonic stress components which are assumed to be constant acting across depth, i.e., $\sigma'_{xx} = -3$ and $\sigma'_{zz} = -2$. σ''_{xx} and σ''_{zz} are the components induced by gravitational loading, i.e.:

$$\begin{aligned}\sigma''_{xx} &= \frac{\nu}{1-\nu}\{\sigma_{yy}\} \\ &= \frac{\nu}{1-\nu}a_{yy} + \frac{\nu}{1-\nu}(b_{yy} \times Y)\end{aligned} \tag{8}$$

$$\begin{aligned}\sigma''_{zz} &= \nu(\sigma''_{xx} + \sigma_{yy}) \\ &= \frac{\nu}{1-\nu}a_{yy} + \frac{\nu}{1-\nu}(b_{yy} \times Y)\end{aligned} \tag{9}$$

Similarily, at the top of the model, $Y = 70m$ (where $h' = h = 300m$, and at the bottom of the model where $Y = 0$ (where $h' = 300 + 70$).

therefore

$$a_{yy} = -10.730$$

$$b_{yy} = +0.029$$

From the following two equations:

$$a_{xx} + b_{xx} \times Y = \{-3.0 + \frac{0.25}{1-0.25} \times (-10.73)\} + \frac{0.25}{1-0.25}(0.029 \times Y)$$
$$a_{zz} + b_{zz} \times Y = \{-2.0 + \frac{0.25}{1-0.25} \times (-10.73)\} + \frac{0.25}{1-0.25}(0.029 \times Y)$$

we obtain:

$$\begin{aligned} a_{xx} &= -6.576667 \\ b_{xx} &= \quad 0.0096667 \\ a_{zz} &= -5.576667 \\ b_{xx} &= \quad 0.0096667 \end{aligned}$$

Summarizing, we have:

$$\begin{aligned} a_{xx} &= -6.576667 \\ b_{xx} &= \quad 0.0096667 \\ a_{yy} &= -10.7300 \\ b_{yy} &= \quad 0.029 \\ a_{zz} &= -5.576667 \\ b_{xx} &= \quad 0.0096667 \\ a_{xy} &= \quad 0.0 \\ b_{xy} &= \quad 0.0 \end{aligned}$$

Note that the calculation of these coefficients are dependent on the coordinate system you selected for your model.

Figure 8 shows the boundary constraints and boundary tractions for this example. The input data for `MSHGEN` and `EPFEC`, `genin.dat` and `epfecin.dat`, are shown, respectively, in Fig. 9 and Fig. 10.

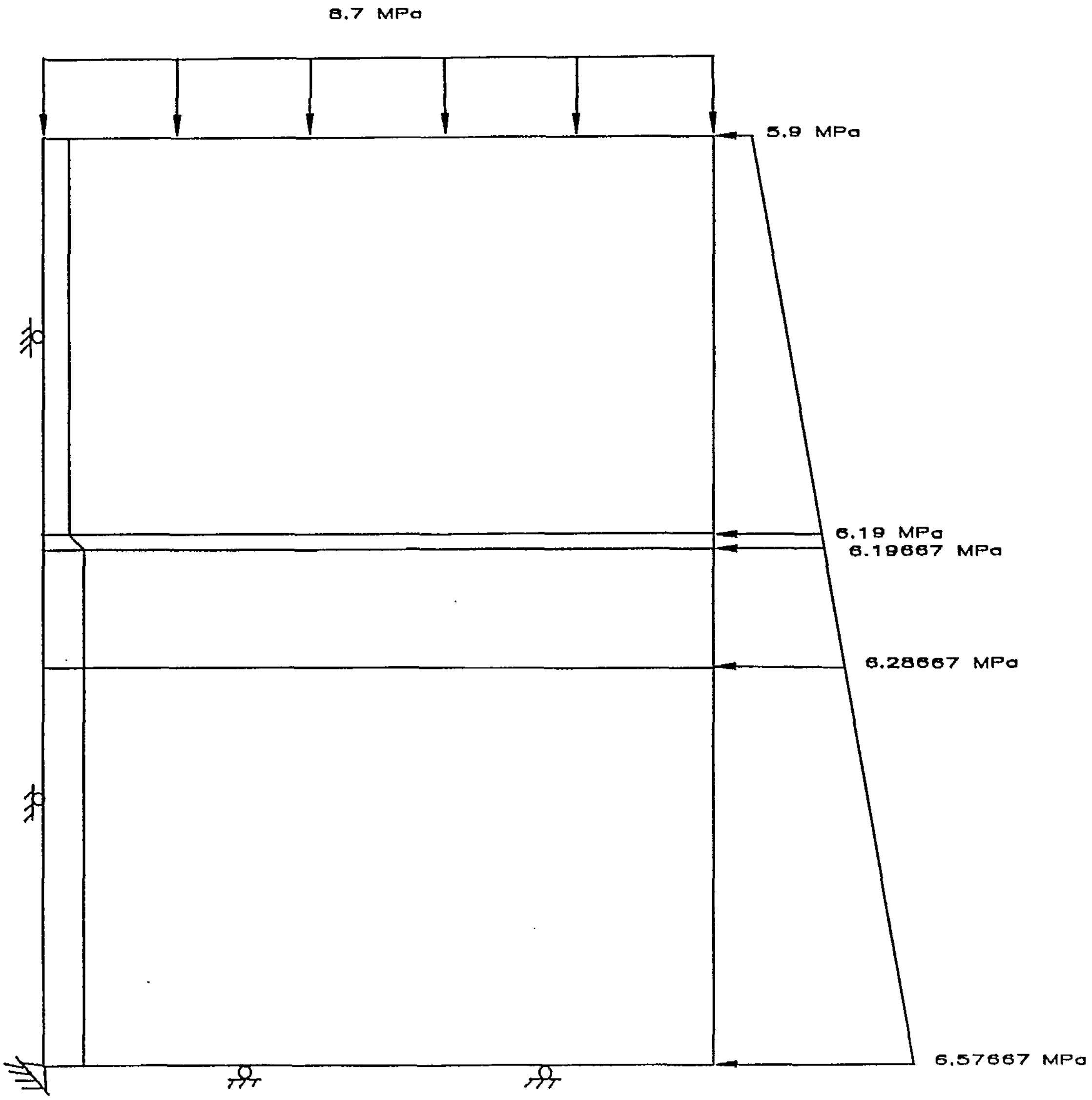


Fig. 8. A schematic diagram showing the boundary constraints and tractions - Example 1C

```
'Example No. 1C - gravity, uniform tectonic stress and initial stress'
  26     8     2     4     2     0
   4    10
   6     4     1     6
   1     3        0.00    0.00
   2     2        3.00    0.00
   3     3       50.00    0.00
   4     1        0.00   30.00
   5     0        3.00   30.00
   6     1       50.00   30.00
   7     1        0.00   39.00
   8     0        3.00   39.00
   9     1       50.00   39.00
  10     1        0.00   40.00
  11     0        2.00   40.00
  12     1       50.00   40.00
  13     1        0.00   70.00
  14     0        2.00   70.00
  15     1       50.00   70.00
  16     0       17.50    0.00
  17     0        0.00   20.00
  18     0        3.00   20.00
  19     1       50.00   20.00
  20     0       17.50   30.00
  21     0       17.50   39.00
  22     0       17.50   40.00
  23     0        0.00   50.00
  24     0        2.00   50.00
  25     1       50.00   50.00
  26     0       17.50   70.00
   1     1     2     5     4     0    18     0    17     1     0     0
   2     2     3     6     5    16    19    20    18     1     0     1
   2 6.5766667 6.2866667
   3     4     5     8     7     0     0     0     0     1     2     0
   4     5     6     9     8    20     0    21     0     1     0     1
   2 6.2866667 6.1996667
   5     7     8    11    10     0     0     0     0     1     2     0
   6     8     9    12    11    21     0    22     0     1     0     1
   2 6.1996667 6.1900000
   7    10    11    14    13     0    24     0    23     1     0     1
   3      8.70      8.70
   8    11    12    15    14    22    25    26    24     1     0     2
   2 6.1900000 5.9000000
   3      8.70      8.70
```

Fig. 9 MSHGEN input data - Example 1C

```
  50   20     0     2        0.0        -1.0        1.0
   0
   1     0.029
  4.0E+05      0.25        0.50       35.0        0.0
   2     0.000
      0.0      0.00        0.0        0.0        0.0
   0
 -6.576667,0.0096667
-10.730000,0.0290000
 -5.576667,0.0096667
  0.0,      0.0
****** Evaluating the state of initial stresses ******
   1
****** Excavating the underground opening ******
   2
```

Fig. 10 EPFEC input data - Example 1C

Assignment No. 2:

Run the model with uniform tectonic stresses (Example 1C), and examine the results.

Case 4 - Arbitrary Tectonic Stresses:

Let's assume again that the vertical stress σ_{yy} is due to gravity and the horizonal stresses are given as follows:

$$\sigma_{yy} = a_{yy} + b_{yy} \times Y$$
$$\sigma_{xx} = 1.5\sigma_{yy} \tag{10}$$
$$\sigma_{zz} = 2.0\sigma_{yy} \tag{11}$$

The evaluation of these initial stress coefficients for this case is simple and straight forward.

The calculation of a_{yy} and b_{yy} is same as before:

$$a_{yy} = -10.73$$
$$b_{yy} = 0.0290$$

From Eqs. 10 and 11 we have:

$$\begin{aligned}\sigma_{xx} &= 1.5\sigma_{yy} \\ &= 1.5(-10.73 + 0.029Y) \\ \sigma_{zz} &= 2.0\sigma_{yy} \\ &= 2.0(-10.73 + 0.029Y)\end{aligned}$$

Therefore, we have:

$$\begin{aligned}a_{xx} &= -16.095 \\ b_{xx} &= +0.0435 \\ a_{yy} &= -10.7300 \\ b_{yy} &= +0.02900 \\ a_{zz} &= -21.460 \\ b_{zz} &= +0.0580 \\ a_{xy} &= 0.0 \\ b_{xy} &= 0.0\end{aligned}$$

The input data for MSHGEN and EPFEC, genin.dat and epfecin.dat for the example 1D, are given in Fig. 11 and Fig. 12 respectively.

```
'Example No. 1D - gravity, arbitrary tectonic stress, and initial stress'
  26    8    2    4    2    0
   4   10
   6    4    1    6
   1    3         0.00   0.00
   2    2         3.00   0.00
   3    2        50.00   0.00
   4    1         0.00  30.00
   5    0         3.00  30.00
   6    0        50.00  30.00
   7    1         0.00  39.00
   8    0         3.00  39.00
   9    0        50.00  39.00
  10    1         0.00  40.00
  11    0         2.00  40.00
  12    0        50.00  40.00
  13    1         0.00  70.00
  14    0         2.00  70.00
  15    0        50.00  70.00
  16    0        17.50   0.00
  17    0         0.00  20.00
  18    0         3.00  20.00
  19    0        50.00  20.00
  20    0        17.50  30.00
  21    0        17.50  39.00
  22    0        17.50  40.00
  23    0         0.00  50.00
  24    0         2.00  50.00
  25    0        50.00  50.00
  26    0        17.50  70.00
   1    1    2    5    4    0   18    0   17    1    0    0
   2    2    3    6    5   16   19   20   18    1    0    1
   2 16.095      14.7900
   3    4    5    8    7    0    0    0    0    1    2    0
   4    5    6    9    8   20    0   21    0    1    0    1
   2 14.790      14.3985
   5    7    8   11   10    0    0    0    0    1    2    0
   6    8    9   12   11   21    0   22    0    1    0    1
   2 14.3985     14.3550
   7   10   11   14   13    0   24    0   23    1    0    1
   3       8.70        8.70
   8   11   12   15   14   22   25   26   24    1    0    2
   2 14.3550     13.0500
   3  8.70        8.70
```

Fig. 11 MSHGEN input data - Example 1D

```
   50    20     0     2        0.0         -1.0         1.0
    0
    1     0.029
   4.0E+05       0.25        5.00        40.0         0.0
    2     0.000
      0.0       0.00        0.0         0.0         0.0
    0
-16.0950, 0.04350
-10.7300, 0.02900
-21.4600, 0.05800
  0.0,      0.0
****** Evaluating the state of initial stresses ******
    1
****** Excavating the underground opening ******
    2
```

Fig. 12 EPFEC input data - Example 1D

Assignment No. 3:

1. Run the model with the specified loading as given above, and examine the state of stresses. Are the tractions applied along the boundaries compatible with the initial stresses?

ANOTHER EXAMPLE WITH MSHGEN

Finite element meshes can be designed in different ways using the mesh-generator MSHGEN. To demonstrate the capability of MSHGEN we will re-design the mesh for the same horse-shoe shaped mine geometry as we discribed in the previous example (Figs. 2, 3).

The new zone diagram and its associated key diagram for the new mesh are shown in Fig. 8.

Usually the boundary constraints generated by MSHGEN are correct, however, there are exceptions.

In this case, the output file generated by MSHGEN, genout.dat, is shown in Fig. 9. It is noted that constraints at several nodes, marked by "**", are incorrect. Therefore, genout.dat has to be modiffied before you run the interface program EPFEC which will merge the modified genout.dat with additional input data (epfecin.dat) and produces the input file required by PCEPFE, i.e., epfein.dat.

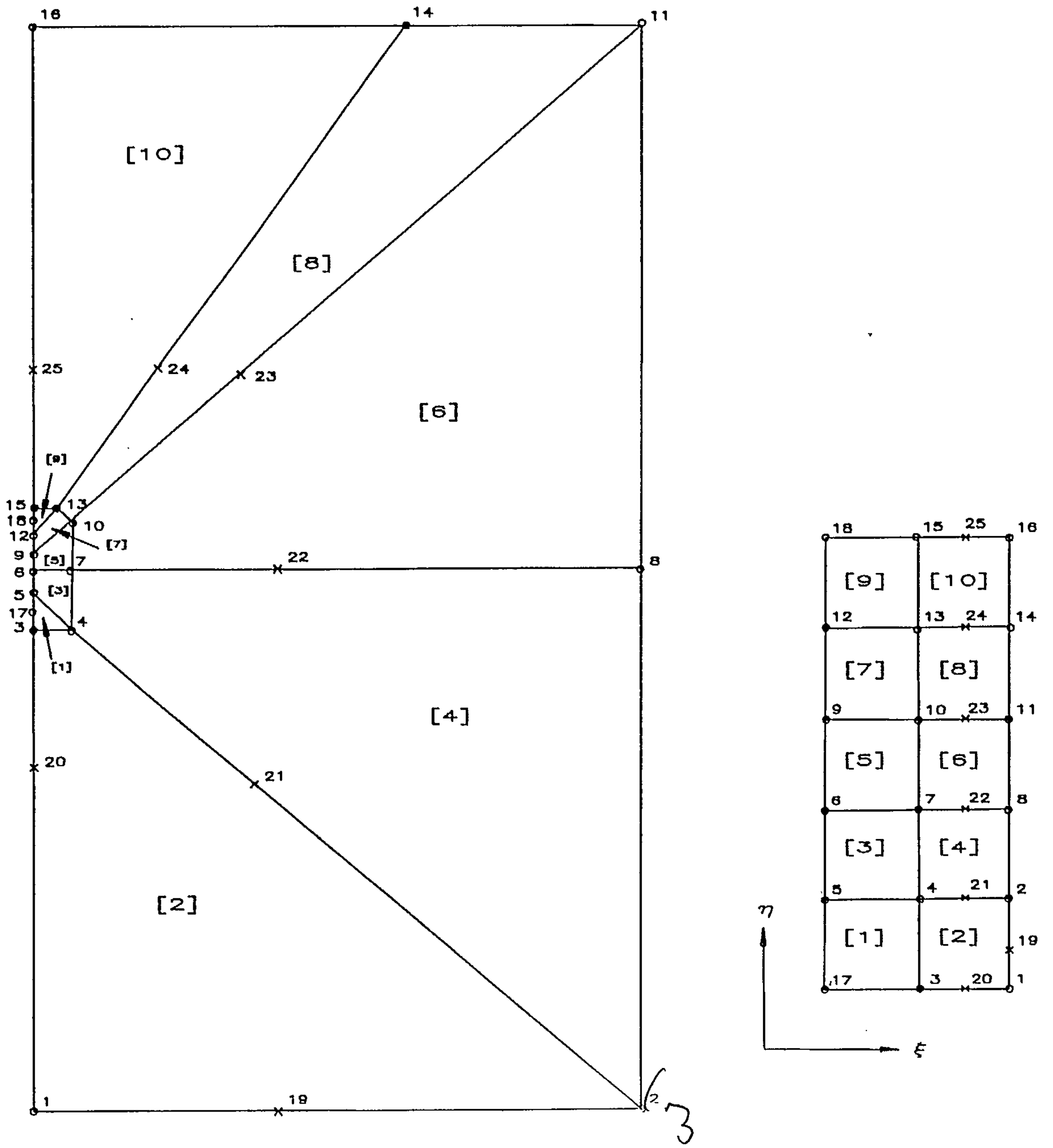


Fig. 8 Zone diagram with triangular zones

```
'Example 2 - horse-shoe shaped U/G opening, gravity Loading, no initial stress'
  24   10    2    5    2    0
   2    3
   3    3    3    3    3
   1    2       0.00   0.00
   2    2      40.00   0.00
   3    1       0.00  25.00
   4    0       3.00  25.00
   5    1       0.00  26.00
   6    1       0.00  28.00
   7    1       0.00  30.00
   8    0       3.00  30.00
   9    1      40.00  30.00
  10    1       0.00  31.50
  11    0       3.00  34.00
  12    1      40.00  60.00
  13    1       0.00  33.00
  14    0       2.00  35.00
  15    0      20.00  60.00
  16    1       0.00  34.00
  17    1       0.00  35.00
  18    1       0.00  60.00
  19    1       0.00  16.00
  20    0      16.40  16.00
  21    0      16.40  30.00
  22    1       0.00  44.00
  23    0       8.50  44.00
  24    0      16.00  43.00
   1    5    3    4    6    0    0    0    0    1    1    0
   2    3    1    2    4   19    0   20    0    1    0    0
   3    6    4    8    7    0    0    0    0    1    1    0
   4    4    2    9    8   20    0   21    0    1    0    0
   5    7    8   11   10    0    0    0    0    1    2    0
   6    8    9   12   11   21    0   24    0    1    0    0
   7   10   11   14   13    0    0    0    0    1    2    0
   8   11   12   15   14   24    0   23    0    1    0    1
   2      8.70      8.70
   9   13   14   17   16    0    0    0    0    1    2    0
  10   14   15   18   17   23    0   22    0    1    0    1
   2      8.70      8.70
```

Fig. 9 Input data for MSHGEN - genin.dat

110

```
100   20    1    2        0.0          0.0        1.0
  0
  1     0.029
 4.0E+05      0.25       10.00      40.0        0.0
  2     0.000
     0.0       0.00        0.0        0.0       0.0
  0
****** 1st sub-problem - excavating the lower level of the U/G opening ******
  1
****** 2nd sub-problem - excavating the upper level of the U/G opening ******
  2
```

Fig. 10 Input data for EPFEC - epfecin.dat

```
   96   75    2     6     1
Example 2 - horse-shoe shaped U/G opening, gravity Loading, no Initial Stress
    1    1  0.0000000E+00  0.4150000E+02
    2    1  0.0000000E+00  0.4075000E+02
    3    1  0.0000000E+00  0.4000000E+02
    4    1  0.0000000E+00  0.3333333E+02
    5    1  0.0000000E+00  0.2000000E+02
    6    2  0.0000000E+00  0.0000000E+00      **
    7    1  0.0000000E+00  0.4200000E+02
    8    0  0.5000000E+00  0.4100000E+02
    9    0  0.9999999E+00  0.4000000E+02
   10    0  0.1777777E+01  0.3362963E+02
   11    0  0.5518518E+01  0.2029629E+02
   12    2  0.1222222E+02  0.0000000E+00
   13    1  0.0000000E+00  0.4250000E+02
   14    0  0.1000000E+01  0.4125000E+02
   15    0  0.2000000E+01  0.4000000E+02
   16    0  0.5037036E+01  0.3392592E+02
   17    0  0.1400000E+02  0.2059259E+02
   18    2  0.2888889E+02  0.0000000E+00
   19    1  0.0000000E+00  0.4300000E+02
   20    0  0.1500000E+01  0.4150000E+02
   21    0  0.3000000E+01  0.4000000E+02
   22    0  0.9777777E+01  0.3422222E+02
   23    0  0.2544444E+02  0.2088889E+02
   24    2  0.5000000E+02  0.0000000E+00      **
   25    1  0.0000000E+00  0.4366666E+02
   26    0  0.1500000E+01  0.4266667E+02
   27    0  0.3000000E+01  0.4166666E+02
   28    0  0.1007408E+02  0.3781481E+02
   29    0  0.2574074E+02  0.2892592E+02
   30    1  0.5000000E+02  0.1500000E+02
   31    1  0.0000000E+00  0.4433333E+02
   32    0  0.1500000E+01  0.4383333E+02
   33    0  0.3000000E+01  0.4333333E+02
   34    0  0.1037037E+02  0.4140741E+02
   35    0  0.2603704E+02  0.3696296E+02
   36    1  0.5000000E+02  0.3000000E+02
   37    1  0.0000000E+00  0.4500000E+02
   38    0  0.1500000E+01  0.4500000E+02
   39    0  0.3000000E+01  0.4500000E+02
   40    0  0.1066667E+02  0.4500000E+02
   41    0  0.2633333E+02  0.4500000E+02
   42    1  0.5000000E+02  0.4500000E+02
   43    1  0.0000000E+00  0.4550000E+02
   44    0  0.1500000E+01  0.4591666E+02
   45    0  0.3000000E+01  0.4633333E+02
   46    0  0.1066667E+02  0.4851852E+02
   47    0  0.2633334E+02  0.5307407E+02
   48    1  0.5000000E+02  0.6000000E+02
   49    1  0.0000000E+00  0.4600000E+02
   50    0  0.1500000E+01  0.4683333E+02
   51    0  0.3000000E+01  0.4766666E+02
   52    0  0.1066667E+02  0.5203703E+02
   53    0  0.2633333E+02  0.6114815E+02
   54    1  0.5000000E+02  0.7500000E+02
   55    1  0.0000000E+00  0.4650000E+02
```

Fig. 11 Output data generated by MSHGEN (genout.dat)- nodes with incorrect constraints are marked by '**'

56	0	0.1500000E+01	0.4775000E+02
57	0	0.3000000E+01	0.4900000E+02
58	0	0.1066667E+02	0.5555555E+02
59	0	0.2633333E+02	0.6922222E+02
60	1	0.5000000E+02	0.9000000E+02
61	1	0.0000000E+00	0.4700000E+02
62	0	0.1333333E+01	0.4816666E+02
63	0	0.2666667E+01	0.4933333E+02
64	0	0.9370371E+01	0.5592592E+02
65	0	0.2303704E+02	0.6948148E+02
66	0	0.4366667E+02	0.9000000E+02
67	1	0.0000000E+00	0.4750000E+02
68	0	0.1166667E+01	0.4858333E+02
69	0	0.2333333E+01	0.4966666E+02
70	0	0.8074072E+01	0.5629630E+02
71	0	0.1974074E+02	0.6974075E+02
72	0	0.3733333E+02	0.9000000E+02
73	1	0.0000000E+00	0.4800000E+02
74	0	0.1000000E+01	0.4900000E+02
75	0	0.2000000E+01	0.5000000E+02
76	0	0.6777778E+01	0.5666666E+02
77	0	0.1644444E+02	0.7000000E+02
78	0	0.3100000E+02	0.9000000E+02
79	1	0.0000000E+00	0.4833333E+02
80	0	0.6666667E+00	0.4916667E+02
81	0	0.1333333E+01	0.5000000E+02
82	0	0.4518518E+01	0.5666666E+02
83	0	0.1096296E+02	0.7000000E+02
84	0	0.2066667E+02	0.9000000E+02
85	1	0.0000000E+00	0.4866666E+02
86	0	0.3333333E+00	0.4933333E+02
87	0	0.6666666E+00	0.5000000E+02
88	0	0.2259259E+01	0.5666666E+02
89	0	0.5481481E+01	0.7000000E+02
90	0	0.1033333E+02	0.9000000E+02
91	1	0.0000000E+00	0.4900000E+02
92	1	0.0000000E+00	0.4950000E+02
93	1	0.0000000E+00	0.5000000E+02
94	1	0.0000000E+00	0.5666666E+02
95	1	0.0000000E+00	0.7000000E+02
96	1	0.0000000E+00	0.9000000E+02

1	1	2	8	7	1	1	0
2	2	3	9	8	1	1	0
3	3	4	10	9	1	3	0
4	4	5	11	10	1	3	0
5	5	6	12	11	1	3	0
6	7	8	14	13	1	1	0
7	8	9	15	14	1	1	0
8	9	10	16	15	1	3	0
9	10	11	17	16	1	3	0
10	11	12	18	17	1	3	0
11	13	14	20	19	1	1	0
12	14	15	21	20	1	1	0
13	15	16	22	21	1	3	0
14	16	17	23	22	1	3	0
15	17	18	24	23	1	3	0
16	19	20	26	25	1	1	0
17	20	21	27	26	1	1	0
18	21	22	28	27	1	3	0
19	22	23	29	28	1	3	0
20	23	24	30	29	1	3	0

Fig. 11 (continued) Output data generated by MSHGEN (genout.dat)- nodes with incorrect constraints are marked by '**'

21	25	26	32	31	1	1	0
22	26	27	33	32	1	1	0
23	27	28	34	33	1	3	0
24	28	29	35	34	1	3	0
25	29	30	36	35	1	3	0
26	31	32	38	37	1	1	0
27	32	33	39	38	1	1	0
28	33	34	40	39	1	3	0
29	34	35	41	40	1	3	0
30	35	36	42	41	1	3	0
31	37	38	44	43	1	2	0
32	38	39	45	44	1	2	0
33	39	40	46	45	1	3	0
34	40	41	47	46	1	3	0
35	41	42	48	47	1	3	0
36	43	44	50	49	1	2	0
37	44	45	51	50	1	2	0
38	45	46	52	51	1	3	0
39	46	47	53	52	1	3	0
40	47	48	54	53	1	3	0
41	49	50	56	55	1	2	0
42	50	51	57	56	1	2	0
43	51	52	58	57	1	3	0
44	52	53	59	58	1	3	0
45	53	54	60	59	1	3	0
46	55	56	62	61	1	2	0
47	56	57	63	62	1	2	0
48	57	58	64	63	1	3	0
49	58	59	65	64	1	3	0
50	59	60	66	65	1	3	1
2	8.700000			8.700000			
51	61	62	68	67	1	2	0
52	62	63	69	68	1	2	0
53	63	64	70	69	1	3	0
54	64	65	71	70	1	3	0
55	65	66	72	71	1	3	1
2	8.700000			8.700000			
56	67	68	74	73	1	2	0
57	68	69	75	74	1	2	0
58	69	70	76	75	1	3	0
59	70	71	77	76	1	3	0
60	71	72	78	77	1	3	1
2	8.700000			8.700000			
61	73	74	80	79	1	2	0
62	74	75	81	80	1	2	0
63	75	76	82	81	1	3	0
64	76	77	83	82	1	3	0
65	77	78	84	83	1	3	1
2	8.700000			8.700000			
66	79	80	86	85	1	2	0
67	80	81	87	86	1	2	0
68	81	82	88	87	1	3	0
69	82	83	89	88	1	3	0
70	83	84	90	89	1	3	1
2	8.700000			8.700000			
71	85	86	92	91	1	2	0
72	86	87	93	92	1	2	0
73	87	88	94	93	1	3	0
74	88	89	95	94	1	3	0
75	89	90	96	95	1	3	1
2	8.700000			8.700000			

Fig. 11 (continued) Output data generated by MSHGEN (genout.dat) - nodes with incorrect constraints are marked by '**'

Assignment 4:

Refer to Fig. 8, and assume the model is loaded with gravity only, please modify `genin.dat` (Fig. 9) and `epfecin.dat` (Fig. 10) so that:

1. ensure that all the boundary constraints are correct;
2. calculate and enter initial stresses coefficients assuming that the top of the model (Fig. 8) is located at 300m below the ground surface;
3. mining step 1 - excavating zone 1 and zone 2;
4. mining step 2 - backfilling zone 1 and zone 2;
5. mining step 3 - excavating zones 5, 7 and 9.

Note: For faster turn around, please use a large C value to prevent any yielding, i.e., an elastic analysis only.

Example :

No. of nodal points 24
" " Elements 10
Blank common storage needed 185
" " " assigned 30000

Table 1

MRL/CANMET NUMERICAL MODELLING CAPABILITIES

Canadian Mine Technology Laboratory

MODELS	SAP2D	PCSAP2D	QUAD	EPFE	PCEPFE	DRUKPRA	NEAT	TEMPFE	NAOS	GEOROC	BMINES	NONSAP	SAP3D	BIT3D	PCBEM	BITEMJ	BEAP	BEAPDD	BEAPM	ENERBRAY	MINTAB	PCMINTAB
F.E.	x	x	x	x	(x)	x	x	x	x	x	x	x	x									
B.E.														x	(x)	x	x		x	x		
D.D.																		x	x		x	(x)
2 D	x	x	x	x	(x)	x	x	x	x	x	x				(x)	x				x		
3 D											x	x	x	x			x	x			x	(x)
Axisymmetric									x	x	x											
Static, linear	x	x	x	x	(x)	x	x		x	x	x	x	x	x	(x)	x	x	x		x	x	(x)
Stress/displacement	x	x	x	x	(x)	x	x		x	x	x	x	x	x	(x)	x	x	x		x	x	(x)
Temperature/heat flux								x														
Energy release																				x	x	x
Dynamic												x										
Non-linear			x	(x)	(x)	x	x			x	x	x				x						
Joints/faults			x								x					x			x			
Progressive failure				x	(x)																	
Transient										x	x											
Thermal stress	x	x									x											
Excavation	x	x	x	x	(x)	x	x			x	x		x								x	(x)
Backfill			x	x	(x)	x	x			x	x		x								x	(x)
Substructuring						x																
Restart			x			x	x			x	x					x					x	(x)
Pre-processor	x	x	?	x	(x)	x	x		x	x	x		x	x	(x)	x	?	?	?		x	(x)
Post-processor	x	x	?	x	(x)	x			x		x		x		(x)	x	?	?	?		x	(x)
Interactive		x			(x)										(x)		x	x	x			(x)
Documentation	g	g	?	g	g	f	f		g	g	g		f	f	f	f	f	?	?	f	g	g
Sources	1	1	*	1	1	1	1	1	1	1	2	3	1	4	1	5	*	*	*	1	1	1

Documentation: g - good; f - fair;

Sources: 1 - MRL/CANMET; 2 - U.S.B.M.; 3 - Univ. of California, Berkley; 4 - Dr. T.A. Cruse, Southwest Research Institute, San Antonio Tx. 5 - CSIRO; * - under development.

Table 1

MRL/CANMET NUMERICAL MODELLING CAPABILITIES

Canadian Mine Technology Laboratory

MODELS	SAP2D	PCSAP2D	QUAD	EPFE	PCEPFE	DRUKPRA	NEAT	TEMPFE	NAOS	GEOROC	BMINES	NONSAP	SAP3D	BIT3D	PCBEM	BITEMJ	BEAP	BEAPDD	BEAPM	ENERBRAY	MINTAB	PCMINTAB
F.E.	x	x	x	x	(x)	x	x	x	x	x	x	x	x									
B.E.														x	(x)	x	x		x	x		
D.D.																		x	x		x	(x)
2 D	x	x	x	x	(x)	x	x	x	x	x	x				(x)	x				x		
3 D											x	x	x	x			x	x			x	(x)
Axisymmetric									x	x	x											
Static, linear	x	x	x	x	(x)	x	x		x	x	x	x	x	x	(x)	x	x	x		x	x	(x)
Stress/displacement	x	x	x	x	(x)	x	x		x	x	x	x	x	x	(x)	x	x	x		x	x	(x)
Temperature/heat flux								x														
Energy release																				x	x	x
Dynamic												x										
Non-linear			x	(x)	(x)	x	x			x	x	x				x						
Joints/faults			x								x					x			x			
Progressive failure				x	(x)																	
Transient										x	x											
Thermal stress	x	x									x											
Excavation	x	x	x	x	(x)	x	x			x	x		x								x	(x)
Backfill			x	x	(x)	x	x			x	x		x								x	(x)
Substructuring						x																
Restart			x			x	x			x	x					x					x	(x)
Pre-processor	x	x	?	x	(x)	x	x		x	x	x		x	x	(x)	x	?	?	?		x	(x)
Post-processor	x	x	?	x	(x)	x			x		x		x		(x)	x	?	?	?		x	(x)
Interactive		x			(x)										(x)		x	x	x			(x)
Documentation	g	g	?	g	(g)	f	f		g	g	g		f	f	f	f	f	?	?	f	g	g
Sources	1	1	*	1	1	1	1	1	1	1	2	3	1	4	1	5	*	*	*	1	1	1

Documentation: g - good; f - fair;
Sources: 1 - MRL/CANMET; 2 - U.S.B.M.; 3 - Univ. of California, Berkley; 4 - Dr. T.A. Cruse, Southwest Research Institute, San Antonio Tx. 5 - CSIRO; * - under development.