SCIENTIFIC NOTEBOOK
Study of Nearfield Rock Mass Response

by

Amitava Ghosh

SCIENTIFIC NOTEBOOK
Study of Nearfield Rock Mass Response

by

Amitava Ghosh

Southwest Research Institute
Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

June 12, 1998

Table of Contents

List of Figures **Page**

List of Tables

1. INITIAL ENTRIES

Scientific Note Book: # 250

Issued to: Amitava Ghosh

Issue Date: January 2, 1998

Printing Period:

Project Title: Study of Nearfield Rock Mass Response Around Emplacement Drifts (RDTME KTI)

Project Staff: Amitava Ghosh

By agreement with the CNWRA QA, this notebook is to be printed at approximate quarterly intervals. This computerized Scientific Notebook is intended to address the criteria of CNWRA QAP-001.

[Amitava Ghosh, January 10, 1998]

1.1. OBJECTIVES

The objective of this study is to simulate the rock mass response in the nearfield of the emplacement drifts in the proposed high-level waste repository at Yucca Mountain, Nevada, under geostatic and thermal loads. The analyses will be carried out at drift scale while considering the degradation of rock mass and concrete liners to the extent possible.

[Amitava Ghosh, May 15, 1998]

1.2. COMPUTERS, COMPUTER CODES, AND DATA FILES

The computer code selected for these analyses is ABAQUS (version 5.6 and higher updates) (Hibbitt, Karlsson & Sorensen, Inc., 1996). ABAQUS is a general purpose finite element code capable of both thermal and mechanical analyses. The analyses are carried out using the computer systems given in table 1-1. Using the Xwindow system, the computer system *performer* is accessed from the computer system *snowwhite*. All calculations are carried out on the *performer* while the display of results, using ABAQUS POST, is done on the *snowwhite* using the Xwindow system.

Table 1-1. Computer, operating system, and compiler used in the simulations.

Machine Name	Machine Type	Operating System	Compiler	Location
performer	Silicon Graphics Onyx	IRIX 5.3	NONE	Building 189
snowwhite	SUN SPARC station 20	SUNOS 4.1	f77 (SUN)	Building 189

[Amitava Ghosh, May 25, 1998]

2. DEVELOPMENT OF THE FINITE ELEMENT MESH OF THE MODELED REGION

A two-dimensional drift scale model has been developed to study the response of the rock mass surrounding the emplacement drifts at the proposed high-level nuclear waste repository at Yucca Mountain, Nevada. The finite element mesh of the drift scale model has been developed in several separate segments due to nonavailability of any mesh generator, such as, ABAQUS/PRE. The model consists of seven parallel emplacement drifts bounded by rock mass, extending to infinity, at the sides. Exploiting the symmetry, only right half of the model is meshed and analyzed. The symmetry plane/line goes through the middle of the fourth drift, as shown in figure 2-1.

Development of the mesh in the model has been carried out in two steps: (i) mesh developed around the drifts and (ii) mesh developed in the remaining region. Several issues were considered while developing the mesh around the drifts. Sometimes the issues are somewhat contradictory to one another. For example, the mesh around the emplacement drifts should be relatively fine as the gradient of the stress field, both excavation and thermally induced, is expected to be large in this region. On the other hand, ABAQUS requires longer time to complete a run and significant computer resources are necessary if there are large number of elements in a model. It has also been decided that the excavation of the drifts will be simulated in the model. Therefore, the mesh should be designed so that the elements representing the excavated drifts can be removed from the model with relative ease.

Remaining region of the model does not require relatively finer mesh as the stress gradient is expected to be small in this zone. Consequently, relatively larger size elements have been selected to model this region. Transition from finer to coarser mesh is extremely tedious to be developed manually. Bonding two adjacent surfaces has been used to accomplish this.

[Amitava Ghosh, May 25, 1998]

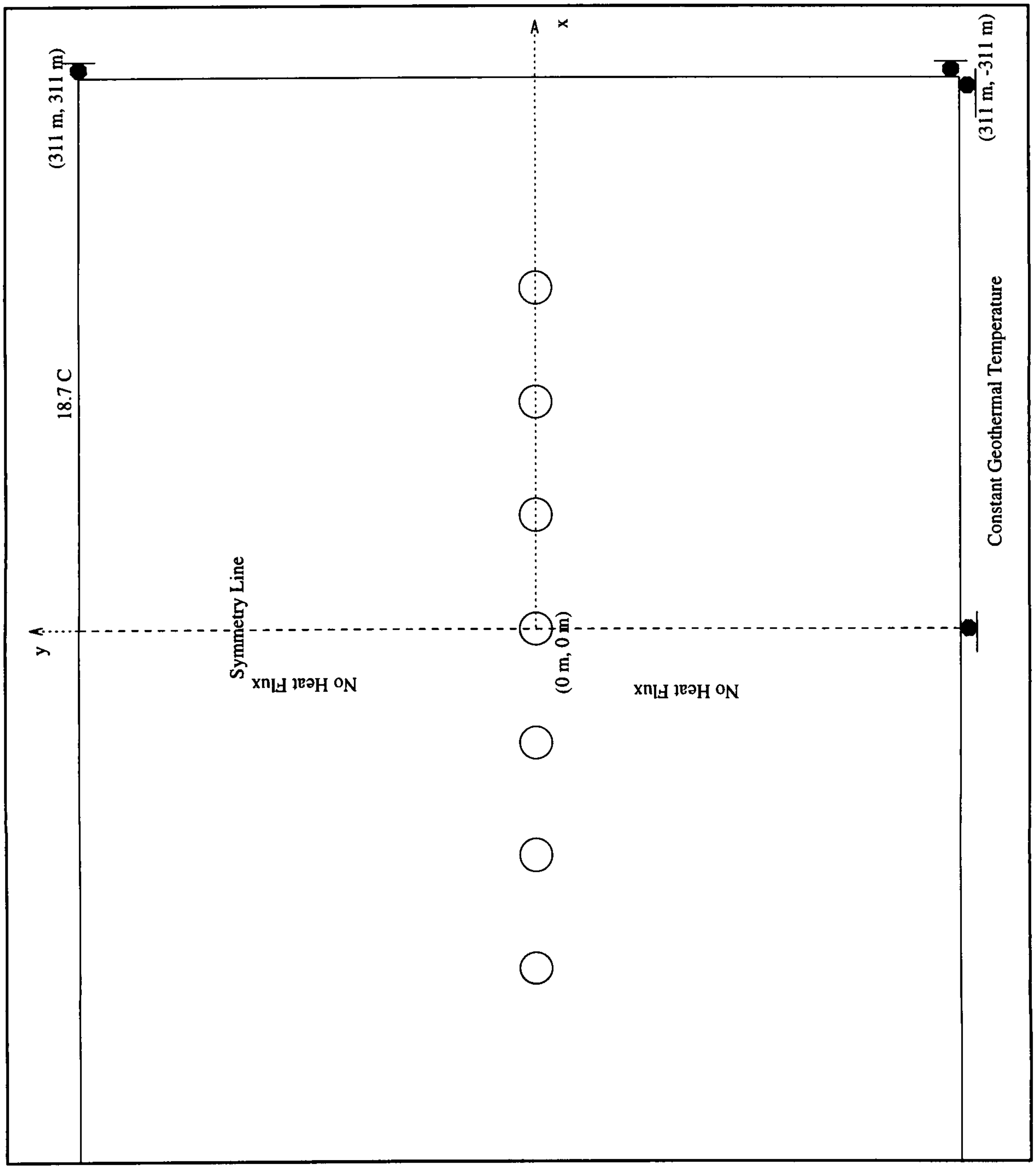

Figure 2-1. The ABAQUS model of nearfield thremomechanical study

2.1 DEVELOPMENT OF THE MESH AROUND THE EMPLACEMENT DRIFTS

The mesh around the four drifts has been developed using a three-step process:

1. develop the mesh outside the drift boundary develop the mesh inside the drift boundary (this region will be excavated)
2. bond the two meshes along the drift boundary so that the region responds as a single continuum before the excavation of the drifts.

Before developing any mesh, a few nodes have been defined. The mesh has been developed with respect to these nodes.

The centers of all four drifts (node numbers 100, 200, 300, and 400 of drifts 1, 2, 3, and 4 respectively) are defined as well as the points needed to define a square box around each drift. As the spacing between the centers of two adjacent drifts is 28 m, the box size is also fixed at 28 m × 28 m. Each square box is centered on the corresponding center of the drift with its sides parallel to vertical and horizontal directions. Each square box spanned from the centerline of one pillar to the centerline of the next pillar.

Eighteen quadrilateral elements have been used to describe each quadrant of the drift with a diameter of 5 m. Similarly, two adjacent sides that are opposite to the circular arc (each quadrant of the drift) are also described by eighteen quadrilateral elements (a total of nineteen nodes for describing each side). After specifying the nodes on both the arc and the straight line sections, nodes have been generated with a bias value of 0.8 so that the elements are smallest at the drift boundaries. Element size gradually increases away from the drift. There is a total of ten elements in a row from the drift boundary to the end of the corresponding square box. Consequently, each full box (28 m × 28 m) is described by 360 elements. ABAQUS needs the nodal definition of one master element in a region of the mesh. After that, it can generate other elements in the region from the definition of the master element and the specified generation rule.

Both constant strain triangle and quadrilateral elements have been used to model the interior of the drifts. It should be noted that these elements will be taken out of the model after arriving at the initial equilibrium to simulate the excavation of the drifts. Three circular rows of elements have been used to model the interior of each drift. The innermost row is composed of triangular elements while rest of the elements are quadrilaterals. Only 20 elements have been used in each row of the drift interior so that the angle of each triangular element at the node coincident with the drift is 18°. Larger number of elements will make this angle more acute and the element shape becomes distorted significantly. Results from these distorted elements will be in doubt and ABAQUS produces warning messages about this distorted shape of these elements.

Radial thickness/size of the triangular elements is 1.0 m. The quadrilateral elements in the inner row have 1.3 m thickness. The outer row of quadrilateral elements has a thickness of 0.2 m so that by changing the material properties these elements can simulate liner to be placed inside the drifts.

Elements in both interior and exterior regions of a drift are unconnected and will not know the existence of each other unless connected together to respond similarly along the common boundary, that is, the drift wall. These regimes need to be tied together so that they respond as a single entity. In ABAQUS, tying the two regions can be accomplished in the following way. First, elements of both regions across the common boundary are defined using the *ELSET command. Then the corresponding surfaces of both regions are defined using the *SURFACE DEFINITION command. For each surface definition, either S_1 (surface defined by nodes 1 and 2) or S_2 (surface defined by nodes 2 and 3) or S_3 (surface defined by nodes 3 and 4) or S_4 (surface defined by nodes 4 and 1) has to be specified. Finally, these two surfaces are tied together by the *CONTACT PAIR, INTERACTION = *nojoint*, TIED, ADJUST=0.01 command. A dummy material property *nojoint* has been specified. The parameter ADJUST=0.01 will allow ABAQUS to adjust the nodes that are more than 0.01 m apart to lie on both the slave and master surfaces. By definition, the first surface specified in the *CONTACT PAIR command is the slave surface. In the whole mesh, all master surfaces have been defined in such a way that they will be affected by the imposed perturbation and the corresponding slave surfaces will conform to them.

[Amitava Ghosh, May 25, 1998]

2.2 DEVELOPMENT OF THE MESH IN REMAINING REGION OF THE MODEL

In the remaining region of the model, the mesh has been developed in such a way that the model size increases from drift region to the boundary of the model. A bias parameter equal to 0.9 is used in conjunction with the *NFILL command to accomplish this mesh gradation. The elements and the associated nodes have been developed in a way similar to that used to develop mesh around the drifts. There is a total of ten segments used to develop the finite element mesh in this region: BASE1, TOP1, BASE2, TOP2, BASE3, TOP3, BASE4, TOP4, SIDE1, AND SIDE2. The bounding coordinates, nude numbers, and element numbers for each of these ten segments are given below.

2.2.1 Segment BASE1

This segment is directly below the drift region and above the BASE2 region.

Bounding coordinates are: (0,-64), (0,-14), (98,-14), (98,-64)
Node numbers range from 30001 to 32801, 30002 to 32802,..., 30021, to 32821
Element numbers range from 30001 to 32701, 30002 to 32702,..., 30020 to 32720

2.2.2 Segment TOP1

This segment is directly above the drift region and below the TOP2 region.

Bounding coordinates are: (0,14), (0,64), (98,64), (98,14)
Node numbers range from 40001 to 42801, 40002 to 42802,..., 40021 to 42821
Element numbers range from 40001 to 42701, 40002 to 42702,..., 40020 to 42720

2.2.3 Segment BASE2

This segment is directly below the BASE1 region.

Bounding coordinates are: (0,-311), (98,-311), (98,-64), (0,-64)
Node numbers range from 80001 to 81201, 80002 to 81202,..., 80025 to 81125
Element numbers range from 80001 to 81101, 80002 to 81102,..., 80024 to 81124

2.2.4 Segment TOP2

This segment is directly above the TOP1 region.

Bounding coordinates are: (0,64), (98,64), (98,311), (0,311)
Node numbers range from 85001 to 86201, 85002 to 86202,..., 85025 to 86225
Element numbers range from 85001 to 86101, 85002 to 86102,..., 85024 to 86124

2.2.5 Segment BASE3

This segment is directly below the SIDE1 region.

Bounding coordinates are: (150,-311), (150,-64), (98,-64), (98,-311)
Node numbers range from 81201 to 81801, 81202 to 81802,..., 81225 to 81825
Element numbers range from 81201 to 81701, 81202 to 81702,..., 81224 to 81724

2.2.6 Segment TOP3

This segment is directly above the SIDE1 region.

Bounding coordinates are: (150,64), (150,311), (98,311), (98,64)
Node numbers range from 86201 to 86801, 86202 to 86802,..., 86225 to 86825
Element numbers range from 86201 to 86701, 86202 to 86702,..., 86224 to 86724

2.2.7 Segment BASE4

This segment is directly below the SIDE2 region.

Bounding coordinates are: (311,-311), (311,-64), (150,-64), (150,-311)
Node numbers range from 81801 to 83601, 81802 to 83602,..., 81825 to 83625
Element numbers range from 81801 to 83501, 81802 to 83502,..., 81824 to 83524

2.2.8 Segment TOP4

This segment is directly above the SIDE2 region.

Bounding coordinates are: (311,64), (311,311), (150,311), (150,64)
Node numbers range from 86801 to 88601, 86802 to 88602,..., 86825 to 88625
Element numbers range from 86801 to 88501, 86802 to 88502,..., 86824 to 88524

2.2.9 Segment SIDE1

This segment is at the side of the drift region.

Bounding coordinates are: (98,-64), (98,64), (150,64), (150,-64)
Node numbers range from 20001 to 21501, 20002 to 21502,..., 20051 to 21551
Element numbers range from 20001 to 21501, 20002 to 21402,..., 20050 to 21450

2.2.10 Segment SIDE2

This segment is directly adjacent to the drift region.

Bounding coordinates are: (150,-64), (311,-64), (150,-64), (311,64)
Node numbers range from 24001 to 25801, 24002 to 25802,..., 24016 to 25816
Element numbers range from 24001 to 25701, 24002 to 25702,..., 24015 to 25715

[Amitava Ghosh, May 25, 1998]

2.3 BONDING OF DIFFERENT REGIONS

Bonding of different regions has been carried out following the procedure described in section 2.1.

[Amitava Ghosh, May 25, 1998]

REFERENCES

Brechtel, C.E., M. Lin, E. Martin, and D.S. Kessel. 1995. *Geotechnical Characterization of the North Ramp of the Exploratory Studies Facility, Volume I of II Data Summary*. SAND95-0488/1 UC–814. Albuquerque, NM: Sandia National Laboratories

Hibbitt, Karlsson & Sorensen, Inc. 1996. *ABAQUS/Standard User's Manual.* Volumes I and II. Pautucket, RI: Hibbitt, Karlsson & Sorensen, Inc.

Hoek, E., and E.T. Brown. 1982. *Underground Excavations in Rock.* London, England: Institution of Mining and Metallurgy.

Date: 11/12/98
Sender: Amitava Ghosh
To: Bruce Mabrito
cc: Asadul Chowdhury, Amitava Ghosh
Priority: Urgent
Receipt requested
Subject: RE: Entry in Scientific Notebook No. 250

Bruce:

There was no entry in Scientific Notebook # 250 for last quarter. I am sorry it took so long to respond.

Amit Ghosh

SCIENTIFIC NOTE BOOK # 250
Study of Nearfield Rock Mass Response

by

Amitava Ghosh

Southwest Research Institute
Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

January 19, 1999

Table of Contents

List of Figures **Page**

List of Tables **Page**

1. INITIAL ENTRIES

Scientific Note Book: # 250

Issued to: Amitava Ghosh

Issue Date: January 2, 1998

Printing Period:

Project Title: Study of Nearfield Rock Mass Response Around Emplacement Drifts (RDTME KTI)

Project Staff: Amitava Ghosh

By agreement with the CNWRA QA, this notebook is to be printed at approximate quarterly intervals. This computerized Scientific Notebook is intended to address the criteria of CNWRA QAP-001.

[Amitava Ghosh, January 10, 1998]

1.1. Objectives

The objective of this study is to simulate the rock mass response in the nearfield of the emplacement drifts in the proposed high-level waste repository at Yucca Mountain, Nevada, under geostatic and thermal loads. The analyses will be carried out at drift scale while considering the degradation of rock mass and concrete liners to the extent possible.

[Amitava Ghosh, May 15, 1998]

1.2. Computers, Computer Codes, and Data Files

The computer code selected for these analyses is ABAQUS (version 5.6 and higher updates) (Hibbitt, Karlsson & Sorensen, Inc., 1996). ABAQUS is a general purpose finite element code capable of both thermal and mechanical analyses. The analyses are carried out using the computer systems given in table 1-1. Using the Xwindow system, the computer system *performer* is accessed from the computer system *snowwhite*. All calculations are carried out on the *performer* while the display of results, using ABAQUS POST, is done on the *snowwhite* using the Xwindow system.

Table 1-1. Computer, operating system, and compiler used in the simulations.

Machine Name	Machine Type	Operating System	Compiler	Location
performer	Silicon Graphics Onyx	IRIX 5.3	NONE	Building 189
snowwhite	SUN SPARCstation 20	SUNOS 4.1	f77 (SUN)	Building 189

[Amitava Ghosh, May 25, 1998]

The computer system performer has been upgraded to *pluto*. Hereafter, all runs of ABAQUS will be carried out on *pluto*.

Table 1-2. Computer, operating system, and compiler used in the simulations (modified).

Machine Name	Machine Type	Operating System	Compiler	Location
pluto	Silicon Graphics Onyx2	IRIX 6.5	NONE	Building 189
snowwhite	SUN SPARCstation 20	SUNOS 4.1	f77 (SUN)	Building 189

[Amitava Ghosh, January 18, 1999]

2. DEVELOPMENT OF THE FINITE ELEMENT MESH OF THE MODELED REGION

A two-dimensional drift scale model has been developed to study the response of the rock mass surrounding the emplacement drifts at the proposed high-level nuclear waste repository at Yucca Mountain, Nevada. The finite element mesh of the drift scale model has been developed in several separate segments due to nonavailability of any mesh generator, such as, ABAQUS/PRE. The model consists of seven parallel emplacement drifts bounded by rock mass, extending to infinity, at the sides. Exploiting the symmetry, only right half of the model is meshed and analyzed. The symmetry plane/line goes through the middle of the fourth drift, as shown in figure 2-1.

Development of the mesh in the model has been carried out in two steps: (i) mesh developed around the drifts and (ii) mesh developed in the remaining region. Several issues were considered while developing the mesh around the drifts. Sometimes the issues are somewhat contradictory to one another. For example, the mesh around the emplacement drifts should be relatively fine as the gradient of the stress field, both excavation and thermally induced, is expected to be large in this region. On the other hand, ABAQUS requires longer time to complete a run and significant computer resources are necessary if there are large number of elements in a model. It has also been decided that the excavation of the drifts will be simulated in the model. Therefore, the mesh should be designed so that the elements representing the excavated drifts can be removed from the model with relative ease.

Remaining region of the model does not require relatively finer mesh as the stress gradient is expected to be small in this zone. Consequently, relatively larger size elements have been selected to model this region. Transition from finer to coarser mesh is extremely tedious to be developed manually. Bonding two adjacent surfaces has been used to accomplish this.

[Amitava Ghosh, May 25, 1998]

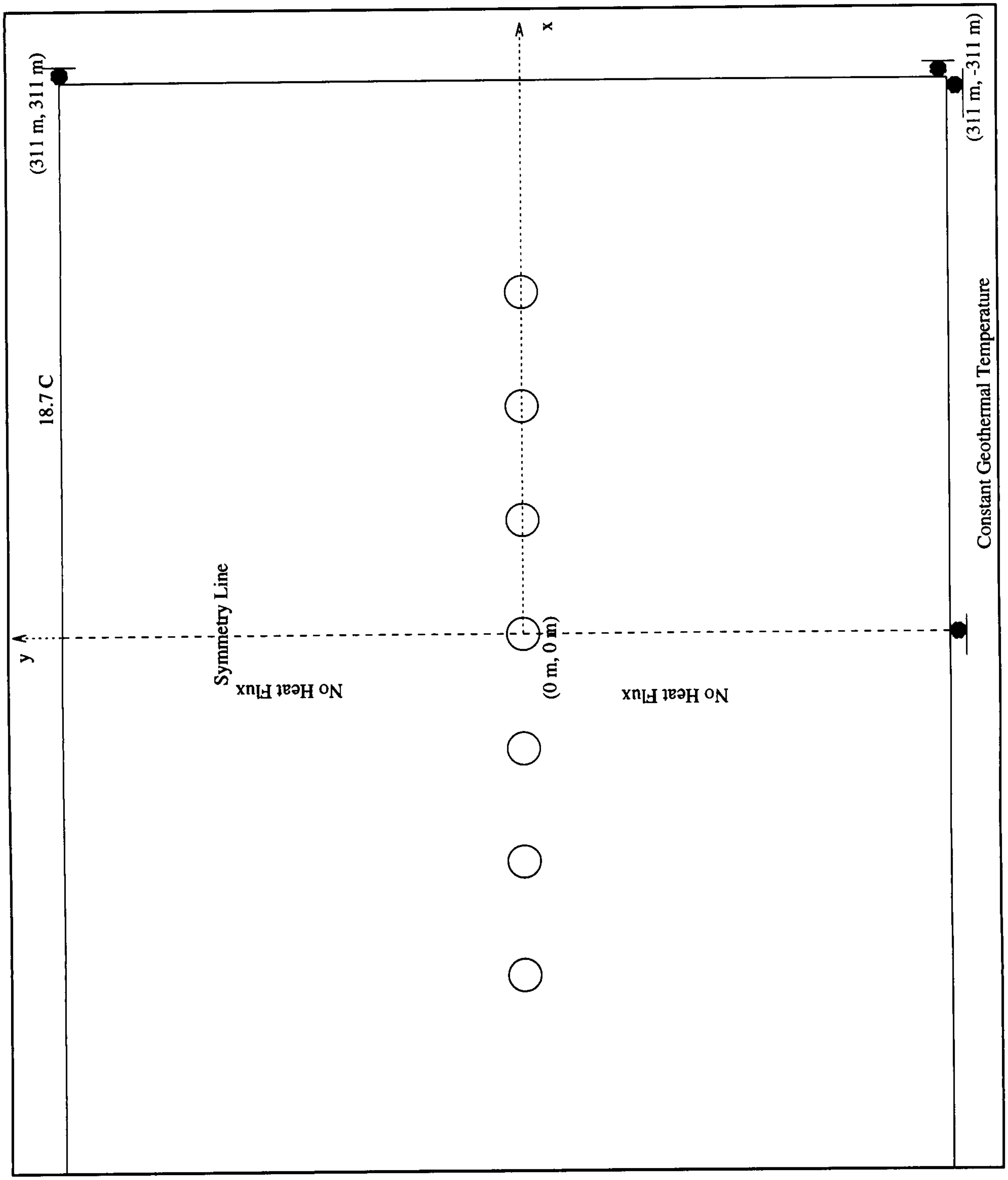

Figure 2-1. The ABAQUS model of nearfield thermomechanical study

2.1 DEVELOPMENT OF THE MESH AROUND THE EMPLACEMENT DRIFTS

The mesh around the four drifts has been developed using a three-step process:

1. develop the mesh outside the drift boundary
2. develop the mesh inside the drift boundary (this region will be excavated)
3. bond the two meshes along the drift boundary so that the region responds as a single continuum before the excavation of the drifts.

Before developing any mesh, a few nodes have been defined. The mesh has been developed with respect to these nodes.

The centers of all four drifts (node numbers 100, 200, 300, and 400 of drifts 1, 2, 3, and 4 respectively) are defined as well as the points needed to define a square box around each drift. As the spacing between the centers of two adjacent drifts is 28 m, the box size is also fixed at 28 m × 28 m. Each square box is centered on the corresponding center of the drift with its sides parallel to vertical and horizontal directions. Each square box spanned from the centerline of one pillar to the centerline of the next pillar.

Eighteen quadrilateral elements have been used to describe each quadrant of the drift with a diameter of 5 m. Similarly, two adjacent sides that are opposite to the circular arc (each quadrant of the drift) are also described by eighteen quadrilateral elements (a total of nineteen nodes for describing each side). After specifying the nodes on both the arc and the straight line sections, nodes have been generated with a bias value of 0.8 so that the elements are smallest at the drift boundaries. Element size gradually increases away from the drift. There is a total of ten elements in a row from the drift boundary to the end of the corresponding square box. Consequently, each full box (28 m × 28 m) is described by 360 elements. ABAQUS needs the nodal definition of one master element in a region of the mesh. After that, it can generate other elements in the region from the definition of the master element and the specified generation rule.

Both constant strain triangle and quadrilateral elements have been used to model the interior of the drifts. It should be noted that these elements will be taken out of the model after arriving at the initial equilibrium to simulate the excavation of the drifts. Three circular rows of elements have been used to model the interior of each drift. The innermost row is composed of triangular elements while rest of the elements are quadrilaterals. Only 20 elements have been used in each row of the drift interior so that the angle of each triangular element at the node coincident with the drift is 18°. Larger number of elements will make this angle more acute and the element shape becomes distorted significantly. Results from these distorted elements will be in doubt and ABAQUS produces warning messages about this distorted shape of these elements.

Radial thickness/size of the triangular elements is 1.0 m. The quadrilateral elements in the inner row have 1.3 m thickness. The outer row of quadrilateral elements has a thickness of 0.2 m so that by changing the material properties these elements can simulate liner to be placed inside the drifts.

Elements in both interior and exterior regions of a drift are unconnected and will not know the existence of each other unless connected together to respond similarly along the common boundary, that is, the drift wall. These regimes need to be tied together so that they respond as a single entity. In ABAQUS, tying the two regions can be accomplished in the following way. First, elements of both regions across the common boundary are defined using the *ELSET command. Then the corresponding surfaces of both regions are defined using the *SURFACE DEFINITION command. For each surface definition, either S_1 (surface defined by nodes 1 and 2) or S_2 (surface defined by nodes 2 and 3) or S_3 (surface defined by nodes 3 and 4) or S_4 (surface defined by nodes 4 and 1) has to be specified. Finally, these two surfaces are tied together by the *CONTACT PAIR, INTERACTION = *nojoint*, TIED, ADJUST=0.01 command. A dummy material property *nojoint* has been specified. The parameter ADJUST=0.01 will allow ABAQUS to adjust the nodes that are more than 0.01 m apart to lie on both the slave and master surfaces. By definition, the first surface specified in the *CONTACT PAIR command is the slave surface. In the whole mesh, all master surfaces have been defined in such a way that they will be affected by the imposed perturbation and the corresponding slave surfaces will conform to them.

[Amitava Ghosh, May 25, 1998]

2.2 DEVELOPMENT OF THE MESH IN REMAINING REGION OF THE MODEL

In the remaining region of the model, the mesh has been developed in such a way that the model size increases from drift region to the boundary of the model. A bias parameter equal to 0.9 is used in conjunction with the *NFILL command to accomplish this mesh gradation. The elements and the associated nodes have been developed in a way similar to that used to develop mesh around the drifts. There is a total of ten segments used to develop the finite element mesh in this region: BASE1, TOP1, BASE2, TOP2, BASE3, TOP3, BASE4, TOP4, SIDE1, AND SIDE2. The bounding coordinates, nude numbers, and element numbers for each of these ten segments are given below.

2.2.1 Segment BASE1

This segment is directly below the drift region and above the BASE2 region.

Bounding coordinates are: (0,-64), (0,-14), (98,-14), (98,-64)
Node numbers range from 30001 to 32801, 30002 to 32802,..., 30021, to 32821
Element numbers range from 30001 to 32701, 30002 to 32702,..., 30020 to 32720

2.2.2 Segment TOP1

This segment is directly above the drift region and below the TOP2 region.

Bounding coordinates are: (0,14), (0,64), (98,64), (98,14)
Node numbers range from 40001 to 42801, 40002 to 42802,..., 40021 to 42821
Element numbers range from 40001 to 42701, 40002 to 42702,..., 40020 to 42720

2.2.3 Segment BASE2

This segment is directly below the BASE1 region.

Bounding coordinates are: (0,-311), (98,-311), (98,-64), (0,-64)
Node numbers range from 80001 to 81201, 80002 to 81202,..., 80025 to 81125
Element numbers range from 80001 to 81101, 80002 to 81102,..., 80024 to 81124

2.2.4 Segment TOP2

This segment is directly above the TOP1 region.

Bounding coordinates are: (0,64), (98,64), (98,311), (0,311)
Node numbers range from 85001 to 86201, 85002 to 86202,..., 85025 to 86225
Element numbers range from 85001 to 86101, 85002 to 86102,..., 85024 to 86124

2.2.5 Segment BASE3

This segment is directly below the SIDE1 region.

Bounding coordinates are: (150,-311), (150,-64), (98,-64), (98,-311)
Node numbers range from 81201 to 81801, 81202 to 81802,..., 81225 to 81825
Element numbers range from 81201 to 81701, 81202 to 81702,..., 81224 to 81724

2.2.6 Segment TOP3

This segment is directly above the SIDE1 region.

Bounding coordinates are: (150,64), (150,311), (98,311), (98,64)
Node numbers range from 86201 to 86801, 86202 to 86802,..., 86225 to 86825
Element numbers range from 86201 to 86701, 86202 to 86702,..., 86224 to 86724

2.2.7 Segment BASE4

This segment is directly below the SIDE2 region.

Bounding coordinates are: (311,-311), (311,-64), (150,-64), (150,-311)
Node numbers range from 81801 to 83601, 81802 to 83602,..., 81825 to 83625
Element numbers range from 81801 to 83501, 81802 to 83502,..., 81824 to 83524

2.2.8 Segment TOP4

This segment is directly above the SIDE2 region.

Bounding coordinates are: (311,64), (311,311), (150,311), (150,64)
Node numbers range from 86801 to 88601, 86802 to 88602,..., 86825 to 88625
Element numbers range from 86801 to 88501, 86802 to 88502,..., 86824 to 88524

2.2.9 Segment SIDE1

This segment is at the side of the drift region.

Bounding coordinates are: (98,-64), (98,64), (150,64), (150,-64)
Node numbers range from 20001 to 21501, 20002 to 21502,..., 20051 to 21551
Element numbers range from 20001 to 21501, 20002 to 21402,..., 20050 to 21450

2.2.10 Segment SIDE2

This segment is directly adjacent to the drift region.

Bounding coordinates are: (150,-64), (311,-64), (150,-64), (311,64)
Node numbers range from 24001 to 25801, 24002 to 25802,..., 24016 to 25816
Element numbers range from 24001 to 25701, 24002 to 25702,..., 24015 to 25715

[Amitava Ghosh, May 25, 1998]

2.3 BONDING OF DIFFERENT REGIONS

Bonding of different regions has been carried out following the procedure described in section 2.1.

[Amitava Ghosh, May 25, 1998]

2.4 Calculation of Initial Temperature Distribution in the Model From Geothermal Gradient

The model assumes an average ground surface rock temperature of 18.7° C (Bonabian, 1997). The geothermal gradient with depth at the Yucca Mountain site is (CRWMS/M&O, 1995, Table 9.2-2, pp. 22):

Gradient = 0.020° C/m from ground surface to less than 150 m
Gradient = 0.018° C/m from depth 150 m to less than 400 m
Gradient = 0.030° C/m from depth 400 m and deeper.
An assumption has been made that the gradient remains constant at 0.030° C/m beyond 541 m following the VA document (Bonabian, 1997). Consequently, the temperature T at depth d is:

T = 18.7 + 0.020 * d if d < 150 m
T = 18.7 + 0.020 * 150 + 0.018 * (d - 150) if 150 m > d < 400 m
T = 18.7 + 0.020 * 150 + 0.018 * (400 - 150) + 0.030 * (d - 400) if d > 400 m.

A computer program, named *geothermal.f*, has been developed to calculate the temperature at each node of the ABAQUS mesh. ABAQUS requires that the data file should contain the node number and initial temperature. To verify that the code is calculating the initial temperature distribution within the modeled region correctly, along with a node number x and y coordinates of the node were written to a file for plotting. A contour plot in the vertical plane and a three-dimensional plot are shown in figures 2-2 and 2-3. Both figures show that the temperature starts increasing with depth with no correlation with the x direction. As expected, the rate or gradient of the temperature increase is initially small. It increases at large depths.

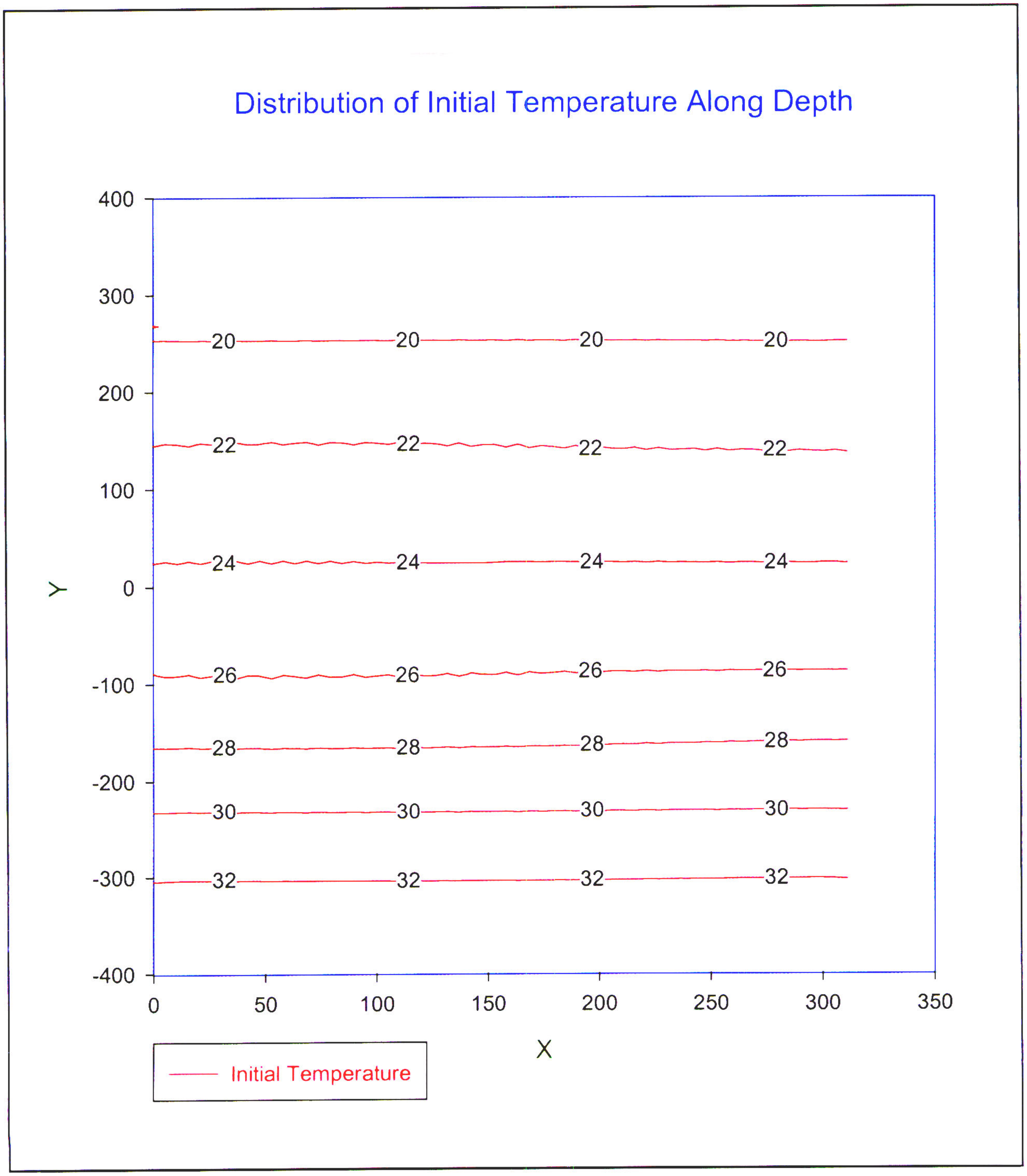

Figure 2-2. Contour plot of initial temperature distribution with depth in the ABAQUS model

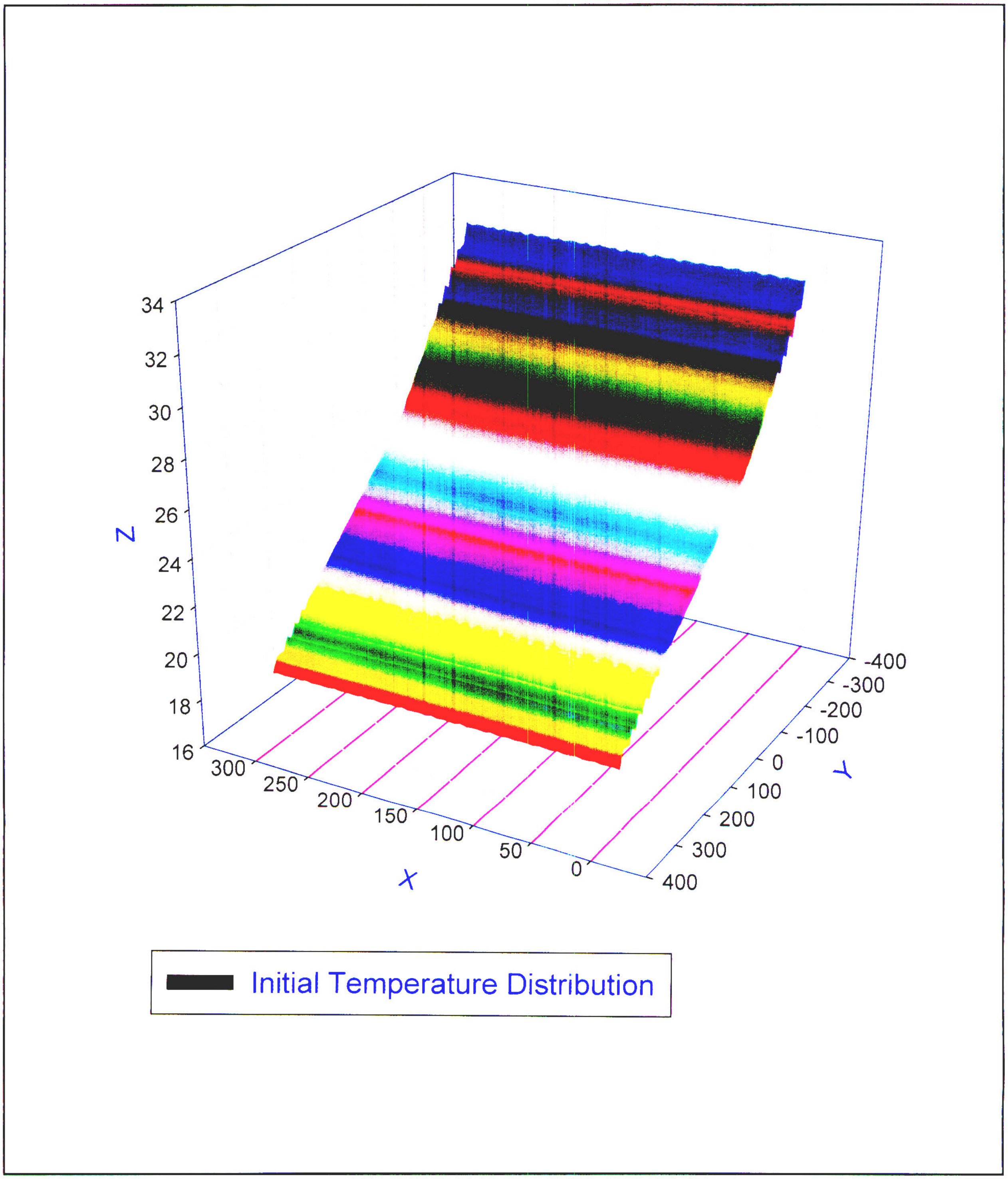

Figure 2-3. 3D plot of initial temperature distribution with depth in the ABAQUS model

REFERENCES

Brechtel, C.E., M. Lin, E. Martin, and D.S. Kessel. 1995. *Geotechnical Characterization of the North Ramp of the Exploratory Studies Facility, Volume I of II Data Summary*. SAND95-0488/1 UC-814. Albuquerque, NM: Sandia National Laboratories.

Bonabian, S. 1997. *Repository Ground Support Analysis for Viability Assessment*. Document Identifier BCAA00000-01717-0200-00004 Rev 00, Las Vegas, NV: Civilian Radioactive Waste Management System/Management & Operating Contractor.

Civilian Radioactive Waste Management System/Management & Operating Contractor. 1995. *Thermomechanical Analyses*. Document No. BC0000000-01717-5705-00013 Rev 00. Las vegas, NV: TRW Environmental Safety Systems, Inc.

Hibbitt, Karlsson & Sorensen, Inc. 1996. *ABAQUS/Standard User's Manual*. Volumes I and II. Pautucket, RI: Hibbitt, Karlsson & Sorensen, Inc.

Hoek, E., and E.T. Brown. 1982. *Underground Excavations in Rock*. London, England: Institution of Mining and Metallurgy.

APPENDIX A

Source Code of *geothermal.f*

```
      PROGRAM geo_temperature
c
c***********************************************************************
c
c      This program calculates the initial temperature at each node
c      point from given geothermal gradient at YM and average ground
c      surface rock temperature (18.7C). The thermal gradients are:
c
c      0 to 150 m:    0.019 degree C/m
c      150 to 400 m:  0.020 degree C/m
c      400 to 700 m:  0.030 degree C/m
c
c      These data are based on Table 9.2-2 Rock Surface Temperature
c      and Thermal Gradient, Thermomechanical Analyses, TRW Environmental
c      Safety Systems, Inc., Document No. BC0000000-01717-5705-00013,
c      Rev. 00, June 14, 1995, and Section 4.3.4 Thermal Gradient,
c      Repository Ground Support Analysis for Viability Assessment,
c      CRWMS/M&O, Document No. BCAA00000-01717-0200-00004 Rev. 00, 1997.
c
c      Author: Amitava Ghosh
c      Date:   January 4, 1999
c
c***********************************************************************
c

      IMPLICIT NONE
      INTEGER maxnode
      PARAMETER (maxnode=10000)

c

      REAL y(maxnode),temperature(maxnode),x(maxnode)
      REAL z,thickness,gradient1,gradient2,gradient3
      REAL depth1,depth2,depth3,depth

      INTEGER nodenum(maxnode)
      INTEGER i,nodecount,rd,wt

      CHARACTER*80 nodefile,outfile

      LOGICAL ondisk

      DATA rd,wt /15,16/
      DATA gradient1,gradient2,gradient3 /0.019,0.018,0.030/

c

12    WRITE (*,101)'output file name => '
      READ (*,'(a)') outfile


      inquire (FILE=outfile, EXIST=ondisk)

      if (ondisk) then
        write (*,103) outfile
        go to 12
      end if

      open (wt,file=outfile,status='new')


15    WRITE (*,101)'Node file => '
      READ (*,'(a)') nodefile

      inquire (FILE=nodefile, EXIST=ondisk)

      if (.NOT.ondisk) then
        write (*,105)
        go to 15
      end if

      open (rd,file=nodefile,status='old')
```

```
101    FORMAT (//a45,$)
103    format (//a60//,' File exists.  Please try again ...'/)
105    format (//a60//,' File allnodes.def does not exit.  ',
     &                 'Please try again ...'/)


c
c *** Read node data
c

       nodecount = 0

100    READ (rd,*,END=110) nodenum(nodecount+1),x(nodecount+1),
     &                     y(nodecount+1),z,thickness

       nodecount = nodecount + 1

       GOTO 100

110    WRITE (*,*) nodecount,' node coordinates read from Node file'

c
c ***  Calculate geothermal temperature at each node using depth y and
c      given geothermal gradient information
c

       DO i = 1, nodecount

         depth = 311.0 - y(i)

         IF ((depth - 150.0).LE.0.0) THEN

           depth1 = depth
           depth2 = 0.0
           depth3 = 0.0

         ELSEIF ((depth - 400.0).LE.0.0) THEN

           depth1 = 150.0
           depth2 = depth - 150.0
           depth3 = 0.0

         ELSE

           depth1 = 150.0
           depth2 = 250.0
           depth3 = depth - 400.0

         END IF

c

         temperature(i) = 18.7 + gradient1*depth1 + gradient2*depth2
     &                         + gradient3*depth3

       END DO

c
c *** Write the results to the output file
c

       DO i = 1, nodecount

         WRITE (wt,201) nodenum(i),temperature(i)

       END DO

201    FORMAT (1x,i8,',',2x,(f10.4,2x))
       STOP
       END
```

No original text entered into this scientific notebook has been removed.

A Ghosh
Amitava Ghosh
2/9/1999

MARIA ✓

S/N #250

Date: 7/9/99
Sender: Amitava Ghosh
To: Bruce Mabrito
cc: Asadul Chowdhury
Priority: Normal
Subject: Re:July 1, 1999 Call For Electronic Scientific Notebooks

---

Bruce:

There was no entry to Scientific Notebook # 250 in the last quarter.

Thanks,

Amit Ghosh

```
_______________________Reply Separator___________________
Subject:     July 1, 1999 Call For Electronic Scientific Notebooks
Author:      Bruce Mabrito
Date:        7/1/1999 12:37 AM
```

CNWRA Electronic Scientific Notebook holders:

This is your quarterly call for CNWRA electronic scientific notebooks, effective July 1, 1999.

The addresses listed above have one or more electronic scientific notebooks assigned to them and they are requested to print out a copy and provide it to QA for inclusion into the appropriate folder. For the past year we have asked that your submittals not be bound, so that we could wait to bind them as books, but not "thin books." This quarter, we will look at the "thickness" of the electronic scientific notebook folders and if they have reached what appears to be an "appropriate number of pages," we will ask you if you agree that it is time to bind the pages into a bound book. We typically have an original and a copy made into a book, so that QA can retain the original and you can have a copy for your records.

At the present time, QA records show there are 19 electronic scientific notebooks numbers issued to 13 individuals. Call me if you have questions on this July 1 Electronic S/N call.
Bruce x 5149

Date: 10/7/99
Sender: Bruce Mabrito
To: Maria Padilla
Priority: Normal
Subject: Fwd:Re:Quarterly Call for Electronic Scientific Notebook Pri

Maria,

Here is one more. Bruce

_____________________Forward Header_____________________

Subject: Re:Quarterly Call for Electronic Scientific Notebook Printou
Author: Amitava Ghosh
Date: 10/7/99 11:42 AM

Bruce:

There was no entry in Scientific Notebook #250 for this period.

Thanks,

Amit Ghosh

_____________________Reply Separator_____________________

Subject: Quarterly Call for Electronic Scientific Notebook Printouts
Author: Bruce Mabrito
Date: 10/1/1999 11:48 AM

TO CNWRA ELECTRONIC SCIENTIFIC NOTEBOOK HOLDERS:

This is the first call for printed copies of your Electronic Scientific Notebook. As always, if you believe that a sufficient amount of your notebook has been printed and is ready to be bound by SwRI Publications, please let Maria or myself know that. This quarter we do have several electronic scientific notebook sections that appear to be ready to be bound into one volume.

Also, please note that R. Pabalan, R. Fedors, S. Painter and E. Pearcy will pass along this email message to Drs. Greathouse, Or, Heckert, and Stothoff to have them submit one copy of their Electronic Scientific Notebook to you and you can provide it to QA.

Thanks for you attention to this important activity. Bruce Mabrito x 5149

Date: 1/6/00
Sender: Amitava Ghosh
To: Bruce Mabrito
Priority: Normal
Subject: Re:Quarterly Call for Electronic Scientific Notebooks

---

Bruce:

There was no entry for Scientific Notebook # 250 over the last quarter.

Thanks,

Amit Ghosh

____________________Reply Separator____________________
Subject: Quarterly Call for Electronic Scientific Notebooks
Author: Bruce Mabrito
Date: 1/6/2000 12:45 PM

This is the January 2000 "quarterly call" for printouts of electronic scientific notebooks in accordance with QAP-001.

This is also an opportunity to verify that QA Records are up to date, showing the following individuals and the Electronic Scientific Notebooks we have assigned:

Amit Armstrong	**Electronic Scientific Notebook**	**No.**	**214**
Rui Chen		**274**	
Charles Connor		**115**	
David Farrell		**317**	
Randy Fedors/D. Or		**354**	
Amit Ghosh		**250**	
Britt Hill		**88**	
Alka Jain/David Turner	**379**		
Peter LaFemina		**322**	
		380	
Sitakanta Mohanty		**170**	
Roberto Pabalan		**185**	
		278	
J. Greathouse/D. Turner		**359**	
Scott Painter		**282**	
		318	
		334	
		335	
C. Heckert/Scott Painter		**364**	
Stuart Stothoff/E. Pearcy		**163**	
Lietai Yang		**373**	

Certain consultants will have to be contacted by CNWRA staff to remind them to send in their respective printouts.

As always, when the work and documentation of the work in the Electronic Scientific Notebook is completed, we would appreciate you turning in your final notebook printout. A complete or multi-volume printed scientific notebook can then be reviewed by the EM and subsequently retained in QA Records for the long term.

If there are any errors noted in the above list, please bring them to my attention by calling X 5149 or sending me an e-mail note. Bruce

All entries into Scientific Notebook No. 250E from January 2, 1998, have been made by Amitava Ghosh.

A Ghosh
October 3, 2000

No original text entered into this Scientific Notebook has been removed.

A Ghosh
(AMITAVA GHOSH)
October 3, 2000