WASTE ISOLATION PILOT PLANT
Sandia National Laboratories

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SCM Coordinator's Name *(print)* — Signature — Date

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SANTOS – Verification and Qualification Document

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Abstract

Due to the complexity of structural response calculations used to solve real physical problems, the variety of codes available for performing these calculations, and the importance of accurate predictions when these are used to assess conditions encountered in the field, confidence must be established in the consistency and accuracy of the modeling techniques and the computer codes which are used. This document describes a suite of verification and qualification problems which have been solved with SANTOS. They range from simple single-element problems that are used to verify specific constitutive model or other feature implementations in the code to the highly nonlinear, large deformation, complex drift problems of previous benchmarking exercises. The range of problems solved is intended to thoroughly exercise SANTOS thereby resulting in a code that has been extensively verified and qualified.

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Acknowledgment

The efforts of the SANTOS computer program developer, C. M. Stone, in developing the code, on his many suggestions for verification problems, and on his efforts at helping to resolve difficulties with the code as they arose during verification are gratefully acknowledged. In addition, the efforts of the many individuals who ran early versions of the code and provided helpful comments during its development and debugging phases are gratefully acknowledged, as well. This report was prepared with the support of the Waste Isolation Pilot Plant (WIPP) Project, as such, the support of WIPP Principal Investigator B. M. Butcher is also gratefully acknowledged.

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Preface

This verification and qualification document is intended as a companion document to *SANTOS – A Two-Dimensional Finite Element Program for the Quasistatic, Large Deformation, Inelastic Response of Solids*, SAND90–0543. It was separated from the theory and user's manual in order to make both documents easier to use. The novice user should probably refer to the theory and user's document, first, before attempting to duplicate the problems described herein.

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Introduction

This document was written with two purposes in mind. First, and foremost, it is intended as an ancillary document to the SANTOS theory and user's manual (Stone, 1995). It can help the novice user in learning to use SANTOS, initially, by providing numerous detailed input instructions for simple example problems along with the accompanying solutions, and it can be of help to more experienced users who wish to try new features in the code. In addition, the document was also written to satisfy the Waste Isolation Pilot Plant (WIPP) project quality assurance requirements related to documentation of codes in use by the project. The WIPP is a research and development facility authorized to demonstrate the safe disposal of low-level radioactive wastes arising from the defense activities of the United States. It is being developed by the U. S. Department of Energy (DOE) and is located in southeastern New Mexico in a bedded salt formation at a depth of about 650 m below the surface. Several WIPP-specific geomechanics problems are included herein to document the qualification of this code for use on the WIPP project.

Due to the complexity of structural response calculations used to solve real physical problems, the variety of codes available for performing these calculations, and the importance of accurate predictions when these are used to assess conditions encountered in the field, confidence must be established in the consistency and accuracy of the modeling techniques and computer codes which are selected for use. This confidence ultimately must be gained by comparing code predictions with analytic solutions, experimental data, and measured field observations. When agreement is reached between the predictions from the code and the data measured in the field, the code is considered "validated." This means that there is an assurance that the model as embodied in the computer code is a *correct* representation of the physical process or system for which it was intended (Silling, 1983).

There are two additional terms that are related to validation. These are "verification" and "qualification" and these can, in fact, be viewed as steps taken along the path to validation. Verification is the demonstration that a computer code does correctly what it is supposed to do. In other words, all algorithms and constitutive relations are programmed correctly although they may or may not be valid for a particular application. Qualification is related to the use of computer codes for solving real physical problems. A code is qualified for a particular application if it has been verified and if the combination of solution techniques, constitutive equations, geometric discretization, and boundary conditions, all consistent with the limitations of the code, lead to an *acceptable* solution to the physical problem (Morgan et al., 1981).

The question of what is an acceptable solution is relative depending on the complexity of the problem being solved. When many nonlinearities affect the solution, there may be more variation in the range of what is considered to be an acceptable solution. Thus, to assess the predictive capability of a code, "benchmarking" is often used. Benchmarking, in this context, is defined as the comparison of predictions obtained with one code to those obtained with other codes having presumably similar capabilities (Morgan et al., 1981). While benchmarking can be used for either verification or qualification, in this document, benchmarking will be associated with qualification rather than verification because prior to

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performing the benchmark calculations described herein, the code was subjected to extensive verification.

The remainder of this document describes a suite of verification and qualification problems which have been solved with the SANTOS finite element computer program and, as such, the SANTOS theory and user's manual (Stone 1995) is incorporated herewith as the primary reference for all of the problems described herein. They range from simple single-element problems that are used to verify specific features or constitutive model implementations in the code to the highly nonlinear, large deformation, complex geomechanics problems of previous benchmarking exercises. The range of problems solved is intended to thoroughly exercise SANTOS, and thus result in a code that has been extensively verified and qualified for WIPP applications. Each of the following problems is relatively self-contained. The problem and specific aspects of the code that are exercised are first described. The analytic solution (for the case of verification problems) or solutions from other codes (for the qualification problems) are then presented and discussed. The SANTOS solution along with all input/output is then presented. The SANTOS solution is then compared to the analytic or other solutions, and the results of the comparison are discussed. A final section for each problem contains references for all other cited literature.

References

1. Morgan, H. S, R. D. Krieg, and R. V. Matalucci, *Comparative Analysis of Nine Structural Codes Used in the Second WIPP Benchmark Problem*, SAND81-1389, Sandia National Laboratories, Albuquerque, New Mexico, November 1981.
2. Silling, S. A., *Final Technical Position on Documentation of Computer Codes for High-Level Waste Management*, NUREG-0856, U. S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, 1983.
3. Stone, C. M., SANTOS – *A Two-Dimensional Finite Element Program for the Quasistatic, Large Deformation, Inelastic Response of Solids*, SAND90-0543, Sandia National Laboratories, Albuquerque, New Mexico, 1995.

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Problem 1 – Large Rotation Problem

This problem demonstrates that SANTOS can correctly analyze the stress state in a large rotation problem.

Problem Description

A unit cube is initially loaded with a pressure on its top horizontal face (equal in value to its initial vertical stress). The other faces are not loaded. The cube is then rotated 90 degrees clockwise, as shown in Figure 1.1. The cube is rotated in ten increments from its original starting position.

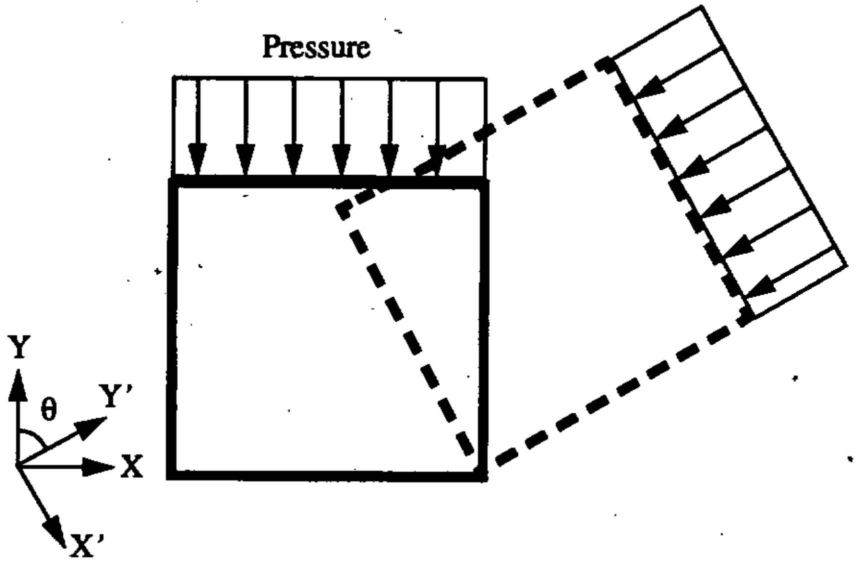

Figure 1.1 Problem Geometry and Boundary Conditions

Analytic Solution

The two-dimensional stress state in the body can be expressed by the following equations taken from Fung (1965).

$$\sigma_{xx}' = \sigma_{xx}\cos^2\theta + \sigma_{yy}\sin^2\theta + \tau_{xy}\sin(2\theta) \qquad \textbf{(EQ 1.1)}$$

$$\sigma_{yy}' = \sigma_{xx}\sin^2\theta + \sigma_{yy}\cos^2\theta - \tau_{xy}\sin(2\theta) \qquad \textbf{(EQ 1.2)}$$

$$\tau_{xy}' = \left(\frac{-\sigma_{xx} + \sigma_{yy}}{2}\right)\sin(2\theta) + \tau_{xy}\cos(2\theta) \qquad \textbf{(EQ 1.3)}$$

where the unprimed stresses are those in the unrotated cube.

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A value of 10,000 is used for the pressure in this specific example and the cube is treated as an elastic material with a Young's modulus of 1.0E6. Notice that, σ_{xx} and τ_{xy} are equal to zero, meaning that initially both the horizontal and the shear stresses in the system are zero. Because of the value of pressure used in this example, the initial vertical stress in the cube is -10,000. However, as the cube is rotated, the analytic solution given by Equations 1.1, 1.2, and 1.3 indicates that:

- The horizontal stress will increase with θ to a final value of -10,000 at a value of $\theta = 90^{\circ}$;
- The vertical stress will decrease with θ to a final value of zero at a value of $\theta = 90^{\circ}$; and
- The shear stress will increase with θ to a maximum, at a value of $\theta = 45^{\circ}$, and then will decrease back to zero at $\theta = 90^{\circ}$.

SANTOS Solution

Problem Discretization

A single element (4-node quadrilateral) is used in the analysis.

Input Data

A listing of the SANTOS input file is given in APPENDIX A.

Output Listing

A partial listing of the printed output showing pertinent problem information is given in APPENDIX A.

Discussion of Results

A comparison of analytically-derived results and those predicted by SANTOS is shown in Figure 1.2. The SANTOS predictions are the same as the analytical ones, demonstrating that SANTOS correctly handles large rotation stress transformations.

References

1. Fung, Y. C., *Foundations of Solid Mechanics*, Prentice-Hall, 1965.

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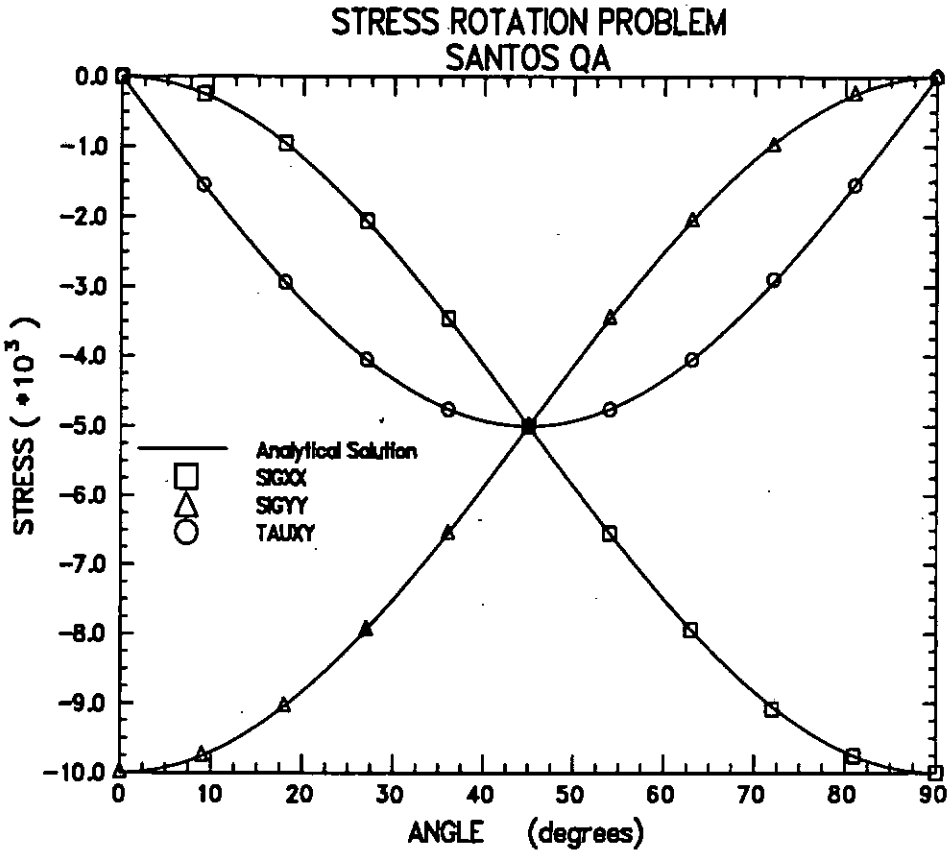

Figure 1.2 Rotated Stress Plot

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Problem 2 – Delete Material Option Problem

This problem checks the delete material option in SANTOS by removing materials from a hanging bar and observing changes in the support reactions due to the change in body mass.

Problem Description

A linear, elastic isotropic rod is hanging from a pinned support in a constant gravity field, as shown in Figure 2.1. The rod is composed of five materials each with the same volume and mechanical properties. The materials are sequentially deleted, starting with the material farthest from the pinned support and continuing until one material remains.

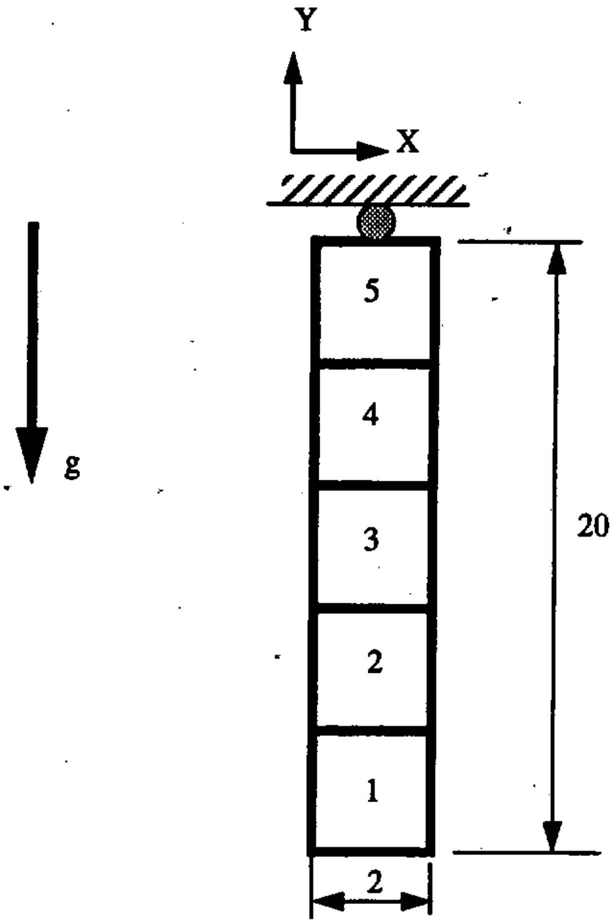

Figure 2.1 Problem Geometry and Boundary Conditions

Analytic Solution

The delete option is considered to be working properly if it correctly computes the vertical support reaction in the body after each material deletion. The reaction can be computed analytically as follows:

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$$R = \sum_{i=1}^{N} \rho g V_i - \sum_{j=1}^{N^*} \rho g V_j \qquad \text{(EQ 2.1)}$$

where N is the total number of material blocks and N^* is the number of material blocks removed. The above equation applies for $0 < N^* \le N$.

Specific values used for this example were: $\rho = 1.0$; $g = 5.0$;and $N = 5$. An elastic material with $E = 1.0\times10^4$ and the geometric dimensions shown in Figure 2.1 was used. Thus, before any material is removed, $R = 200$. This value decreases by 40 with every material block removed. After material blocks 1 to 4 are removed, the reaction reaches a final value of 40.

SANTOS Solution

Problem Discretization

A 160 element (4-node quadrilateral) mesh is used in the SANTOS calculations and is shown in Figure 2.2.

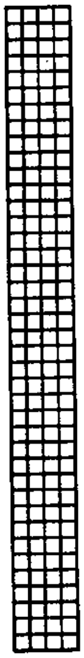

Figure 2.2 Finite Element Mesh

Input Data

A listing of the input table for SANTOS can be found in APPENDIX B.

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Output Listing

A partial listing of the SANTOS output can be found in APPENDIX B.

Discussion of Results

The plot of computed reaction forces versus the analytical solution (the solid line) is shown in Figure 2.3. The stair-step shape with time is a result of removing one material block at each specific time. Thus, the first material block, consisting of 32 elements in the SANTOS analysis, was removed at $t = 1.0$; then the second material block of 32 elements was removed at $t = 2.0$, and so forth. The delete option is seen to work correctly in SANTOS.

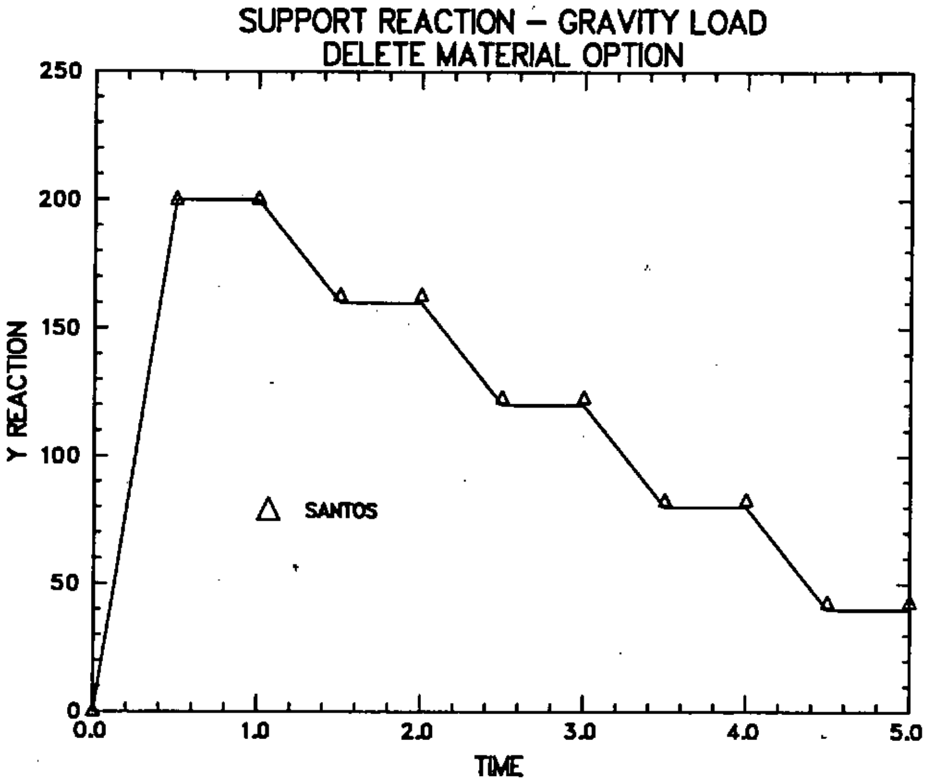

Figure 2.3 Support Reaction Plot

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Problem 3 – Prescribed Force Option Problem

This problem tests the SANTOS prescribed force option.

Problem Description

A slender cantilever beam of linear, elastic, isotropic material is loaded at its tip with a concentrated load that varies with time, i.e., the load starts off at zero and linearly increases with time to some final value. The vertical endpoint displacement and vertical (shear) reaction of the beam are computed analytically and compared with the SANTOS solution.

Analytic Solution

The model geometry and boundary conditions are shown in Figure 3.1. The shear force at the support is equal to the concentrated load. The vertical displacement of the end point of the beam, at any time, is computed using the following formula taken from Young, 1989:

$$\Delta = \frac{PL^3}{3EI} \qquad \textbf{(EQ 3.1)}$$

where P is the concentrated load, L is the beam length, I is the beam's moment of inertia, and E is the Young's modulus. The solution given by Equation 3.1 above is valid for slender beams; consequently, the beam is given a length to depth ratio of 30 to 1.

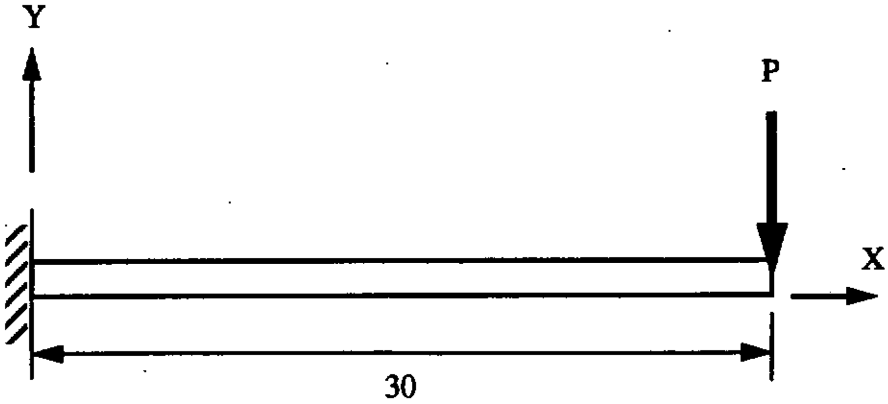

Figure 3.1 Concentrated Load Problem

For specific comparisons between analytic and computed solutions, P is defined to start off at a value of zero, initially, and to increase linearly to a final value of 20 at a time of 2.0. In addition, a value of 1.0E7 is used for E, and a value of 1/12 is used for I. With these values, the analytic solution of Equation 3.1 indicates that the vertical displacement of the end point should increase linearly from a value of zero, initially, to a final value of 0.216.

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Similarly, the vertical reaction at the left end should increase linearly from a value of zero, initially, to a final value of 20.

SANTOS Solution

Problem Discretization

A 120 element (4-node quadrilateral) mesh is used in the SANTOS analysis and is shown in Figure 3.2.

Figure 3.2 Finite Element Mesh

Input Data

A listing of the SANTOS input file is given in APPENDIX C.

Output Listing

A partial listing of the printed output from SANTOS, showing pertinent problem information, is also given in APPENDIX C.

Discussion of Results

The plots of end point vertical displacement and vertical reaction with time (It should be noted that time here really only corresponds to increase in load, P) are shown in Figure 3.3 and Figure 3.4. The symbols represent the computed values, while the solid line represents the analytic solution. Comparison of the computed and analytic results shown in the figures indicates that the implementation of the prescribed force option in SANTOS is correct.

References

2. Young, W. C., *Roark's Formulas for Stress & Strain*, 6th ed., McGraw-Hill, 1989, pp100.

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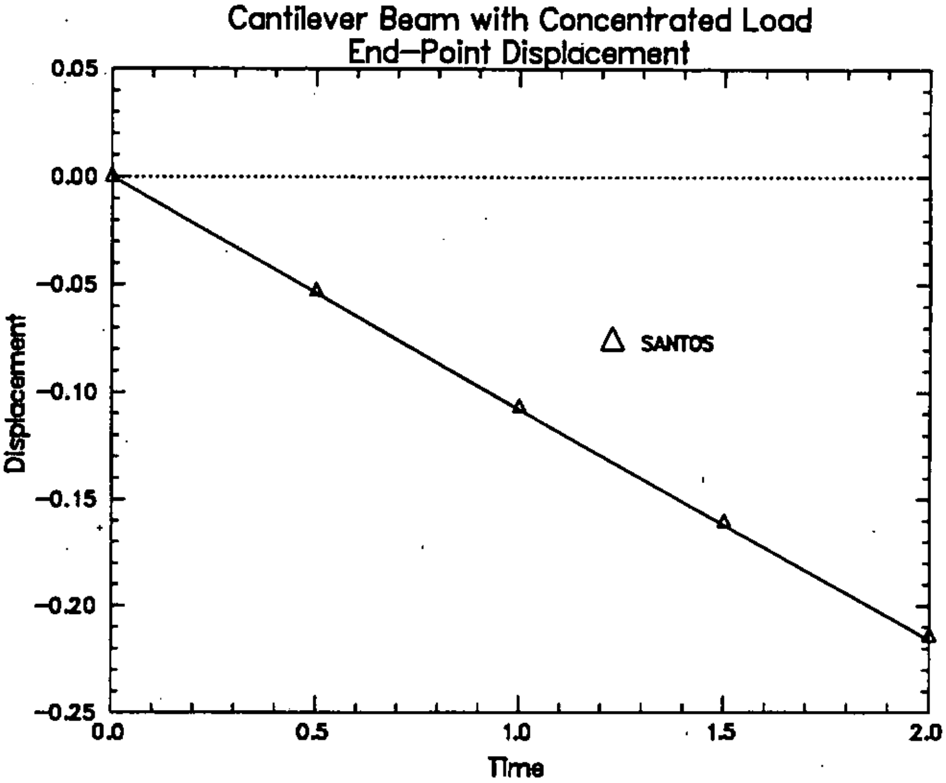

Figure 3.3 End-Point Displacement

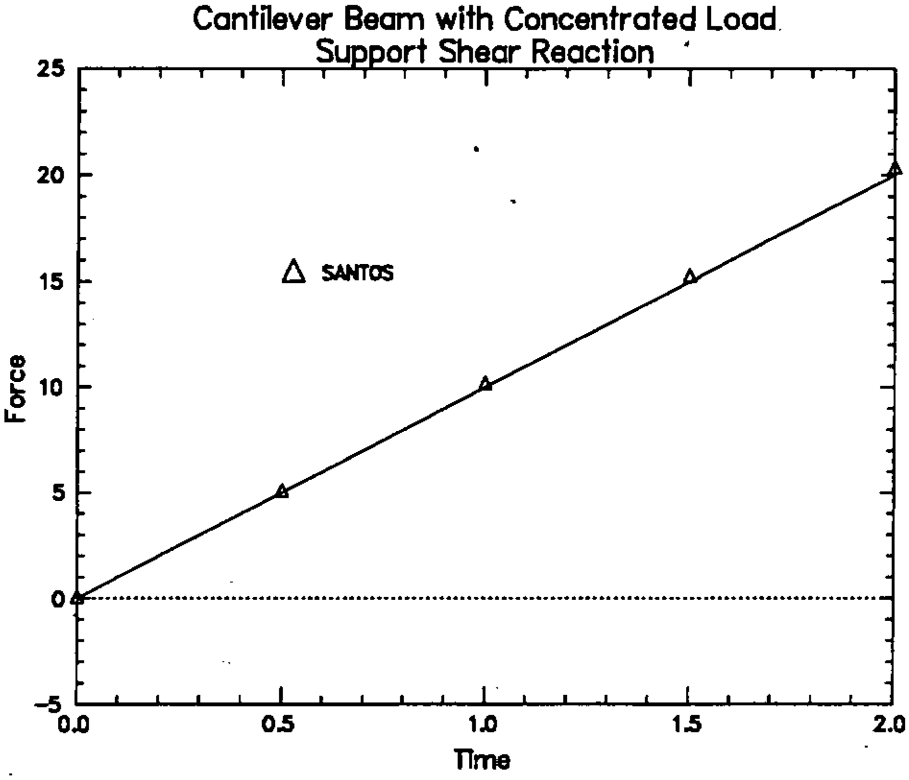

Figure 3.4 Support Shear Reaction

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Problem 4 – Distributed Load Function Problem

This problem tests the SANTOS distributed load function option. This option specifies that an external file is to be read. Said file contains nodal values of a distributed force per unit volume. The value of force per unit volume is multiplied by the "nodal volume" (i.e., one-fourth of the volume of each surrounding element containing the node in question) to obtain the magnitude of the required loading.

Problem Description

A two-dimensional cube of linear, elastic, isotropic material is loaded vertically with a uniformly distributed load that varies with time, i.e., the load starts off at zero and linearly increases with time to some final value. The vertical displacement and vertical reaction force of the cube are computed analytically and compared with the SANTOS solution.

Analytic Solution

The model geometry and boundary conditions are shown in Figure 4.1. The reaction forces are computed by multiplying the area of the load surface by the distributed load. The vertical displacement of the top surface of the cube is computed with the following formula:

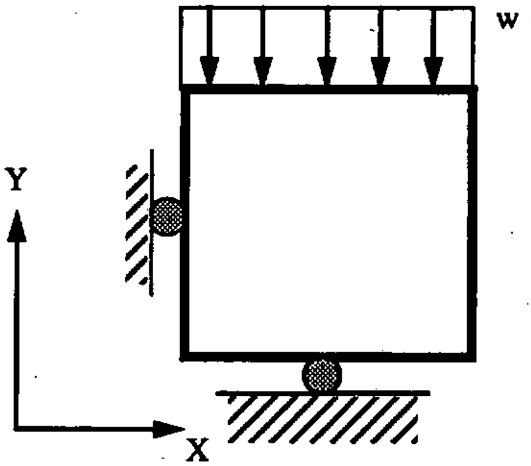

Figure 4.1 Distributed Load Problem

$$u = \frac{wL^2}{AE} \qquad \textbf{(EQ 4.1)}$$

where w is the distributed load, L is the in-plane cube length (a unit depth out-of-plane is used), A is the cross-sectional area under the applied load, and E is the Young's modulus.

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Specific values used in this example were: $L = 4.0$; $E = 1.0\times10^7$; $\nu = 0$ (Poisson's ratio, ν, is set to zero to produce one-dimensional response); and w starting off at zero and linearly increasing with time to a maximum value of 200 at time 2.0. According to the analytic solution, with the use of these values, the vertical reaction should start off at zero and linearly increase to a maximum value of 800 at time 2.0, and the vertical displacement should start off at zero and increase linearly to a value of 8.0E-5.

SANTOS Solution

Problem Discretization

A 16 element (4-node quadrilateral) mesh is used in the analysis and is shown in Figure 4.2.

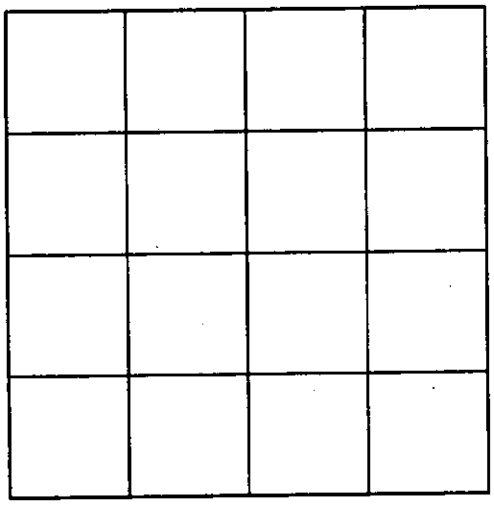

Figure 4.2 Finite Element Mesh

Input Data

A listing of the SANTOS input file is given in APPENDIX D. The distributed loads input into SANTOS were created by using a separate fortran program written specifically for the verification problem to generate the external file required and read by SANTOS when the distributed load option is used. The listing of the fortran program DISTLF used to generate the external file is given in APPENDIX D.

Output Listing

A partial listing of the printed output showing pertinent problem information is given in APPENDIX D.

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Discussion of Results

The plots of vertical displacement and reaction force are shown in Figure 4.3 and Figure 4.4, respectively, for both the computed and analytic solutions (the analytic solution is shown as the solid line in both figures). Agreement of computed and analytic results, as seen in the figures, indicates that the implementation of the distributed load option in SANTOS is correct.

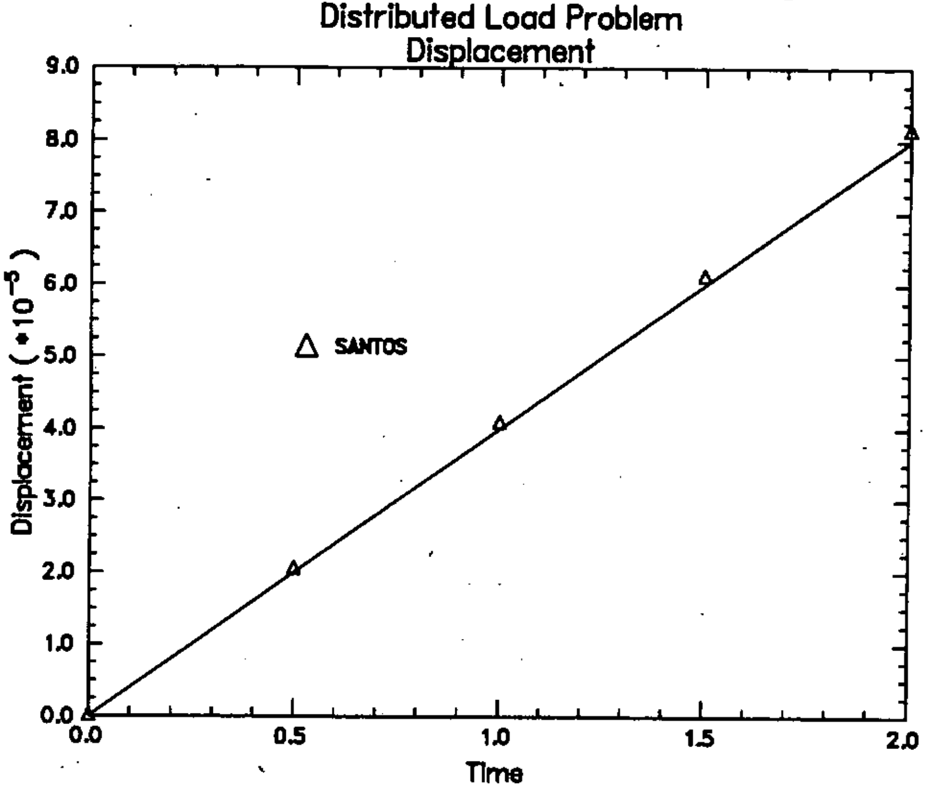

Figure 4.3 Axial Displacement

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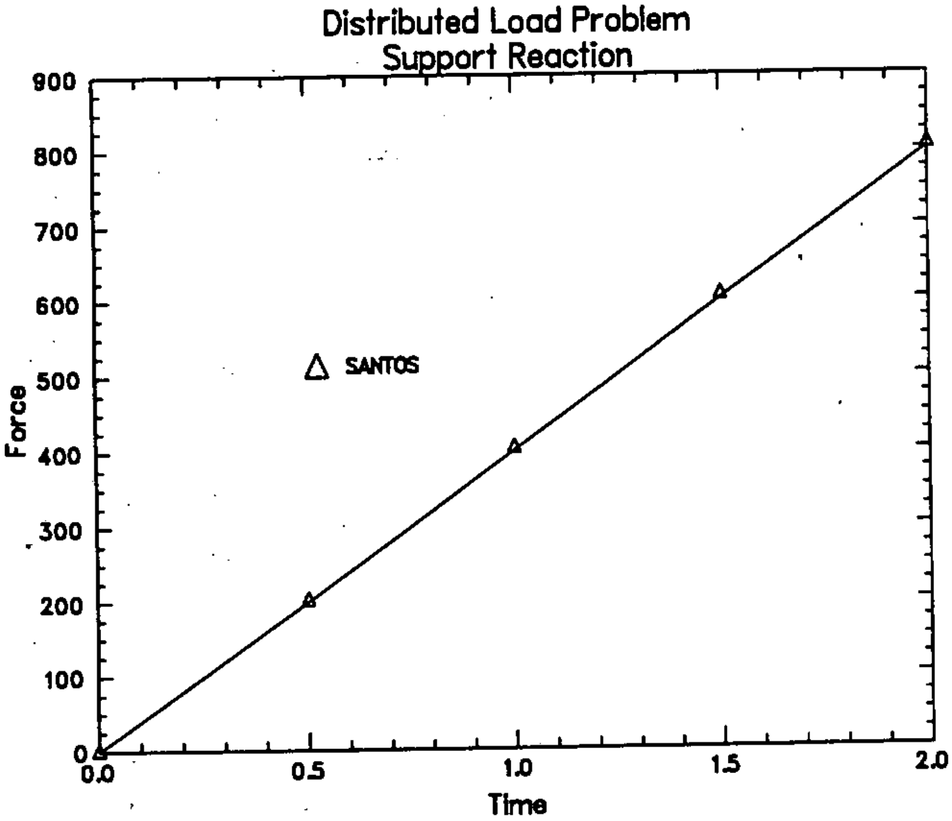

Figure 4.4 Support Reaction Force

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Problem 5 – Adaptive Pressure Option Problem

This problem checks the adaptive pressure option in SANTOS by comparing the pressure behavior of an ideal gas in an expanding spherical cavity with a numerical solution.

Problem Description

A linear elastic hollow sphere is initially pressurized with P_o, and the internal surface of the sphere expands radially outward increasing the volume of the cavity. Under adiabatic conditions the pressure of the gas will decrease in direct proportion to the volume expansion of the cavity.

Analytic Solution

The behavior of an ideal gas can be described by the following formula (Resnick and Halliday, 1966):

$$\frac{PV}{T} = K \qquad \textbf{(EQ 5.1)}$$

where P is the pressure, V is the volume, T is the absolute temperature, and K is the universal gas constant. Because adiabatic conditions are assumed in this verification problem, pressure is solely a function of volume change. This relationship between pressure and volume can be written as follows:

$$P = P_o\frac{V_o}{V} \qquad \textbf{(EQ 5.2)}$$

where P_o and V_o represent the initial pressure and initial volume, respectively. Figure 5.1 shows the specific geometry and boundary conditions of the problem considered here. Also, the material properties used in this analysis correspond to those for an elastic material with: $E = 1 \times 10^7$ and $\nu = 0.3$.

SANTOS Solution

Problem Discretization

A 400 element mesh (4 node-quadrilaterals) is used in the SANTOS calculations and is shown in Figure 5.2.

Input Data

A listing of the SANTOS input file is given in APPENDIX E. In order to use the adaptive pressure option in SANTOS the user is required to write a subroutine that describes the geometry and pressure boundary conditions that are relevant to the calculations. The

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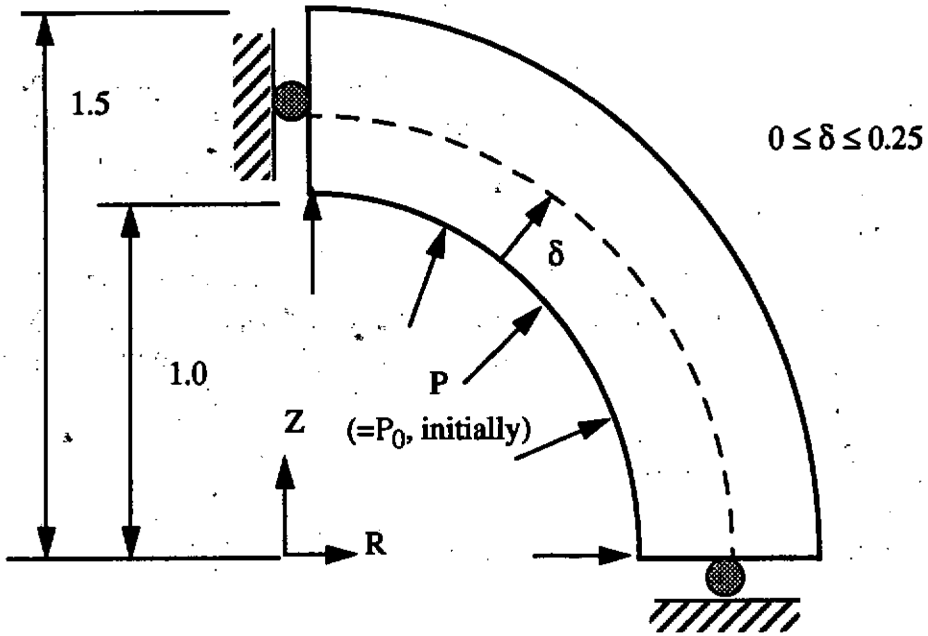

Figure 5.1 Problem Geometry and Boundary Conditions

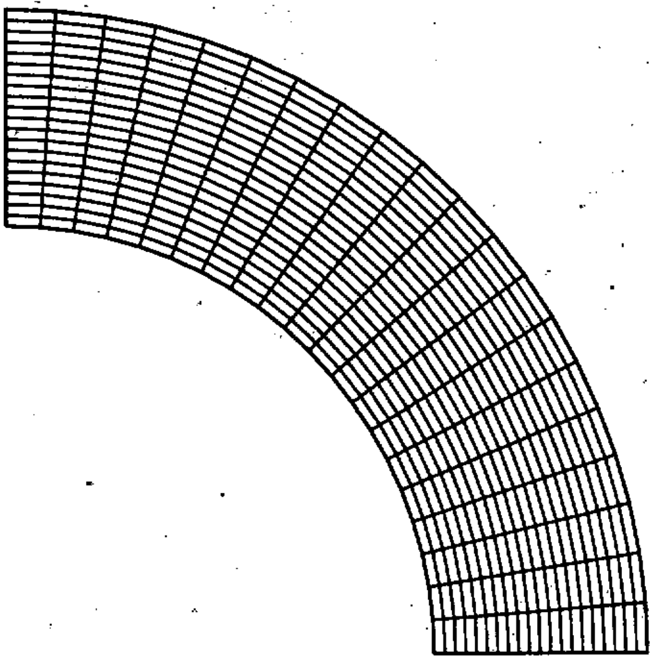

Figure 5.2 Finite Element Mesh

subroutine is compiled into the SANTOS code at the time of execution. A listing of the FORTRAN subroutine used to solve the verification problem is also given in APPENDIX E.

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Output Listing

A partial listing of the printed output showing pertinent problem information is given in APPENDIX E.

Discussion of Results

The comparison of the pressure versus volume predictions made with the analytic solution (the solid line) and SANTOS is shown in Figure 5.3. From the graph it can be seen that the SANTOS adaptive pressure option is working correctly.

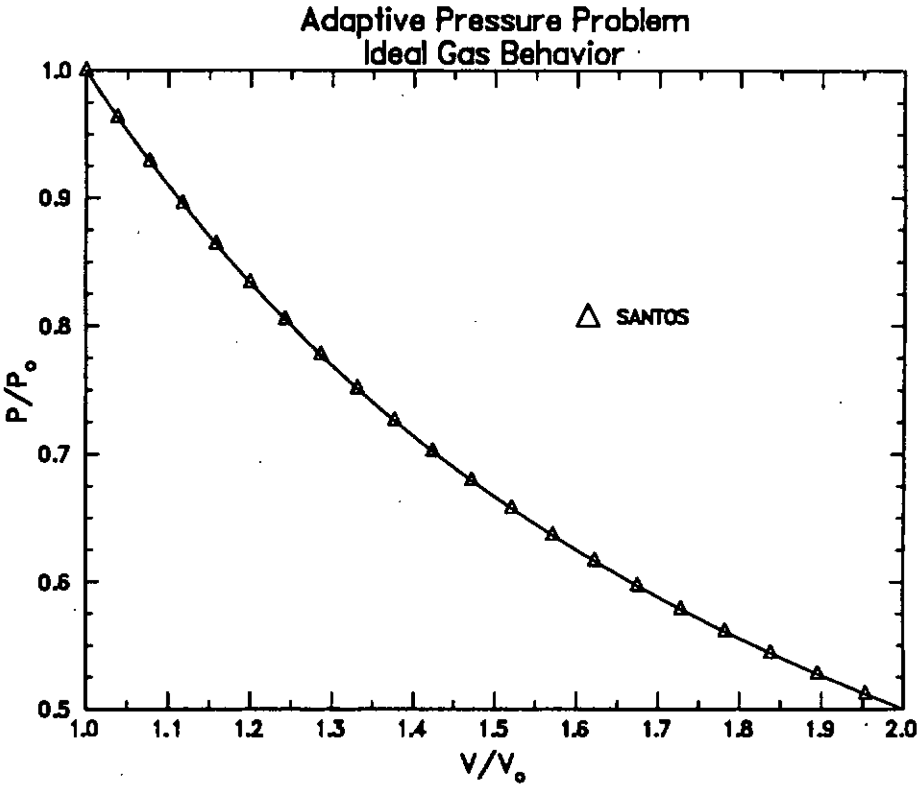

Figure 5.3 Pressure Versus Volume

References

1. Resnick, R., and D. Halliday, *Physics - Part I,* John Wiley & Sons, Inc., NY, 1966

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Problem 6 – Spinning Disk Problem

This calculation demonstrates that SANTOS can correctly analyze centrifugal acceleration problems in an axisymmetric geometry. The radial displacement profile predicted by SANTOS is compared to the analytic solution.

Problem Description

A linear elastic hollow disk is spun at a constant angular velocity and the calculation determines the radial displacement of the disk. The geometry of the problem and boundary conditions are shown in Figure 6.1.

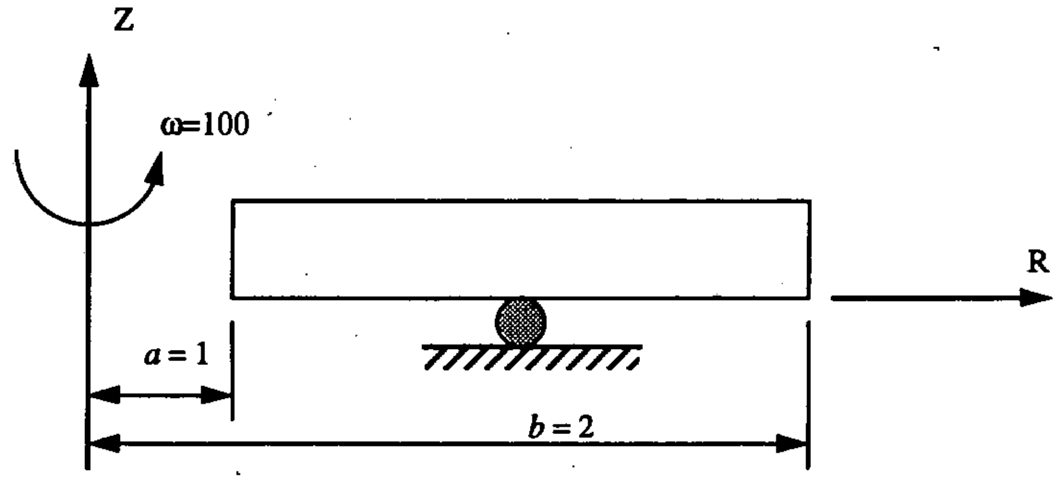

Figure 6.1 Problem Geometry and Boundary Conditions

Analytic Solution

The radial displacement function for the spinning disk is taken from Timoshenko (1958) and is shown below as.

$$u = -N\frac{r^3}{8} + C_1 r + \frac{C_2}{r} \qquad \textbf{(EQ 6.1)}$$

where the constants N, C_1, and C_2 are defined as:

$$N = \left(1-\nu^2\right)\frac{\gamma\omega^2}{gE}, \qquad \textbf{(EQ 6.2)}$$

$$C_1 = \frac{3+\nu}{8\,(1+\nu)}\left(a^2+b^2\right)N\text{, and} \qquad \textbf{(EQ 6.3)}$$

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$$C_2 = \frac{3+\nu}{8(1-\nu)}a^2b^2N. \qquad \textbf{(EQ 6.4)}$$

The geometry and material constants used in the above equations are as follows:

a = inner radius of the disk,
b = outer radius of the disk,
ν = Poisson's ratio,
E = Young's Modulus,
g = gravitational acceleration,
γ = weight density of the disk (Force/Length^3),
ω = angular velocity of the disk, and
r = radial distance $(a \le r \le b)$.

For specific comparisons between analytic and computed solutions, the following values were used in this example: $a = 1.0$; $b = 2.0$; $\nu = 0.3$; $E = 2.07\times10^{11}$; $g = 9.8066$; $\gamma = 21250$; and $\omega = 100$.

SANTOS Solution

Problem Discretization

The finite element mesh used in the SANTOS analysis is shown in Figure 6.2. It contains 640 four-node quadrilateral elements.

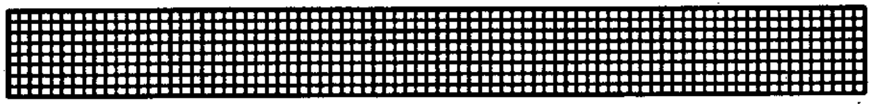

Figure 6.2 Finite Element Mesh

Input Data

A listing of the SANTOS input file is given in APPENDIX F.

Output Listing

A listing of the printed output showing pertinent problem information is given in APPENDIX F.

Information Only

Discussion of Results

A comparison of analytic results (shown as the solid line) and those predicted by SANTOS is shown in Figure 6.3. The SANTOS predictions are essentially the same as the analytical ones, demonstrating that SANTOS correctly analyzes axisymmetric centrifugal acceleration problems.

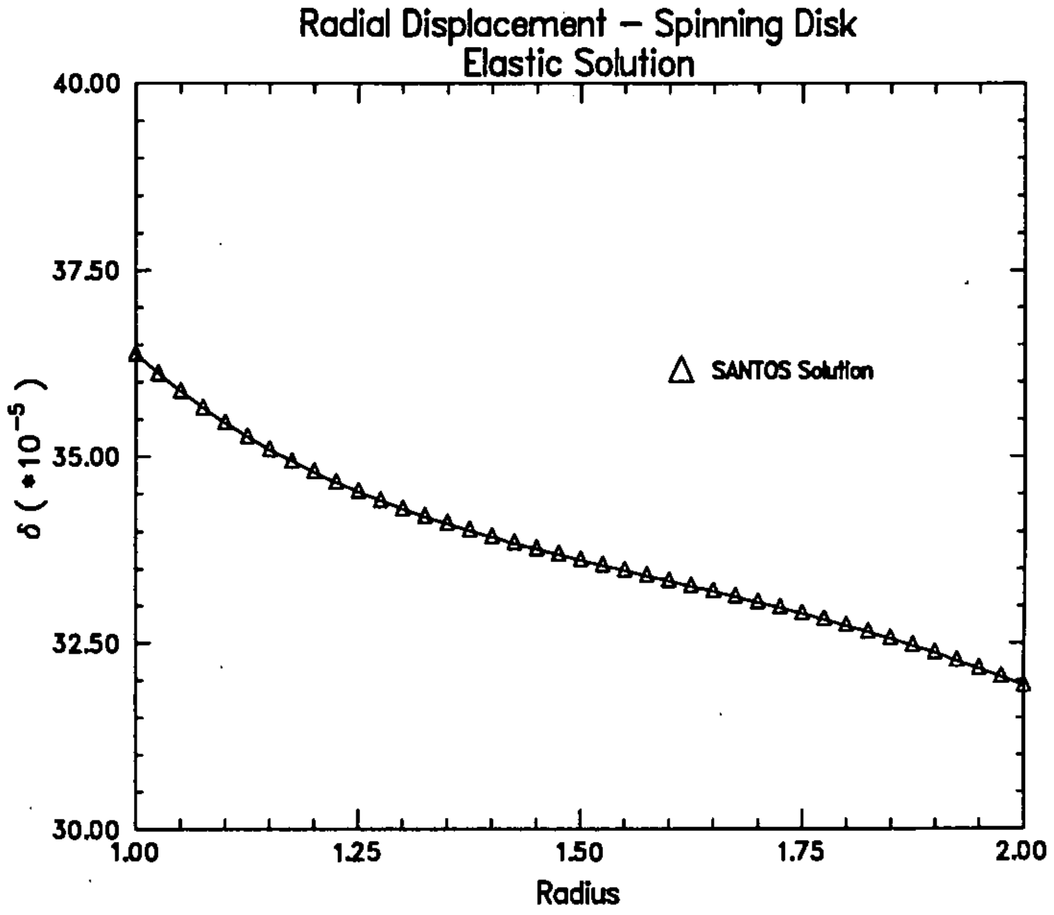

Figure 6.3 Radial Displacement Plot

References

1. Timoshenko, S., *Strength of Materials, Part II, Advanced Theory and Problems*, Van Norstrand Reinhold Company, 1958, pp. 214-215.

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Problem 7 – Pressure and Gravity Loaded Beam Problems

In this problem SANTOS solves an elastic beam bending problem for two loading conditions. The beam undergoes large bending deformation that tests the stability of the hourglass algorithm in SANTOS, as well as the capability of SANTOS to analyze large deformation problems.

Problem Description

A thin cantilever beam (30 to 1 length/depth ratio) is loaded with a pressure on its top horizontal surface in one load case, as shown in Figure 7.2, and is gravity-loaded in another case, as shown in Figure 7.1. The gravity and pressure loads are made large enough that the elastic beam undergoes a large displacement. An elastic analytic solution to the large displacement-rotation problem has been developed by Holden (1972) and the SANTOS results are compared to Holden's solution.

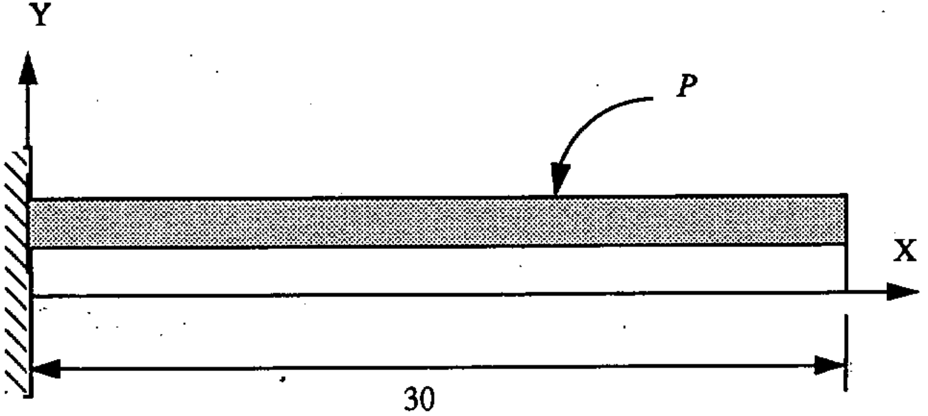

Figure 7.1 Cantilever Beam with Pressure Load

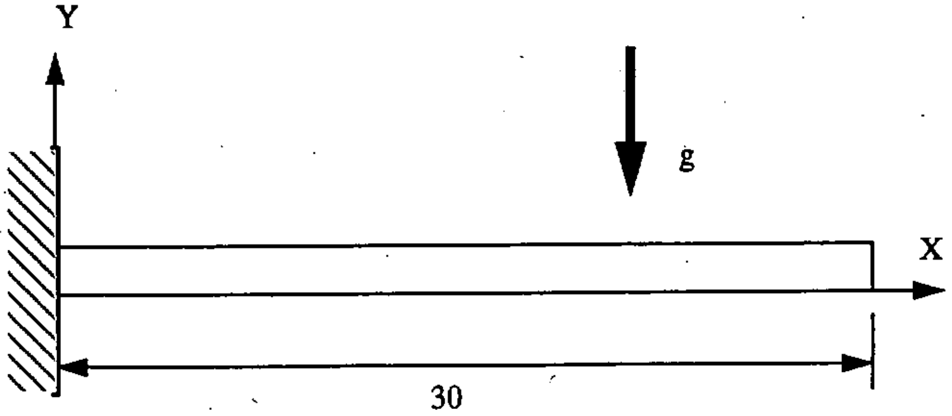

Figure 7.2 Cantilever Beam with Gravity Load

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Analytic Solution

For the gravity-loaded problem Holden uses the following equation:

$$\frac{d^2\theta}{d^2\bar{s}} = -k\bar{s}\cos\theta, \qquad \textbf{(EQ 7.1)}$$

developed from the Euler-Bernouilli theory of beam bending for the slope of the elastic beam in his calculations. For the pressure-loading case the following expression was solved to find the deflected shape of the beam:

$$\frac{d^2\theta}{d^2\bar{s}} = -k\bar{s}, \qquad \textbf{(EQ 7.2)}$$

where the variables used in the above equation are defined as follows:

θ = slope of the beam's neutral axis to the reference x-axis,
$\bar{s}$ = the non-dimensional coordinate system, with $\bar{s} = x/L$,
L = length of the beam,
k = the non-dimensional load parameter, with $k = wL^3/EI)$,
w = the load per unit beam length (the gravity load, ρg, or the pressure, P),
E = Young's modulus, and
I = moment of inertia.

Equations 7.1 and 7.2 are ordinary differential equation that can be solved when subjected to the boundary conditions for a cantilever beam. The boundary conditions are:

$$\frac{d\theta}{d\bar{s}} = 0 \text{ at } \bar{s} = 0 \text{ (the free end) and} \qquad \textbf{(EQ 7.3)}$$

$$\theta = 0 \text{ at } \bar{s} = 1 \text{ (the fixed end).} \qquad \textbf{(EQ 7.4)}$$

The normalized horizontal and vertical displacements of the free-end of the cantilever can then be represented, respectively, by the following integral expressions:

$$\frac{h}{L} = \int_0^1 \cos\theta d\bar{s} \text{ and} \qquad \textbf{(EQ 7.5)}$$

$$\frac{\delta}{L} = \int_0^1 \sin\theta d\bar{s}. \qquad \textbf{(EQ 7.6)}$$

Numerical integration of Equations 7.5 and 7.6 leads to the "analytic" solution for the horizontal and vertical displacements.

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To generate the analytic solution for the gravity-loaded beam, the following specific values were used in this example problem: $L = 30$; $I = 1/12$; $E = 1.0\times10^{7}$; $\nu = 0$; $\rho = 400$; and g in the y-direction that varies linearly with time, starting at zero and reaching a maximum value of -1.55 at time $t = 1.55$. Similarly, to generate the analytic solution for the pressure-loaded beam, the following specific values were used in this example problem: $L = 30$; $I = 1/12$; $E = 1.0\times10^{7}$; $\nu = 0$; and P that varies linearly with time, starting at zero and reaching a maximum value of 620 at time $t = 1.55$. Using these specific values yields a k that ranges from 0 to approximately 20, for comparison with Holden's published results.

SANTOS Solution

Problem Discretization

A 102-element mesh was used for the SANTOS calculation and is shown in Figure 7.3. The beam model has a length to depth ratio of 30 to 1, which insures the deflection of the beam is governed by bending and is comparable with verification calculations done with the JAC2D finite element code (Biffle and Blanford, 1994).

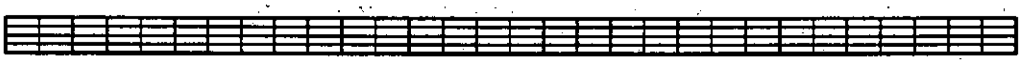

Figure 7.3 Finite Element Mesh Undeformed

Input Data

A listing of the SANTOS input file is given in APPENDIX G.

Output Listing

A partial listing of the printed output showing pertinent problem information is given in APPENDIX G.

Discussion of Results

The situation analyzed with SANTOS also considers load cases with k varying from 0 to 20, as was the case for the analytic solution. The plots of the free-end deflections for both the analytic and the SANTOS computed solutions are shown in Figure 7.4, for the gravity-loaded case and in Figure 7.5, for the pressure-loaded case, respectively. The gravity analysis indicates a very close correspondence between the predictions made with SANTOS and the results from the analytic solution. A sample deformed mesh of the SANTOS gravity-load problem is also shown in Figure 7.6 for k equal to 6.5.

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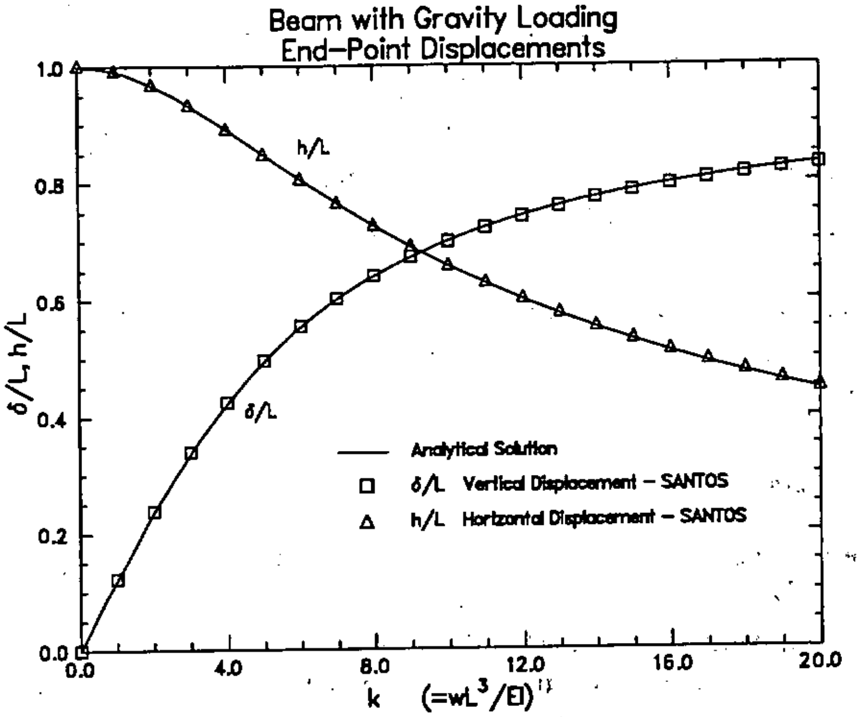

Figure 7.4 Gravity Beam End-Point Displacements

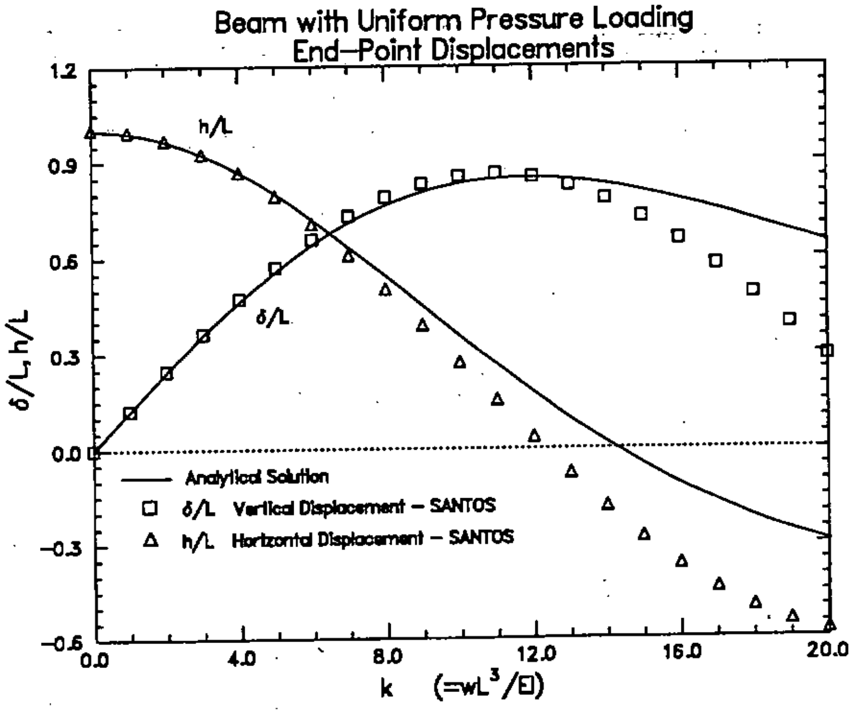

Figure 7.5 Pressure Beam End-Point Displacements

In the pressure load calculation there is good agreement between SANTOS and the analytical solution up to k = 10, where the two solutions diverge. The SANTOS results

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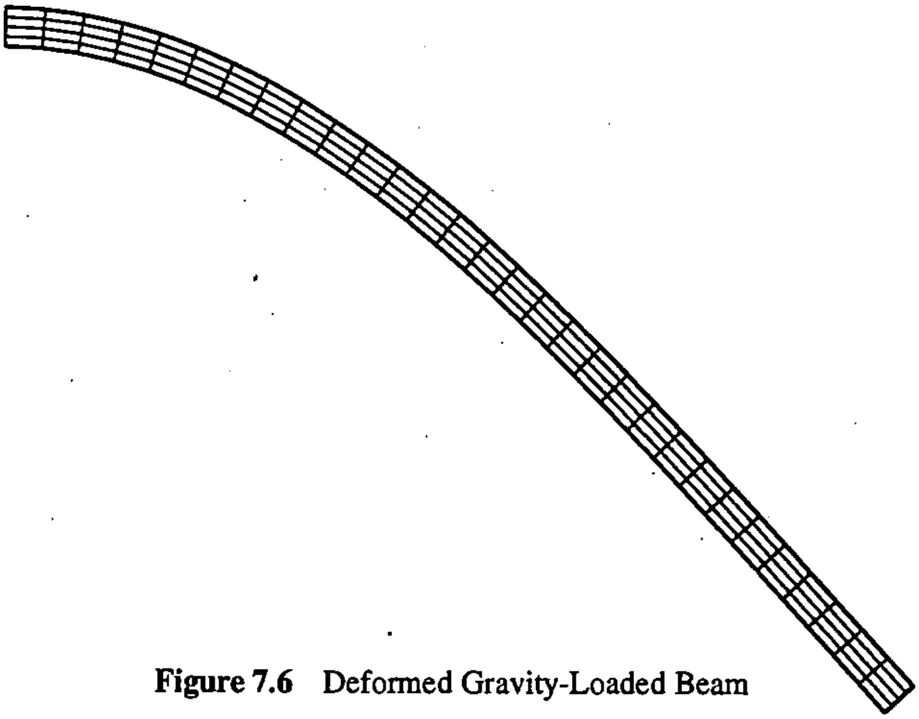

Figure 7.6 Deformed Gravity-Loaded Beam

appear to be stiffer than the analytic results under higher loads. The JAC2D analysis of the same problem produced the same results. Biffle and Blanford (1994) suggest that this difference is due to the beam bending back upon itself such that the radius of curvature of the bending is no longer as large as the depth of the beam. The analytical solution is to a one-dimensional model wherein the thickness of the beam does not explicitly enter into the calculation.

References

1. Holden, J. T., "On the Finite Deflections of Thin Beams," *International Journal of Solids and Structures*," vol. 8, pp. 1051-1055, 1972.

2. Biffle, J. H. and M. L. Blanford, *JAC2D-A Two-Dimensional Finite Element Computer Program for the Nonlinear Quasi-Static Response of Solids with the Conjugate Gradient Method*, SAND93-1891, Sandia National Laboratories, Albuquerque, NM, May, 1994.

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Problem 8 – Tension Release Option Problem

This problem tests the SANTOS tension release option in the contact surface algorithm by analyzing the forced separation of two elastic blocks.

Problem Description

Two elastic bodies are initially in contact, one resting on the other, with a frictionless interface between them. The smaller body is subjected to a tensile traction on its top surface that linearly increases from 0 at $t = 0$ to 10,000 at $t = 1$. The nodal tensile release force, f_r, on the contact surface is set for 1,000. This means that once the force at a node on the contact surface reaches this value, it will release. The tensile release option should work correctly by releasing the top block once all the nodes on the interface reach this force value. The separation of the two blocks will be reflected in the step drop of the vertical reaction at the bottom supports. The geometry and boundary conditions of the problem are shown in Figure 8.1.

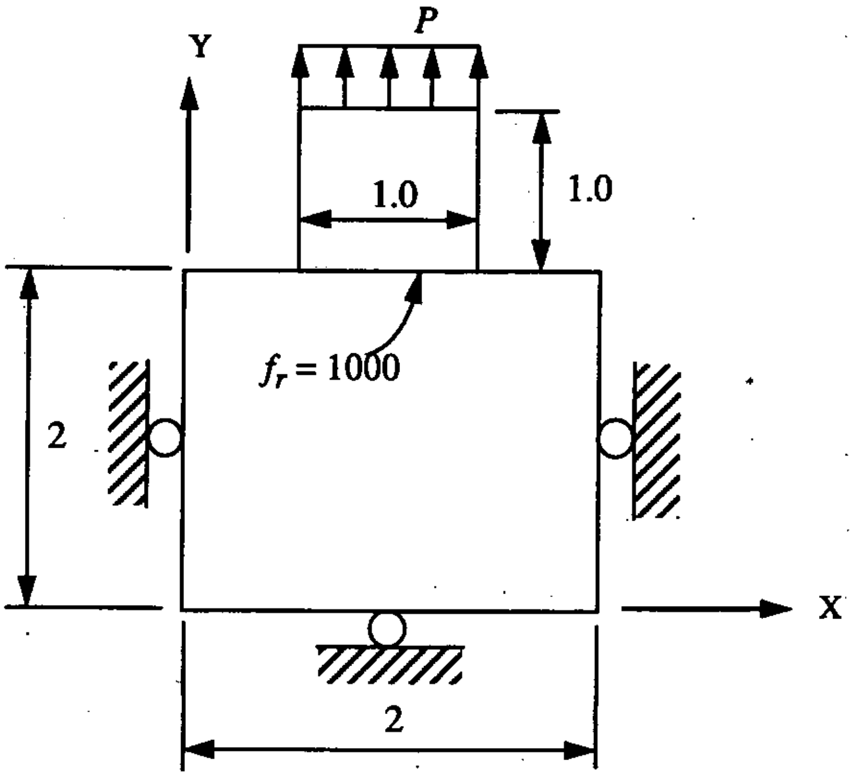

Figure 8.1 Problem Geometry and Boundary Conditions

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Analytic Solution

The vertical reaction will increase linearly to a value of 5,000 and then step drop to 0 at time, t=0.5. Both elastic bodies had a Young's modulus of $E = 30 \times 10^6$ and a Poisson's ratio of $\nu = 0.3$.

SANTOS Solution

Problem Discretization

The finite element mesh used in the SANTOS calculation is shown in Figure 8.2 and is composed of 26 elements (4 node quadrilaterals). A single element is used to model the lower body, containing the master surface, and 25 elements make up the upper body, containing the slave surface. Thus, there are four "internal" and two "external" nodes on the interface for a total of six slave nodes.

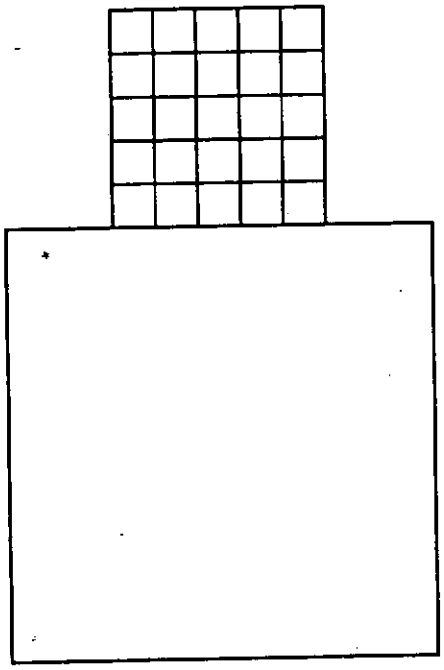

Figure 8.2 Finite Element Mesh

Input Data

The listings of the SANTOS input file for the calculation is given in APPENDIX H.

Output Listing

The output listing for the analysis is in APPENDIX H.

Information Only

Discussion of Results

The support reaction predicted by the SANTOS analysis is plotted against the closed-form solution (dashed line) in Figure 8.3. At *t* = 0.5, the four internal nodes on the interface each reach a value of 1,000 and release. Immediately thereafter, the load is transfered to the two external nodes causing the force in each of them to reach a value of 1,000 and release as well. The SANTOS results show excellent agreement with the analytical solution. From these calculations it appears the tensile release option of the contact surface algorithm in SANTOS is working correctly.

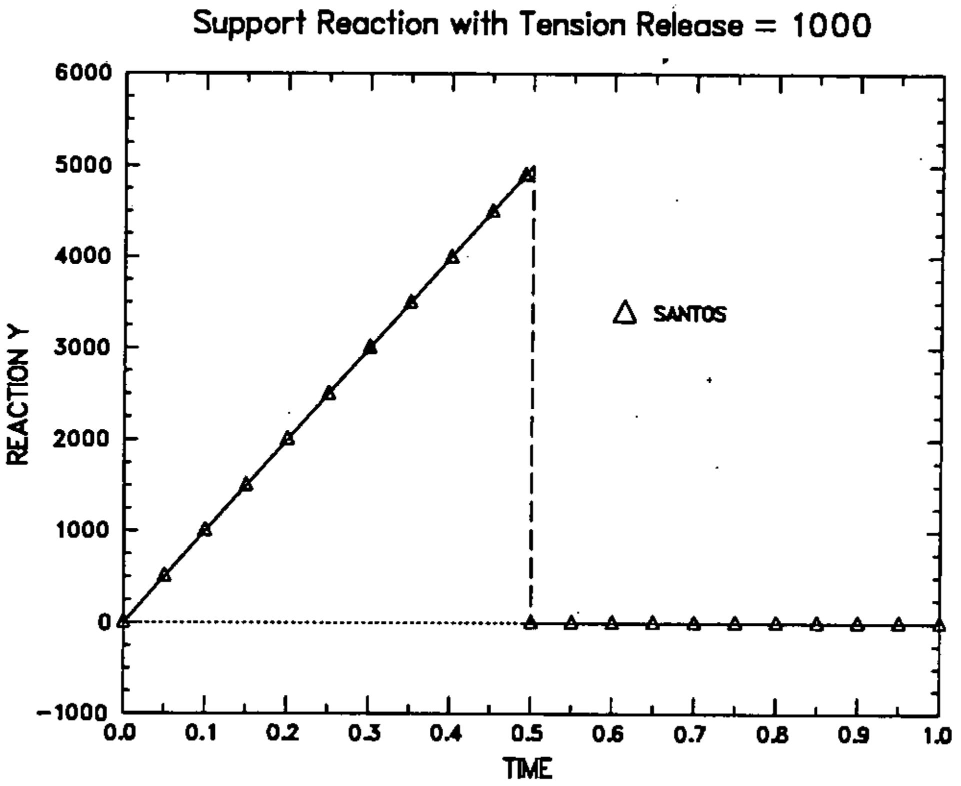

Figure 8.3 Plot of Vertical Support Reaction

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Problem 9 – Rigid Sliding Surface Option Problem

This problem tests the SANTOS rigid sliding surface option by analyzing the slippage of an elastic beam on a rigid surface with different coefficients of friction.

Problem Description

An elastic beam is resting upon a rigid half-space. It is restrained against horizontal movement on its left edge and is subjected to an initial vertical downward displacement on its top surface. It is pulled by a horizontal pressure on its right edge. The displacement of the right edge of the beam is resisted by the frictional force developed on the interface of the beam and the rigid surface upon which it rests. The vertical displacement is constant and the horizontal pressure is linearly increased to a magnitude that exceeds the maximum frictional resistance of the beam. Figure 9.1 shows the geometry and boundary conditions of the problem.

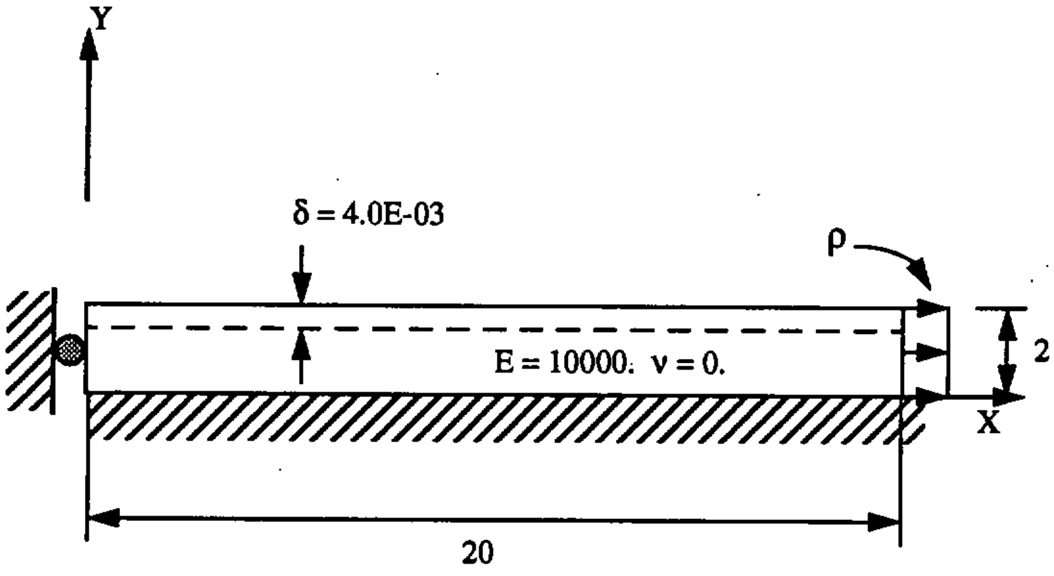

Figure 9.1 Problem Geometry and Boundary Conditions

Analytic Solution

The formulation of a closed-form solution of the problem begins with the static summation of forces in the horizontal direction:

$$\Sigma F_x = 0 = \rho h t - \mu p x. \qquad \textbf{(EQ 9.1)}$$

This is shown on the free body diagram in Figure 9.2, where ρ is the horizontal pressure, *h* is the beam thickness, *p* is the vertical pressure (arising from the vertical displacement boundary condition), μ is the coefficient of friction, *x* is the slipping length of the beam,

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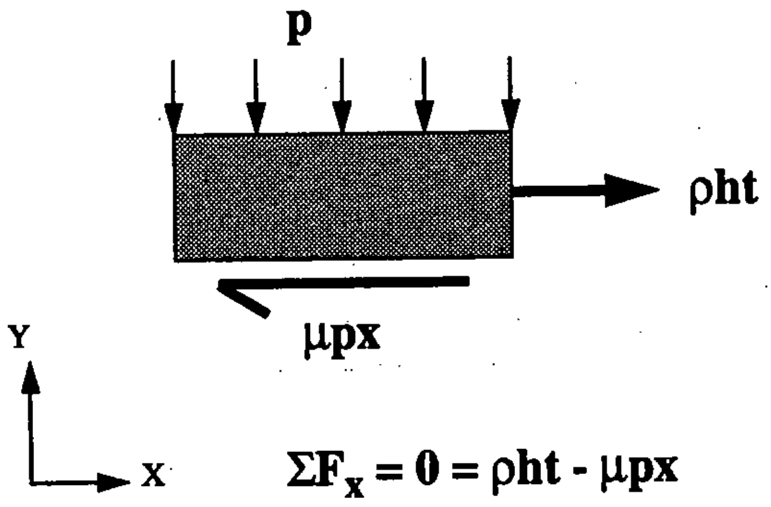

Figure 9.2 Free Body Diagram of Forces

and *t* is the non-dimensional time parameter. The slipped length of the beam can be computed by rearranging the above equation to yield:

$$x = \frac{\rho h t}{\mu p}. \qquad \text{(EQ 9.2)}$$

An equation relating the displacement of the beam to the applied forces can be derived from a functional, developed from energy principles (It is assumed the beam is one-dimensional, which greatly simplifies the solution):

$$J(u) = \frac{1}{2}\int_0^L \left[Eh\left(\frac{\partial u}{dx}\right)^2\right]dx + \int_0^L \mu p u dx - F \cdot u(L). \qquad \text{(EQ 9.3)}$$

Here *E* is the Young's modulus, *L* is the total length of the beam undergoing slippage, *u* is the displacement function, and *F* is the horizontal force applied to the right edge of the beam $(F = \rho h t)$. The beam is assumed to be of unit width. A differential equation describing the displacement function *u* can be derived by taking the first variation of the functional with respect to *u*, as follows:

$$\frac{\partial J}{\partial u} = -Eh \cdot \frac{\partial^2 u}{\partial x^2} + \mu p = 0. \qquad \text{(EQ 9.4)}$$

Integrating twice with respect to *x*, the following analytical expression for *u* is derived:

$$u = \frac{\mu p x^2}{Eh} + C_1 x + C_2. \qquad \text{(EQ 9.5)}$$

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The integration constants C_1 and C_2 are derived from the following boundary conditions:

$$u(0) = 0 \Rightarrow C_2 = 0 \qquad \textbf{(EQ 9.6)}$$

$$\text{and } \frac{\partial u(L)}{\partial x} = \frac{\rho h t}{E h} = \frac{\mu p L}{E h} + C_1. \qquad \textbf{(EQ 9.7)}$$

Solving for C_1 yields:

$$C_1 = \frac{\rho h t - \mu p L}{E h}. \qquad \textbf{(EQ 9.8)}$$

The general expression for horizontal displacement then becomes:

$$u = \frac{\mu p x^2}{2 E h} + \frac{\rho h t x}{E h} - \frac{\mu p L x}{E h}. \qquad \textbf{(EQ 9.9)}$$

The equation can be further simplified for the case of the displacement of the right-hand side of the beam by noting that:

$$L = \frac{\rho h t}{\mu p} \qquad \textbf{(EQ 9.10)}$$

and solving the general displacement equation for $x = L$. The result is the following equation:

$$u(L) = \frac{\rho^2 h t^2}{2 \mu p E}. \qquad \textbf{(EQ 9.11)}$$

Specific values used in this example to generate values for comparison with the SANTOS predictions were: $E = 1.0\times10^4$; $\nu = 0$ (Poisson's ratio, ν, set to zero); $\delta = 4.0\times10^{-3}$ (which corresponds to $p = 20$); $h = 2$; and $\mu = 0.1, 0.2, 0.5, 0.7$ with respectively corresponding maximum values of $\rho = 35, 58.75, 125, 170$.

SANTOS Solution

Problem Discretization

The finite element mesh used in the SANTOS analysis is shown in Figure 9.3 and is composed of 160 elements (4 node quadrilaterals).

Input Data

The listings of the SANTOS input files for the calculations are given in APPENDIX I.

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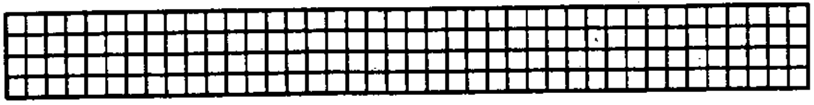

Figure 9.3 Finite Element Mesh

Output Listing

The output listings for the analyses are in APPENDIX I.

Discussion of Results

Four SANTOS analyses were performed using coefficients of friction of 0.1, 0.2, 0.5, and 0.7. A horizontal pressure was applied to the right-hand side of the beam, varying linearly in magnitude from a value of $\rho = 0$ at time, $t = 0$, to a maximum of $\rho =$ "P" at time, $t = 1.0$. The value of "P" was different for each analysis and was chosen to be large enough to induce full slip along the bottom of the beam and exceed the total frictional resistance of the beam. In order to simulate a one-dimensional geometry in the finite element model a *vertical displacement* boundary condition was used on the top surface of the beam in lieu of a *vertical pressure*. This was done because the finite element solutions begin to deviate from the analytic solutions when a *vertical pressure* boundary condition is used and friction coefficients exceed 0.5. This occurs because of shear distortions which arise in the beam as the frictional stresses which develop in the beam become more significant. Thus, although the downward *vertical displacement* of 0.004 units corresponds to a *vertical pressure of* $p = 20$, the use of a *vertical displacement* boundary condition rather than a vertical pressure boundary condition decreases the amount of shear distortion in the mesh which arises from the horizontal pressure and frictional stresses on the beam. The horizontal end-point displacements are plotted in Figure 9.4. The figures shows excellent agreement between the SANTOS predictions of horizontal displacements and the analytic solutions (shown as the solid lines).

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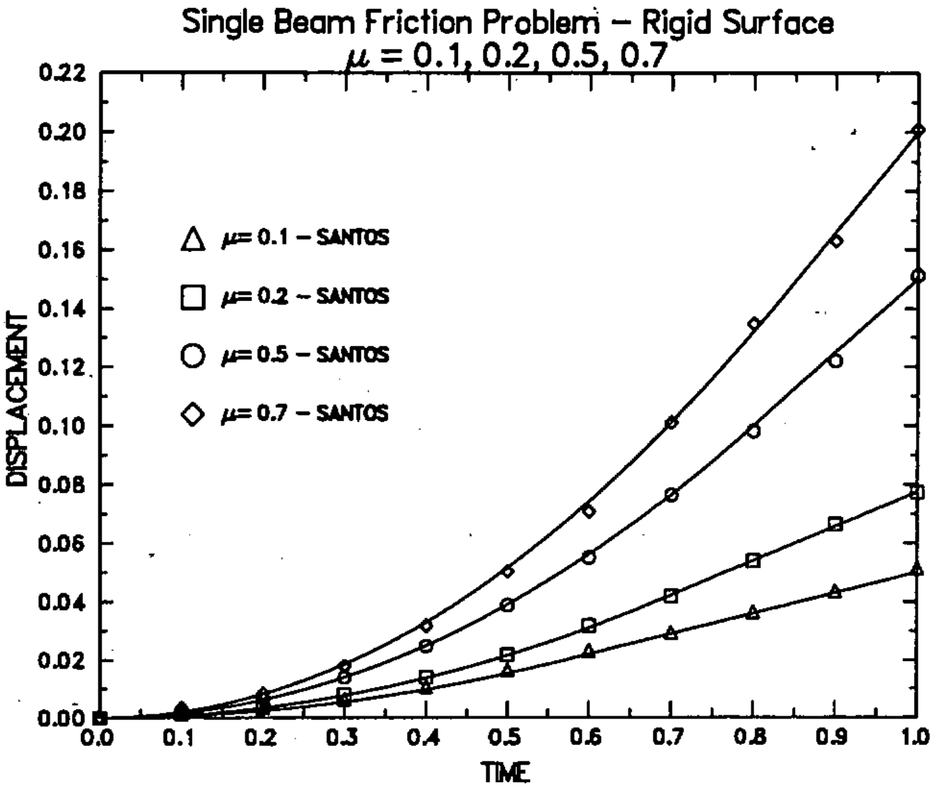

Figure 9.4 End-Point Horizontal Displacements

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Problem 10 – Double Elastic Beam Contact Sliding Problem

This problem tests the SANTOS contact surface algorithm by analyzing the slippage of one elastic beam relative to another that it is in contact with (this system will be referred to herein as a double elastic beam). The computed results for relative slip are then compared to those obtained using a closed-form solution.

Problem Description

Two elastic beams of depth, *h*, and original length, *L*, and possessing different Young's moduli (E_1 for the top beam and E_2 for the bottom beam) are held in contact by a pressure, *P*, acting uniformly along their length as shown in Figure 10.1. The softer top beam is subjected to the vertical pressure on its top horizontal surface. The stiffer bottom beam rests upon frictionless roller supports that restrict vertical, but not horizontal displacements. Both beams are restrained against horizontal displacement on their left-hand sides and have the same cross-sectional areas. A tensile axial force, *F*, is applied to the right end of each beam, and this force increases linearly with time. The boundary conditions for the problem are also shown in Figure 10.1. When the loads are applied, slippage occurs on the interface of the beams due to differences in axial stiffness, i.e., the softer beam tends to elongate more than the stiffer beam. As a result, the softer beam now has a deformed length, l_1, while the stiffer beam now has a deformed length, l_2, as depicted in Figure 10.1. If a coordinate, *x*, along the length is taken to be measured with respect to an origin at the left end, the beams slip with respect to each other beyond some point (originally at L_0) which has now displaced to l_0, but do not slip before that point is reached. The horizontal displacement of

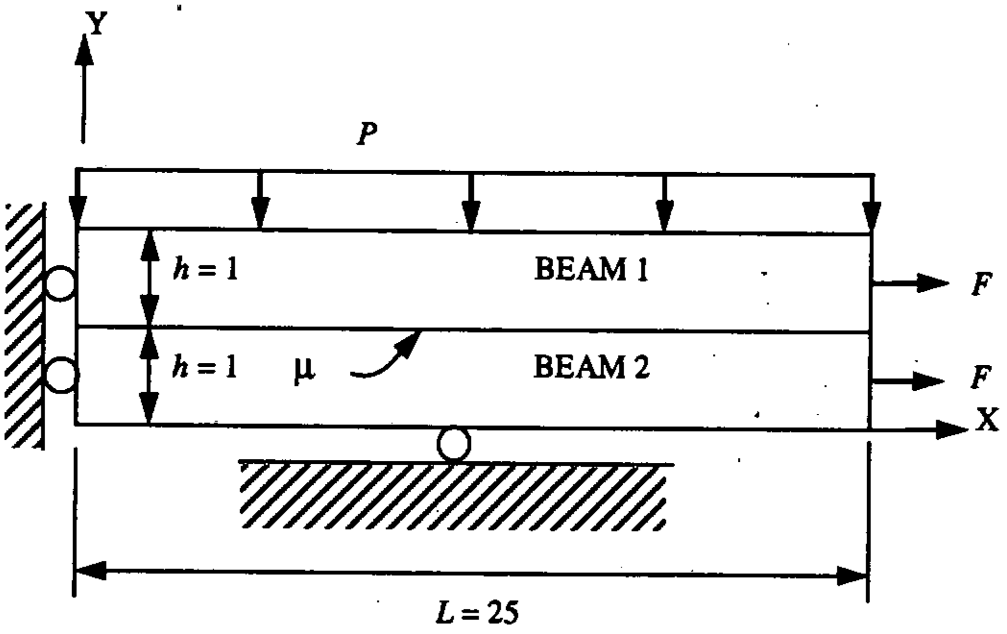

Figure 10.1 Problem Geometry and Boundary Conditions

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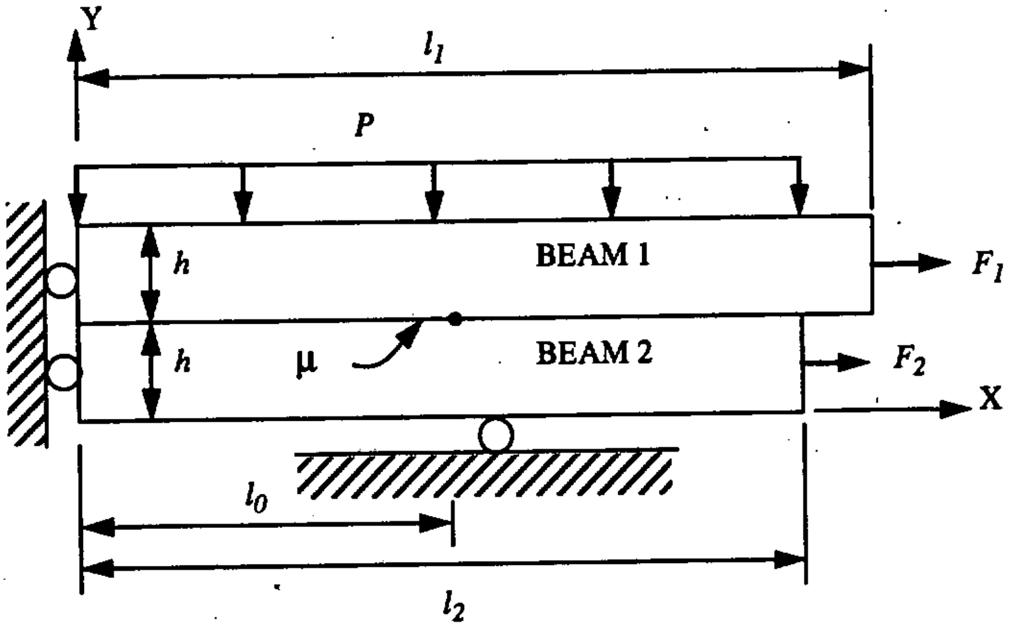

Figure 10.2 Problem Deformed Geometry

the beams at the point of application of the axial loads will be a function of the frictional forces developed on the interface (which has a coefficient of friction, μ, acting on it) and the axial stiffnesses of the two beams.

Analytic Solution

The analytic solution was originally developed by R. D. Krieg in 1986 at Sandia National Laboratories in a set of informal notes. Krieg's analytic solution is re-developed herein for the purpose of formally documenting it and so that it may be used to compare with the SANTOS results.

The analytic solution assumes a one-dimensional geometry and small displacements. Furthermore, it is assumed that the axial strains are constant in zones of slip and non-slip. The solution examines the problem in three parts. The first part examines displacements and stress states in the beams along the zone where there is no slip (i.e., $0 \le x \le l_0$; we will refer to this as Zone A). The second develops the relationship between stress and displacement in the "slipped-off" portion of the top beam ($l_2 \le x \le l_1$; referred to as Zone C), where the upper beam is no longer in contact with the lower beam and only Beam 1 exists for purposes of developing the displacement equation. The third examines the stress and displacement states in the portions of the upper and lower beams where slippage has occurred and both are still in contact with each other ($l_0 \le x \le l_2$; referred to as Zone B).

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Zone A

The strains and displacements in the top beam (Beam 1) and bottom beam (Beam 2) are the same in the non-slip zone of the interface. This strain equivalence can be expressed as:

$$\varepsilon_1^A = \varepsilon_2^A. \qquad \textbf{(EQ 10.1)}$$

Using linear, elastic constitutive relationships Equation 10.1 can be rewritten as:

$$\sigma_1^A = \sigma_2^A\left(\frac{E_1}{E_2}\right), \qquad \textbf{(EQ 10.2)}$$

where E_1 and E_2 are the Young's moduli for Beam 1 and Beam 2, respectively, and σ_1^A and σ_2^A are the corresponding axial stresses in each beam throughout Zone A. The displacement of each beam at $x = l_0$ in the non-slip zone can be expressed as the integral of the constant axial strain over the length of the zone (l_0),

$$u_2^{x = l_0} = u_1^{x = l_0} = u_0 = \int_0^{l_0} \varepsilon_1^A dx = \frac{\sigma_1^A l_0}{E_1} \qquad \textbf{(EQ 10.3)}$$

where $u_2^{x = l_0}$ is the displacement of Beam 2 at $x = l_0$ and $u_1^{x = l_0}$ is the displacement of Beam 1 at $x = l_0$ (hereafter, the superscript will be be understood to denote the x-location along the respective beam, if lowercase, or the range of x, if uppercase).

Before proceeding, it is useful to introduce the following variables for defining the deformation of the beams:

$$l_o = u_o + L, \qquad \textbf{(EQ 10.4)}$$

$$l_1 = u_1^{l_1} + L, \qquad \textbf{(EQ 10.5)}$$

$$\text{and } l_2 = u_2^{l_2} + L, \qquad \textbf{(EQ 10.6)}$$

where L is the original (undeformed) length of the beams, u_0 is the displacement of both beams at $x = l_0$ (because up to this point, there is no relative slip between the two), $u_1^{l_1}$

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is the displacement of the right end of the upper beam (at $x = l_1$), and $u_2^{l_2}$ is the displacement of the right end of the bottom beam (at $x = l_2$).

Zone C

The displacement of the top beam in Zone C is related to the displacement of the bottom beam through the following relationship:

$$u_1^{l_1} = u_2^{l_2} + \int_{l_2}^{l_1} \varepsilon_1^C dx = u_2^{l_2} + \varepsilon_1^C (l_1 - l_2) \qquad \textbf{(EQ 10.7)}$$

where ε_1^C is the axial strain in the top beam in Zone C. Using constitutive relations to substitute for the strain, ε_1^C, gives:

$$u_1^{l_1} = u_2^{l_2} + \frac{\sigma_1^C}{E_1}(l_1 - l_2) \qquad \textbf{(EQ 10.8)}$$

where σ_1^C is the axial stress in the top beam in Zone C. Substituting the axial force carried by the top beam for the axial stress, σ_1^C, yields:

$$u_1^{l_1} = u_2^{l_2} + \frac{F_1}{E_1 h}(l_1 - l_2)\,. \qquad \textbf{(EQ 10.9)}$$

Zone B

A differential equation is created describing the displacement of the top beam in Zone B by requiring the horizontal forces acting upon a differential element of beam to equal zero (see Figure 10.3 for details):

$$df = \mu P dx\,. \qquad \textbf{(EQ 10.10)}$$

Integrating both sides of the equation yields the following:

$$\int_{f_1^x}^{f_1^e} df = \int_x^{l_2} \mu P dx \qquad \textbf{(EQ 10.11)}$$

and $f_1^e - f_1^x = \mu P (l_2 - x)$ **(EQ 10.12)**

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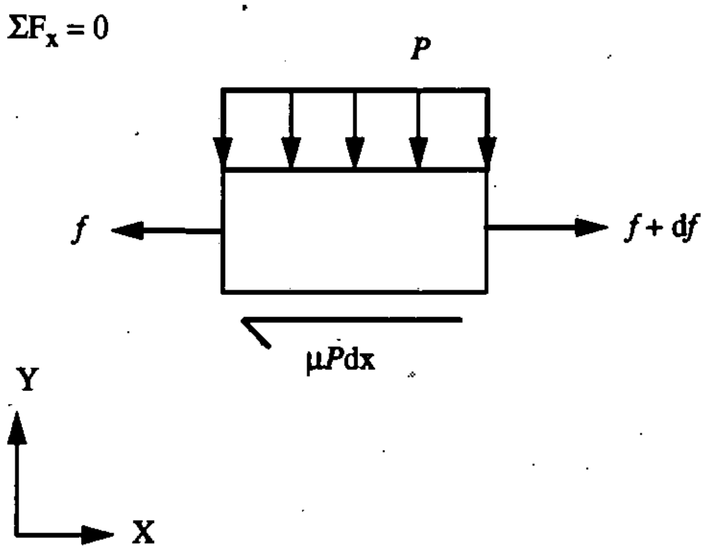

Figure 10.3 Differential Force Element - Top Beam

where f_1^x is the internal force in Beam 1 at some arbitrary location x within Zone B (the stresses are not constant in this zone) and f_1^e is the internal force in Beam 1 at the right end of Zone B. Substituting stresses for the internal force, f_1^x, we get:

$$f_1^e - \sigma_1^x h = \mu P (l_2 - x) \qquad \textbf{(EQ 10.13)}$$

where σ_1^x is the stress in Beam 1 at some arbitrary location x in Zone B. Noting that for $x = l_0$, we have $f_1^e = F_1$ (because of no-slip), so that the above equation becomes:

$$F_1 - \sigma_1^{l_0} h = \mu p (l_2 - l_0) \, . \qquad \textbf{(EQ 10.14)}$$

Using the constitutive relationship to replace σ_1^x in Equation 10.13 creates the following displacement differential equation:

$$f_1^e - E_1 h \frac{du_1}{dx} = \mu P (l_2 - x) \, . \qquad \textbf{(EQ 10.15)}$$

Rearranging variables and integrating both sides, we get:

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$$E_1 h \int_{u_0}^{u_1^x} du_1 = \int_{l_0}^{x} \left[f_1^e - \mu P (l_2 - x) \right] dx \text{, or} \qquad \textbf{(EQ 10.16)}$$

$$E_1 h \left(u_1^x - u_0 \right) = f_1^e (x - l_0) - \mu P \left[l_2 (x - l_0) - \frac{\left(x^2 - l_0^2 \right)}{2} \right] \qquad \textbf{(EQ 10.17)}$$

where u_1^x is the displacement of Beam 1 at some arbitrary location x within Zone B. Evaluating the displacement at $x = l_2$ (the right end of Zone B) and noting that $f_1^e = F_1$ at $x = l_2$ gives the displacement relationship:

$$E_1 h \left(u_1^{l_2} - u_0 \right) = (l_2 - l_0) \left[F_1 - \frac{\mu P}{2} (l_2 - l_0) \right]. \qquad \textbf{(EQ 10.18)}$$

Using the same methodology for the bottom beam (Beam 2) in Zone B, we get the following two equations:

$$F_2 - \sigma_2^{l_0} h = -\mu p (l_2 - l_0) \text{, and} \qquad \textbf{(EQ 10.19)}$$

$$E_2 h \left(u_2^{l_2} - u_0 \right) = (l_2 - l_0) \left[F_2 + \frac{\mu P}{2} (l_2 - l_0) \right] . \qquad \textbf{(EQ 10.20)}$$

Six equations (Equations 10.2, 10.3, 10.14, 10.18, 10.19, and 10.20) in six unknowns have been have been developed that will define the end-point displacements of both beams, because for small displacements we recognize that $l_1 \cong l_2 \cong L$. Furthermore, we also note that $F_1 = F_2 = F$; $\sigma_1^{l_0} = \sigma_1^A$; and $\sigma_2^{l_0} = \sigma_2^A$. The six equations thus become:

$$\sigma_1^A = \sigma_2^A \left(\frac{E_1}{E_2} \right), \qquad \textbf{(EQ 10.21)}$$

$$u_0 = \frac{\sigma_1^A l_0}{E_1}, \qquad \textbf{(EQ 10.22)}$$

$$F - \sigma_1^A h = \mu p (L - l_0) , \qquad \textbf{(EQ 10.23)}$$

$$E_1 h \left(u_1^L - u_0 \right) = (L - l_0) \left[F - \frac{\mu p}{2} (L - l_0) \right] , \qquad \textbf{(EQ 10.24)}$$

$$F - \sigma_2^A h = -\mu p (L - l_0) , \qquad \textbf{(EQ 10.25)}$$

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$$\text{and} \quad E_2 h\left(u_2^L - u_0\right) = (L - l_0)\left[F + \frac{\mu p}{2}(L - l_0)\right] \quad . \qquad \textbf{(EQ 10.26)}$$

The six unknowns, σ_1^A, σ_2^A, u_0, l_0, u_1^L, and u_2^L, can be found by simultaneous solution of the above six equations. Doing so results in the displacement formulas for variables u_0, u_1^L, and u_2^L as follows:

$$u_0 = \frac{2F}{h(E_1 + E_2)}\left[L - \frac{F(E_2 - E_1)}{\mu P(E_1 + E_2)}\right], \qquad \textbf{(EQ 10.27)}$$

$$u_1^L = u_0 + \frac{F^2(E_2 - E_1)}{\mu P h E_1 (E_1 + E_2)}\left[\frac{3E_1 + E_2}{2(E_1 + E_2)}\right] \quad , \qquad \textbf{(EQ 10.28)}$$

$$\text{and} \quad u_2^L = u_0 + \frac{F^2(E_2 - E_1)}{\mu P h E_2 (E_1 + E_2)}\left[\frac{E_1 + 3E_2}{2(E_1 + E_2)}\right] \quad . \qquad \textbf{(EQ 10.29)}$$

The variables u_0, u_1^L, and u_2^L, as defined by Equations 10.27, 10.28, and 10.29, represent the non-slip horizontal displacement of the beams, the end-point displacement of the top beam, and the end-point displacement of the bottom beam, respectively.

SANTOS Solution

Problem Discretization

The finite element mesh is shown in Figure 10.4 and is composed of 130 elements (4 node quadrilaterals). In the finite element model the top beam is slightly shorter (24.8 units) than the bottom beam (25 units). This small deviation from the analytical model prevents node tracking problems in SANTOS. As the top beam slides over and off the bottom beam, the slide line algorithm can no longer track the end-point slave node. The shortened top beam geometry insures the slave node remains in contact with the master surface while not compromising the solution.

Figure 10.4 Finite Element Mesh

Information Only

Two analysis cases are examined for different combinations of Young's modulus and coefficients of friction. The first case calculates end-point displacements for a coefficient of friction of 0.4 and a Young's modulus ratio (bottom beam modulus, $E_2 = 9000$, to top beam modulus, $E_1 = 3000$) of 3 to 1. The second calculation uses a coefficient of friction of 0.5 and a Young's modulus ratio of 10 ($E_2 = 8000$) to 1 ($E_1 = 800$). In both problems the Poisson ratios of both beam are set to zero (to minimize two-dimensional effects); the pressure is set to $P = 1$; and the end force on each beam increases linearly from zero initially to $F = 10$ at $t = 10$. Both beams are also of unit height, h.

Input Data

The listings of the SANTOS input files for the calculations are given in APPENDIX J.

Output Listing

The output listings for the analyses are in APPENDIX J.

Discussion of Results

The end-point displacements predicted by the SANTOS analyses are plotted against the closed-form solutions in Figure 10.5, for the first case, and Figure 10.6, for the second case. The SANTOS results show excellent agreement with the analytic solution (shown as the solid lines in both figures), and it can be concluded that the sliding part of the contact algorithm is working correctly in SANTOS.

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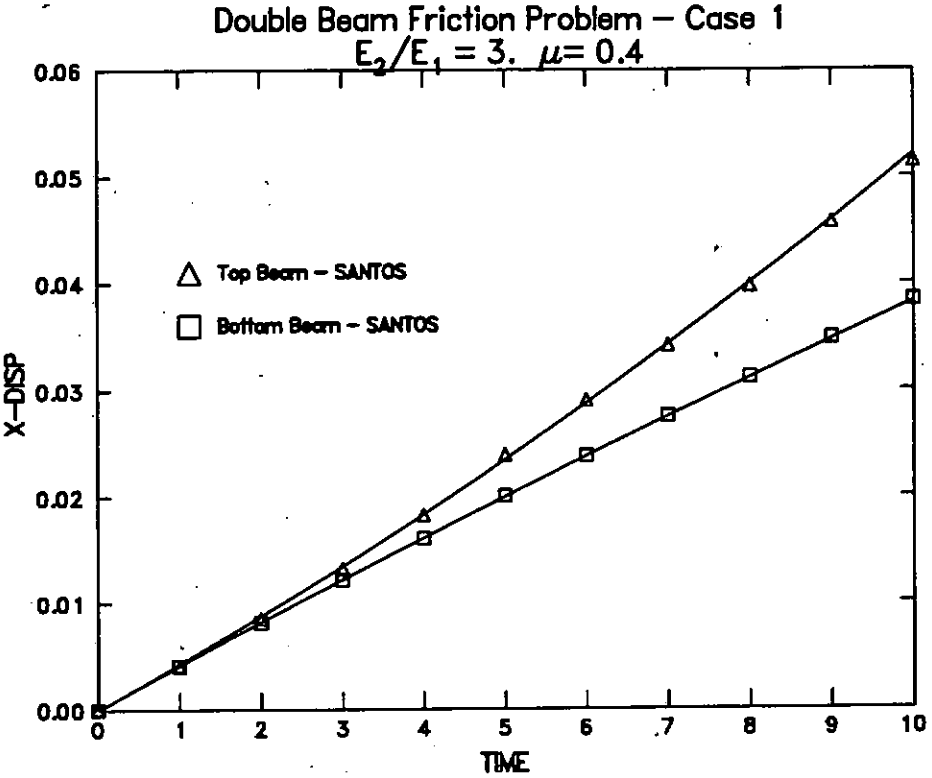

Figure 10.5 End-Point Displacements for Case 1

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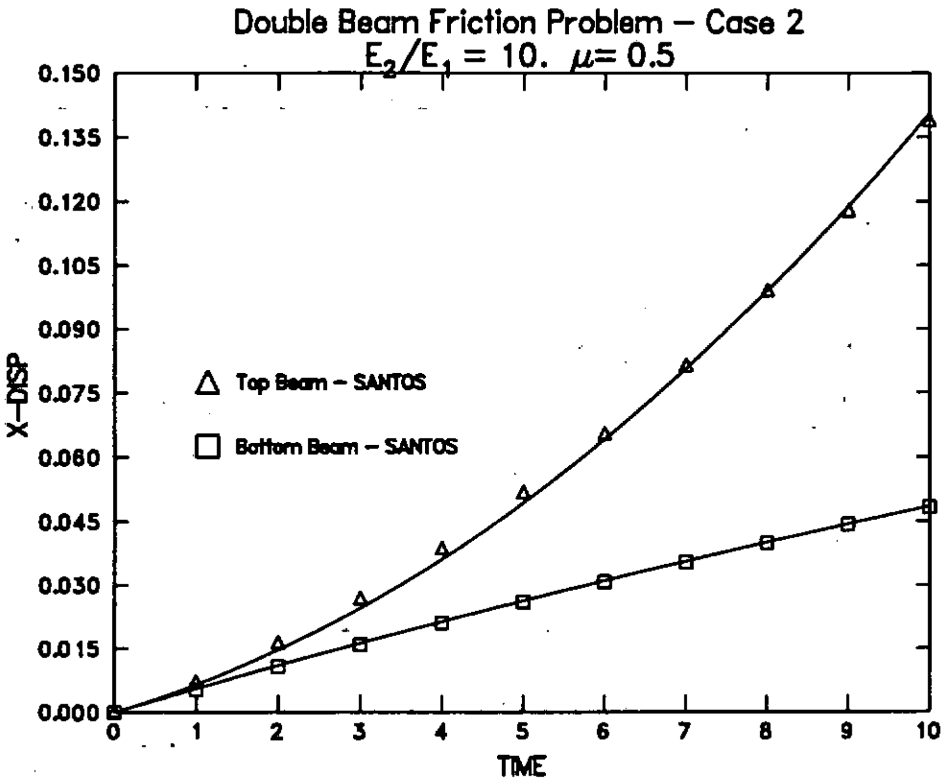

Figure 10.6 End-Point Displacements for Case 2

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Problem 11 – Elastic/Plastic Analysis of a Thick-Walled Hollow Sphere

This problem tests the elastic/plastic constitutive model in SANTOS by analyzing both the pressurization and the thermal loading of a hollow sphere. Three cases are analyzed: an isothermal pressurized elastic/perfectly-plastic sphere, an isothermal pressurized elastic/plastic with linear strain hardening sphere, and an thermally loaded elastic/perfectly-plastic sphere.

Problem Description

The sphere analyzed in all three cases has an internal radius of one and an outer radius of two, as shown in Figure 11.1. For the isothermal loading cases, the internal pressure on the inner surface of the sphere is such that the sphere starts off at initial yield on the inner surface. The pressure is then increased until the sphere becomes fully plastic through the thickness. In the thermal problem a radial temperature gradient is applied that causes initial yield on the inner surface of the sphere and the temperature is increased, expanding the plastic zone.

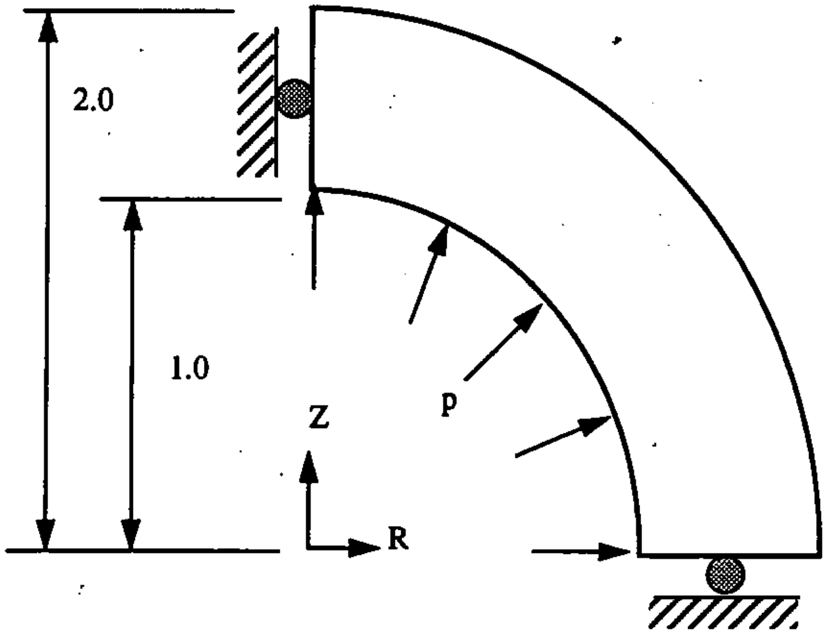

Figure 11.1 Problem Geometry and Boundary Conditions For Pressurized Cases

Analytic Solution

Pressure Loading Cases

The analytic solutions for these problems were derived by Mendelson (1968). For the isothermal pressurized loading cases the elastic/plastic interface expands radially outward

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from the inner surface of the sphere according to the equations below, taken from Mendelson. The first equation:

$$P = 2\ln\rho_c + \frac{2}{3}\left(1 - \frac{1}{\beta_c^3}\right), \qquad \textbf{(EQ 11.1)}$$

is for the elastic/perfectly-plastic material, and the second equation

$$P = \frac{\frac{4m}{3}(1-\nu)\left(1-1/\beta^3\right)\rho_c^3 + 2(1-m)\ln\rho_c + \frac{2}{3}(1-m)\left(1-1/\beta_c^3\right)}{1-m+2m(1-\nu)}, \qquad \textbf{(EQ 11.2)}$$

is for a linear strain hardening material. The non-dimensional variables used in the above equations are:

$P = p/\sigma_y$, ratio of applied internal pressure to material yield stress,
$\rho_c = c/a$, ratio of elastic/plastic interface radius to the sphere's internal radius,
$\beta_c = b/c$, ratio of sphere's outer radius to the elastic/plastic interface radius,
$\beta = b/a$, ratio of sphere's outer to inner radii,
m = ratio of the hardening modulus to the Youngs' modulus, and
ν = Poisson's ratio.

Expressions for the non-dimensional effective stress functions for both the elastic/perfectly-plastic case and the elastic/plastic with linear strain hardening case can also be found in Mendelson (1968). However, Biffle and Blanford (1994) discovered that the effective stress function for the linear strain hardening material in Mendelson is incorrect, and the corrected equation from the JAC2D manual (Biffle and Blanford, 1994) is shown below. The expression:

$$S = |\sigma_\theta - \sigma_r|/\sigma_y \qquad \textbf{(EQ 11.3)}$$

gives the dimensionless effective stress in the outer elastic region of elastic/perfectly-plastic material, which simply reduces to:

$$S = c^3/r^3, \qquad \textbf{(EQ 11.4)}$$

once the interface radius, *c*, is computed. By definition, the dimensionless effective stress is unity in the plastic region for the elastic/perfectly plastic case. For the elastic/plastic with linear hardening case, the dimensionless effective stress in the elastic region is the same as given above. In the plastic region, the dimensionless effective stress for this case is given by:

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$$S = \frac{1 - m + 2m(1-\nu)c^3/r^3}{1 - m + 2m(1-\nu)}. \qquad \textbf{(EQ 11.5)}$$

Specific values used in this example to generate a solution for comparison with computed results from SANTOS for the elastic/perfectly-plastic case are: $\sigma_y = 1.0\times10^4$; $a = 1.0$: $b = 2.0$; $E = 2.07\times10^{11}$; and $\nu = 0.3$. The applied internal pressure used in the SANTOS analysis is shown in Table 11.1. The load increases with time to produce a plastic zone in the sphere that initiates at the inner surface and eventually encompasses the entire thickness. Similarly, specific values used in this example to generate a solution for comparison with computed results from SANTOS for the elastic/plastic with linear hardening case are: $\sigma_y = 1.0\times10^4$; $a = 1.0$: $b = 2.0$; $m = 0.1$; $E = 2.07\times10^{11}$; and $\nu = 0.3$. The applied internal pressure used in the SANTOS analysis is shown in Table 11.2. Again, the load increases with time to produce a plastic zone in the sphere that initiates at the inner surface of the sphere and eventually envelopes the entire thickness. However, because of the strain hardening in this case, a higher final pressure is required to yield the entire thickness of the sphere. Figure 11.2 and Figure 11.3 show the non-dimensional analytic effective stresses using these values, plotted as a function of radius, for loadings starting from plastic yield on the inner surface of the sphere to full plastic yielding of the sphere (the analytical solutions are plotted as solid lines).

Table 11.1 Applied Pressure History for Elastic/Perfectly-Plastic Case

Time	Pressure, p
0.0	0.0
1.0	5833.0
1.25	9501.9
1.5	11963.5
1.75	13392.8
2.0	13900.0

Temperature Loading Case

The temperature gradient used in the thermal analysis of an elastic/perfectly-plastic hollow sphere is derived from the steady-state solution of a hollow sphere with a constant temperature of T_o on the inner surface and zero temperature on the outer surface. The radial temperature gradient is given in Mendelson as:

Information Only

Table 11.2 Applied Pressure History for Elastic/Plastic With Linear Hardening Case

Time	Pressure, p
0.0	0.0
1.0	5833.0
1.25	9756.5
1.5	13003.2
1.75	15798.4
2.0	18278.8

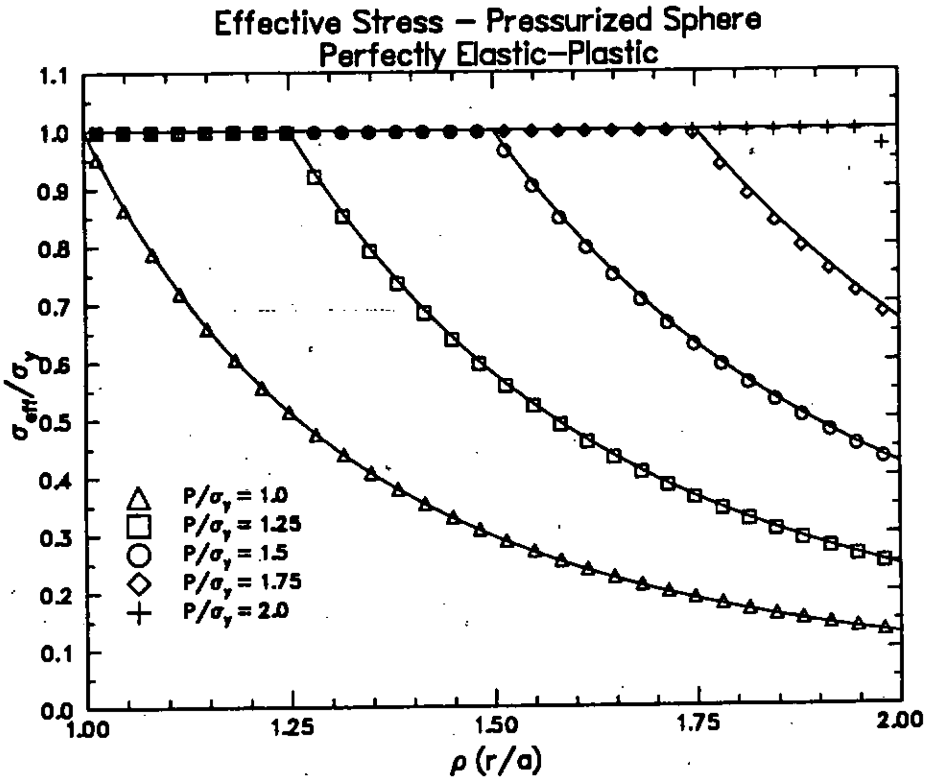

Figure 11.2 Elastic/Perfectly Plastic Hollow Sphere

$$T = \frac{T_o a}{(b-a)}\left(\frac{b}{r}-1\right) \qquad \textbf{(EQ 11.6)}$$

where a, b are the inner and outer radii of the sphere and r is the radial distance, such that $(a \le r \le b)$. The thermal problem differs from the previous elastic/plastic calculations in that two plastic zones are created with higher temperatures. Initially yield occurs on the

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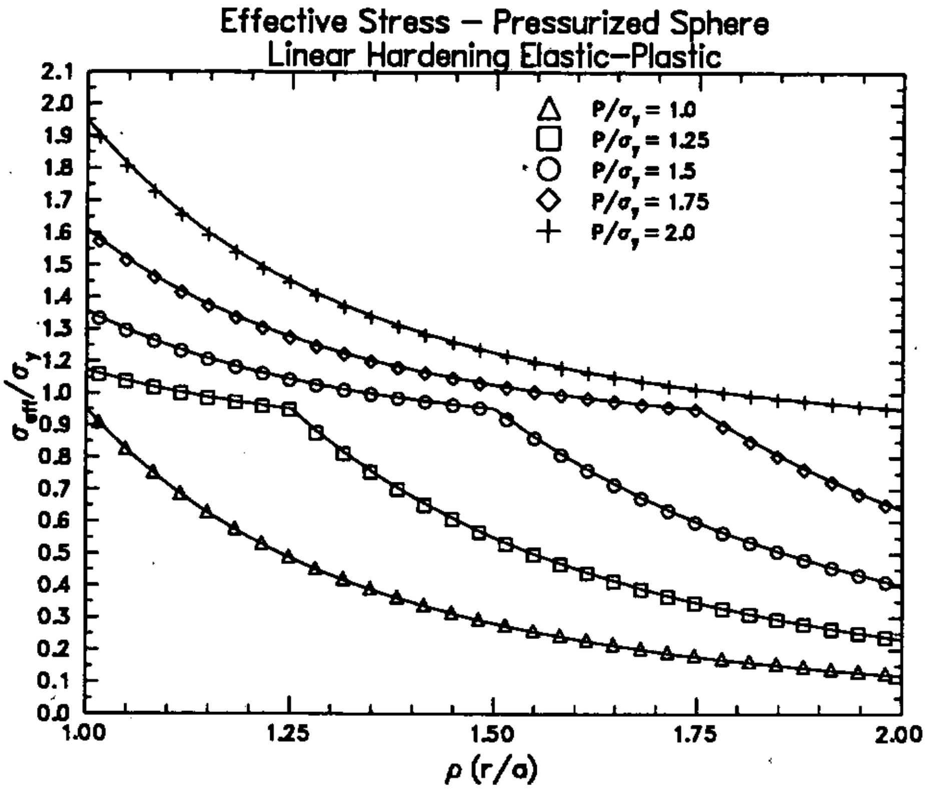

Figure 11.3 Elastic/Plastic Hollow Sphere with Linear Hardening

inner radius of the sphere due to compressive tangential stresses, and the elastic/plastic interface expands radially outward with higher thermal loads. The temperature required to initiate yielding on the inner surface of the sphere can be found by solving the following dimensionless thermal load equation:

$$\tau = \frac{E\alpha T_o}{\sigma_y(1-\nu)}\,, \qquad \textbf{(EQ 11.7)}$$

for T_0, where $\tau(T_0)$ is found by setting $c = a$ in the following equation:

$$\tau = 2\left(\frac{c}{a}-\frac{c}{b}\right)\left[\frac{1-c^3/b^3+\ln\left(c^3/a^3\right)}{(2+c/b)\,(1-c/b)^2}\right], \qquad \textbf{(EQ 11.8)}$$

which is used for determining the radius c of the initial elastic/plastic interface. In the foregoing, α is the linear coefficient of thermal expansion and E is the Young's Modulus. In this specific example, we use: $\alpha = 1.0\times10^{-5}$; $E = 1.0\times10^{7}$; $\nu = 0.3$; $\sigma_y = 1.0\times10^{4}$; $a = 1.0$; and $b = 2.0$. Using these values, the inner surface temperature, T_o, required to initiate yielding, at $r = a$, is 98°.

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When the plastic boundary (expanding radially outward) has advanced to a radius c_1 as determined by solving the following equation:

$$\ln\frac{c_1}{a} = \frac{2b}{3c_1}\left(1-\frac{c_1}{b}\right)^2 \qquad \textbf{(EQ 11.9)}$$

for c_1, a second yield surface is initiated at the outer surface of the sphere due to tensile tangential stresses. For this specific example, c_1 has a value of 1.197 and occurs at an inner surface temperature of 264.8° as determined by use of Equation 11.8. Above this critical temperature, the elastic/plastic interface from the second yield zone expands radially inward with increasing temperatures while the inner plastic zone continues to spread outward. An elastic region is sandwiched between the expanding plastic zones.

The dimensionless effective stress in both plastic zones is equal to unity and the following equation:

$$S = \left|B\frac{3b^3}{2r^3} - \tau\frac{ab}{2r(b-a)}\right| \qquad \textbf{(EQ 11.10)}$$

is used to define the dimensionless stress in the elastic zone, with B defined as follows:

$$B = \frac{2c^3}{b^3}\left[\frac{1-c/b+\ln(c/a)}{(2+c/b)(1-c/b)^2}\right]. \qquad \textbf{(EQ 11.11)}$$

However, B as determined with Equation 11.11 is the elastic stress function that can be used only prior to the creation of the second plastic zone. When there are two plastic zones, Equation 11.8 is no longer valid and the locations of both elastic/plastic interfaces have to be solved-for simultaneously using the following two equations (Biffle and Blanford, 1994):

$$\tau = 2\left(\frac{d}{a}-\frac{d}{b}\right)\left(1+\frac{c^2/d^2}{1-c/d}\right), \text{ and} \qquad \textbf{(EQ 11.12)}$$

$$\ln\left(\frac{cd}{ab}\right) = \frac{2c}{3d}\left[\frac{d}{c}-1\right]^2, \qquad \textbf{(EQ 11.13)}$$

where d is the radius to the second elastic/plastic interface. The resulting new B function to be used in the dimensionless effective stress function (Equation 11.10) above is:

$$B = 2\frac{c^3}{b^3}\left[\frac{d/c}{3(1-c/d)}\right]. \qquad \textbf{(EQ 11.14)}$$

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Using the specific values for the thermal problem as detailed above, Figure 11.4 shows the analytic nondimensional effective stress (solid lines) for this case as T_0 increases from 98° to 600°.

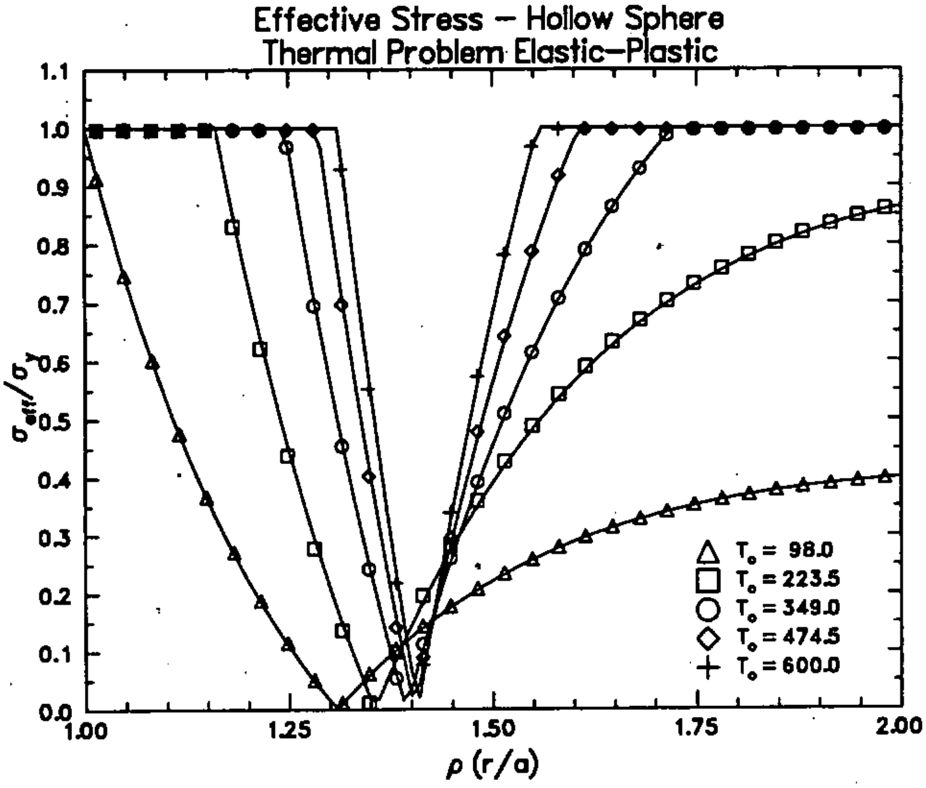

Figure 11.4 Elastic/Perfectly Plastic Hollow Sphere – Temperature Case

SANTOS Solution

Problem Discretization

The finite element mesh used in the SANTOS analyses is shown in Figure 11.5 and is composed of 600 elements (4 node quadrilaterals)

Input Data

A listing of the input file is given in APPENDIX K.

Output Listing

A partial listing of the printed output showing pertinent problem information is given in APPENDIX K.

Information Only

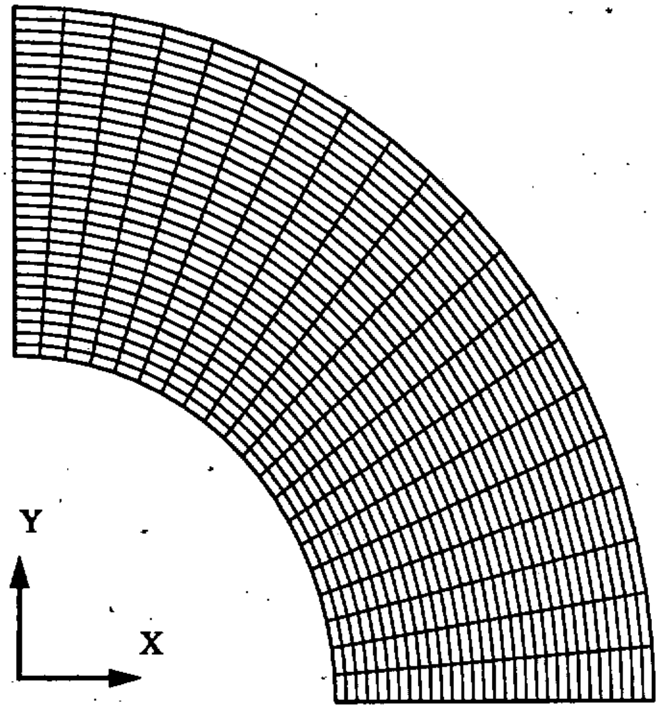

Figure 11.5 Finite Element Mesh

Discussion of Results

The results predicted by SANTOS are also shown in Figures 11.2 to 11.4. As can be seen in the plots of the normalized effective stresses, the computed results match the analytic results almost exactly. It can be concluded that the implementation of the elastic/plastic constitutive model in SANTOS is correct for isothermal and temperature dependent problems. It is should be noted in Figure 11.2 that for the plot of effective stresses in the case where the sphere is fully plastic, the SANTOS solution does not predict a fully plastic sphere. The normalized effective stress for the element on the outer radius of the sphere is slightly less than one although the pressure input to SANTOS is the theoretical value that could induce full plastic yield of the sphere. For a load case where the sphere becomes fully plastic, the solution continues to iterate because the material is flowing in an unrestrained manner.

References

1. Mendelson, A., *PLASTICITY: Theory and Application, Macmillan* Co.,NY, 1968.

2. Biffle, J. H. and M. L. Blanford, *JAC2D-A Two-Dimensional Finite Element Computer Program for the Nonlinear Quasi-Static Response of Solids with the Conjugate Gradient Method*, SAND93-1891, Sandia National Laboratories, Albuquerque, NM, May, 1994.

Information Only

Problem 12 – Restart Option Problem

This problem tests the SANTOS restart (read and write) option by re-analyzing the elastic/perfectly plastic hollow sphere temperature problem described in Problem 11.

Problem Description

A hollow sphere made of elastic/perfectly plastic material is loaded by a radial temperature gradient that initiates plastic yield on both the outer and inner radii of the sphere. This problem was analyzed in Problem 11 of the verification and qualification problem set.

Analytic Solution

See Problem 11 of the verification and qualification problem set for the analytic solution and for specific material properties and geometric parameters used for this example.

SANTOS Solution

Problem Discretization

The finite element mesh is shown in Figure 11.5 and is composed of 600 elements (4 node quadrilaterals)

Input Data

A listing of the SANTOS input files for both the restart write and restart read calculations are given in APPENDIX L.

Output Listing

The output listings for both the restart write and restart read analyses are listed in APPENDIX L.

Discussion of Results

To test the restart option in SANTOS two analyses were performed. The first produced the restart tape and was run to time 3 (the original calculation was run out to time 5). The second calculation restarts the first at time 3 and concludes at time 5. Figure 12.1 shows the non-dimensional effective stress plots for times 3, 4, and 5 produced by the restart analysis along with those from the original continuous analysis. The results are shown to overlay, meaning that the restart option (read and write) in SANTOS is working correctly.

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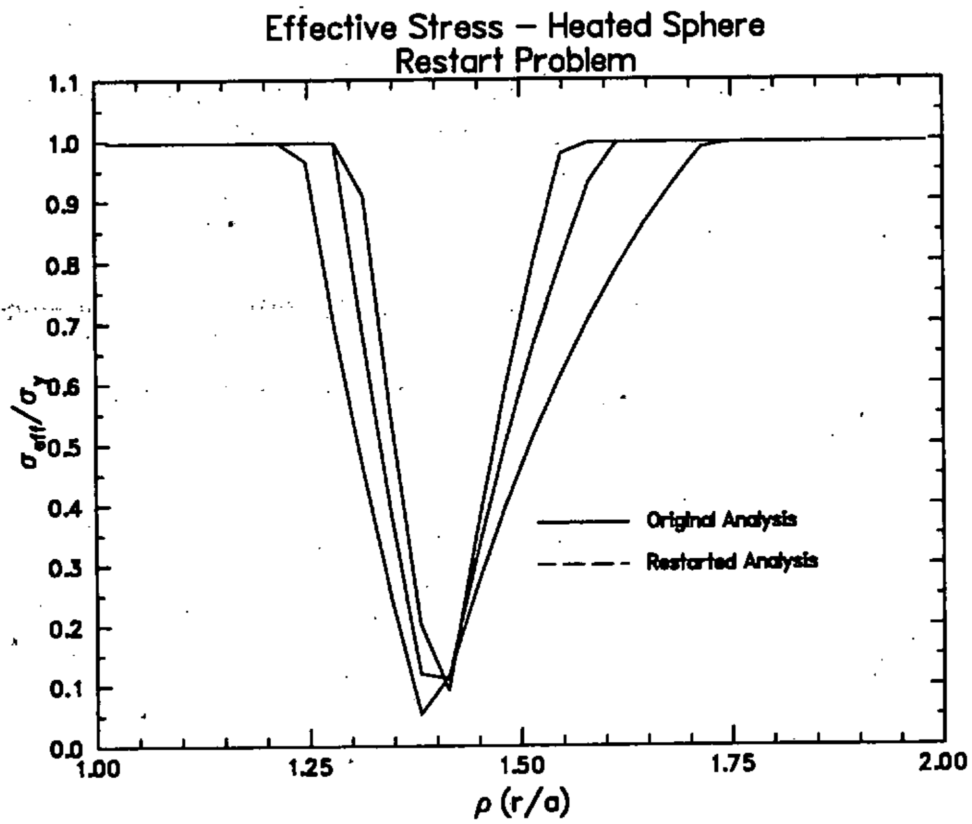

Figure 12.1 Effective Stress Comparison

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Problem 13 – Sloping Roller Option Problem

This problem checks the sloping roller option in SANTOS by comparing the stresses computed using this option to those produced by a calculation using a complete geometric description of the body in question.

Problem Description

A hollow sphere of elastic/perfectly plastic material is loaded with radial thermal gradients that create plastic and elastic zones through the thickness of the sphere. This problem was analyzed in Problem 11 of the verification problem set using a hemispherical model of the sphere. In this calculation a 36° wedge of the sphere is modeled using the sloping roller option. Figure 13.1 depicts the geometry and boundary conditions used in the sloping roller calculation.

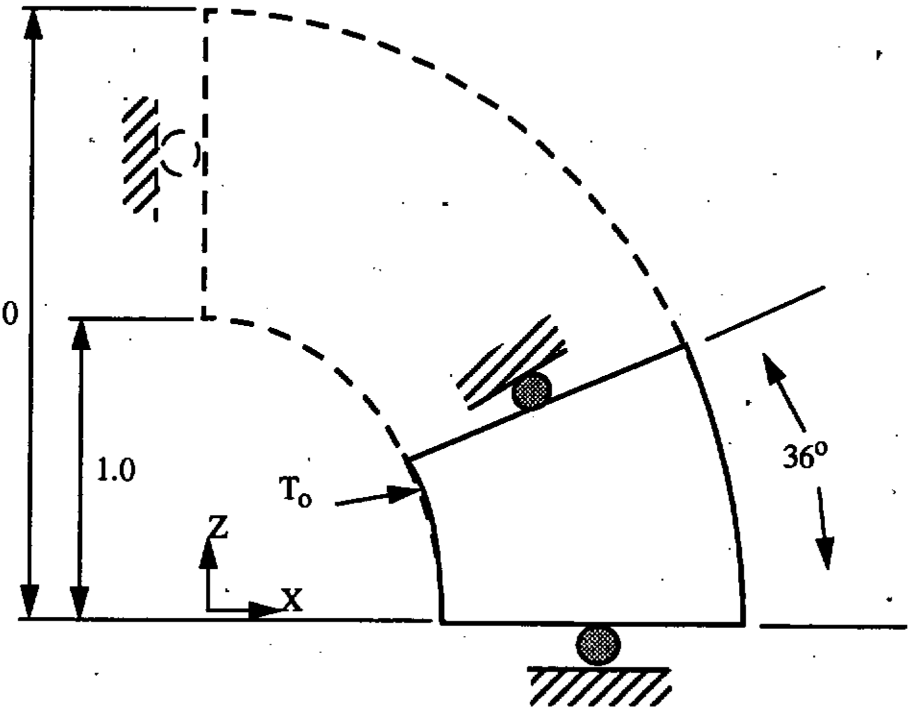

Figure 13.1 Sloping Roller Geometry and Boundary Conditions

Analytic Solution

The analytical solution to this problem was derived by Mendelson (1968) and is discussed in fuller detail in Problem 11 of the verification problem set.

Information Only

SANTOS Solution

In this specific example, we use the same material and geometric parameters as for Problem 11: $\alpha = 1.0\times10^{-5}$; $E = 1.0\times10^{7}$; $\nu = 0.3$; $\sigma_y = 1.0\times10^{4}$; $a = 1.0$; and $b = 2.0$.

Problem Discretization

A 240 element mesh (4 node-quadrilateral) is used in the SANTOS calculation and is shown in Figure 13.2.

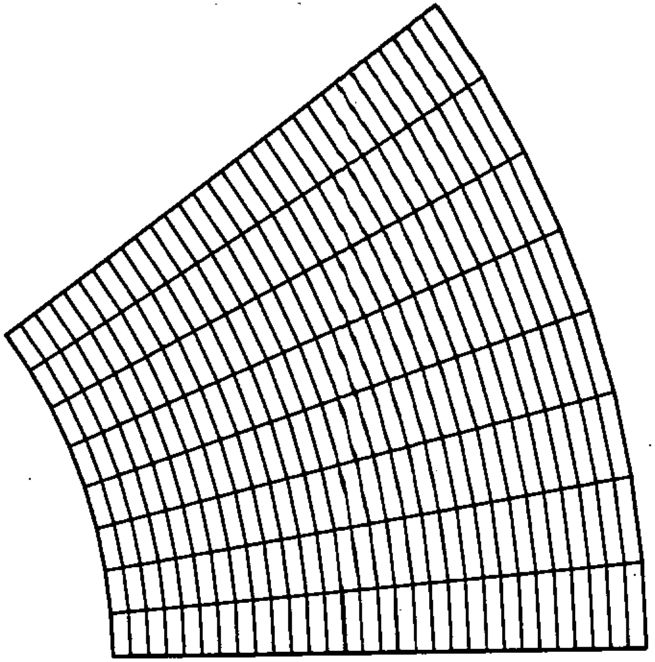

Figure 13.2 Finite Element Mesh

Input Data

A listing of the SANTOS input file is given in APPENDIX M.

Output Listing

A partial listing of the printed output showing pertinent problem information is given in APPENDIX M.

Discussion of Results

The calculation using the sloping roller option in SANTOS successfully recreated the effective stress profiles, as shown in Figure 13.3, that were plotted in Problem 11 of the verification problem set. The sloping roller option is correctly working in SANTOS.

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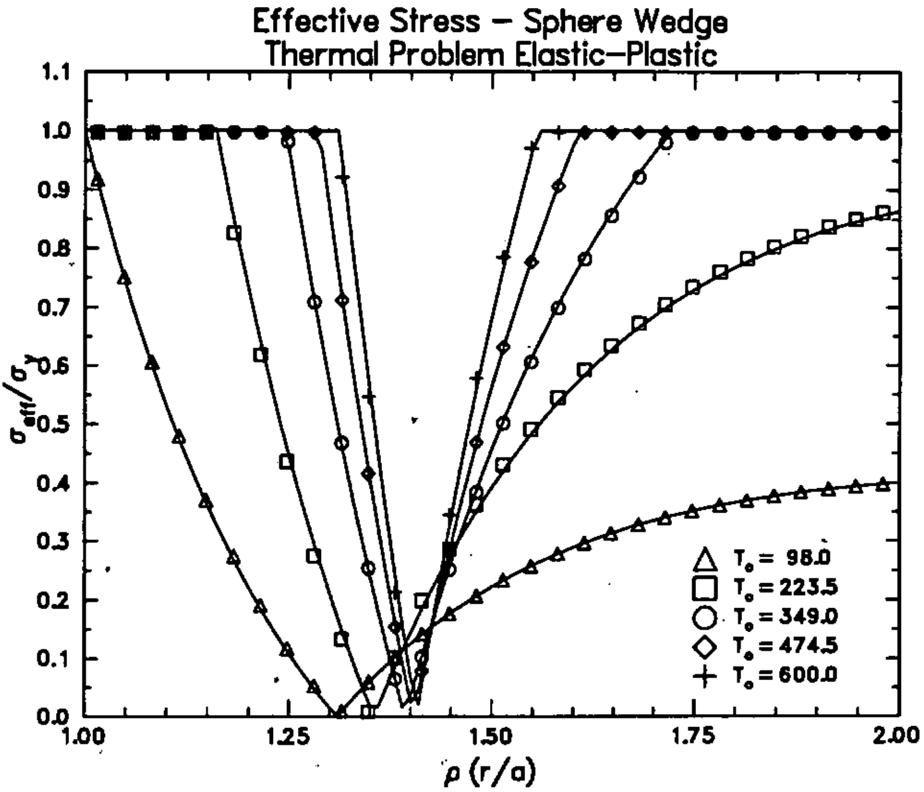

Figure 13.3 Effective Stress Plot

References

1. Mendelson, A. *PLASTICITY: Theory and Application*, Macmillan Co.,NY, 1968.

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Problem 14 – Creep Relaxation Problem

This problem tests SANTOS power law creep constitutive model by analyzing a creep relaxation problem.

Problem Description

A stress-free, isotropic, and homogeneous hollow cylinder undergoes an axial displacement δ at time zero. The calculation determines the axial creep stress relaxation in the cylinder over time when δ is kept constant.

Analytic Solution

This problem was used to verify the power law creep model in SANCHO (Stone, et. al, 1985). The total strain rate can be decomposed into elastic and inelastic (creep) parts as follows:

$$\dot{\varepsilon}_{tot} = \dot{\varepsilon}_{el} + \dot{\varepsilon}_{c}. \qquad \textbf{(EQ 14.1)}$$

The total strain rate is zero for the stress relaxation problem in question, after the displacement, δ, is initially applied. This being the case, the governing equation becomes:

$$\dot{\varepsilon}_{el} = -\dot{\varepsilon}_{c}\text{, or, } -\frac{\dot{\sigma}}{E} = \dot{\varepsilon}_{c} \qquad \textbf{(EQ 14.2)}$$

where E is the Young's modulus. The effective creep strain rate using the power law creep model is defined as follows:

$$\dot{\varepsilon}_{c} = D\bar{\sigma}^{n}e^{\left(\frac{-Q}{RT}\right)}. \qquad \textbf{(EQ 14.3)}$$

The parameters D and n are material constants. They, along with the remaining parameters used in the above equation, are further defined as follows:

D is the leading coefficient,
$\bar{\sigma}$ is the effective stress (and in this case equal to the axial stress),
n is the power on the effective stress,
Q is the activation energy,
R is the universal gas constant,
and T is the reference temperature.

Substitution of Equation 14.3 into Equation 14.2 leads to an ordinary differential equation. Integration of the equation, following separation of variables, leads to the closed form solution for the axial stress as a function of time. This is given by:

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$$\sigma_z(t) = \left[\sigma_z^{1-n}(0) + EDe^{\left(\frac{-Q}{RT}\right)}(n-1)t\right]^{\frac{1}{1-n}} \qquad \textbf{(EQ 14.4)}$$

where $\sigma_z(t)$ is the axial stress as a function of time and $\sigma_z(0)$ is the elastic axial stress value induced initially by the application of the displacement, δ.

Specific values used in this example are as follows: $\delta = 0.001$; $E = 24.75\times10^9$; $\nu = 0$; $D = 5.79\times10^{-36}$; $n = 4.9$; and $Q/(RT) = 20.13$. Using these specific values, the elastic response induced by application of the displacement δ at time zero is found to lead to an initial axial stress of 24.75 MPa. The axial stress relaxes thereafter monotonically with time, attempting to reach a steady-state value.

SANTOS Solution

Problem Discretization

A single element (4-mode quadrilateral) is used in the analysis and the problem geometry and boundary conditions are shown in Figure 14.1.

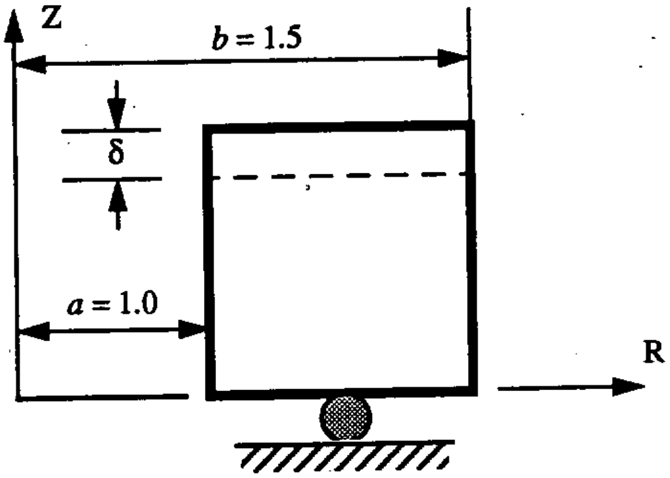

Figure 14.1 Thick-Walled Cylinder Axially Deformed at t = 0.

Input Data

A listing of the SANTOS input file is given in APPENDIX N.

Output Listing

A partial listing of the printed output showing pertinent problem information is given in APPENDIX N.

Information Only

Discussion of Results

A comparison of analytically-derived Von Mises stresses with those predicted by SANTOS is shown in Figure 14.2. The SANTOS solution follows the analytical solution of Equation 14.4 (shown as the solid line) very closely, verifying that the SANTOS implementation of the power-creep law is functioning correctly.

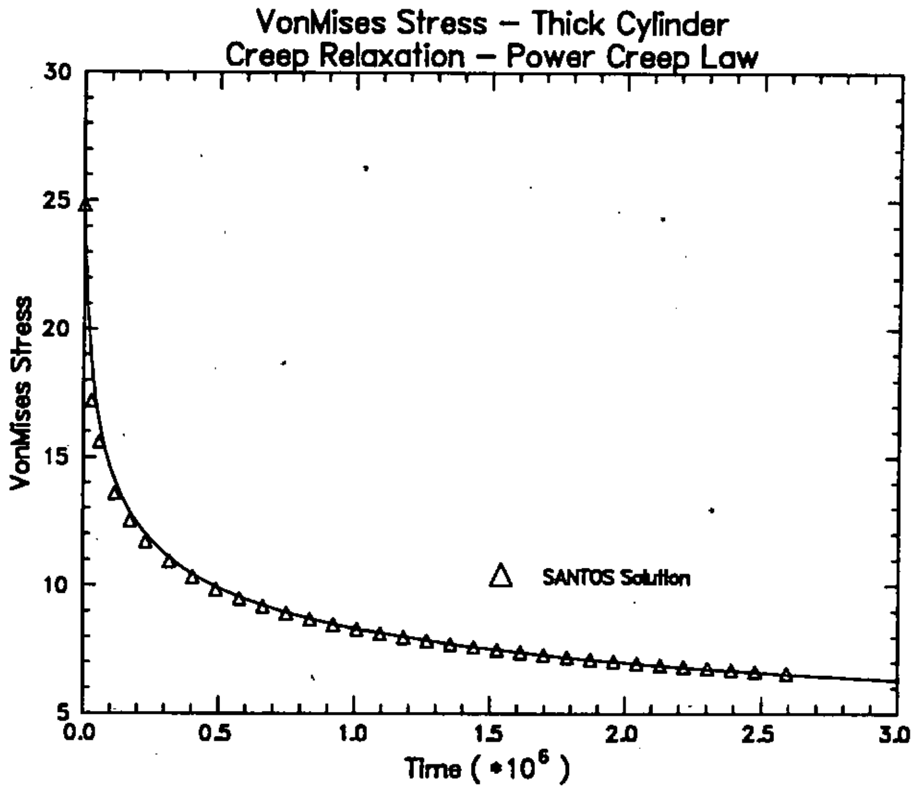

Figure 14.2 Von Mises Stress Plot - Power Creep Law

References

1. Stone, C. M., R. D. Krieg, and Z. E. Beisinger, *SANCHO – A Finite Element Computer Program for the Quasistatic, Large Deformation, Inelastic Response of Two-Dimensional Solids*, SAND84-2618, Sandia National Laboratories, Albuquerque, New Mexico, April 1985.

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Problem 15 – Linear Viscoelastic Constitutive Model Implementation Problem

This problem checks the implementation of a linear viscoelastic constitutive model (Stone and Costin, 1985) into SANTOS by analyzing an internally pressurized thick-walled cylinder.

Problem Description

A thick-walled cylinder representing a rocket motor is subjected to an instantaneous pressure on its inner surface. The solid propellant is modelled as a linear viscoelastic material with an elastic bulk response and is assumed to behave as a Maxwell body in shear. The propellant is restrained on its outer radius by a thin steel casing. It is desired to know the time dependent response of the propellant under the pressure load. Figure 15.1 shows the problem geometry and boundary conditions.

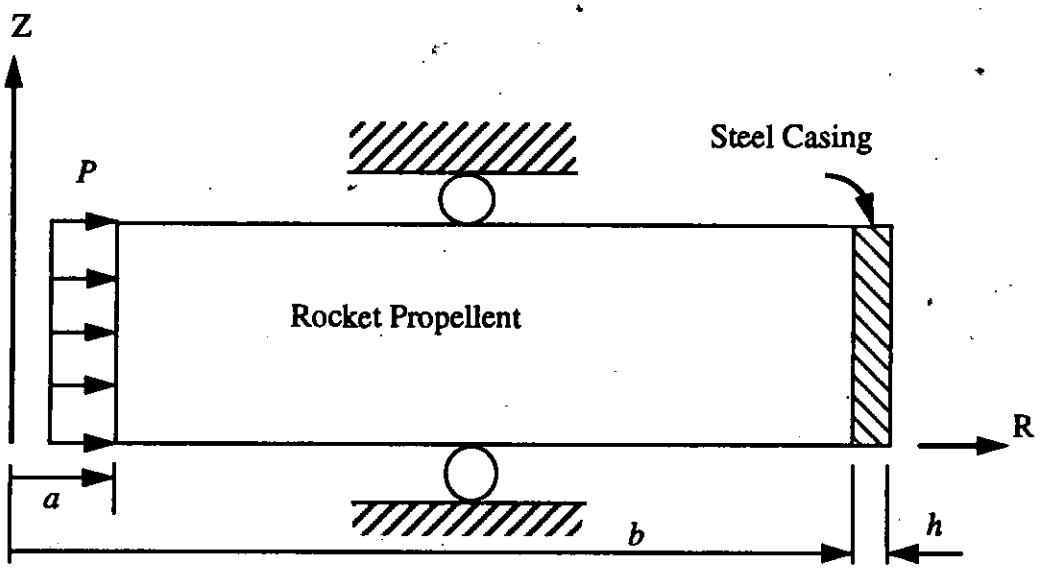

Figure 15.1 Problem Geometry and Boundary Conditions

Analytic Solution

An analytical solution to this problem has been developed by Lee et al. (1959) and Stone and Costin (1985) used this problem to test their linear viscoelastic constitutive model implementation in the SANCHO finite element program (Stone et al., 1985). Lee et al. make use of the Laplace transform to generate the following equation:

$$\bar{\sigma}_{rr} = -\frac{p}{p}\frac{\left[333p^2 + 656p + 320\right] + \left(b^2/r^2\right)\left[147p^2 + 144p\right]}{921p^2 + 1232p + 320} \qquad \textbf{(EQ 15.1)}$$

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in terms of the transform parameter, p, for the transformed radial stress, and

$$\bar{\sigma}_{\theta\theta} = -\frac{P}{p}\frac{p\left[333p^2+656p+320\right]-\left(b^2/r^2\right)\left[147p^2+144p\right]}{921p^2+1232p+320} \qquad \textbf{(EQ 15.2)}$$

for the transformed circumferential stress, where P is the applied internal pressure, b is the outer radius, and r is the radial distance. The equations can be inverted directly to give, for example:

$$\sigma_{rr} = -P\left[\{0.3616+\frac{0.005282}{0.9849}\left(1-e^{-0.9849t}\right)+\frac{0.2233}{0.3528}\left(1-e^{-0.3528t}\right)\} \qquad \textbf{(EQ 15.3)}\right.$$
$$\left.+\frac{b^2}{r^2}\{0.1596-\frac{0.001320}{0.9849}\left(1-e^{-0.9849t}\right)-\frac{0.05583}{0.3528}\left(1-e^{-0.3528t}\right)\}\right]$$

for the actual radial stress (that will be used to compare with the SANTOS solution), and a similar equation can also be found for the actual circumferential stress. Note that these equations assume the use of specific values for material and geometric properties in both the propellant and the casing. The equivalent values used in the SANTOS analysis for the propellant are as follows: $a = 2$; $b = 4$; $K = 1\times10^5$; $K^{\infty} = 1\times10^5$; $\beta^k = 1$; $G^{\infty} = 0$: $G_1 = 3.75\times10^4$; $G_2 = G_3 = 0$; $\beta_1^s = \beta_2^s = \beta_3^s = 1$; $C_1 = 7.6$; $C_2 = 277$; and $T_0 = 373$. The values used for the casing were as follows: $h = 1/8$; $E = 3\times10^7$; $\nu = 0.3015$; $\sigma_Y = 1\times10^6$; $H = 1\times10^6$; and $\beta = 1$ (Note that although an elastic/plastic material model was used for the casing, the loading was such that it remained within the elastic regime throughout the analysis). A constant internal pressure of $P = 1000$ was also used in the analysis.

SANTOS Solution

Problem Discretization

A 23 element mesh (4 node-quadrilateral) is used in the calculation and is shown in Figure 15.2.

Input Data

A listing of the SANTOS input file is given in APPENDIX O.

Output Listing

A partial listing of the printed output showing pertinent problem information is given in APPENDIX O.

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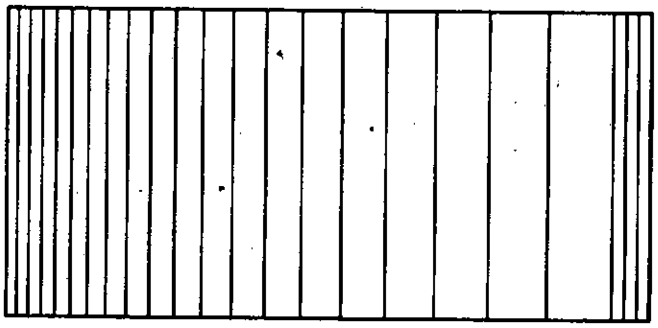

Figure 15.2 Finite Element Mesh

Discussion of Results

In Figure 15.3 and Figure 15.4 the normalized radial and circumferential stress profiles, respectively, are plotted for different times after the application of the pressure load, P. As it can be seen in the plots, the SANTOS stress predictions match the analytic solutions (shown as the solid curves) very well.

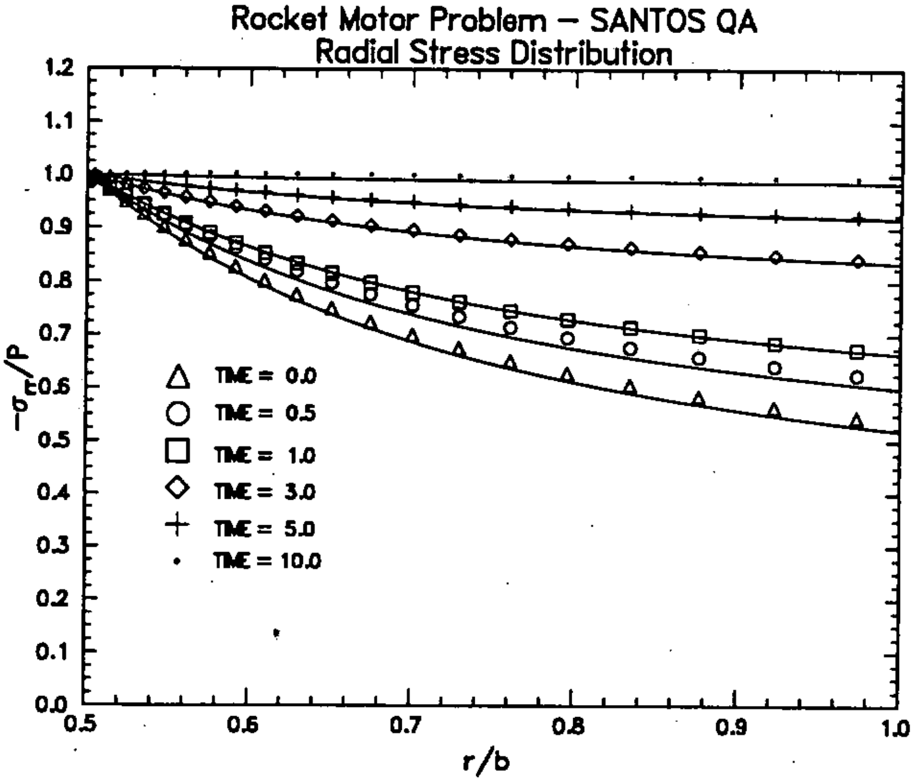

Figure 15.3 Radial Stress Plot

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References

1. Lee, E. H., J. R. M. Radock, and W. B. Woodward,"Stress Analysis for Linear Viscoelastic Materials," *Transactions of the Society of Rheology*, III, 1959, pp. 41-59.

2. Stone, C. M. and L. S. Costin, *A Linear Viscoelastic Material Model for SANCHO*, SAND85-1836, Sandia National Laboratories, Albuquerque, New Mexico., October,1985.

3. Stone, C. M., R. D. Krieg, and Z. E. Beisinger, *SANCHO: A Finite Element Computer Program for the Quasistatic, Large Deformation, Inelastic Response of Two-Dimensional Solids*, SAND84-2618, Sandia National Laboratories, Albuquerque, New Mexico., April, 1985.

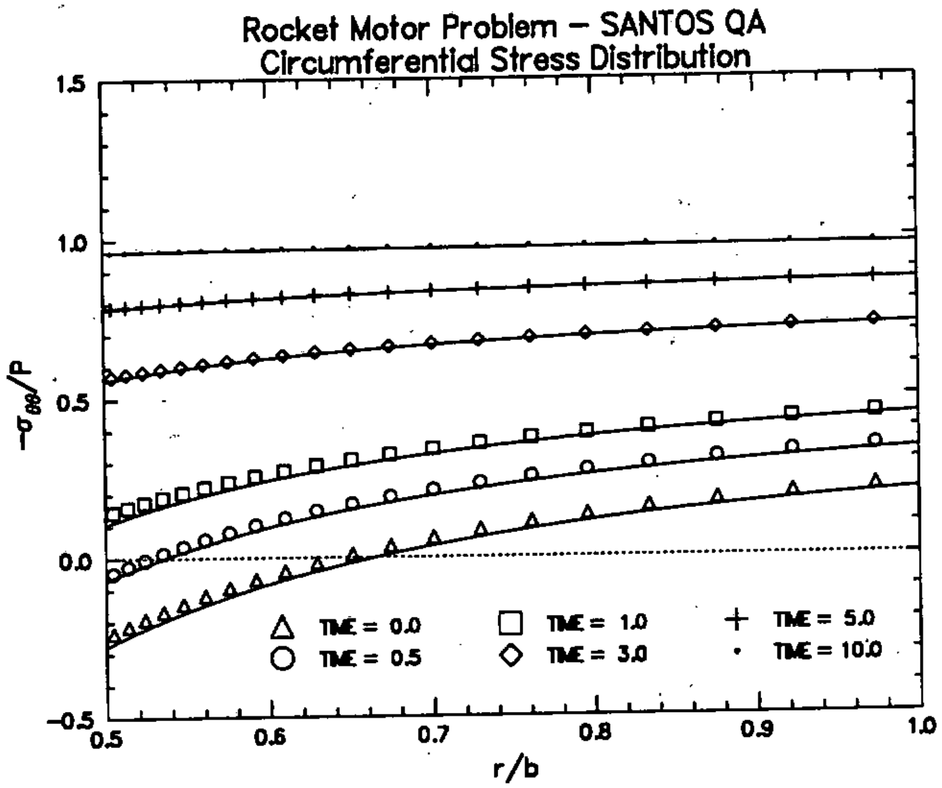

Figure 15.4 Circumferential Stress Plot

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Problem 16 – M-D Constitutive Model Implementation Test Problem

This problem tests the SANTOS implementation of the M-D constitutive model with a Tresca flow condition, as described by Munson et al. (1989), on a shaft closure analysis. The SANTOS results are compared to those computed with the SPECTROM-32 code (Callahan et al., 1986). This configuration was chosen because it tests the implementation of the model itself without including the additional complexities and influences of stratigraphy and sliding surfaces into the solution that would be inherent in a disposal-room-type problem.

Problem Description

A vertical shaft of 6.5 m diameter is assumed to be excavated instantaneously at time zero at a depth of 655.3 m in bedded salt. The material at the depth of interest is subject to an in situ lithostatic stress of -15 MPa and immediately begins to close the shaft opening as it begins to creep. An analysis is done to determine the rate and amount of closure of the shaft at this depth.

Other Solution (In Lieu of Analytic Solution)

There is no analytic solution to this problem. Consequently, to gauge the adequacy of the solution, the percent closure of the shaft computed with SANTOS is compared to that found in Munson et al. (1992). The results from that analysis were computed with SPECTROM-32. Figure 16.1 shows the problem geometry used in both the present and the Munson et al. analyses. Specific values of inner and outer radii (a and b, respectively), initial stress (σ_o),

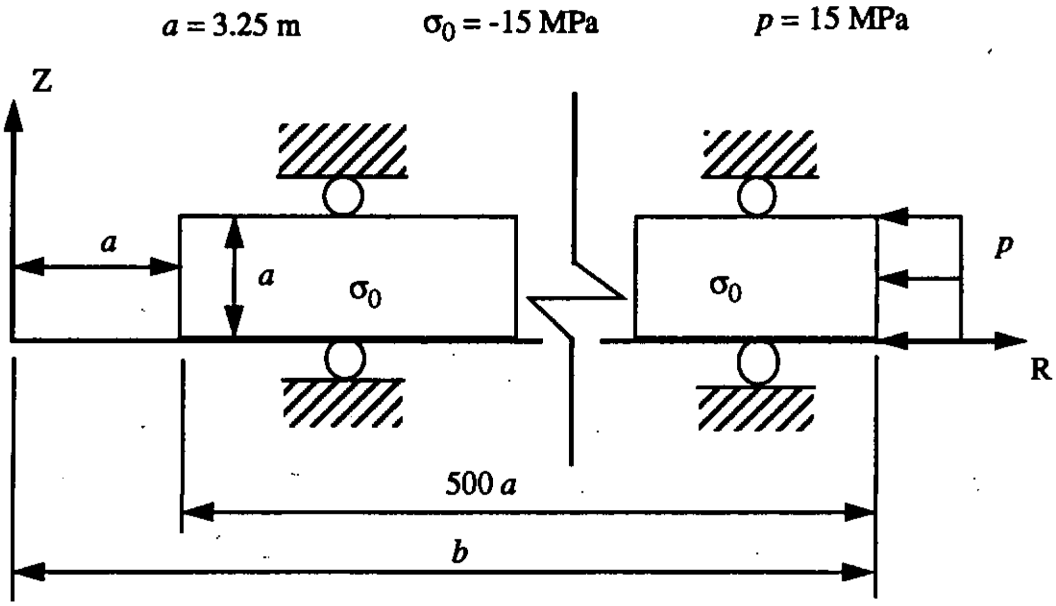

Figure 16.1 Problem Geometry and Boundary Conditions

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and applied pressure (*p*) used in the analysis are also shown on the figure. The elastic and creep properties used in this analysis are shown in Table 16.1 and Table 16.2, respectively. The creep parameters listed in the table are those given by Munson, et al. (1989) for clean salt.

Table 16.1 Elastic Properties

G MPa	E MPa	ν
12,400	31,000	0.25

Table 16.2 Creep Properties

Parameters (units)	Clean Salt
A_1 (/sec)	8.386E22
Q_1 (cal/mole)	25,000
n_1	5.5
B_1 (/sec)	6.086E6
A_2 (/sec)	9.672E12
Q_2 (cal/mole)	10,000
n_2	5.0
B_2 (/sec)	3.034E-2
σ_o (MPa)	20.57
q	5,335
M	3.0
K_o	6.275E5
c (/T)	9.198E-3
α	-17.37
β	-7.738
δ	0.58

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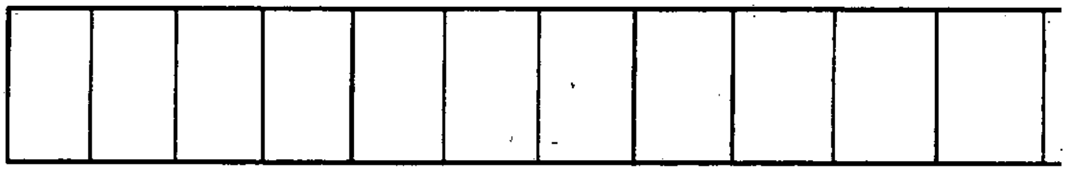

Figure 16.2 Detail of Finite Element Mesh near the Shaft Opening

SANTOS Solution

Problem Discretization

A 128 element (4-node quadrilateral) mesh is used in the SANTOS analysis and is shown in Figure 16.2. The figure shows only a "close-up" of the mesh near the shaft opening, because the full mesh is very large.

Input Data

A listing of the SANTOS input is in APPENDIX P.

Output Listing

A partial listing of the printed output showing pertinent problem information is given in APPENDIX P.

Discussion of Results

The SANTOS predictions of shaft closure are shown in Figure 16.3 and compare very well with the SPECTROM-32 results (shown as the solid line) that were presented in Munson et al. (1992) for the first two years of the analysis. The agreement between the predictions indicates that the implementation of the M-D constitutive model in SANTOS is correct.

References

1. Callahan, G. D., A. F. Fossum, and D. K. Svalstad, *Documentation of SPECTROM 32: A Finite Element Thermomechanical Stress Analysis Program*, RSI-0269, RE/SPEC Inc., Rapid City, South Dakota, 1986.

2. Munson, D. E., A. F. Fossum, and P. E. Senseny, *Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures*, SAND88-2948, Sandia National Laboratories, Albuquerque, New Mexico, February 1989.

3. Munson, D. E., K. L. DeVries, D. M. Schiermeister, W. F. DeYonge, and R. L. Jones, "Measured and Calculated Closures of Open and Brine Filled Shafts and Deep Vertical Boreholes in Salt," *Proceedings of the 33rd U. S. Symposium on Rock Mechanics*, Tillerson & Wawersik (eds), Balkema, Rotterdam, 1992.

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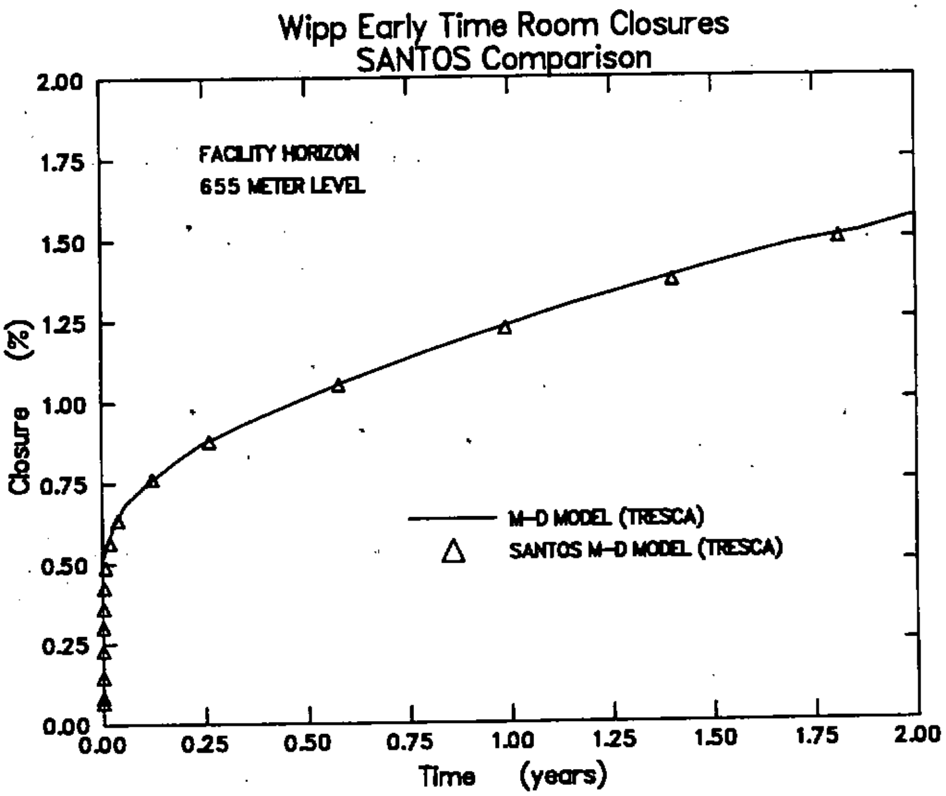

Figure 16.3 Per-Cent Closure of Shaft SANTOS Results

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Problem 17 – Upsetting of a Cylindrical Billet

This qualification problem examines the behavior of a cylindrical metallic billet that has undergone a 60% upset by compression between two flat, rigid dies. This is the standard test case for a metal forming application defined in Lippmann (1979). The time history of the die force is to be compared to computational results by Taylor (1981). The die force is governed by large deformation, inelastic material behavior in conjunction with complex contact surface response.

Problem Description

This verification problem examines the behavior of a cylindrical metallic billet that has undergone a 60% upset by compression between two flat, rigid dies. The billet has as initial dimensions a length of 30 mm and a diameter of 20 mm. The die material is assumed to be elastic-plastic with linear strain hardening. The material properties are taken from Lippmann (1979). The billet has a Young's modulus of 200 GPa and a Poisson's ratio of 0.3. The initial yield stress of the material is 700 MPa with a hardening modulus of 300 MPa.

Other Solutions (In Lieu of Analytic Solution)

The nonlinear nature of this calculation precludes the use of an analytic solution. The upset die force vs. die displacement curve is compared to computational results obtained by Taylor (1981).

SANTOS Solution

Problem Discretization

The axisymmetric option in SANTOS is used and only the top half of the billet is modeled since the middle surface of the billet can be viewed as a plane of symmetry. The middle surface of the billet is given a prescribed 9.0 mm vertical displacement which compresses the billet against the top rigid die. The rigid die is modeled using the RIGID SURFACE option in SANTOS. The die surface is assumed to be rough which results in a no slip condition between the billet and die. This behavior can be achieved by specifying the friction value as FIXED on the RIGID SURFACE option. During deformation it is expected that the external surface of the billet will fold and come into contact with the rigid die, which means that the definition of the side set associated with the rigid surface must include both elements along the top of the billet and elements along the external radial boundary. One hundred load steps were taken for this analysis.

The finite element mesh used in this analysis is shown in Figure 17.1. Also shown on the figure are the applied boundary conditions. The mesh contains 247 nodes and 216 uniform strain, quadrilateral elements.

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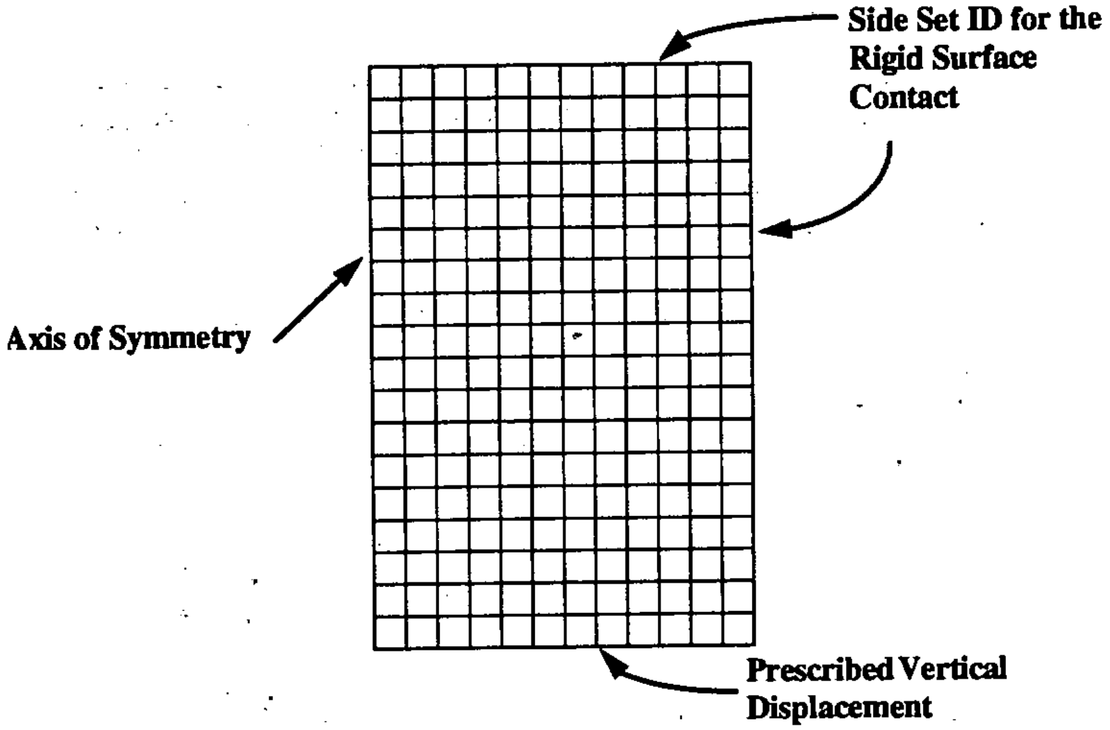

Figure 17.1 Mesh Discretization and Boundary Conditions Used for the Analysis of the Upsetting of a Cylindrical Billet.

Input Data

A complete listing of the input data file that was used for the cylindrical billet analysis is given in APPENDIX Q.

Output Listing

The SANTOS printed output for the upsetting of a cylindrical billet problem is also provided as a section in APPENDIX Q.

Discussion of Results

Figure 17.2 shows the deformed shape of the billet at several different times during the upset process. The folding of the billet's external surface is clearly seen as well as its contact with the rigid die. A close-up of the billet's final deformed shape at 60% upset is shown in Figure 17.3. Figure 17.4 shows a comparison of the upset force vs. die displacement with results taken from Taylor (1981). The agreement is seen to be excellent until the die displacement reaches 7.0 mm. At this value of displacement, the billet is folding and the first nodal point on the external surface is just coming into contact with the rigid surface. The slight difference in the upset force seen in the figure at die displacements greater than 7.0 mm is related to the contact occurring between the folding billet and the

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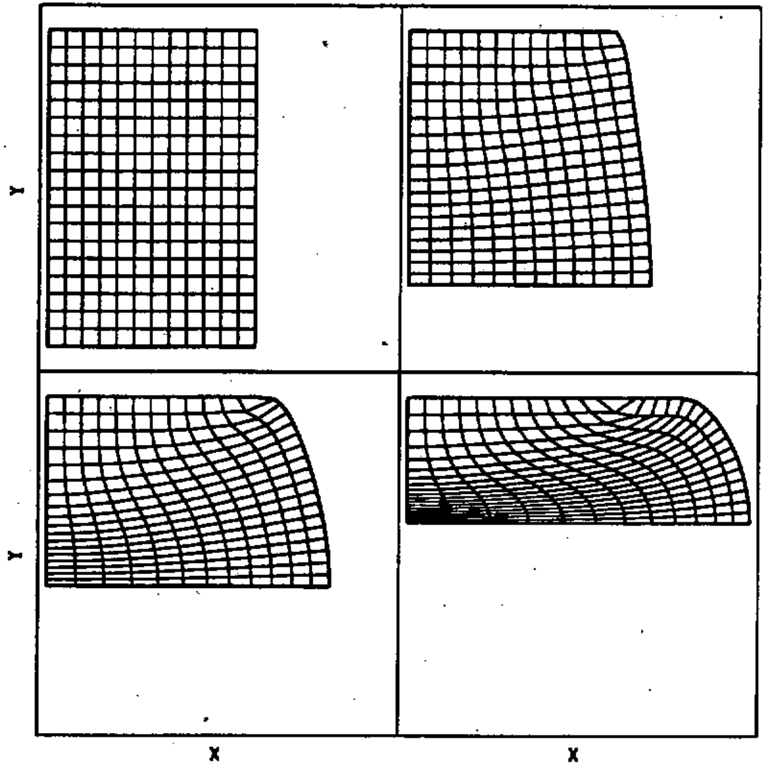

Figure 17.2 Plots of the Deforming Billet at Various Times During the Upset. Plots Shown Correspond to Non-Dimensional Times of 0., 0.33, 0.667, and 1.0.

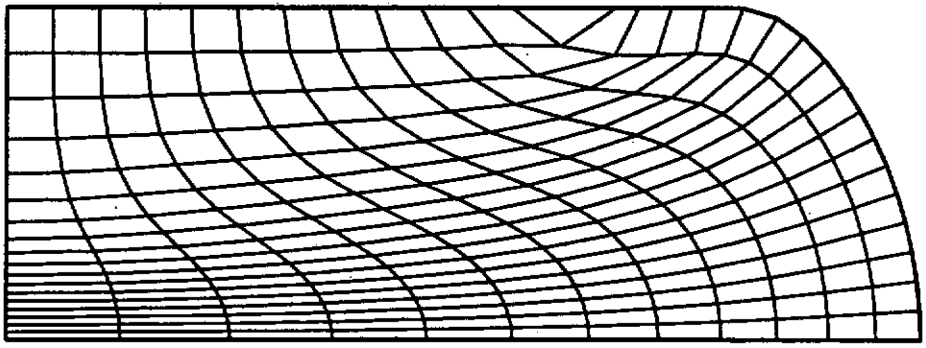

Figure 17.3 Final Deformed Shape of the Billet After 60% Upset.

rigid surface. This agreement of the SANTOS results with those of Taylor (1981) suggests that SANTOS is adequate for performing metal-forming applications analyses.

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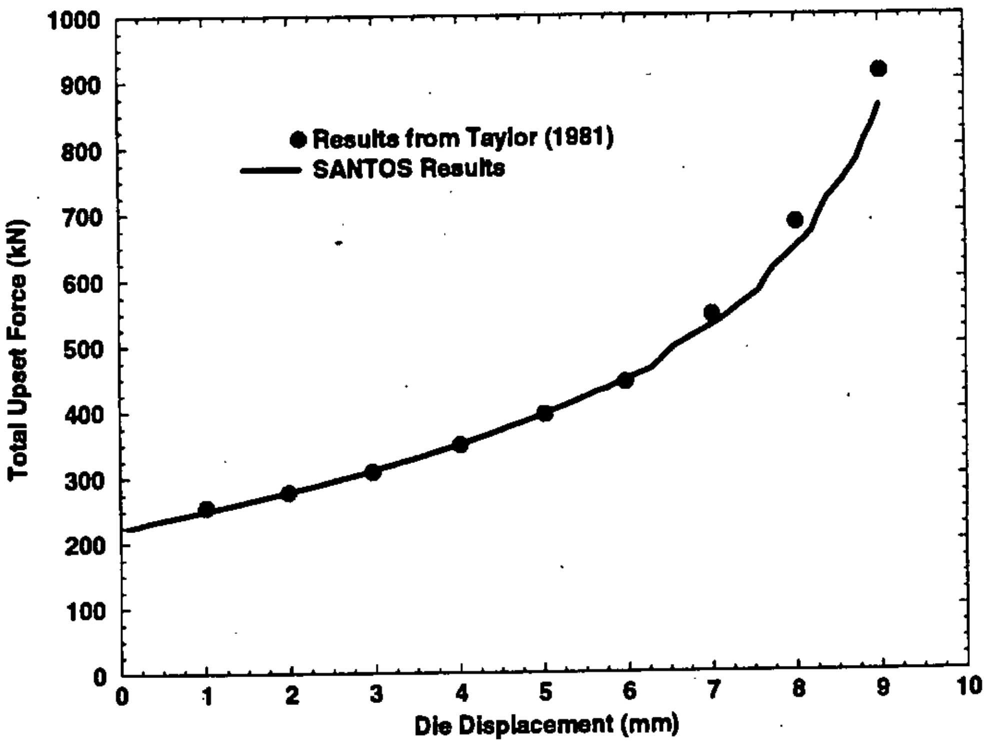

Figure 17.4 Comparison of SANTOS Calculation With Numerical Results Taken From Taylor (1981) for the Upset of a Cylindrical Billet.

References

1. Taylor, L. M., *A Finite Element Analysis for Large Deformation Metal Forming Problems Involving Contact and Friction*, Ph.D. Thesis, University of Texas at Austin, 1981.
2. Lippmann, H., *Metal Forming Plasticity*, Springer Verlag, Berlin, 1979.

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Problem 18 – Isothermal WIPP Benchmark II Problem

This problem is a geomechanics problem in which the creep response of a long series of parallel underground tunnels (drifts) is modeled. The drifts are surrounded by rock salt and other rock layers similar to those found at the storage horizon of the Waste Isolation Pilot Plant (WIPP). The WIPP is a research and development facility authorized to demonstrate the safe disposal of low-level radioactive wastes arising from the defense activities of the United States. It is being developed by the U. S. Department of Energy (DOE) and is located in southeastern New Mexico in a bedded salt formation at a depth of about 650 m below the surface.

This problem considers large displacements, large strains, and power law creep for an unheated drift configuration in a complicated stratigraphy. At the time that the problem was originally devised (Krieg, et al. 1980), the isothermal drift was considered to be representative of a configuration that might be used for storing nonheat-producing transuranic (TRU) waste at the WIPP. As such, it is included here because it is one of four WIPP qualification problems traditionally used to assess a code's adequacy for performing salt repository analyses.

Problem Description

The problem geometry allows the use of a vertical plane of symmetry passing through the center of a drift and a symmetry plane between drifts to produce an equivalent single drift plane strain model. The boundary conditions and the layered stratigraphy are shown in Figure 1.1 (Morgan, et al. 1981). The drift is rectangular in cross-section, with a height of 3.96 m and a width of 10.06 m. The horizontal extent from the center of the drift to the symmetry plane between drifts is 20.27 m. The upper and lower boundaries are approximately 50 m above and below the drift, respectively. These distances were chosen so that room response would not be affected by boundary conditions.

Boundary conditions, because of symmetry, were such that horizontal displacements were specified to be zero along the vertical boundaries. Along the upper and lower boundaries, uniform pressures were specified. Although the loads were specified such that the drift configuration was in static equilibrium, vertical constraints were needed to preclude rigid body motion. Thus, the top anhydrite layer was fixed along the edge at the pillar centerline, as indicated on the figure. The surfaces of the room were traction-free, and the room was assumed to appear instantaneously at time zero. The initial temperature throughout the configuration was 300 K and remained constant throughout the 10-year simulation.

The stratigraphy was comprised of five different geologic materials. The layers identified as halite, argillaceous halite, and 10% anhydrite/polyhalite–90% halite were modeled using an elastic–secondary creep model of the form:

$$\dot{\varepsilon} = D\sigma^{n}e^{-\frac{Q}{RT}}, \qquad \textbf{(EQ 18.1)}$$

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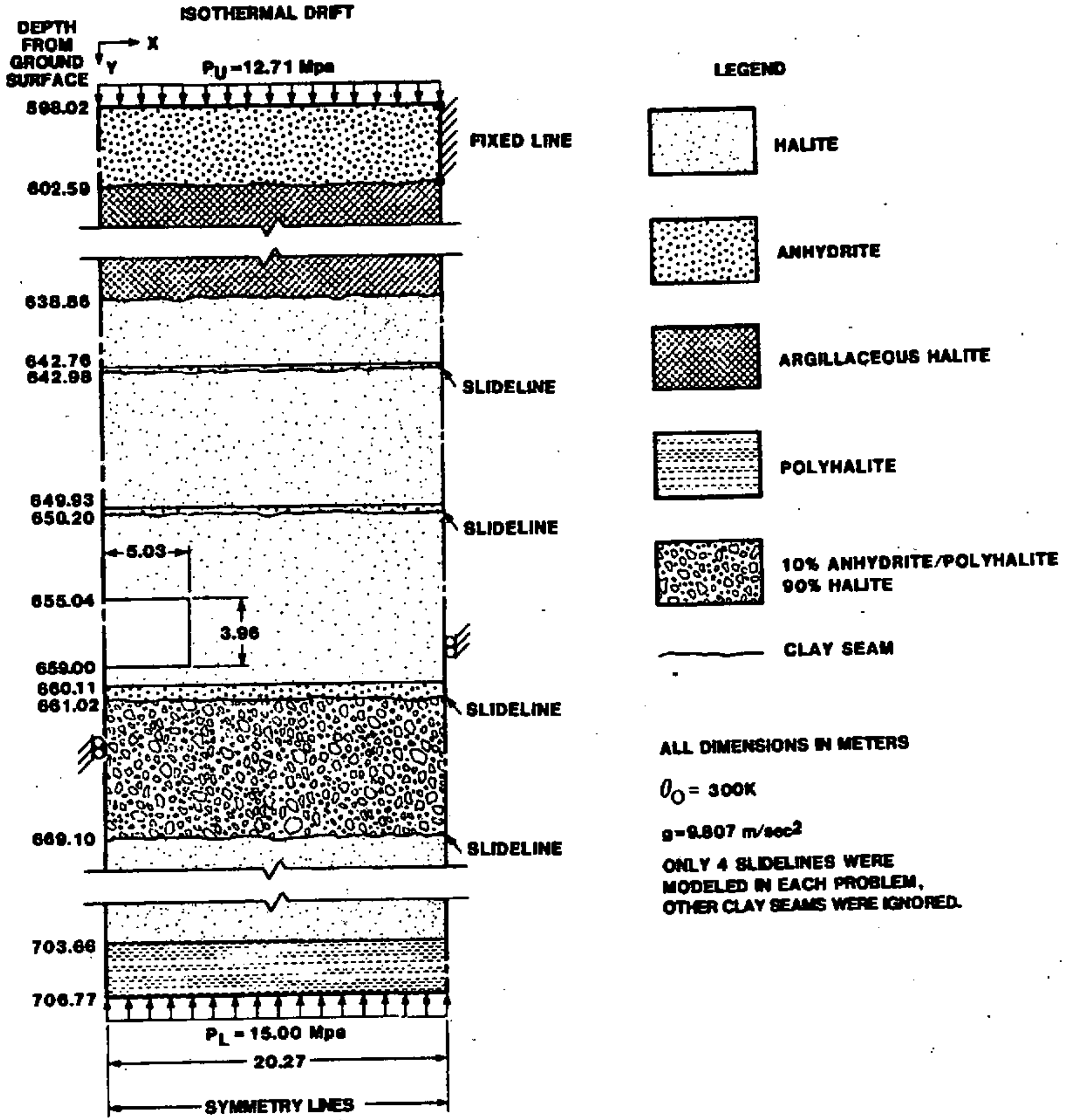

Figure 18.1 Benchmark II Isothermal Drift Configuration (Morgan, et al. 1981)

where $\dot{\bar{\varepsilon}}$ is the effective creep strain rate and $\bar{\sigma}$ is the effective stress ($\bar{\sigma} = \sqrt{\frac{3}{2}\sigma'_{ij}\sigma'_{ij}}$), with the variables, σ_{ij} and σ'_{ij}, being the components of the stress tensor and the deviatoric stress tensor, respectively. The parameters D and n are material constants determined from creep data analysis. T is the temperature in degrees Kelvin, Q is the activation energy in cal/mole, and R is the universal gas constant (1.987 cal/mole-K). The anhydrite and polyhalite layers were assumed to respond elastically. The mechanical material properties used for this analysis are given in Table 18.1.

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Table 18.1 Material Properties Used for Benchmark II Isothermal Analysis

Material	Young's Modulus (Pa)	Poisson's Ratio	D ($Pa^{-4.9}sec^{-1}$)	n	Q (kcal/mole)
Halite	2.48E10	0.25	5.79E-36	4.9	12.0
Argillaceous Halite	2.48E10	0.25	1.74E-35	4.9	12.0
10% A-P, 90% H	2.65E10	0.25	5.21E-36	4.9	12.0
Anhydrite	7.24E10	0.33			
Polyhalite	7.24E10	0.33			

The initial stress state was assumed to be lithostatic with $\sigma_{xx} = \sigma_{yy} = \sigma_{zz} = -21252y$, where y is the depth in meters and stresses are in pascals. The mechanical loads acting on the model consisted of the overburden uniform pressures specified along the top and bottom boundaries (12.71 and 15.00 MPa, respectively) and body force loads due to gravity. There were four active clay seams which were modeled using contact surfaces with the coefficient of friction, μ, set to zero.

Other Solutions (In Lieu of Analytic Solution)

The nonlinear nature of repository calculations makes it difficult to demonstrate that the codes being used for performing the design and evaluation of these facilities are accurate; the reason for this being that exact solutions for long-term repository calculations of this type do not exist. Consequently, the WIPP project has determined that benchmarking against other codes is an acceptable first step in demonstrating the adequacy of a code for performing these types of analyses. Figure 18.2 and Figure 18.3 show some results from a previous benchmark exercise (Morgan, et al. 1981) that used nine codes to solve the isothermal problem described herein. The results from that benchmark study for vertical closure and pillar midheight horizontal displacement are provided for comparison to the results from the present analysis.

SANTOS Solution

Problem Discretization

The finite element mesh used in this analysis is shown in Figure 18.4. Also shown on the figure are the applied boundary conditions. The mesh contains 1,371 nodes and 1,204 elements. The grading of the mesh, in general, is such that finer elements occur near the

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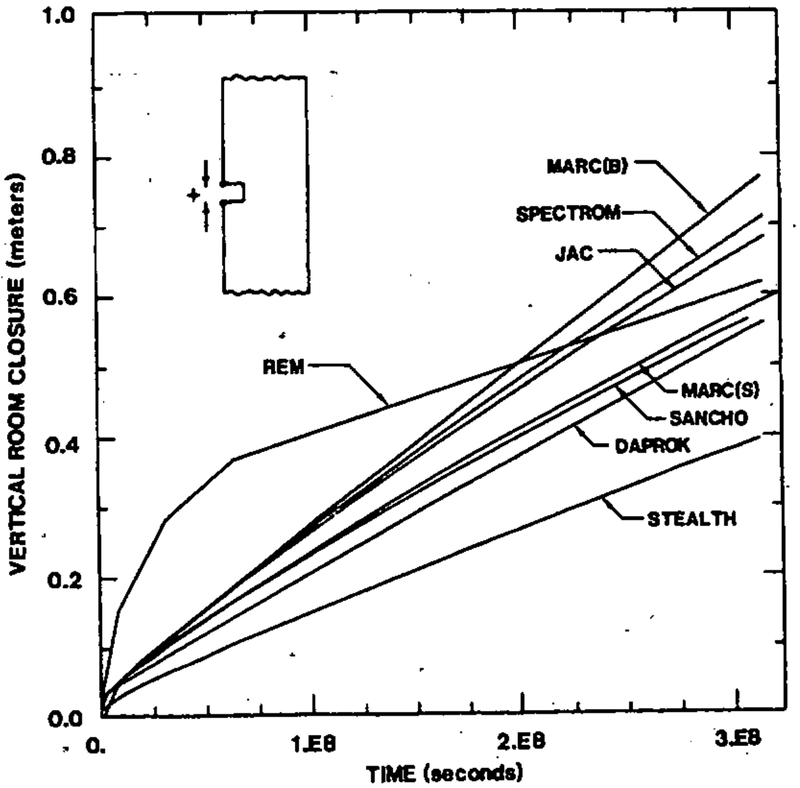

Figure 18.2 Vertical Closure History Results from Benchmark II Exercise – Isothermal Drift (Morgan, et al. 1981)

room where the stress gradients will be higher. In some of the layers, however, the gradation in the vertical direction was dictated by the locations of the layer boundaries.

Input Data

A complete listing of the input data file that was used for the Benchmark II isothermal analysis is given in APPENDIX R. Also included in this appendix, as a separate section, is a listing of the FORTRAN subroutine "INITST" that was used to compute the initial stresses in the configuration for the analysis.

Output Listing

The SANTOS printed output for the Benchmark II isothermal problem is also provided as a section in APPENDIX R.

Discussion of Results

Figure 18.5 and Figure 18.6 show the SANTOS vertical closure and pillar midheight horizontal displacement history results, respectively, along with two digitized curves from the Benchmark II study to allow the reader to see where the SANTOS results fall within the Benchmark II range. A comparison of the SANTOS results with the entire range of results predicted in the Benchmark II exercise is given in Table 18.2 for times of 1 year, 5 years,

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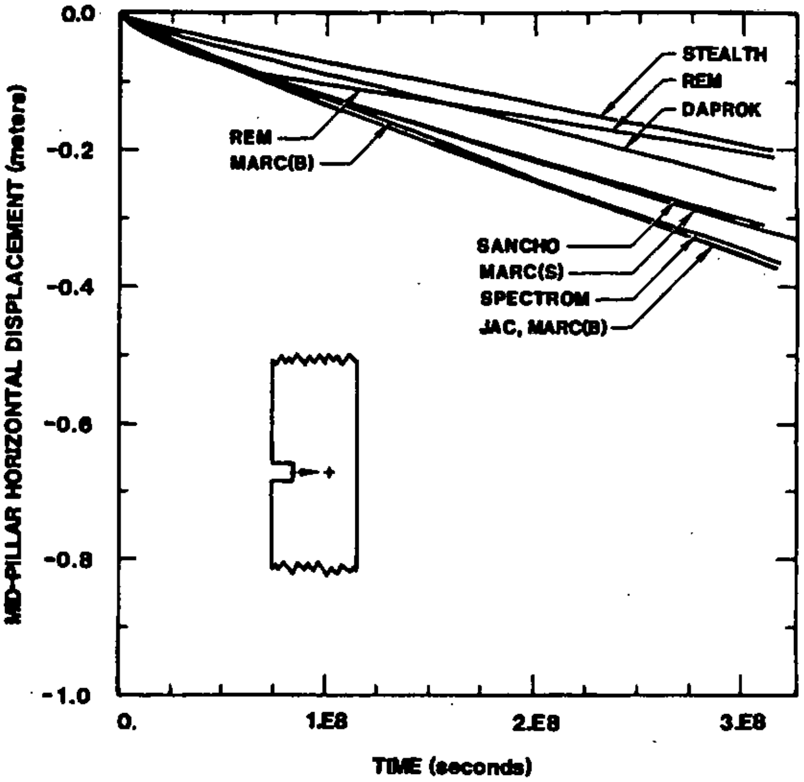

Figure 18.3 Midpillar Horizontal Displacement History Results from Benchmark II Exercise – Isothermal Drift (Morgan, et al. 1981)

Table 18.2 Comparison of SANTOS Results For The Isothermal Problem With Those Computed In Benchmark II Exercise

Time (years)		Vertical Closure (meters)	Midpillar Horizontal Displacement (meters)
1.0	Benchmark II Range	0.06 to 0.28	-0.03 to -0.06
	SANTOS Value	0.097	-0.044
5.0	Benchmark II Range	0.22 to 0.46	-0.11 to -0.21
	SANTOS Value	0.342	-0.174
10.0	Benchmark II Range	0.39 to 0.77	-0.20 to -0.38
	SANTOS Value	0.614	-0.321

and 10 years. The table shows that in all cases, the SANTOS results fall within the Benchmark II exercise ranges, indicating that SANTOS gives comparable results for the isothermal drift problem.

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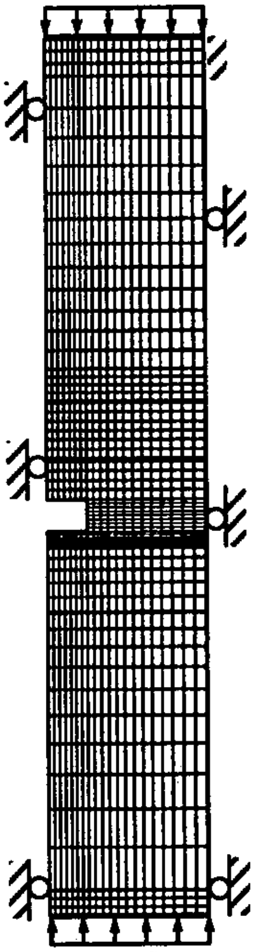

Figure 18.4 Santos Mesh Used For Benchmark II Isothermal Problem

References

1. Krieg, R. D., H. S. Morgan, and T. O. Hunter, *Second Benchmark Problem for WIPP Structural Computations*, SAND80–1331, Sandia National Laboratories, Albuquerque, New Mexico, December 1980.

2. Morgan, H. S., R. D. Krieg, and R. V. Matalucci, *Comparative Analysis of Nine Structural Codes Used in the Second WIPP Benchmark Problem*, SAND81–1389, Sandia National Laboratories, Albuquerque, New Mexico, November 1981.

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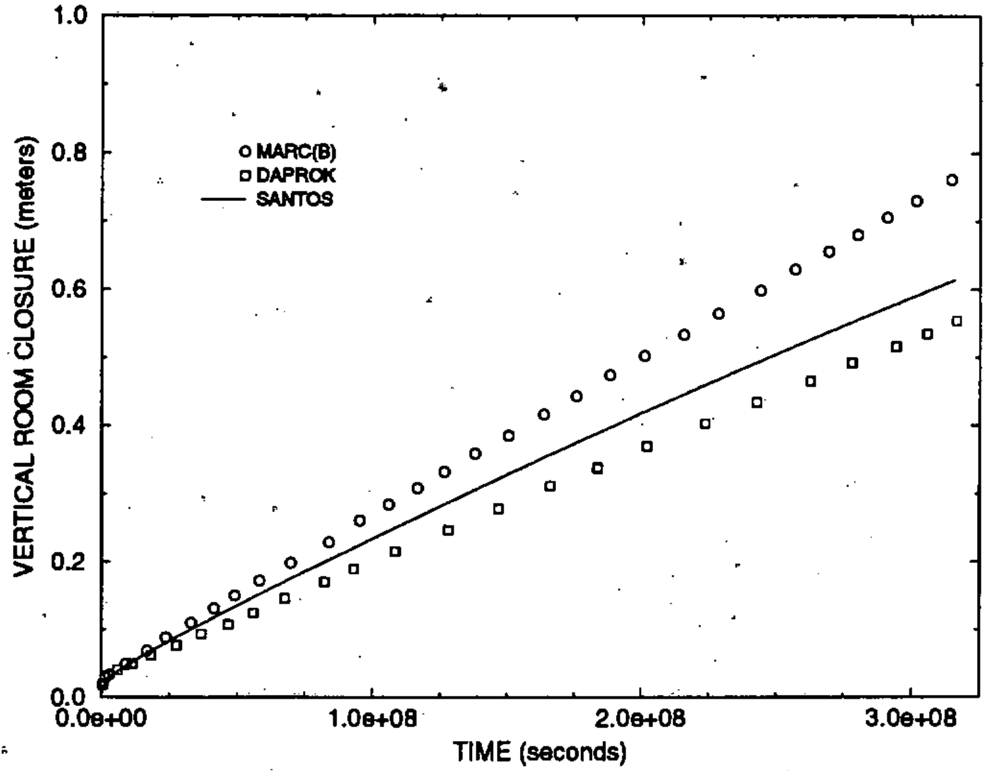

Figure 18.5 Vertical Closure History Computed With SANTOS for Benchmark II Isothermal Problem

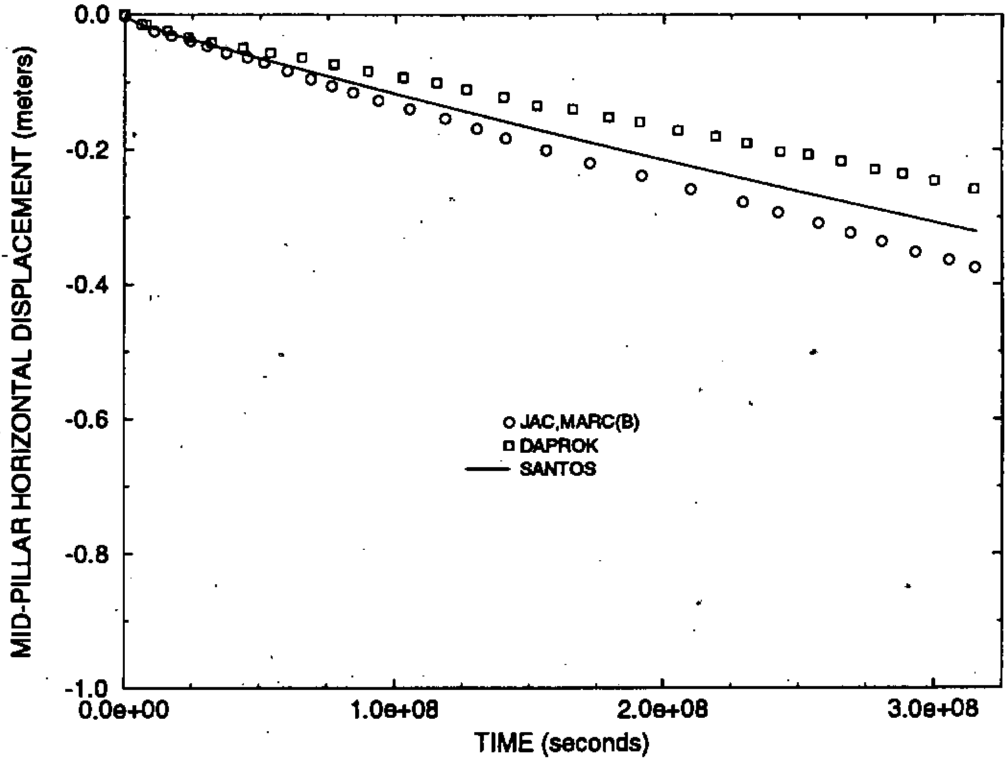

Figure 18.6 Midpillar Horizontal Displacement History Computed With SANTOS for Benchmark II Isothermal Problem

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Problem 19 – Heated WIPP Benchmark II Problem

Again, as for the isothermal case of Problem 18, this problem models a repository horizon which consists of a long series of parallel drifts at the WIPP. Once again, it considers large displacements, large strains, and power law creep but this time for a heated drift configuration in a complicated stratigraphy. At the time that the problem was originally devised (Krieg, et al. 1980), the heated drift was considered to be representative of a configuration that might be used for emplacing heat-producing high-level waste experiments at the WIPP. This drift had different dimensions than the isothermal one and it was located at a different depth in the geologic formation. However, the boundary conditions and applied loads were basically the same as those for the isothermal drift. It is included in this document because it also is one of four WIPP qualification problems traditionally used to assess a code's adequacy for performing salt repository analyses.

Problem Description

Two separate two-dimensional models were used for the heated Benchmark II analysis: a thermal model and a structural model. Only one-way coupling between the thermal and structural responses was considered, i.e., the thermal response was assumed to be unaffected by the structural deformations. The thermal model was used to compute temperatures in the configuration around the opening for the 5 year simulation period. The finite element code COYOTE II (Gartling and Hogan, 1994) was used for this calculation. The temperatures were then used as input to SANTOS so that thermal expansion and creep property changes induced by changes in temperature could be included in the structural response. Because high temperature and stress gradients occur in different regions, the thermal and structural calculations required mesh refinement in different areas. Thus, the thermal and structural finite element meshes used for the heated Benchmark II calculation were different, and nodal temperatures computed in the COYOTE II calculation had to be interpolated to the nodes of the structural mesh. The interpolation code MERLIN II (Gartling, 1991) was used to perform this task.

As was the case for the isothermal problem, the geometry for the heated configuration allows us to use a vertical plane of symmetry passing through the center of a drift and a symmetry plane between drifts to produce an equivalent single drift plane strain model. The problem definition and stratigraphy are shown in Figure 19.1. The drift is again rectangular in cross-section, with a height of 4.57 m and a width of 4.58 m. The horizontal extent from the center of the drift to the symmetry plane between drifts is 22.86 m. The upper and lower boundaries are approximately 50 m above and below the drift, respectively. These distances were chosen so that the room response would not be affected by the boundary conditions.

Thermal Model

In the thermal model, all boundaries were assumed to be adiabatic, and the entire formation was prescribed to have an initial temperature of 300 K. The thermal load was applied at time zero as a heat source that was modeled to simulate waste canisters placed at regular

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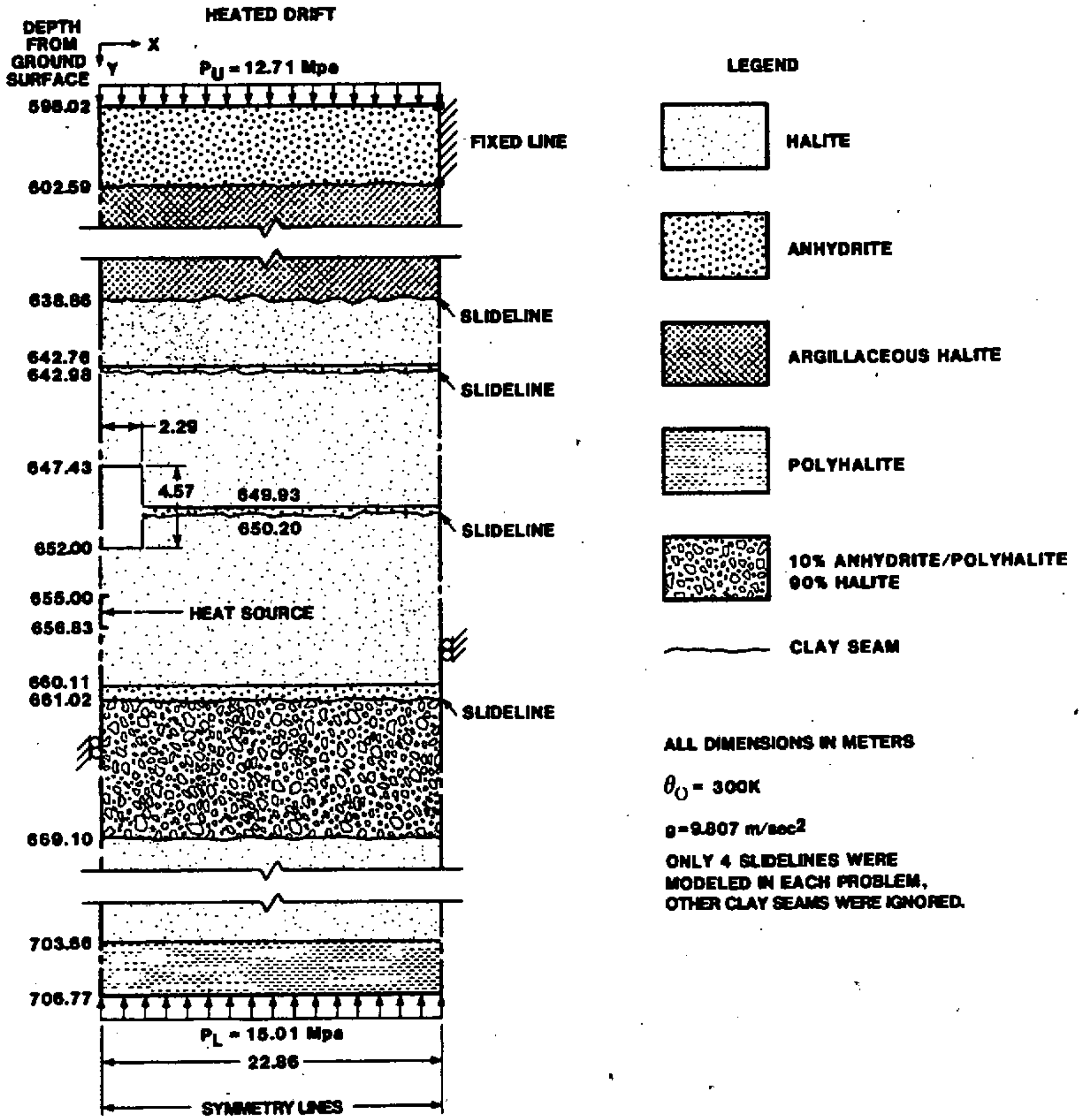

Figure 19.1 Benchmark II Heated Drift Configuration (Morgan, et al. 1981)

intervals beneath the floor. This led to a temperature increase with time throughout the simulation. The heat source was modeled as being continuously distributed along the drift length and had a time-dependent output of the form:

$$q = 169.5\exp\left(-7.326\times10^{-10}t\right) \qquad \textbf{(EQ 19.1)}$$

where q is the thermal load in watts/meter along the drift centerline and t is the time in seconds. The waste was idealized as a plane source with no x-direction dimension. The heat output was uniformly distributed over the 1.83 m height of the source. The thermal properties of all stratigraphic materials were assumed to be the same as those for halite. This assumption, which simplified the meshing for the thermal calculation, is a slight

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deviation from the Benchmark II definition for the thermal aspects of the heated problem but was appropriate because previous calculations (Stone, 1983) have shown that thermal responses computed with an all-salt stratigraphy and with a layered stratigraphy are essentially the same. Heat transfer through the salt was modeled with a nonlinear thermal conductivity of the form:

$$k = \lambda_0\left(\frac{\theta}{300}\right)^{\gamma} \qquad \textbf{(EQ 19.2)}$$

where k is the conductivity, θ is the absolute temperature in Kelvin, and λ_0 and γ are material constants. The room area was assumed to consist of an "equivalent thermal material" with a conductivity which allows radiation heat transfer in the room to be simulated by conduction. Thus, thermal radiation between the surfaces of the drift was simulated by an artificial thermal "material" in the drift with an "equivalent conductance." This "material" provided no structural support and, in fact, was used only in the thermal model but not in the structural model. The thermal finite element mesh used for the analysis is shown in Figure 19.2, and consists of four-node, isoparametric, quadrilateral elements.

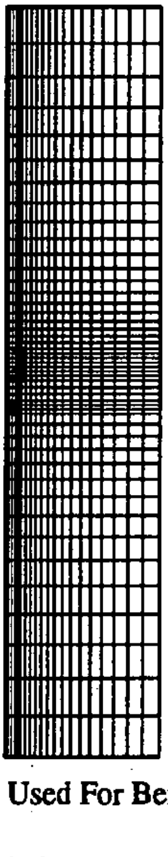

Figure 19.2 Thermal Mesh Used For Benchmark II Heated Problem

The mesh contains 960 elements and 1029 nodal points. The room area modeled with the "equivalent thermal material" is outlined by the heavy line in the figure. The thermal properties of halite and the "equivalent thermal material," which were used in this calculation, are presented in Table 19.1.

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Table 19.1 Material Properties Used for Benchmark II Heated Problem – Thermal Analysis

Material	Density, ρ, kg/m^3	Specific Heat, C_p, J/(kg-K)	Thermal Conduct. Parameter, λ_0, W/(m-K)	Thermal Conduct. Parameter, γ,
Halite	2167	860	5.0	1.14
"Equiv. Thermal Material"	1.000	1000	50.0	0.00

Structural Model

In the structural model, boundary conditions were such that horizontal displacements were specified to be zero along the vertical boundaries, as shown in Figure 19.1. Along the upper and lower boundaries, uniform pressures were specified. As was the case for the isothermal problem, vertical constraints were needed to preclude rigid body motion, thus, the top anhydrite layer was fixed along the edge at the pillar centerline, as indicated on the figure. The surfaces of the room were traction-free, and the room was assumed to appear instantaneously at time zero. The initial stress state was assumed to be lithostatic with $\sigma_{xx} = \sigma_{yy} = \sigma_{zz} = -21252y$, where y is the depth in meters and stresses are in pascals.

The entire stratigraphy was used in the structural model and was comprised of five different geologic materials. The layers identified as halite, argillaceous halite, and 10% anhydrite/polyhalite–90% halite were modeled using an elastic–secondary creep model of the form:

$$\dot{\varepsilon} = D\bar{\sigma}^{n} e^{-\frac{Q}{RT}}, \qquad \textbf{(EQ 19.3)}$$

where $\dot{\varepsilon}$ is the effective creep strain rate and $\bar{\sigma}$ is the effective stress ($\bar{\sigma} = \sqrt{\frac{3}{2}\sigma'_{ij}\sigma'_{ij}}$), with the variables, σ_{ij} and σ'_{ij}, being the components of the stress tensor and the deviatoric stress tensor, respectively. The parameters D and n are material constants determined from creep data analysis. T is the temperature in degrees Kelvin, Q is the activation energy in cal/mole, and R is the universal gas constant (1.987 cal/mole-K). The anhydrite and polyhalite layers were assumed to respond elastically. The mechanical material properties used for this analysis are given in Table 19.2.

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Table 19.2 Material Properties Used for Benchmark II Heated Problem – Structural Analysis

Material	Young's Modulus (Pa)	Poisson's Ratio	D ($Pa^{-4.9}sec^{-1}$)	n	Q (kcal/mole)	Coeff. of Linear Thermal Exp., α, K^{-1}
Halite	2.48E10	0.25	5.79E-36	4.9	12.0	45.0E-6
Argillaceous Halite	2.48E10	0.25	1.74E-35	4.9	12.0	40.0E-6
10% A-P, 90% H	2.65E10	0.25	5.21E-36	4.9	12.0	42.7E-6
Anhydrite	7.24E10	0.33				20.0E-6
Polyhalite	7.24E10	0.33				24.0E-6

The mechanical loads acting on the model consisted of the overburden uniform pressures specified along the top and bottom boundaries (12.71 and 15.01 MPa, respectively) and body force loads due to gravity. There were four active clay seams which were modeled using contact surfaces with the coefficient of friction, μ, set to zero.

Other Solutions (In Lieu of Analytic Solution)

The nonlinear nature of repository calculations makes it difficult to demonstrate that the codes being used for performing the design and evaluation of these facilities are accurate, because the exact solution for a long term repository calculation of this type does not exist. Consequently, the WIPP project has determined that benchmarking against other codes is an acceptable first step in demonstrating the adequacy of a code for performing these types of analyses. Figure 19.3 and Figure 19.4 show some results from a previous benchmark exercise (Morgan, et al. 1981) that used nine structural codes to solve the heated problem described herein. The results from that benchmark study for vertical closure and pillar midheight horizontal displacement are provided for comparison to the results from the present analysis.

SANTOS Solution

Problem Discretization

The finite element mesh used in this analysis is shown in Figure 19.5. Also shown on the figure are the applied boundary conditions. The mesh contains 926 nodes and 798 elements. The grading of the mesh, in general, is such that finer elements occur near the room where the stress gradients will be higher. In some of the layers, however, the gradation in the vertical direction was dictated by the locations of the layer boundaries.

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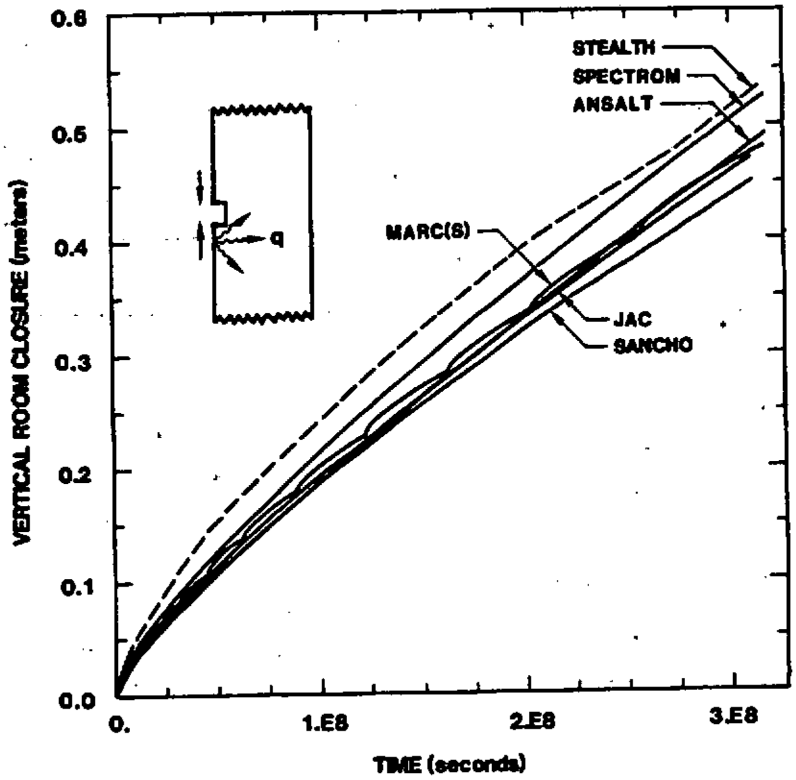

Figure 19.3 Vertical Closure History Results from Benchmark II Exercise – Heated Drift (Morgan, et al. 1981)

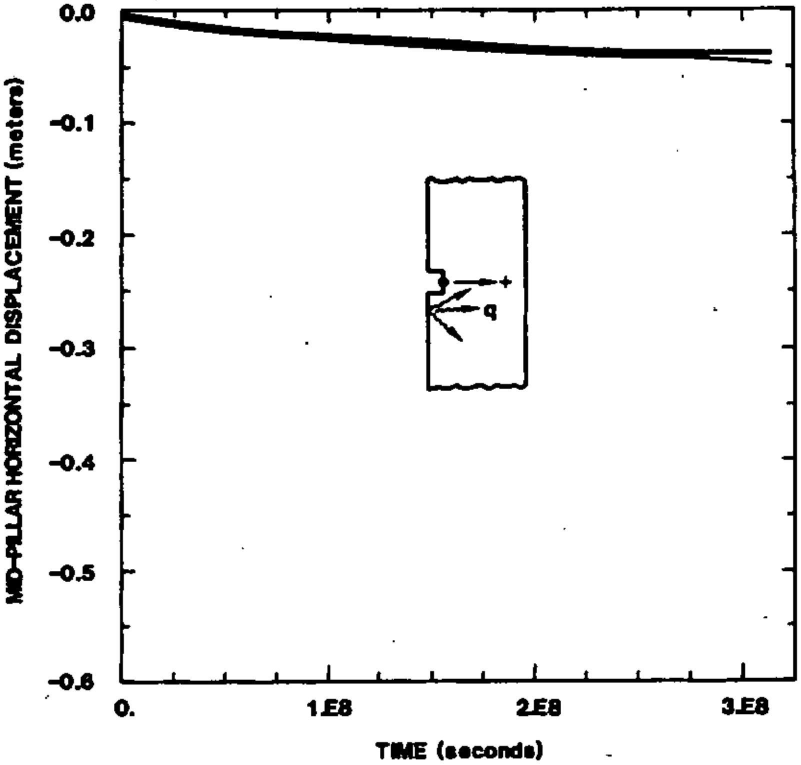

Figure 19.4 Midpillar Horizontal Displacement History Results from Benchmark II Exercise – Heated Drift (Morgan, et al. 1981)

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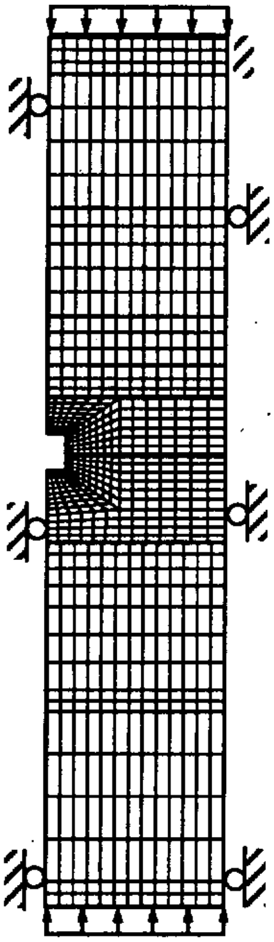

Figure 19.5 Santos Mesh Used For Benchmark II Heated Problem

Input Data

A complete listing of the input data file that was used for the Benchmark II heated analysis is given in APPENDIX S. Also included in this appendix is a listing of the FORTRAN subroutine "INITST" that was used to compute the initial stresses in the configuration.

Output Listing

The SANTOS printed output for the Benchmark II heated problem is also provided as a section in APPENDIX S.

Discussion of Results

Figure 19.6 and Figure 19.7 show the SANTOS vertical closure and pillar midheight displacement history results along with two digitized curves from the Benchmark II study to allow the reader to see where the SANTOS results fall within the Benchmark II range. A comparison of the SANTOS results with the entire range of results predicted in the Benchmark II exercise is given in Table 19.3 for times of 1 year, 3 years, and 5 years. The

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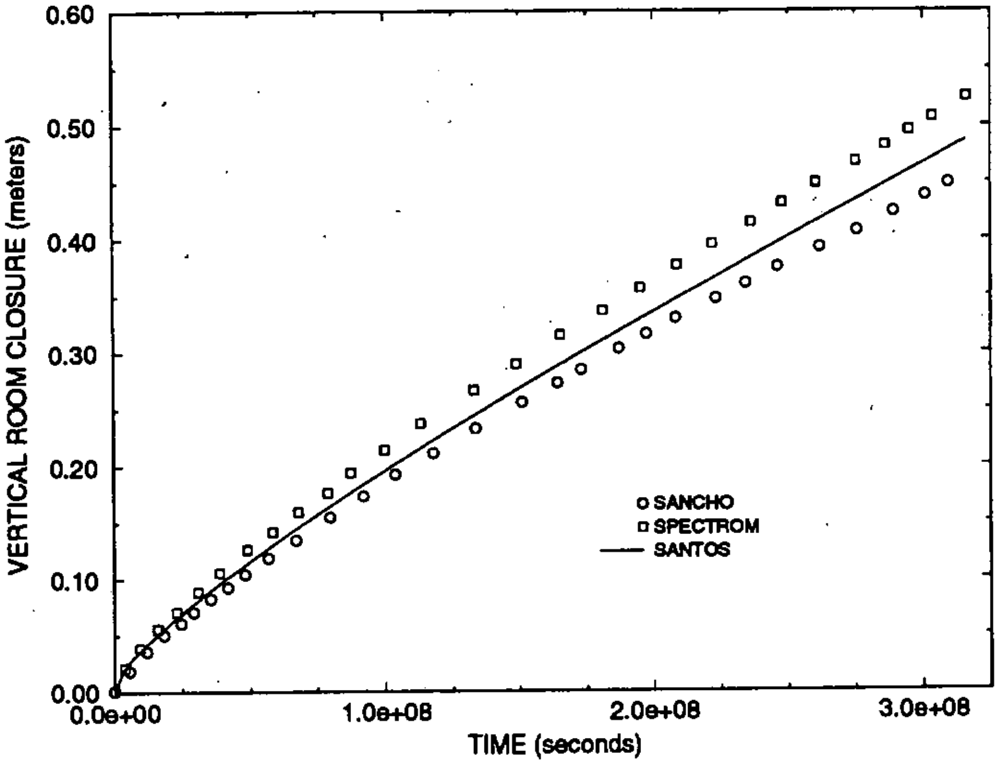

Figure 19.6 Vertical Closure History Computed With SANTOS for Benchmark II Heated Problem

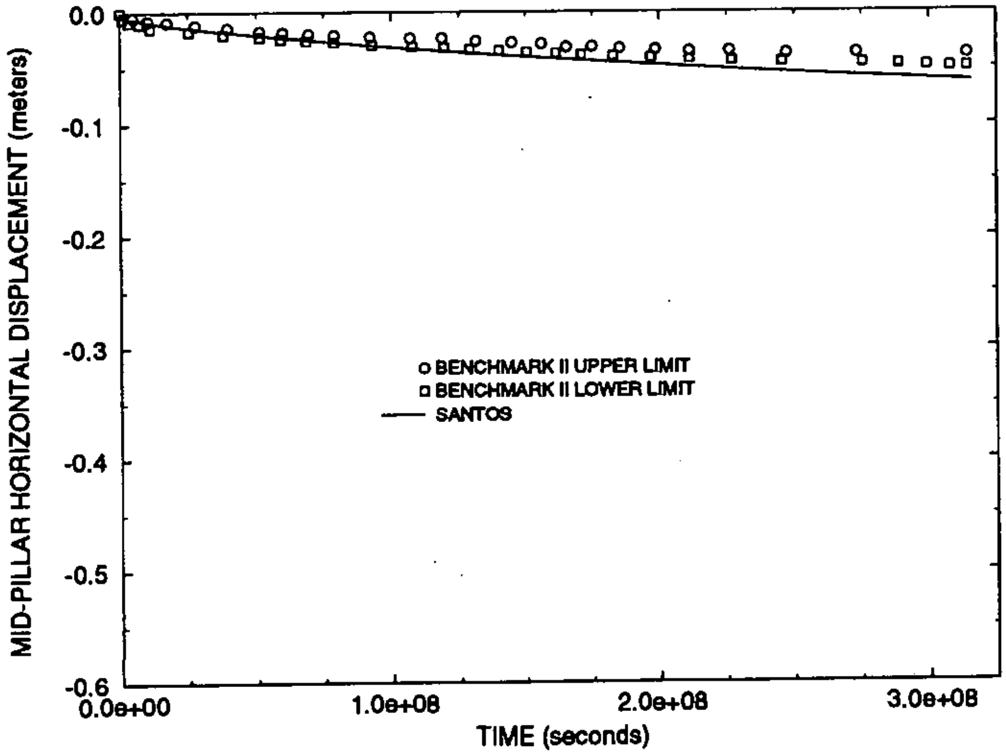

Figure 19.7 Midpillar Horizontal Displacement History Computed With SANTOS for Benchmark II Heated Problem

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Table 19.3 Comparison of SANTOS Results For The Heated Problem With Those Computed In Benchmark II Exercise

Time (years)		Vertical Closure (meters)	Midpillar Horizontal Displacement (meters)
1.0	Benchmark II Range	0.07 to 0.11	~ -0.02
	SANTOS Value	0.083	-0.016
3.0	Benchmark II Range	0.18 to 0.23	~ -0.03
	SANTOS Value	0.188	-0.030
5.0	Benchmark II Range	0.45 to 0.53	-0.04 to -0.05
	SANTOS Value	0.486	-0.063

table shows that for the case of vertical closure, the SANTOS results fall within the Benchmark II exercise ranges, and for the mid-pillar displacement, they are of the same order (being only slightly larger at the end of the 5-year simulation). The table thus indicates that SANTOS yields results that are comparable to those from the codes that participated in the Benchmark II exercise for the heated drift problem.

References

1. Gartling, D. K., *MERLIN II – A Computer Program to Transfer Solution Data Between Finite Element Meshes*, SAND89–2989, Sandia National Laboratories, Albuquerque, New Mexico, July 1991.

2. Gartling, D. K. and R. E. Hogan, *COYOTE II – A Finite Element Computer Program for Nonlinear Heat Conduction Problems*, SAND94–1179, Sandia National Laboratories, Albuquerque, New Mexico, October 1994.

3. Krieg, R. D., H. S. Morgan, and T. O. Hunter, *Second Benchmark Problem for WIPP Structural Computations*, SAND80–1331, Sandia National Laboratories, Albuquerque, New Mexico, December 1980.

4. Morgan, H. S., R. D. Krieg, and R. V. Matalucci, *Comparative Analysis of Nine Structural Codes Used in the Second WIPP Benchmark Problem*, SAND81–1389, Sandia National Laboratories, Albuquerque, New Mexico, November 1981.

5. Stone, C. M., "Analyses of the Heated WIPP In-Situ Experiments," Memo to D. E. Munson, Sandia National Laboratories, Albuquerque, New Mexico, February 16, 1983.

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Problem 20 – Isothermal WIPP Parallel Calculation

This problem a geomechanics problem in which the creep response of a long series of parallel underground tunnels (drifts) is modeled. The drifts are surrounded by rock salt and other rock layers similar to those found at the storage horizon of the Waste Isolation Pilot Plant (WIPP). The WIPP is a research and development facility authorized to demonstrate the safe disposal of low-level radioactive wastes arising from the defense activities of the United States. It is being developed by the U. S. Department of Energy (DOE) and is located in southeastern New Mexico in a bedded salt formation at a depth of about 650 m below the surface.

This problem again considers large displacements, large strains, and power law creep for an unheated drift configuration in a complicated stratigraphy. This problem was originally chosen (Munson and Morgan 1986) because it represented one of the proposed storage room configurations at the WIPP. This isothermal drift was considered to be representative of a typical room in an infinite panel of rooms designed for storing nonheat-producing transuranic (TRU) waste at the WIPP site. It is included here because it is one of four WIPP qualification problems traditionally used to assess a code's adequacy for performing salt repository analyses.

Problem Description

The two-dimensional planar configuration shown in Figure 20.1 was used in the isothermal calculation as the idealization of a single, long room in an infinite array of long, parallel rooms. The left boundary represents a symmetry plane through the center of the room, while the right boundary represents a symmetry plane through the center of the pillar separating adjacent rooms. The distance between the left and right boundaries is 20.27 m, and the room is 3.96 m high by 10.06 m wide. The floor level of the room is 6.40 m below Clay G, the reference from which all vertical distances are measured. Clay G is 650.43 m below the ground surface. The upper and lower boundaries are approximately 50 m above and below the drift, respectively. These distances were chosen so that room response would not be affected by boundary conditions.

Boundary conditions were such that horizontal displacements were specified to be zero along the vertical boundaries. A pressure of 13.57 MPa, which represents the weight of the overlying rock is applied to the top boundary. An average overburden density of 2320 kg/m^3 and a gravitational acceleration of 9.79 m/s^2 were used to determine this pressure. An average density of 2300 kg/m^3 was used for all stratigraphic layers to compute the pressure of 15.96 MPa applied at the bottom boundary. Body forces representing the weight of the rock were also applied, as was an initial lithostatic stress state that varied linearly with depth. The overburden density and average configuration density defined above were used to compute the initial stress state. Although the loads were specified such that the drift configuration was in static equilibrium, vertical constraints were needed to preclude rigid body motion. Thus, the top anhydrite layer was fixed along the edge at the pillar centerline, as indicated on the figure. In the out-of-plane direction, the room was considered to be

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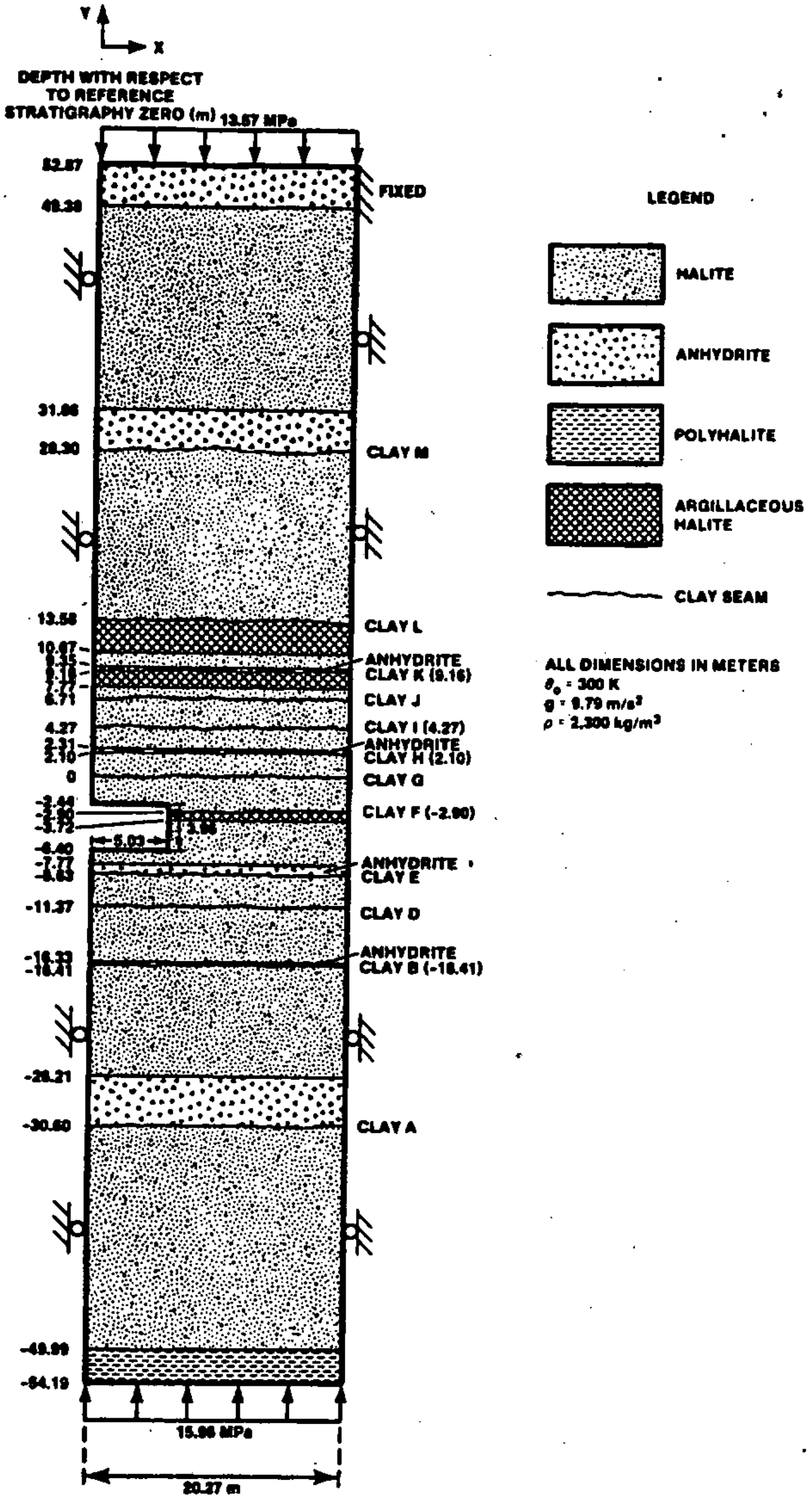

Figure 20.1 Parallel Calculation – Isothermal Drift Configuration (Morgan, et al. 1987)

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infinitely long so that a plane strain condition could be assumed. The surfaces of the room were traction-free, and the room was assumed to appear instantaneously at time zero. The initial temperature throughout the configuration was 300 K and remained constant throughout the 10-year simulation.

The stratigraphy was comprised of five different geologic materials: halite, argillaceous halite, anhydrite, polyhalite, and clay seams. The layers identified as halite and argillaceous halite, were modeled using an elastic–secondary creep model of the form:

$$\dot{\bar{\varepsilon}} = D\bar{\sigma}^n e^{-\frac{Q}{RT}}, \qquad \textbf{(EQ 20.1)}$$

where $\dot{\bar{\varepsilon}}$ is the effective creep strain rate and $\bar{\sigma}$ is the effective stress ($\bar{\sigma} = \sqrt{\frac{3}{2}\sigma'_{ij}\sigma'_{ij}}$), with the variables, σ_{ij} and σ'_{ij}, being the components of the stress tensor and the deviatoric stress tensor, respectively. The parameters D and n are material constants determined from creep data analysis. T is the temperature in degrees Kelvin, Q is the activation energy in cal/mole, and R is the universal gas constant (1.987 cal/mole-K). The anhydrite and polyhalite layers were assumed to respond elastically. The clay seams in the stratigraphy are very thin layers between layers of more competent rock. Structurally, these seams represent interfaces where the more competent layers can slip with respect to each other. A dry friction model, with a coefficient of friction, μ=0.4, was specified for describing clay seam behavior. Of the 12 clay seams shown in the figure, only Clays D through J were modeled. The mechanical material properties used for this analysis are given in Table 20.1.

Table 20.1 Material Properties Used for Parallel Calculation Isothermal Analysis

Material	Young's Modulus (Pa)	Poisson's Ratio	D ($Pa^{-4.9}sec^{-1}$)	n	Q (kcal/mole)
Halite	3.10E10	0.25	5.79E-36	4.9	12.0
Argillaceous Halite	3.10E10	0.25	1.74E-35	4.9	12.0
Anhydrite	7.51E10	0.35			
Polyhalite	5.53E10	0.36			

Other Solutions (In Lieu of Analytic Solution)

The nonlinear nature of repository calculations makes it difficult to demonstrate that the codes being used for performing the design and evaluation of these facilities are accurate;

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the reason for this being that exact solutions for long-term repository calculations of this type do not exist. Consequently, the WIPP project has determined that benchmarking against other codes is an acceptable first step in demonstrating the adequacy of a code for performing these types of analyses. Figure 20.2 and Figure 20.3 show some results from a previous benchmark exercise (Morgan, et al. 1987) that used three codes to solve the isothermal problem described herein. The results from that benchmark study for vertical closure and pillar midheight horizontal displacement are provided for comparison to the results from the present analysis.

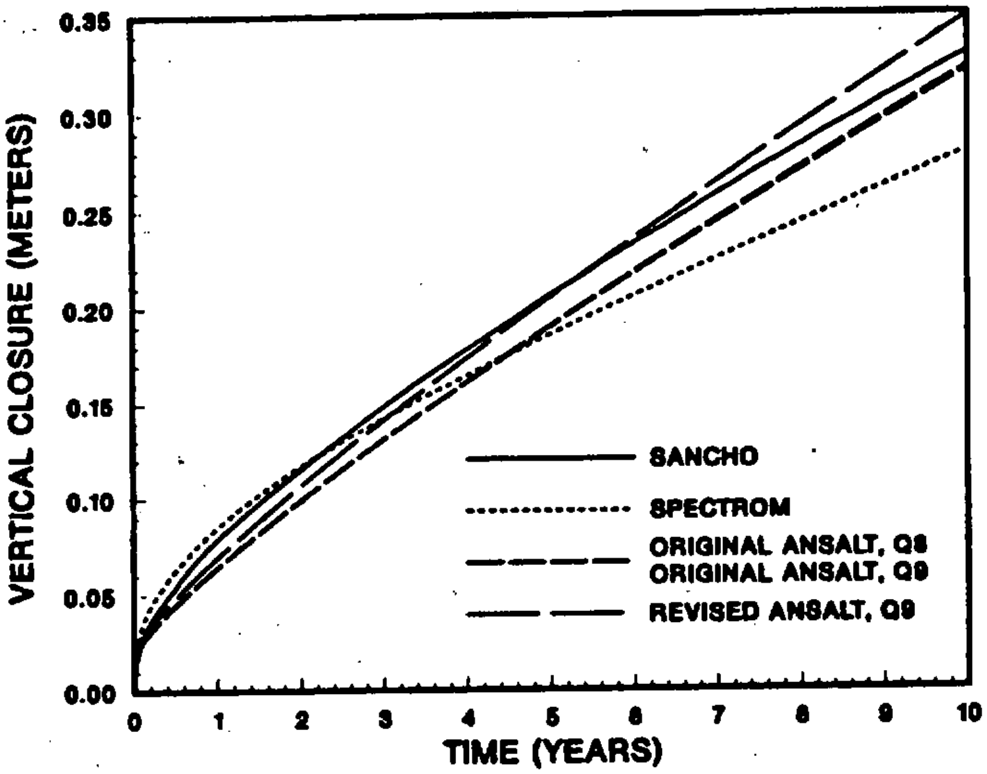

Figure 20.2 Vertical Closure History Results from Parallel Calculation Exercise – Isothermal Drift (Morgan, et al. 1987)

SANTOS Solution

Problem Discretization

The finite element mesh used in this analysis is shown in Figure 20.4. Also shown on the figure are the applied boundary conditions. The mesh contains 1,761 nodes and 1,476 elements. The grading of the mesh, in general, is such that finer elements occur near the room where the stress gradients will be higher. In some of the layers, however, the gradation in the vertical direction was dictated by the locations of the layer boundaries.

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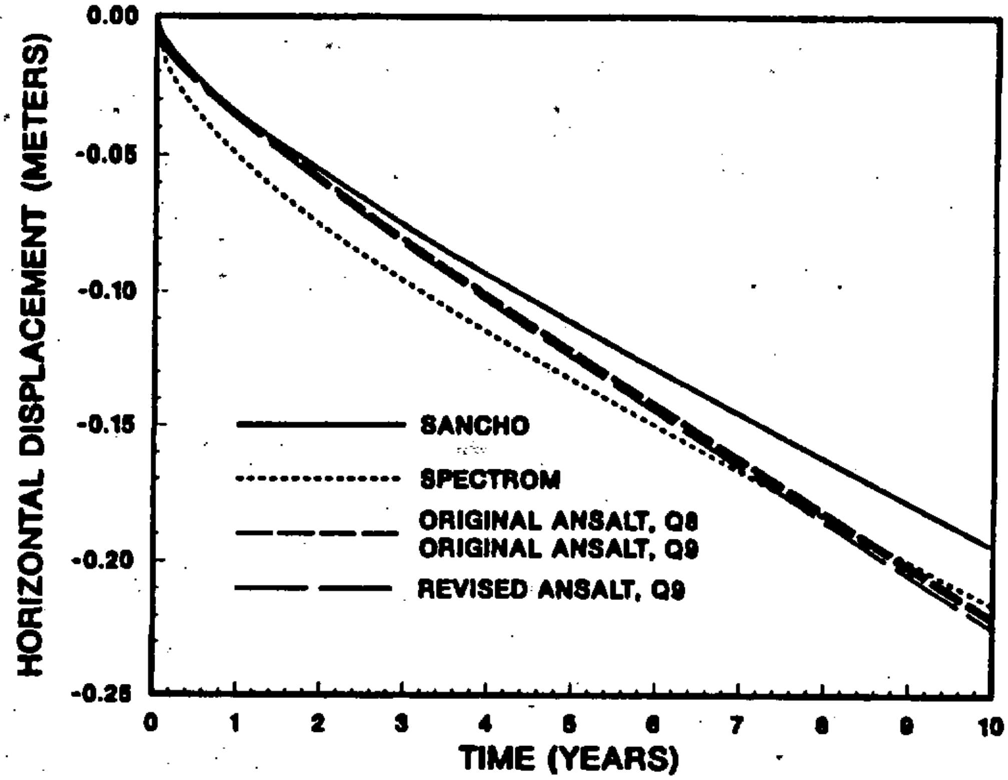

Figure 20.3 Midpillar Horizontal Displacement History Results from Parallel Calculation Exercise – Isothermal Drift (Morgan, et al. 1987)

Input Data

A complete listing of the input data file that was used for the Parallel Calculation isothermal analysis is given in APPENDIX T. Also included in this appendix, as a separate section, is a listing of the FORTRAN subroutine "INITST" that was used to compute the initial stresses in the configuration for the analysis.

Output Listing

The SANTOS printed output for the Parallel Calculation isothermal problem is also provided as a section in APPENDIX T.

Discussion of Results

Figure 20.5 and Figure 20.6 show the SANTOS vertical closure and pillar midheight horizontal displacement history results, respectively, along with two digitized curves from the Parallel Calculation exercise to allow the reader to see where the SANTOS results fall within the Parallel Calculation range. A comparison of the SANTOS results with the entire range of results predicted in the Parallel Calculation exercise is given in Table 20.2 for times of 1 year, 5 years, and 10 years. The table shows that in all cases, the SANTOS

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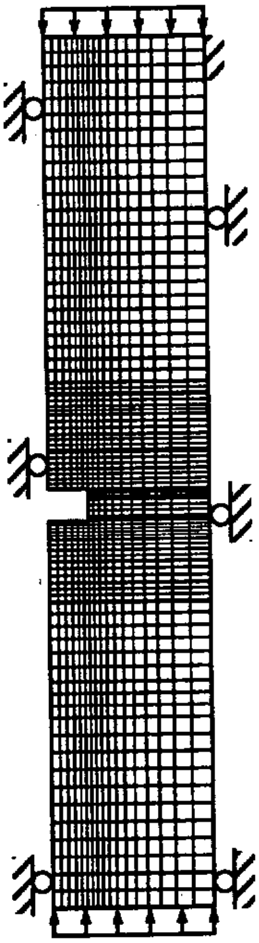

Figure 20.4 Santos Mesh Used For Parallel Calculation Isothermal Problem

results fall very close to the lower end of the Parallel Calculation exercise ranges (within about 5 %), indicating that SANTOS gives comparable results for the isothermal drift problem.

References

1. Morgan, H. S., M. Wallner, and D. E. Munson, *Results of an International Parallel Calculations Exercise Comparing Creep Responses Predicted With Three Computer Codes for Two Excavations in Rock Salt*, SAND87–2125, Sandia National Laboratories, Albuquerque, New Mexico, November 1987.

2. Munson, D. E. and H. S. Morgan, *Methodology for Performing Parallel Design Calculations (Nuclear Waste Repository Application)*, SAND85–0324, Sandia National Laboratories, Albuquerque, New Mexico, May 1986.

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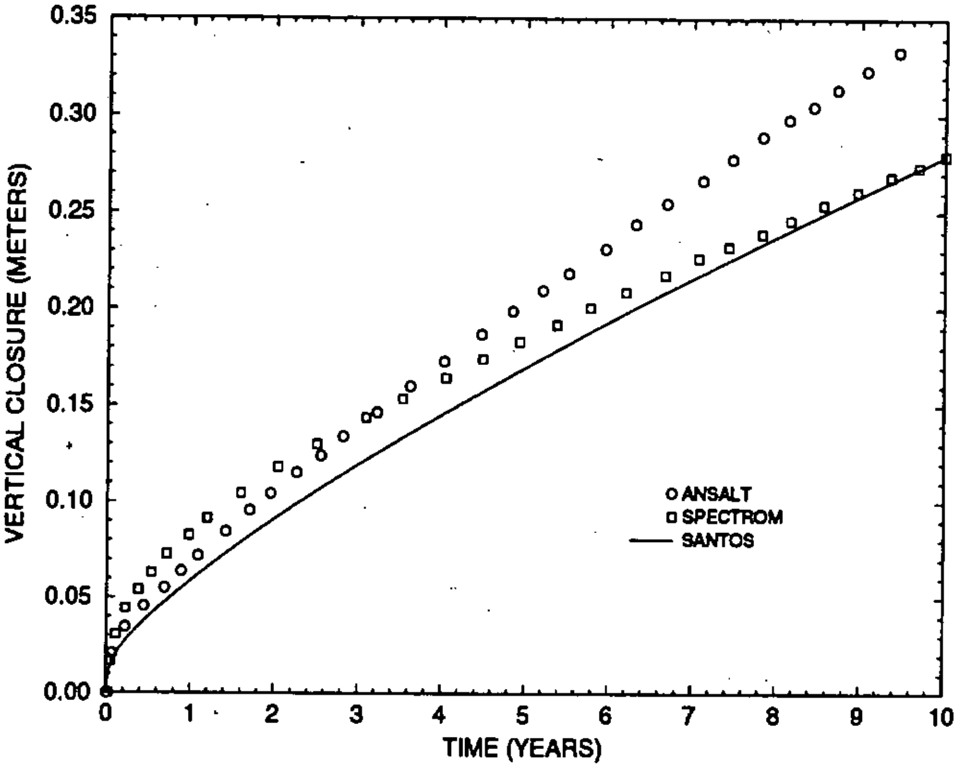

Figure 20.5 Vertical Closure History Computed With SANTOS for Parallel Calculation Isothermal Problem

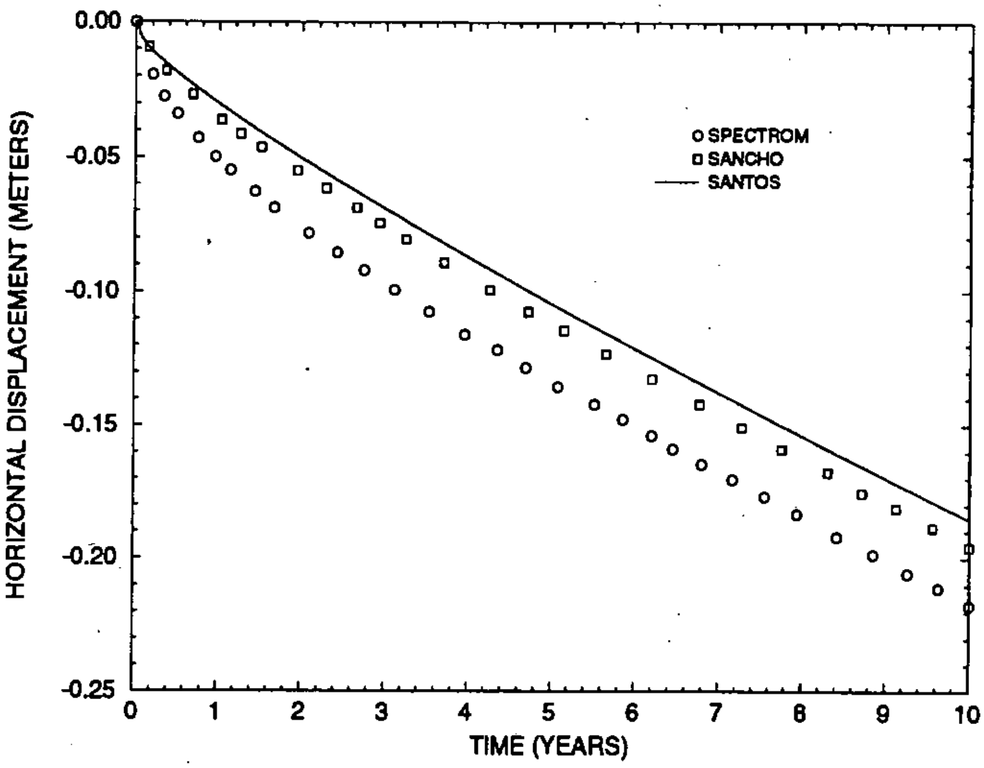

Figure 20.6 Midpillar Horizontal Displacement History Computed With SANTOS for Parallel Calculation Isothermal Problem

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Table 20.2 Comparison of SANTOS Results For The Isothermal Problem With Those Computed In Parallel Calculation Exercise

Time (years)		Vertical Closure (meters)	Midpillar Horizontal Displacement (meters)
1.0	Parallel Calculation Exercise Range	0.06 to 0.09	-0.03 to -0.05
	SANTOS Value	0.059	-0.030
5.0	Parallel Calculation Exercise Range	0.18 to 0.20	-0.11 to -0.13
	SANTOS Value	0.170	-0.104
10.0	Parallel Calculation Exercise Range	0.28 to 0.35	-0.19 to -0.23
	SANTOS Value	0.279	-0.185

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Problem 21 – Heated WIPP Parallel Calculation

This problem is another of the problems analyzed in the Parallel Calculation exercise and is the heated room companion to Problem 20. Once again it models a repository horizon which consists of a long series of parallel drifts. It considers large displacements, large strains, and power law creep for a heated drift configuration in a complicated stratigraphy. This problem was originally chosen (Munson and Morgan 1986) because it was representative of a drift configuration at the WIPP in which experiments with higher heat loads were to be performed to provide data for the commercial waste program that was at one time considering storing high-level waste in salt. This heated drift was considered to be representative of a typical room in an infinite array of rooms subjected to a thermal load of 18 W/m^2. This thermal load corresponded to the heat load applied to the central room of a three-room array that comprises a large-scale experiment at the WIPP (Munson 1983). It is included here because it is again one of four WIPP qualification problems traditionally used to assess a code's adequacy for performing salt repository analyses.

Problem Description

Two separate two-dimensional models were used for the heated Parallel Calculation: a thermal model and a structural model. Only one-way coupling between the thermal and structural responses was considered, i.e., the thermal response was assumed to be unaffected by the structural deformations. The thermal model was used to compute temperatures in the configuration around the opening for the 5 year simulation period. The finite element code COYOTE II (Gartling, 1981) was used for this calculation. The temperatures were then used as input to SANTOS so that thermal expansion and creep property changes induced by changes in temperature could be included in the structural response. Because high temperature and stress gradients occur in different regions, the thermal and structural calculations required mesh refinement in different areas. Thus, the thermal and structural finite element meshes used for the heated Parallel Calculation were different, and nodal temperatures computed in the COYOTE II calculation had to be interpolated to the nodes of the structural mesh. The interpolation code MERLIN II (Gartling, 1991) was used to perform this task.

As was the case for the isothermal problem, the geometry for the heated configuration allows us to use a vertical plane of symmetry passing through the center of a drift and a symmetry plane between drifts to produce an equivalent single drift plane strain model. The problem definition and stratigraphy are shown in Figure 21.1. The upper and lower boundaries are approximately 50 m above and below the drift, respectively. These distances were chosen so that the room response would not be affected by the boundary conditions. The room is square in cross-section, with a height and width of 5.50 m. The horizontal extent from the center of the drift to the symmetry plane between drifts is 11.75 m. The room is infinitely long in the out-of-plane direction. The floor is located 1.08 m below Clay G in the same stratigraphy as was used in the isothermal calculation. The room was subjected to thermal loading provided by heaters placed beneath the floor, as shown in the figure, and spaced at regular intervals in the out-of-plane direction. These

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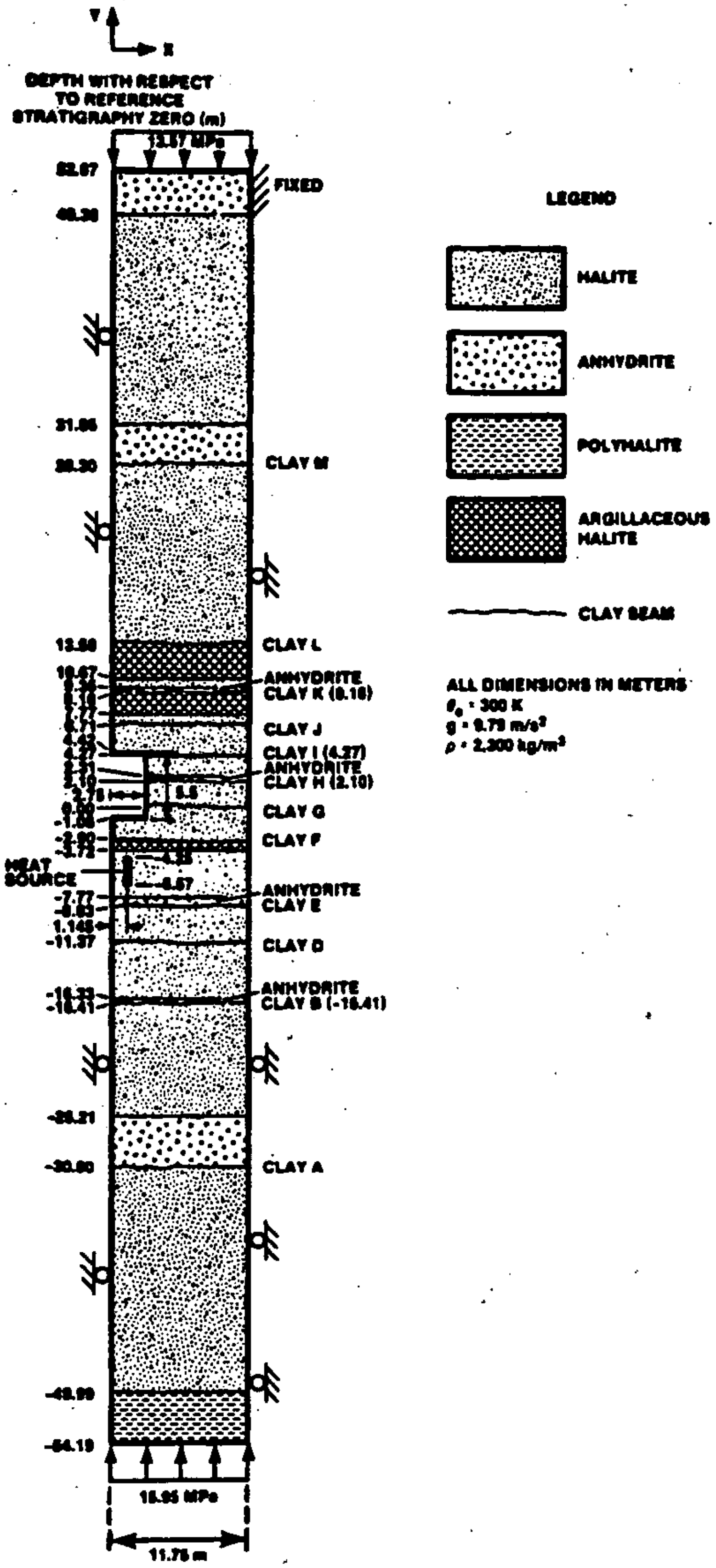

Figure 21.1 Parallel Calculation – Heated Drift Configuration (Morgan, et al. 1987)

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discrete heaters were approximated, in the calculation, as a continuous heat source in the out-of-plane direction.

Thermal Model

In the thermal model, all boundaries were assumed to be adiabatic, and the entire formation was prescribed to have an initial temperature of 300 K. The configuration remained at this temperature for the first six months of the simulation, during which isothermal creep closure was taking place. Then heating of the salt began. The heaters were modeled as a volumetric heat source with a thirty-year half life. The source was prescribed to be 2.316 m long and 0.61 m in diameter, with its center positioned 5.41 m below Clay G and 1.145 m from the left symmetry plane, as shown in Figure 21.1. Each heater was prescribed to have an output of 0.47 kW, and spacing between the heaters in the out-of-plane direction was defined to be 2.29 m. Using this information, the equivalent uniformly distributed heat flux to be used in the planar calculation could be computed. The resulting flux was of the form:

$$q = 145.3\exp(-7.327\times10^{-10}t) \qquad \textbf{(EQ 21.1)}$$

where q is the heat flux in W/m^3 and t is the time in seconds. The thermal response was computed for the 4.5 year period following the initial six month unheated period. In the thermal calculation, the thermal properties of all stratigraphic materials were assumed to be the same as those for halite. This assumption, which simplified the meshing for the thermal calculation, was appropriate because previous calculations have shown that thermal responses computed with an all-salt stratigraphy and with a layered stratigraphy are essentially the same (Stone, 1983). Only heat transfer by conduction was considered, and the salt was prescribed to have a nonlinear thermal conductivity of the form:

$$k = \lambda_0\left(\frac{300}{\theta}\right)^{\gamma} \qquad \textbf{(EQ 21.2)}$$

where k is the conductivity, θ is the absolute temperature in Kelvin, and λ_0 and γ are material constants. The room area was assumed to consist of an "equivalent thermal material" with a conductivity which allows radiation heat transfer in the room to be simulated by conduction. Thus, thermal radiation between the surfaces of the drift was simulated by an artificial thermal "material" in the drift with an "equivalent conductance." This "material" provided no structural support and, in fact, was used only in the thermal model but not in the structural model. The thermal finite element mesh used for the analysis is shown in Figure 21.2, and consists of four-node, isoparametric, quadrilateral elements. The mesh contains 774 elements and 836 nodal points. The thermal properties of halite and the "equivalent thermal material," which were used in this calculation, are presented in Table 21.1.

Structural Model

In the structural model, boundary conditions were such that horizontal displacements were specified to be zero along the vertical boundaries, as shown in Figure 21.1. A pressure of

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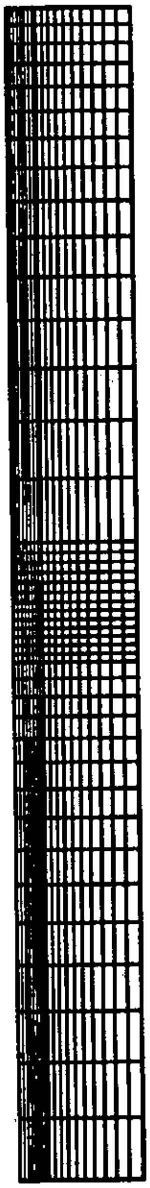

Figure 21.2 Thermal Mesh Used For Heated Parallel Calculation

13.57 MPa, which represents the weight of the overlying rock is applied to the top boundary. An average overburden density of 2320 kg/m^3 and a gravitational acceleration of 9.79 m/s^2 were used to determine this pressure. An average density of 2300 kg/m^3 was used for all stratigraphic layers to compute the pressure of 15.95 MPa applied at the bottom boundary. Body forces representing the weight of the rock were also applied, as was an initial lithostatic stress state that varied linearly with depth. The overburden density and average configuration density defined above were used to compute the initial stress state. Although the loads were specified such that the drift configuration was in static equilibrium, vertical constraints were needed to preclude rigid body motion. Thus, the top anhydrite layer was fixed along the edge at the pillar centerline, as indicated on the figure. In the out-of-plane direction, the room was considered to be infinitely long so that a plane

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Table 21.1 Material Properties Used for Heated Parallel Calculation – Thermal Analysis

Material	Density, ρ, kg/m^3	Specific Heat, C_p, J/(kg-K)	Thermal Conduct. Parameter, λ_0, W/(m-K)	Thermal Conduct. Parameter, γ,
Halite	2300	860	5.0	1.14
"Equiv. Thermal Material"	1000	1000	50.0	0.00

strain condition could be assumed. The surfaces of the room were traction-free, and the room was assumed to appear instantaneously at time zero.

The entire stratigraphy was used in the structural model and was comprised of five different geologic materials: halite, argillaceous halite, anhydrite, polyhalite, and clay seams. The layers identified as halite and argillaceous halite were modeled using an elastic–secondary creep model of the form:

$$\dot{\varepsilon} = D\bar{\sigma}^n e^{-\frac{Q}{RT}}, \qquad \textbf{(EQ 21.3)}$$

where $\dot{\varepsilon}$ is the effective creep strain rate and $\bar{\sigma}$ is the effective stress ($\bar{\sigma} = \sqrt{\frac{3}{2}\sigma'_{ij}\sigma'_{ij}}$), with the variables, σ_{ij} and σ'_{ij}, being the components of the stress tensor and the deviatoric stress tensor, respectively. The parameters D and n are material constants determined from creep data analysis. T is the temperature in degrees Kelvin, Q is the activation energy in cal/mole, and R is the universal gas constant (1.987 cal/mole-K). The mechanical material properties of halite and argillaceous halite used for this analysis are given in Table 21.2.

The anhydrite and polyhalite layers were assumed this time to have elastic volumetric behavior and elastic-plastic deviatoric behavior (instead of as isotropic and elastic materials in the isothermal calculation). The deviatoric yield stress was a function of the mean stress with the pressure dependence defined by the Drucker-Prager yield criterion:

$$\sqrt{J'_2} = C - aJ_1, \qquad \textbf{(EQ 21.4)}$$

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Table 21.2 Material Properties for Halite and Arg. Halite Used in Heated Parallel Calculation – Structural Analysis

Material	Young's Modulus (Pa)	Poisson's Ratio	D ($Pa^{-4.9}sec^{-1}$)	n	Q (kcal/mole)	Coeff. of Linear Thermal Exp., α, K^{-1}
Halite	3.10E10	0.25	5.79E-36	4.9	12.0	45.0E-6
Argillaceous Halite	3.10E10	0.25	1.74E-35	4.9	12.0	40.0E-6

where J'_2 is the second invariant of the deviatoric stress ($\sqrt{J'_2} = \bar{\sigma}/\sqrt{3}$), J_1 is the first stress invariant ($J_1 = \sigma_{ii}$), and C and a are constants. The mechanical material properties of anhydrite and polyhalite used for this analysis are given in Table 21.3

Table 21.3 Material Properties for Anhydrite and Polyhalite Used in Heated Parallel Calculation – Structural Analysis

Material	Young's Modulus (Pa)	Poisson's Ratio	C MPa	a	Coeff. of Linear Thermal Exp., α, K^{-1}
Anhydrite	7.51E10	0.35	1.35	0.450	20.0E-6
Polyhalite	5.53E10	0.36	1.42	0.473	24.0E-6

The clay seams in the stratigraphy are very thin layers between layers of more competent rock. Structurally, these seams represent interfaces where the more competent layers can slip with respect to each other. A dry friction model, with a coefficient of friction, μ=0.4, was specified for describing clay seam behavior. Of the 12 clay seams shown in the figure, only Clays D through L were modeled.

Other Solutions (In Lieu of Analytic Solution)

The nonlinear nature of repository calculations makes it difficult to demonstrate that the codes being used for performing the design and evaluation of these facilities are accurate, because the exact solution for a long term repository calculation of this type does not exist. Consequently, the WIPP project has determined that benchmarking against other codes is an acceptable first step in demonstrating the adequacy of a code for performing these types of analyses. Figure 21.3 and Figure 21.4 show some results from a previous benchmark

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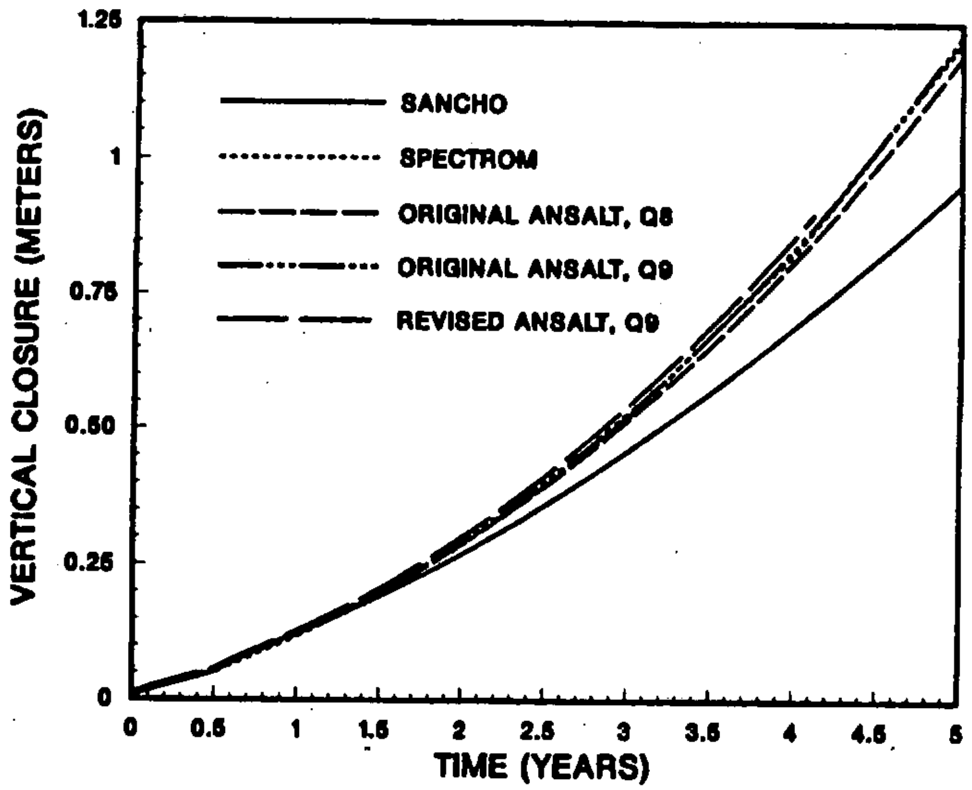

Figure 21.3 Vertical Closure History Results from Parallel Calculation Exercise – Heated Drift (Morgan, et al. 1987)

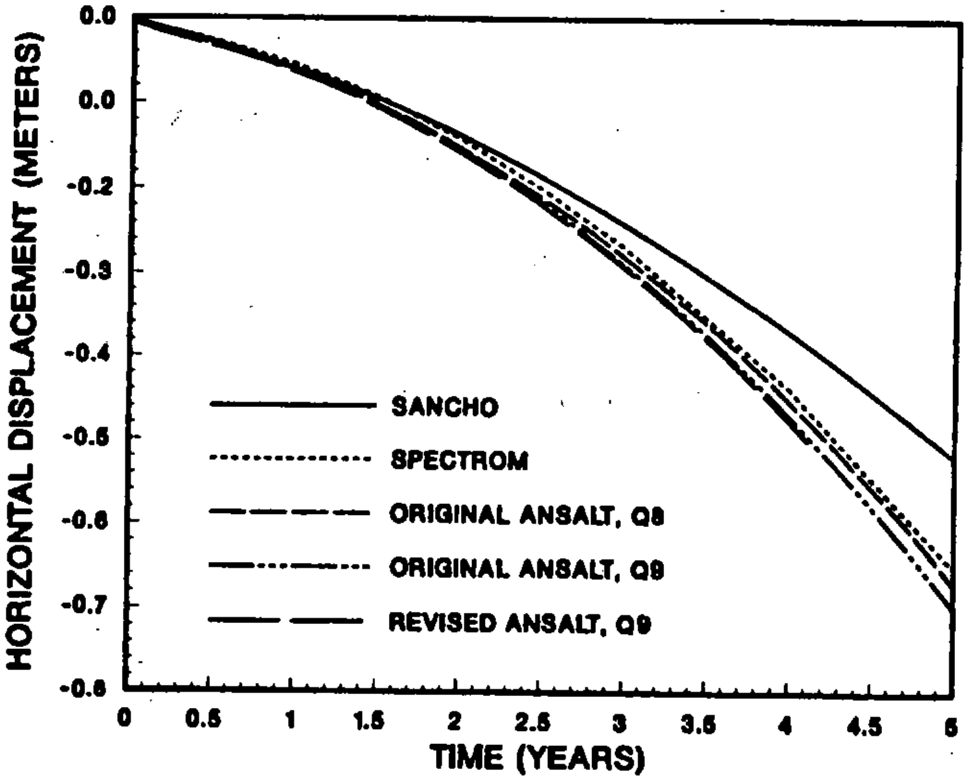

Figure 21.4 Midpillar Horizontal Displacement History Results from Parallel Calculation Exercise – Heated Drift (Morgan, et al. 1987)

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exercise (Morgan, et al. 1987) that used three structural codes to solve the heated problem described herein. The results from that benchmark study for vertical closure and pillar midheight horizontal displacement are provided for comparison to the results from the present analysis..

SANTOS Solution

Problem Discretization

The finite element mesh used in this analysis is shown in Figure 21.5. Also shown on the figure are the applied boundary conditions. The mesh contains 1,675 nodes and 1,396 elements. The grading of the mesh, in general, is such that finer elements occur near the room where the stress gradients will be higher. In some of the layers, however, the gradation in the vertical direction was dictated by the locations of the layer boundaries.

Input Data

A complete listing of the input data file that was used for the Parallel Calculation heated problem is given in APPENDIX U. Also included in this appendix is a listing of the FORTRAN subroutine "INITST" used to compute the initial stresses in the configuration.

Output Listing

The SANTOS printed output for the Parallel Calculation heated problem is also provided as a section in APPENDIX U.

Discussion of Results

Figure 21.6 and Figure 21.7 show the SANTOS vertical closure and pillar midheight displacement history results, respectively, along with two digitized curves from the Parallel Calculation exercise to allow the reader to see where the SANTOS results fall within the Parallel Calculation range. A comparison of the SANTOS results with the entire range of results predicted in the Parallel Calculation exercise is given in Table 21.4 for times of 1 year, 3 years, and 5 years. The table shows that in all cases, the SANTOS results fall very close to the lower end of the Parallel Calculation exercise ranges (generally within about 9 %), indicating that SANTOS gives comparable results for the heated drift problem.

References

1. Gartling, D. K., *MERLIN II – A Computer Program to Transfer Solution Data Between Finite Element Meshes*, SAND89–2989, Sandia National Laboratories, Albuquerque, New Mexico, July 1991.

2. Gartling, D. K. and R. E. Hogan, *COYOTE II – A Finite Element Computer Program for Nonlinear Heat Conduction Problems*, SAND94–1179, Sandia National Laboratories, Albuquerque, New Mexico, October 1994.

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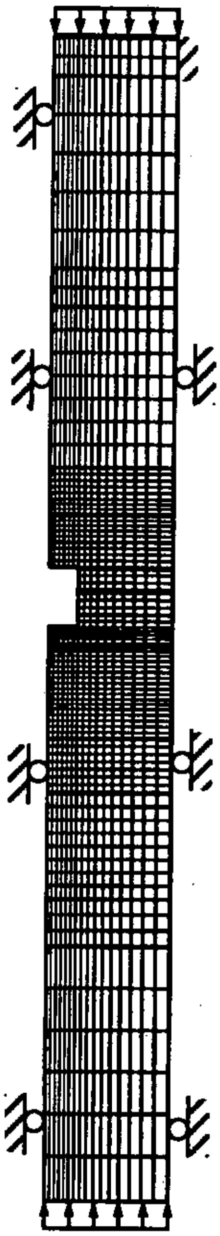

Figure 21.5 Santos Mesh Used For Heated Parallel Calculation

3. Morgan, H. S., M. Wallner, and D. E. Munson, *Results of an International Parallel Calculations Exercise Comparing Creep Responses Predicted With Three Computer Codes for Two Excavations in Rock Salt*, SAND87–2125, Sandia National Laboratories, Albuquerque, New Mexico, November 1987.

4. Munson, D. E., *Test Plan: 12-W/m^2 Mockup for Defense High-Level Waste (DHLW)*, Sandia National Laboratories, Albuquerque, New Mexico, June 1983.

5. Munson, D. E. and H. S. Morgan, *Methodology for Performing Parallel Design Calculations (Nuclear Waste Repository Application)*, SAND85–0324, Sandia National Laboratories, Albuquerque, New Mexico, May 1986.

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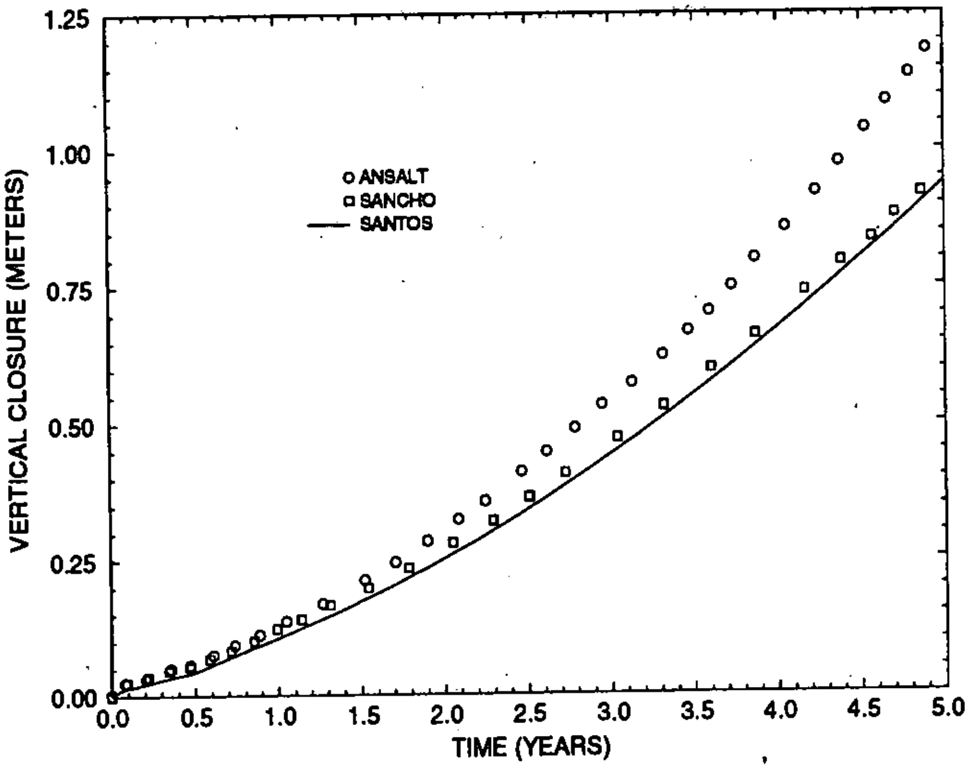

Figure 21.6 Vertical Closure History Computed With SANTOS for Parallel Calculation Heated Problem

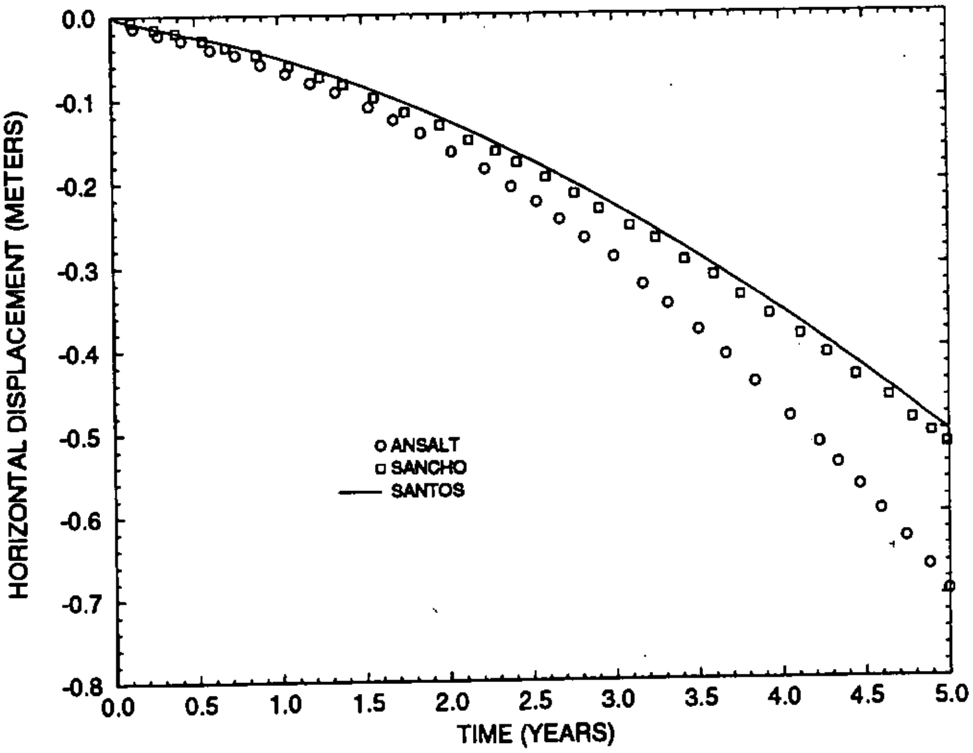

Figure 21.7 Midpillar Horizontal Displacement History Computed With SANTOS for Parallel Calculation Heated Problem

Information Only

Table 21.4 Comparison of SANTOS Results For The Heated Problem With Those Computed in Parallel Calculation Exercise

Time (years)		Vertical Closure (meters)	Midpillar Horizontal Displacement (meters)
1.0	Parallel Calculation Exercise Range	0.11 to 0.13	-0.06 to -0.07
	SANTOS Value	0.107	-0.051
3.0	Parallel Calculation Exercise Range	0.45 to 0.55	-0.25 to -0.31
	SANTOS Value	0.443	-0.229
5.0	Parallel Calculation Exercise Range	0.95 to 1.25	-0.52 to -0.71
	SANTOS Value	0.939	-0.503

6. Stone, C. M., "Analyses of the Heated WIPP In-Situ Experiments," Memo to D. E. Munson, Sandia National Laboratories, Albuquerque, New Mexico, February 16, 1983.

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APPENDIX A

Input/Output Data For Problem 1 – Large Rotation Problem

The following two sections present the input data and the formatted output for the single-element large rotation problem.

FASTQ and SANTOS Input Data For The Large Rotation Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the large rotation problem.

Information Only

```
TITLE
 ONE ELEMENT ROTATION PROBLEM - SANTOS QA TEST PROBLEM - 10/21/94
POINT   1      0.       1.
POINT   2      1.       1.
POINT   3      1.       0.
POINT   4      0.       0.
LINE    1   STR   1    2    0     1   1.0
LINE    2   STR   2    3    0     1   1.0
LINE    3   STR   3    4    0     1   1.0
LINE    4   STR   4    1    0     1   1.0
POINBC  4   4
POINBC  3   3
ELEMBC  5   1
SCHEME  0   MP
REGION  1   1 -1   -2   -3   -4
EXIT
```

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```
TITLE
SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94
PLANE STRAIN
MAXIMUM ITERATIONS 400
RESIDUAL TOLERANCE .01
INITIAL STRESS,CONSTANT,0.,-10000.,0.,0.
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS 1.0E06
POISSONS RATIO 0.
END
FUNCTION,2
 0.0000000, 0.0000000
 0.4000000, 0.0123117
 0.8000000, 0.0489436
 1.2000000, 0.1089938
 1.6000000, 0.1909835
 2.0000000, 0.2928941
 2.4000000, 0.4122159
 2.8000000, 0.5460110
 3.6000000, 0.8435554
 4.0000000, 0.9999833
END
FUNCTION,3
 0.0000000, 0.0000000
 0.4000000, 0.1564346
 0.8000000, 0.3090174
 1.2000000, 0.4539911
 1.6000000, 0.5877860
 2.0000000, 0.7071076
 2.4000000, 0.8090178
 2.8000000, 0.8910072
 3.2000000, 0.9510553
 3.6000000, 0.9876868
 4.0000000, 1.0000000
END
FUNCTION,4
  0.  10000.
  4.  10000.
STEP CONTROL
  10 4.
END
PLOT TIME
  1 4.
END
OUTPUT TIME
  1 4.
END
PRESCRIBED DISPLACEMENT X 4 2 1.
PRESCRIBED DISPLACEMENT Y 4 3 1.
NO DISPLACEMENT X 3
NO DISPLACEMENT Y 3
PRESSURE 5 4 1.
EXIT
```

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SANTOS Output For The Large Rotation Problem

The following section presents a portion of the SANTOS printed output for the single-element large rotation analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

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WPO# 35675 March 27, 1996

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS



                VERSION 2.0.0
     COPYRIGHT 1994, SANDIA CORPORATION


               PROGRAMMED BY:

              CHARLES M. STONE
         ENGINEERING SCIENCES CENTER
        SANDIA NATIONAL LABORATORIES
        ALBUQUERQUE, NEW MEXICO 87185

          DERIVED FROM PRONTO2D BY
    LEE M. TAYLOR AND DENNIS P. FLANAGAN



        RUN ON 03/04/96 AT 14:38:47
      RUN ON A Cray0J90 UNDER UniCo8.0
```

INPUT STREAM IMAGES

```
LINE ---------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94
  3: PLANE STRAIN
  4: MAXIMUM ITERATIONS 400
  5: RESIDUAL TOLERANCE .01
  6: INITIAL STRESS,CONSTANT,0.,-10000.,0.,0.
  7: MATERIAL,1,ELASTIC,1.
  8: YOUNGS MODULUS 1.0E06
  9: POISSONS RATIO 0.
 10: END
 11: FUNCTION,2
 12:  0.0000000, 0.0000000
 13:  0.4000000, 0.0123117
 14:  0.8000000, 0.0489436
 15:  1.2000000, 0.1089938
 16:  1.6000000, 0.1909835
 17:  2.0000000, 0.2928941
 18:  2.4000000, 0.4122159
 19:  2.8000000, 0.5460110
 20:  3.6000000, 0.8435554
 21:  4.0000000, 0.9999833
 22: END
 23: FUNCTION,3
 24:  0.0000000, 0.0000000
 25:  0.4000000, 0.1564346
 26:  0.8000000, 0.3090174
 27:  1.2000000, 0.4539911
 28:  1.6000000, 0.5877860
 29:  2.0000000, 0.7071076
 30:  2.4000000, 0.8090178
 31:  2.8000000, 0.8910072
 32:  3.2000000, 0.9510553
 33:  3.6000000, 0.9876868
```

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```
34:  4.0000000, 1.0000000
35: END
36: FUNCTION,4
37:   0.  10000.
38:   4.  10000.
39: STEP CONTROL
40:   10 4.
41: END
42: PLOT TIME
43:   1 4.
44: END
45: OUTPUT TIME
46:   1 4.
47: END
48: PRESCRIBED DISPLACEMENT X 4 2 1.
49: PRESCRIBED DISPLACEMENT Y 4 3 1.
50: NO DISPLACEMENT X 3
51: NO DISPLACEMENT Y 3
52: PRESSURE 5 4 1.
53: EXIT
    -----------------------------------------------------------------------------
```

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```
                    P R O B L E M   T I T L E

        SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94



                 P R O B L E M   D E F I N I T I O N

   NUMBER OF ELEMENTS .......................            1
   NUMBER OF NODES ..........................            4
   NUMBER OF MATERIALS ......................            1
   NUMBER OF FUNCTIONS ......................            3
   NUMBER OF CONTACT SURFACES ...............            0
   NUMBER OF RIGID SURFACES .................            0
   NUMBER OF MATERIAL POINTS MONITORED .....            0
   ANALYSIS TYPE ............................ PLANE STRAIN
   GLOBAL CONVERGENCE MEASURE ...............
   RESIDUAL TOLERANCE .......................   1.000E-02
   MAXIMUM NUMBER OF ITERATIONS .............          400
   ITERATIONS FOR INTERMEDIATE PRINT .......            8
   MAXIMUM RESIDUAL TOLERANCE ...............   6.000E-01
   PREDICTOR SCALE FACTOR FUNCTION .........            0
   MINIMUM DAMPING FACTOR ...................   2.000E-01
   EFFECTIVE MODULUS STATUS ................. CONSTANT
   INITIAL STRESS DISTRIBUTION APPLIED .....
   SCALE FACTOR APPLIED TO TIME STEP .......   1.000E+00
   STRAIN SOFTENING SCALE FACTOR ...........   1.000E+00
   HOURGLASS STIFFNESS FACTOR ..............   5.000E-02
   HOURGLASS VISCOSITY FACTOR ..............   0.000E+00



                L O A D   S T E P   D E F I N I T I O N S
```

```
  TIME          NO. OF STEPS          TIME
0.000E+00            10             4.000E+00



      P R I N T E D   O U T P U T   F R E Q U E N C Y

  TIME      STEPS BETWEEN PRINTS        TIME
0.000E+00             1             4.000E+00



      P L O T T E D   O U T P U T   F R E Q U E N C Y

  TIME      STEPS BETWEEN PLOTS         TIME
0.000E+00             1             4.000E+00



      M A T E R I A L   D E F I N I T I O N S

 MATERIAL TYPE ........................ELASTIC
 MATERIAL ID ..........................           1
 DENSITY .............................  1.000E+00
 MATERIAL PROPERTIES:
         YOUNGS MODULUS        =    1.000E+06
         POISSONS RATIO        =    0.000E+00
```

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```
              F U N C T I O N   D E F I N I T I O N S

FUNCTION ID .........       2      NUMBER OF POINTS ....      10

                 N        S            F(S)
                 1    0.000E+00     0.000E+00
                 2    4.000E-01     1.231E-02
                 3    8.000E-01     4.894E-02
                 4    1.200E+00     1.090E-01
                 5    1.600E+00     1.910E-01
                 6    2.000E+00     2.929E-01
                 7    2.400E+00     4.122E-01
                 8    2.800E+00     5.460E-01
                 9    3.600E+00     8.436E-01
                10    4.000E+00     1.000E+00

FUNCTION ID .........       3      NUMBER OF POINTS ....      11

                 N        S            F(S)
                 1    0.000E+00     0.000E+00
                 2    4.000E-01     1.564E-01
                 3    8.000E-01     3.090E-01
                 4    1.200E+00     4.540E-01
                 5    1.600E+00     5.878E-01
                 6    2.000E+00     7.071E-01
                 7    2.400E+00     8.090E-01
                 8    2.800E+00     8.910E-01
                 9    3.200E+00     9.511E-01
                10    3.600E+00     9.877E-01
                11    4.000E+00     1.000E+00
```

```
FUNCTION ID .........       4     NUMBER OF POINTS ....       2

                   N         S            F(S)
                   1     0.000E+00     1.000E+04
                   2     4.000E+00     1.000E+04



N O  D I S P L A C E M E N T  B O U N D A R Y  C O N D I T I O N S

                NODE SET FLAG      DIRECTION
                      3                X
                      3                Y



P R E S C R I B E D  D I S P L A C E M E N T  B O U N D A R Y  C O N D I T I O N S

     NODE SET     DIRECTION     FUNCTION      SCALE          A0            B0
       FLAG                        ID         FACTOR
        4             X            2        1.000E+00         -             -
        4             Y            3        1.000E+00         -             -



P R E S S U R E  B O U N D A R Y  C O N D T I O N S

             SURFACE        FUNCTION      SCALE
               FLAG          NUMBER       FACTOR
```

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```
        5              4      1.000E+00



              E N D   O F   D A T A   I N P U T   P H A S E
                     2.040E-01 CPU SECONDS USED
                               2 WORDS ALLOCATED



       E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                     1.174E-02 CPU SECONDS USED
                               4 WORDS ALLOCATED



          V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                    NODAL          ELEMENT        GLOBAL
                    -----          -------        ------
                    DISPLX         SIGXX          FX
                    DISPLY         SIGYY          FY
                                   SIGZZ          RX
                                   TAUXY          RY
                                                  ITER
                                                  RMAG

   **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****
```

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
8	4.000E-01	3.993E-01	8.001E-01	7.057E+03	5.080E+04	719.87	8
16	4.000E-01	4.000E-01	8.000E-01	6.973E+03	1.094E+04	156.83	16
24	4.000E-01	4.000E-01	8.016E-01	7.039E+03	9.640E+03	136.96	24
32	4.000E-01	4.000E-01	8.000E-01	7.142E+03	6.977E+03	97.69	32
40	4.000E-01	4.000E-01	8.141E-01	7.118E+03	7.293E+03	102.46	40
48	4.000E-01	4.000E-01	8.016E-01	6.989E+03	6.703E+03	95.91	48
56	4.000E-01	4.000E-01	9.000E-01	7.047E+03	5.483E+03	77.81	56
64	4.000E-01	4.000E-01	8.004E-01	7.139E+03	5.001E+03	70.05	64
72	4.000E-01	4.000E-01	9.000E-01	7.082E+03	4.086E+03	57.70	72
80	4.000E-01	4.000E-01	8.004E-01	7.019E+03	3.728E+03	53.10	80
88	4.000E-01	4.000E-01	8.000E-01	7.071E+03	3.055E+03	43.20	88
96	4.000E-01	4.000E-01	8.250E-01	7.110E+03	2.784E+03	39.15	96
104	4.000E-01	4.000E-01	8.001E-01	7.066E+03	2.270E+03	32.13	104
112	4.000E-01	4.000E-01	8.000E-01	7.046E+03	1.811E+03	25.70	112
120	4.000E-01	4.000E-01	8.008E-01	7.079E+03	1.684E+03	23.79	120
128	4.000E-01	4.000E-01	8.000E-01	7.089E+03	1.355E+03	19.11	128
136	4.000E-01	4.000E-01	8.063E-01	7.063E+03	1.244E+03	17.61	136
144	4.000E-01	4.000E-01	8.000E-01	7.059E+03	1.015E+03	14.38	144
152	4.000E-01	4.000E-01	8.500E-01	7.079E+03	8.858E+02	12.51	152
160	4.000E-01	4.000E-01	8.002E-01	7.079E+03	7.605E+02	10.74	160
168	4.000E-01	4.000E-01	8.000E-01	7.065E+03	6.234E+02	8.82	168
176	4.000E-01	4.000E-01	8.016E-01	7.066E+03	5.675E+02	8.03	176
184	4.000E-01	4.000E-01	8.000E-01	7.076E+03	4.640E+02	6.56	184
192	4.000E-01	4.000E-01	8.125E-01	7.074E+03	4.168E+02	5.89	192
200	4.000E-01	4.000E-01	8.000E-01	7.067E+03	3.460E+02	4.90	200
208	4.000E-01	4.000E-01	9.000E-01	7.070E+03	2.811E+02	3.98	208
216	4.000E-01	4.000E-01	8.004E-01	7.075E+03	2.588E+02	3.66	216
224	4.000E-01	4.000E-01	8.000E-01	7.072E+03	2.106E+02	2.98	224
232	4.000E-01	4.000E-01	8.031E-01	7.068E+03	1.942E+02	2.75	232
240	4.000E-01	4.000E-01	8.000E-01	7.071E+03	1.574E+02	2.23	240
248	4.000E-01	4.000E-01	8.250E-01	7.073E+03	1.441E+02	2.04	248
256	4.000E-01	4.000E-01	8.001E-01	7.071E+03	1.173E+02	1.66	256

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264	4.000E-01	4.000E-01	8.000E-01	7.070E+03	9.366E+01	1.32	264
272	4.000E-01	4.000E-01	8.008E-01	7.071E+03	8.714E+01	1.23	272
280	4.000E-01	4.000E-01	8.000E-01	7.072E+03	7.006E+01	0.99	280
288	4.000E-01	4.000E-01	8.063E-01	7.071E+03	6.434E+01	0.91	288
296	4.000E-01	4.000E-01	8.000E-01	7.070E+03	5.248E+01	0.74	296
304	4.000E-01	4.000E-01	8.000E-01	7.071E+03	4.334E+01	0.61	304
312	4.000E-01	4.000E-01	8.063E-01	7.071E+03	3.818E+01	0.54	312
320	4.000E-01	4.000E-01	8.000E-01	7.071E+03	3.244E+01	0.46	320
328	4.000E-01	4.000E-01	8.500E-01	7.071E+03	2.740E+01	0.39	328
336	4.000E-01	4.000E-01	8.002E-01	7.071E+03	2.412E+01	0.34	336
344	4.000E-01	4.000E-01	8.000E-01	7.071E+03	1.935E+01	0.27	344
352	4.000E-01	4.000E-01	8.016E-01	7.071E+03	1.784E+01	0.25	352
360	4.000E-01	4.000E-01	8.000E-01	7.071E+03	1.455E+01	0.21	360
368	4.000E-01	4.000E-01	8.125E-01	7.071E+03	1.298E+01	0.18	368
376	4.000E-01	4.000E-01	8.000E-01	7.071E+03	1.095E+01	0.15	376
384	4.000E-01	4.000E-01	9.000E-01	7.071E+03	8.697E+00	0.12	384
392	4.000E-01	4.000E-01	8.004E-01	7.071E+03	8.261E+00	0.12	392

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/04/96 ,AT 14:38:47
  SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

***********************************************************************
SUMMARY OF DATA AT STEP NUMBER     1, TIME = 4.000E-01
NUMBER OF ITERATIONS =       400, TOTAL NUMBER OF ITERATIONS =       400
FINAL CONVERGENCE TOLERANCE = 9.142E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION =-1.564E+03
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-9.877E+03
SUM OF REACTION FORCES IN X-DIRECTION =-7.845E+02
SUM OF REACTION FORCES IN Y-DIRECTION =-4.942E+03
***********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 4.000E-01  STEP NUMBER     1 ****



STEP      TIME        TIME      DAMPING     APPLIED    RESIDUAL     PERCENT     TOTAL
                      STEP      FACTOR    LOAD NORM   LOAD NORM   IMBALANCE     STEPS
    8  8.000E-01  4.000E-01  8.008E-01  7.058E+03  5.796E+03      82.12       408
   16  8.000E-01  4.000E-01  8.000E-01  7.033E+03  5.537E+03      78.73       416
   24  8.000E-01  4.000E-01  8.000E-01  7.116E+03  3.588E+03      50.42       424
   32  8.000E-01  4.000E-01  8.000E-01  7.066E+03  2.911E+03      41.19       432
   40  8.000E-01  4.000E-01  8.063E-01  7.038E+03  2.650E+03      37.65       440
   48  8.000E-01  4.000E-01  6.570E-01  7.075E+03  2.016E+03      28.49       448
   56  8.000E-01  4.000E-01  8.057E-01  7.088E+03  1.288E+03      18.17       456
   64  8.000E-01  4.000E-01  8.000E-01  7.065E+03  1.150E+03      16.28       464
   72  8.000E-01  4.000E-01  7.813E-01  7.062E+03  6.710E+02       9.50       472
   80  8.000E-01  4.000E-01  8.062E-01  7.073E+03  5.292E+02       7.48       480
   88  8.000E-01  4.000E-01  8.008E-01  7.077E+03  4.968E+02       7.02       488
   96  8.000E-01  4.000E-01  8.500E-01  7.068E+03  4.411E+02       6.24       496
  104  8.000E-01  4.000E-01  8.002E-01  7.067E+03  3.753E+02       5.31       504
  112  8.000E-01  4.000E-01  8.000E-01  7.074E+03  3.098E+02       4.38       512
  120  8.000E-01  4.000E-01  8.016E-01  7.074E+03  2.800E+02       3.96       520
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128	8.000E-01	4.000E-01	8.000E-01	7.069E+03	2.308E+02	3.27	528
136	8.000E-01	4.000E-01	8.125E-01	7.069E+03	2.056E+02	2.91	536
144	8.000E-01	4.000E-01	8.000E-01	7.073E+03	1.721E+02	2.43	544
152	8.000E-01	4.000E-01	9.000E-01	7.072E+03	1.387E+02	1.96	552
160	8.000E-01	4.000E-01	8.004E-01	7.069E+03	1.287E+02	1.82	560
168	8.000E-01	4.000E-01	8.000E-01	7.071E+03	1.039E+02	1.47	568
176	8.000E-01	4.000E-01	8.031E-01	7.072E+03	9.651E+01	1.36	576
184	8.000E-01	4.000E-01	8.000E-01	7.071E+03	7.774E+01	1.10	584
192	8.000E-01	4.000E-01	8.250E-01	7.070E+03	7.152E+01	1.01	592
200	8.000E-01	4.000E-01	8.001E-01	7.071E+03	5.802E+01	0.82	600
208	8.000E-01	4.000E-01	8.000E-01	7.072E+03	4.646E+01	0.66	608
216	8.000E-01	4.000E-01	8.008E-01	7.071E+03	4.316E+01	0.61	616
224	8.000E-01	4.000E-01	8.000E-01	7.071E+03	3.470E+01	0.49	624
232	8.000E-01	4.000E-01	8.063E-01	7.071E+03	3.191E+01	0.45	632
240	8.000E-01	4.000E-01	8.000E-01	7.071E+03	2.595E+01	0.37	640
248	8.000E-01	4.000E-01	8.000E-01	7.071E+03	2.151E+01	0.30	648
256	8.000E-01	4.000E-01	8.063E-01	7.071E+03	1.886E+01	0.27	656
264	8.000E-01	4.000E-01	8.000E-01	7.071E+03	1.612E+01	0.23	664
272	8.000E-01	4.000E-01	8.500E-01	7.071E+03	1.352E+01	0.19	672
280	8.000E-01	4.000E-01	8.002E-01	7.071E+03	1.199E+01	0.17	680
288	8.000E-01	4.000E-01	8.000E-01	7.071E+03	9.548E+00	0.14	688
296	8.000E-01	4.000E-01	8.016E-01	7.071E+03	8.875E+00	0.13	696
304	8.000E-01	4.000E-01	8.000E-01	7.071E+03	7.177E+00	0.10	704
312	8.000E-01	4.000E-01	8.125E-01	7.071E+03	6.459E+00	0.09	712
320	8.000E-01	4.000E-01	8.000E-01	7.071E+03	5.405E+00	0.08	720
328	8.000E-01	4.000E-01	9.000E-01	7.071E+03	4.325E+00	0.06	728
336	8.000E-01	4.000E-01	8.004E-01	7.071E+03	4.080E+00	0.06	736
344	8.000E-01	4.000E-01	8.000E-01	7.071E+03	3.211E+00	0.05	744
352	8.000E-01	4.000E-01	8.031E-01	7.071E+03	3.084E+00	0.04	752
360	8.000E-01	4.000E-01	8.000E-01	7.071E+03	2.384E+00	0.03	760
368	8.000E-01	4.000E-01	8.250E-01	7.071E+03	2.298E+00	0.03	768
376	8.000E-01	4.000E-01	8.001E-01	7.071E+03	1.770E+00	0.03	776
384	8.000E-01	4.000E-01	8.000E-01	7.071E+03	1.495E+00	0.02	784
392	8.000E-01	4.000E-01	8.008E-01	7.071E+03	1.315E+00	0.02	792

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WPO# 35675 March 27, 1996

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 SANTOS, VERSION 2.0.0    ,RUN ON 03/04/96 ,AT 14:38:47
  SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER      2, TIME = 8.000E-01
NUMBER OF ITERATIONS =        400, TOTAL NUMBER OF ITERATIONS =        800
FINAL CONVERGENCE TOLERANCE = 1.581E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION =-3.090E+03
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-9.511E+03
SUM OF REACTION FORCES IN X-DIRECTION =-1.545E+03
SUM OF REACTION FORCES IN Y-DIRECTION =-4.755E+03
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 8.000E-01  STEP NUMBER     2 ****



STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
   8  1.200E+00  4.000E-01  8.008E-01  7.058E+03  5.803E+03     82.21       808
  16  1.200E+00  4.000E-01  8.250E-01  7.031E+03  6.483E+03     92.20       816
  24  1.200E+00  4.000E-01  8.509E-01  7.134E+03  4.820E+03     67.56       824
  32  1.200E+00  4.000E-01  8.002E-01  7.052E+03  4.365E+03     61.90       832
  40  1.200E+00  4.000E-01  8.016E-01  7.026E+03  4.026E+03     57.31       840
  48  1.200E+00  4.000E-01  8.000E-01  7.102E+03  3.301E+03     46.48       848
  56  1.200E+00  4.000E-01  8.000E-01  7.097E+03  2.668E+03     37.60       856
  64  1.200E+00  4.000E-01  7.625E-01  7.058E+03  1.460E+03     20.69       864
  72  1.200E+00  4.000E-01  7.999E-01  7.058E+03  1.153E+03     16.34       872
  80  1.200E+00  4.000E-01  8.000E-01  7.079E+03  9.476E+02     13.39       880
  88  1.200E+00  4.000E-01  8.125E-01  7.080E+03  8.398E+02     11.86       888
  96  1.200E+00  4.000E-01  8.000E-01  7.064E+03  7.086E+02     10.03       896
 104  1.200E+00  4.000E-01  9.000E-01  7.066E+03  5.663E+02      8.01       904
 112  1.200E+00  4.000E-01  8.004E-01  7.077E+03  5.299E+02      7.49       912
 120  1.200E+00  4.000E-01  8.000E-01  7.074E+03  4.245E+02      6.00       920
```

128	1.200E+00	4.000E-01	8.031E-01	7.066E+03	3.972E+02	5.62	928
136	1.200E+00	4.000E-01	8.000E-01	7.070E+03	3.177E+02	4.49	936
144	1.200E+00	4.000E-01	7.918E-01	7.073E+03	1.711E+02	2.42	944
152	1.200E+00	4.000E-01	8.000E-01	7.072E+03	1.466E+02	2.07	952
160	1.200E+00	4.000E-01	8.000E-01	7.070E+03	1.163E+02	1.65	960
168	1.200E+00	4.000E-01	8.031E-01	7.071E+03	1.104E+02	1.56	968
176	1.200E+00	4.000E-01	8.000E-01	7.072E+03	8.637E+01	1.22	976
184	1.200E+00	4.000E-01	8.250E-01	7.071E+03	8.239E+01	1.17	984
192	1.200E+00	4.000E-01	8.001E-01	7.070E+03	6.399E+01	0.91	992
200	1.200E+00	4.000E-01	8.000E-01	7.071E+03	5.370E+01	0.76	1000
208	1.200E+00	4.000E-01	8.008E-01	7.072E+03	4.738E+01	0.67	1008
216	1.200E+00	4.000E-01	8.000E-01	7.071E+03	4.025E+01	0.57	1016
224	1.200E+00	4.000E-01	8.063E-01	7.071E+03	3.500E+01	0.49	1024
232	1.200E+00	4.000E-01	8.000E-01	7.071E+03	3.012E+01	0.43	1032
240	1.200E+00	4.000E-01	8.000E-01	7.071E+03	2.360E+01	0.33	1040
248	1.200E+00	4.000E-01	7.135E-01	7.071E+03	1.823E+01	0.26	1048
256	1.200E+00	4.000E-01	7.997E-01	7.071E+03	1.205E+01	0.17	1056
264	1.200E+00	4.000E-01	8.500E-01	7.071E+03	1.087E+01	0.15	1064
272	1.200E+00	4.000E-01	8.002E-01	7.071E+03	9.191E+00	0.13	1072
280	1.200E+00	4.000E-01	8.000E-01	7.071E+03	7.623E+00	0.11	1080
288	1.200E+00	4.000E-01	8.016E-01	7.071E+03	6.851E+00	0.10	1088
296	1.200E+00	4.000E-01	8.000E-01	7.071E+03	5.684E+00	0.08	1096
304	1.200E+00	4.000E-01	7.953E-01	7.071E+03	2.820E+00	0.04	1104
312	1.200E+00	4.000E-01	8.000E-01	7.071E+03	2.481E+00	0.04	1112
320	1.200E+00	4.000E-01	6.579E-01	7.071E+03	1.730E+00	0.02	1120
328	1.200E+00	4.000E-01	7.994E-01	7.071E+03	1.040E+00	0.01	1128
336	1.200E+00	4.000E-01	8.000E-01	7.071E+03	8.596E-01	0.01	1136
344	1.200E+00	4.000E-01	8.500E-01	7.071E+03	7.515E-01	0.01	1144

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    SANTOS, VERSION 2.0.0     ,RUN ON 03/04/96 ,AT 14:38:47
     SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

   *************************************************************************
   SUMMARY OF DATA AT STEP NUMBER      3, TIME = 1.200E+00
   NUMBER OF ITERATIONS =        349, TOTAL NUMBER OF ITERATIONS =       1149
   FINAL CONVERGENCE TOLERANCE = 9.759E-03
   SUM OF EXTERNAL FORCES IN X-DIRECTION =-4.540E+03
   SUM OF EXTERNAL FORCES IN Y-DIRECTION =-8.910E+03
   SUM OF REACTION FORCES IN X-DIRECTION =-2.270E+03
   SUM OF REACTION FORCES IN Y-DIRECTION =-4.455E+03
   *************************************************************************


   **** PLOT TAPE WRITTEN AT TIME = 1.200E+00  STEP NUMBER     3 ****



 STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
     8  1.600E+00  4.000E-01  7.164E-01  7.098E+03  4.861E+03     68.48      1157
    16  1.600E+00  4.000E-01  8.247E-01  7.034E+03  3.349E+03     47.61      1165
    24  1.600E+00  4.000E-01  8.001E-01  7.093E+03  2.026E+03     28.56      1173
    32  1.600E+00  4.000E-01  8.000E-01  7.078E+03  1.666E+03     23.54      1181
    40  1.600E+00  4.000E-01  8.000E-01  7.052E+03  1.363E+03     19.33      1189
    48  1.600E+00  4.000E-01  8.563E-01  7.075E+03  1.317E+03     18.62      1197
    56  1.600E+00  4.000E-01  8.502E-01  7.087E+03  1.233E+03     17.40      1205
    64  1.600E+00  4.000E-01  8.002E-01  7.065E+03  1.095E+03     15.49      1213
    72  1.600E+00  4.000E-01  7.961E-01  7.063E+03  5.898E+02      8.35      1221
    80  1.600E+00  4.000E-01  7.048E-01  7.071E+03  4.723E+02      6.68      1229
    88  1.600E+00  4.000E-01  7.996E-01  7.075E+03  3.017E+02      4.26      1237
    96  1.600E+00  4.000E-01  8.500E-01  7.070E+03  2.739E+02      3.87      1245
   104  1.600E+00  4.000E-01  7.557E-01  7.068E+03  2.215E+02      3.13      1253
   112  1.600E+00  4.000E-01  7.998E-01  7.072E+03  1.695E+02      2.40      1261
   120  1.600E+00  4.000E-01  8.000E-01  7.073E+03  1.349E+02      1.91      1269
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128	1.600E+00	4.000E-01	8.000E-01	7.071E+03	1.122E+02	1.59	1277
136	1.600E+00	4.000E-01	8.016E-01	7.070E+03	1.006E+02	1.42	1285
144	1.600E+00	4.000E-01	7.956E-01	7.071E+03	5.418E+01	0.77	1293
152	1.600E+00	4.000E-01	8.500E-01	7.072E+03	4.742E+01	0.67	1301
160	1.600E+00	4.000E-01	8.002E-01	7.071E+03	4.218E+01	0.60	1309
168	1.600E+00	4.000E-01	8.016E-01	7.071E+03	3.769E+01	0.53	1317
176	1.600E+00	4.000E-01	8.000E-01	7.071E+03	3.135E+01	0.44	1325
184	1.600E+00	4.000E-01	8.033E-01	7.071E+03	2.560E+01	0.36	1333
192	1.600E+00	4.000E-01	7.655E-01	7.071E+03	1.478E+01	0.21	1341
200	1.600E+00	4.000E-01	7.999E-01	7.071E+03	1.151E+01	0.16	1349
208	1.600E+00	4.000E-01	8.016E-01	7.071E+03	1.081E+01	0.15	1357
216	1.600E+00	4.000E-01	8.125E-01	7.071E+03	9.536E+00	0.13	1365
224	1.600E+00	4.000E-01	8.000E-01	7.071E+03	8.064E+00	0.11	1373
232	1.600E+00	4.000E-01	9.000E-01	7.071E+03	6.425E+00	0.09	1381
240	1.600E+00	4.000E-01	8.004E-01	7.071E+03	6.033E+00	0.09	1389
248	1.600E+00	4.000E-01	8.000E-01	7.071E+03	4.814E+00	0.07	1397
256	1.600E+00	4.000E-01	8.031E-01	7.071E+03	4.523E+00	0.06	1405
264	1.600E+00	4.000E-01	8.000E-01	7.071E+03	3.604E+00	0.05	1413
272	1.600E+00	4.000E-01	8.250E-01	7.071E+03	3.348E+00	0.05	1421
280	1.600E+00	4.000E-01	8.001E-01	7.071E+03	2.693E+00	0.04	1429
288	1.600E+00	4.000E-01	8.000E-01	7.071E+03	2.173E+00	0.03	1437
296	1.600E+00	4.000E-01	8.008E-01	7.071E+03	2.007E+00	0.03	1445
304	1.600E+00	4.000E-01	8.000E-01	7.071E+03	1.620E+00	0.02	1453
312	1.600E+00	4.000E-01	8.063E-01	7.071E+03	1.487E+00	0.02	1461
320	1.600E+00	4.000E-01	8.000E-01	7.071E+03	1.209E+00	0.02	1469
328	1.600E+00	4.000E-01	8.500E-01	7.071E+03	1.063E+00	0.02	1477
336	1.600E+00	4.000E-01	8.002E-01	7.071E+03	9.028E-01	0.01	1485
344	1.600E+00	4.000E-01	8.000E-01	7.071E+03	7.492E-01	0.01	1493

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/04/96 ,AT 14:38:47
  SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     4, TIME = 1.600E+00
NUMBER OF ITERATIONS =        346, TOTAL NUMBER OF ITERATIONS =      1495
FINAL CONVERGENCE TOLERANCE = 9.848E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION =-5.878E+03
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-8.090E+03
SUM OF REACTION FORCES IN X-DIRECTION =-2.938E+03
SUM OF REACTION FORCES IN Y-DIRECTION =-4.045E+03
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.600E+00  STEP NUMBER     4 ****
```

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/04/96 ,AT 14:38:47
  SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    10, TIME = 4.000E+00
NUMBER OF ITERATIONS =        400, TOTAL NUMBER OF ITERATIONS =      3859
FINAL CONVERGENCE TOLERANCE = 1.572E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION =-1.000E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 2.884E+00
SUM OF REACTION FORCES IN X-DIRECTION =-4.998E+03
SUM OF REACTION FORCES IN Y-DIRECTION = 1.849E+00
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 4.000E+00  STEP NUMBER    10 ****
```

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```
10 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


     E N D   O F   S O L U T I O N   P H A S E
          1.866E+00 CPU SECONDS USED
                  4 WORDS ALLOCATED
```

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APPENDIX B

Input/Output Data For Problem 2 – Delete Material Option Problem

The following two sections present the input data and the formatted output for the delete material option verification problem.

FASTQ and SANTOS Input Data For The Delete Material Option Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the delete material option problem.

Information Only

```
TITLE
 GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA
POINT   1      0.      0.
POINT   2      1.      0.
POINT   3      2.      0.
POINT   4      0.     -4.
POINT   5      2.     -4.
POINT   6      0.     -8.
POINT   7      2.     -8.
POINT   8      0.    -12.
POINT   9      2.    -12.
POINT  10      0.    -16.
POINT  11      2.    -16.
POINT  12      0.    -20.
POINT  13      2.    -20.
LINE    1   STR   1    2    0    2   1.0
LINE    2   STR   2    3    0    2   1.0
LINE    3   STR   1    4    0    8   1.0
LINE    4   STR   3    5    0    8   1.0
LINE    5   STR   4    5    0    4   1.0
LINE    6   STR   4    6    0    8   1.0
LINE    7   STR   5    7    0    8   1.0
LINE    8   STR   6    7    0    4   1.0
LINE    9   STR   6    8    0    8   1.0
LINE   10   STR   7    9    0    8   1.0
LINE   11   STR   8    9    0    4   1.0
LINE   12   STR   8   10    0    8   1.0
LINE   13   STR   9   11    0    8   1.0
LINE   14   STR  10   11    0    4   1.0
LINE   15   STR  10   12    0    8   1.0
LINE   16   STR  11   13    0    8   1.0
LINE   17   STR  12   13    0    4   1.0
 POINBC  1   2
 NODEBC  2   1  2
 SCHEME  0   MP
 REGION  1   5  -1  -2  -4  -5  -3
 REGION  2   4  -5  -7  -8  -6
 REGION  3   3  -8 -10 -11  -9
 REGION  4   2 -11 -13 -14 -12
 REGION  5   1 -14 -16 -17 -15
 END
```

Information Only

```
TITLE
 GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA
PLANE STRAIN
MAXIMUM ITERATIONS,1000
RESIDUAL TOLERANCE 0.1
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
MATERIAL,2,ELASTIC,1.
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
MATERIAL,3,ELASTIC,1.
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
MATERIAL,4,ELASTIC,1.TITLE
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
MATERIAL,5,ELASTIC,1.
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
DELETE MATERIAL 1 1.0
DELETE MATERIAL 2 2.0
DELETE MATERIAL 3 3.0
DELETE MATERIAL 4 4.0
FUNCTION,1
  0.,1.
  5.,1.
END
STEP CONTROL
  10,5.
END
PLOT TIME
  1,5.
END
OUTPUT TIME
  2,5.
END
GRAVITY,1,0.,-5.,0.
NO DISPLACEMENT,X,1
NO DISPLACEMENT,Y,2
EXIT
```

Information Only

SANTOS Output For The Delete Material Option Problem

The following section presents the SANTOS printed output for the delete material option analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end.

Information Only

WPO# 35675 March 27, 1996

```
 SSSSSS   AAAAA   N    NN   TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN     TT     OO   OO  SS
SS       AA   AA  NNN  NN     TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN     TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN     TT     OO   OO       SS
     SS  AA   AA  NN   NN     TT     OO   OO       SS
SSSSSS   AA   AA  NN    N     TT      OOOOO   SSSSSS



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              DERIVED FROM PRONTO2D BY
        LEE M. TAYLOR AND DENNIS P. FLANAGAN



            RUN ON 03/04/96 AT 15:16:43
          RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                                   INPUT STREAM IMAGES
LINE -----------------------------------------------------------------------
  1: TITLE
  2:  GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA
  3: PLANE STRAIN
  4: MAXIMUM ITERATIONS,1000
  5: RESIDUAL TOLERANCE 0.1
  6: MATERIAL,1,ELASTIC,1.
  7: YOUNGS MODULUS 10000.
  8: POISSONS RATIO 0.
  9: END
 10: MATERIAL,2,ELASTIC,1.
 11: YOUNGS MODULUS 10000.
 12: POISSONS RATIO 0.
 13: END
 14: MATERIAL,3,ELASTIC,1.
 15: YOUNGS MODULUS 10000.
 16: POISSONS RATIO 0.
 17: END
 18: MATERIAL,4,ELASTIC,1.
 19: YOUNGS MODULUS 10000.
 20: POISSONS RATIO 0.
 21: END
 22: MATERIAL,5,ELASTIC,1.
 23: YOUNGS MODULUS 10000.
 24: POISSONS RATIO 0.
 25: END
 26: DELETE MATERIAL 1 1.0
 27: DELETE MATERIAL 2 2.0
 28: DELETE MATERIAL 3 3.0
 29: DELETE MATERIAL 4 4.0
 30: FUNCTION,1
 31:   0.,1.
 32:   5.,1.
 33: END
 34: STEP CONTROL
```

```
35:   10,5.
36: END
37: PLOT TIME
38:   1,5.
39: END
40: OUTPUT TIME
41:   2,5.
42: END
43: GRAVITY,1,0.,-5.,0.
44: NO DISPLACEMENT,X,1
45: NO DISPLACEMENT,Y,2
46: EXIT
    -------------------------------------------------------------------------
```

Information Only

Information Only

```
                 P R O B L E M  T I T L E

    GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA



               P R O B L E M   D E F I N I T I O N

      NUMBER OF ELEMENTS .......................         160
      NUMBER OF NODES ..........................         205
      NUMBER OF MATERIALS ......................           5
      NUMBER OF FUNCTIONS ......................           1
      NUMBER OF CONTACT SURFACES ...............           0
      NUMBER OF RIGID SURFACES .................           0
      NUMBER OF MATERIAL POINTS MONITORED .....            0
      ANALYSIS TYPE ............................ PLANE STRAIN
      GLOBAL CONVERGENCE MEASURE ...............
      RESIDUAL TOLERANCE .......................  1.000E-01
      MAXIMUM NUMBER OF ITERATIONS .............        1000
      ITERATIONS FOR INTERMEDIATE PRINT .......          410
      MAXIMUM RESIDUAL TOLERANCE ...............  6.000E-01
      PREDICTOR SCALE FACTOR FUNCTION .........            0
      MINIMUM DAMPING FACTOR ...................  2.000E-01
      EFFECTIVE MODULUS STATUS ................. CONSTANT
      GRAVITY LOADS APPLIED ....................
      SCALE FACTOR APPLIED TO TIME STEP .......   1.000E+00
      STRAIN SOFTENING SCALE FACTOR ...........   1.000E+00
      HOURGLASS STIFFNESS FACTOR ..............   5.000E-02
      HOURGLASS VISCOSITY FACTOR ..............   0.000E+00



              L O A D   S T E P   D E F I N I T I O N S
```

```
   TIME           NO. OF STEPS          TIME
0.000E+00              10            5.000E+00


       P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME     STEPS BETWEEN PRINTS         TIME
0.000E+00               2            5.000E+00


       P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME     STEPS BETWEEN PLOTS          TIME
0.000E+00               1            5.000E+00


       M A T E R I A L   D E F I N I T I O N S


 MATERIAL TYPE ........................ELASTIC
 MATERIAL ID ..........................           5
 DENSITY ..............................   1.000E+00
 MATERIAL PROPERTIES:
        YOUNGS MODULUS        =     1.000E+04
        POISSONS RATIO        =     0.000E+00
```

Information Only

Information Only

```
MATERIAL TYPE .........................ELASTIC
MATERIAL ID ..........................          4
DENSITY ..............................  1.000E+00
MATERIAL PROPERTIES:
       YOUNGS MODULUS        =    1.000E+04
       POISSONS RATIO        =    0.000E+00

MATERIAL TYPE .........................ELASTIC
MATERIAL ID ..........................          3
DENSITY ..............................  1.000E+00
MATERIAL PROPERTIES:
       YOUNGS MODULUS        =    1.000E+04
       POISSONS RATIO        =    0.000E+00

MATERIAL TYPE .........................ELASTIC
MATERIAL ID ..........................          2
DENSITY ..............................  1.000E+00
MATERIAL PROPERTIES:
       YOUNGS MODULUS        =    1.000E+04
       POISSONS RATIO        =    0.000E+00

MATERIAL TYPE .........................ELASTIC
MATERIAL ID ..........................          1
DENSITY ..............................  1.000E+00
MATERIAL PROPERTIES:
       YOUNGS MODULUS        =    1.000E+04
       POISSONS RATIO        =    0.000E+00


ELEMENT MATERIAL BLOCK DELETION
```

Information Only

```
                    MATERIAL ID     DELETION TIME
                         1            1.000E+01
                         2            4.000E+00
                         3            3.000E+00
                         4            2.000E+00
                         5            1.000E+00



               F U N C T I O N   D E F I N I T I O N S


        FUNCTION ID .........      1     NUMBER OF POINTS ....      2

                   N        S           F(S)
                   1    0.000E+00    1.000E+00
                   2    5.000E+00    1.000E+00



   N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                NODE SET FLAG      DIRECTION
                      1                X
                      2                Y



                E N D   O F   D A T A   I N P U T   P H A S E
                     1.975E-01 CPU SECONDS USED
```

```
                    6 WORDS ALLOCATED



     E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                 1.230E-02 CPU SECONDS USED
                    205 WORDS ALLOCATED



      V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

               NODAL          ELEMENT        GLOBAL
               -----          -------        ------
               DISPLX         SIGXX          FX
               DISPLY         SIGYY          FY
                              SIGZZ          RX
                              TAUXY          RY
                              STATUS         ITER
                                             RMAG


**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****



**** PLOT TAPE WRITTEN AT TIME = 5.000E-01  STEP NUMBER     1 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/04/96 ,AT 15:16:43
 GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      2, TIME = 1.000E+00
NUMBER OF ITERATIONS =       359, TOTAL NUMBER OF ITERATIONS =       741
FINAL CONVERGENCE TOLERANCE = 9.899E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 6.465E-14
SUM OF REACTION FORCES IN Y-DIRECTION =-2.002E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     2 ****



**** PLOT TAPE WRITTEN AT TIME = 1.500E+00  STEP NUMBER     3 ****
```

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/04/96 ,AT 15:16:43
GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     4, TIME = 2.000E+00
NUMBER OF ITERATIONS =        288, TOTAL NUMBER OF ITERATIONS =       1300
FINAL CONVERGENCE TOLERANCE = 9.177E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.000E+02
SUM OF REACTION FORCES IN X-DIRECTION =-2.831E-13
SUM OF REACTION FORCES IN Y-DIRECTION =-1.623E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER     4 ****



**** PLOT TAPE WRITTEN AT TIME = 2.500E+00  STEP NUMBER     5 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/04/96 ,AT 15:16:43
 GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      6, TIME = 3.000E+00
NUMBER OF ITERATIONS =        247, TOTAL NUMBER OF ITERATIONS =       1758
FINAL CONVERGENCE TOLERANCE = 9.904E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.000E+02
SUM OF REACTION FORCES IN X-DIRECTION =-1.092E-13
SUM OF REACTION FORCES IN Y-DIRECTION =-1.224E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 3.000E+00  STEP NUMBER     6 ****



**** PLOT TAPE WRITTEN AT TIME = 3.500E+00  STEP NUMBER     7 ****
```

Information Only

```
SANTOS, VERSION 2.0.0     ,RUN ON 03/04/96 ,AT 15:16:43
GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     8, TIME = 4.000E+00
NUMBER OF ITERATIONS =       154, TOTAL NUMBER OF ITERATIONS =      2108
FINAL CONVERGENCE TOLERANCE = 9.542E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.000E+02
SUM OF REACTION FORCES IN X-DIRECTION =-2.302E-14
SUM OF REACTION FORCES IN Y-DIRECTION =-8.240E+01
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 4.000E+00  STEP NUMBER     8 ****



**** PLOT TAPE WRITTEN AT TIME = 4.500E+00  STEP NUMBER     9 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/04/96 ,AT 15:16:43
 GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    10, TIME = 5.000E+00
NUMBER OF ITERATIONS =        85, TOTAL NUMBER OF ITERATIONS =     2262
FINAL CONVERGENCE TOLERANCE = 9.704E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.000E+02
SUM OF REACTION FORCES IN X-DIRECTION =-2.690E-14
SUM OF REACTION FORCES IN Y-DIRECTION =-4.257E+01
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 5.000E+00  STEP NUMBER    10 ****




           10 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                 E N D   O F   S O L U T I O N   P H A S E
                      4.137E+00 CPU SECONDS USED
                           205 WORDS ALLOCATED
```

Information Only

Intentionally Left Blank

Information Only

APPENDIX C

Input/Output Data For Problem 3 – Prescribed Force Option Problem

The following two sections present the input data and the formatted output for the prescribed force option problem.

FASTQ and SANTOS Input Data For The Prescribed Force Option Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the prescribed force option problem.

Information Only

```
TITLE
 BEAM PROBLEM - 30 TO 1 BEAM - FORCE B.C. - SANTOS QA - 11/30/94
POINT    1    0.     0.
POINT    2   30.     0.
POINT    3   30.     0.5
POINT    4   30.     1.
POINT    5    0.     1.
LINE     1   STR     1     2     0     30
LINE     2   STR     2     3     0      2
LINE     3   STR     3     4     0      2
LINE     4   STR     4     5     0     30
LINE     5   STR     1     5     0      4
POINBC   1    3
NODEBC   2    5
SCHEME   0MP
REGION   1    1    -1    -2    -3    -4   -5
EXIT
```

Information Only

```
TITLE
 30 TO 1 BEAM WITH CONCENTRATED FORCE - SANTOS QA - 11/30/94
PLANE STRAIN
RESIDUAL TOLERANCE, 0.1
MAXIMUM ITERATIONS, 20000
MAXIMUM TOLERANCE, 1000
NO DAMPING,120,20
MATERIAL,1,ELASTIC,1.0
YOUNGS MODULUS = 1.0E+7
POISSONS RATIO = 0.0
END
FUNCTION, 1  $ FUNCTION USED TO DEFINE PRESCRIBED FORCE
   0.   0.
   2.  20.
END
STEP CONTROL
  400,2.
END
PLOT TIME
  100,2.
END
OUTPUT TIME
  400,2.
END
NO DISPLACEMENT Y,2
NO DISPLACEMENT X,2
PRESCRIBED FORCE,Y,1,1,-1.
EXIT
```

Information Only

SANTOS Output For The Prescribed Force Option Problem

The following section presents a portion of the SANTOS printed output for the prescribed force option analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

```
  SSSSSS   AAAAA   N    NN  TTTTTT   OOOOO   SSSSSS
 SS       AA   AA  NN   NN    TT    OO   OO SS
 SS       AA   AA  NNN  NN    TT    OO   OO SS
  SSSSS   AAAAAAA  NN N NN    TT    OO   OO  SSSSS
      SS  AA   AA  NN  NNN    TT    OO   OO      SS
      SS  AA   AA  NN   NN    TT    OO   OO      SS
 SSSSSS   AA   AA  NN    N    TT     OOOOO  SSSSSS



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               DERIVED FROM PRONTO2D BY
         LEE M. TAYLOR AND DENNIS P. FLANAGAN



            RUN ON 03/08/96 AT 11:19:06
          RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                           INPUT STREAM IMAGES
LINE -----------------------------------------------------------------
  1: TITLE
  2:  30 TO 1 BEAM WITH CONCENTRATED FORCE - SANTOS QA - 11/30/94
  3: PLANE STRAIN
  4: RESIDUAL TOLERANCE, 0.1
  5: MAXIMUM ITERATIONS, 20000
  6: MAXIMUM TOLERANCE, 1000
  7: NO DAMPING,120,20
  8: MATERIAL,1,ELASTIC,1.0
  9: YOUNGS MODULUS = 1.0E+7
 10: POISSONS RATIO = 0.0
 11: END
 12: FUNCTION, 1  $ FUNCTION USED TO DEFINE PRESCRIBED FORCE
 13:    0.   0.
 14:    2.  20.
 15: END
 16: STEP CONTROL
 17:   400,2.
 18: END
 19: PLOT TIME
 20:   100,2.
 21: END
 22: OUTPUT TIME
 23:   400,2.
 24: END
 25: NO DISPLACEMENT Y,2
 26: NO DISPLACEMENT X,2
 27: PRESCRIBED FORCE,Y,1,1,-1.
 28: EXIT
     -----------------------------------------------------------------
```

```
                P R O B L E M   T I T L E

   30 TO 1 BEAM WITH CONCENTRATED FORCE - SANTOS QA - 11/30/94



           P R O B L E M   D E F I N I T I O N

    NUMBER OF ELEMENTS ......................        120
    NUMBER OF NODES .........................        155
    NUMBER OF MATERIALS .....................          1
    NUMBER OF FUNCTIONS .....................          1
    NUMBER OF CONTACT SURFACES ..............          0
    NUMBER OF RIGID SURFACES ................          0
    NUMBER OF MATERIAL POINTS MONITORED .....          0
    ANALYSIS TYPE ........................... PLANE STRAIN
    GLOBAL CONVERGENCE MEASURE ..............
    RESIDUAL TOLERANCE ......................  1.000E-01
    MAXIMUM NUMBER OF ITERATIONS ............      20000
    ITERATIONS FOR INTERMEDIATE PRINT .......        310
    MAXIMUM RESIDUAL TOLERANCE ..............  1.000E+03
    PREDICTOR SCALE FACTOR FUNCTION .........          0
    MINIMUM DAMPING FACTOR ..................  2.000E-01
    EFFECTIVE MODULUS STATUS ................ CONSTANT
    NO DAMPING OPTION ....................... ACTIVE
       NUMBER OF NO DAMPING ITERATIONS ......        120
       NUMBER OF LOAD STEPS WITH NO DAMPING .         20
    SCALE FACTOR APPLIED TO TIME STEP .......  1.000E+00
    STRAIN SOFTENING SCALE FACTOR ...........  1.000E+00
    HOURGLASS STIFFNESS FACTOR ..............  5.000E-02
    HOURGLASS VISCOSITY FACTOR ..............  0.000E+00
```

Information Only

```
         L O A D   S T E P   D E F I N I T I O N S


  TIME           NO. OF STEPS          TIME
0.000E+00           400              2.000E+00



         P R I N T E D   O U T P U T   F R E Q U E N C Y


  TIME      STEPS BETWEEN PRINTS          TIME
0.000E+00           400                 2.000E+00



         P L O T T E D   O U T P U T   F R E Q U E N C Y


  TIME      STEPS BETWEEN PLOTS           TIME
0.000E+00           100                 2.000E+00



         M A T E R I A L   D E F I N I T I O N S


MATERIAL TYPE .........................ELASTIC
MATERIAL ID ..........................           1
DENSITY ..............................   1.000E+00
MATERIAL PROPERTIES:
       YOUNGS MODULUS         =     1.000E+07
       POISSONS RATIO         =     0.000E+00
```

Information Only

```
            F U N C T I O N   D E F I N I T I O N S

      FUNCTION ID .........       1     NUMBER OF POINTS ....      2

                   N       S            F(S)
                   1     0.000E+00     0.000E+00
                   2     2.000E+00     2.000E+01



   N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                NODE SET FLAG     DIRECTION
                     2                Y
                     2                X



 P R E S C R I B E D   N O D A L   F O R C E   B O U N D A R Y   C O N D I T I O N S

     NODE SET     DIRECTION    FUNCTION     SCALE          A0          B0
       FLAG                       ID        FACTOR
        1             Y           1       -1.000E+00        -           -
```

Information Only

Information Only

```
              E N D   O F   D A T A   I N P U T   P H A S E
                      1.209E-01 CPU SECONDS USED
                              6 WORDS ALLOCATED


     E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                      1.147E-02 CPU SECONDS USED
                            155 WORDS ALLOCATED


     V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                NODAL          ELEMENT        GLOBAL
                -----          -------        ------
                DISPLX         SIGXX          FX
                DISPLY         SIGYY          FY
                               SIGZZ          RX
                               TAUXY          RY
                                              ITER
                                              RMAG


  **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****


STEP     TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT   TOTAL
                    STEP      FACTOR     LOAD NORM  LOAD NORM   IMBALANCE  STEPS
  310  5.000E-03  5.000E-03  1.000E+00  5.000E-02  1.287E-02     25.73      310
```

620	5.000E-03	5.000E-03	9.989E-01	5.000E-02	1.110E-02	22.20	620
930	5.000E-03	5.000E-03	9.978E-01	5.000E-02	9.991E-03	19.98	930
1240	5.000E-03	5.000E-03	9.983E-01	5.000E-02	9.107E-03	18.21	1240
1550	5.000E-03	5.000E-03	9.980E-01	5.000E-02	8.297E-03	16.59	1550
1860	5.000E-03	5.000E-03	9.964E-01	5.000E-02	8.132E-03	16.26	1860
2170	5.000E-03	5.000E-03	9.986E-01	5.000E-02	8.011E-03	16.02	2170
2480	5.000E-03	5.000E-03	9.993E-01	5.000E-02	7.989E-03	15.98	2480
2790	5.000E-03	5.000E-03	1.000E+00	5.000E-02	7.878E-03	15.76	2790
3100	5.000E-03	5.000E-03	9.996E-01	5.000E-02	7.610E-03	15.22	3100
3410	5.000E-03	5.000E-03	9.996E-01	5.000E-02	7.323E-03	14.65	3410
3720	5.000E-03	5.000E-03	9.997E-01	5.000E-02	7.058E-03	14.12	3720
4030	5.000E-03	5.000E-03	9.996E-01	5.000E-02	6.729E-03	13.46	4030
4340	5.000E-03	5.000E-03	9.995E-01	5.000E-02	6.481E-03	12.96	4340
4650	5.000E-03	5.000E-03	9.994E-01	5.000E-02	6.199E-03	12.40	4650
4960	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.894E-03	11.79	4960
5270	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.608E-03	11.22	5270
5580	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.328E-03	10.66	5580
5890	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.060E-03	10.12	5890
6200	5.000E-03	5.000E-03	9.994E-01	5.000E-02	4.860E-03	9.72	6200
6510	5.000E-03	5.000E-03	9.995E-01	5.000E-02	4.612E-03	9.22	6510
6820	5.000E-03	5.000E-03	9.995E-01	5.000E-02	4.351E-03	8.70	6820
7130	5.000E-03	5.000E-03	9.995E-01	5.000E-02	4.111E-03	8.22	7130
7440	5.000E-03	5.000E-03	9.995E-01	5.000E-02	3.864E-03	7.73	7440
7750	5.000E-03	5.000E-03	9.995E-01	5.000E-02	3.654E-03	7.31	7750
8060	5.000E-03	5.000E-03	9.995E-01	5.000E-02	3.456E-03	6.91	8060
8370	5.000E-03	5.000E-03	9.994E-01	5.000E-02	3.244E-03	6.49	8370
8680	5.000E-03	5.000E-03	9.994E-01	5.000E-02	3.058E-03	6.12	8680
8990	5.000E-03	5.000E-03	9.994E-01	5.000E-02	2.884E-03	5.77	8990
9300	5.000E-03	5.000E-03	9.994E-01	5.000E-02	2.702E-03	5.40	9300
9610	5.000E-03	5.000E-03	9.994E-01	5.000E-02	2.550E-03	5.10	9610
9920	5.000E-03	5.000E-03	9.994E-01	5.000E-02	2.404E-03	4.81	9920

Information Only

Information Only

```
  SANTOS, VERSION 2.0.0    ,RUN ON 03/08/96 ,AT 11:19:06
 30 TO 1 BEAM WITH CONCENTRATED FORCE - SANTOS QA - 11/30/94

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER   400, TIME = 2.000E+00
NUMBER OF ITERATIONS =         28, TOTAL NUMBER OF ITERATIONS =     66249
FINAL CONVERGENCE TOLERANCE = 9.636E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.000E+01
SUM OF REACTION FORCES IN X-DIRECTION = 1.663E-01
SUM OF REACTION FORCES IN Y-DIRECTION =-1.998E+01
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER   400 ****




            4 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                  E N D  O F  S O L U T I O N  P H A S E
                      1.007E+02 CPU SECONDS USED
                            155 WORDS ALLOCATED
```

APPENDIX D

Input/Output Data For Problem 4 – Distributed Load Function Problem

The following three sections present the input data, the distributed force subroutine, and the formatted output, respectively, for the distributed load function verification problem.

FASTQ and SANTOS Input Data For The Distributed Load Function Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the distributed load function problem.

Information Only

```
TITLE
   DISTRIBUTED LOAD PROBLEM -  16 ELEMENT
POINT  1      0.      0.
POINT  2      4.      0.
POINT  3      4.      4.
POINT  4      0.      4.
LINE   1      str  1     2     0     4    1.0
LINE   2      str  2     3     0     4    1.0
LINE   3      str  3     4     0     4    1.0
LINE   4      str  1     4     0     4    1.0
NODEBC    1   4
NODEBC    2   1
SCHEME    MP
REGION    1   1   -1    -2    -3   -4
END
```

Information Only

```
TITLE
 DISTRIBUTED LOAD PROBLEM  - SANTOS QA - 12/4/94
PLANE STRAIN
MAXIMUM ITERATIONS, 10000
MAXIMUM TOLERANCE, 1000
MATERIAL,1,ELASTIC,1.0
YOUNGS MODULUS = 1.0E+7
POISSONS RATIO = 0.0
END
DISTRIBUTED LOAD
STEP CONTROL
  4,2.
END
PLOT TIME
  1,2.
END
OUTPUT TIME
  4,2.
END
NO DISPLACEMENT Y,2
NO DISPLACEMENT X,1
EXIT
```

Information Only

Distributed Force Subroutine For The Distributed Load Function Problem

This section presents a listing of the DISTL subroutine that was used in SANTOS to specify the distributed loading for the distributed load function problem analysis.

Information Only

```
c
c.....program distl
c
c.....this program calculates the distributed force for the qa test
c.....problem for santos
c.....programmer: J. F. Holland, Technadyne  12/1/94
c
      dimension fx(500),fy(500)
      common /gpa/ coord(500,2),nummod,numel
      character*16 ofile,mfile,jfile
c
c....open files
c
      ofile = 'sant_distl.dist'
      mfile = 'sant_distl.g'
      jfile = 'sant_distl.log'
      open(unit=12,file=ofile,status='new',form='unformatted')
      open(unit=11,file=mfile,status='old',form='unformatted')
      open(unit=13,file=jfile,status='new',form='formatted')
c
c
      wa = 100.
      wb = 100.
      call genny
      write(*,25) numel,nummod
 25   format(/,t5,'# of elements = ',i5,2x,'# of nodes = ',i5)
      i = 0
      do while ( i .le. 2 )
         fac = i
         n = 0
         do while ( n .lt. nummod )
            n = n + 1
            fx(n) = 0.
            fy(n) = 0.
        enddo
        mm = 21
        do while ( mm .lt. 25 )
          fy(mm) = fy(mm) + 114.286*fac
          fy(mm+1) = fy(mm+1) + 114.286*fac
          mm = mm + 1
        enddo
        write(12) fac,(fx(k),k = 1,nummod),(fy(m),m = 1,nummod)
c
c.....force check
c
         fsum = 0.
         n = 0
         do while ( n .lt. nummod)
            n = n + 1
            fsum = fsum + fy(n)
         enddo
         write(*,30) fac,fsum
 30      format(/,t10,'time = ',e11.4,2x,'total load = ',e11.4,/)
         write(13,35) fac
```

Information Only

```
          write(13,40) (n,fy(n),n = 1,nummod)
 35       format(/,t5,'time = ',e11.4,/)
 40       format(t10,'node = ',i5,2x,'fy = ',e11.4)
          i = i + 1
      enddo
c
c
      close (11)
      close (12)
      close (13)
c
c
      stop
      end
c
c
      SUBROUTINE GENNY
c
c.....THIS SUBROUTINE READS THE FASTQ GENESIS DATA BASE
c
      COMMON /GPA/ COORD(500,2),NUMNOD,NUMEL
c
c.....READ DATA FROM THE GENESIS FILE
c
      READ (11)
c
c
      READ (11) NUMNOD,NDIM,NUMEL,NELBLK,NUMNPS,LNPSNL,NUMESS,LESSEL,
     *LESSNL,IVERS
c
c.....READ IN THE COORDINATE DATA
c
      READ (11) ( ( COORD(I,J), I = 1,NUMNOD ), J = 1,NDIM )
c
c
      return
      end
```

Information Only

SANTOS Output For The Distributed Load Function Problem

The following section presents the SANTOS printed output for the distributed load function analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echos input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end.

Information Only

Information Only

```
 SSSSSS    AAAAA    N     NN  TTTTTT    OOOOO    SSSSSS
SS        AA   AA  NN     NN    TT     OO   OO  SS
SS        AA   AA  NNN    NN    TT     OO   OO  SS
 SSSSS    AAAAAAA  NN N   NN    TT     OO   OO   SSSSS
     SS   AA   AA  NN   NNN     TT     OO   OO       SS
     SS   AA   AA  NN    NN     TT     OO   OO       SS
SSSSSS    AA   AA  NN     N     TT      OOOOO   SSSSSS



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                   PROGRAMMED BY:

                 CHARLES M. STONE
            ENGINEERING SCIENCES CENTER
           SANDIA NATIONAL LABORATORIES
           ALBUQUERQUE, NEW MEXICO 87185

             DERIVED FROM PRONTO2D BY
        LEE M. TAYLOR AND DENNIS P. FLANAGAN



            RUN ON 03/05/96 AT 08:33:57
          RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

```
                         INPUT STREAM IMAGES
LINE -----------------------------------------------------------------------
  1: TITLE
  2:  DISTRIBUTED LOAD PROBLEM  - SANTOS QA - 12/4/94
  3: PLANE STRAIN
  4: MAXIMUM ITERATIONS, 10000
  5: MAXIMUM TOLERANCE, 1000
  6: MATERIAL,1,ELASTIC,1.0
  7: YOUNGS MODULUS = 1.0E+7
  8: POISSONS RATIO = 0.0
  9: END
 10: DISTRIBUTED LOAD
 11: STEP CONTROL
 12:   4,2.
 13: END
 14: PLOT TIME
 15:   1,2.
 16: END
 17: OUTPUT TIME
 18:   4,2.
 19: END
 20: NO DISPLACEMENT Y,2
 21: NO DISPLACEMENT X,1
 22: EXIT
     -----------------------------------------------------------------------
```

Information Only

```
                    P R O B L E M   T I T L E

        DISTRIBUTED LOAD PROBLEM   - SANTOS QA - 12/4/94



                  P R O B L E M   D E F I N I T I O N

          NUMBER OF ELEMENTS .......................          16
          NUMBER OF NODES ..........................          25
          NUMBER OF MATERIALS ......................           1
          NUMBER OF FUNCTIONS ......................           0
          NUMBER OF CONTACT SURFACES ...............           0
          NUMBER OF RIGID SURFACES .................           0
          NUMBER OF MATERIAL POINTS MONITORED .....           0
          ANALYSIS TYPE ............................ PLANE STRAIN
          GLOBAL CONVERGENCE MEASURE ...............
          RESIDUAL TOLERANCE .......................  5.000E-01
          MAXIMUM NUMBER OF ITERATIONS .............      10000
          ITERATIONS FOR INTERMEDIATE PRINT .......          50
          MAXIMUM RESIDUAL TOLERANCE ...............  1.000E+03
          PREDICTOR SCALE FACTOR FUNCTION .........           0
          MINIMUM DAMPING FACTOR ...................  2.000E-01
          EFFECTIVE MODULUS STATUS ................. CONSTANT
          DISTRIBUTED BODY LOADS APPLIED ..........
          SCALE FACTOR APPLIED TO TIME STEP .......  1.000E+00
          STRAIN SOFTENING SCALE FACTOR ...........  1.000E+00
          HOURGLASS STIFFNESS FACTOR ..............  5.000E-02
          HOURGLASS VISCOSITY FACTOR ..............  0.000E+00



                L O A D   S T E P   D E F I N I T I O N S
```

```
   TIME           NO. OF STEPS          TIME
 0.000E+00             4             2.000E+00


       P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME     STEPS BETWEEN PRINTS         TIME
 0.000E+00             4             2.000E+00


       P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME     STEPS BETWEEN PLOTS          TIME
 0.000E+00             1             2.000E+00


       M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE .........................ELASTIC
  MATERIAL ID ...........................          1
  DENSITY ...............................  1.000E+00
  MATERIAL PROPERTIES:
         YOUNGS MODULUS        =    1.000E+07
         POISSONS RATIO        =    0.000E+00
```

Information Only

Information Only

```
N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                NODE SET FLAG       DIRECTION
                      2                 Y
                      1                 X



                E N D   O F   D A T A   I N P U T   P H A S E
                        9.717E-02 CPU SECONDS USED
                                10 WORDS ALLOCATED



        E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                        1.962E-02 CPU SECONDS USED
                                25 WORDS ALLOCATED



     V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                  NODAL         ELEMENT        GLOBAL
                  -----         -------        ------
                  DISPLX        SIGXX          FX
                  DISPLY        SIGYY          FY
                                SIGZZ          RX
                                TAUXY          RY
```

```
                                   ITER
                                   RMAG


    **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****



 STEP       TIME        TIME       DAMPING     APPLIED     RESIDUAL     PERCENT     TOTAL
                        STEP        FACTOR    LOAD NORM   LOAD NORM    IMBALANCE    STEPS
    50  5.000E-01   5.000E-01   4.505E-01   1.010E+02   5.983E-01       0.59        50

    **** PLOT TAPE WRITTEN AT TIME = 5.000E-01   STEP NUMBER     1 ****


    **** PLOT TAPE WRITTEN AT TIME = 1.000E+00   STEP NUMBER     2 ****


    **** PLOT TAPE WRITTEN AT TIME = 1.500E+00   STEP NUMBER     3 ****
```

Information Only

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 08:33:57

 DISTRIBUTED LOAD PROBLEM  - SANTOS QA - 12/4/94

***********************************************************************
SUMMARY OF DATA AT STEP NUMBER     4, TIME = 2.000E+00
NUMBER OF ITERATIONS =          3, TOTAL NUMBER OF ITERATIONS =          62
FINAL CONVERGENCE TOLERANCE = 2.590E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 8.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 6.558E-05
SUM OF REACTION FORCES IN Y-DIRECTION = 7.958E+02
***********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER     4 ****





            4 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                  E N D  O F  S O L U T I O N  P H A S E
                     4.873E-02 CPU SECONDS USED
                           50 WORDS ALLOCATED
```

APPENDIX E

Input/Output Data For Problem 5 – Adaptive Pressure Option Problem

The following three sections present the input data, the pressure subroutine, and the formatted output, respectively, for the adaptive pressure option verification problem.

FASTQ and SANTOS Input Data For The Adaptive Pressure Option Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the adaptive pressure option problem.

Information Only

```
TITLE
 HOLLOW CYLINDER - SANTOS QA TEST PROBLEM - 10/24/94
POINT    1      0.        0.
POINT    2      1.        0.
POINT    3      0.        1.
POINT    4      0.        1.5
POINT    5      1.5       0.
LINE     1    CIRC  2    3    1    20   1.0
LINE     2    STR   3    4    0    20   1.0
LINE     3    CIRC  5    4    1    20   1.0
LINE     4    STR   2    5    0    20   1.0
NODEBC   1    2
NODEBC   2    4
NODEBC   4    1
ELEMBC   3    1
SCHEME   0    MP
REGION   1     1    -1   -2   -3   -4
EXIT
```

Information Only

```
TITLE
  SANTOS QA PROBLEM - ADAPTIVE PRESSURE PROBLEM - AXISYMMETRIC
AXISYMMETRIC
MAXIMUM ITERATIONS 40000
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS, 1.E+7
POISSONS RATIO, 0.3
END
FUNCTION 2  $ DISPLACEMENT FUNCTION
   0.      0.
   1.E-4   0.
  10.      0.25
END
STEP CONTROL
   1   1.E-4
  20  10.
END
OUTPUT TIME
   0   1.E-4
   0  10.
END
PLOT TIME
   1   1.E-4
   1  10.
END
ADAPTIVE PRESSURE 3 0. 0.
PRESCRIBED DISPLACEMENT RADIAL 4 2 1. 0. 0.
NO DISPLACEMENT Y  2
NO DISPLACEMENT X  1
EXIT
```

Information Only

Pressure Subroutine For The Adaptive Pressure Option Problem

This section presents a listing of the FPRES subroutine that was used in SANTOS to specify the pressure within a cavity for the adaptive pressure option analysis.

Information Only

```
c
c.....subroutine fpres
c
c.....this subroutine is used to develop pressure within a cavity
c.....for qa test of the adpative pressure function
c.....programmer: J. F. Holland, Technadyne
c
      subroutine fpres(volume,time,pgas)
      common /john/ vol1,nacho
c
c
      po = 1.E+1
      if( time .le. 1.e-4 ) nacho = 1
c
c....this assumes the gas behaves as an ideal gas. When the volume
c....of the cavity increases there is a proportional decrease in the
c....pressure of the gas
c
      if( volume .ne. 0. .and. nacho .eq. 1 ) then
         vol1 = volume
         nacho = 0
      endif
      if( time .gt. 0. ) then
         pgas = po*vol1/volume
      else
         pgas = po
      endif
c
c
      return
      end
```

Information Only

SANTOS Output For The Adaptive Pressure Option Problem

The following section presents a portion of the SANTOS printed output for the adaptive pressure option analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of the first few hundred lines of output and the last few tens of line of output, is provided

Information Only

```
 SSSSSS  AAAAA   N    NN TTTTTT   OOOOO   SSSSSS
SS      AA  AA  NN   NN   TT    OO   OO SS
SS      AA  AA  NNN  NN   TT    OO   OO SS
 SSSSS  AAAAAAA NN N NN   TT    OO   OO  SSSSS
     SS AA  AA  NN  NNN   TT    OO   OO      SS
     SS AA  AA  NN   NN   TT    OO   OO      SS
SSSSSS  AA  AA  NN    N   TT     OOOOO  SSSSSS



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            DERIVED FROM PRONTO2D BY
       LEE M. TAYLOR AND DENNIS P. FLANAGAN



           RUN ON 03/05/96 AT 13:30:39
         RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

```
                              INPUT STREAM IMAGES
LINE --------------------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - ADAPTIVE PRESSURE PROBLEM - AXISYMMETRIC
  3: AXISYMMETRIC
  4: MAXIMUM ITERATIONS 40000
  5: MATERIAL,1,ELASTIC,1.
  6: YOUNGS MODULUS, 1.E+7
  7: POISSONS RATIO, 0.3
  8: END
  9: FUNCTION 2  $ DISPLACEMENT FUNCTION
 10:    0.       0.
 11:    1.E-4    0.
 12:   10.       0.25
 13: END
 14: STEP CONTROL
 15:    1   1.E-4
 16:   20  10.
 17: END
 18: OUTPUT TIME
 19:    0   1.E-4
 20:    0  10.
 21: END
 22: PLOT TIME
 23:    1   1.E-4
 24:    1  10.
 25: END
 26: ADAPTIVE PRESSURE 3 0. 0.
 27: PRESCRIBED DISPLACEMENT RADIAL 4 2 1. 0. 0.
 28: NO DISPLACEMENT Y  2
 29: NO DISPLACEMENT X  1
 30: EXIT
     ---------------------------------------------------------------------------
```

Information Only

```
                 P R O B L E M   T I T L E

SANTOS QA PROBLEM - ADAPTIVE PRESSURE PROBLEM - AXISYMMETRIC



                  P R O B L E M   D E F I N I T I O N

  NUMBER OF ELEMENTS .......................        400
  NUMBER OF NODES ..........................        441
  NUMBER OF MATERIALS ......................          1
  NUMBER OF FUNCTIONS ......................          1
  NUMBER OF CONTACT SURFACES ...............          0
  NUMBER OF RIGID SURFACES .................          0
  NUMBER OF MATERIAL POINTS MONITORED .....           0
  ANALYSIS TYPE ............................ AXISYMMETRIC
  GLOBAL CONVERGENCE MEASURE ...............
  RESIDUAL TOLERANCE .......................  5.000E-01
  MAXIMUM NUMBER OF ITERATIONS .............      40000
  ITERATIONS FOR INTERMEDIATE PRINT .......         882
  MAXIMUM RESIDUAL TOLERANCE ...............  6.000E-01
  PREDICTOR SCALE FACTOR FUNCTION .........           0
  MINIMUM DAMPING FACTOR ...................  2.000E-01
  EFFECTIVE MODULUS STATUS ................. CONSTANT
  ADAPTIVE PRESSURE B. C. APPLIED .........
  SCALE FACTOR APPLIED TO TIME STEP .......   1.000E+00
  STRAIN SOFTENING SCALE FACTOR ...........   1.000E+00
  HOURGLASS STIFFNESS FACTOR ...............  1.000E-02
  HOURGLASS VISCOSITY FACTOR ...............  3.000E-02



                L O A D   S T E P   D E F I N I T I O N S
```

Information Only

Information Only

```
    TIME           NO. OF STEPS          TIME
  0.000E+00              1             1.000E-04
  1.000E-04             20             1.000E+01



            P R I N T E D   O U T P U T   F R E Q U E N C Y


    TIME      STEPS BETWEEN PRINTS        TIME
  0.000E+00             0              1.000E-04
  1.000E-04             0              1.000E+01



            P L O T T E D   O U T P U T   F R E Q U E N C Y


    TIME      STEPS BETWEEN PLOTS         TIME
  0.000E+00             1              1.000E-04
  1.000E-04             1              1.000E+01



            M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE ........................ELASTIC
  MATERIAL ID ..........................          1
  DENSITY ..............................  1.000E+00
  MATERIAL PROPERTIES:
          YOUNGS MODULUS        =     1.000E+07
```

Information Only

```
                 POISSONS RATIO          =    3.000E-01


                F U N C T I O N   D E F I N I T I O N S

         FUNCTION ID .........      2     NUMBER OF POINTS ....      3

                     N       S            F(S)
                     1   0.000E+00     0.000E+00
                     2   1.000E-04     0.000E+00
                     3   1.000E+01     2.500E-01



       N O  D I S P L A C E M E N T  B O U N D A R Y  C O N D I T I O N S

                  NODE SET FLAG    DIRECTION
                        2              Y
                        1              X



     P R E S C R I B E D  D I S P L A C E M E N T  B O U N D A R Y  C O N D I T I O N S

       NODE SET   DIRECTION   FUNCTION   SCALE        A0          B0
         FLAG                    ID      FACTOR
          4          RAD          2     1.000E+00  0.000E+00   0.000E+00
```

Information Only

```
A D A P T I V E   P R E S S U R E   B O U N D A R Y   C O N D I T I O N S

                    SURFACE          REFERENCE
                      FLAG             VALUE
                        3            0.000E+00 0.000E+00 0.000E+00



                E N D   O F   D A T A   I N P U T   P H A S E
                         1.461E-01 CPU SECONDS USED
                                63 WORDS ALLOCATED



        E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                         1.350E-02 CPU SECONDS USED
                               441 WORDS ALLOCATED



           V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                    NODAL          ELEMENT          GLOBAL
                    -----          -------          ------
                    DISPLX         SIGXX            FX
                    DISPLY         SIGYY            FY
                                   SIGZZ            RX
                                   TAUXY            RY
```

```
                          ITER
                          RMAG
                          PGAS
                          VOLUME

**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****


**** PLOT TAPE WRITTEN AT TIME = 1.000E-04  STEP NUMBER     1 ****


**** PLOT TAPE WRITTEN AT TIME = 5.001E-01  STEP NUMBER     2 ****


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     3 ****


**** PLOT TAPE WRITTEN AT TIME = 1.500E+00  STEP NUMBER     4 ****


**** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER     5 ****
```

Information Only

Information Only

```
**** PLOT TAPE WRITTEN AT TIME = 2.500E+00   STEP NUMBER      6 ****

**** PLOT TAPE WRITTEN AT TIME = 3.000E+00   STEP NUMBER      7 ****

**** PLOT TAPE WRITTEN AT TIME = 3.500E+00   STEP NUMBER      8 ****

**** PLOT TAPE WRITTEN AT TIME = 4.000E+00   STEP NUMBER      9 ****

**** PLOT TAPE WRITTEN AT TIME = 4.500E+00   STEP NUMBER     10 ****

**** PLOT TAPE WRITTEN AT TIME = 5.000E+00   STEP NUMBER     11 ****

**** PLOT TAPE WRITTEN AT TIME = 5.500E+00   STEP NUMBER     12 ****

**** PLOT TAPE WRITTEN AT TIME = 6.000E+00   STEP NUMBER     13 ****
```

```
**** PLOT TAPE WRITTEN AT TIME = 6.500E+00  STEP NUMBER    14 ****

**** PLOT TAPE WRITTEN AT TIME = 7.000E+00  STEP NUMBER    15 ****

**** PLOT TAPE WRITTEN AT TIME = 7.500E+00  STEP NUMBER    16 ****

**** PLOT TAPE WRITTEN AT TIME = 8.000E+00  STEP NUMBER    17 ****

**** PLOT TAPE WRITTEN AT TIME = 8.500E+00  STEP NUMBER    18 ****

**** PLOT TAPE WRITTEN AT TIME = 9.000E+00  STEP NUMBER    19 ****

**** PLOT TAPE WRITTEN AT TIME = 9.500E+00  STEP NUMBER    20 ****
```

Information Only

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 13:30:39
 SANTOS QA PROBLEM - ADAPTIVE PRESSURE PROBLEM - AXISYMMETRIC

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    21, TIME = 1.000E+01
NUMBER OF ITERATIONS =       307, TOTAL NUMBER OF ITERATIONS =      5022
FINAL CONVERGENCE TOLERANCE = 4.850E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 6.277E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 4.000E+00
SUM OF REACTION FORCES IN X-DIRECTION =-1.817E+06
SUM OF REACTION FORCES IN Y-DIRECTION = 1.154E+06
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+01  STEP NUMBER    21 ****




           21 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                E N D   O F   S O L U T I O N   P H A S E
                     2.514E+01 CPU SECONDS USED
                           441 WORDS ALLOCATED
```

APPENDIX F

Input/Output Data For Problem 6 – Spinning Disk Problem

The following two sections present the input data and the formatted output for the spinning disk verification problem.

FASTQ and SANTOS Input Data For The Spinning Disk Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the spinning disk problem.

Information Only

```
TITLE
 SPINNING DISK - SANTOS QA TEST PROBLEM - 10/14/94 - QUAD MESH
POINT    1       1.        0.
POINT    2       1.        0.1
POINT    3       2.        0.1
POINT    4       2.        0.
LINE     1    STR   1    2    0     8   1.0
LINE     2    STR   2    3    0    80   1.0
LINE     3    STR   3    4    0     8   1.0
LINE     4    STR   4    1    0    80   1.0
NODEBC   1    2
NODEBC   2    4
SCHEME   0    MP
REGION   1     1   -1   -2   -3   -4
EXIT
```

Information Only

```
TITLE
  SANTOS QA PROBLEM - SPINNING DISK - 10/14/94
AXISYMMETRIC
MAXIMUM ITERATIONS,2000
RESIDUAL TOLERANCE 0.1
MATERIAL,1,ELASTIC,2.1669E+03
YOUNGS MODULUS 2.07E+11
POISSONS RATIO 0.3
END
FUNCTION,1
  0.,1.
  1.,1.
END
STEP CONTROL
  1,1.
END
PLOT TIME
 1,1.
END
OUTPUT TIME
 1,1.
END
$ NO DISPLACEMENT,Y,1
NO DISPLACEMENT,Y,2
GRAVITY,1,0.,0.,100.
GLOBAL CONVERGENCE,1.E-8
EXIT
```

Information Only

SANTOS Output For The Spinning Disk Problem

The following section presents the SANTOS printed output for the spinning disk analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem-descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end.

Information Only

```
 SSSSSS    AAAAA    N     NN  TTTTTT    OOOOO    SSSSSS
SS        AA   AA   NN    NN    TT     OO   OO  SS
SS        AA   AA   NNN   NN    TT     OO   OO  SS
 SSSSS    AAAAAAA   NN N  NN    TT     OO   OO   SSSSS
     SS   AA   AA   NN  NNN     TT     OO   OO       SS
     SS   AA   AA   NN   NN     TT     OO   OO       SS
SSSSSS    AA   AA   NN    N     TT      OOOOO   SSSSSS



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                    PROGRAMMED BY:

                   CHARLES M. STONE
              ENGINEERING SCIENCES CENTER
             SANDIA NATIONAL LABORATORIES
             ALBUQUERQUE, NEW MEXICO 87185

               DERIVED FROM PRONTO2D BY
          LEE M. TAYLOR AND DENNIS P. FLANAGAN



              RUN ON 03/05/96 AT 14:05:39
            RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                         INPUT STREAM IMAGES
LINE ---------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - SPINNING DISK - 10/14/94
  3: AXISYMMETRIC
  4: MAXIMUM ITERATIONS,2000
  5: RESIDUAL TOLERANCE 0.1
  6: MATERIAL,1,ELASTIC,2.1669E+03
  7: YOUNGS MODULUS 2.07E+11
  8: POISSONS RATIO 0.3
  9: END
 10: FUNCTION,1
 11:   0.,1.
 12:   1.,1.
 13: END
 14: STEP CONTROL
 15:   1,1.
 16: END
 17: PLOT TIME
 18:  1,1.
 19: END
 20: OUTPUT TIME
 21:  1,1.
 22: END
 23: $ NO DISPLACEMENT,Y,1
 24: NO DISPLACEMENT,Y,2
 25: GRAVITY,1,0.,0.,100.
 26: GLOBAL CONVERGENCE,1.E-8
 27: EXIT
     ---------------------------------------------------------------
```

```
               P R O B L E M   T I T L E

     SANTOS QA PROBLEM - SPINNING DISK - 10/14/94


            P R O B L E M   D E F I N I T I O N

      NUMBER OF ELEMENTS ......................        640
      NUMBER OF NODES .........................        729
      NUMBER OF MATERIALS .....................          1
      NUMBER OF FUNCTIONS .....................          1
      NUMBER OF CONTACT SURFACES ..............          0
      NUMBER OF RIGID SURFACES ................          0
      NUMBER OF MATERIAL POINTS MONITORED .....          0
      ANALYSIS TYPE ........................... AXISYMMETRIC
      GLOBAL CONVERGENCE MEASURE ..............
      RESIDUAL TOLERANCE ......................  1.000E-01
      MAXIMUM NUMBER OF ITERATIONS ............       2000
      ITERATIONS FOR INTERMEDIATE PRINT .......       1458
      MAXIMUM RESIDUAL TOLERANCE ..............  6.000E-01
      PREDICTOR SCALE FACTOR FUNCTION .........          0
      MINIMUM DAMPING FACTOR ..................  2.000E-01
      EFFECTIVE MODULUS STATUS ................ CONSTANT
      GRAVITY LOADS APPLIED ...................
      SCALE FACTOR APPLIED TO TIME STEP .......  1.000E+00
      STRAIN SOFTENING SCALE FACTOR ...........  1.000E+00
      HOURGLASS STIFFNESS FACTOR ..............  1.000E-02
      HOURGLASS VISCOSITY FACTOR ..............  3.000E-02


             L O A D   S T E P   D E F I N I T I O N S
```

Information Only

```
   TIME          NO. OF STEPS           TIME
 0.000E+00            1              1.000E+00


        P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PRINTS         TIME
 0.000E+00            1                1.000E+00


        P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PLOTS          TIME
 0.000E+00            1                1.000E+00


        M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE .......................ELASTIC
  MATERIAL ID ..........................          1
  DENSITY ..............................   2.167E+03
  MATERIAL PROPERTIES:
        YOUNGS MODULUS        =    2.070E+11
        POISSONS RATIO        =    3.000E-01
```

Information Only

Information Only

```
                F U N C T I O N   D E F I N I T I O N S

        FUNCTION ID .........        1     NUMBER OF POINTS ....       2

                        N         S            F(S)
                        1     0.000E+00     1.000E+00
                        2     1.000E+00     1.000E+00



      N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                   NODE SET FLAG     DIRECTION
                         2               Y



                 E N D   O F   D A T A   I N P U T   P H A S E
                          1.533E-01 CPU SECONDS USED
                                162 WORDS ALLOCATED



         E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                          1.295E-02 CPU SECONDS USED
                                729 WORDS ALLOCATED
```

Information Only

```
V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                 NODAL          ELEMENT        GLOBAL
                 -----          -------        ------
                 DISPLX         SIGXX          FX
                 DISPLY         SIGYY          FY
                                SIGZZ          RX
                                TAUXY          RY
                                               ITER
                                               RMAG


 **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****



STEP     TIME        TIME      DAMPING     APPLIED     RESIDUAL    PERCENT     TOTAL
                     STEP      FACTOR     LOAD NORM   LOAD NORM   IMBALANCE    STEPS
 1458  1.000E+00  1.000E+00  9.893E-01  2.057E+05   8.817E+02       0.43       1458
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/05/96 ,AT 14:05:39
  SANTOS QA PROBLEM - SPINNING DISK - 10/14/94

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      1, TIME = 1.000E+00
NUMBER OF ITERATIONS =       1781, TOTAL NUMBER OF ITERATIONS =       1781
FINAL CONVERGENCE TOLERANCE = 9.994E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 5.058E+06
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 6.454E+01
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     1 ****




           1 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                 E N D   O F   S O L U T I O N   P H A S E
                      1.329E+01 CPU SECONDS USED
                            729 WORDS ALLOCATED
```

Intentionally Left Blank

Information Only

APPENDIX G

Input/Output Data For Problem 7 – Pressure and Gravity Loaded Beam Problems

The following two sections present the input data and the formatted output for the pressure and gravity loaded beam verification problems.

FASTQ and SANTOS Input Data For The Pressure and Gravity Loaded Beam Problems

This section presents a listing of each of the FASTQ and SANTOS input data files that were used for the mesh geneartion and analysis of the pressure and gravity loaded beam problems.

Information Only

```
TITLE
JAC BEAM SAMPLE PROBLEM - 30 TO 1 BEAM
POINT    1    0.     0.
POINT    2   30.     0.
POINT    3   30.     1.
POINT    4    0.     1.
LINE     1   STR     1     2     0    30
LINE     2   STR     2     3     0     4
LINE     3   STR     4     3     0    30
LINE     4   STR     1     4     0     4
REGION   1    1     -1    -2    -3    -4
NODEBC   1    1
NODEBC   2    2
NODEBC   3    3
NODEBC   4    4
ELEMBC   10   1
ELEMBC   20   2
ELEMBC   30   3
ELEMBC   40   4
SCHEME
EXIT
```

Information Only

Gravity Loaded Beam

```
TITLE
 30 TO 1 BEAM WITH GRAVITY LOADS - SANTOS QA PROBLEM
RESIDUAL TOLERANCE, 0.5
MAXIMUM ITERATIONS, 3000
INTERMEDIATE PRINT, 100
MAXIMUM TOLERANCE, 1000
NO DAMPING, 100, 50
PLANE STRAIN
STEP CONTROL
 310 1.55
 END
PLOT TIME
 10 1.55
END
OUTPUT TIME
 1 1.55
 END
PLOT NODAL DISPLACEMENT
PLOT ELEMENT STRESS,VONMISES
NO DISPLACEMENT Y, 4
NO DISPLACEMENT X, 4
GRAVITY,1,0.,1.,0.
FUNCTION, 1  $ FUNCTION TO DEFINE GRAVITY LOADS
0.  0.
2.  -2.
END
MATERIAL, 1, ELASTIC, 400.
YOUNGS MODULUS = 1.E7
POISSONS RATIO = 0.0
END
EXIT
```

Information Only

Pressure Loaded Beam

```
TITLE
 30 TO 1 BEAM WITH APPLIED PRESSURE
RESIDUAL TOLERANCE, 0.5
MAXIMUM ITERATIONS, 3000
INTERMEDIATE PRINT, 100
MAXIMUM TOLERANCE, 1000
NO DAMPING, 100, 50
PLANE STRAIN
STEP CONTROL
 1550 1.55
 END
PLOT TIME
 10 1.55
 END
OUTPUT TIME
 1 1.55
 END
PLOT NODAL DISPLACEMENT
PLOT ELEMENT STRESS,VONMISES
NO DISPLACEMENT Y, 4
NO DISPLACEMENT X, 4
PRESSURE, 30, 1, 400.
FUNCTION, 1  $ FUNCTION TO DEFINE PRESCRIBED DISPLACEMENT
0.  0.
2.  2.
END
MATERIAL, 1, ELASTIC, 2167.
YOUNGS MODULUS = 1.E7
POISSONS RATIO = 0.0
END
EXIT
```

Information Only

SANTOS Output For The Pressure and Gravity Loaded Beam Problems

The following section presents a portion of the SANTOS printed output for the pressure and gravity loaded beam analyses. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

Information Only

WPO# 35675 March 27, 1996

Gravity Loaded Beam

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS



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              ENGINEERING SCIENCES CENTER
             SANDIA NATIONAL LABORATORIES
             ALBUQUERQUE, NEW MEXICO 87185

               DERIVED FROM PRONTO2D BY
        LEE M. TAYLOR AND DENNIS P. FLANAGAN



             RUN ON 03/06/96 AT 14:24:50
            RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

```
                        INPUT STREAM IMAGES
LINE -----------------------------------------------------------------------
  1: TITLE
  2:  30 TO 1 BEAM WITH GRAVITY LOADS - SANTOS QA PROBLEM
  3: RESIDUAL TOLERANCE, 0.5
  4: MAXIMUM ITERATIONS, 3000
  5: INTERMEDIATE PRINT, 100
  6: MAXIMUM TOLERANCE, 1000
  7: NO DAMPING, 100, 50
  8: PLANE STRAIN
  9: STEP CONTROL
 10:  310 1.55
 11:  END
 12: PLOT TIME
 13:  10 1.55
 14: END
 15: OUTPUT TIME
 16:  1 1.55
 17:  END
 18: PLOT NODAL DISPLACEMENT
 19: PLOT ELEMENT STRESS,VONMISES
 20: NO DISPLACEMENT Y, 4
 21: NO DISPLACEMENT X, 4
 22: GRAVITY,1,0.,1.,0.
 23: FUNCTION, 1  $ FUNCTION TO DEFINE GRAVITY LOADS
 24: 0.   0.
 25: 2.   -2.
 26: END
 27: MATERIAL, 1, ELASTIC, 400.
 28: YOUNGS MODULUS = 1.E7
 29: POISSONS RATIO = 0.0
 30: END
 31: EXIT
     -----------------------------------------------------------------------
```

```
                  P R O B L E M   T I T L E

     30 TO 1 BEAM WITH GRAVITY LOADS - SANTOS QA PROBLEM


                P R O B L E M   D E F I N I T I O N

      NUMBER OF ELEMENTS .........................       120
      NUMBER OF NODES ............................       155
      NUMBER OF MATERIALS ........................         1
      NUMBER OF FUNCTIONS ........................         1
      NUMBER OF CONTACT SURFACES .................         0
      NUMBER OF RIGID SURFACES ...................         0
      NUMBER OF MATERIAL POINTS MONITORED ........         0
      ANALYSIS TYPE .............................. PLANE STRAIN
      GLOBAL CONVERGENCE MEASURE .................
      RESIDUAL TOLERANCE .........................  5.000E-01
      MAXIMUM NUMBER OF ITERATIONS ...............      3000
      ITERATIONS FOR INTERMEDIATE PRINT ..........       100
      MAXIMUM RESIDUAL TOLERANCE .................  1.000E+03
      PREDICTOR SCALE FACTOR FUNCTION ............         0
      MINIMUM DAMPING FACTOR .....................  2.000E-01
      EFFECTIVE MODULUS STATUS ................... CONSTANT
      NO DAMPING OPTION .......................... ACTIVE
         NUMBER OF NO DAMPING ITERATIONS .........       100
         NUMBER OF LOAD STEPS WITH NO DAMPING .         50
      GRAVITY LOADS APPLIED ......................
      SCALE FACTOR APPLIED TO TIME STEP ..........  1.000E+00
      STRAIN SOFTENING SCALE FACTOR ..............  1.000E+00
      HOURGLASS STIFFNESS FACTOR .................  5.000E-02
      HOURGLASS VISCOSITY FACTOR .................  0.000E+00
```

Information Only

```
          L O A D   S T E P   D E F I N I T I O N S


    TIME              NO. OF STEPS            TIME
  0.000E+00               310              1.550E+00



          P R I N T E D   O U T P U T   F R E Q U E N C Y


    TIME       STEPS BETWEEN PRINTS           TIME
  0.000E+00               1                1.550E+00



          P L O T T E D   O U T P U T   F R E Q U E N C Y


    TIME       STEPS BETWEEN PLOTS            TIME
  0.000E+00              10                1.550E+00



          M A T E R I A L   D E F I N I T I O N S


   MATERIAL TYPE ........................ELASTIC
   MATERIAL ID ..........................             1
   DENSITY ..............................  4.000E+02
   MATERIAL PROPERTIES:
          YOUNGS MODULUS         =    1.000E+07
```

Information Only

```
              POISSONS RATIO          =    0.000E+00



             F U N C T I O N   D E F I N I T I O N S

         FUNCTION ID .........      1     NUMBER OF POINTS ....      2

                      N        S          F(S)
                      1    0.000E+00   0.000E+00
                      2    2.000E+00  -2.000E+00



     N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                NODE SET FLAG      DIRECTION
                     4                 Y
                     4                 X



                E N D   O F   D A T A   I N P U T   P H A S E
                       1.605E-01 CPU SECONDS USED
                              72 WORDS ALLOCATED
```

Information Only

```
           E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                           1.186E-02 CPU SECONDS USED
                              155 WORDS ALLOCATED



             V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                       NODAL        ELEMENT      GLOBAL
                       -----        -------      ------
                       DISPLX       SIGXX        FX
                       DISPLY       SIGYY        FY
                                    SIGZZ        RX
                                    TAUXY        RY
                                    VONMISES     ITER
                                                 RMAG


     **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****



 STEP     TIME        TIME      DAMPING     APPLIED     RESIDUAL    PERCENT     TOTAL
                      STEP      FACTOR     LOAD NORM   LOAD NORM   IMBALANCE    STEPS
   100  5.000E-03  5.000E-03  1.000E+00  5.081E+00  4.815E+00     94.77       100
   200  5.000E-03  5.000E-03  9.971E-01  5.081E+00  4.664E+00     91.79       200
   300  5.000E-03  5.000E-03  9.976E-01  5.081E+00  4.585E+00     90.25       300
   400  5.000E-03  5.000E-03  9.979E-01  5.081E+00  4.445E+00     87.49       400
   500  5.000E-03  5.000E-03  9.983E-01  5.081E+00  4.362E+00     85.86       500
   600  5.000E-03  5.000E-03  9.983E-01  5.081E+00  4.339E+00     85.40       600
   700  5.000E-03  5.000E-03  9.985E-01  5.081E+00  4.267E+00     83.98       700
   800  5.000E-03  5.000E-03  9.987E-01  5.081E+00  4.161E+00     81.89       800
   900  5.000E-03  5.000E-03  9.989E-01  5.081E+00  4.041E+00     79.55       900
  1000  5.000E-03  5.000E-03  9.988E-01  5.081E+00  3.967E+00     78.08      1000
```

Information Only

1100	5.000E-03	5.000E-03	9.991E-01	5.081E+00	3.912E+00	76.99	1100
1200	5.000E-03	5.000E-03	9.989E-01	5.081E+00	3.851E+00	75.79	1200
1300	5.000E-03	5.000E-03	9.988E-01	5.081E+00	3.848E+00	75.73	1300
1400	5.000E-03	5.000E-03	9.988E-01	5.081E+00	3.847E+00	75.71	1400
1500	5.000E-03	5.000E-03	9.989E-01	5.081E+00	3.792E+00	74.63	1500
1600	5.000E-03	5.000E-03	9.990E-01	5.081E+00	3.735E+00	73.52	1600
1700	5.000E-03	5.000E-03	9.990E-01	5.081E+00	3.762E+00	74.05	1700
1800	5.000E-03	5.000E-03	9.991E-01	5.081E+00	3.740E+00	73.61	1800
1900	5.000E-03	5.000E-03	9.993E-01	5.081E+00	3.749E+00	73.80	1900
2000	5.000E-03	5.000E-03	9.994E-01	5.081E+00	3.741E+00	73.63	2000
2100	5.000E-03	5.000E-03	9.995E-01	5.081E+00	3.697E+00	72.76	2100
2200	5.000E-03	5.000E-03	9.999E-01	5.081E+00	3.670E+00	72.24	2200
2300	5.000E-03	5.000E-03	1.000E+00	5.081E+00	3.631E+00	71.47	2300
2400	5.000E-03	5.000E-03	1.000E+00	5.081E+00	3.563E+00	70.13	2400
2500	5.000E-03	5.000E-03	1.000E+00	5.081E+00	3.541E+00	69.70	2500
2600	5.000E-03	5.000E-03	1.000E+00	5.081E+00	3.492E+00	68.73	2600
2700	5.000E-03	5.000E-03	9.999E-01	5.081E+00	3.471E+00	68.32	2700
2800	5.000E-03	5.000E-03	9.998E-01	5.081E+00	3.420E+00	67.31	2800
2900	5.000E-03	5.000E-03	9.997E-01	5.081E+00	3.345E+00	65.83	2900

Information Only

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 14:24:50
30 TO 1 BEAM WITH GRAVITY LOADS - SANTOS QA PROBLEM

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER     1, TIME = 5.000E-03
NUMBER OF ITERATIONS =      3000, TOTAL NUMBER OF ITERATIONS =      3000
FINAL CONVERGENCE TOLERANCE = 6.500E+01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-6.000E+01
SUM OF REACTION FORCES IN X-DIRECTION = 9.400E-02
SUM OF REACTION FORCES IN Y-DIRECTION =-2.977E+01
*********************************************************************
  .
  .
  .
  .
  .

STEP       TIME        TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                       STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  100   1.545E+00   5.000E-03   9.800E-01  1.570E+03  8.148E+00      0.52     238637
```

```
  SANTOS, VERSION 2.0.0     ,RUN ON 03/06/96 ,AT 14:24:50
  30 TO 1 BEAM WITH GRAVITY LOADS - SANTOS QA PROBLEM

 *********************************************************************
 SUMMARY OF DATA AT STEP NUMBER   309, TIME = 1.545E+00
 NUMBER OF ITERATIONS =       133, TOTAL NUMBER OF ITERATIONS =    238670
 FINAL CONVERGENCE TOLERANCE = 4.997E-01
 SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
 SUM OF EXTERNAL FORCES IN Y-DIRECTION =-1.854E+04
 SUM OF REACTION FORCES IN X-DIRECTION =-2.809E+01
 SUM OF REACTION FORCES IN Y-DIRECTION =-1.860E+04
 *********************************************************************


STEP      TIME      TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  100  1.550E+00 5.000E-03 9.922E-01 1.575E+03 8.063E+00      0.51     238770
```

Information Only

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 14:24:50
 30 TO 1 BEAM WITH GRAVITY LOADS - SANTOS QA PROBLEM

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER   310, TIME = 1.550E+00
NUMBER OF ITERATIONS =       141, TOTAL NUMBER OF ITERATIONS =    238811
FINAL CONVERGENCE TOLERANCE = 5.000E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-1.860E+04
SUM OF REACTION FORCES IN X-DIRECTION =-3.491E+01
SUM OF REACTION FORCES IN Y-DIRECTION =-1.866E+04
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.550E+00  STEP NUMBER   310 ****




           31 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                 E N D  O F  S O L U T I O N  P H A S E
                      3.626E+02 CPU SECONDS USED
                            155 WORDS ALLOCATED
```

Pressure Loaded Beam

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS



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              DERIVED FROM PRONTO2D BY
         LEE M. TAYLOR AND DENNIS P. FLANAGAN



            RUN ON 03/06/96 AT 14:32:10
           RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                              INPUT STREAM IMAGES
LINE ---------------------------------------------------------------------------
  1: TITLE
  2:  30 TO 1 BEAM WITH APPLIED PRESSURE
  3: RESIDUAL TOLERANCE, 0.5
  4: MAXIMUM ITERATIONS, 3000
  5: INTERMEDIATE PRINT, 100
  6: MAXIMUM TOLERANCE, 1000
  7: NO DAMPING, 100, 50
  8: PLANE STRAIN
  9: STEP CONTROL
 10:  1550 1.55
 11:  END
 12: PLOT TIME
 13:  10 1.55
 14:  END
 15: OUTPUT TIME
 16:  1 1.55
 17:  END
 18: PLOT NODAL DISPLACEMENT
 19: PLOT ELEMENT STRESS,VONMISES
 20: NO DISPLACEMENT Y, 4
 21: NO DISPLACEMENT X, 4
 22: PRESSURE, 30, 1, 400.
 23: FUNCTION, 1  $ FUNCTION TO DEFINE PRESCRIBED DISPLACEMENT
 24: 0.  0.
 25: 2.  2.
 26: END
 27: MATERIAL, 1, ELASTIC, 2167.
 28: YOUNGS MODULUS = 1.E7
 29: POISSONS RATIO = 0.0
 30: END
 31: EXIT
    ----------------------------------------------------------------------------
```

Information Only

```
                 P R O B L E M   T I T L E

         30 TO 1 BEAM WITH APPLIED PRESSURE


              P R O B L E M   D E F I N I T I O N

          NUMBER OF ELEMENTS ......................        120
          NUMBER OF NODES .........................        155
          NUMBER OF MATERIALS .....................          1
          NUMBER OF FUNCTIONS .....................          1
          NUMBER OF CONTACT SURFACES ..............          0
          NUMBER OF RIGID SURFACES ................          0
          NUMBER OF MATERIAL POINTS MONITORED .....          0
          ANALYSIS TYPE ........................... PLANE STRAIN
          GLOBAL CONVERGENCE MEASURE ..............
          RESIDUAL TOLERANCE ......................  5.000E-01
          MAXIMUM NUMBER OF ITERATIONS ............       3000
          ITERATIONS FOR INTERMEDIATE PRINT .......        100
          MAXIMUM RESIDUAL TOLERANCE ..............  1.000E+03
          PREDICTOR SCALE FACTOR FUNCTION .........          0
          MINIMUM DAMPING FACTOR ..................  2.000E-01
          EFFECTIVE MODULUS STATUS ................ CONSTANT
          NO DAMPING OPTION ....................... ACTIVE
             NUMBER OF NO DAMPING ITERATIONS ......        100
             NUMBER OF LOAD STEPS WITH NO DAMPING .         50
          SCALE FACTOR APPLIED TO TIME STEP .......  1.000E+00
          STRAIN SOFTENING SCALE FACTOR ...........  1.000E+00
          HOURGLASS STIFFNESS FACTOR ..............  5.000E-02
          HOURGLASS VISCOSITY FACTOR ..............  0.000E+00
```

Information Only

```
          L O A D   S T E P   D E F I N I T I O N S


   TIME          NO. OF STEPS          TIME
 0.000E+00           1550            1.550E+00




          P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PRINTS        TIME
 0.000E+00             1             1.550E+00




          P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PLOTS         TIME
 0.000E+00            10             1.550E+00




          M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE .........................ELASTIC
  MATERIAL ID ..........................          1
  DENSITY ..............................  2.167E+03
  MATERIAL PROPERTIES:
         YOUNGS MODULUS        =    1.000E+07
         POISSONS RATIO        =    0.000E+00
```

Information Only

```
            F U N C T I O N   D E F I N I T I O N S

      FUNCTION ID .........     1     NUMBER OF POINTS ....      2

                N        S            F(S)
                1    0.000E+00     0.000E+00
                2    2.000E+00     2.000E+00


  N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

              NODE SET FLAG      DIRECTION
                    4                Y
                    4                X


  P R E S S U R E   B O U N D A R Y   C O N D T I O N S

           SURPACE       FUNCTION     SCALE
            FLAG          NUMBER      FACTOR
             30             1       4.000E+02
```

Information Only

```
                 E N D   O F   D A T A   I N P U T   P H A S E
                      1.415E-01 CPU SECONDS USED
                              72 WORDS ALLOCATED



          E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                      1.174E-02 CPU SECONDS USED
                             155 WORDS ALLOCATED



            V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                       NODAL          ELEMENT        GLOBAL
                       -----          -------        ------
                       DISPLX         SIGXX          FX
                       DISPLY         SIGYY          FY
                                      SIGZZ          RX
                                      TAUXY          RY
                                      VONMISES       ITER
                                                     RMAG


   **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****


STEP      TIME        TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP       FACTOR    LOAD NORM   LOAD NORM  IMBALANCE   STEPS
  100  1.000E-03  1.000E-03  1.000E+00  2.173E+00  4.084E+00    188.00       100
```

Information Only

200	1.000E-03	1.000E-03	1.000E+00	2.173E+00	4.510E+00	207.59	200
300	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.048E+00	140.29	300
400	1.000E-03	1.000E-03	1.000E+00	2.173E+00	4.364E+00	200.87	400
500	1.000E-03	1.000E-03	1.000E+00	2.173E+00	4.520E+00	208.07	500
600	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.608E+00	166.09	600
700	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.636E+00	167.34	700
800	1.000E-03	1.000E-03	1.000E+00	2.173E+00	4.253E+00	195.76	800
900	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.338E+00	153.66	900
1000	1.000E-03	1.000E-03	1.000E+00	2.173E+00	4.229E+00	194.66	1000
1100	1.000E-03	1.000E-03	1.000E+00	2.173E+00	4.476E+00	206.02	1100
1200	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.380E+00	155.56	1200
1300	1.000E-03	1.000E-03	1.000E+00	2.173E+00	4.206E+00	193.58	1300
1400	1.000E-03	1.000E-03	1.000E+00	2.173E+00	4.478E+00	206.14	1400
1500	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.449E+00	158.77	1500
1600	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.728E+00	171.62	1600
1700	1.000E-03	1.000E-03	1.000E+00	2.173E+00	4.683E+00	215.55	1700
1800	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.133E+00	144.19	1800
1900	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.905E+00	179.74	1900
2000	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.061E+00	140.89	2000
2100	1.000E-03	1.000E-03	1.000E+00	2.173E+00	3.644E+00	167.73	2100
2200	1.000E-03	1.000E-03	9.979E-01	2.173E+00	3.424E+00	157.60	2200
2300	1.000E-03	1.000E-03	8.506E-01	2.173E+00	9.953E-01	45.81	2300
2400	1.000E-03	1.000E-03	1.000E+00	2.173E+00	7.479E-01	34.42	2400
2500	1.000E-03	1.000E-03	9.983E-01	2.173E+00	7.293E-01	33.57	2500
2600	1.000E-03	1.000E-03	1.000E+00	2.173E+00	7.240E-01	33.33	2600
2700	1.000E-03	1.000E-03	9.976E-01	2.173E+00	7.150E-01	32.91	2700
2800	1.000E-03	1.000E-03	9.953E-01	2.173E+00	7.051E-01	32.46	2800
2900	1.000E-03	1.000E-03	9.980E-01	2.173E+00	6.937E-01	31.93	2900

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 14:32:10
 30 TO 1 BEAM WITH APPLIED PRESSURE

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     1, TIME = 1.000E-03
NUMBER OF ITERATIONS =      3000, TOTAL NUMBER OF ITERATIONS =      3000
FINAL CONVERGENCE TOLERANCE = 3.149E+01
SUM OF EXTERNAL FORCES IN X-DIRECTION =-3.089E-03
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-1.200E+01
SUM OF REACTION FORCES IN X-DIRECTION =-1.425E-03
SUM OF REACTION FORCES IN Y-DIRECTION =-7.233E+00
**********************************************************************
```

```
SANTOS, VERSION 2.0.0     ,RUN ON 03/06/96 ,AT 14:32:10
30 TO 1 BEAM WITH APPLIED PRESSURE

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER  1549, TIME = 1.549E+00
NUMBER OF ITERATIONS =        47, TOTAL NUMBER OF ITERATIONS =    268694
FINAL CONVERGENCE TOLERANCE = 4.962E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION =-1.233E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 5.530E+03
SUM OF REACTION FORCES IN X-DIRECTION =-1.239E+04
SUM OF REACTION FORCES IN Y-DIRECTION = 5.626E+03
**********************************************************************
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/06/96 ,AT 14:32:10
 30 TO 1 BEAM WITH APPLIED PRESSURE

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER  1550, TIME = 1.550E+00
NUMBER OF ITERATIONS =         35, TOTAL NUMBER OF ITERATIONS =    268729
FINAL CONVERGENCE TOLERANCE = 4.991E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION =-1.233E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 5.541E+03
SUM OF REACTION FORCES IN X-DIRECTION =-1.238E+04
SUM OF REACTION FORCES IN Y-DIRECTION = 5.635E+03
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.550E+00  STEP NUMBER  1550 ****




          155 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                 E N D  O F  S O L U T I O N  P H A S E
                      4.220E+02 CPU SECONDS USED
                            155 WORDS ALLOCATED
```

Information Only

Intentionally Left Blank

Information Only

APPENDIX H

Input/Output Data For Problem 8 – Tension Release Option Problem

The following two sections present the input data and the formatted output for the tension release option verification problem.

FASTQ and SANTOS Input Data For The Tension Release Option Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the tension release option problem.

Information Only

```
TITLE
 TEST OF CONTACT SURFACE TENSION RELEASE
POINT     1      0.0      0.0
POINT     2      2.0      0.0
POINT     3      2.0      2.0
POINT     4      0.0      2.0
POINT     5      0.5      2.0
POINT     6      1.5      2.0
POINT     7      1.5      3.0
POINT     8      0.5      3.0
LINE      1      STR      1        2        0       1
LINE      2      STR      2        3        0       1
LINE      3      STR      3        4        0       1
LINE      4      STR      1        4        0       1
LINE      5      STR      5        6        0       5
LINE      6      STR      6        7        0       5
LINE      7      STR      8        7        0       5
LINE      8      STR      5        8        0       5
REGION    1      1     -1     -2     -3     -4
REGION    2      2     -5     -6     -7     -8
NODEBC    1      1
NODEBC    2      2
NODEBC    3      3
NODEBC    4      4
SIDEBC   10      7
SIDEBC  100      3
SIDEBC  200      5
SCHEME
EXIT
```

Information Only

```
TITLE
  SANTOS QA PROBLEM - TENSION RELEASE CHECK
PLANE STRAIN
MAXIMUM ITERATIONS 5000
RESIDUAL TOLERANCE,1.
INTERMEDIATE PRINT = 100
MAXIMUM TOLERANCE = 100000.
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS 30.e+6
POISSIONS RATIO 0.3
END
MATERIAL,2,ELASTIC,1.
YOUNGS MODULUS 30.e+6
POISSIONS RATIO 0.3
END
PLOT,NODAL,DISPLACEMENTS,RESIDUALS
PLOT,ELEMENT,STRESS
PLOT,STATE,EQPS
FUNCTION 1
   0.,0.0
   1.,1.
END
STEP CONTROL
 100,1.
END
OUTPUT TIME
  1,1.
END
PLOT TIME
  1,1.
END
PRESSURE, 10, 1, -10000.
NO DISPLACEMENT X 1
NO DISPLACEMENT X 2
NO DISPLACEMENT X 3
NO DISPLACEMENT X 4
NO DISPLACEMENT Y 1
NO DISPLACEMENT Y 2
NO DISPLACEMENT Y 3
NO DISPLACEMENT Y 4
CONTACT SURFACE 100 200 0. 1.e-6 1000.
EXIT
```

Information Only

SANTOS Output For The Tension Release Option Problem

The following section presents a portion of the SANTOS printed output for the tension release option analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

WPO# 35675 March 27, 1996

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS



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             DERIVED FROM PRONTO2D BY
       LEE M. TAYLOR AND DENNIS P. FLANAGAN


           RUN ON 03/05/96 AT 14:24:01
          RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

```
                               INPUT STREAM IMAGES
LINE ---------------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - TENSION RELEASE CHECK
  3: PLANE STRAIN
  4: MAXIMUM ITERATIONS 5000
  5: RESIDUAL TOLERANCE,1.
  6: INTERMEDIATE PRINT = 100
  7: MAXIMUM TOLERANCE = 100000.
  8: MATERIAL,1,ELASTIC,1.
  9: YOUNGS MODULUS 30.e+6
 10: POISSIONS RATIO 0.3
 11: END
 12: MATERIAL,2,ELASTIC PLASTIC,1.
 13: YOUNGS MODULUS 10.e+6
 14: POISSIONS RATIO 0.3
 15: YIELD STRESS 1.0e+4
 16: HARDENING MODULUS 17000.
 17: BETA 0.
 18: END
 19: PLOT,NODAL,DISPLACEMENTS,RESIDUALS
 20: PLOT,ELEMENT,STRESS
 21: PLOT,STATE,EQPS
 22: FUNCTION 1
 23:    0.,0.0
 24:    1.,1.
 25: END
 26: STEP CONTROL
 27:  100,1.
 28: END
 29: OUTPUT TIME
 30:   1,1.
 31: END
 32: PLOT TIME
 33:   1,1.
 34: END
```

Information Only

```
35: PRESSURE, 10, 1, -10000.
36: NO DISPLACEMENT X 1
37: NO DISPLACEMENT X 2
38: NO DISPLACEMENT X 3
39: NO DISPLACEMENT X 4
40: NO DISPLACEMENT Y 1
41: NO DISPLACEMENT Y 2
42: NO DISPLACEMENT Y 3
43: NO DISPLACEMENT Y 4
44: CONTACT SURFACE 100 200 0. 1.e-6 1000.
45: EXIT
    ------------------------------------------------------------------------
```

Information Only

Information Only

```
                P R O B L E M   T I T L E

           SANTOS QA PROBLEM - TENSION RELEASE CHECK



             P R O B L E M   D E F I N I T I O N

   NUMBER OF ELEMENTS ......................         26
   NUMBER OF NODES .........................         40
   NUMBER OF MATERIALS .....................          2
   NUMBER OF FUNCTIONS .....................          1
   NUMBER OF CONTACT SURFACES ..............          1
   NUMBER OF RIGID SURFACES ................          0
   NUMBER OF MATERIAL POINTS MONITORED .....          0
   ANALYSIS TYPE ........................... PLANE STRAIN
   GLOBAL CONVERGENCE MEASURE ..............
   RESIDUAL TOLERANCE ......................  1.000E+00
   MAXIMUM NUMBER OF ITERATIONS ............       5000
   ITERATIONS FOR INTERMEDIATE PRINT .......        100
   MAXIMUM RESIDUAL TOLERANCE ..............  1.000E+05
   PREDICTOR SCALE FACTOR FUNCTION .........          0
   MINIMUM DAMPING FACTOR ..................  2.000E-01
   EFFECTIVE MODULUS STATUS ................ CONSTANT
   SCALE FACTOR APPLIED TO TIME STEP .......  1.000E+00
   STRAIN SOFTENING SCALE FACTOR ...........  1.000E+00
   HOURGLASS STIFFNESS FACTOR ..............  5.000E-02
   HOURGLASS VISCOSITY FACTOR ..............  0.000E+00



            L O A D   S T E P   D E F I N I T I O N S
```

Information Only

```
   TIME          NO. OF STEPS           TIME
 0.000E+00           100             1.000E+00



      P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PRINTS        TIME
 0.000E+00            1               1.000E+00



      P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PLOTS         TIME
 0.000E+00            1               1.000E+00



      M A T E R I A L   D E F I N I T I O N S


 MATERIAL TYPE ........................ELASTIC
 MATERIAL ID ..........................         1
 DENSITY .............................. 1.000E+00
 MATERIAL PROPERTIES:
        YOUNGS MODULUS        =    3.000E+07
        POISSONS RATIO        =    3.000E-01


 MATERIAL TYPE ........................ELASTIC PLASTIC
```

Information Only

```
MATERIAL ID ...........................                2
DENSITY ...............................       1.000E+00
MATERIAL PROPERTIES:
        YOUNGS MODULUS       =       1.000E+07
        POISSONS RATIO       =       3.000E-01
        YIELD STRESS         =       1.000E+04
        HARDENING MODULUS    =       1.700E+04
        BETA                 =       0.000E+00



      F U N C T I O N   D E F I N I T I O N S


   FUNCTION ID .........      1     NUMBER OF POINTS ....      2

              N       S            F(S)
              1    0.000E+00    0.000E+00
              2    1.000E+00    1.000E+00



N O  D I S P L A C E M E N T  B O U N D A R Y  C O N D I T I O N S

           NODE SET FLAG      DIRECTION
                1                X
                2                X
                3                X
                4                X
                1                Y
                2                Y
                3                Y
                4                Y
```

Information Only

```
                 C O N T A C T   S U R F A C E S

SURFACE  SURFACE 1  SURFACE 2  PENALTY    COEFFICIENT  PENETRATION   TENSION
NUMBER     FLAG       FLAG     FACTOR     OF FRICTION  MULTIPLIER    RELEASE
   1       100         200    0.000E+00    0.000E+00   1.000E-06    1.000E+03




P R E S S U R E   B O U N D A R Y   C O N D T I O N S

          SURFACE       FUNCTION     SCALE
           FLAG          NUMBER      FACTOR
            10              1     -1.000E+04



                  E N D   O F   D A T A   I N P U T   P H A S E
                       1.790E-01 CPU SECONDS USED
                                8 WORDS ALLOCATED



     E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                       1.197E-02 CPU SECONDS USED
                               40 WORDS ALLOCATED
```

```
V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

              NODAL         ELEMENT       GLOBAL
              -----         -------       ------
              DISPLX        SIGXX         FX
              DISPLY        SIGYY         FY
              RESIDX        SIGZZ         RX
              RESIDY        TAUXY         RY
              RESID         EQPS          ITER
                                          RMAG

**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     1, TIME = 1.000E-02
NUMBER OF ITERATIONS =        64, TOTAL NUMBER OF ITERATIONS =         64
FINAL CONVERGENCE TOLERANCE = 9.061E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 1.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 1.010E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E-02  STEP NUMBER     1 ****
```

Information Only

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
 SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     2, TIME = 2.000E-02
NUMBER OF ITERATIONS =         3, TOTAL NUMBER OF ITERATIONS =        67
FINAL CONVERGENCE TOLERANCE = 6.976E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 2.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 2.025E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.000E-02  STEP NUMBER     2 ****
```

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     3, TIME = 3.000E-02
NUMBER OF ITERATIONS =         3, TOTAL NUMBER OF ITERATIONS =        70
FINAL CONVERGENCE TOLERANCE = 9.260E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 3.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 3.022E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 3.000E-02  STEP NUMBER     3 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     4, TIME = 4.000E-02
NUMBER OF ITERATIONS =         4, TOTAL NUMBER OF ITERATIONS =        74
FINAL CONVERGENCE TOLERANCE = 9.426E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 4.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 4.037E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 4.000E-02  STEP NUMBER     4 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     5, TIME = 5.000E-02
NUMBER OF ITERATIONS =         5, TOTAL NUMBER OF ITERATIONS =        79
FINAL CONVERGENCE TOLERANCE = 6.569E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 5.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 5.023E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 5.000E-02  STEP NUMBER     5 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      6, TIME = 6.000E-02
NUMBER OF ITERATIONS =          3, TOTAL NUMBER OF ITERATIONS =        82
FINAL CONVERGENCE TOLERANCE = 8.735E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 6.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 6.012E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 6.000E-02  STEP NUMBER     6 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     7, TIME = 7.000E-02
NUMBER OF ITERATIONS =        11, TOTAL NUMBER OF ITERATIONS =         93
FINAL CONVERGENCE TOLERANCE = 9.029E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 7.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 6.989E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 7.000E-02  STEP NUMBER     7 ****
```

Information Only

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER     8, TIME = 8.000E-02
NUMBER OF ITERATIONS =          6, TOTAL NUMBER OF ITERATIONS =        99
FINAL CONVERGENCE TOLERANCE = 6.581E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 8.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 7.983E+02
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 8.000E-02  STEP NUMBER     8 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     9, TIME = 9.000E-02
NUMBER OF ITERATIONS =         4, TOTAL NUMBER OF ITERATIONS =       103
FINAL CONVERGENCE TOLERANCE = 5.868E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 9.000E+02
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 8.999E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 9.000E-02  STEP NUMBER     9 ****
```

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER    10, TIME = 1.000E-01
NUMBER OF ITERATIONS =         4, TOTAL NUMBER OF ITERATIONS =      107
FINAL CONVERGENCE TOLERANCE = 9.712E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 1.000E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 9.964E+02
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E-01  STEP NUMBER    10 ****
```

Information Only

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    11, TIME = 1.100E-01
NUMBER OF ITERATIONS =           5, TOTAL NUMBER OF ITERATIONS =       112
FINAL CONVERGENCE TOLERANCE = 4.984E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 1.100E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 1.100E+03
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.100E-01  STEP NUMBER    11 ****
```

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
 SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    12, TIME = 1.200E-01
NUMBER OF ITERATIONS =          5, TOTAL NUMBER OF ITERATIONS =       117
FINAL CONVERGENCE TOLERANCE = 3.957E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 1.200E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 1.199E+03
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.200E-01  STEP NUMBER    12 ****
```

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    13, TIME = 1.300E-01
NUMBER OF ITERATIONS =         3, TOTAL NUMBER OF ITERATIONS =      120
FINAL CONVERGENCE TOLERANCE = 6.837E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 1.300E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 1.302E+03
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.300E-01  STEP NUMBER    13 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER    14, TIME = 1.400E-01
NUMBER OF ITERATIONS =          5, TOTAL NUMBER OF ITERATIONS =        125
FINAL CONVERGENCE TOLERANCE = 7.218E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 1.400E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 1.400E+03
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.400E-01  STEP NUMBER    14 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
  SANTOS QA PROBLEM - TENSION RELEASE CHECK

***********************************************************************
SUMMARY OF DATA AT STEP NUMBER    15, TIME = 1.500E-01
NUMBER OF ITERATIONS =          5, TOTAL NUMBER OF ITERATIONS =        130
FINAL CONVERGENCE TOLERANCE = 9.802E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 1.500E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 1.501E+03
***********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.500E-01  STEP NUMBER    15 ****
```

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 14:24:01
 SANTOS QA PROBLEM - TENSION RELEASE CHECK

***********************************************************************
SUMMARY OF DATA AT STEP NUMBER   100, TIME = 1.000E+00
NUMBER OF ITERATIONS =      5000, TOTAL NUMBER OF ITERATIONS =    255310
FINAL CONVERGENCE TOLERANCE = 5.134E+01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 9.306E+03
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 2.537E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 0.000E+00
***********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER   100 ****




          100 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                E N D  O F  S O L U T I O N  P H A S E
                     2.892E+02 CPU SECONDS USED
                            40 WORDS ALLOCATED
```

Information Only

APPENDIX I

Input/Output Data For Problem 9 – Rigid Sliding Surface Option Problem

The following two sections present the input data and the formatted output for the rigid sliding surface option verification problem.

FASTQ and SANTOS Input Data For The Rigid Sliding Surface Option Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for mesh generation and for each of the analyses of the rigid sliding surface option problem.

Information Only

```
TITLE
 FRICTIONAL SLIP PROBLEM - ONE BEAM - SANTOS QA TEST PROBLEM - v.
disp
POINT    1       0.         0.
POINT    2       0.         2.
POINT    3      20.         2.
POINT    4      20.         0.
LINE     1   STR   1    2    0     4   1.0
LINE     2   STR   2    3    0    40   1.0
LINE     3   STR   3    4    0     4   1.0
LINE     4   STR   4    1    0    40   1.0
NODEBC   1   1
NODEBC   3   2
ELEMBC   4   3
ELEMBC   5   4
SCHEME   0   MP
REGION   1    1   -1   -2   -3   -4
EXIT
```

Information Only

Case of $\mu = 0.1$

```
TITLE
  SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.1
PLANE STRAIN
MAXIMUM ITERATIONS,20000
RESIDUAL TOLERANCE 0.1
TIME STEP SCALE 1.0
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
FUNCTION,1
  0.,1.
  1.,1.
END
FUNCTION,2
   0.,0.
   1.,1.
END
STEP CONTROL
  1000.,1.
END
PLOT TIME
 10.,1.
END
OUTPUT TIME
 1000.,1.
END
NO DISPLACEMENT,X,1
PRESCRIBED DISPLACEMENT Y 3 1 -4.E-3 0. 0.
PRESSURE,4,2,-35.
RIGID SURFACE,5,0.,0.,0.,1.,0.1
EXIT
```

Information Only

Case of $\mu = 0.2$

```
TITLE
  SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.2
PLANE STRAIN
MAXIMUM ITERATIONS,20000
RESIDUAL TOLERANCE 0.1
TIME STEP SCALE 1.0
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
FUNCTION,1
  0.,1.
  1.,1.
END
FUNCTION,2
   0.,0.
   1.,1.
END
STEP CONTROL
  1000.,1.
END
PLOT TIME
 10.,1.
END
OUTPUT TIME
 1000.,1.
END
NO DISPLACEMENT,X,1
PRESCRIBED DISPLACEMENT Y 3 1 -4.E-3 0. 0.
PRESSURE,4,2,-58.75
RIGID SURFACE,5,0.,0.,0.,1.,0.2
EXIT
```

Information Only

Case of $\mu = 0.5$

```
TITLE
  SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.5
PLANE STRAIN
MAXIMUM ITERATIONS,20000
RESIDUAL TOLERANCE 0.1
TIME STEP SCALE 1.05
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
FUNCTION,1
  0.,1.
  1.,1.
END
FUNCTION,2
   0.,0.
   1.,1.
END
STEP CONTROL
  1000.,1.
END
PLOT TIME
 10.,1.
END
OUTPUT TIME
 1000.,1.
END
NO DISPLACEMENT,X,1
PRESCRIBED DISPLACEMENT Y 3 1 -4.E-3 0. 0.
PRESSURE,4,2,-125.
RIGID SURFACE,5,0.,0.,0.,1.,0.5
EXIT
```

Information Only

Case of $\mu = 0.7$

```
TITLE
  SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.7
PLANE STRAIN
MAXIMUM ITERATIONS,20000
RESIDUAL TOLERANCE 0.1
TIME STEP SCALE 1.05
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
FUNCTION,1
  0.,1.
  1.,1.
END
FUNCTION,2
   0.,0.
   1.,1.
END
STEP CONTROL
  1000.,1.
END
PLOT TIME
 10.,1.
END
OUTPUT TIME
 1000.,1.
END
NO DISPLACEMENT,X,1
PRESCRIBED DISPLACEMENT Y 3 1 -4.E-3 0. 0.
PRESSURE,4,2,-170.
RIGID SURFACE,5,0.,0.,0.,1.,0.7
EXIT
```

Information Only

SANTOS Output For The Rigid Sliding Surface Option Problem

The following section presents a portion of the SANTOS printed output for each of the rigid sliding surface option analyses. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

Case of $\mu = 0.1$

```
 SSSSSS   AAAAA   N     NN  TTTTTT   OOOOO    SSSSSS
SS       AA   AA  NN    NN    TT    OO   OO  SS
SS       AA   AA  NNN   NN    TT    OO   OO  SS
 SSSSS   AAAAAAA  NN N  NN    TT    OO   OO   SSSSS
     SS  AA   AA  NN  NNN     TT    OO   OO       SS
     SS  AA   AA  NN   NN     TT    OO   OO       SS
SSSSSS   AA   AA  NN    N     TT     OOOOO   SSSSSS



                 VERSION 2.0.0
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                PROGRAMMED BY:

               CHARLES M. STONE
         ENGINEERING SCIENCES CENTER
         SANDIA NATIONAL LABORATORIES
         ALBUQUERQUE, NEW MEXICO 87185

           DERIVED FROM PRONTO2D BY
      LEE M. TAYLOR AND DENNIS P. FLANAGAN



          RUN ON 03/07/96 AT 09:05:24
        RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

INPUT STREAM IMAGES

```
LINE ---------------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.1
  3: PLANE STRAIN
  4: MAXIMUM ITERATIONS,20000
  5: RESIDUAL TOLERANCE 0.1
  6: TIME STEP SCALE 1.0
  7: MATERIAL,1,ELASTIC,1.
  8: YOUNGS MODULUS 10000.
  9: POISSONS RATIO 0.
 10: END
 11: FUNCTION,1
 12:   0.,1.
 13:   1.,1.
 14: END
 15: FUNCTION,2
 16:    0.,0.
 17:    1.,1.
 18: END
 19: STEP CONTROL
 20:   1000.,1.
 21: END
 22: PLOT TIME
 23:  10.,1.
 24: END
 25: OUTPUT TIME
 26:  1000.,1.
 27: END
 28: NO DISPLACEMENT,X,1
 29: PRESCRIBED DISPLACEMENT Y 3 1 -4.E-3 0. 0.
 30: PRESSURE,4,2,-35.
 31: RIGID SURFACE,5,0.,0.,0.,1.,0.1
 32: EXIT
```

Information Only

```
            P R O B L E M   T I T L E

    SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.1


            P R O B L E M   D E F I N I T I O N

  NUMBER OF ELEMENTS .........................          160
  NUMBER OF NODES ............................          205
  NUMBER OF MATERIALS ........................            1
  NUMBER OF FUNCTIONS ........................            2
  NUMBER OF CONTACT SURFACES .................            0
  NUMBER OF RIGID SURFACES ...................            1
  NUMBER OF MATERIAL POINTS MONITORED ........            0
  ANALYSIS TYPE ..............................  PLANE STRAIN
  GLOBAL CONVERGENCE MEASURE .................
  RESIDUAL TOLERANCE .........................   1.000E-01
  MAXIMUM NUMBER OF ITERATIONS ...............        20000
  ITERATIONS FOR INTERMEDIATE PRINT ..........          410
  MAXIMUM RESIDUAL TOLERANCE .................   6.000E-01
  PREDICTOR SCALE FACTOR FUNCTION ............            0
  MINIMUM DAMPING FACTOR .....................   2.000E-01
  EFFECTIVE MODULUS STATUS ...................  CONSTANT
  SCALE FACTOR APPLIED TO TIME STEP ..........   1.000E+00
  STRAIN SOFTENING SCALE FACTOR ..............   1.000E+00
  HOURGLASS STIFFNESS FACTOR .................   5.000E-02
  HOURGLASS VISCOSITY FACTOR .................   0.000E+00


            L O A D   S T E P   D E F I N I T I O N S
```

Information Only

Information Only

```
    TIME           NO. OF STEPS          TIME
 0.000E+00             1000           1.000E+00



       P R I N T E D   O U T P U T   F R E Q U E N C Y


    TIME     STEPS BETWEEN PRINTS         TIME
 0.000E+00             1000           1.000E+00



       P L O T T E D   O U T P U T   F R E Q U E N C Y


    TIME     STEPS BETWEEN PLOTS          TIME
 0.000E+00              10            1.000E+00



       M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE ........................ELASTIC
  MATERIAL ID ..........................               1
  DENSITY ..............................      1.000E+00
  MATERIAL PROPERTIES:
         YOUNGS MODULUS         =    1.000E+04
         POISSONS RATIO         =    0.000E+00
```

Information Only

FUNCTION DEFINITIONS

```
FUNCTION ID .........        1     NUMBER OF POINTS ....       2

                 N        S            F(S)
                 1    0.000E+00     1.000E+00
                 2    1.000E+00     1.000E+00

FUNCTION ID .........        2     NUMBER OF POINTS ....       2

                 N        S            F(S)
                 1    0.000E+00     0.000E+00
                 2    1.000E+00     1.000E+00
```

NO DISPLACEMENT BOUNDARY CONDITIONS

```
         NODE SET FLAG      DIRECTION
               1                X
```

PRESCRIBED DISPLACEMENT BOUNDARY CONDITIONS

```
  NODE SET    DIRECTION    FUNCTION    SCALE         A0         B0
    FLAG                      ID       FACTOR
     3            Y           1      -4.000E-03       -          -
```

```
                    R I G I D   S U R F A C E S

SURFACE  SIDE SET  COEFFICIENT        X0         Y0         NX         NY
 NUMBER    FLAG    OF FRICTION
   1        5      0.100          0.000E+00 0.000E+00 0.000E+00 1.000E+00



P R E S S U R E   B O U N D A R Y   C O N D T I O N S

          SURFACE       FUNCTION      SCALE
            FLAG         NUMBER       FACTOR
              4             2      -3.500E+01



                E N D   O F   D A T A   I N P U T   P H A S E
                      1.394E-01 CPU SECONDS USED
                             46 WORDS ALLOCATED



      E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                      1.190E-02 CPU SECONDS USED
                            205 WORDS ALLOCATED
```

Information Only

Information Only

```
            V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                    NODAL          ELEMENT        GLOBAL
                    -----          -------        ------
                    DISPLX         SIGXX          FX
                    DISPLY         SIGYY          FY
                                   SIGZZ          RX
                                   TAUXY          RY
                                                  ITER
                                                  RMAG


 **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****



 **** PLOT TAPE WRITTEN AT TIME = 1.000E-02  STEP NUMBER    10 ****



 **** PLOT TAPE WRITTEN AT TIME = 2.000E-02  STEP NUMBER    20 ****



 **** PLOT TAPE WRITTEN AT TIME = 3.000E-02  STEP NUMBER    30 ****



 **** PLOT TAPE WRITTEN AT TIME = 4.000E-02  STEP NUMBER    40 ****
```

```
**** PLOT TAPE WRITTEN AT TIME = 5.000E-02  STEP NUMBER    50 ****

**** PLOT TAPE WRITTEN AT TIME = 6.000E-02  STEP NUMBER    60 ****

**** PLOT TAPE WRITTEN AT TIME = 7.000E-02  STEP NUMBER    70 ****

**** PLOT TAPE WRITTEN AT TIME = 8.000E-02  STEP NUMBER    80 ****

**** PLOT TAPE WRITTEN AT TIME = 9.000E-02  STEP NUMBER    90 ****

**** PLOT TAPE WRITTEN AT TIME = 1.000E-01  STEP NUMBER   100 ****

**** PLOT TAPE WRITTEN AT TIME = 1.100E-01  STEP NUMBER   110 ****
```

Information Only

```
**** PLOT TAPE WRITTEN AT TIME = 1.200E-01  STEP NUMBER   120 ****

**** PLOT TAPE WRITTEN AT TIME = 1.300E-01  STEP NUMBER   130 ****

**** PLOT TAPE WRITTEN AT TIME = 1.400E-01  STEP NUMBER   140 ****

**** PLOT TAPE WRITTEN AT TIME = 1.500E-01  STEP NUMBER   150 ****

**** PLOT TAPE WRITTEN AT TIME = 1.600E-01  STEP NUMBER   160 ****

**** PLOT TAPE WRITTEN AT TIME = 1.700E-01  STEP NUMBER   170 ****

**** PLOT TAPE WRITTEN AT TIME = 1.800E-01  STEP NUMBER   180 ****
```

Information Only

```
**** PLOT TAPE WRITTEN AT TIME = 1.900E-01  STEP NUMBER   190 ****


**** PLOT TAPE WRITTEN AT TIME = 2.000E-01  STEP NUMBER   200 ****
 .
 .
 .
 .
 .

**** PLOT TAPE WRITTEN AT TIME = 9.900E-01  STEP NUMBER   990 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 09:05:24
  SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.1

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER  1000, TIME = 1.000E+00
NUMBER OF ITERATIONS =         26, TOTAL NUMBER OF ITERATIONS =     27562
FINAL CONVERGENCE TOLERANCE = 6.437E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 6.986E+01
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.221E-02
SUM OF REACTION FORCES IN X-DIRECTION = 3.020E+01
SUM OF REACTION FORCES IN Y-DIRECTION = 4.014E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER  1000 ****




          100 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                 E N D  O F  S O L U T I O N  P H A S E
                      6.294E+01 CPU SECONDS USED
                            205 WORDS ALLOCATED
```

Information Only

Case of $\mu = 0.2$

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS


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                 PROGRAMMED BY:

               CHARLES M. STONE
          ENGINEERING SCIENCES CENTER
          SANDIA NATIONAL LABORATORIES
         ALBUQUERQUE, NEW MEXICO 87185

            DERIVED FROM PRONTO2D BY
     LEE M. TAYLOR AND DENNIS P. FLANAGAN


          RUN ON 03/07/96 AT 09:13:21
        RUN ON A Cray0J90 UNDER Unico8.0
```

Information Only

Information Only

```
                              INPUT STREAM IMAGES
LINE -----------------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.2
  3: PLANE STRAIN
  4: MAXIMUM ITERATIONS,20000
  5: RESIDUAL TOLERANCE 0.1
  6: TIME STEP SCALE 1.0
  7: MATERIAL,1,ELASTIC,1.
  8: YOUNGS MODULUS 10000.
  9: POISSONS RATIO 0.
 10: END
 11: FUNCTION,1
 12:   0.,1.
 13:   1.,1.
 14: END
 15: FUNCTION,2
 16:    0.,0.
 17:    1.,1.
 18: END
 19: STEP CONTROL
 20:   1000.,1.
 21: END
 22: PLOT TIME
 23:  10.,1.
 24: END
 25: OUTPUT TIME
 26:  1000.,1.
 27: END
 28: NO DISPLACEMENT,X,1
 29: PRESCRIBED DISPLACEMENT Y 3 1 -4.E-3 0. 0.
 30: PRESSURE,4,2,-58.75
 31: RIGID SURFACE,5,0.,0.,0.,1.,0.2
 32: EXIT
```

Information Only

```
               P R O B L E M   T I T L E

        SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.2



                P R O B L E M   D E F I N I T I O N

         NUMBER OF ELEMENTS ......................         160
         NUMBER OF NODES .........................         205
         NUMBER OF MATERIALS .....................           1
         NUMBER OF FUNCTIONS .....................           2
         NUMBER OF CONTACT SURFACES ..............           0
         NUMBER OF RIGID SURFACES ................           1
         NUMBER OF MATERIAL POINTS MONITORED .....           0
         ANALYSIS TYPE ........................... PLANE STRAIN
         GLOBAL CONVERGENCE MEASURE ..............
         RESIDUAL TOLERANCE ......................  1.000E-01
         MAXIMUM NUMBER OF ITERATIONS ............       20000
         ITERATIONS FOR INTERMEDIATE PRINT .......         410
         MAXIMUM RESIDUAL TOLERANCE ..............  6.000E-01
         PREDICTOR SCALE FACTOR FUNCTION .........           0
         MINIMUM DAMPING FACTOR ..................  2.000E-01
         EFFECTIVE MODULUS STATUS ................ CONSTANT
         SCALE FACTOR APPLIED TO TIME STEP .......  1.000E+00
         STRAIN SOFTENING SCALE FACTOR ...........  1.000E+00
         HOURGLASS STIFFNESS FACTOR ..............  5.000E-02
         HOURGLASS VISCOSITY FACTOR ..............  0.000E+00



              L O A D   S T E P   D E F I N I T I O N S
```

Information Only

```
   TIME           NO. OF STEPS          TIME
 0.000E+00            1000            1.000E+00



       P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME     STEPS BETWEEN PRINTS        TIME
 0.000E+00          1000              1.000E+00



       P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME     STEPS BETWEEN PLOTS         TIME
 0.000E+00           10               1.000E+00



       M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE ........................ELASTIC
  MATERIAL ID .........................            1
  DENSITY ............................. 1.000E+00
  MATERIAL PROPERTIES:
         YOUNGS MODULUS        =    1.000E+04
         POISSONS RATIO        =    0.000E+00
```

Information Only

```
              F U N C T I O N   D E F I N I T I O N S

     FUNCTION ID .........       1     NUMBER OF POINTS ....       2

                    N        S             F(S)
                    1    0.000E+00     1.000E+00
                    2    1.000E+00     1.000E+00

     FUNCTION ID .........       2     NUMBER OF POINTS ....       2

                    N        S             F(S)
                    1    0.000E+00     0.000E+00
                    2    1.000E+00     1.000E+00



  N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                NODE SET FLAG     DIRECTION
                      1               X



P R E S C R I B E D   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

   NODE SET     DIRECTION     FUNCTION     SCALE          A0          B0
     FLAG                        ID        FACTOR
      3             Y             1      -4.000E-03        -           -
```

```
                  R I G I D   S U R F A C E S

SURFACE  SIDE SET  COEFFICIENT         X0          Y0          NX          NY
 NUMBER    FLAG    OF FRICTION
    1        5     0.200          0.000E+00 0.000E+00 0.000E+00 1.000E+00



P R E S S U R E   B O U N D A R Y   C O N D T I O N S

          SURFACE       FUNCTION     SCALE
           FLAG          NUMBER      FACTOR
             4              2     -5.875E+01



               E N D   O F   D A T A   I N P U T   P H A S E
                      1.405E-01 CPU SECONDS USED
                             46 WORDS ALLOCATED



      E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                      1.179E-02 CPU SECONDS USED
                            205 WORDS ALLOCATED
```

Information Only

```
                V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                         NODAL          ELEMENT         GLOBAL
                         -----          -------         ------
                         DISPLX         SIGXX           FX
                         DISPLY         SIGYY           FY
                                        SIGZZ           RX
                                        TAUXY           RY
                                                        ITER
                                                        RMAG


 **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****


 **** PLOT TAPE WRITTEN AT TIME = 1.000E-02  STEP NUMBER    10 ****


 **** PLOT TAPE WRITTEN AT TIME = 2.000E-02  STEP NUMBER    20 ****

.
.
.
.

 **** PLOT TAPE WRITTEN AT TIME = 9.900E-01  STEP NUMBER   990 ****
```

Information Only

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 09:13:21
 SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.2

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER  1000, TIME = 1.000E+00
NUMBER OF ITERATIONS =         34, TOTAL NUMBER OF ITERATIONS =     26544
FINAL CONVERGENCE TOLERANCE = 7.994E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.173E+02
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-7.973E-02
SUM OF REACTION FORCES IN X-DIRECTION = 3.935E+01
SUM OF REACTION FORCES IN Y-DIRECTION = 4.020E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER  1000 ****





          100 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                END OF SOLUTION PHASE
                  5.966E+01 CPU SECONDS USED
                        205 WORDS ALLOCATED
```

Case of $\mu = 0.5$

```
 SSSSSS   AAAAA   N    NN  TTTTTT   OOOOO   SSSSSS
SS       AA   AA  NN   NN    TT    OO   OO SS
SS       AA   AA  NNN  NN    TT    OO   OO SS
 SSSSS   AAAAAAA  NN N NN    TT    OO   OO  SSSSS
     SS  AA   AA  NN  NNN    TT    OO   OO      SS
     SS  AA   AA  NN   NN    TT    OO   OO      SS
SSSSSS   AA   AA  NN    N    TT     OOOOO  SSSSSS



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               CHARLES M. STONE
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         ALBUQUERQUE, NEW MEXICO 87185

           DERIVED FROM PRONTO2D BY
     LEE M. TAYLOR AND DENNIS P. FLANAGAN



         RUN ON 04/19/95 AT 08:43:18
       RUN ON A CrayY-MP UNDER UniCo7.0
```

Information Only

Information Only

```
                              INPUT STREAM IMAGES
LINE --------------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.5
  3: PLANE STRAIN
  4: MAXIMUM ITERATIONS,20000
  5: RESIDUAL TOLERANCE 0.1
  6: TIME STEP SCALE 1.05
  7: MATERIAL,1,ELASTIC,1.
  8: YOUNGS MODULUS 10000.
  9: POISSONS RATIO 0.
 10: END
 11: FUNCTION,1
 12:   0.,1.
 13:   1.,1.
 14: END
 15: FUNCTION,2
 16:    0.,0.
 17:    1.,1.
 18: END
 19: STEP CONTROL
 20:   1000.,1.
 21: END
 22: PLOT TIME
 23:  10.,1.
 24: END
 25: OUTPUT TIME
 26:  1000.,1.
 27: END
 28: NO DISPLACEMENT,X,1
 29: PRESCRIBED DISPLACEMENT Y 3 1 -4.E-3 0. 0.
 30: PRESSURE,4,2,-125.
 31: RIGID SURFACE,5,0.,0.,0.,1.,0.5
 32: EXIT
     -------------------------------------------------------------------------
```

```
                P R O B L E M   T I T L E

       SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.5


               P R O B L E M   D E F I N I T I O N

         NUMBER OF ELEMENTS .......................        160
         NUMBER OF NODES ..........................        205
         NUMBER OF MATERIALS ......................          1
         NUMBER OF FUNCTIONS ......................          2
         NUMBER OF CONTACT SURFACES ...............          0
         NUMBER OF RIGID SURFACES .................          1
         NUMBER OF MATERIAL POINTS MONITORED ......          0
         ANALYSIS TYPE ............................ PLANE STRAIN
         GLOBAL CONVERGENCE MEASURE ...............
         RESIDUAL TOLERANCE .......................  1.000E-01
         MAXIMUM NUMBER OF ITERATIONS .............      20000
         ITERATIONS FOR INTERMEDIATE PRINT ........        410
         MAXIMUM RESIDUAL TOLERANCE ...............  6.000E-01
         PREDICTOR SCALE FACTOR FUNCTION ..........          0
         MINIMUM DAMPING FACTOR ...................  2.000E-01
         EFFECTIVE MODULUS STATUS ................. CONSTANT
         SCALE FACTOR APPLIED TO TIME STEP ........  1.050E+00
         STRAIN SOFTENING SCALE FACTOR ............  1.000E+00
         HOURGLASS STIFFNESS FACTOR ...............  5.000E-02
         HOURGLASS VISCOSITY FACTOR ...............  0.000E+00


             L O A D   S T E P   D E F I N I T I O N S
```

Information Only

Information Only

```
      TIME            NO. OF STEPS           TIME
    0.000E+00            1000              1.000E+00



           P R I N T E D   O U T P U T   F R E Q U E N C Y

      TIME      STEPS BETWEEN PRINTS         TIME
    0.000E+00           1000               1.000E+00



           P L O T T E D   O U T P U T   F R E Q U E N C Y

      TIME      STEPS BETWEEN PLOTS          TIME
    0.000E+00            10                1.000E+00



           M A T E R I A L   D E F I N I T I O N S

    MATERIAL TYPE ........................ELASTIC
    MATERIAL ID ..........................          1
    DENSITY ..............................  1.000E+00
    MATERIAL PROPERTIES:
            YOUNGS MODULUS         =     1.000E+04
            POISSONS RATIO         =     0.000E+00
```

Information Only

FUNCTION DEFINITIONS

```
FUNCTION ID .........        1     NUMBER OF POINTS ....       2

              N        S            F(S)
              1    0.000E+00     1.000E+00
              2    1.000E+00     1.000E+00

FUNCTION ID .........        2     NUMBER OF POINTS ....       2

              N        S            F(S)
              1    0.000E+00     0.000E+00
              2    1.000E+00     1.000E+00
```

NO DISPLACEMENT BOUNDARY CONDITIONS

```
NODE SET FLAG      DIRECTION
      1                X
```

PRESCRIBED DISPLACEMENT BOUNDARY CONDITIONS

```
NODE SET    DIRECTION    FUNCTION    SCALE        A0          B0
  FLAG                      ID       FACTOR
   3            Y           1     -4.000E-03       -           -
```

```
                  R I G I D   S U R F A C E S

SURFACE  SIDE SET  COEFFICIENT      X0          Y0          NX          NY
 NUMBER    FLAG    OF FRICTION
   1         5     0.500        0.000E+00  0.000E+00  0.000E+00  1.000E+00




P R E S S U R E   B O U N D A R Y   C O N D T I O N S

          SURFACE       FUNCTION     SCALE
            FLAG         NUMBER      FACTOR
              4              2    -1.250E+02




               E N D   O F   D A T A   I N P U T   P H A S E
                        5.999E-02 CPU SECONDS USED
                               46 WORDS ALLOCATED




         E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                        5.838E-03 CPU SECONDS USED
                              205 WORDS ALLOCATED
```

Information Only

Information Only

```
            V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                      NODAL          ELEMENT        GLOBAL
                      -----          -------        ------
                      DISPLX         SIGXX          FX
                      DISPLY         SIGYY          FY
                                     SIGZZ          RX
                                     TAUXY          RY
                                                    ITER
                                                    RMAG

**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****


**** PLOT TAPE WRITTEN AT TIME = 1.000E-02  STEP NUMBER    10 ****


**** PLOT TAPE WRITTEN AT TIME = 2.000E-02  STEP NUMBER    20 ****
  .
  .
  .
  .

**** PLOT TAPE WRITTEN AT TIME = 9.900E-01  STEP NUMBER   990 ****
```

```
SANTOS, VERSION 2.0.0    ,RUN ON 04/19/95 ,AT 08:43:18
 SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.5

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER  1000, TIME = 1.000E+00
NUMBER OF ITERATIONS =         47, TOTAL NUMBER OF ITERATIONS =     24307
FINAL CONVERGENCE TOLERANCE = 6.767E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 2.495E+02
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-5.521E-01
SUM OF REACTION FORCES IN X-DIRECTION = 5.481E+01
SUM OF REACTION FORCES IN Y-DIRECTION = 4.033E+02
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER  1000 ****






          100 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                 E N D   O F   S O L U T I O N   P H A S E
                      3.131E+01 CPU SECONDS USED
                            205 WORDS ALLOCATED
```

Information Only

Information Only

Case of $\mu = 0.7$

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS


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          ALBUQUERQUE, NEW MEXICO 87185

            DERIVED FROM PRONTO2D BY
     LEE M. TAYLOR AND DENNIS P. FLANAGAN


          RUN ON 03/07/96 AT 09:18:40
        RUN ON A Cray0J90 UNDER Unico8.0
```

Information Only

```
                         INPUT STREAM IMAGES
LINE -----------------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.7
  3: PLANE STRAIN
  4: MAXIMUM ITERATIONS,20000
  5: RESIDUAL TOLERANCE 0.1
  6: TIME STEP SCALE 1.05
  7: MATERIAL,1,ELASTIC,1.
  8: YOUNGS MODULUS 10000.
  9: POISSONS RATIO 0.
 10: END
 11: FUNCTION,1
 12:   0.,1.
 13:   1.,1.
 14: END
 15: FUNCTION,2
 16:    0.,0.
 17:    1.,1.
 18: END
 19: STEP CONTROL
 20:   1000.,1.
 21: END
 22: PLOT TIME
 23:  10.,1.
 24: END
 25: OUTPUT TIME
 26:  1000.,1.
 27: END
 28: NO DISPLACEMENT,X,1
 29: PRESCRIBED DISPLACEMENT Y 3 1 -4.E-3 0. 0.
 30: PRESSURE,4,2,-170.
 31: RIGID SURFACE,5,0.,0.,0.,1.,0.7
 32: EXIT
```

```
               P R O B L E M   T I T L E

     SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.7


                 P R O B L E M   D E F I N I T I O N

       NUMBER OF ELEMENTS .......................          160
       NUMBER OF NODES ..........................          205
       NUMBER OF MATERIALS ......................            1
       NUMBER OF FUNCTIONS ......................            2
       NUMBER OF CONTACT SURFACES ...............            0
       NUMBER OF RIGID SURFACES .................            1
       NUMBER OF MATERIAL POINTS MONITORED .....             0
       ANALYSIS TYPE ........................... PLANE STRAIN
       GLOBAL CONVERGENCE MEASURE ...............
       RESIDUAL TOLERANCE .......................   1.000E-01
       MAXIMUM NUMBER OF ITERATIONS ............        20000
       ITERATIONS FOR INTERMEDIATE PRINT .......          410
       MAXIMUM RESIDUAL TOLERANCE ..............    6.000E-01
       PREDICTOR SCALE FACTOR FUNCTION .........            0
       MINIMUM DAMPING FACTOR ..................    2.000E-01
       EFFECTIVE MODULUS STATUS ................ CONSTANT
       SCALE FACTOR APPLIED TO TIME STEP .......    1.050E+00
       STRAIN SOFTENING SCALE FACTOR ...........    1.000E+00
       HOURGLASS STIFFNESS FACTOR ..............    5.000E-02
       HOURGLASS VISCOSITY FACTOR ..............    0.000E+00


            L O A D   S T E P   D E F I N I T I O N S
```

Information Only

Information Only

```
    TIME           NO. OF STEPS          TIME
 0.000E+00             1000           1.000E+00



            P R I N T E D   O U T P U T   F R E Q U E N C Y


    TIME      STEPS BETWEEN PRINTS         TIME
 0.000E+00            1000              1.000E+00



            P L O T T E D   O U T P U T   F R E Q U E N C Y


    TIME      STEPS BETWEEN PLOTS          TIME
 0.000E+00             10               1.000E+00



            M A T E R I A L   D E F I N I T I O N S


 MATERIAL TYPE ........................ELASTIC
 MATERIAL ID ..........................            1
 DENSITY ..............................   1.000E+00
 MATERIAL PROPERTIES:
         YOUNGS MODULUS        =     1.000E+04
         POISSONS RATIO        =     0.000E+00
```

```
                    F U N C T I O N   D E F I N I T I O N S

          FUNCTION ID .........       1     NUMBER OF POINTS ....       2

                         N       S            F(S)
                         1   0.000E+00    1.000E+00
                         2   1.000E+00    1.000E+00

          FUNCTION ID .........       2     NUMBER OF POINTS ....       2

                         N       S            F(S)
                         1   0.000E+00    0.000E+00
                         2   1.000E+00    1.000E+00



       N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                   NODE SET FLAG      DIRECTION
                         1                X



    P R E S C R I B E D   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

       NODE SET     DIRECTION     FUNCTION     SCALE          A0           B0
         FLAG                        ID        FACTOR
          3             Y             1      -4.000E-03        -            -
```

Information Only

Information Only

```
                     R I G I D   S U R F A C E S

SURFACE  SIDE SET  COEFFICIENT        X0         Y0         NX         NY
 NUMBER    FLAG    OF FRICTION
   1         5     0.700         0.000E+00  0.000E+00  0.000E+00  1.000E+00



P R E S S U R E   B O U N D A R Y   C O N D T I O N S

           SURFACE       FUNCTION     SCALE
            FLAG          NUMBER      FACTOR
              4              2     -1.700E+02



                E N D   O F   D A T A   I N P U T   P H A S E
                      1.436E-01 CPU SECONDS USED
                             46 WORDS ALLOCATED



       E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                      1.182E-02 CPU SECONDS USED
                            205 WORDS ALLOCATED
```

Information Only

```
V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                 NODAL         ELEMENT        GLOBAL
                 -----         -------        ------
                 DISPLX        SIGXX          FX
                 DISPLY        SIGYY          FY
                               SIGZZ          RX
                               TAUXY          RY
                                              ITER
                                              RMAG


**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****


**** PLOT TAPE WRITTEN AT TIME = 1.000E-02  STEP NUMBER    10 ****


**** PLOT TAPE WRITTEN AT TIME = 2.000E-02  STEP NUMBER    20 ****


**** PLOT TAPE WRITTEN AT TIME = 3.000E-02  STEP NUMBER    30 ****


**** PLOT TAPE WRITTEN AT TIME = 4.000E-02  STEP NUMBER    40 ****
```

```
**** PLOT TAPE WRITTEN AT TIME = 5.000E-02  STEP NUMBER    50 ****

**** PLOT TAPE WRITTEN AT TIME = 6.000E-02  STEP NUMBER    60 ****

**** PLOT TAPE WRITTEN AT TIME = 7.000E-02  STEP NUMBER    70 ****

**** PLOT TAPE WRITTEN AT TIME = 8.000E-02  STEP NUMBER    80 ****

**** PLOT TAPE WRITTEN AT TIME = 9.000E-02  STEP NUMBER    90 ****

**** PLOT TAPE WRITTEN AT TIME = 1.000E-01  STEP NUMBER   100 ****

**** PLOT TAPE WRITTEN AT TIME = 1.100E-01  STEP NUMBER   110 ****
```

Information Only

```
**** PLOT TAPE WRITTEN AT TIME = 1.200E-01  STEP NUMBER   120 ****


**** PLOT TAPE WRITTEN AT TIME = 1.300E-01  STEP NUMBER   130 ****


**** PLOT TAPE WRITTEN AT TIME = 1.400E-01  STEP NUMBER   140 ****


**** PLOT TAPE WRITTEN AT TIME = 1.500E-01  STEP NUMBER   150 ****


**** PLOT TAPE WRITTEN AT TIME = 1.600E-01  STEP NUMBER   160 ****


**** PLOT TAPE WRITTEN AT TIME = 1.700E-01  STEP NUMBER   170 ****


**** PLOT TAPE WRITTEN AT TIME = 1.800E-01  STEP NUMBER   180 ****
```

Information Only

```
**** PLOT TAPE WRITTEN AT TIME = 1.900E-01  STEP NUMBER   190 ****

**** PLOT TAPE WRITTEN AT TIME = 2.000E-01  STEP NUMBER   200 ****
  .
  .
  .
  .

**** PLOT TAPE WRITTEN AT TIME = 9.900E-01  STEP NUMBER   990 ****
```

Information Only

```
SANTOS, VERSION 2.0.0     ,RUN ON 03/07/96 ,AT 09:18:40
 SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.7

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER  1000, TIME = 1.000E+00
NUMBER OF ITERATIONS =        32, TOTAL NUMBER OF ITERATIONS =      23686
FINAL CONVERGENCE TOLERANCE = 9.265E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION = 3.393E+02
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-1.406E+00
SUM OF REACTION FORCES IN X-DIRECTION = 5.690E+01
SUM OF REACTION FORCES IN Y-DIRECTION = 4.040E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER  1000 ****




          100 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                    E N D   O F   S O L U T I O N   P H A S E
                         5.421E+01 CPU SECONDS USED
                               205 WORDS ALLOCATED
```

Information Only

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Information Only

APPENDIX J

Input/Output Data For Problem 10 – Double Elastic Beam Contact Sliding Problem

The following two sections present the input data and the formatted output for the double elastic beam contact sliding verification problem.

FASTQ and SANTOS Input Data For The Double Elastic Beam Contact Sliding Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for mesh generation and for each of the analyses of the double elastic beam contact sliding problem.

Information Only

```
TITLE
 FRICTIONAL SLIP PROBLEM - DOUBLE BEAM - SANTOS QA TEST PROBLEM
POINT    1      0.        1.
POINT    2      0.        2.
POINT    3     25.        2.
POINT    4     25.        1.
POINT    5      0.        1.
POINT    6      0.        0.
POINT    7     25.5       0.
POINT    8     25.5       1.
LINE     1   STR   1    2    0     1   1.0
LINE     2   STR   2    3    0    65   1.0
LINE     3   STR   3    4    0     1   1.0
LINE     4   STR   4    1    0    65   1.0
LINE     5   STR   5    6    0     1   1.0
LINE     6   STR   6    7    0    65   1.0
LINE     7   STR   7    8    0     1   1.0
LINE     8   STR   8    5    0    65   1.0
NODEBC   1   1
NODEBC   2   6
NODEBC   8   5
ELEMBC   3   2
ELEMBC   4   3
ELEMBC   5   4
ELEMBC   6   8
ELEMBC   7   7
SCHEME   0   MP
REGION   1    1   -1   -2   -3   -4
REGION   2    2   -5   -8   -7   -6
EXIT
```

Information Only

Case 1 Input

```
TITLE
 SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.4 - E2/E1 = 3
PLANE STRAIN
MAXIMUM ITERATIONS = 3000
RESIDUAL TOLERANCE = 0.50
MAXIMUM TOLERANCE =  1000.0
ELASTIC SOLUTION
PREDICTOR SCALE FACTOR = 3
TIME STEP SCALE = 0.70
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS 3000.
POISSONS RATIO 0.
END
MATERIAL,2,ELASTIC,1.
YOUNGS MODULUS 9000.
POISSONS RATIO 0.
END
FUNCTION,1
  0.,1.
 10.,1.
END
FUNCTION,2
   0.,0.
  10.,1.
END
STEP CONTROL
  100.,10.
END
PLOT TIME
 1.,10.
END
OUTPUT TIME
 10.,10.
END
PLOT NODAL,REACTION,RESIDUAL
NO DISPLACEMENT,X,1
NO DISPLACEMENT,X,8
NO DISPLACEMENT,Y,2
CONTACT SURFACE,6,5,0.4,1.E-3,1.E+40
PRESSURE,3,1,1.
PRESSURE,4,2,-10.
PRESSURE,7,2,-10.
EXIT
```

Information Only

Case 2 Input

```
TITLE
 SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.5 - E2/E1 = 10
PLANE STRAIN
MAXIMUM ITERATIONS = 3000
RESIDUAL TOLERANCE = 0.50
MAXIMUM TOLERANCE =  1000.0
ELASTIC SOLUTION
PREDICTOR SCALE FACTOR = 3
TIME STEP SCALE = 0.70
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS 800.
POISSONS RATIO 0.
END
MATERIAL,2,ELASTIC,1.
YOUNGS MODULUS 8000.
POISSONS RATIO 0.
END
FUNCTION,1
   0.,1.
  10.,1.
END
FUNCTION,2
   0.,0.
  10.,1.
END
STEP CONTROL
  100.,10.
END
PLOT TIME
 1.,10.
END
OUTPUT TIME
 10.,10.
END
PLOT NODAL,REACTION,RESIDUAL
NO DISPLACEMENT,X,1
NO DISPLACEMENT,X,8
NO DISPLACEMENT,Y,2
CONTACT SURFACE,6,5,0.5,1.E-3,1.E+40
PRESSURE,3,1,1.
PRESSURE,4,2,-10.
PRESSURE,7,2,-10.
EXIT
```

Information Only

SANTOS Output For The Double Elastic Beam Contact Sliding Problem

The following section presents a portion of the SANTOS printed output for each of the double elastic beam contact sliding analyses. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echos input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

Case 1 Output

```
 SSSSSS   AAAAA    N     NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN     NN    TT     OO   OO  SS
SS       AA   AA  NNN    NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N   NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN   NNN     TT     OO   OO       SS
     SS  AA   AA  NN    NN     TT     OO   OO       SS
SSSSSS   AA   AA  NN     N     TT      OOOOO   SSSSSS



                VERSION 2.0.0
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               PROGRAMMED BY:

              CHARLES M. STONE
         ENGINEERING SCIENCES CENTER
        SANDIA NATIONAL LABORATORIES
        ALBUQUERQUE, NEW MEXICO 87185

          DERIVED FROM PRONTO2D BY
     LEE M. TAYLOR AND DENNIS P. FLANAGAN



        RUN ON 03/07/96 AT 09:37:06
      RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                              INPUT STREAM IMAGES
LINE ----------------------------------------------------------------------------
  1: TITLE
  2:  SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.4 - E2/E1 = 3
  3: PLANE STRAIN
  4: MAXIMUM ITERATIONS = 3000
  5: RESIDUAL TOLERANCE = 0.50
  6: MAXIMUM TOLERANCE =  1000.0
  7: ELASTIC SOLUTION
  8: PREDICTOR SCALE FACTOR = 3
  9: TIME STEP SCALE = 0.70
 10: MATERIAL,1,ELASTIC,1.
 11: YOUNGS MODULUS 3000.
 12: POISSONS RATIO 0.
 13: END
 14: MATERIAL,2,ELASTIC,1.
 15: YOUNGS MODULUS 9000.
 16: POISSONS RATIO 0.
 17: END
 18: FUNCTION,1
 19:   0.,1.
 20:  10.,1.
 21: END
 22: FUNCTION,2
 23:    0.,0.
 24:   10.,1.
 25: END
 26: STEP CONTROL
 27:   100.,10.
 28: END
 29: PLOT TIME
 30:  1.,10.
 31: END
 32: OUTPUT TIME
 33:  10.,10.
 34: END
```

```
35: PLOT NODAL,REACTION,RESIDUAL
36: NO DISPLACEMENT,X,1
37: NO DISPLACEMENT,X,8
38: NO DISPLACEMENT,Y,2
39: CONTACT SURFACE,6,5,0.4,1.E-3,1.E+40
40: PRESSURE,3,1,1.
41: PRESSURE,4,2,-10.
42: PRESSURE,7,2,-10.
43: EXIT
    ------------------------------------------------------------------------
```

Information Only

Information Only

```
                 P R O B L E M   T I T L E

      SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.4 - E2/E1 = 3


                P R O B L E M   D E F I N I T I O N

         NUMBER OF ELEMENTS .......................        130
         NUMBER OF NODES ..........................        264
         NUMBER OF MATERIALS ......................          2
         NUMBER OF FUNCTIONS ......................          2
         NUMBER OF CONTACT SURFACES ...............          1
         NUMBER OF RIGID SURFACES .................          0
         NUMBER OF MATERIAL POINTS MONITORED .....           0
         ANALYSIS TYPE ............................ PLANE STRAIN
         GLOBAL CONVERGENCE MEASURE ...............
         RESIDUAL TOLERANCE .......................  5.000E-01
         MAXIMUM NUMBER OF ITERATIONS .............       3000
         ITERATIONS FOR INTERMEDIATE PRINT .......         528
         MAXIMUM RESIDUAL TOLERANCE ...............  1.000E+03
         PREDICTOR SCALE FACTOR FUNCTION ..........          3
         MINIMUM DAMPING FACTOR ...................  2.000E-01
         EFFECTIVE MODULUS STATUS ................. CONSTANT
         ELASTIC SOLUTION REQUESTED ...............
         SCALE FACTOR APPLIED TO TIME STEP .......   7.000E-01
         STRAIN SOFTENING SCALE FACTOR ...........   1.000E+00
         HOURGLASS STIFFNESS FACTOR ...............  5.000E-02
         HOURGLASS VISCOSITY FACTOR ...............  0.000E+00


              L O A D   S T E P   D E F I N I T I O N S
```

Information Only

```
   TIME          NO. OF STEPS          TIME
 0.000E+00           100            1.000E+01



      P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PRINTS         TIME
 0.000E+00            10            1.000E+01



      P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PLOTS          TIME
 0.000E+00             1            1.000E+01



      M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE ........................ELASTIC
  MATERIAL ID .........................              1
  DENSITY ............................. 1.000E+00
  MATERIAL PROPERTIES:
         YOUNGS MODULUS        =    3.000E+03
         POISSONS RATIO        =    0.000E+00
```

Information Only

```
        MATERIAL TYPE ........................ELASTIC
        MATERIAL ID ..........................          2
        DENSITY ..............................  1.000E+00
        MATERIAL PROPERTIES:
               YOUNGS MODULUS         =    9.000E+03
               POISSONS RATIO         =    0.000E+00



             F U N C T I O N   D E F I N I T I O N S


    FUNCTION ID .........        1     NUMBER OF POINTS ....       2

                     N        S            F(S)
                     1    0.000E+00    1.000E+00
                     2    1.000E+01    1.000E+00


    FUNCTION ID .........        2     NUMBER OF POINTS ....       2

                     N        S            F(S)
                     1    0.000E+00    0.000E+00
                     2    1.000E+01    1.000E+00



N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

              NODE SET FLAG     DIRECTION
                    1               X
                    8               X
                    2               Y
```

Information Only

```
                 C O N T A C T   S U R F A C E S

SURFACE  SURFACE 1  SURFACE 2  PENALTY   COEFFICIENT  PENETRATION  TENSION
NUMBER     FLAG       FLAG     FACTOR    OF FRICTION  MULTIPLIER   RELEASE
   1         6          5    0.000E+00    4.000E-01    1.000E-03  1.000E+40




P R E S S U R E   B O U N D A R Y   C O N D T I O N S

          SURFACE       FUNCTION      SCALE
           FLAG          NUMBER       FACTOR
             3              1       1.000E+00
             4              2      -1.000E+01
             7              2      -1.000E+01




                 E N D   O F   D A T A   I N P U T   P H A S E
                     1.813E-01 CPU SECONDS USED
                             70 WORDS ALLOCATED



       E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                     1.918E-02 CPU SECONDS USED
```

```
                264 WORDS ALLOCATED


  V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

            NODAL         ELEMENT       GLOBAL
            -----         -------       ------
            DISPLX        SIGXX         FX
            DISPLY        SIGYY         FY
            RESIDX        SIGZZ         RX
            RESIDY        TAUXY         RY
            RESID                       ITER
            REACTX                      RMAG
            REACTY
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/07/96 ,AT 09:37:06
 SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.4 - E2/E1 = 3

********************************************************************
SUMMARY OF DATA AT STEP NUMBER     0, TIME = 0.000E+00
NUMBER OF ITERATIONS =       104, TOTAL NUMBER OF ITERATIONS =       104
FINAL CONVERGENCE TOLERANCE = 4.639E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 8.062E-06
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.500E+01
SUM OF REACTION FORCES IN X-DIRECTION = 7.289E-04
SUM OF REACTION FORCES IN Y-DIRECTION =-2.500E+01
********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 0.000E+00  STEP NUMBER     0 ****



**** PLOT TAPE WRITTEN AT TIME = 1.000E-01  STEP NUMBER     1 ****



STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528  2.000E-01  1.000E-01  7.490E-01  3.095E+00  2.301E-02      0.74      1104
 1056  2.000E-01  1.000E-01  8.542E-01  3.095E+00  4.098E-01     13.24      1632


**** PLOT TAPE WRITTEN AT TIME = 2.000E-01  STEP NUMBER     2 ****



STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528  3.000E-01  1.000E-01  5.747E-01  3.104E+00  1.284E+00     41.38      2242
 1056  3.000E-01  1.000E-01  7.751E-01  3.104E+00  1.705E-02      0.55      2770
```

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```
 **** PLOT TAPE WRITTEN AT TIME = 3.000E-01  STEP NUMBER      3 ****


STEP       TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528   4.000E-01  1.000E-01  9.388E-01  3.115E+00  4.175E-02      1.34       3305
 1056   4.000E-01  1.000E-01  8.647E-01  3.115E+00  1.896E-02      0.61       3833
 1584   4.000E-01  1.000E-01  7.233E-01  3.115E+00  6.253E-01     20.08       4361

 **** PLOT TAPE WRITTEN AT TIME = 4.000E-01  STEP NUMBER      4 ****


STEP       TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528   5.000E-01  1.000E-01  4.887E-01  3.129E+00  6.310E-02      2.02       5020

 **** PLOT TAPE WRITTEN AT TIME = 5.000E-01  STEP NUMBER      5 ****


STEP       TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528   6.000E-01  1.000E-01  8.005E-01  3.147E+00  5.518E-01     17.53       5914
 1056   6.000E-01  1.000E-01  8.470E-01  3.147E+00  5.971E-01     18.97       6442

 **** PLOT TAPE WRITTEN AT TIME = 6.000E-01  STEP NUMBER      6 ****
```

```
STEP      TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR     LOAD NORM   LOAD NORM  IMBALANCE   STEPS
  528  7.000E-01  1.000E-01  4.547E-01  3.168E+00  4.061E-01      12.82      7008
 1056  7.000E-01  1.000E-01  7.677E-01  3.168E+00  1.820E-01       5.75      7536

   **** PLOT TAPE WRITTEN AT TIME = 7.000E-01  STEP NUMBER     7 ****


STEP      TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR     LOAD NORM   LOAD NORM  IMBALANCE   STEPS
  528  8.000E-01  1.000E-01  7.722E-01  3.191E+00  4.031E-02       1.26      8271

   **** PLOT TAPE WRITTEN AT TIME = 8.000E-01  STEP NUMBER     8 ****


STEP      TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR     LOAD NORM   LOAD NORM  IMBALANCE   STEPS
  528  9.000E-01  1.000E-01  8.564E-01  3.218E+00  8.800E-01      27.35      9242
 1056  9.000E-01  1.000E-01  8.636E-01  3.218E+00  6.459E-01      20.07      9770

   **** PLOT TAPE WRITTEN AT TIME = 9.000E-01  STEP NUMBER     9 ****


STEP      TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR     LOAD NORM   LOAD NORM  IMBALANCE   STEPS
  528  1.000E+00  1.000E-01  9.307E-01  3.247E+00  1.043E+00      32.11     10518
```

Information Only

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 09:37:06
 SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.4 - E2/E1 = 3

************************************************************************
SUMMARY OF DATA AT STEP NUMBER    10, TIME = 1.000E+00
NUMBER OF ITERATIONS =      1010, TOTAL NUMBER OF ITERATIONS =     11000
FINAL CONVERGENCE TOLERANCE = 4.923E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.999E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.500E+01
SUM OF REACTION FORCES IN X-DIRECTION = 1.859E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-2.502E+01
************************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER    10 ****


STEP     TIME     TIME     DAMPING    APPLIED   RESIDUAL   PERCENT   TOTAL
                  STEP     FACTOR    LOAD NORM  LOAD NORM  IMBALANCE  STEPS
  528  1.100E+00 1.000E-01 8.816E-01 3.279E+00 1.187E-01     3.62    11528

 **** PLOT TAPE WRITTEN AT TIME = 1.100E+00  STEP NUMBER    11 ****


STEP     TIME     TIME     DAMPING    APPLIED   RESIDUAL   PERCENT   TOTAL
                  STEP     FACTOR    LOAD NORM  LOAD NORM  IMBALANCE  STEPS
  528  1.200E+00 1.000E-01 8.257E-01 3.314E+00 8.438E-02     2.55    12565

 **** PLOT TAPE WRITTEN AT TIME = 1.200E+00  STEP NUMBER    12 ****
```

Information Only

```
STEP      TIME       TIME       DAMPING    APPLIED   RESIDUAL    PERCENT     TOTAL
                     STEP       FACTOR    LOAD NORM  LOAD NORM  IMBALANCE    STEPS
  528  1.300E+00  1.000E-01  9.384E-01  3.352E+00  9.784E-02      2.92      13570
 1056  1.300E+00  1.000E-01  3.576E-01  3.352E+00  5.247E-01     15.65      14098


   **** PLOT TAPE WRITTEN AT TIME = 1.300E+00   STEP NUMBER    13 ****


STEP      TIME       TIME       DAMPING    APPLIED   RESIDUAL    PERCENT     TOTAL
                     STEP       FACTOR    LOAD NORM  LOAD NORM  IMBALANCE    STEPS
  528  1.400E+00  1.000E-01  9.839E-01  3.392E+00  1.214E+00     35.80      15144

   **** PLOT TAPE WRITTEN AT TIME = 1.400E+00   STEP NUMBER    14 ****


STEP      TIME       TIME       DAMPING    APPLIED   RESIDUAL    PERCENT     TOTAL
                     STEP       FACTOR    LOAD NORM  LOAD NORM  IMBALANCE    STEPS
  528  1.500E+00  1.000E-01  7.964E-01  3.434E+00  2.333E-01      6.79      16007

   **** PLOT TAPE WRITTEN AT TIME = 1.500E+00   STEP NUMBER    15 ****


STEP      TIME       TIME       DAMPING    APPLIED   RESIDUAL    PERCENT     TOTAL
                     STEP       FACTOR    LOAD NORM  LOAD NORM  IMBALANCE    STEPS
  528  1.600E+00  1.000E-01  8.067E-01  3.479E+00  2.328E-01      6.69      17034
 1056  1.600E+00  1.000E-01  9.003E-01  3.479E+00  7.399E-01     21.27      17562

   **** PLOT TAPE WRITTEN AT TIME = 1.600E+00   STEP NUMBER    16 ****
```

```
STEP       TIME       TIME      DAMPING     APPLIED     RESIDUAL    PERCENT     TOTAL
                      STEP      FACTOR     LOAD NORM   LOAD NORM   IMBALANCE    STEPS
  528  1.700E+00  1.000E-01  7.796E-01  3.526E+00  1.789E-01       5.07       18411

  **** PLOT TAPE WRITTEN AT TIME = 1.700E+00  STEP NUMBER    17 ****


STEP       TIME       TIME      DAMPING     APPLIED     RESIDUAL    PERCENT     TOTAL
                      STEP      FACTOR     LOAD NORM   LOAD NORM   IMBALANCE    STEPS
  528  1.800E+00  1.000E-01  8.447E-01  3.576E+00  2.882E-01       8.06       19226
 1056  1.800E+00  1.000E-01  9.385E-01  3.576E+00  1.546E-01       4.32       19754

  **** PLOT TAPE WRITTEN AT TIME = 1.800E+00  STEP NUMBER    18 ****


STEP       TIME       TIME      DAMPING     APPLIED     RESIDUAL    PERCENT     TOTAL
                      STEP      FACTOR     LOAD NORM   LOAD NORM   IMBALANCE    STEPS
  528  1.900E+00  1.000E-01  8.766E-01  3.627E+00  3.296E-01       9.09       20304
 1056  1.900E+00  1.000E-01  5.260E-01  3.627E+00  7.429E-02       2.05       20832

  **** PLOT TAPE WRITTEN AT TIME = 1.900E+00  STEP NUMBER    19 ****


STEP       TIME       TIME      DAMPING     APPLIED     RESIDUAL    PERCENT     TOTAL
                      STEP      FACTOR     LOAD NORM   LOAD NORM   IMBALANCE    STEPS
  528  2.000E+00  1.000E-01  6.640E-01  3.680E+00  1.716E-01       4.66       21581
 1056  2.000E+00  1.000E-01  9.563E-01  3.680E+00  2.231E-01       6.06       22109
```

Information Only

Information Only

```
SANTOS, VERSION 2.0.0     ,RUN ON 03/07/96 ,AT 09:37:06
SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.4 - E2/E1 = 3

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER    20, TIME = 2.000E+00
NUMBER OF ITERATIONS =       1104, TOTAL NUMBER OF ITERATIONS =     22157
FINAL CONVERGENCE TOLERANCE = 4.629E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 3.999E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.501E+01
SUM OF REACTION FORCES IN X-DIRECTION = 3.849E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-2.503E+01
*********************************************************************


 **** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER    20 ****


STEP      TIME       TIME      DAMPING     APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  528  2.100E+00  1.000E-01  8.328E-01  3.736E+00  9.068E-01     24.27     22685

 **** PLOT TAPE WRITTEN AT TIME = 2.100E+00  STEP NUMBER    21 ****
.
.
.


 **** PLOT TAPE WRITTEN AT TIME = 9.900E+00  STEP NUMBER    99 ****


STEP      TIME       TIME      DAMPING     APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  528  1.000E+01  1.000E-01  8.761E-01  1.046E+01  7.670E-01      7.33     92235
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/07/96 ,AT 09:37:06
 SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.4 - E2/E1 = 3

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER   100, TIME = 1.000E+01
NUMBER OF ITERATIONS =       906, TOTAL NUMBER OF ITERATIONS =     92613
FINAL CONVERGENCE TOLERANCE = 4.424E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.999E+01
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.506E+01
SUM OF REACTION FORCES IN X-DIRECTION = 1.963E+01
SUM OF REACTION FORCES IN Y-DIRECTION =-2.512E+01
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+01  STEP NUMBER   100 ****




          101 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                 E N D   O F   S O L U T I O N   P H A S E
                      1.184E+03 CPU SECONDS USED
                            264 WORDS ALLOCATED
```

Case 2 Output

```
 SSSSSS   AAAAA   N    NN  TTTTTT   OOOOO   SSSSSS
SS       AA   AA  NN   NN    TT    OO   OO SS
SS       AA   AA  NNN  NN    TT    OO   OO SS
 SSSSS   AAAAAAA  NN N NN    TT    OO   OO  SSSSS
     SS  AA   AA  NN  NNN    TT    OO   OO      SS
     SS  AA   AA  NN   NN    TT    OO   OO      SS
SSSSSS   AA   AA  NN    N    TT     OOOOO  SSSSSS



                      VERSION 2.0.0
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                     PROGRAMMED BY:

                    CHARLES M. STONE
              ENGINEERING SCIENCES CENTER
             SANDIA NATIONAL LABORATORIES
             ALBUQUERQUE, NEW MEXICO 87185

                DERIVED FROM PRONTO2D BY
         LEE M. TAYLOR AND DENNIS P. FLANAGAN



              RUN ON 03/07/96 AT 09:58:59
            RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                                   INPUT STREAM IMAGES
LINE --------------------------------------------------------------------------
   1: TITLE
   2:  SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.5 - E2/E1 = 10
   3: PLANE STRAIN
   4: MAXIMUM ITERATIONS = 3000
   5: RESIDUAL TOLERANCE = 0.50
   6: MAXIMUM TOLERANCE =  1000.0
   7: ELASTIC SOLUTION
   8: PREDICTOR SCALE FACTOR = 3
   9: TIME STEP SCALE = 0.70
  10: MATERIAL,1,ELASTIC,1.
  11: YOUNGS MODULUS 800.
  12: POISSONS RATIO 0.
  13: END
  14: MATERIAL,2,ELASTIC,1.
  15: YOUNGS MODULUS 8000.
  16: POISSONS RATIO 0.
  17: END
  18: FUNCTION,1
  19:    0.,1.
  20:   10.,1.
  21: END
  22: FUNCTION,2
  23:    0.,0.
  24:   10.,1.
  25: END
  26: STEP CONTROL
  27:   100.,10.
  28: END
  29: PLOT TIME
  30:  1.,10.
  31: END
  32: OUTPUT TIME
  33:  10.,10.
  34: END
```

```
35: PLOT NODAL,REACTION,RESIDUAL
36: NO DISPLACEMENT,X,1
37: NO DISPLACEMENT,X,8
38: NO DISPLACEMENT,Y,2
39: CONTACT SURFACE,6,5,0.5,1.E-3,1.E+40
40: PRESSURE,3,1,1.
41: PRESSURE,4,2,-10.
42: PRESSURE,7,2,-10.
43: EXIT
    ---------------------------------------------------------------------------
```

Information Only

```
                  PROBLEM TITLE

SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.5 - E2/E1 = 10


                PROBLEM DEFINITION

   NUMBER OF ELEMENTS ......................        130
   NUMBER OF NODES .........................        264
   NUMBER OF MATERIALS .....................          2
   NUMBER OF FUNCTIONS .....................          2
   NUMBER OF CONTACT SURFACES ..............          1
   NUMBER OF RIGID SURFACES ................          0
   NUMBER OF MATERIAL POINTS MONITORED .....          0
   ANALYSIS TYPE ........................... PLANE STRAIN
   GLOBAL CONVERGENCE MEASURE ..............
   RESIDUAL TOLERANCE ......................  5.000E-01
   MAXIMUM NUMBER OF ITERATIONS ............       3000
   ITERATIONS FOR INTERMEDIATE PRINT .......        528
   MAXIMUM RESIDUAL TOLERANCE ..............  1.000E+03
   PREDICTOR SCALE FACTOR FUNCTION .........          3
   MINIMUM DAMPING FACTOR ..................  2.000E-01
   EFFECTIVE MODULUS STATUS ................ CONSTANT
   ELASTIC SOLUTION REQUESTED ..............
   SCALE FACTOR APPLIED TO TIME STEP .......  7.000E-01
   STRAIN SOFTENING SCALE FACTOR ...........  1.000E+00
   HOURGLASS STIFFNESS FACTOR ..............  5.000E-02
   HOURGLASS VISCOSITY FACTOR ..............  0.000E+00


              LOAD STEP DEFINITIONS
```

Information Only

Information Only

```
    TIME          NO. OF STEPS          TIME
  0.000E+00           100             1.000E+01


           P R I N T E D   O U T P U T   F R E Q U E N C Y

    TIME     STEPS BETWEEN PRINTS        TIME
  0.000E+00           10              1.000E+01


           P L O T T E D   O U T P U T   F R E Q U E N C Y

    TIME     STEPS BETWEEN PLOTS         TIME
  0.000E+00           1               1.000E+01


           M A T E R I A L   D E F I N I T I O N S

  MATERIAL TYPE .........................ELASTIC
  MATERIAL ID ..........................          1
  DENSITY .............................. 1.000E+00
  MATERIAL PROPERTIES:
         YOUNGS MODULUS        =     8.000E+02
         POISSONS RATIO        =     0.000E+00
```

Information Only

```
          MATERIAL TYPE ........................ELASTIC
          MATERIAL ID ..........................          2
          DENSITY ..............................  1.000E+00
          MATERIAL PROPERTIES:
                 YOUNGS MODULUS        =    8.000E+03
                 POISSONS RATIO        =    0.000E+00



               F U N C T I O N   D E F I N I T I O N S

      FUNCTION ID .........       1     NUMBER OF POINTS ....      2

                     N        S           F(S)
                     1    0.000E+00    1.000E+00
                     2    1.000E+01    1.000E+00

      FUNCTION ID .........       2     NUMBER OF POINTS ....      2

                     N        S           F(S)
                     1    0.000E+00    0.000E+00
                     2    1.000E+01    1.000E+00



 N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                 NODE SET FLAG     DIRECTION
                      1                X
                      8                X
                      2                Y
```

Information Only

```
                  C O N T A C T   S U R F A C E S

SURFACE   SURFACE 1   SURFACE 2   PENALTY   COEFFICIENT   PENETRATION   TENSION
NUMBER      FLAG        FLAG      FACTOR    OF FRICTION   MULTIPLIER    RELEASE
   1          6            5    0.000E+00    5.000E-01    1.000E-03    1.000E+40



P R E S S U R E   B O U N D A R Y   C O N D T I O N S

          SURFACE       FUNCTION      SCALE
            FLAG         NUMBER       FACTOR
              3             1       1.000E+00
              4             2      -1.000E+01
              7             2      -1.000E+01



                    E N D   O F   D A T A   I N P U T   P H A S E
                          1.818E-01 CPU SECONDS USED
                                 70 WORDS ALLOCATED



             E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                          1.859E-02 CPU SECONDS USED
```

```
                     264 WORDS ALLOCATED



   V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

            NODAL         ELEMENT        GLOBAL
            -----         -------        ------
            DISPLX        SIGXX          FX
            DISPLY        SIGYY          FY
            RESIDX        SIGZZ          RX
            RESIDY        TAUXY          RY
            RESID                        ITER
            REACTX                       RMAG
            REACTY
```

Information Only

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 09:58:59
SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.5 - E2/E1 = 10

**************************************************************************
SUMMARY OF DATA AT STEP NUMBER      0, TIME = 0.000E+00
NUMBER OF ITERATIONS =         90, TOTAL NUMBER OF ITERATIONS =          90
FINAL CONVERGENCE TOLERANCE = 4.971E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 6.738E-06
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.500E+01
SUM OF REACTION FORCES IN X-DIRECTION =-6.200E-05
SUM OF REACTION FORCES IN Y-DIRECTION =-2.505E+01
**************************************************************************


 **** PLOT TAPE WRITTEN AT TIME = 0.000E+00  STEP NUMBER     0 ****



STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528  1.000E-01  1.000E-01  7.312E-01  3.091E+00  5.132E-01     16.61       618

 **** PLOT TAPE WRITTEN AT TIME = 1.000E-01  STEP NUMBER     1 ****



STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528  2.000E-01  1.000E-01  5.012E-01  3.095E+00  4.069E-01     13.14      1281

 **** PLOT TAPE WRITTEN AT TIME = 2.000E-01  STEP NUMBER     2 ****
```

```
STEP       TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528  3.000E-01  1.000E-01  9.001E-01  3.104E+00  2.298E-02       0.74       2279

   **** PLOT TAPE WRITTEN AT TIME = 3.000E-01   STEP NUMBER      3 ****


STEP       TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528  4.000E-01  1.000E-01  9.557E-01  3.115E+00  1.081E-01       3.47       3307

   **** PLOT TAPE WRITTEN AT TIME = 4.000E-01   STEP NUMBER      4 ****


STEP       TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528  5.000E-01  1.000E-01  9.534E-01  3.129E+00  6.129E-01      19.58       4176

   **** PLOT TAPE WRITTEN AT TIME = 5.000E-01   STEP NUMBER      5 ****


STEP       TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  528  6.000E-01  1.000E-01  6.759E-01  3.147E+00  2.094E-01       6.66       5125
```

Information Only

```
     **** PLOT TAPE WRITTEN AT TIME = 6.000E-01   STEP NUMBER     6 ****


  STEP      TIME       TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                       STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
    528  7.000E-01  1.000E-01  9.554E-01  3.168E+00  3.521E-01     11.12      6063

     **** PLOT TAPE WRITTEN AT TIME = 7.000E-01   STEP NUMBER     7 ****


  STEP      TIME       TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                       STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
    528  8.000E-01  1.000E-01  9.555E-01  3.191E+00  1.620E-02      0.51      6966

     **** PLOT TAPE WRITTEN AT TIME = 8.000E-01   STEP NUMBER     8 ****


  STEP      TIME       TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                       STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
    528  9.000E-01  1.000E-01  7.044E-01  3.218E+00  2.442E-01      7.59      7585

     **** PLOT TAPE WRITTEN AT TIME = 9.000E-01   STEP NUMBER     9 ****


  STEP      TIME       TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                       STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
    528  1.000E+00  1.000E-01  6.301E-01  3.247E+00  3.056E-01      9.41      8435
```

Information Only

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 09:58:59
 SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.5 - E2/E1 = 10

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    10, TIME = 1.000E+00
NUMBER OF ITERATIONS =       701, TOTAL NUMBER OF ITERATIONS =      8608
FINAL CONVERGENCE TOLERANCE = 4.980E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.998E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.501E+01
SUM OF REACTION FORCES IN X-DIRECTION = 1.838E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-2.501E+01
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER    10 ****



STEP      TIME      TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  528  1.100E+00  1.000E-01  8.699E-01  3.280E+00  2.718E-02      0.83     9136

**** PLOT TAPE WRITTEN AT TIME = 1.100E+00  STEP NUMBER    11 ****



STEP      TIME      TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  528  1.200E+00  1.000E-01  8.329E-01  3.314E+00  2.055E-01      6.20     9876

**** PLOT TAPE WRITTEN AT TIME = 1.200E+00  STEP NUMBER    12 ****
```

Information Only

```
STEP       TIME       TIME       DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP       FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
 528  1.300E+00  1.000E-01  8.390E-01  3.352E+00  5.889E-01     17.57      10634

 **** PLOT TAPE WRITTEN AT TIME = 1.300E+00  STEP NUMBER    13 ****


STEP       TIME       TIME       DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP       FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
 528  1.400E+00  1.000E-01  9.988E-01  3.392E+00  2.230E-02      0.66      11436

 **** PLOT TAPE WRITTEN AT TIME = 1.400E+00  STEP NUMBER    14 ****


STEP       TIME       TIME       DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP       FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
 528  1.500E+00  1.000E-01  7.730E-01  3.434E+00  6.661E-01     19.39      12283

 **** PLOT TAPE WRITTEN AT TIME = 1.500E+00  STEP NUMBER    15 ****


STEP       TIME       TIME       DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP       FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
 528  1.600E+00  1.000E-01  5.275E-01  3.479E+00  1.404E-01      4.03      13208
```

Information Only

```
     **** PLOT TAPE WRITTEN AT TIME = 1.600E+00  STEP NUMBER    16 ****


 STEP      TIME      TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
   528  1.700E+00  1.000E-01  5.246E-01  3.526E+00  5.904E-01    16.74     14067

     **** PLOT TAPE WRITTEN AT TIME = 1.700E+00  STEP NUMBER    17 ****


 STEP      TIME      TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
   528  1.800E+00  1.000E-01  7.015E-01  3.576E+00  7.791E-01    21.79     14724

     **** PLOT TAPE WRITTEN AT TIME = 1.800E+00  STEP NUMBER    18 ****


 STEP      TIME      TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
   528  1.900E+00  1.000E-01  9.100E-01  3.627E+00  1.874E-02     0.52     15726

     **** PLOT TAPE WRITTEN AT TIME = 1.900E+00  STEP NUMBER    19 ****


 STEP      TIME      TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
   528  2.000E+00  1.000E-01  9.133E-01  3.680E+00  3.086E-02     0.84     16261
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 09:58:59
 SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.5 - E2/E1 = 10

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER    20, TIME = 2.000E+00
NUMBER OF ITERATIONS =       921, TOTAL NUMBER OF ITERATIONS =     16654
FINAL CONVERGENCE TOLERANCE = 4.801E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 3.995E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.502E+01
SUM OF REACTION FORCES IN X-DIRECTION = 3.874E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-2.499E+01
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER    20 ****



STEP      TIME      TIME      DAMPING    APPLIED   RESIDUAL   PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE  STEPS
  528  2.100E+00  1.000E-01  9.238E-01  3.736E+00  3.518E-02     0.94    17182

**** PLOT TAPE WRITTEN AT TIME = 2.100E+00  STEP NUMBER    21 ****



STEP      TIME      TIME      DAMPING    APPLIED   RESIDUAL   PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE  STEPS
  528  2.200E+00  1.000E-01  7.931E-01  3.793E+00  8.951E-01    23.60    17726

**** PLOT TAPE WRITTEN AT TIME = 2.200E+00  STEP NUMBER    22 ****
```

Information Only

```
**** PLOT TAPE WRITTEN AT TIME = 9.900E+00  STEP NUMBER    99 ****


STEP      TIME       TIME      DAMPING     APPLIED    RESIDUAL     PERCENT     TOTAL
                     STEP      FACTOR     LOAD NORM   LOAD NORM   IMBALANCE    STEPS
  528  1.000E+01  1.000E-01  9.111E-01  1.045E+01  6.909E-01       6.61      70814
```

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 09:58:59
SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.5 - E2/E1 = 10

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER   100, TIME = 1.000E+01
NUMBER OF ITERATIONS =       634, TOTAL NUMBER OF ITERATIONS =     70920
FINAL CONVERGENCE TOLERANCE = 4.937E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.996E+01
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.520E+01
SUM OF REACTION FORCES IN X-DIRECTION = 1.961E+01
SUM OF REACTION FORCES IN Y-DIRECTION =-2.520E+01
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+01  STEP NUMBER   100 ****




          101 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                E N D  O F  S O L U T I O N  P H A S E
                    9.011E+02 CPU SECONDS USED
                          264 WORDS ALLOCATED
```

Information Only

APPENDIX K

Input/Output Data For Problem 11 – Elastic/Plastic Analysis of a Thick-Walled Hollow Sphere

The following two sections present the input data and the formatted output for the elastic/plastic analysis of a thick-walled hollow sphere.

FASTQ and SANTOS Input Data For The Elastic/Plastic Analysis of a Thick-Walled Hollow Sphere

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of each case of the elastic/plastic thick-walled hollow sphere problem.

Information Only

```
TITLE
 HOLLOW CYLINDER - SANTOS QA TEST PROBLEM
POINT    1       0.        0.
POINT    2       1.        0.
POINT    3       0.        1.
POINT    4       0.        2.
POINT    5       2.        0.
LINE     1    CIRC   2    3    1    20    1.0
LINE     2    STR    3    4    0    30    1.0
LINE     3    CIRC   5    4    1    20    1.0
LINE     4    STR    2    5    0    30    1.0
NODEBC   1    2
NODEBC   2    4
ELEMBC   3    1
SCHEME   0    MP
REGION   1     1   -1   -2   -3   -4
EXIT
```

Information Only

Elastic/Perfectly-Plastic

```
TITLE
  SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95
AXISYMMETRIC
MAXIMUM ITERATIONS 20000
RESIDUAL TOLERANCE .01
MATERIAL,1,ELASTIC PLASTIC,1.0
YOUNGS MODULUS 2.07E+11
POISSONS RATIO 0.3
YIELD STRESS 10000.
HARDENING MODULUS 0.
BETA 0.
END
FUNCTION,1
  0.        0.
  1.      5833.
  1.25    9501.9
  1.5    11963.5
  1.75   13392.8
  2.     13900.0
END
STEP CONTROL
  1,1.
  1,1.25
  1,1.50
  1,1.75
  1,2.0
END
PLOT TIME
 1,1.
 1,1.25
 1,1.50
 1,1.75
 1,2.0
END
OUTPUT TIME
 1,1.
 1,1.25
 1,1.50
 1,1.75
 1,2.0
END
NO DISPLACEMENT,X,1
NO DISPLACEMENT,Y,2
PRESSURE,3,1,1.
EXIT
```

Information Only

Elastic/Plastic with Hardening

```
TITLE
  SANTOS QA PROBLEM - HOLLOW SPHERE - 10/26/94 - HARDENING M = 0.1
AXISYMMETRIC
MAXIMUM ITERATIONS 20000
RESIDUAL TOLERANCE .01
MATERIAL,1,ELASTIC PLASTIC,1.0
YOUNGS MODULUS 2.07E+11
POISSONS RATIO 0.3
YIELD STRESS 10000.
HARDENING MODULUS 2.07E+10
BETA 0.
END
FUNCTION,1
  0.        0.
  1.      5833.
  1.25    9756.5
  1.5    13003.2
  1.75   15798.4
  2.     18278.8
END
STEP CONTROL
  1,1.
  1,1.25
  1,1.50
  1,1.75
  1,2.0
END
PLOT TIME
 1,1.
 1,1.25
 1,1.50
 1,1.75
 1,2.0
END
OUTPUT TIME
 1,1.
 1,1.25
 1,1.50
 1,1.75
 1,2.0
END
NO DISPLACEMENT,X,1
NO DISPLACEMENT,Y,2
PRESSURE,3,1,1.
EXIT
```

Information Only

Elastic/Perfectly-Plastic with Temperature

```
TITLE
  SANTOS QA PROBLEM - HOLLOW SPHERE - 12/14/94 - TEMPERATURE PROBLEM
AXISYMMETRIC
MAXIMUM ITERATIONS 20000
RESIDUAL TOLERANCE .5
MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
YOUNGS MODULUS 1.E+7
POISSONS RATIO 0.3
YIELD STRESS 10000.
HARDENING MODULUS 0.
BETA 0.
END
THERMAL STRESS EXTERNAL
PLOT ELEMENT STRESS TEMPERATURE
FUNCTION 1  $ THERMAL STRAIN FOR ALPHA = 1.E-5
     0.    0.
  1000.    1.E-2
END
STEP CONTROL
  4,1.
  4,2,
  4,3.
  4,4.
  4,5.
END
PLOT TIME
  1,1.
  4,2.
  4,3.
  4,4.
  4,5.
END
OUTPUT TIME
  4,1.
  4,2.
  4,3.
  4,4.
  4,5.
END
NO DISPLACEMENT,X,1
NO DISPLACEMENT,Y,2
EXIT
```

Information Only

SANTOS Output For The Elastic/Plastic Analysis of a Thick-Walled Hollow Sphere

The following section presents a portion of the SANTOS printed output for each case of the elastic/plastic analysis of a thick-walled hollow sphere. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

WPO# 35675 March 27, 1996

Elastic/Perfectly-Plastic

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS



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                   CHARLES M. STONE
             ENGINEERING SCIENCES CENTER
             SANDIA NATIONAL LABORATORIES
            ALBUQUERQUE, NEW MEXICO 87185

               DERIVED FROM PRONTO2D BY
         LEE M. TAYLOR AND DENNIS P. FLANAGAN


             RUN ON 03/06/96 AT 09:57:53
           RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                              INPUT STREAM IMAGES
LINE ---------------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95
  3: AXISYMMETRIC
  4: MAXIMUM ITERATIONS 20000
  5: RESIDUAL TOLERANCE .01
  6: MATERIAL,1,ELASTIC PLASTIC,1.0
  7: YOUNGS MODULUS 2.07E+11
  8: POISSONS RATIO 0.3
  9: YIELD STRESS 10000.
 10: HARDENING MODULUS 0.
 11: BETA 0.
 12: END
 13: FUNCTION,1
 14:   0.         0.
 15:   1.      5833.
 16:   1.25    9501.9
 17:   1.5    11963.5
 18:   1.75   13392.8
 19:   2.     13900.0
 20: END
 21: STEP CONTROL
 22:   1,1.
 23:   1,1.25
 24:   1,1.50
 25:   1,1.75
 26:   1,2.0
 27: END
 28: PLOT TIME
 29:  1,1.
 30:  1,1.25
 31:  1,1.50
 32:  1,1.75
 33:  1,2.0
 34: END
```

```
OUTPUT TIME
 1,1.
 1,1.25
 1,1.50
 1,1.75
 1,2.0
END
NO DISPLACEMENT,X,1
NO DISPLACEMENT,Y,2
PRESSURE,3,1,1.
EXIT
------------------------------------------------------------------------
```

Information Only

```
                    P R O B L E M   T I T L E

          SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95



                P R O B L E M   D E F I N I T I O N

   NUMBER OF ELEMENTS ........................        600
   NUMBER OF NODES ...........................        651
   NUMBER OF MATERIALS .......................          1
   NUMBER OF FUNCTIONS .......................          1
   NUMBER OF CONTACT SURFACES ...............           0
   NUMBER OF RIGID SURFACES .................           0
   NUMBER OF MATERIAL POINTS MONITORED .....            0
   ANALYSIS TYPE ........................... AXISYMMETRIC
   GLOBAL CONVERGENCE MEASURE ..............
   RESIDUAL TOLERANCE ......................   1.000E-02
   MAXIMUM NUMBER OF ITERATIONS ............       20000
   ITERATIONS FOR INTERMEDIATE PRINT .......        1302
   MAXIMUM RESIDUAL TOLERANCE ..............   6.000E-01
   PREDICTOR SCALE FACTOR FUNCTION .........           0
   MINIMUM DAMPING FACTOR ..................   2.000E-01
   EFFECTIVE MODULUS STATUS ................  CONSTANT
   SCALE FACTOR APPLIED TO TIME STEP .......   1.000E+00
   STRAIN SOFTENING SCALE FACTOR ...........   1.000E+00
   HOURGLASS STIFFNESS FACTOR ..............   1.000E-02
   HOURGLASS VISCOSITY FACTOR ..............   3.000E-02



              L O A D   S T E P   D E F I N I T I O N S
```

Information Only

```
  TIME            NO. OF STEPS           TIME
0.000E+00               1             1.000E+00
1.000E+00               1             1.250E+00
1.250E+00               1             1.500E+00
1.500E+00               1             1.750E+00
1.750E+00               1             2.000E+00


     P R I N T E D   O U T P U T   F R E Q U E N C Y


  TIME       STEPS BETWEEN PRINTS          TIME
0.000E+00               1             1.000E+00
1.000E+00               1             1.250E+00
1.250E+00               1             1.500E+00
1.500E+00               1             1.750E+00
1.750E+00               1             2.000E+00


     P L O T T E D   O U T P U T   F R E Q U E N C Y


  TIME       STEPS BETWEEN PLOTS           TIME
0.000E+00               1             1.000E+00
1.000E+00               1             1.250E+00
1.250E+00               1             1.500E+00
1.500E+00               1             1.750E+00
1.750E+00               1             2.000E+00
```

Information Only

Information Only

```
                M A T E R I A L   D E F I N I T I O N S


            MATERIAL TYPE ........................ELASTIC PLASTIC
            MATERIAL ID ...........................          1
            DENSITY ...............................   1.000E+00
            MATERIAL PROPERTIES:
                   YOUNGS MODULUS         =      2.070E+11
                   POISSONS RATIO         =      3.000E-01
                   YIELD STRESS           =      1.000E+04
                   HARDENING MODULUS      =      0.000E+00
                   BETA                   =      0.000E+00



                F U N C T I O N   D E F I N I T I O N S


         FUNCTION ID .........       1     NUMBER OF POINTS ....        6

                     N        S            F(S)
                     1    0.000E+00     0.000E+00
                     2    1.000E+00     5.833E+03
                     3    1.250E+00     9.502E+03
                     4    1.500E+00     1.196E+04
                     5    1.750E+00     1.339E+04
                     6    2.000E+00     1.390E+04



      N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                  NODE SET FLAG     DIRECTION
```

Information Only

```
                1                X
                2                Y




P R E S S U R E   B O U N D A R Y   C O N D T I O N S

        SURFACE       FUNCTION      SCALE
         FLAG          NUMBER       FACTOR
           3              1       1.000E+00




           E N D   O F   D A T A   I N P U T   P H A S E
                  1.899E-01 CPU SECONDS USED
                         62 WORDS ALLOCATED




     E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                  1.408E-02 CPU SECONDS USED
                        651 WORDS ALLOCATED




     V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

               NODAL         ELEMENT        GLOBAL
               -----         -------        ------
```

```
DISPLX      SIGXX      FX
DISPLY      SIGYY      FY
            SIGZZ      RX
            TAUXY      RY
                       ITER
                       RMAG

**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 09:57:53
  SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER     1, TIME = 1.000E+00
NUMBER OF ITERATIONS =      1040, TOTAL NUMBER OF ITERATIONS =      1040
FINAL CONVERGENCE TOLERANCE = 9.594E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION = 4.577E+03
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 2.917E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 2.917E+03
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     1 ****
```

Information Only

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 09:57:53
 SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER     5, TIME = 2.000E+00
NUMBER OF ITERATIONS =     10558, TOTAL NUMBER OF ITERATIONS =     13290
FINAL CONVERGENCE TOLERANCE = 9.723E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.091E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 6.950E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 6.947E+03
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER     5 ****




            5 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                E N D   O F   S O L U T I O N   P H A S E
                     9.974E+01 CPU SECONDS USED
                            651 WORDS ALLOCATED
```

WPO# 35675 March 27, 1996

Elastic/Plastic with Hardening

```
 SSSSSS   AAAAA   N    NN  TTTTTT   OOOOO   SSSSSS
SS       AA   AA  NN   NN    TT    OO   OO SS
SS       AA   AA  NNN  NN    TT    OO   OO SS
 SSSSS   AAAAAAA  NN N NN    TT    OO   OO  SSSSS
     SS  AA   AA  NN  NNN    TT    OO   OO      SS
     SS  AA   AA  NN   NN    TT    OO   OO      SS
SSSSSS   AA   AA  NN    N    TT     OOOOO  SSSSSS



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            ENGINEERING SCIENCES CENTER
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           ALBUQUERQUE, NEW MEXICO 87185

             DERIVED FROM PRONTO2D BY
         LEE M. TAYLOR AND DENNIS P. FLANAGAN


           RUN ON 03/06/96 AT 09:57:15
          RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

```
                        INPUT STREAM IMAGES
LINE ------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - HOLLOW SPHERE - 10/26/94 - HARDENING M = 0.1
  3: AXISYMMETRIC
  4: MAXIMUM ITERATIONS 20000
  5: RESIDUAL TOLERANCE .01
  6: MATERIAL,1,ELASTIC PLASTIC,1.0
  7: YOUNGS MODULUS 2.07E+11
  8: POISSONS RATIO 0.3
  9: YIELD STRESS 10000.
 10: HARDENING MODULUS 2.07E+10
 11: BETA 0.
 12: END
 13: FUNCTION,1
 14:   0.         0.
 15:   1.      5833.
 16:   1.25    9756.5
 17:   1.5    13003.2
 18:   1.75   15798.4
 19:   2.     18278.8
 20: END
 21: STEP CONTROL
 22:   1,1.
 23:   1,1.25
 24:   1,1.50
 25:   1,1.75
 26:   1,2.0
 27: END
 28: PLOT TIME
 29:  1,1.
 30:  1,1.25
 31:  1,1.50
 32:  1,1.75
 33:  1,2.0
 34: END
```

Information Only

```
35: OUTPUT TIME
36:  1,1.
37:  1,1.25
38:  1,1.50
39:  1,1.75
40:  1,2.0
41: END
42: NO DISPLACEMENT,X,1
43: NO DISPLACEMENT,Y,2
44: PRESSURE,3,1,1.
45: EXIT
    ------------------------------------------------------------------------
```

Information Only

Information Only

```
                P R O B L E M   T I T L E

      SANTOS QA PROBLEM - HOLLOW SPHERE - 10/26/94 - HARDENING M = 0.1



             P R O B L E M   D E F I N I T I O N

      NUMBER OF ELEMENTS ......................         600
      NUMBER OF NODES .........................         651
      NUMBER OF MATERIALS .....................           1
      NUMBER OF FUNCTIONS .....................           1
      NUMBER OF CONTACT SURFACES ..............           0
      NUMBER OF RIGID SURFACES ................           0
      NUMBER OF MATERIAL POINTS MONITORED .....           0
      ANALYSIS TYPE ........................... AXISYMMETRIC
      GLOBAL CONVERGENCE MEASURE ..............
      RESIDUAL TOLERANCE ......................   1.000E-02
      MAXIMUM NUMBER OF ITERATIONS ............       20000
      ITERATIONS FOR INTERMEDIATE PRINT .......        1302
      MAXIMUM RESIDUAL TOLERANCE ..............   6.000E-01
      PREDICTOR SCALE FACTOR FUNCTION .........           0
      MINIMUM DAMPING FACTOR ..................   2.000E-01
      EFFECTIVE MODULUS STATUS ................ CONSTANT
      SCALE FACTOR APPLIED TO TIME STEP .......   1.000E+00
      STRAIN SOFTENING SCALE FACTOR ...........   1.000E+00
      HOURGLASS STIFFNESS FACTOR ..............   1.000E-02
      HOURGLASS VISCOSITY FACTOR ..............   3.000E-02



             L O A D   S T E P   D E F I N I T I O N S
```

```
    TIME            NO. OF STEPS            TIME
  0.000E+00              1               1.000E+00
  1.000E+00              1               1.250E+00
  1.250E+00              1               1.500E+00
  1.500E+00              1               1.750E+00
  1.750E+00              1               2.000E+00



          P R I N T E D   O U T P U T   F R E Q U E N C Y


    TIME      STEPS BETWEEN PRINTS          TIME
  0.000E+00              1               1.000E+00
  1.000E+00              1               1.250E+00
  1.250E+00              1               1.500E+00
  1.500E+00              1               1.750E+00
  1.750E+00              1               2.000E+00



          P L O T T E D   O U T P U T   F R E Q U E N C Y


    TIME      STEPS BETWEEN PLOTS           TIME
  0.000E+00              1               1.000E+00
  1.000E+00              1               1.250E+00
  1.250E+00              1               1.500E+00
  1.500E+00              1               1.750E+00
  1.750E+00              1               2.000E+00
```

Information Only

WPO# 35675 March 27, 1996

```
        M A T E R I A L   D E F I N I T I O N S

      MATERIAL TYPE .......................ELASTIC PLASTIC
      MATERIAL ID .........................         1
      DENSITY .............................   1.000E+00
      MATERIAL PROPERTIES:
              YOUNGS MODULUS        =     2.070E+11
              POISSONS RATIO        =     3.000E-01
              YIELD STRESS          =     1.000E+04
              HARDENING MODULUS     =     2.070E+10
              BETA                  =     0.000E+00


        F U N C T I O N   D E F I N I T I O N S

   FUNCTION ID .........      1     NUMBER OF POINTS ....       6

              N         S            F(S)
              1    0.000E+00    0.000E+00
              2    1.000E+00    5.833E+03
              3    1.250E+00    9.757E+03
              4    1.500E+00    1.300E+04
              5    1.750E+00    1.580E+04
              6    2.000E+00    1.828E+04


  N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

              NODE SET FLAG     DIRECTION
```

Information Only

K-22

```
                   1                  X
                   2                  Y




      P R E S S U R E   B O U N D A R Y   C O N D T I O N S

                SURFACE      FUNCTION     SCALE
                  FLAG        NUMBER      FACTOR
                    3            1      1.000E+00




                   E N D   O F   D A T A   I N P U T   P H A S E
                          2.070E-01 CPU SECONDS USED
                                 62 WORDS ALLOCATED




          E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                          1.416E-02 CPU SECONDS USED
                                651 WORDS ALLOCATED




            V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                      NODAL         ELEMENT       GLOBAL
                      -----         -------       ------
```

Information Only

```
               DISPLX        SIGXX         FX
               DISPLY        SIGYY         FY
                             SIGZZ         RX
                             TAUXY         RY
                                           ITER
                                           RMAG

**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****
```

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 09:57:15
 SANTOS QA PROBLEM - HOLLOW SPHERE - 10/26/94 - HARDENING M = 0.1

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      1, TIME = 1.000E+00
NUMBER OF ITERATIONS =        536, TOTAL NUMBER OF ITERATIONS =       536
FINAL CONVERGENCE TOLERANCE = 9.644E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION = 4.577E+03
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 2.917E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 2.915E+03
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     1 ****
```

Information Only

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 09:57:15
  SANTOS QA PROBLEM - HOLLOW SPHERE - 10/26/94 - HARDENING M = 0.1

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     5, TIME = 2.000E+00
NUMBER OF ITERATIONS =       348, TOTAL NUMBER OF ITERATIONS =      2007
FINAL CONVERGENCE TOLERANCE = 9.886E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.434E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 9.139E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 9.137E+03
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER     5 ****




             5 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                   E N D   O F   S O L U T I O N   P H A S E
                       1.505E+01 CPU SECONDS USED
                             651 WORDS ALLOCATED
```

Elastic/Perfectly-Plastic with Temperature

```
 SSSSSS    AAAAA    N     NN  TTTTTT    OOOOO    SSSSSS
SS        AA   AA   NN    NN    TT     OO   OO  SS
SS        AA   AA   NNN   NN    TT     OO   OO  SS
 SSSSS    AAAAAAA   NN N  NN    TT     OO   OO   SSSSS
     SS   AA   AA   NN  NNN     TT     OO   OO       SS
     SS   AA   AA   NN   NN     TT     OO   OO       SS
SSSSSS    AA   AA   NN    N     TT      OOOOO   SSSSSS



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                ENGINEERING SCIENCES CENTER
               SANDIA NATIONAL LABORATORIES
               ALBUQUERQUE, NEW MEXICO 87185

                  DERIVED FROM PRONTO2D BY
            LEE M. TAYLOR AND DENNIS P. FLANAGAN


               RUN ON 03/06/96 AT 10:13:06
             RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                           INPUT STREAM IMAGES
LINE ----------------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - HOLLOW SPHERE - 12/14/94 - TEMPERATURE PROBLEM
  3: AXISYMMETRIC
  4: MAXIMUM ITERATIONS 20000
  5: RESIDUAL TOLERANCE .5
  6: MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
  7: YOUNGS MODULUS 1.E+7
  8: POISSONS RATIO 0.3
  9: YIELD STRESS 10000.
 10: HARDENING MODULUS 0.
 11: BETA 0.
 12: END
 13: THERMAL STRESS EXTERNAL 1000.
 14: PLOT ELEMENT STRESS TEMPERATURE
 15: FUNCTION 1  $ THERMAL STRAIN FOR ALPHA = 1.E-5
 16:       0.    0.
 17:   1000.    1.E-2
 18: END
 19: STEP CONTROL
 20:   4,1.
 21:   4,2,
 22:   4,3.
 23:   4,4.
 24:   4,5.
 25: END
 26: PLOT TIME
 27:   1,1.
 28:   4,2.
 29:   4,3.
 30:   4,4.
 31:   4,5.
 32: END
 33: OUTPUT TIME
 34:   4,1.
```

```
35:   4,2.
36:   4,3.
37:   4,4.
38:   4,5.
39: END
40: NO DISPLACEMENT,X,1
41: NO DISPLACEMENT,Y,2
42: EXIT
    ------------------------------------------------------------------------
```

Information Only

Information Only

```
                    P R O B L E M   T I T L E

 SANTOS QA PROBLEM - HOLLOW SPHERE - 12/14/94 - TEMPERATURE PROBLEM


                P R O B L E M   D E F I N I T I O N

  NUMBER OF ELEMENTS .......................        600
  NUMBER OF NODES ..........................        651
  NUMBER OF MATERIALS ......................          1
  NUMBER OF FUNCTIONS ......................          1
  NUMBER OF CONTACT SURFACES ...............          0
  NUMBER OF RIGID SURFACES .................          0
  NUMBER OF MATERIAL POINTS MONITORED .....           0
  ANALYSIS TYPE ............................ AXISYMMETRIC
  GLOBAL CONVERGENCE MEASURE ...............
  RESIDUAL TOLERANCE .......................  5.000E-01
  MAXIMUM NUMBER OF ITERATIONS .............      20000
  ITERATIONS FOR INTERMEDIATE PRINT .......        1302
  MAXIMUM RESIDUAL TOLERANCE ...............  6.000E-01
  PREDICTOR SCALE FACTOR FUNCTION .........           0
  MINIMUM DAMPING FACTOR ...................  2.000E-01
  EFFECTIVE MODULUS STATUS ................. CONSTANT
  THERMAL STRESS ANALYSIS PERFORMED ....... EXTERNAL
     THERMAL FORCE MAGNITUDE ...............  1.000E+03
  SCALE FACTOR APPLIED TO TIME STEP .......   1.000E+00
  STRAIN SOFTENING SCALE FACTOR ...........   1.000E+00
  HOURGLASS STIFFNESS FACTOR ..............   1.000E-02
  HOURGLASS VISCOSITY FACTOR ..............   3.000E-02


              L O A D   S T E P   D E F I N I T I O N S
```

```
   TIME              NO. OF STEPS            TIME
 0.000E+00                4               1.000E+00
 1.000E+00                4               2.000E+00
 2.000E+00                4               3.000E+00
 3.000E+00                4               4.000E+00
 4.000E+00                4               5.000E+00



         P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PRINTS          TIME
 0.000E+00            4                 1.000E+00
 1.000E+00            4                 2.000E+00
 2.000E+00            4                 3.000E+00
 3.000E+00            4                 4.000E+00
 4.000E+00            4                 5.000E+00



         P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PLOTS           TIME
 0.000E+00            1                 1.000E+00
 1.000E+00            4                 2.000E+00
 2.000E+00            4                 3.000E+00
 3.000E+00            4                 4.000E+00
 4.000E+00            4                 5.000E+00
```

Information Only

Information Only

```
              M A T E R I A L   D E F I N I T I O N S


        MATERIAL TYPE .........................ELASTIC PLASTIC
        MATERIAL ID ..........................          1
        DENSITY ..............................   1.000E+00
        THERMAL STRAIN ID ....................          1
        THERMAL STRAIN SCALE FACTOR ..........   1.000E+00
        MATERIAL PROPERTIES:
                YOUNGS MODULUS         =    1.000E+07
                POISSONS RATIO         =    3.000E-01
                YIELD STRESS           =    1.000E+04
                HARDENING MODULUS      =    0.000E+00
                BETA                   =    0.000E+00



              F U N C T I O N   D E F I N I T I O N S


     FUNCTION ID .........      1     NUMBER OF POINTS ....      2

                 N        S            F(S)
                 1    0.000E+00     0.000E+00
                 2    1.000E+03     1.000E-02



   N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                NODE SET FLAG     DIRECTION
```

Information Only

```
                    1                X
                    2                Y




                 E N D   O F   D A T A   I N P U T   P H A S E
                       1.880E-01 CPU SECONDS USED
                              62 WORDS ALLOCATED




         E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                       2.355E-02 CPU SECONDS USED
                             651 WORDS ALLOCATED




           V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                    NODAL          ELEMENT        GLOBAL
                    -----          -------        ------
                    DISPLX         SIGXX          FX
                    DISPLY         SIGYY          FY
                                   SIGZZ          RX
                                   TAUXY          RY
                                   TEMP           ITER
                                                  RMAG

 **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****
```

```
**** PLOT TAPE WRITTEN AT TIME = 2.500E-01   STEP NUMBER      1 ****

**** PLOT TAPE WRITTEN AT TIME = 5.000E-01   STEP NUMBER      2 ****

**** PLOT TAPE WRITTEN AT TIME = 7.500E-01   STEP NUMBER      3 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/06/96 ,AT 10:13:06
  SANTOS QA PROBLEM - HOLLOW SPHERE - 12/14/94 - TEMPERATURE PROBLEM

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER     4, TIME = 1.000E+00
NUMBER OF ITERATIONS =       136, TOTAL NUMBER OF ITERATIONS =       749
FINAL CONVERGENCE TOLERANCE = 4.266E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-2.171E+01
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     4 ****
```

Information Only

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 10:13:06
  SANTOS QA PROBLEM - HOLLOW SPHERE - 12/14/94 - TEMPERATURE PROBLEM

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    20, TIME = 5.000E+00
NUMBER OF ITERATIONS =        484, TOTAL NUMBER OF ITERATIONS =      3824
FINAL CONVERGENCE TOLERANCE = 4.494E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 5.939E+00
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 5.000E+00  STEP NUMBER    20 ****




             8 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                    E N D  O F  S O L U T I O N  P H A S E
                      2.982E+01 CPU SECONDS USED
                            651 WORDS ALLOCATED
```

APPENDIX L

Input/Output Data For Problem 12 – Restart Option Problem

The following two sections present the input data and the formatted output for the restart option verification problem.

FASTQ and SANTOS Input Data For The Restart Option Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for mesh generation and for each part of the analysis of the restart option problem.

Information Only

```
TITLE
 HOLLOW CYLINDER - SANTOS QA TEST PROBLEM
POINT   1      0.       0.
POINT   2      1.       0.
POINT   3      0.       1.
POINT   4      0.       2.
POINT   5      2.       0.
LINE    1   CIRC  2    3    1    20   1.0
LINE    2   STR   3    4    0    30   1.0
LINE    3   CIRC  5    4    1    20   1.0
LINE    4   STR   2    5    0    30   1.0
NODEBC  1   2
NODEBC  2   4
ELEMBC  3   1
SCHEME  0   MP
REGION  1    1   -1   -2   -3   -4
EXIT
```

Information Only

Restart Write

```
TITLE
  SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART WRITE
AXISYMMETRIC
MAXIMUM ITERATIONS 20000
RESIDUAL TOLERANCE .5
MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
YOUNGS MODULUS 1.E+7
POISSONS RATIO 0.3
YIELD STRESS 10000.
HARDENING MODULUS 0.
BETA 0.
END
THERMAL STRESS EXTERNAL 1000.
PLOT ELEMENT STRESS TEMPERATURE
FUNCTION 1  $ THERMAL STRAIN FOR ALPHA = 1.E-5
     0.     0.
  1000.     1.E-2
END
STEP CONTROL
  4,1.
  4,2,
  4,3.
END
PLOT TIME
  1,1.
  4,2.
  4,3.
END
OUTPUT TIME
  4,1.
  4,2.
  4,3.
END
WRITE RESTART 1
NO DISPLACEMENT,X,1
NO DISPLACEMENT,Y,2
EXIT
```

Information Only

Restart Read

```
TITLE
  SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART READ
AXISYMMETRIC
MAXIMUM ITERATIONS 20000
RESIDUAL TOLERANCE .5
MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
YOUNGS MODULUS 1.E+7
POISSONS RATIO 0.3
YIELD STRESS 10000.
HARDENING MODULUS 0.
BETA 0.
END
THERMAL STRESS EXTERNAL 1000.
PLOT ELEMENT STRESS TEMPERATURE
FUNCTION 1  $ THERMAL STRAIN FOR ALPHA = 1.E-5
     0.     0.
  1000.     1.E-2
END
STEP CONTROL
  4,3.
  4,4.
  4,5.
END
PLOT TIME
  4,3.
  4,4.
  4,5.
END
OUTPUT TIME
  4,3.
  4,4.
  4,5.
END
READ RESTART,12
NO DISPLACEMENT,X,1
NO DISPLACEMENT,Y,2
EXIT
```

Information Only

SANTOS Output For The Restart Option Problem

The following section presents the SANTOS printed output for each part of the restart option analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end.

Information Only

Information Only

Restart Write

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS





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                   PROGRAMMED BY:

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             ENGINEERING SCIENCES CENTER
            SANDIA NATIONAL LABORATORIES
            ALBUQUERQUE, NEW MEXICO 87185

              DERIVED FROM PRONTO2D BY
        LEE M. TAYLOR AND DENNIS P. FLANAGAN



            RUN ON 03/05/96 AT 16:12:49
          RUN ON A Cray0J90 UNDER UniCo8.0
```

```
                                INPUT STREAM IMAGES
LINE -----------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART WRITE
  3: AXISYMMETRIC
  4: MAXIMUM ITERATIONS 20000
  5: RESIDUAL TOLERANCE .5
  6: MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
  7: YOUNGS MODULUS 1.E+7
  8: POISSONS RATIO 0.3
  9: YIELD STRESS 10000.
 10: HARDENING MODULUS 0.
 11: BETA 0.
 12: END
 13: THERMAL STRESS EXTERNAL 1000.
 14: PLOT ELEMENT STRESS TEMPERATURE
 15: FUNCTION 1  $ THERMAL STRAIN FOR ALPHA = 1.E-5
 16:       0.     0.
 17:    1000.    1.E-2
 18: END
 19: STEP CONTROL
 20:   4,1.
 21:   4,2,
 22:   4,3.
 23: END
 24: PLOT TIME
 25:   1,1.
 26:   4,2.
 27:   4,3.
 28: END
 29: OUTPUT TIME
 30:   4,1.
 31:   4,2.
 32:   4,3.
 33: END
 34: WRITE RESTART 1
```

Information Only

```
35: NO DISPLACEMENT,X,1
36: NO DISPLACEMENT,Y,2
37: EXIT
```

Information Only

```
                    P R O B L E M   T I T L E

 SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART WRITE


              P R O B L E M   D E F I N I T I O N

  NUMBER OF ELEMENTS .......................          600
  NUMBER OF NODES ..........................          651
  NUMBER OF MATERIALS ......................            1
  NUMBER OF FUNCTIONS ......................            1
  NUMBER OF CONTACT SURFACES ...............            0
  NUMBER OF RIGID SURFACES .................            0
  NUMBER OF MATERIAL POINTS MONITORED .....             0
  ANALYSIS TYPE ............................  AXISYMMETRIC
  GLOBAL CONVERGENCE MEASURE ...............
  RESIDUAL TOLERANCE .......................    5.000E-01
  MAXIMUM NUMBER OF ITERATIONS .............        20000
  ITERATIONS FOR INTERMEDIATE PRINT .......          1302
  MAXIMUM RESIDUAL TOLERANCE ...............    6.000E-01
  PREDICTOR SCALE FACTOR FUNCTION .........             0
  MINIMUM DAMPING FACTOR ...................    2.000E-01
  EFFECTIVE MODULUS STATUS .................  CONSTANT
  THERMAL STRESS ANALYSIS PERFORMED .......  EXTERNAL
     THERMAL FORCE MAGNITUDE ...............    1.000E+03
  INCREMENTS BETWEEN RESTART TIMES ........             1
  SCALE FACTOR APPLIED TO TIME STEP .......    1.000E+00
  STRAIN SOFTENING SCALE FACTOR ...........    1.000E+00
  HOURGLASS STIFFNESS FACTOR ..............    1.000E-02
  HOURGLASS VISCOSITY FACTOR ..............    3.000E-02
```

Information Only

```
              L O A D   S T E P   D E F I N I T I O N S


      TIME             NO. OF STEPS             TIME
    0.000E+00                4               1.000E+00
    1.000E+00                4               2.000E+00
    2.000E+00                4               3.000E+00



              P R I N T E D   O U T P U T   F R E Q U E N C Y


      TIME       STEPS BETWEEN PRINTS           TIME
    0.000E+00                4               1.000E+00
    1.000E+00                4               2.000E+00
    2.000E+00                4               3.000E+00



              P L O T T E D   O U T P U T   F R E Q U E N C Y


      TIME       STEPS BETWEEN PLOTS            TIME
    0.000E+00                1               1.000E+00
    1.000E+00                4               2.000E+00
    2.000E+00                4               3.000E+00



              M A T E R I A L   D E F I N I T I O N S
```

Information Only

```
        MATERIAL TYPE ........................ELASTIC PLASTIC
        MATERIAL ID ..........................      1
        DENSITY ..............................  1.000E+00
        THERMAL STRAIN ID ....................      1
        THERMAL STRAIN SCALE FACTOR ..........  1.000E+00
        MATERIAL PROPERTIES:
               YOUNGS MODULUS          =     1.000E+07
               POISSONS RATIO          =     3.000E-01
               YIELD STRESS            =     1.000E+04
               HARDENING MODULUS       =     0.000E+00
               BETA                    =     0.000E+00


             F U N C T I O N   D E F I N I T I O N S


    FUNCTION ID .........       1     NUMBER OF POINTS ....       2

                  N        S           F(S)
                  1    0.000E+00    0.000E+00
                  2    1.000E+03    1.000E-02


N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

               NODE SET FLAG      DIRECTION
                     1                X
                     2                Y
```

Information Only

Information Only

```
            E N D   O F   D A T A   I N P U T   P H A S E
                    1.733E-01 CPU SECONDS USED
                           62 WORDS ALLOCATED



      E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                    2.266E-02 CPU SECONDS USED
                          651 WORDS ALLOCATED



        V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                   NODAL          ELEMENT        GLOBAL
                   -----          -------        ------
                   DISPLX         SIGXX          FX
                   DISPLY         SIGYY          FY
                                  SIGZZ          RX
                                  TAUXY          RY
                                  TEMP           ITER
                                                 RMAG


**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****



**** PLOT TAPE WRITTEN AT TIME = 2.500E-01  STEP NUMBER     1 ****
```

```
     **** RESTART TAPE WRITTEN AT TIME = 2.500E-01  STEP NUMBER     1 ****

**** PLOT TAPE WRITTEN AT TIME = 5.000E-01  STEP NUMBER     2 ****

     **** RESTART TAPE WRITTEN AT TIME = 5.000E-01  STEP NUMBER     2 ****

**** PLOT TAPE WRITTEN AT TIME = 7.500E-01  STEP NUMBER     3 ****

     **** RESTART TAPE WRITTEN AT TIME = 7.500E-01  STEP NUMBER     3 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/05/96 ,AT 16:12:49
  SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART WRITE

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     4, TIME = 1.000E+00
NUMBER OF ITERATIONS =        136, TOTAL NUMBER OF ITERATIONS =       749
FINAL CONVERGENCE TOLERANCE = 4.266E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-2.171E+01
**********************************************************************



**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     4 ****




     **** RESTART TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     4 ****

     **** RESTART TAPE WRITTEN AT TIME = 1.250E+00  STEP NUMBER     5 ****

     **** RESTART TAPE WRITTEN AT TIME = 1.500E+00  STEP NUMBER     6 ****

     **** RESTART TAPE WRITTEN AT TIME = 1.750E+00  STEP NUMBER     7 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/05/96 ,AT 16:12:49
  SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART WRITE

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     8, TIME = 2.000E+00
NUMBER OF ITERATIONS =        93, TOTAL NUMBER OF ITERATIONS =      1196
FINAL CONVERGENCE TOLERANCE = 4.914E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 5.276E+01
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER     8 ****



     **** RESTART TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER     8 ****

     **** RESTART TAPE WRITTEN AT TIME = 2.250E+00  STEP NUMBER     9 ****

     **** RESTART TAPE WRITTEN AT TIME = 2.500E+00  STEP NUMBER    10 ****

     **** RESTART TAPE WRITTEN AT TIME = 2.750E+00  STEP NUMBER    11 ****
```

Information Only

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 16:12:49
  SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART WRITE

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    12, TIME = 3.000E+00
NUMBER OF ITERATIONS =       227, TOTAL NUMBER OF ITERATIONS =      2184
FINAL CONVERGENCE TOLERANCE = 4.739E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-2.677E+01
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 3.000E+00  STEP NUMBER    12 ****



     **** RESTART TAPE WRITTEN AT TIME = 3.000E+00  STEP NUMBER    12 ****




            6 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                 E N D  O F  S O L U T I O N  P H A S E
                      1.710E+01 CPU SECONDS USED
                            651 WORDS ALLOCATED
```

WPO# 35675 March 27, 1996

Restart Read

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS



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            DERIVED FROM PRONTO2D BY
      LEE M. TAYLOR AND DENNIS P. FLANAGAN



           RUN ON 03/05/96 AT 16:48:17
         RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                              INPUT STREAM IMAGES
LINE -----------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART READ
  3: AXISYMMETRIC
  4: MAXIMUM ITERATIONS 20000
  5: RESIDUAL TOLERANCE .5
  6: MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
  7: YOUNGS MODULUS 1.E+7
  8: POISSONS RATIO 0.3
  9: YIELD STRESS 10000.
 10: HARDENING MODULUS 0.
 11: BETA 0.
 12: END
 13: THERMAL STRESS EXTERNAL 1000.
 14: PLOT ELEMENT STRESS TEMPERATURE
 15: FUNCTION 1  $ THERMAL STRAIN FOR ALPHA = 1.E-5
 16:       0.     0.
 17:   1000.    1.E-2
 18: END
 19: STEP CONTROL
 20:   4,3.
 21:   4,4.
 22:   4,5.
 23: END
 24: PLOT TIME
 25:   4,3.
 26:   4,4.
 27:   4,5.
 28: END
 29: OUTPUT TIME
 30:   4,3.
 31:   4,4.
 32:   4,5.
 33: END
 34: READ RESTART,12
```

```
35: NO DISPLACEMENT,X,1
36: NO DISPLACEMENT,Y,2
37: EXIT
```

Information Only

Information Only

```
                 P R O B L E M   T I T L E

     SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART READ



                P R O B L E M   D E F I N I T I O N

        NUMBER OF ELEMENTS ......................         600
        NUMBER OF NODES .........................         651
        NUMBER OF MATERIALS .....................           1
        NUMBER OF FUNCTIONS .....................           1
        NUMBER OF CONTACT SURFACES ..............           0
        NUMBER OF RIGID SURFACES ................           0
        NUMBER OF MATERIAL POINTS MONITORED .....           0
        ANALYSIS TYPE ........................... AXISYMMETRIC
        GLOBAL CONVERGENCE MEASURE ..............
        RESIDUAL TOLERANCE ......................  5.000E-01
        MAXIMUM NUMBER OF ITERATIONS ............       20000
        ITERATIONS FOR INTERMEDIATE PRINT .......        1302
        MAXIMUM RESIDUAL TOLERANCE ..............  6.000E-01
        PREDICTOR SCALE FACTOR FUNCTION .........           0
        MINIMUM DAMPING FACTOR ..................  2.000E-01
        EFFECTIVE MODULUS STATUS ................ CONSTANT
        THERMAL STRESS ANALYSIS PERFORMED ....... EXTERNAL
           THERMAL FORCE MAGNITUDE ..............  1.000E+03
        RESTART DATA READ AT STEP NUMBER ........          12
        SCALE FACTOR APPLIED TO TIME STEP .......  1.000E+00
        STRAIN SOFTENING SCALE FACTOR ...........  1.000E+00
        HOURGLASS STIFFNESS FACTOR ..............  1.000E-02
        HOURGLASS VISCOSITY FACTOR ..............  3.000E-02
```

Information Only

```
            L O A D   S T E P   D E F I N I T I O N S


     TIME          NO. OF STEPS          TIME
   0.000E+00            4              3.000E+00
   3.000E+00            4              4.000E+00
   4.000E+00            4              5.000E+00



            P R I N T E D   O U T P U T   F R E Q U E N C Y


     TIME      STEPS BETWEEN PRINTS        TIME
   0.000E+00            4              3.000E+00
   3.000E+00            4              4.000E+00
   4.000E+00            4              5.000E+00



            P L O T T E D   O U T P U T   F R E Q U E N C Y


     TIME      STEPS BETWEEN PLOTS         TIME
   0.000E+00            4              3.000E+00
   3.000E+00            4              4.000E+00
   4.000E+00            4              5.000E+00



            M A T E R I A L   D E F I N I T I O N S
```

Information Only

```
MATERIAL TYPE ..........................ELASTIC PLASTIC
MATERIAL ID ..........................          1
DENSITY ..............................    1.000E+00
THERMAL STRAIN ID ....................          1
THERMAL STRAIN SCALE FACTOR ..........    1.000E+00
MATERIAL PROPERTIES:
        YOUNGS MODULUS          =    1.000E+07
        POISSONS RATIO          =    3.000E-01
        YIELD STRESS            =    1.000E+04
        HARDENING MODULUS       =    0.000E+00
        BETA                    =    0.000E+00


       F U N C T I O N   D E F I N I T I O N S


FUNCTION ID .........      1     NUMBER OF POINTS ....       2

              N        S           F(S)
              1    0.000E+00    0.000E+00
              2    1.000E+03    1.000E-02


N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                NODE SET FLAG      DIRECTION
                      1                X
                      2                Y
```

Information Only

```
          E N D   O F   D A T A   I N P U T   P H A S E
                1.727E-01 CPU SECONDS USED
                       62 WORDS ALLOCATED




E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                2.317E-02 CPU SECONDS USED
                      651 WORDS ALLOCATED




   V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

            NODAL         ELEMENT       GLOBAL
            -----         -------       ------
            DISPLX        SIGXX         FX
            DISPLY        SIGYY         FY
                          SIGZZ         RX
                          TAUXY         RY
                          TEMP          ITER
                                        RMAG


**** THIS JOB WAS RESTARTED AT TIME = 3.000E+00  STEP NUMBER    12 ****
```

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/05/96 ,AT 16:48:17
  SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART READ

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    16, TIME = 4.000E+00
NUMBER OF ITERATIONS =       213, TOTAL NUMBER OF ITERATIONS =      2917
FINAL CONVERGENCE TOLERANCE = 4.764E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-3.147E+01
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 4.000E+00  STEP NUMBER    16 ****
```

Information Only

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/05/96 ,AT 16:48:17
  SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART READ

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER    20, TIME = 5.000E+00
NUMBER OF ITERATIONS =       484, TOTAL NUMBER OF ITERATIONS =      3824
FINAL CONVERGENCE TOLERANCE = 4.494E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 5.939E+00
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 5.000E+00  STEP NUMBER    20 ****




            2 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                 E N D   O F   S O L U T I O N   P H A S E
                      1.240E+01 CPU SECONDS USED
                            651 WORDS ALLOCATED
```

Intentionally Left Blank

Information Only

APPENDIX M

Input/Output Data For Problem 13 – Sloping Roller Option Problem

The following two sections present the input data and the formatted output for the sloping roller option verification problem.

FASTQ and SANTOS Input Data For The Sloping Roller Option Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the sloping roller option problem.

Information Only

```
TITLE
 HOLLOW SPHERE - SANTOS QA TEST PROBLEM - QUARTER SPHERE
POINT   1      0.           0.
POINT   2      1.           0.
POINT   3      0.809016994  0.587785252
POINT   4      1.618033989  1.175570505
POINT   5      2.           0.
LINE    1    CIRC  2    3    1    8    1.0
LINE    2    STR   3    4    0    30   1.0
LINE    3    CIRC  5    4    1    8    1.0
LINE    4    STR   2    5    0    30   1.0
NODEBC  1    2
NODEBC  2    4
ELEMBC  3    1
SCHEME  0    MP
REGION  1     1   -1   -2   -3   -4
EXIT
```

Information Only

```
TITLE
 SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM
AXISYMMETRIC
MAXIMUM ITERATIONS 20000
RESIDUAL TOLERANCE .5
MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
YOUNGS MODULUS 1.E+7
POISSONS RATIO 0.3
YIELD STRESS 1.E+4
HARDENING MODULUS 0.
BETA 0.
END
THERMAL STRESS EXTERNAL 1000.
PLOT ELEMENT STRESS TEMPERATURE
FUNCTION 1  $ THERMAL STRAIN FOR ALPHA = 1.E-5
     0.    0.
  1000.    1.E-2
END
STEP CONTROL
  4,1.
  4,2,
  4,3.
  4,4.
  4,5.
END
PLOT TIME
  1,1.
  4,2.
  4,3.
  4,4.
  4,5.
END
OUTPUT TIME
  1,1.
  4,2.
  4,3.
  4,4.
  4,5.
END
SLOPING ROLLER,1,-0.5877853,0.809017
NO DISPLACEMENT,Y,2
EXIT
```

Information Only

SANTOS Output For The Sloping Roller Option Problem

The following section presents the SANTOS printed output for the sloping roller option analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem-descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end.

Information Only

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS



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                 PROGRAMMED BY:

                CHARLES M. STONE
          ENGINEERING SCIENCES CENTER
         SANDIA NATIONAL LABORATORIES
         ALBUQUERQUE, NEW MEXICO 87185

           DERIVED FROM PRONTO2D BY
      LEE M. TAYLOR AND DENNIS P. FLANAGAN


          RUN ON 03/06/96 AT 11:07:08
         RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                        INPUT STREAM IMAGES
LINE -----------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM
  3: AXISYMMETRIC
  4: MAXIMUM ITERATIONS 20000
  5: RESIDUAL TOLERANCE .5
  6: MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
  7: YOUNGS MODULUS 1.E+7
  8: POISSONS RATIO 0.3
  9: YIELD STRESS 1.E+4
 10: HARDENING MODULUS 0.
 11: BETA 0.
 12: END
 13: THERMAL STRESS EXTERNAL 1000.
 14: PLOT ELEMENT STRESS TEMPERATURE
 15: FUNCTION 1  $ THERMAL STRAIN FOR ALPHA = 1.E-5
 16:       0.    0.
 17:   1000.    1.E-2
 18: END
 19: STEP CONTROL
 20:   4,1.
 21:   4,2,
 22:   4,3.
 23:   4,4.
 24:   4,5.
 25: END
 26: PLOT TIME
 27:   1,1.
 28:   4,2.
 29:   4,3.
 30:   4,4.
 31:   4,5.
 32: END
 33: OUTPUT TIME
 34:   1,1.
```

```
35:   4,2.
36:   4,3.
37:   4,4.
38:   4,5.
39: END
40: SLOPING ROLLER,1,-0.5877853,0.809017
41: NO DISPLACEMENT,Y,2
42: EXIT
    -------------------------------------------------------------------------
```

Information Only

Information Only

```
                    P R O B L E M   T I T L E

SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM


                    P R O B L E M   D E F I N I T I O N

  NUMBER OF ELEMENTS .......................         240
  NUMBER OF NODES ..........................         279
  NUMBER OF MATERIALS ......................           1
  NUMBER OF FUNCTIONS ......................           1
  NUMBER OF CONTACT SURFACES ...............           0
  NUMBER OF RIGID SURFACES .................           0
  NUMBER OF MATERIAL POINTS MONITORED .....            0
  ANALYSIS TYPE ............................ AXISYMMETRIC
  GLOBAL CONVERGENCE MEASURE ...............
  RESIDUAL TOLERANCE .......................  5.000E-01
  MAXIMUM NUMBER OF ITERATIONS .............      20000
  ITERATIONS FOR INTERMEDIATE PRINT .......         558
  MAXIMUM RESIDUAL TOLERANCE ...............  6.000E-01
  PREDICTOR SCALE FACTOR FUNCTION .........           0
  MINIMUM DAMPING FACTOR ...................  2.000E-01
  EFFECTIVE MODULUS STATUS ................. CONSTANT
  THERMAL STRESS ANALYSIS PERFORMED ....... EXTERNAL
     THERMAL FORCE MAGNITUDE ...............  1.000E+03
  SCALE FACTOR APPLIED TO TIME STEP .......   1.000E+00
  STRAIN SOFTENING SCALE FACTOR ...........   1.000E+00
  HOURGLASS STIFFNESS FACTOR ...............  1.000E-02
  HOURGLASS VISCOSITY FACTOR ...............  3.000E-02


                    L O A D   S T E P   D E F I N I T I O N S
```

```
     TIME             NO. OF STEPS            TIME
  0.000E+00                 4              1.000E+00
  1.000E+00                 4              2.000E+00
  2.000E+00                 4              3.000E+00
  3.000E+00                 4              4.000E+00
  4.000E+00                 4              5.000E+00


         P R I N T E D   O U T P U T   F R E Q U E N C Y


     TIME      STEPS BETWEEN PRINTS          TIME
  0.000E+00                 1              1.000E+00
  1.000E+00                 4              2.000E+00
  2.000E+00                 4              3.000E+00
  3.000E+00                 4              4.000E+00
  4.000E+00                 4              5.000E+00


         P L O T T E D   O U T P U T   F R E Q U E N C Y


     TIME      STEPS BETWEEN PLOTS           TIME
  0.000E+00                 1              1.000E+00
  1.000E+00                 4              2.000E+00
  2.000E+00                 4              3.000E+00
  3.000E+00                 4              4.000E+00
  4.000E+00                 4              5.000E+00
```

Information Only

```
          M A T E R I A L   D E F I N I T I O N S

      MATERIAL TYPE ........................ELASTIC PLASTIC
      MATERIAL ID ..........................         1
      DENSITY ..............................  1.000E+00
      THERMAL STRAIN ID ....................         1
      THERMAL STRAIN SCALE FACTOR ..........  1.000E+00
      MATERIAL PROPERTIES:
              YOUNGS MODULUS         =     1.000E+07
              POISSONS RATIO         =     3.000E-01
              YIELD STRESS           =     1.000E+04
              HARDENING MODULUS      =     0.000E+00
              BETA                   =     0.000E+00


          F U N C T I O N   D E F I N I T I O N S

     FUNCTION ID .........       1     NUMBER OF POINTS .....      2

              N        S            F(S)
              1    0.000E+00     0.000E+00
              2    1.000E+03     1.000E-02


   N O  D I S P L A C E M E N T  B O U N D A R Y  C O N D I T I O N S

              NODE SET FLAG      DIRECTION
```

Information Only

```
                2                Y



   P R E S C R I B E D   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

      NODE SET    DIRECTION   FUNCTION    SCALE          A0            B0
        FLAG                     ID       FACTOR
         1           ROL          0     0.000E+00   -5.878E-01    8.090E-01



                   E N D   O F   D A T A   I N P U T   P H A S E
                         1.773E-01 CPU SECONDS USED
                                62 WORDS ALLOCATED



          E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                         2.195E-02 CPU SECONDS USED
                               279 WORDS ALLOCATED



            V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                     NODAL        ELEMENT       GLOBAL
                     -----        -------       ------
                     DISPLX       SIGXX         FX
```

Information Only

```
DISPLY        SIGYY        FY
              SIGZZ        RX
              TAUXY        RY
              TEMP         ITER
                           RMAG

**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/06/96 ,AT 11:07:08
  SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM

***********************************************************************
SUMMARY OF DATA AT STEP NUMBER     1, TIME = 2.500E-01
NUMBER OF ITERATIONS =        505, TOTAL NUMBER OF ITERATIONS =       505
FINAL CONVERGENCE TOLERANCE = 4.712E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION =-2.246E+01
SUM OF REACTION FORCES IN Y-DIRECTION =-4.725E+01
***********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.500E-01  STEP NUMBER     1 ****
```

Information Only

```
SANTOS, VERSION 2.0.0     ,RUN ON 03/06/96 ,AT 11:07:08
 SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM

*****************************************************************************
SUMMARY OF DATA AT STEP NUMBER      2, TIME = 5.000E-01
NUMBER OF ITERATIONS =          47, TOTAL NUMBER OF ITERATIONS =         552
FINAL CONVERGENCE TOLERANCE = 4.671E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION =-4.917E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-1.036E+01
*****************************************************************************


**** PLOT TAPE WRITTEN AT TIME = 5.000E-01  STEP NUMBER      2 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 11:07:08
  SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     3, TIME = 7.500E-01
NUMBER OF ITERATIONS =        10, TOTAL NUMBER OF ITERATIONS =       562
FINAL CONVERGENCE TOLERANCE = 3.765E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 1.189E+01
SUM OF REACTION FORCES IN Y-DIRECTION = 2.497E+01
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 7.500E-01  STEP NUMBER     3 ****
```

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 11:07:08
 SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER     4, TIME = 1.000E+00
NUMBER OF ITERATIONS =        21, TOTAL NUMBER OF ITERATIONS =       583
FINAL CONVERGENCE TOLERANCE = 4.940E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 2.329E+01
SUM OF REACTION FORCES IN Y-DIRECTION = 4.893E+01
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     4 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 11:07:08
  SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     8, TIME = 2.000E+00
NUMBER OF ITERATIONS =       168, TOTAL NUMBER OF ITERATIONS =      1000
FINAL CONVERGENCE TOLERANCE = 4.643E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION =-5.088E+01
SUM OF REACTION FORCES IN Y-DIRECTION =-1.071E+02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER     8 ****.
```

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 11:07:08
 SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER    12, TIME = 3.000E+00
NUMBER OF ITERATIONS =        35, TOTAL NUMBER OF ITERATIONS =      1341
FINAL CONVERGENCE TOLERANCE = 4.474E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 1.078E+01
SUM OF REACTION FORCES IN Y-DIRECTION = 2.257E+01
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 3.000E+00  STEP NUMBER    12 ****



STEP       TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR    LOAD NORM   LOAD NORM  IMBALANCE   STEPS
  558  3.750E+00  2.500E-01  1.000E+00  2.169E+03  2.339E+01      1.08      2151
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 11:07:08
  SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM

***********************************************************************
SUMMARY OF DATA AT STEP NUMBER    16, TIME = 4.000E+00
NUMBER OF ITERATIONS =       205, TOTAL NUMBER OF ITERATIONS =      2530
FINAL CONVERGENCE TOLERANCE = 4.884E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION =-3.331E+01
SUM OF REACTION FORCES IN Y-DIRECTION =-7.016E+01
***********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 4.000E+00  STEP NUMBER    16 ****
```

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 11:07:08
 SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER    20, TIME = 5.000E+00
NUMBER OF ITERATIONS =          4, TOTAL NUMBER OF ITERATIONS =      3047
FINAL CONVERGENCE TOLERANCE = 4.903E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 2.062E+01
SUM OF REACTION FORCES IN Y-DIRECTION = 4.323E+01
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 5.000E+00  STEP NUMBER    20 ****




            8 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                  E N D  O F  S O L U T I O N  P H A S E
                     9.954E+00 CPU SECONDS USED
                           279 WORDS ALLOCATED
```

Information Only

APPENDIX N

Input/Output Data For Problem 14 – Creep Relaxation Problem

The following two sections present the input data and the formatted output for the creep relaxation verification problem.

FASTQ and SANTOS Input Data For The Creep Relaxation Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the single-element creep relaxation problem.

Information Only

```
TITLE
 CREEP RELAXATION PROBLEM - SANTOS - AXISYMMETRIC
POINT    1    1.       0.
POINT    2    1.5      0.
POINT    3    1.5      1.
POINT    4    1.       1.
LINE     1   STR    1    2    0     1   1.
LINE     2   STR    2    3    0     1   1.
LINE     3   STR    4    3    0     1   1.
LINE     4   STR    1    4    0     1   1.
NODEBC   2    1
NODEBC   3    3
SCHEME   0 MP
REGION   1    1   -1   -2   -3   -4
EXIT
```

Information Only

```
TITLE
  SANTOS QA PROBLEM - CREEP RELAXATION PROBLEM - AXISYMMETRIC - 11/9/94
AXISYMMETRIC
ELASTIC SOLUTION
MAXIMUM ITERATIONS 40000
MATERIAL,1,POWER LAW CREEP,1.
TWO MU 24.75E+9
BULK MODULUS 8.25E+9
CREEP CONSTANT 5.79E-36
STRESS EXPONENT 4.9
THERMAL CONSTANT 20.13
END
FUNCTION 1  $ PRESCRIBED DISPLACEMENT FUNCTION
   0.        -0.001
   2.592E+6 -0.001
END
STEP CONTROL
   1  1.
  90  2.592E+6
END
OUTPUT TIME
   0  1.
   0  2.592E+6
END
PLOT TIME
   1  1.
   1  2.592E+6
END
PRESCRIBED DISPLACEMENT Y 3 1 1.0
NO DISPLACEMENT Y  2
PLOT ELEMENT STRESS VONMISES
EXIT
```

Information Only

SANTOS Output For The Creep Relaxation Problem

The following section presents a portion of the SANTOS printed output for the single-element creep relaxation analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

WPO# 35675 March 27, 1996

```
 SSSSSS  AAAAA   N    NN  TTTTTT   OOOOO   SSSSSS
SS      AA   AA  NN   NN    TT    OO   OO SS
SS      AA   AA  NNN  NN    TT    OO   OO SS
 SSSSS  AAAAAAA  NN N NN    TT    OO   OO  SSSSS
     SS AA   AA  NN  NNN    TT    OO   OO      SS
     SS AA   AA  NN   NN    TT    OO   OO      SS
SSSSSS  AA   AA  NN    N    TT     OOOOO  SSSSSS



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                   CHARLES M. STONE
              ENGINEERING SCIENCES CENTER
             SANDIA NATIONAL LABORATORIES
             ALBUQUERQUE, NEW MEXICO 87185

               DERIVED FROM PRONTO2D BY
         LEE M. TAYLOR AND DENNIS P. FLANAGAN



             RUN ON 03/07/96 AT 11:19:16
           RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                              INPUT STREAM IMAGES
LINE -------------------------------------------------------------------------
  1: TITLE
  2:   SANTOS QA PROBLEM - CREEP RELAXATION PROBLEM - AXISYMMETRIC - 11/9/94
  3: AXISYMMETRIC
  4: ELASTIC SOLUTION
  5: MAXIMUM ITERATIONS 40000
  6: MATERIAL,1,POWER LAW CREEP,1.
  7: TWO MU 24.75E+9
  8: BULK MODULUS 8.25E+9
  9: CREEP CONSTANT 5.79E-36
 10: STRESS EXPONENT 4.9
 11: THERMAL CONSTANT 20.13
 12: END
 13: FUNCTION 1  $ PRESCRIBED DISPLACEMENT FUNCTION
 14:    0.        -0.001
 15:    2.592E+6 -0.001
 16: END
 17: STEP CONTROL
 18:    1  1.
 19:   90  2.592E+6
 20: END
 21: OUTPUT TIME
 22:    0  1.
 23:    0  2.592E+6
 24: END
 25: PLOT TIME
 26:    1  1.
 27:    1  2.592E+6
 28: END
 29: PRESCRIBED DISPLACEMENT Y 3 1 1.0
 30: NO DISPLACEMENT Y  2
 31: PLOT ELEMENT STRESS VONMISES
 32: EXIT
     -------------------------------------------------------------------------
```

```
                   P R O B L E M   T I T L E

SANTOS QA PROBLEM - CREEP RELAXATION PROBLEM - AXISYMMETRIC - 11/9/94


                   P R O B L E M   D E F I N I T I O N

NUMBER OF ELEMENTS .......................          1
NUMBER OF NODES ..........................          4
NUMBER OF MATERIALS ......................          1
NUMBER OF FUNCTIONS ......................          1
NUMBER OF CONTACT SURFACES ...............          0
NUMBER OF RIGID SURFACES .................          0
NUMBER OF MATERIAL POINTS MONITORED ......          0
ANALYSIS TYPE ............................ AXISYMMETRIC
GLOBAL CONVERGENCE MEASURE ...............
RESIDUAL TOLERANCE ....................... 5.000E-01
MAXIMUM NUMBER OF ITERATIONS .............     40000
ITERATIONS FOR INTERMEDIATE PRINT ........          8
MAXIMUM RESIDUAL TOLERANCE ............... 6.000E-01
PREDICTOR SCALE FACTOR FUNCTION ..........          0
MINIMUM DAMPING FACTOR ................... 2.000E-01
EFFECTIVE MODULUS STATUS ................. CONSTANT
ELASTIC SOLUTION REQUESTED ...............
SCALE FACTOR APPLIED TO TIME STEP ........ 1.000E+00
STRAIN SOFTENING SCALE FACTOR ............ 1.000E+00
HOURGLASS STIFFNESS FACTOR ............... 1.000E-02
HOURGLASS VISCOSITY FACTOR ............... 3.000E-02


                   L O A D   S T E P   D E F I N I T I O N S
```

Information Only

Information Only

```
   TIME            NO. OF STEPS           TIME
 0.000E+00              1              1.000E+00
 1.000E+00             90              2.592E+06



        P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PRINTS         TIME
 0.000E+00              0              1.000E+00
 1.000E+00              0              2.592E+06



        P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PLOTS          TIME
 0.000E+00              1              1.000E+00
 1.000E+00              1              2.592E+06



        M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE ........................POWER LAW CREEP
  MATERIAL ID ..........................        1
  DENSITY .............................. 1.000E+00
  MATERIAL PROPERTIES:
        TWO MU                 =    2.475E+10
```

Information Only

```
           BULK MODULUS          =    8.250E+09
           CREEP CONSTANT        =    5.790E-36
           STRESS EXPONENT       =    4.900E+00
           THERMAL CONSTANT      =    2.013E+01


          F U N C T I O N   D E F I N I T I O N S

     FUNCTION ID .........       1     NUMBER OF POINTS ....       2

               N        S           F(S)
               1    0.000E+00   -1.000E-03
               2    2.592E+06   -1.000E-03


  N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

             NODE SET FLAG    DIRECTION
                   2              Y


P R E S C R I B E D   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

   NODE SET    DIRECTION   FUNCTION    SCALE         A0          B0
     FLAG                     ID       FACTOR
      3            Y          1      1.000E+00       -           -
```

Information Only

```
          E N D   O F   D A T A   I N P U T   P H A S E
               1.363E-01 CPU SECONDS USED
                     4 WORDS ALLOCATED



  E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
               1.039E-02 CPU SECONDS USED
                     4 WORDS ALLOCATED



    V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

            NODAL        ELEMENT      GLOBAL
            -----        -------      ------
            DISPLX       SIGXX        FX
            DISPLY       SIGYY        FY
                         SIGZZ        RX
                         TAUXY        RY
                         VONMISES     ITER
                                      RMAG
```

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/07/96 ,AT 11:19:16
  SANTOS QA PROBLEM - CREEP RELAXATION PROBLEM - AXISYMMETRIC - 11/9/94

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     0, TIME = 0.000E+00
NUMBER OF ITERATIONS =          3, TOTAL NUMBER OF ITERATIONS =         3
FINAL CONVERGENCE TOLERANCE = 7.107E-13
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-1.548E+07
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 0.000E+00  STEP NUMBER     0 ****



**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     1 ****



STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
    8  2.880E+04  2.880E+04  8.012E-01  7.667E+06  3.063E+06     39.95       14
   16  2.880E+04  2.880E+04  8.250E-01  7.799E+06  8.903E+05     11.42       22
   24  2.880E+04  2.880E+04  8.251E-01  7.770E+06  3.353E+05      4.31       30
   32  2.880E+04  2.880E+04  8.001E-01  7.772E+06  6.192E+04      0.80       38
   40  2.880E+04  2.880E+04  8.031E-01  7.779E+06  6.320E+04      0.81       46
   48  2.880E+04  2.880E+04  8.031E-01  7.774E+06  4.557E+04      0.59       54

**** PLOT TAPE WRITTEN AT TIME = 2.880E+04  STEP NUMBER     2 ****
```

```
STEP       TIME        TIME      DAMPING     APPLIED    RESIDUAL     PERCENT    TOTAL
                       STEP       FACTOR    LOAD NORM  LOAD NORM   IMBALANCE    STEPS
   8  5.760E+04  2.880E+04  8.490E-01  6.804E+06  3.311E+06       48.67        67
  16  5.760E+04  2.880E+04  8.502E-01  6.805E+06  1.670E+06       24.54        75
  24  5.760E+04  2.880E+04  6.095E-01  6.805E+06  5.531E+05        8.13        83
  32  5.760E+04  2.880E+04  9.133E-01  6.805E+06  1.736E+05        2.55        91
  40  5.760E+04  2.880E+04  8.286E-01  6.805E+06  1.453E+05        2.13        99

  **** PLOT TAPE WRITTEN AT TIME = 5.760E+04   STEP NUMBER       3 ****


STEP       TIME        TIME      DAMPING     APPLIED    RESIDUAL     PERCENT    TOTAL
                       STEP       FACTOR    LOAD NORM  LOAD NORM   IMBALANCE    STEPS
   8  8.640E+04  2.880E+04  8.565E-01  6.299E+06  8.077E+05       12.82       115
  16  8.640E+04  2.880E+04  8.002E-01  6.300E+06  3.252E+05        5.16       123
  24  8.640E+04  2.880E+04  6.565E-01  6.300E+06  1.092E+05        1.73       131

  **** PLOT TAPE WRITTEN AT TIME = 8.640E+04   STEP NUMBER       4 ****


STEP       TIME        TIME      DAMPING     APPLIED    RESIDUAL     PERCENT    TOTAL
                       STEP       FACTOR    LOAD NORM  LOAD NORM   IMBALANCE    STEPS
   8  1.152E+05  2.880E+04  8.568E-01  5.953E+06  3.083E+05        5.18       141

  **** PLOT TAPE WRITTEN AT TIME = 1.152E+05   STEP NUMBER       5 ****
```

Information Only

```
**** PLOT TAPE WRITTEN AT TIME = 1.440E+05   STEP NUMBER      6 ****


STEP        TIME        TIME       DAMPING     APPLIED    RESIDUAL    PERCENT     TOTAL
                        STEP       FACTOR     LOAD NORM  LOAD NORM   IMBALANCE    STEPS
   8    1.728E+05   2.880E+04   8.568E-01   5.481E+06   1.046E+05      1.91        162

 **** PLOT TAPE WRITTEN AT TIME = 1.728E+05   STEP NUMBER      7 ****


 **** PLOT TAPE WRITTEN AT TIME = 2.016E+05   STEP NUMBER      8 ****


 **** PLOT TAPE WRITTEN AT TIME = 2.304E+05   STEP NUMBER      9 ****


 **** PLOT TAPE WRITTEN AT TIME = 2.592E+05   STEP NUMBER     10 ****


 **** PLOT TAPE WRITTEN AT TIME = 2.880E+05   STEP NUMBER     11 ****
```

Information Only

```
STEP       TIME        TIME       DAMPING      APPLIED     RESIDUAL     PERCENT     TOTAL
                       STEP       FACTOR     LOAD NORM    LOAD NORM    IMBALANCE    STEPS
    8  3.168E+05   2.880E+04  8.570E-01   4.810E+06   7.495E+04        1.56          193


 **** PLOT TAPE WRITTEN AT TIME = 3.168E+05   STEP NUMBER    12 ****



 **** PLOT TAPE WRITTEN AT TIME = 3.456E+05   STEP NUMBER    13 ****



 **** PLOT TAPE WRITTEN AT TIME = 3.744E+05   STEP NUMBER    14 ****
 .
 .
 .
 .

 **** PLOT TAPE WRITTEN AT TIME = 2.563E+06   STEP NUMBER    90 ****
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 11:19:16
  SANTOS QA PROBLEM - CREEP RELAXATION PROBLEM - AXISYMMETRIC - 11/9/94

***********************************************************************
SUMMARY OF DATA AT STEP NUMBER    91, TIME = 2.592E+06
NUMBER OF ITERATIONS =          3, TOTAL NUMBER OF ITERATIONS =       454
FINAL CONVERGENCE TOLERANCE = 1.152E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-4.050E+06
***********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.592E+06  STEP NUMBER    91 ****




           92 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                END OF SOLUTION PHASE
                     3.459E-01 CPU SECONDS USED
                             4 WORDS ALLOCATED
```

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APPENDIX O

Input/Output Data For Problem 15 – Linear Viscoelastic Constitutive Model Implementation Problem

The following two sections present the input data and the formatted output for the linear viscoelastic constitutive model implementation verification problem.

FASTQ and SANTOS Input Data For The Linear Viscoelastic Constitutive Model Implementation Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh geneartion and analysis of the linear viscoelastic constitutive model implementation problem.

Information Only

```
TITLE
 SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY
POINT     1     0.500       0.
POINT     2     0.500       0.25
POINT     3     1.000       0.25
POINT     4     1.03125     0.25
POINT     5     1.03125     0.
POINT     6     1.000       0.
LINE    1    STR    1    2    0    1    1.0
LINE    2    STR    2    3    0   20    1.1
LINE    3    STR    3    4    0    3    1.0
LINE    4    STR    4    5    0    1    1.0
LINE    5    STR    5    6    0    3    1.0
LINE    6    STR    1    6    0   20    1.1
LINE    7    STR    3    6    0    1    1.0
ELEMBC   4    1
NODEBC   1    2    3    5    6
SCHEME   OMP
REGION   1    1   -1   -2   -7   -6
REGION   2    2   -3   -4   -5   -7
END
```

Information Only

```
TITLE
 SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY
AXISYMMETRIC
ELASTIC SOLUTION
RESIDUAL TOLERANCE 0.5
MAXIMUM ITERATIONS  2000
MAXIMUM TOLERANCE 50.
INTERMEDIATE PRINT 10
MATERIAL,1,LINEAR VISCOELASTIC,15.6   $ ROCKET PROPELLANT
BULK 1.E+05
BULK INF 1.E+05
BULK RELAX 1.
SHEAR INF 0.
SHEAR ONE 3.75E+04
SHEAR TWO 0.
SHEAR THREE 0.
RELAX ONE 1.
RELAX TWO 1.
RELAX THREE 1.
C1 7.6
C2 277.
TEMPO 373.
END
MATERIAL,2,ELASTIC PLASTIC,98.   $ STEEL OUTER CASING
YOUNGS MODULUS 3.E+07
POISSONS RATIO 0.3015
YIELD STRESS 1.E+06
HARDENING MODULUS 1.E+06
BETA 1
END
FUNCTION 1   $ PRESSURE HISTORY
  0.,1000.
 10.,1000.
END
STEP CONTROL
  10,1.
   9,10.
END
OUTPUT TIME
  1,1.
  1,10.
END
PLOT TIME
  1,1.
  1,10.
END
PLOT,NODAL,DISPLACEMENT,RESIDUAL
PLOT,ELEMENT,STRESS,STRAIN
PLOT,STATE,BLKDECAY,DECAYX1,DECAYY1,DECAYZ1,DECAYX2,DECAYY2,DECAYZ2
PRESSURE,4,1,1.
NO DISPLACEMENT,Y,1
EXIT
```

Information Only

SANTOS Output For The Linear Viscoelastic Constitutive Model Implementation Problem

The following section presents a portion of the SANTOS printed output for the linear viscoelastic constitutive model implementation analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

WPO# 35675 March 27, 1996

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS


                    VERSION 2.0.0
           COPYRIGHT 1994, SANDIA CORPORATION


                   PROGRAMMED BY:

                  CHARLES M. STONE
             ENGINEERING SCIENCES CENTER
            SANDIA NATIONAL LABORATORIES
            ALBUQUERQUE, NEW MEXICO 87185

               DERIVED FROM PRONTO2D BY
          LEE M. TAYLOR AND DENNIS P. FLANAGAN


            RUN ON 03/07/96 AT 14:38:29
          RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

```
                              INPUT STREAM IMAGES
LINE -----------------------------------------------------------------------
  1: TITLE
  2:  SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY
  3: AXISYMMETRIC
  4: ELASTIC SOLUTION
  5: RESIDUAL TOLERANCE 0.5
  6: MAXIMUM ITERATIONS  5000
  7: MAXIMUM TOLERANCE 0.5
  8: INTERMEDIATE PRINT 10
  9: MATERIAL,1,LINEAR VISCOELASTIC,15.6    $ ROCKET PROPELLANT
 10: BULK 1.E+05
 11: BULK INF 1.E+05
 12: BULK RELAX 1.
 13: SHEAR INF 0.
 14: SHEAR ONE 3.75E+04
 15: SHEAR TWO 0.
 16: SHEAR THREE 0.
 17: RELAX ONE 1.
 18: RELAX TWO 1.
 19: RELAX THREE 1.
 20: C1 7.6
 21: C2 277.
 22: TEMPO 373.
 23: END
 24: MATERIAL,2,ELASTIC PLASTIC,98.    $ STEEL OUTER CASING
 25: YOUNGS MODULUS 3.E+07
 26: POISSONS RATIO 0.3015
 27: YIELD STRESS 1.E+06
 28: HARDENING MODULUS 1.E+06
 29: BETA 1
 30: END
 31: FUNCTION 1    $ PRESSURE HISTORY
 32:   0.,1000.
 33:  10.,1000.
 34: END
```

Information Only

```
35: STEP CONTROL
36:   10,1.
37:    9,10.
38: END
39: OUTPUT TIME
40:   1,1.
41:   1,10.
42: END
43: PLOT TIME
44:   1,1.
45:   1,10.
46: END
47: PLOT,NODAL,DISPLACEMENT,RESIDUAL
48: PLOT,ELEMENT,STRESS,STRAIN
49: PLOT,STATE,BLKDECAY,DECAYX1,DECAYY1,DECAYZ1,DECAYX2,DECAYY2,DECAYZ2
50: PRESSURE,4,1,1.
51: NO DISPLACEMENT,Y,1
52: EXIT
    -------------------------------------------------------------------------
```

Information Only

Information Only

```
            P R O B L E M   T I T L E

     SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY


             P R O B L E M   D E F I N I T I O N

       NUMBER OF ELEMENTS .......................       23
       NUMBER OF NODES ..........................       48
       NUMBER OF MATERIALS ......................        2
       NUMBER OF FUNCTIONS ......................        1
       NUMBER OF CONTACT SURFACES ...............        0
       NUMBER OF RIGID SURFACES .................        0
       NUMBER OF MATERIAL POINTS MONITORED .....         0
       ANALYSIS TYPE ............................ AXISYMMETRIC
       GLOBAL CONVERGENCE MEASURE ...............
       RESIDUAL TOLERANCE ....................... 5.000E-01
       MAXIMUM NUMBER OF ITERATIONS .............     5000
       ITERATIONS FOR INTERMEDIATE PRINT .......        10
       MAXIMUM RESIDUAL TOLERANCE ............... 5.000E-01
       PREDICTOR SCALE FACTOR FUNCTION .........         0
       MINIMUM DAMPING FACTOR ................... 2.000E-01
       EFFECTIVE MODULUS STATUS ................. CONSTANT
       ELASTIC SOLUTION REQUESTED ..............
       SCALE FACTOR APPLIED TO TIME STEP ....... 1.000E+00
       STRAIN SOFTENING SCALE FACTOR ........... 1.000E+00
       HOURGLASS STIFFNESS FACTOR .............. 1.000E-02
       HOURGLASS VISCOSITY FACTOR .............. 3.000E-02


            L O A D   S T E P   D E F I N I T I O N S
```

Information Only

```
   TIME           NO. OF STEPS          TIME
 0.000E+00             10            1.000E+00
 1.000E+00              9            1.000E+01


       P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PRINTS        TIME
 0.000E+00             1             1.000E+00
 1.000E+00             1             1.000E+01


       P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PLOTS         TIME
 0.000E+00             1             1.000E+00
 1.000E+00             1             1.000E+01


       M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE ........................LINEAR VISCOELASTIC
  MATERIAL ID ..........................          1
  DENSITY ..............................  1.560E+01
  MATERIAL PROPERTIES:
        BULK                   =     1.000E+05
```

Information Only

```
          BULK INF                  =     1.000E+05
          BULK RELAX                =     1.000E+00
          SHEAR INF                 =     0.000E+00
          SHEAR ONE                 =     3.750E+04
          SHEAR TWO                 =     0.000E+00
          SHEAR THREE               =     0.000E+00
          RELAX ONE                 =     1.000E+00
          RELAX TWO                 =     1.000E+00
          RELAX THREE               =     1.000E+00
          C1                        =     7.600E+00
          C2                        =     2.770E+02
          TEMP0                     =     3.730E+02


     MATERIAL TYPE ........................ELASTIC PLASTIC
     MATERIAL ID ..........................         2
     DENSITY ..............................   9.800E+01
     MATERIAL PROPERTIES:
          YOUNGS MODULUS            =     3.000E+07
          POISSONS RATIO            =     3.015E-01
          YIELD STRESS              =     1.000E+06
          HARDENING MODULUS         =     1.000E+06
          BETA                      =     1.000E+00



          F U N C T I O N   D E F I N I T I O N S


  FUNCTION ID .........      1     NUMBER OF POINTS ....      2

               N       S           F(S)
               1   0.000E+00    1.000E+03
               2   1.000E+01    1.000E+03
```

```
N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                 NODE SET FLAG      DIRECTION
                       1                Y



P R E S S U R E   B O U N D A R Y   C O N D T I O N S

             SURFACE        FUNCTION      SCALE
               FLAG          NUMBER       FACTOR
                 4              1       1.000E+00



                    E N D   O F   D A T A   I N P U T   P H A S E
                           2.074E-01 CPU SECONDS USED
                                  48 WORDS ALLOCATED



          E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                           1.170E-02 CPU SECONDS USED
                                  48 WORDS ALLOCATED
```

Information Only

Information Only

```
                    V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                                   NODAL        ELEMENT      GLOBAL
                                   -----        -------      ------
                                   DISPLX       SIGXX        FX
                                   DISPLY       SIGYY        FY
                                   RESIDX       SIGZZ        RX
                                   RESIDY       TAUXY        RY
                                   RESID        EPSXX        ITER
                                                EPSYY        RMAG
                                                EPSZZ
                                                EPSXY
                                                BLKDECAY
                                                DECAYX1
                                                DECAYY1
                                                DECAYZ1
                                                DECAYX2
                                                DECAYY2
                                                DECAYZ2

  STEP       TIME        TIME       DAMPING     APPLIED     RESIDUAL     PERCENT     TOTAL
                         STEP       FACTOR     LOAD NORM   LOAD NORM    IMBALANCE    STEPS
     10   0.000E+00   9.956E-02   9.996E-01   8.850E+01   1.537E+02     173.72        10
     20   0.000E+00   9.953E-02   1.000E+00   8.867E+01   1.179E+02     132.93        20
     30   0.000E+00   9.954E-02   7.648E-01   8.887E+01   9.929E+01     111.73        30
     40   0.000E+00   9.952E-02   8.250E-01   8.892E+01   5.962E+01      67.05        40
     50   0.000E+00   9.951E-02   8.520E-01   8.893E+01   5.414E+01      60.88        50
     60   0.000E+00   9.952E-02   8.626E-01   8.892E+01   5.486E+01      61.69        60
     70   0.000E+00   9.952E-02   9.624E-01   8.892E+01   5.432E+01      61.08        70
     80   0.000E+00   9.950E-02   9.976E-01   8.892E+01   5.715E+01      64.28        80
     90   0.000E+00   9.952E-02   8.246E-01   8.891E+01   5.352E+01      60.20        90
    100   0.000E+00   9.952E-02   8.065E-01   8.891E+01   5.098E+01      57.33       100
    110   0.000E+00   9.952E-02   8.000E-01   8.891E+01   5.061E+01      56.92       110
```

120	0.000E+00	9.952E-02	9.779E-01	8.891E+01	5.040E+01	56.69	120
130	0.000E+00	9.952E-02	9.998E-01	8.891E+01	4.994E+01	56.16	130
140	0.000E+00	9.951E-02	1.000E+00	8.892E+01	4.917E+01	55.30	140
150	0.000E+00	9.952E-02	1.000E+00	8.892E+01	4.776E+01	53.71	150
160	0.000E+00	9.951E-02	1.000E+00	8.892E+01	4.578E+01	51.48	160
170	0.000E+00	9.951E-02	1.000E+00	8.893E+01	4.371E+01	49.15	170
180	0.000E+00	9.951E-02	1.000E+00	8.893E+01	4.123E+01	46.36	180
190	0.000E+00	9.951E-02	1.000E+00	8.894E+01	3.801E+01	42.74	190
200	0.000E+00	9.951E-02	1.000E+00	8.895E+01	3.474E+01	39.06	200
210	0.000E+00	9.950E-02	1.000E+00	8.895E+01	3.135E+01	35.24	210
220	0.000E+00	9.951E-02	1.000E+00	8.896E+01	2.727E+01	30.65	220
230	0.000E+00	9.950E-02	1.000E+00	8.897E+01	2.304E+01	25.90	230
240	0.000E+00	9.950E-02	1.000E+00	8.898E+01	1.903E+01	21.39	240
250	0.000E+00	9.949E-02	1.000E+00	8.899E+01	1.461E+01	16.42	250
260	0.000E+00	9.950E-02	1.000E+00	8.900E+01	9.854E+00	11.07	260
270	0.000E+00	9.949E-02	9.994E-01	8.901E+01	5.486E+00	6.16	270
280	0.000E+00	9.949E-02	9.990E-01	8.902E+01	2.385E+00	2.68	280
290	0.000E+00	9.948E-02	9.980E-01	8.903E+01	4.848E+00	5.45	290
300	0.000E+00	9.948E-02	9.978E-01	8.904E+01	9.208E+00	10.34	300
310	0.000E+00	9.948E-02	9.958E-01	8.905E+01	1.310E+01	14.71	310
320	0.000E+00	9.948E-02	9.934E-01	8.906E+01	1.730E+01	19.43	320
330	0.000E+00	9.948E-02	9.974E-01	8.906E+01	2.150E+01	24.14	330
340	0.000E+00	9.947E-02	1.000E+00	8.907E+01	2.499E+01	28.05	340
350	0.000E+00	9.947E-02	1.000E+00	8.908E+01	2.831E+01	31.79	350
360	0.000E+00	9.947E-02	1.000E+00	8.909E+01	3.175E+01	35.64	360
370	0.000E+00	9.947E-02	1.000E+00	8.909E+01	3.457E+01	38.81	370
380	0.000E+00	9.946E-02	1.000E+00	8.910E+01	3.685E+01	41.36	380
390	0.000E+00	9.947E-02	9.999E-01	8.910E+01	3.908E+01	43.86	390
400	0.000E+00	9.946E-02	1.000E+00	8.910E+01	4.105E+01	46.07	400
410	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.223E+01	47.39	410
420	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.314E+01	48.41	420
430	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.399E+01	49.36	430
440	0.000E+00	9.946E-02	9.000E-01	8.911E+01	4.412E+01	49.52	440
450	0.000E+00	9.946E-02	9.868E-01	8.911E+01	4.380E+01	49.15	450
460	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.336E+01	48.66	460
470	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.263E+01	47.84	470

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480	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.129E+01	46.34	480
490	0.000E+00	9.947E-02	1.000E+00	8.910E+01	3.959E+01	44.43	490
500	0.000E+00	9.946E-02	9.999E-01	8.910E+01	3.775E+01	42.36	500
510	0.000E+00	9.947E-02	1.000E+00	8.909E+01	3.542E+01	39.76	510
520	0.000E+00	9.947E-02	1.000E+00	8.909E+01	3.270E+01	36.71	520
530	0.000E+00	9.947E-02	9.994E-01	8.908E+01	2.981E+01	33.46	530
540	0.000E+00	9.947E-02	9.990E-01	8.907E+01	2.670E+01	29.98	540
550	0.000E+00	9.948E-02	9.989E-01	8.907E+01	2.329E+01	26.15	550
560	0.000E+00	9.947E-02	9.978E-01	8.906E+01	1.972E+01	22.14	560
570	0.000E+00	9.948E-02	9.959E-01	8.905E+01	1.616E+01	18.14	570
580	0.000E+00	9.948E-02	9.977E-01	8.904E+01	1.242E+01	13.95	580
590	0.000E+00	9.948E-02	9.927E-01	8.904E+01	8.534E+00	9.58	590
600	0.000E+00	9.949E-02	1.000E+00	8.903E+01	4.761E+00	5.35	600
610	0.000E+00	9.949E-02	1.000E+00	8.902E+01	1.136E+00	1.28	610

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 14:38:29
SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      0, TIME = 0.000E+00
NUMBER OF ITERATIONS =         612, TOTAL NUMBER OF ITERATIONS =       612
FINAL CONVERGENCE TOLERANCE = 4.699E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.259E+02
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 7.958E-13
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 0.000E+00  STEP NUMBER     0 ****
.
.
.
.
.

**** PLOT TAPE WRITTEN AT TIME = 9.000E+00  STEP NUMBER    18 ****


STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL   PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
   10  1.000E+01  1.000E+00  9.999E-01  9.003E+01  9.794E+00     10.88     12069
   20  1.000E+01  1.000E+00  1.000E+00  9.003E+01  1.292E+01     14.35     12079
   30  1.000E+01  1.000E+00  1.000E+00  9.002E+01  7.203E+00      8.00     12089
   40  1.000E+01  1.000E+00  1.000E+00  9.002E+01  3.922E+00      4.36     12099
   50  1.000E+01  1.000E+00  8.531E-01  9.001E+01  5.839E+00      6.49     12109
   60  1.000E+01  1.000E+00  9.948E-01  9.001E+01  3.481E+00      3.87     12119
   70  1.000E+01  1.000E+00  9.899E-01  9.001E+01  2.073E+00      2.30     12129
   80  1.000E+01  1.000E+00  1.000E+00  9.002E+01  3.355E+00      3.73     12139
   90  1.000E+01  1.000E+00  1.000E+00  9.002E+01  2.401E+00      2.67     12149
```

Information Only

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```
SANTOS, VERSION 2.0.0     ,RUN ON 03/07/96 ,AT 14:38:29
     SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY

    **********************************************************************
    SUMMARY OF DATA AT STEP NUMBER    19, TIME = 1.000E+01
    NUMBER OF ITERATIONS =        98, TOTAL NUMBER OF ITERATIONS =     12157
    FINAL CONVERGENCE TOLERANCE = 3.600E-01
    SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.273E+02
    SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
    SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
    SUM OF REACTION FORCES IN Y-DIRECTION = 1.364E-12
    **********************************************************************


    **** PLOT TAPE WRITTEN AT TIME = 1.000E+01  STEP NUMBER    19 ****




              20 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                   E N D   O F   S O L U T I O N   P H A S E
                        1.062E+01 CPU SECONDS USED
                               48 WORDS ALLOCATED
```

APPENDIX P

Input/Output Data For Problem 16 – M-D Constitutive Model Implementation Test Problem

The following two sections present the input data and the formatted output for the M-D constitutive model implementation test problem.

FASTQ and SANTOS Input Data For The M-D Constitutive Model Implementation Test Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the M-D constitutive model implementation test problem.

Information Only

```
TITLE
 SHAFT MESH 128 ELEMENTS - SANTOS/SANCHO CHECK
POINT     1      3.2500000000E+00      0.0000000000E+00
POINT     2      1625.                 0.0000000000E+00
POINT     3      1625.                 3.2500000000E+00
POINT     4      3.2500000000E+00      3.2500000000E+00
LINE      1    STR     1     2     0   128  1.0250
LINE      2    STR     2     3     0     1  1.0000
LINE      3    STR     4     3     0   128  1.0250
LINE      4    STR     4     1     0     1  1.0000
REGION     1     1    -1    -2    -3    -4
SCHEME    0 M
BODY       1
LINEBC     1     4
LINEBC     2     1     3
LINEBC     3     2
SIDEBC     1     4
SIDEBC     2     1     3
SIDEBC     3     2
EXIT
```

Information Only

```
TITLE
     SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)
AXISYM
STEP CONTROL
 3650 3.1536E8
END
OUTPUT TIME
  1 3.1536E8
END
PLOT TIME
 1 3.1536E8
END
ELASTIC SOLUTION
RESIDUAL TOLERANCE = .01
MAXIMUM ITERATIONS = 5000
INTERMEDIATE PRINT = 100
MAXIMUM TOLERANCE = 100.
MINIMUM DAMPING FACTOR = .2
INITIAL STRESS = CONSTANT = -15.E6 = -15.E6 = -15.0E6 = 0.
HOURGLASS STIFFENING = .005
AUTO STEP 0.02 2.592e6 NOREDUCE 1.E-3
PLOT NODAL DISPLACEMENT
PLOT ELEMENT STRESS
PLOT STATE EQCS
FUNCTION 1
 0. 1.
7.22E8 1.
END
PRESSURE, 3, 1, 15.0E6
NO DISPLACEMENT, Y, 2
MATERIAL, 1, M-D CREEP MODEL, 2300.
TWO MU = 24.8E9
BULK MODULUS = 20.66E9
A1 = 8.386E22
Q1/R = 41.94
N1 = 5.5
B1 = 6.086E6
A2 = 9.672E12
Q2/R = 16.776
N2 = 5.0
B2 = 3.034E-2
SIG0 = 20.57E6
QLC = 5335.
M = 3.0
K0 = 6.275E5
C = 2.759
ALPHA = -17.37
BETA = -7.738
DELTLC = 0.58
RN3 = 2.0
AMULT = 0.95
END
EXIT
```

Information Only

SANTOS Output For The M-D Constitutive Model Implementation Test Problem

The following section presents a portion of the SANTOS printed output for the M-D constitutive model implementation test problem. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

WPO# 35675 March 27, 1996

```
 SSSSSS   AAAAA   N    NN   TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN     TT      OO   OO   SS
SS       AA   AA  NNN  NN     TT      OO   OO   SS
 SSSSS   AAAAAAA  NN N NN     TT      OO   OO    SSSSS
     SS  AA   AA  NN  NNN     TT      OO   OO        SS
     SS  AA   AA  NN   NN     TT      OO   OO        SS
SSSSSS   AA   AA  NN    N     TT       OOOOO   SSSSSS



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             ENGINEERING SCIENCES CENTER
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            ALBUQUERQUE, NEW MEXICO 87185

               DERIVED FROM PRONTO2D BY
         LEE M. TAYLOR AND DENNIS P. FLANAGAN



            RUN ON 03/07/96 AT 15:28:27
          RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                                  INPUT STREAM IMAGESTITLE
  SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)
LINE ------------------------------------------------------------------------------
  1: TITLE
  2:      SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)
  3: AXISYM
  4: STEP CONTROL
  5:  3650 3.1536E8
  6: END
  7: OUTPUT TIME
  8:   1 3.1536E8
  9: END
 10: PLOT TIME
 11:  1 3.1536E8
 12: END
 13: ELASTIC SOLUTION
 14: RESIDUAL TOLERANCE = .01
 15: MAXIMUM ITERATIONS = 5000
 16: INTERMEDIATE PRINT = 100
 17: MAXIMUM TOLERANCE = 100.
 18: MINIMUM DAMPING FACTOR = .2
 19: INITIAL STRESS = CONSTANT = -15.E6 = -15.E6 = -15.0E6 = 0.
 20: HOURGLASS STIFFENING = .005
 21: AUTO STEP 0.02 2.592e6 NOREDUCE 1.E-3
 22: PLOT NODAL DISPLACEMENT
 23: PLOT ELEMENT STRESS
 24: PLOT STATE EQCS
 25: FUNCTION 1
 26:  0. 1.
 27: 7.22E8 1.
 28: END
 29: PRESSURE, 3, 1, 15.0E6
 30: NO DISPLACEMENT, Y, 2
 31: MATERIAL, 1, M-D CREEP MODEL, 2300.
 32: TWO MU = 24.8E9
 33: BULK MODULUS = 20.66E9
```

```
34: A1 = 8.386E22
35: Q1/R = 41.94
36: N1 = 5.5
37: B1 = 6.086E6
38: A2 = 9.672E12
39: Q2/R = 16.776
40: N2 = 5.0
41: B2 = 3.034E-2
42: SIG0 = 20.57E6
43: QLC = 5335.
44: M = 3.0
45: K0 = 6.275E5
46: C = 2.759
47: ALPHA = -17.37
48: BETA = -7.738
49: DELTLC = 0.58
50: RN3 = 2.0
51: AMULT = 0.95
52: END
53: EXIT
    -----------------------------------------------------------------------
```

Information Only

```
                P R O B L E M   T I T L ETITLE
SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)

          SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)


              P R O B L E M   D E F I N I T I O N

      NUMBER OF ELEMENTS ......................       128
      NUMBER OF NODES .........................       258
      NUMBER OF MATERIALS .....................         1
      NUMBER OF FUNCTIONS .....................         1
      NUMBER OF CONTACT SURFACES ..............         0
      NUMBER OF RIGID SURFACES ................         0
      NUMBER OF MATERIAL POINTS MONITORED .....         0
      ANALYSIS TYPE ........................... AXISYMMETRIC
      GLOBAL CONVERGENCE MEASURE ..............
      RESIDUAL TOLERANCE ......................  1.000E-02
      MAXIMUM NUMBER OF ITERATIONS ............      5000
      ITERATIONS FOR INTERMEDIATE PRINT .......       100
      MAXIMUM RESIDUAL TOLERANCE ..............  1.000E+02
      PREDICTOR SCALE FACTOR FUNCTION .........         0
      MINIMUM DAMPING FACTOR ..................  2.000E-01
      EFFECTIVE MODULUS STATUS ................ CONSTANT
      INITIAL STRESS DISTRIBUTION APPLIED .....
      ELASTIC SOLUTION REQUESTED ..............
      SCALE FACTOR APPLIED TO TIME STEP .......  1.000E+00
      STRAIN SOFTENING SCALE FACTOR ...........  1.000E+00
      HOURGLASS STIFFNESS FACTOR ..............  5.000E-03
      HOURGLASS VISCOSITY FACTOR ..............  0.000E+00
```

Information Only

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```
          L O A D   S T E P   D E F I N I T I O N S


   TIME             NO. OF STEPS              TIME
 0.000E+00              3650               3.154E+08




          P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME       STEPS BETWEEN PRINTS              TIME
 0.000E+00               1                  3.154E+08




          P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME       STEPS BETWEEN PLOTS               TIME
 0.000E+00               1                  3.154E+08




          M A T E R I A L   D E F I N I T I O N S


 MATERIAL TYPE .........................M-D CREEP MODEL
 MATERIAL ID ..........................           1
 DENSITY ..............................   2.300E+03
 MATERIAL PROPERTIES:
        TWO MU                   =     2.480E+10
        BULK MODULUS             =     2.066E+10
```

```
A1                      =     8.386E+22
Q1/R                    =     4.194E+01
N1                      =     5.500E+00
B1                      =     6.086E+06
A2                      =     9.672E+12
Q2/R                    =     1.678E+01
N2                      =     5.000E+00
B2                      =     3.034E-02
SIG0                    =     2.057E+07
QLC                     =     5.335E+03
M                       =     3.000E+00
K0                      =     6.275E+05
C                       =     2.759E+00
ALPHA                   =    -1.737E+01
BETA                    =    -7.738E+00
DELTLC                  =     5.800E-01
RN3                     =     2.000E+00
AMULT                   =     9.500E-01



          F U N C T I O N   D E F I N I T I O N S


     FUNCTION ID .........       1      NUMBER OF POINTS ....      2

                 N        S          F(S)
                 1    0.000E+00    1.000E+00
                 2    7.220E+08    1.000E+00



   N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S
```

Information Only

```
                 NODE SET FLAG      DIRECTION
                       2                Y



         P R E S S U R E   B O U N D A R Y   C O N D T I O N S

                   SURFACE       FUNCTION     SCALE
                    FLAG          NUMBER      FACTOR
                      3              1      1.500E+07



                 E N D   O F   D A T A   I N P U T   P H A S E
                         2.183E-01 CPU SECONDS USED
                                262 WORDS ALLOCATED



            E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                         1.149E-02 CPU SECONDS USED
                                258 WORDS ALLOCATED



             V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                      NODAL         ELEMENT        GLOBAL
```

Information Only

```
-----        -------      ------
DISPLX       SIGXX        FX
DISPLY       SIGYY        FY
             SIGZZ        RX
             TAUXY        RY
             EQCS         ITER
                          RMAG
```

Information Only

Information Only

```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/07/96 ,AT 15:28:27
     SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      0, TIME = 0.000E+00
NUMBER OF ITERATIONS =        52, TOTAL NUMBER OF ITERATIONS =        52
FINAL CONVERGENCE TOLERANCE = 9.445E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION =-7.922E+10
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-3.906E-02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 0.000E+00  STEP NUMBER     0 ****
```

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 15:28:27
     SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     1, TIME = 1.000E-03
NUMBER OF ITERATIONS =         55, TOTAL NUMBER OF ITERATIONS =       107
FINAL CONVERGENCE TOLERANCE = 8.537E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION =-7.922E+10
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-3.906E-02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E-03  STEP NUMBER     1 ****

.
.
.
.

**** PLOT TAPE WRITTEN AT TIME = 3.147E+08  STEP NUMBER   220 ****



STEP      TIME      TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
 100   3.154E+08  6.111E+05  9.436E-01  5.602E+10  5.628E+06      0.01     30664
```

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/07/96 ,AT 15:28:27TITLE
SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)
     SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER   221, TIME = 3.154E+08
NUMBER OF ITERATIONS =       150, TOTAL NUMBER OF ITERATIONS =     30714
FINAL CONVERGENCE TOLERANCE = 1.000E-02
SUM OF EXTERNAL FORCES IN X-DIRECTION =-7.922E+10
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 1.563E-02
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 3.154E+08  STEP NUMBER   221 ****




          222 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                 E N D  O F  S O L U T I O N  P H A S E
                      2.606E+02 CPU SECONDS USED
                            258 WORDS ALLOCATED
```

Information Only

Intentionally Left Blank

Information Only

APPENDIX Q

Input/Output For Problem 17 – Upsetting of a Cylindrical Billet

The following sections present the input data and the formatted output for the upsetting of a cylindrical billet problem.

FASTQ and SANTOS Input Data For The Problem of Upsetting of a Cylindrical Billet

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the upset of a cylindrical billet.

Information Only

```
TITLE
          STEEL BILLET
POINT       1         0.000E+00          0.000E+00
POINT       2         1.000E+01          0.000E+00
POINT       3         1.000E+01          1.500E+01
POINT       4         0.000E+00          1.500E+01
LINE        1    STR        1       2       0     12   1.0000
LINE        2    STR        2       3       0     18   1.0000
LINE        3    STR        3       4       0     12   1.0000
LINE        4    STR        4       1       0     18   1.0000
REGION      1       1      -1      -2      -3      -4
SCHEME      0  M
LINEBC 1 1
LINEBC 2 2
LINEBC 3 3
LINEBC 4 4
SIDEBC 100 1
SIDEBC 300 3
SIDEBC 200 2
SIDEBC 400 4
SIDEBC 500 2 3
EXIT
```

Information Only

```
TITLE
  UPSETTING OF A CYLINDRICAL BILLET
AXISYMMETRIC
STEP CONTROL
100,1
END
INTERMEDIATE PRINT= 100
MAXIMUM ITERATIONS = 3000
RESIDUAL TOLERANCE = 0.5
MAXIMUM TOLERANCE =  100.0
OUTPUT TIME
5,1
END
PLOT TIME
1,1
END
PLOT NODAL = DISPLACEMENT,REACTION,RESIDUAL
PLOT ELEMENT = VONMISES,PRESSURE
PLOT STATE = EQPS
NO DISPLACEMENT,X = 4
PRESCRIBED DISPLACMENT,Y = 1,1,9.
FUNCTION = 1
0,0
1,1
END
RIGID SURFACE = 500 , 0., 15., 0., -1., FIXED
MATERIAL,1,ELASTIC PLASTIC,7.833E-6
YOUNGS MODULUS = 200 , POISSONS RATIO = .3
YIELD STRESS = .7 , HARDENING MODULUS = .3 , BETA = 1
END
EXIT
```

Information Only

SANTOS Output For The Problem of Upsetting of a Cylindrical Billet

The following section presents a portion of the SANTOS printed output for the problem of upsetting of a cylindrical billet. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS



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          ALBUQUERQUE, NEW MEXICO 87185

             DERIVED FROM PRONTO2D BY
       LEE M. TAYLOR AND DENNIS P. FLANAGAN



             RUN ON 03/29/96 AT 08:53:01
          RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

```
                         INPUT STREAM IMAGES
LINE ---------------------------------------------------------------
  1: TITLE
  2:   UPSETTING OF A CYLINDRICAL BILLET
  3: AXISYMMETRIC
  4: STEP CONTROL
  5: 100,1
  6: END
  7: INTERMEDIATE PRINT= 100
  8: MAXIMUM ITERATIONS = 3000
  9: RESIDUAL TOLERANCE = 0.5
 10: MAXIMUM TOLERANCE =  100.0
 11: OUTPUT TIME
 12: 5,1
 13: END
 14: PLOT TIME
 15: 1,1
 16: END
 17: PLOT NODAL = DISPLACEMENT,REACTION,RESIDUAL
 18: PLOT ELEMENT = VONMISES,PRESSURE
 19: PLOT STATE = EQPS
 20: NO DISPLACEMENT,X = 4
 21: PRESCRIBED DISPLACMENT,Y = 1,1,9.
 22: FUNCTION = 1
 23: 0,0
 24: 1,1
 25: END
 26: RIGID SURFACE = 500 , 0., 15., 0., -1., FIXED
 27: MATERIAL,1,ELASTIC PLASTIC,7.833E-6
 28: YOUNGS MODULUS = 200 , POISSONS RATIO = .3
 29: YIELD STRESS = .7 , HARDENING MODULUS = .3 , BETA = 1
 30: END
 31: EXIT
    ---------------------------------------------------------------
```

Information Only

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```
                    P R O B L E M   T I T L E

             UPSETTING OF A CYLINDRICAL BILLET



                    P R O B L E M   D E F I N I T I O N

               NUMBER OF ELEMENTS ......................          216
               NUMBER OF NODES .........................          247
               NUMBER OF MATERIALS .....................            1
               NUMBER OF FUNCTIONS .....................            1
               NUMBER OF CONTACT SURFACES ..............            0
               NUMBER OF RIGID SURFACES ................            1
               NUMBER OF MATERIAL POINTS MONITORED .....            0
               ANALYSIS TYPE ........................... AXISYMMETRIC
               GLOBAL CONVERGENCE MEASURE ..............
               RESIDUAL TOLERANCE ......................   5.000E-01
               MAXIMUM NUMBER OF ITERATIONS ............         3000
               ITERATIONS FOR INTERMEDIATE PRINT .......          100
               MAXIMUM RESIDUAL TOLERANCE ..............   1.000E+02
               PREDICTOR SCALE FACTOR FUNCTION .........            0
               MINIMUM DAMPING FACTOR ..................   2.000E-01
               EFFECTIVE MODULUS STATUS ................ CONSTANT
               SCALE FACTOR APPLIED TO TIME STEP .......   1.000E+00
               STRAIN SOFTENING SCALE FACTOR ...........   1.000E+00
               HOURGLASS STIFFNESS FACTOR ..............   1.000E-02
               HOURGLASS VISCOSITY FACTOR ..............   3.000E-02



                    L O A D   S T E P   D E F I N I T I O N S
```

Information Only

```
   TIME          NO. OF STEPS          TIME
0.000E+00            100            1.000E+00


        P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME     STEPS BETWEEN PRINTS       TIME
0.000E+00            5              1.000E+00


        P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME     STEPS BETWEEN PLOTS        TIME
0.000E+00            1              1.000E+00


        M A T E R I A L   D E F I N I T I O N S


MATERIAL TYPE ..........................ELASTIC PLASTIC
MATERIAL ID ...........................          1
DENSITY ...............................   7.833E-06
MATERIAL PROPERTIES:
          YOUNGS MODULUS         =    2.000E+02
          POISSONS RATIO         =    3.000E-01
          YIELD STRESS           =    7.000E-01
          HARDENING MODULUS      =    3.000E-01
          BETA                   =    1.000E+00
```

Information Only

```
              F U N C T I O N   D E F I N I T I O N S

      FUNCTION ID .........      1     NUMBER OF POINTS ....      2

                     N      S            F(S)
                     1    0.000E+00    0.000E+00
                     2    1.000E+00    1.000E+00



   N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                NODE SET FLAG      DIRECTION
                     4                 X



 P R E S C R I B E D   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

      NODE SET    DIRECTION    FUNCTION    SCALE          A0          B0
        FLAG                      ID       FACTOR
         1            Y           1      9.000E+00        -           -
```

Information Only

```
                       R I G I D   S U R F A C E S

 SURFACE  SIDE SET  COEFFICIENT          X0        Y0        NX        NY
  NUMBER    FLAG    OF FRICTION
    1        500    FIXED          0.000E+00 1.500E+01 0.000E+00-1.000E+00




                 E N D   O F   D A T A   I N P U T   P H A S E
                           1.421E-01 CPU SECONDS USED
                                 64 WORDS ALLOCATED




          E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                           1.148E-02 CPU SECONDS USED
                                247 WORDS ALLOCATED




            V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                     NODAL        ELEMENT       GLOBAL
                     -----        -------       ------
                     DISPLX       PRESSURE      FX
                     DISPLY       VONMISES      FY
                     RESIDX       EQPS          RX
                     RESIDY                     RY
                     RESID                      ITER
                     REACTX                     RMAG
                     REACTY
```

Information Only

```
**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****


STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL   PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
 100   1.000E-02  9.999E-03  8.570E-01  1.129E+01  4.750E-01     4.21       100

**** PLOT TAPE WRITTEN AT TIME = 1.000E-02  STEP NUMBER      1 ****


STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL   PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
 100   2.000E-02  1.000E-02  9.883E-01  1.155E+01  1.796E-01     1.55       293

**** PLOT TAPE WRITTEN AT TIME = 2.000E-02  STEP NUMBER      2 ****


STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL   PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
 100   3.000E-02  1.000E-02  9.813E-01  1.169E+01  9.353E-02     0.80       469

**** PLOT TAPE WRITTEN AT TIME = 3.000E-02  STEP NUMBER      3 ****
```

```
STEP       TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR    LOAD NORM   LOAD NORM  IMBALANCE    STEPS
  100   4.000E-02  1.000E-02  9.038E-01  1.184E+01  1.275E-01      1.08        581

  **** PLOT TAPE WRITTEN AT TIME = 4.000E-02  STEP NUMBER      4 ****


STEP       TIME       TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                      STEP      FACTOR    LOAD NORM   LOAD NORM  IMBALANCE    STEPS
  100   5.000E-02  1.000E-02  9.686E-01  1.192E+01  1.022E-01      0.86        708
```

Information Only

```
  SANTOS, VERSION 2.0.0    ,RUN ON 03/29/96 ,AT 08:53:01
   UPSETTING OF A CYLINDRICAL BILLET

 **********************************************************************
 SUMMARY OF DATA AT STEP NUMBER      5, TIME = 5.000E-02
 NUMBER OF ITERATIONS =        133, TOTAL NUMBER OF ITERATIONS =        741
 FINAL CONVERGENCE TOLERANCE = 4.965E-01
 SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
 SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
 SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
 SUM OF REACTION FORCES IN Y-DIRECTION =-3.733E+01
 **********************************************************************


 **** PLOT TAPE WRITTEN AT TIME = 5.000E-02  STEP NUMBER     5 ****



STEP      TIME      TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  100  6.000E-02  1.000E-02  9.533E-01  1.206E+01  1.274E-01      1.06        841

 **** PLOT TAPE WRITTEN AT TIME = 6.000E-02  STEP NUMBER     6 ****



STEP      TIME      TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  100  7.000E-02  1.000E-02  8.660E-01  1.214E+01  1.097E-01      0.90        991

 **** PLOT TAPE WRITTEN AT TIME = 7.000E-02  STEP NUMBER     7 ****
```

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```
STEP      TIME      TIME      DAMPING    APPLIED    RESIDUAL   PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE  STEPS
  100  8.000E-02  1.000E-02  8.053E-01  1.230E+01  1.220E-01     0.99      1155


 **** PLOT TAPE WRITTEN AT TIME = 8.000E-02  STEP NUMBER     8 ****



STEP      TIME      TIME      DAMPING    APPLIED    RESIDUAL   PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE  STEPS
  100  9.000E-02  1.000E-02  9.235E-01  1.243E+01  1.330E-01     1.07      1306


 **** PLOT TAPE WRITTEN AT TIME = 9.000E-02  STEP NUMBER     9 ****



STEP      TIME      TIME      DAMPING    APPLIED    RESIDUAL   PERCENT    TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE  STEPS
  100  1.000E-01  1.000E-02  9.387E-01  1.250E+01  9.311E-02     0.74      1458
```

Information Only

```
  SANTOS, VERSION 2.0.0    ,RUN ON 03/29/96 ,AT 08:53:01
   UPSETTING OF A CYLINDRICAL BILLET

 *********************************************************************
 SUMMARY OF DATA AT STEP NUMBER    10, TIME = 1.000E-01
 NUMBER OF ITERATIONS =       124, TOTAL NUMBER OF ITERATIONS =      1482
 FINAL CONVERGENCE TOLERANCE = 4.963E-01
 SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
 SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
 SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
 SUM OF REACTION FORCES IN Y-DIRECTION =-3.924E+01
 *********************************************************************


 **** PLOT TAPE WRITTEN AT TIME = 1.000E-01  STEP NUMBER    10 ****



STEP      TIME       TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  100  1.100E-01  1.000E-02  9.296E-01  1.262E+01  1.005E-01      0.80      1582

 **** PLOT TAPE WRITTEN AT TIME = 1.100E-01  STEP NUMBER    11 ****



STEP      TIME       TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  100  1.200E-01  1.000E-02  9.909E-01  1.277E+01  1.113E-01      0.87      1711

 **** PLOT TAPE WRITTEN AT TIME = 1.200E-01  STEP NUMBER    12 ****
```

Information Only

```
STEP       TIME        TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                       STEP      FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
 100   1.300E-01  1.000E-02  6.597E-01  1.286E+01  1.006E-01      0.78      1845


 **** PLOT TAPE WRITTEN AT TIME = 1.300E-01   STEP NUMBER     13 ****



STEP       TIME        TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                       STEP      FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
 100   1.400E-01  1.000E-02  9.836E-01  1.301E+01  1.144E-01      0.88      1972


 **** PLOT TAPE WRITTEN AT TIME = 1.400E-01   STEP NUMBER     14 ****



STEP       TIME        TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                       STEP      FACTOR     LOAD NORM  LOAD NORM   IMBALANCE   STEPS
 100   1.500E-01  9.999E-03  9.338E-01  1.317E+01  1.445E-01      1.10      2111
```

Information Only

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/29/96 ,AT 08:53:01
  UPSETTING OF A CYLINDRICAL BILLET

 *********************************************************************
 SUMMARY OF DATA AT STEP NUMBER    15, TIME = 1.500E-01
 NUMBER OF ITERATIONS =       138, TOTAL NUMBER OF ITERATIONS =      2149
 FINAL CONVERGENCE TOLERANCE = 4.987E-01
 SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
 SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
 SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
 SUM OF REACTION FORCES IN Y-DIRECTION =-4.126E+01
 *********************************************************************


 **** PLOT TAPE WRITTEN AT TIME = 1.500E-01  STEP NUMBER    15 ****



STEP      TIME       TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  100  1.600E-01  1.000E-02  6.871E-01  1.323E+01  1.006E-01      0.76      2249

 **** PLOT TAPE WRITTEN AT TIME = 1.600E-01  STEP NUMBER    16 ****



STEP      TIME       TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  100  1.700E-01  1.000E-02  9.673E-01  1.332E+01  8.014E-02      0.60      2384

 **** PLOT TAPE WRITTEN AT TIME = 1.700E-01  STEP NUMBER    17 ****
```

Information Only

```
STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM   LOAD NORM  IMBALANCE   STEPS
  100  1.800E-01  1.000E-02  8.793E-01  1.348E+01  1.092E-01      0.81      2496

 **** PLOT TAPE WRITTEN AT TIME = 1.800E-01  STEP NUMBER    18 ****


STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM   LOAD NORM  IMBALANCE   STEPS
  100  1.900E-01  1.000E-02  8.358E-01  1.363E+01  1.212E-01      0.89      2621

 **** PLOT TAPE WRITTEN AT TIME = 1.900E-01  STEP NUMBER    19 ****


STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM   LOAD NORM  IMBALANCE   STEPS
  100  2.000E-01  9.999E-03  6.729E-01  1.378E+01  1.550E-01      1.12      2754
```

Information Only

```
SANTOS, VERSION 2.0.0    ,RUN ON 03/29/96 ,AT 08:53:01
 UPSETTING OF A CYLINDRICAL BILLET

***********************************************************************
SUMMARY OF DATA AT STEP NUMBER    20, TIME = 2.000E-01
NUMBER OF ITERATIONS =        152, TOTAL NUMBER OF ITERATIONS =      2806
FINAL CONVERGENCE TOLERANCE = 4.953E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-4.337E+01
***********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 2.000E-01  STEP NUMBER    20 ****



STEP      TIME       TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  100  9.800E-01  9.991E-03  9.952E-01  4.708E+01  4.996E-01      1.06     13373

**** PLOT TAPE WRITTEN AT TIME = 9.800E-01  STEP NUMBER    98 ****



STEP      TIME       TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
  100  9.900E-01  9.987E-03  9.500E-01  4.816E+01  2.675E+01     55.55     13505
  200  9.900E-01  9.987E-03  9.996E-01  4.756E+01  4.647E-01      0.98     13605

**** PLOT TAPE WRITTEN AT TIME = 9.900E-01  STEP NUMBER    99 ****
```

Information Only

```
SANTOS, VERSION 2.0.0     ,RUN ON 03/29/96 ,AT 08:53:01
 UPSETTING OF A CYLINDRICAL BILLET

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER   100, TIME = 1.000E+00
NUMBER OF ITERATIONS =         96, TOTAL NUMBER OF ITERATIONS =     13779
FINAL CONVERGENCE TOLERANCE = 4.578E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 0.000E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION =-1.356E+02
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER   100 ****




          100 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                  E N D  O F  S O L U T I O N  P H A S E
                     4.126E+01 CPU SECONDS USED
                          247 WORDS ALLOCATED
```

APPENDIX R

Input/Output Data For Problem 18 – Isothermal WIPP Benchmark II Problem

The following three sections present the input data, the initial stress subroutine, and the formatted output, respectively, for the Isothermal WIPP Benchmark II verification problem.

FASTQ and SANTOS Input Data For The Isothermal WIPP Benchmark II Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the Benchmark II isothermal drift problem.

Information Only

```
TITLE
 ISOTHERMAL BENCHMARK II MESH
POINT      1      0.0000000000E+00      -5.9802001953E+02
POINT      2      5.0300002098E+00      -5.9802001953E+02
POINT      3      2.0270000458E+01      -5.9802001953E+02
POINT      4      0.0000000000E+00      -6.0259002686E+02
POINT      5      5.0300002098E+00      -6.0259002686E+02
POINT      6      2.0270000458E+01      -6.0259002686E+02
POINT      7      0.0000000000E+00      -6.3885998535E+02
POINT      8      5.0300002098E+00      -6.3885998535E+02
POINT      9      2.0270000458E+01      -6.3885998535E+02
POINT     10      0.0000000000E+00      -6.4276000977E+02
POINT     11      5.0300002098E+00      -6.4276000977E+02
POINT     12      2.0270000458E+01      -6.4276000977E+02
POINT     13      0.0000000000E+00      -6.4297998047E+02
POINT     14      5.0300002098E+00      -6.4297998047E+02
POINT     15      2.0270000458E+01      -6.4297998047E+02
POINT     16      5.0300002098E+00      -6.4297998047E+02
POINT     17      0.0000000000E+00      -6.4992999268E+02
POINT     18      5.0300002098E+00      -6.4992999268E+02
POINT     19      2.0270000458E+01      -6.4992999268E+02
POINT     20      0.0000000000E+00      -6.5020001221E+02
POINT     21      5.0300002098E+00      -6.5020001221E+02
POINT     22      2.0270000458E+01      -6.5020001221E+02
POINT     23      5.0300002098E+00      -6.5020001221E+02
POINT     24      0.0000000000E+00      -6.5503997803E+02
POINT     25      5.0300002098E+00      -6.5503997803E+02
POINT     26      2.0270000458E+01      -6.5503997803E+02
POINT     27      0.0000000000E+00      -6.5900000000E+02
POINT     28      5.0300002098E+00      -6.5900000000E+02
POINT     29      2.0270000458E+01      -6.5900000000E+02
POINT     30      0.0000000000E+00      -6.6010998535E+02
POINT     31      5.0300002098E+00      -6.6010998535E+02
POINT     32      2.0270000458E+01      -6.6010998535E+02
POINT     33      0.0000000000E+00      -6.6102001953E+02
POINT     34      5.0300002098E+00      -6.6102001953E+02
POINT     35      2.0270000458E+01      -6.6102001953E+02
POINT     36      5.0300002098E+00      -6.6102001953E+02
POINT     37      0.0000000000E+00      -6.6909997559E+02
POINT     38      5.0300002098E+00      -6.6909997559E+02
POINT     39      2.0270000458E+01      -6.6909997559E+02
POINT     40      5.0300002098E+00      -6.6909997559E+02
POINT     41      0.0000000000E+00      -7.0365997314E+02
POINT     42      5.0300002098E+00      -7.0365997314E+02
POINT     43      2.0270000458E+01      -7.0365997314E+02
POINT     44      0.0000000000E+00      -7.0677001953E+02
POINT     45      5.0300002098E+00      -7.0677001953E+02
POINT     46      2.0270000458E+01      -7.0677001953E+02
LINE       1    STR       1         2         0       7   1.0000
LINE       2    STR       2         3         0      13   1.0500
LINE       3    STR       4         1         0       3   1.0000
LINE       4    STR       5         2         0       3   1.0000
LINE       5    STR       6         3         0       3   1.0000
LINE       6    STR       4         5         0       7   1.0000
```

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```
LINE     7   STR    5    6    0   13  1.0500
LINE     8   STR    7    4    0   12  1.0500
LINE     9   STR    8    5    0   12  1.0500
LINE    10   STR    9    6    0   12  1.0500
LINE    11   STR    7    8    0    7  1.0000
LINE    12   STR    8    9    0   13  1.0500
LINE    13   STR   10    7    0    4  1.0000
LINE    14   STR   11    8    0    4  1.0000
LINE    15   STR   12    9    0    4  1.0000
LINE    16   STR   10   11    0    7  1.0000
LINE    17   STR   11   12    0   13  1.0500
LINE    18   STR   13   10    0    1  1.0000
LINE    19   STR   14   11    0    1  1.0000
LINE    20   STR   15   12    0    1  1.0000
LINE    21   STR   13   14    0    7  1.0000
LINE    22   STR   14   15    0   13  1.0500
LINE    23   STR   13   16    0    7  1.0000
LINE    24   STR   16   15    0   13  1.0500
LINE    25   STR   17   13    0    6  1.0000
LINE    26   STR   18   16    0    6  1.0000
LINE    27   STR   19   15    0    6  1.0000
LINE    28   STR   17   18    0    7  1.0000
LINE    29   STR   18   19    0   13  1.0500
LINE    30   STR   20   17    0    1  1.0000
LINE    31   STR   21   18    0    1  1.0000
LINE    32   STR   22   19    0    1  1.0000
LINE    33   STR   20   21    0    7  1.0000
LINE    34   STR   21   22    0   13  1.0500
LINE    35   STR   20   23    0    7  1.0000
LINE    36   STR   23   22    0   13  1.0500
LINE    37   STR   24   20    0    4  1.0000
LINE    38   STR   25   23    0    4  1.0000
LINE    39   STR   26   22    0    4  1.0000
LINE    40   STR   24   25    0    7  1.0000
LINE    41   STR   25   26    0   13  1.0500
LINE    42   STR   28   25    0    8  1.0000
LINE    43   STR   29   26    0    8  1.0000
LINE    44   STR   28   29    0   13  1.0500
LINE    45   STR   27   28    0    7  1.0000
LINE    46   STR   30   27    0    3  1.0000
LINE    47   STR   31   28    0    3  1.0000
LINE    48   STR   32   29    0    3  1.0000
LINE    49   STR   30   31    0    7  1.0000
LINE    50   STR   31   32    0   13  1.0500
LINE    51   STR   33   30    0    3  1.0000
LINE    52   STR   34   31    0    3  1.0000
LINE    53   STR   35   32    0    3  1.0000
LINE    54   STR   33   34    0    7  1.0000
LINE    55   STR   34   35    0   13  1.0500
LINE    56   STR   33   36    0    7  1.0000
LINE    57   STR   36   35    0   13  1.0500
LINE    58   STR   37   33    0    5  0.9000
LINE    59   STR   38   36    0    5  0.9000
LINE    60   STR   39   35    0    5  0.9000
```

Information Only

```
LINE      61   STR    37    38     0     7  1.0000
LINE      62   STR    38    39     0    13  1.0500
LINE      63   STR    37    40     0     7  1.0000
LINE      64   STR    40    39     0    13  1.0500
LINE      65   STR    41    37     0    10  0.9000
LINE      66   STR    42    40     0    10  0.9000
LINE      67   STR    43    39     0    10  0.9000
LINE      68   STR    41    42     0     7  1.0000
LINE      69   STR    42    43     0    13  1.0500
LINE      70   STR    44    41     0     3  1.0000
LINE      71   STR    45    42     0     3  1.0000
LINE      72   STR    46    43     0     3  1.0000
LINE      73   STR    44    45     0     7  1.0000
LINE      74   STR    45    46     0    13  1.0500
REGION     1     4    -6    -4    -1    -3
REGION     2     4    -7    -5    -2    -4
REGION     3     2   -11    -9    -6    -8
REGION     4     2   -12   -10    -7    -9
REGION     5     1   -16   -14   -11   -13
REGION     6     1   -17   -15   -12   -14
REGION     7     4   -21   -19   -16   -18
REGION     8     4   -22   -20   -17   -19
REGION     9     1   -28   -26   -23   -25
REGION    10     1   -29   -27   -24   -26
REGION    11     4   -33   -31   -28   -30
REGION    12     4   -34   -32   -29   -31
REGION    13     1   -40   -38   -35   -37
REGION    14     1   -41   -39   -36   -38
REGION    15     1   -44   -43   -41   -42
REGION    16     1   -49   -47   -45   -46
REGION    17     1   -50   -48   -44   -47
REGION    18     4   -54   -52   -49   -51
REGION    19     4   -55   -53   -50   -52
REGION    20     3   -61   -59   -56   -58
REGION    21     3   -62   -60   -57   -59
REGION    22     1   -68   -66   -63   -65
REGION    23     1   -69   -67   -64   -66
REGION    24     4   -73   -71   -68   -70
REGION    25     4   -74   -72   -69   -71
SCHEME    0 M
BODY       1     2     3     4     5     6     7     8     9    10
11    12 *
     13    14    15    16    17    18    19    20    21    22    23
24    25
LINEBC     2     5
LINEBC     3     3     8    13    18    25    30    37    46    51
58    65 *
     10    15    20    27    32    39    43    48    53    60    67    72
LINEBC     3    70
SIDEBC     1     1     2
SIDEBC     4    21    22
SIDEBC     5    23    24
SIDEBC     6    33    34
SIDEBC     7    35    36
```

Information Only

```
SIDEBC    8    54    55
SIDEBC    9    56    57
SIDEBC   10    61    62
SIDEBC   11    63    64
SIDEBC   22    73    74
EXIT
```

Information Only

```
TITLE
  BENCHMARK II ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/9/95)
RESIDUAL TOLERANCE = .5
MAXIMUM ITERATIONS = 20000
INTERMEDIATE PRINT = 100
MAXIMUM TOLERANCE = 5.
PLANE STRAIN
TIME STEP SCALE = 0.4
PREDICTOR SCALE FACTOR = 2
$HOURGLASS STIFFENING = 0.0005
EFFECTIVE MODULUS = VARIABLE
INITIAL STRESS = USER
GRAVITY = 1 = 0. = -9.8066 = 0.
STEP CONTROL
 400 3.157E8
END
PLOT TIME
 1 3.157E8
END
OUTPUT TIME
 100 3.157E8
END
PLOT NODAL DISPLACEMENT, RESIDUAL
PLOT ELEMENT STRESS, VONMISES, EFFMOD
PLOT STATE EQCS
NO DISPLACEMENT X, 3
NO DISPLACEMENT X, 2
NO DISPLACEMENT Y, 2
FUNCTION = 1
0. 1.
4.E8 1.
END
FUNCTION = 2
0. 0.
4.E8 0.
END
PRESSURE, 1, 1, 12.71E6
PRESSURE, 22, 1, 15.00E6
CONTACT SURFACE, 4, 5, 0., .02, 1.E40
CONTACT SURFACE, 7, 6, 0., .02, 1.E40
CONTACT SURFACE, 9, 8, 0., .02, 1.E40
CONTACT SURFACE, 10, 11, 0., .02, 1.E40
MATERIAL,1,POWER LAW CREEP,2167.
TWO MU = 19.84E9
BULK MODULUS = 16.53E9
CREEP CONSTANT = 5.79E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 20.13
END
MATERIAL,2,POWER LAW CREEP,2167.
TWO MU = 19.84E9
BULK MODULUS = 16.53E9
CREEP CONSTANT = 1.74E-35
STRESS EXPONENT = 4.9
```

Information Only

```
THERMAL CONSTANT = 20.13
END
MATERIAL,3,POWER LAW CREEP,2167.
TWO MU = 21.2E9
BULK MODULUS = 17.66E9
CREEP CONSTANT = 5.21E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 20.13
END
MATERIAL,4,ELASTIC,2167.
YOUNGS MODULUS = 72.4E9
POISSONS RATIO = .33
END
EXIT
```

Information Only

Initial Stress Subroutine For The Isothermal WIPP Benchmark II Problem

This section presents a listing of the INITST subroutine that was used in SANTOS to specify the initial stresses for the Benchmark II isothermal drift analysis.

Information Only

```
      SUBROUTINE INITST( SIG,COORD,LINK,DATMAT,KONMAT,SCREL )
C
C
***********************************************************************
C
C   DESCRIPTION:
C     THIS ROUTINE PROVIDES AN INITIAL STRESS STATE TO SANTOS
C
C   FORMAL PARAMETERS:
C     SIG      REAL        ELEMENT STRESS ARRAY WHICH MUST BE RETURNED
C                          WITH THE REQUIRED STRESS VALUES
C     COORD    REAL        GLOBAL NODAL COORDINATE ARRAY
C     LINK     INTEGER     CONNECTIVITY ARRAY
C     DATMAT   REAL        MATERIAL PROPERTIES ARRAY
C     KONMAT   INTEGER     MATERIAL PROPERTIES INTEGER ARRAY
C
C   CALLED BY: INIT
C
C
***********************************************************************
C
      INCLUDE 'params.blk'
      INCLUDE 'psize.blk'
      INCLUDE 'contrl.blk'
      INCLUDE 'bsize.blk'
      INCLUDE 'timer.blk'
C
      DIMENSION LINK(NELNS,NUMEL),KONMAT(10,NEMBLK),COORD(NNOD,NSPC),
     *          SIG(NSYMM,NUMEL),DATMAT(MCONS,*),SCREL(NEBLK,*)
C
      DO 1000 I = 1,NEMBLK
         MATID = KONMAT(1,I)
         MKIND = KONMAT(2,I)
         ISTRT = KONMAT(3,I)
         IEND = KONMAT(4,I)
            DO 500 J = ISTRT,IEND
               II = LINK( 1,J )
               JJ = LINK( 2,J )
               KK = LINK( 3,J )
               LL = LINK( 4,J )
               ZAVG = 0.25 * ( COORD(II,2) + COORD(JJ,2) + COORD(KK,2) +
     *                 COORD(LL,2) )
               STRESS = 21252. * ( ZAVG )
               SIG(1,J) = STRESS
               SIG(2,J) = STRESS
               SIG(3,J) = STRESS
               SIG(4,J) = 0.0
  500       CONTINUE
 1000 CONTINUE
      RETURN
      END
```

Information Only

SANTOS Output For The Isothermal WIPP Benchmark II Problem

The following section presents a portion of the SANTOS printed output for the Benchmark II isothermal drift analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

WPO# 35675 March 27, 1996

```
  SSSSSS   AAAAA   N     NN  TTTTTT    OOOOO    SSSSSS
SS        AA   AA  NN    NN    TT    OO   OO  SS
SS        AA   AA  NNN   NN    TT    OO   OO  SS
  SSSSS   AAAAAAA  NN N  NN    TT    OO   OO    SSSSS
      SS  AA   AA  NN  NNN     TT    OO   OO        SS
      SS  AA   AA  NN   NN     TT    OO   OO        SS
SSSSSS    AA   AA  NN     N    TT     OOOOO   SSSSSS



                    VERSION 2.0.0
         COPYRIGHT 1994, SANDIA CORPORATION


                    PROGRAMMED BY:

                  CHARLES M. STONE
             ENGINEERING SCIENCES CENTER
            SANDIA NATIONAL LABORATORIES
            ALBUQUERQUE, NEW MEXICO 87185

              DERIVED FROM PRONTO2D BY
        LEE M. TAYLOR AND DENNIS P. FLANAGAN



             RUN ON 03/11/96 AT 13:38:17
           RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                              INPUT STREAM IMAGES
LINE -------------------------------------------------------------------------
  1: TITLE
  2:   BENCHMARK II ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/9/95)
  3: RESIDUAL TOLERANCE = .5
  4: MAXIMUM ITERATIONS = 20000
  5: INTERMEDIATE PRINT = 100
  6: MAXIMUM TOLERANCE = 5.
  7: PLANE STRAIN
  8: TIME STEP SCALE = 0.4
  9: PREDICTOR SCALE FACTOR = 2
 10: $HOURGLASS STIFFENING = 0.0005
 11: EFFECTIVE MODULUS = VARIABLE
 12: INITIAL STRESS = USER
 13: GRAVITY = 1 = 0. = -9.8066 = 0.
 14: STEP CONTROL
 15:  400 3.157E8
 16: END
 17: PLOT TIME
 18:  1 3.157E8
 19: END
 20: OUTPUT TIME
 21:  100 3.157E8
 22: END
 23: PLOT NODAL DISPLACEMENT, RESIDUAL
 24: PLOT ELEMENT STRESS, VONMISES, EFFMOD
 25: PLOT STATE EQCS
 26: NO DISPLACEMENT X, 3
 27: NO DISPLACEMENT X, 2
 28: NO DISPLACEMENT Y, 2
 29: FUNCTION = 1
 30: 0. 1.
 31: 4.E8 1.
 32: END
 33: FUNCTION = 2
 34: 0. 0.
```

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```
4.E8 0.
END
PRESSURE, 1, 1, 12.71E6
PRESSURE, 22, 1, 15.00E6
CONTACT SURFACE, 4, 5, 0., .02, 1.E40
CONTACT SURFACE, 7, 6, 0., .02, 1.E40
CONTACT SURFACE, 9, 8, 0., .02, 1.E40
CONTACT SURFACE, 10, 11, 0., .02, 1.E40
MATERIAL,1,POWER LAW CREEP,2167.
TWO MU = 19.84E9
BULK MODULUS = 16.53E9
CREEP CONSTANT = 5.79E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 20.13
END
MATERIAL,2,POWER LAW CREEP,2167.
TWO MU = 19.84E9
BULK MODULUS = 16.53E9
CREEP CONSTANT = 1.74E-35
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 20.13
END
MATERIAL,3,POWER LAW CREEP,2167.
TWO MU = 21.2E9
BULK MODULUS = 17.66E9
CREEP CONSTANT = 5.21E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 20.13
END
MATERIAL,4,ELASTIC,2167.
YOUNGS MODULUS = 72.4E9
POISSONS RATIO = .33
END
EXIT
-----------------------------------------------------------------------------
```

Information Only

PROBLEM TITLE

BENCHMARK II ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/9/95)

PROBLEM DEFINITION

```
NUMBER OF ELEMENTS ......................        1204
NUMBER OF NODES .........................        1371
NUMBER OF MATERIALS .....................           4
NUMBER OF FUNCTIONS .....................           2
NUMBER OF CONTACT SURFACES ..............           4
NUMBER OF RIGID SURFACES ................           0
NUMBER OF MATERIAL POINTS MONITORED .....           0
ANALYSIS TYPE ........................... PLANE STRAIN
GLOBAL CONVERGENCE MEASURE ..............
RESIDUAL TOLERANCE ......................  5.000E-01
MAXIMUM NUMBER OF ITERATIONS ............      20000
ITERATIONS FOR INTERMEDIATE PRINT .......        100
MAXIMUM RESIDUAL TOLERANCE ..............  5.000E+00
PREDICTOR SCALE FACTOR FUNCTION .........          2
MINIMUM DAMPING FACTOR ..................  2.000E-01
EFFECTIVE MODULUS STATUS ................ VARIABLE
INITIAL STRESS DISTRIBUTION APPLIED .....
GRAVITY LOADS APPLIED ...................
SCALE FACTOR APPLIED TO TIME STEP .......  4.000E-01
STRAIN SOFTENING SCALE FACTOR ...........  1.000E+00
HOURGLASS STIFFNESS FACTOR ..............  5.000E-02
HOURGLASS VISCOSITY FACTOR ..............  0.000E+00
```

LOAD STEP DEFINITIONS

```
   TIME            NO. OF STEPS           TIME
0.000E+00              400              3.157E+08



        P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PRINTS          TIME
0.000E+00            100                3.157E+08



        P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME      STEPS BETWEEN PLOTS           TIME
0.000E+00             1                 3.157E+08



        M A T E R I A L   D E F I N I T I O N S


MATERIAL TYPE ........................ELASTIC
MATERIAL ID ..........................             4
DENSITY ..............................   2.167E+03
MATERIAL PROPERTIES:
        YOUNGS MODULUS        =    7.240E+10
        POISSONS RATIO        =    3.300E-01
```

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```
MATERIAL TYPE .........................POWER LAW CREEP
MATERIAL ID ............................         2
DENSITY ................................  2.167E+03
MATERIAL PROPERTIES:
        TWO MU                 =     1.984E+10
        BULK MODULUS           =     1.653E+10
        CREEP CONSTANT         =     1.740E-35
        STRESS EXPONENT        =     4.900E+00
        THERMAL CONSTANT       =     2.013E+01

MATERIAL TYPE .........................POWER LAW CREEP
MATERIAL ID ............................         1
DENSITY ................................  2.167E+03
MATERIAL PROPERTIES:
        TWO MU                 =     1.984E+10
        BULK MODULUS           =     1.653E+10
        CREEP CONSTANT         =     5.790E-36
        STRESS EXPONENT        =     4.900E+00
        THERMAL CONSTANT       =     2.013E+01

MATERIAL TYPE .........................POWER LAW CREEP
MATERIAL ID ............................         3
DENSITY ................................  2.167E+03
MATERIAL PROPERTIES:
        TWO MU                 =     2.120E+10
        BULK MODULUS           =     1.766E+10
        CREEP CONSTANT         =     5.210E-36
        STRESS EXPONENT        =     4.900E+00
        THERMAL CONSTANT       =     2.013E+01
```

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```
           F U N C T I O N   D E F I N I T I O N S

      FUNCTION ID .........       1     NUMBER OF POINTS ....       2

                   N        S            F(S)
                   1    0.000E+00    1.000E+00
                   2    4.000E+08    1.000E+00

      FUNCTION ID .........       2     NUMBER OF POINTS ....       2

                   N        S            F(S)
                   1    0.000E+00    0.000E+00
                   2    4.000E+08    0.000E+00



    N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

               NODE SET FLAG      DIRECTION
                     3                X
                     2                X
                     2                Y



               C O N T A C T   S U R F A C E S

SURFACE  SURFACE 1  SURFACE 2  PENALTY    COEFFICIENT  PENETRATION   TENSION
NUMBER     FLAG       FLAG     FACTOR     OF FRICTION  MULTIPLIER    RELEASE
   1         4          5     0.000E+00   0.000E+00    2.000E-02   1.000E+40
   2         7          6     0.000E+00   0.000E+00    2.000E-02   1.000E+40
```

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```
     3         9             8   0.000E+00    0.000E+00    2.000E-02    1.000E+40
     4        10            11   0.000E+00    0.000E+00    2.000E-02    1.000E+40



P R E S S U R E   B O U N D A R Y   C O N D T I O N S

           SURFACE        FUNCTION      SCALE
            FLAG           NUMBER       FACTOR
              1               1       1.271E+07
             22               1       1.500E+07



               E N D   O F   D A T A   I N P U T   P H A S E
                        3.115E-01 CPU SECONDS USED
                              122 WORDS ALLOCATED



       E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                        1.842E-02 CPU SECONDS USED
                             1371 WORDS ALLOCATED



         V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                    NODAL           ELEMENT         GLOBAL
```

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```
                -----          -------        ------
                DISPLX         SIGXX          FX
                DISPLY         SIGYY          FY
                RESIDX         SIGZZ          RX
                RESIDY         TAUXY          RY
                RESID          VONMISES       ITER
                               EFFMOD         RMAG
                               EQCS


      **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****



  STEP      TIME        TIME      DAMPING     APPLIED    RESIDUAL    PERCENT    TOTAL
                        STEP      FACTOR     LOAD NORM   LOAD NORM  IMBALANCE   STEPS
    100   7.892E+05   7.891E+05   9.496E-01   9.083E+07   1.708E+07     18.80      100
    200   7.892E+05   7.890E+05   7.382E-01   9.083E+07   1.316E+08    144.85      200
    300   7.892E+05   7.890E+05   7.872E-01   9.083E+07   3.323E+07     36.59      300
    400   7.892E+05   7.890E+05   7.611E-01   9.083E+07   1.137E+08    125.24      400
    500   7.892E+05   7.890E+05   8.404E-01   9.083E+07   2.162E+08    238.04      500
    600   7.892E+05   7.887E+05   7.572E-01   9.083E+07   8.273E+08    910.88      600
    700   7.892E+05   7.889E+05   6.245E-01   9.083E+07   1.849E+08    203.56      700
    800   7.892E+05   7.888E+05   8.085E-01   9.083E+07   6.650E+08    732.20      800
    900   7.892E+05   7.889E+05   8.925E-01   9.083E+07   5.447E+08    599.68      900
   1000   7.892E+05   7.889E+05   9.381E-01   9.083E+07   1.505E+08    165.71     1000
   1100   7.892E+05   7.889E+05   7.677E-01   9.083E+07   2.680E+08    295.05     1100
   1200   7.892E+05   7.889E+05   7.455E-01   9.083E+07   1.897E+08    208.91     1200
   1300   7.892E+05   7.889E+05   7.410E-01   9.083E+07   6.771E+07     74.54     1300
   1400   7.892E+05   7.889E+05   7.446E-01   9.083E+07   4.130E+08    454.75     1400
   1500   7.892E+05   7.889E+05   8.282E-01   9.083E+07   1.724E+08    189.78     1500
   1600   7.892E+05   7.889E+05   8.642E-01   9.083E+07   1.126E+08    123.93     1600
   1700   7.892E+05   7.889E+05   8.877E-01   9.083E+07   8.724E+07     96.06     1700
   1800   7.892E+05   7.889E+05   8.863E-01   9.083E+07   5.421E+07     59.68     1800
   1900   7.892E+05   7.889E+05   9.563E-01   9.083E+07   4.408E+07     48.53     1900
```

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2000	7.892E+05	7.889E+05	8.281E-01	9.083E+07	3.090E+08	340.22	2000
2100	7.892E+05	7.889E+05	7.793E-01	9.083E+07	3.142E+08	345.98	2100
2200	7.892E+05	7.889E+05	9.330E-01	9.083E+07	1.573E+08	173.22	2200
2300	7.892E+05	7.889E+05	9.632E-01	9.083E+07	1.246E+08	137.16	2300
2400	7.892E+05	7.889E+05	8.102E-01	9.083E+07	5.552E+08	611.26	2400
2500	7.892E+05	7.889E+05	8.127E-01	9.083E+07	6.096E+07	67.12	2500
2600	7.892E+05	7.889E+05	9.308E-01	9.083E+07	9.725E+07	107.07	2600
2700	7.892E+05	7.889E+05	8.458E-01	9.083E+07	2.583E+07	28.44	2700
2800	7.892E+05	7.889E+05	8.864E-01	9.083E+07	5.236E+07	57.65	2800
2900	7.892E+05	7.889E+05	8.566E-01	9.083E+07	1.219E+08	134.25	2900
3000	7.892E+05	7.889E+05	8.833E-01	9.083E+07	2.041E+08	224.72	3000
3100	7.892E+05	7.889E+05	6.383E-01	9.083E+07	1.155E+08	127.14	3100
3200	7.892E+05	7.889E+05	7.130E-01	9.083E+07	1.046E+08	115.12	3200
3300	7.892E+05	7.889E+05	7.384E-01	9.083E+07	7.437E+07	81.88	3300
3400	7.892E+05	7.889E+05	7.296E-01	9.083E+07	2.562E+08	282.04	3400
3500	7.892E+05	7.889E+05	8.640E-01	9.083E+07	2.146E+07	23.63	3500
3600	7.892E+05	7.889E+05	6.572E-01	9.083E+07	6.806E+07	74.94	3600
3700	7.892E+05	7.889E+05	8.403E-01	9.083E+07	3.370E+07	37.11	3700
3800	7.892E+05	7.889E+05	8.576E-01	9.083E+07	1.804E+07	19.86	3800
3900	7.892E+05	7.889E+05	7.356E-01	9.083E+07	1.802E+08	198.39	3900
4000	7.892E+05	7.889E+05	9.385E-01	9.083E+07	2.837E+07	31.23	4000
4100	7.892E+05	7.889E+05	9.260E-01	9.083E+07	3.128E+07	34.44	4100
4200	7.892E+05	7.889E+05	8.350E-01	9.083E+07	4.176E+07	45.97	4200
4300	7.892E+05	7.889E+05	5.458E-01	9.083E+07	2.046E+07	22.52	4300
4400	7.892E+05	7.889E+05	8.064E-01	9.083E+07	1.126E+08	123.96	4400
4500	7.892E+05	7.889E+05	9.752E-01	9.083E+07	2.364E+08	260.27	4500
4600	7.892E+05	7.889E+05	9.169E-01	9.083E+07	2.450E+08	269.75	4600
4700	7.892E+05	7.889E+05	8.759E-01	9.083E+07	1.325E+08	145.92	4700
4800	7.892E+05	7.889E+05	7.521E-01	9.083E+07	1.976E+07	21.76	4800
4900	7.892E+05	7.889E+05	9.122E-01	9.083E+07	1.054E+08	116.06	4900
5000	7.892E+05	7.889E+05	9.052E-01	9.083E+07	3.673E+07	40.44	5000
5100	7.892E+05	7.889E+05	7.519E-01	9.083E+07	5.168E+07	56.90	5100
5200	7.892E+05	7.889E+05	9.037E-01	9.083E+07	4.929E+07	54.26	5200
5300	7.892E+05	7.889E+05	7.488E-01	9.083E+07	5.667E+07	62.39	5300
5400	7.892E+05	7.889E+05	9.259E-01	9.083E+07	6.870E+07	75.64	5400
5500	7.892E+05	7.889E+05	5.770E-01	9.083E+07	7.470E+07	82.24	5500

5600	7.892E+05	7.889E+05	8.530E-01	9.083E+07	3.375E+07	37.16	5600
5700	7.892E+05	7.889E+05	7.389E-01	9.083E+07	3.084E+07	33.95	5700
5800	7.892E+05	7.889E+05	6.724E-01	9.083E+07	1.001E+08	110.19	5800
5900	7.892E+05	7.889E+05	8.472E-01	9.083E+07	9.493E+07	104.52	5900
6000	7.892E+05	7.889E+05	5.610E-01	9.083E+07	1.095E+08	120.59	6000
6100	7.892E+05	7.889E+05	6.859E-01	9.083E+07	2.700E+07	29.72	6100
6200	7.892E+05	7.889E+05	5.691E-01	9.083E+07	8.923E+07	98.24	6200
6300	7.892E+05	7.889E+05	8.473E-01	9.083E+07	4.251E+07	46.80	6300
6400	7.892E+05	7.889E+05	7.347E-01	9.083E+07	3.898E+07	42.92	6400
6500	7.892E+05	7.889E+05	9.090E-01	9.083E+07	4.990E+06	5.49	6500
6600	7.892E+05	7.889E+05	9.859E-01	9.083E+07	2.663E+06	2.93	6600
6700	7.892E+05	7.889E+05	8.224E-01	9.083E+07	4.596E+07	50.60	6700
6800	7.892E+05	7.889E+05	8.468E-01	9.083E+07	2.283E+06	2.51	6800
6900	7.892E+05	7.889E+05	7.748E-01	9.083E+07	8.003E+06	8.81	6900
7000	7.892E+05	7.889E+05	9.322E-01	9.083E+07	2.467E+06	2.72	7000
7100	7.892E+05	7.889E+05	8.795E-01	9.083E+07	4.895E+06	5.39	7100
7200	7.892E+05	7.889E+05	8.447E-01	9.083E+07	3.974E+06	4.38	7200
7300	7.892E+05	7.889E+05	9.550E-01	9.083E+07	5.008E+07	55.14	7300
7400	7.892E+05	7.889E+05	9.381E-01	9.083E+07	7.184E+07	79.10	7400
7500	7.892E+05	7.889E+05	9.148E-01	9.083E+07	4.658E+07	51.29	7500
7600	7.892E+05	7.889E+05	7.398E-01	9.083E+07	5.610E+07	61.76	7600
7700	7.892E+05	7.889E+05	6.576E-01	9.083E+07	9.205E+07	101.34	7700
7800	7.892E+05	7.889E+05	7.112E-01	9.083E+07	4.452E+07	49.02	7800
7900	7.892E+05	7.889E+05	8.244E-01	9.083E+07	2.004E+07	22.07	7900
8000	7.892E+05	7.889E+05	8.391E-01	9.083E+07	1.844E+07	20.30	8000
8100	7.892E+05	7.889E+05	7.847E-01	9.083E+07	5.666E+06	6.24	8100
8200	7.892E+05	7.889E+05	7.990E-01	9.083E+07	5.306E+06	5.84	8200
8300	7.892E+05	7.889E+05	9.300E-01	9.083E+07	9.194E+07	101.22	8300
8400	7.892E+05	7.889E+05	8.374E-01	9.083E+07	3.587E+07	39.49	8400
8500	7.892E+05	7.889E+05	8.056E-01	9.083E+07	3.819E+07	42.05	8500
8600	7.892E+05	7.889E+05	6.841E-01	9.083E+07	2.450E+07	26.97	8600
8700	7.892E+05	7.889E+05	7.206E-01	9.083E+07	4.842E+07	53.31	8700
8800	7.892E+05	7.889E+05	6.674E-01	9.083E+07	9.391E+06	10.34	8800
8900	7.892E+05	7.889E+05	9.310E-01	9.083E+07	3.436E+07	37.83	8900
9000	7.892E+05	7.889E+05	7.770E-01	9.083E+07	1.301E+07	14.33	9000
9100	7.892E+05	7.889E+05	9.351E-01	9.083E+07	2.633E+07	28.99	9100

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9200	7.892E+05	7.889E+05	6.985E-01	9.083E+07	1.036E+07	11.41	9200
9300	7.892E+05	7.889E+05	9.193E-01	9.083E+07	1.268E+07	13.96	9300
9400	7.892E+05	7.889E+05	6.557E-01	9.083E+07	8.983E+06	9.89	9400
9500	7.892E+05	7.889E+05	8.871E-01	9.083E+07	1.363E+07	15.01	9500
9600	7.892E+05	7.889E+05	8.909E-01	9.083E+07	2.324E+07	25.59	9600
9700	7.892E+05	7.889E+05	7.183E-01	9.083E+07	1.390E+07	15.31	9700
9800	7.892E+05	7.889E+05	7.473E-01	9.083E+07	7.348E+06	8.09	9800
9900	7.892E+05	7.889E+05	7.484E-01	9.083E+07	3.596E+07	39.59	9900
10000	7.892E+05	7.889E+05	8.870E-01	9.083E+07	1.387E+07	15.27	10000
10100	7.892E+05	7.889E+05	8.053E-01	9.083E+07	2.061E+07	22.70	10100
10200	7.892E+05	7.889E+05	8.833E-01	9.083E+07	8.896E+06	9.79	10200
10300	7.892E+05	7.889E+05	7.242E-01	9.083E+07	8.363E+07	92.08	10300
10400	7.892E+05	7.889E+05	9.380E-01	9.083E+07	5.584E+07	61.48	10400
10500	7.892E+05	7.889E+05	7.688E-01	9.083E+07	3.435E+07	37.82	10500
10600	7.892E+05	7.889E+05	7.546E-01	9.083E+07	1.353E+07	14.89	10600
10700	7.892E+05	7.889E+05	6.794E-01	9.083E+07	7.498E+06	8.26	10700
10800	7.892E+05	7.889E+05	7.166E-01	9.083E+07	1.378E+07	15.17	10800
10900	7.892E+05	7.889E+05	9.112E-01	9.083E+07	1.196E+07	13.17	10900
11000	7.892E+05	7.889E+05	8.876E-01	9.083E+07	2.607E+07	28.70	11000
11100	7.892E+05	7.889E+05	6.906E-01	9.083E+07	1.601E+07	17.63	11100
11200	7.892E+05	7.889E+05	8.159E-01	9.083E+07	2.284E+07	25.15	11200
11300	7.892E+05	7.889E+05	7.582E-01	9.083E+07	8.023E+06	8.83	11300
11400	7.892E+05	7.889E+05	7.195E-01	9.083E+07	2.220E+07	24.44	11400
11500	7.892E+05	7.889E+05	8.598E-01	9.083E+07	1.921E+07	21.15	11500
11600	7.892E+05	7.889E+05	7.841E-01	9.083E+07	8.318E+06	9.16	11600
11700	7.892E+05	7.889E+05	8.352E-01	9.083E+07	3.224E+06	3.55	11700
11800	7.892E+05	7.889E+05	8.361E-01	9.083E+07	3.649E+06	4.02	11800
11900	7.892E+05	7.889E+05	9.137E-01	9.083E+07	1.483E+07	16.33	11900
12000	7.892E+05	7.889E+05	8.267E-01	9.083E+07	1.797E+07	19.79	12000
12100	7.892E+05	7.889E+05	8.912E-01	9.083E+07	2.847E+06	3.13	12100
12200	7.892E+05	7.889E+05	7.123E-01	9.083E+07	1.726E+07	19.01	12200
12300	7.892E+05	7.889E+05	7.446E-01	9.083E+07	1.777E+07	19.56	12300
12400	7.892E+05	7.889E+05	8.899E-01	9.083E+07	2.598E+07	28.60	12400
12500	7.892E+05	7.889E+05	8.368E-01	9.083E+07	1.203E+07	13.25	12500
12600	7.892E+05	7.889E+05	7.624E-01	9.083E+07	1.047E+07	11.53	12600
12700	7.892E+05	7.889E+05	7.442E-01	9.083E+07	9.446E+06	10.40	12700

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12800	7.892E+05	7.889E+05	8.032E-01	9.083E+07	5.460E+06	6.01	12800
12900	7.892E+05	7.889E+05	9.003E-01	9.083E+07	2.343E+06	2.58	12900
13000	7.892E+05	7.889E+05	8.050E-01	9.083E+07	5.004E+06	5.51	13000
13100	7.892E+05	7.889E+05	8.690E-01	9.083E+07	1.751E+07	19.28	13100
13200	7.892E+05	7.889E+05	8.231E-01	9.083E+07	1.313E+07	14.46	13200
13300	7.892E+05	7.889E+05	7.445E-01	9.083E+07	1.549E+07	17.05	13300
13400	7.892E+05	7.889E+05	9.036E-01	9.083E+07	4.740E+06	5.22	13400
13500	7.892E+05	7.889E+05	6.748E-01	9.083E+07	5.883E+06	6.48	13500
13600	7.892E+05	7.889E+05	9.081E-01	9.083E+07	2.978E+06	3.28	13600
13700	7.892E+05	7.889E+05	6.067E-01	9.083E+07	1.395E+07	15.36	13700
13800	7.892E+05	7.889E+05	8.938E-01	9.083E+07	2.078E+07	22.88	13800
13900	7.892E+05	7.889E+05	7.912E-01	9.083E+07	5.464E+06	6.02	13900
14000	7.892E+05	7.889E+05	7.758E-01	9.083E+07	8.073E+06	8.89	14000
14100	7.892E+05	7.889E+05	8.458E-01	9.083E+07	1.425E+07	15.69	14100
14200	7.892E+05	7.889E+05	8.061E-01	9.083E+07	6.260E+06	6.89	14200
14300	7.892E+05	7.889E+05	9.049E-01	9.083E+07	2.142E+07	23.59	14300
14400	7.892E+05	7.889E+05	9.328E-01	9.083E+07	1.112E+07	12.24	14400
14500	7.892E+05	7.889E+05	8.180E-01	9.083E+07	5.746E+06	6.33	14500
14600	7.892E+05	7.889E+05	9.568E-01	9.083E+07	2.714E+06	2.99	14600
14700	7.892E+05	7.889E+05	7.089E-01	9.083E+07	2.945E+06	3.24	14700
14800	7.892E+05	7.889E+05	7.606E-01	9.083E+07	7.438E+06	8.19	14800
14900	7.892E+05	7.889E+05	7.488E-01	9.083E+07	1.185E+07	13.04	14900
15000	7.892E+05	7.889E+05	6.255E-01	9.083E+07	1.260E+07	13.88	15000
15100	7.892E+05	7.889E+05	6.687E-01	9.083E+07	3.722E+06	4.10	15100
15200	7.892E+05	7.889E+05	7.145E-01	9.083E+07	5.951E+06	6.55	15200
15300	7.892E+05	7.889E+05	8.886E-01	9.083E+07	1.867E+06	2.06	15300
15400	7.892E+05	7.889E+05	8.228E-01	9.083E+07	7.314E+06	8.05	15400
15500	7.892E+05	7.889E+05	8.422E-01	9.083E+07	5.546E+06	6.11	15500
15600	7.892E+05	7.889E+05	6.623E-01	9.083E+07	3.050E+06	3.36	15600
15700	7.892E+05	7.889E+05	7.851E-01	9.083E+07	8.714E+06	9.59	15700
15800	7.892E+05	7.889E+05	8.404E-01	9.083E+07	3.011E+06	3.32	15800
15900	7.892E+05	7.889E+05	7.586E-01	9.083E+07	2.434E+06	2.68	15900
16000	7.892E+05	7.889E+05	8.595E-01	9.083E+07	1.098E+07	12.09	16000
16100	7.892E+05	7.889E+05	8.648E-01	9.083E+07	2.179E+06	2.40	16100
16200	7.892E+05	7.889E+05	8.209E-01	9.083E+07	2.750E+06	3.03	16200
16300	7.892E+05	7.889E+05	7.316E-01	9.083E+07	5.180E+06	5.70	16300

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16400	7.892E+05	7.889E+05	7.830E-01	9.083E+07	4.477E+06	4.93	16400
16500	7.892E+05	7.889E+05	8.004E-01	9.083E+07	2.570E+06	2.83	16500
16600	7.892E+05	7.889E+05	9.393E-01	9.083E+07	2.219E+06	2.44	16600
16700	7.892E+05	7.889E+05	7.633E-01	9.083E+07	1.886E+06	2.08	16700
16800	7.892E+05	7.889E+05	7.570E-01	9.083E+07	7.990E+06	8.80	16800
16900	7.892E+05	7.889E+05	8.065E-01	9.083E+07	1.509E+06	1.66	16900
17000	7.892E+05	7.889E+05	7.234E-01	9.083E+07	1.089E+07	11.99	17000
17100	7.892E+05	7.889E+05	6.307E-01	9.083E+07	4.697E+06	5.17	17100
17200	7.892E+05	7.889E+05	7.848E-01	9.083E+07	6.717E+06	7.40	17200
17300	7.892E+05	7.889E+05	8.144E-01	9.083E+07	1.611E+06	1.77	17300
17400	7.892E+05	7.889E+05	7.578E-01	9.083E+07	1.113E+07	12.26	17400
17500	7.892E+05	7.889E+05	8.731E-01	9.083E+07	1.352E+06	1.49	17500
17600	7.892E+05	7.889E+05	8.207E-01	9.083E+07	3.951E+06	4.35	17600
17700	7.892E+05	7.889E+05	9.155E-01	9.083E+07	1.866E+06	2.05	17700
17800	7.892E+05	7.889E+05	8.251E-01	9.083E+07	5.377E+06	5.92	17800
17900	7.892E+05	7.889E+05	8.279E-01	9.083E+07	7.221E+06	7.95	17900
18000	7.892E+05	7.889E+05	7.898E-01	9.083E+07	4.448E+06	4.90	18000
18100	7.892E+05	7.889E+05	4.791E-01	9.083E+07	1.010E+07	11.12	18100
18200	7.892E+05	7.889E+05	8.102E-01	9.083E+07	4.823E+06	5.31	18200
18300	7.892E+05	7.889E+05	7.292E-01	9.083E+07	1.952E+07	21.49	18300
18400	7.892E+05	7.889E+05	8.511E-01	9.083E+07	3.138E+06	3.45	18400
18500	7.892E+05	7.889E+05	8.483E-01	9.083E+07	2.569E+06	2.83	18500
18600	7.892E+05	7.889E+05	8.243E-01	9.083E+07	2.967E+06	3.27	18600
18700	7.892E+05	7.889E+05	6.716E-01	9.083E+07	8.098E+06	8.92	18700
18800	7.892E+05	7.889E+05	9.575E-01	9.083E+07	1.422E+06	1.57	18800
18900	7.892E+05	7.889E+05	8.245E-01	9.083E+07	9.341E+06	10.28	18900
19000	7.892E+05	7.889E+05	8.692E-01	9.083E+07	2.855E+06	3.14	19000
19100	7.892E+05	7.889E+05	8.452E-01	9.083E+07	2.254E+06	2.48	19100
19200	7.892E+05	7.889E+05	7.585E-01	9.083E+07	5.123E+06	5.64	19200
19300	7.892E+05	7.889E+05	6.921E-01	9.083E+07	2.103E+06	2.32	19300
19400	7.892E+05	7.889E+05	8.904E-01	9.083E+07	2.961E+06	3.26	19400
19500	7.892E+05	7.889E+05	7.408E-01	9.083E+07	9.133E+06	10.06	19500
19600	7.892E+05	7.889E+05	7.153E-01	9.083E+07	9.402E+06	10.35	19600
19700	7.892E+05	7.889E+05	8.622E-01	9.083E+07	5.189E+06	5.71	19700
19800	7.892E+05	7.889E+05	7.971E-01	9.083E+07	3.954E+06	4.35	19800
19900	7.892E+05	7.889E+05	8.516E-01	9.083E+07	6.065E+06	6.68	19900

```
**** PLOT TAPE WRITTEN AT TIME = 7.892E+05   STEP NUMBER      1 ****
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```
SANTOS, VERSION 2.0.0    ,RUN ON 03/11/96 ,AT 13:38:17
 BENCHMARK II ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/9/95)

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER   400, TIME = 3.157E+08
NUMBER OF ITERATIONS =      2217, TOTAL NUMBER OF ITERATIONS =   1760666
FINAL CONVERGENCE TOLERANCE = 4.849E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.252E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-3.097E+03
SUM OF REACTION FORCES IN X-DIRECTION = 2.452E+03
SUM OF REACTION FORCES IN Y-DIRECTION =-8.395E+06
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 3.157E+08  STEP NUMBER   400 ****




          400 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


              E N D  O F  S O L U T I O N  P H A S E
                   5.148E+04 CPU SECONDS USED
                        1371 WORDS ALLOCATED
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APPENDIX S

Input/Output Data For Problem 19 – Heated WIPP Benchmark II Problem

The following three sections present the input data, the initial stress subroutine, and the formatted output, respectively, for the Heated WIPP Benchmark II verification problem.

FASTQ and SANTOS Input Data For The Heated WIPP Benchmark II Problem

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the Benchmark II heated drift problem.

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TITLE
          HEATED BENCHMARK II MESH (Structural - 1/17/95)
POINT     1       0.0000000E+00       -6.4742999E+02
POINT     3       2.2900000E+00       -6.4742999E+02
POINT     6       2.2900000E+00       -6.5200000E+02
POINT     7       0.0000000E+00       -6.5200000E+02
POINT   109       2.2900000E+00       -6.4992999E+02
POINT   110       2.2850001E+00       -6.5020001E+02
POINT    11       0.0000000E+00       -6.4696997E+02
POINT    12       2.2900000E+00       -6.4696997E+02
POINT    13       3.2500000E+00       -6.4696997E+02
POINT    14       3.2500000E+00       -6.4742999E+02
POINT   115       3.2500000E+00       -6.4992999E+02
POINT   116       3.2500000E+00       -6.5020001E+02
POINT    17       3.2500000E+00       -6.5200000E+02
POINT    18       3.2500000E+00       -6.5291998E+02
POINT    19       2.2900000E+00       -6.5291998E+02
POINT    20       0.0000000E+00       -6.5291998E+02
POINT   121       2.2900000E+00       -6.5020001E+02
POINT   122       3.2500000E+00       -6.5020001E+02
POINT   123       0.0000000E+00       -6.4297998E+02
POINT   124       0.0000000E+00       -6.4297998E+02
POINT   126       9.2500000E+00       -6.4297998E+02
POINT   127       9.2500000E+00       -6.4992999E+02
POINT   128       9.2500000E+00       -6.5020001E+02
POINT   129       9.2500000E+00       -6.5020001E+02
POINT    30       0.0000000E+00       -6.5500000E+02
POINT    31       0.0000000E+00       -6.5683002E+02
POINT   132       2.2860001E+01       -6.4297998E+02
POINT    33       9.2500000E+00       -6.5683002E+02
POINT   134       2.2860001E+01       -6.4297998E+02
POINT   135       2.2860001E+01       -6.4992999E+02
POINT   136       2.2860001E+01       -6.5020001E+02
POINT   137       2.2860001E+01       -6.5020001E+02
POINT    38       0.0000000E+00       -6.6010999E+02
POINT    39       9.2500000E+00       -6.6010999E+02
POINT    40       2.2860001E+01       -6.6010999E+02
POINT    41       2.2860001E+01       -6.5683002E+02
POINT    46       0.0000000E+00       -5.9802002E+02
POINT    47       2.2860001E+01       -5.9802002E+02
POINT    48       0.0000000E+00       -6.0259003E+02
POINT    49       2.2860001E+01       -6.0259003E+02
POINT    50       0.0000000E+00       -6.1922998E+02
POINT    51       2.2860001E+01       -6.1922998E+02
POINT    52       0.0000000E+00       -6.2377002E+02
POINT    53       2.2860001E+01       -6.2377002E+02
POINT    54       0.0000000E+00       -6.3276001E+02
POINT    55       2.2860001E+01       -6.3276001E+02
POINT   156       0.0000000E+00       -6.3885999E+02
POINT   157       2.2860001E+01       -6.3885999E+02
POINT   158       0.0000000E+00       -6.3885999E+02
POINT   159       2.2860001E+01       -6.3885999E+02
POINT    60       0.0000000E+00       -6.4276001E+02
POINT    61       2.2860001E+01       -6.4276001E+02
```

Information Only

```
POINT    162       0.0000000E+00        -6.6102002E+02
POINT    163       2.2860001E+01        -6.6102002E+02
POINT    164       0.0000000E+00        -6.6102002E+02
POINT    165       2.2860001E+01        -6.6102002E+02
POINT    166       0.0000000E+00        -6.6909998E+02
POINT    167       2.2860001E+01        -6.6909998E+02
POINT    168       0.0000000E+00        -6.6909998E+02
POINT    169       2.2860001E+01        -6.6909998E+02
POINT     70       0.0000000E+00        -6.7960999E+02
POINT     71       2.2860001E+01        -6.7960999E+02
POINT     72       0.0000000E+00        -6.8233002E+02
POINT     73       2.2860001E+01        -6.8233002E+02
POINT     74       0.0000000E+00        -7.0365997E+02
POINT     75       2.2860001E+01        -7.0365997E+02
POINT     76       0.0000000E+00        -7.0677002E+02
POINT     77       2.2860001E+01        -7.0677002E+02
POINT    178       9.2500000E+00        -6.6102002E+02
LINE       2    STR      1      3      0      4    0.000000
LINE       5    STR    109      3      0      5    0.000000
LINE       6    STR    121    109      0      1    0.000000
LINE       7    STR      6    110      0      4    0.000000
LINE       8    STR      7      6      0      4    0.000000
LINE      10    STR      1     11      0      1    0.000000
LINEBC     1     10
LINE      11    STR     11     12      0      4    0.000000
LINE      13    STR     12     13      0      2    0.000000
LINE      14    STR     14     13      0      1    0.000000
LINE      15    STR      3     14      0      2    0.000000
LINE      16    STR    115     14      0      5    0.000000
LINE      17    STR    109    115      0      2    0.000000
LINE      19    STR    110    122      0      2    0.000000
SIDEBC     8     19
LINE      20    STR     17    122      0      4    0.000000
LINE      21    STR      6     17      0      2    0.000000
LINE      22    STR     18     17      0      2    0.000000
LINE      23    STR     19     18      0      2    0.000000
LINE      25    STR     20     19      0      4    0.000000
LINE      26    STR     20      7      0      2    0.000000
LINEBC     1     26
LINE      27    STR    121    116      0      2    0.000000
SIDEBC     9     27
LINE      28    STR     11    123      0      7    1.030000
LINEBC     1     28
LINE      29    STR    123    132      0     13    0.000000
SIDEBC    11     29
LINE      30    STR     13    126      0      7    1.100000
LINE      31    STR    127    126      0      6    1.050000
LINE      32    STR    115    127      0      7    1.050000
LINE      33    STR    116    128      0      7    1.050000
SIDEBC     9     33
LINE      34    STR    122    129      0      7    1.050000
SIDEBC     8     34
LINE      35    STR    123    126      0      6    1.150000
SIDEBC    10     35
```

Information Only

```
LINE      37   STR    20    30    0    3   1.050000
LINEBC     1    37
LINE      38   STR    30    31    0    3   0.000000
LINEBC     1    38
LINE      40   STR    18    33    0    7   1.100000
LINE      42   STR   126   132    0    7   1.050000
SIDEBC    10    42
LINE      43   STR   129    33    0    6   1.050000
LINE      44   STR   128   136    0    7   1.050000
SIDEBC     9    44
LINE      45   STR   129   136    0    7   1.050000
SIDEBC     8    45
LINE      46   STR   135   132    0    6   1.050000
LINEBC     1    46
LINE      47   STR   136   135    0    1   0.000000
LINEBC     1    47
LINE      48   STR   127   135    0    7   1.050000
LINE      49   STR    38    31    0    4   0.000000
LINEBC     1    49
LINE      50   STR    38    39    0    6   1.050000
LINE      51   STR    39    40    0    7   1.050000
LINE      52   STR   136    41    0    6   1.050000
LINEBC     1    52
LINE      53   STR    40    41    0    3   1.050000
LINEBC     1    53
LINE      54   STR    39    33    0    3   1.050000
LINE      58   STR   162    38    0    1   0.000000
LINEBC     1    58
LINE      59   STR   163    40    0    1   0.000000
LINEBC     1    59
LINE      60   STR   162   178    0    6   1.050000
SIDEBC    15    60
LINE      61   STR   178   163    0    7   1.050000
SIDEBC    15    61
LINE      62   STR   162   163    0   13   0.000000
SIDEBC    16    62
LINE      63   STR   162   166    0    4   1.200000
LINEBC     1    63
LINE      64   STR   163   167    0    4   1.200000
LINEBC     1    64
LINE      65   STR   166   167    0   13   0.000000
SIDEBC    19    65
LINE      66   STR   166   167    0   13   0.000000
SIDEBC    20    66
LINE      67   STR    70   166    0    3   0.000000
LINEBC     1    67
LINE      68   STR    71   167    0    3   0.000000
LINEBC     1    68
LINE      69   STR    70    71    0   13   0.000000
LINE      70   STR    72    70    0    2   0.000000
LINEBC     1    70
LINE      71   STR    73    71    0    2   0.000000
LINEBC     1    71
LINE      72   STR    72    73    0   13   0.000000
```

Information Only

```
LINE        73    STR     74     72      0      4     0.000000
LINEBC       1     73
LINE        74    STR     75     73      0      4     0.000000
LINEBC       1     74
LINE        75    STR     74     75      0     13     0.000000
LINE        76    STR     76     74      0      2     0.000000
LINEBC       1     76
LINE        77    STR     77     75      0      2     0.000000
LINEBC       1     77
LINE        78    STR     76     77      0     13     0.000000
SIDEBC      14     78
LINE        79    STR     46     47      0     13     0.000000
SIDEBC      13     79
LINE        80    STR     48     46      0      3     0.000000
LINEBC       1     80
LINE        81    STR     49     47      0      3     0.000000
LINEBC      12     81
LINE        82    STR     48     49      0     13     0.000000
LINE        83    STR     50     48      0      4     0.000000
LINEBC       1     83
LINE        84    STR     51     49      0      4     0.000000
LINEBC       1     84
LINE        85    STR     50     51      0     13     0.000000
LINE        86    STR     52     50      0      2     0.000000
LINEBC       1     86
LINE        87    STR     53     51      0      2     0.000000
LINEBC       1     87
LINE        88    STR     52     53      0     13     0.000000
LINE        89    STR     54     52      0      3     0.000000
LINEBC       1     89
LINE        90    STR     55     53      0      3     0.000000
LINEBC       1     90
LINE        91    STR     54     55      0     13     0.000000
LINE        92    STR    156     54      0      3     0.000000
LINEBC       1     92
LINE        93    STR    157     55      0      3     0.000000
LINEBC       1     93
LINE        94    STR    156    157      0     13     0.000000
SIDEBC      17     94
LINE        95    STR    156    157      0     13     0.000000
SIDEBC      18     95
LINE        96    STR     60    156      0      3     1.300000
LINEBC       1     96
LINE        97    STR     61    157      0      3     1.300000
LINEBC       1     97
LINE        98    STR     60     61      0     13     0.000000
LINE        99    STR    123     60      0      1     0.000000
LINEBC       1     99
LINE       100    STR    132     61      0      1     0.000000
LINEBC       1    100
SIDE         1     20     22
SIDE         2     25     23
SIDE         3     37     38     49
SIDE         4     11     13
```

Information Only

```
SIDE       5     2    15
SIDE       6    25    23
SIDE       7     8    21
SIDE       8    17    32    48
SIDE       9    27    33    44
SIDE      10    43    54
SIDE      11    53    52
SIDE      12    54    40
SIDE      13    60    61
SIDE      14    50    51
REGION     2     1   -10     5   -14     4
REGION     3     1   -26     6   -22     7
REGION     4     1     2     3   -50    12
REGION     5     1    10   -51    11   -45
REGION     6     1    -5   -15   -16   -17
REGION     7     1    -7   -19   -20   -21
REGION     8     4    -6     9   -47     8
REGION     9     1   -28   -11   -13   -30   -35
REGION    10     1   -32   -31   -30   -14   -16
REGION    11     1   -31   -48   -46   -42
REGION    12     1     1   -40   -43   -34
REGION    13     4   -58    13   -59    14
REGION    14     3   -63   -65   -64   -62
REGION    15     1   -67   -69   -68   -65
REGION    16     4   -70   -72   -71   -69
REGION    17     1   -73   -75   -74   -72
REGION    18     5   -76   -78   -77   -75
REGION    19     4   -80   -82   -81   -79
REGION    20     2   -83   -85   -84   -82
REGION    21     4   -86   -88   -87   -85
REGION    22     1   -89   -91   -90   -88
REGION    23     2   -92   -94   -93   -91
REGION    24     1   -96   -98   -97   -95
REGION    25     4   -99   -29  -100   -98
SCHEME     0
EXIT
```

Information Only

```
TITLE
  BENCHMARK II HEATED PROBLEM - SANTOS VERIFICATION (1/17/95)
RESIDUAL TOLERANCE = .50
MAXIMUM ITERATIONS = 10000
INTERMEDIATE PRINT = 100
MAXIMUM TOLERANCE = 5.
THERMAL STRESS, EXTERNAL
PLANE STRAIN
TIME STEP SCALE = .10
PREDICTOR SCALE FACTOR = 3
EFFECTIVE MODULUS = VARIABLE
INITIAL STRESS = USER
GRAVITY = 1 = 0. = -9.8066 = 0.
STEP CONTROL
 1000 3.157E8
END
PLOT TIME
 10 3.157E8
END
OUTPUT TIME
 10 3.157E8
END
PLOT NODAL DISPLACEMENT, REACTION, RESIDUAL
PLOT ELEMENT STRESS, VONMISES, TEMPERATURE, EFFMOD
PLOT STATE EQCS
NO DISPLACEMENT X, 1
NO DISPLACEMENT X, 12
NO DISPLACEMENT Y, 12
FUNCTION = 1
0. 1.
4.E8 1.
END
FUNCTION = 2
299.,-.02
350.,1.
END
FUNCTION = 3
0. 0.
4.E8 0.
END
PRESSURE, 13, 1, 12.71E6
PRESSURE, 14, 1, 15.01E6
CONTACT SURFACE, 8, 9, 0., .02, 1.E40
CONTACT SURFACE, 11, 10, 0., .02, 1.E40
CONTACT SURFACE, 15, 16, 0., .02, 1.E40
CONTACT SURFACE, 18, 17, 0., .02, 1.E40
MATERIAL, 1, POWER LAW CREEP, 2167., 2, 2.25E-3
TWO MU = 19.84E9
BULK MODULUS = 16.53E9
CREEP CONSTANT = 5.79E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 6039.
END
MATERIAL, 2, POWER LAW CREEP, 2167., 2, 2.E-3
```

Information Only

```
TWO MU = 19.84E9
BULK MODULUS = 16.53E9
CREEP CONSTANT = 1.74E-35
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 6039.
END
MATERIAL, 3, POWER LAW CREEP, 2167., 2, 2.135E-3
TWO MU = 21.2E9
BULK MODULUS = 17.66E9
CREEP CONSTANT = 5.21E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 6039.
END
MATERIAL, 4, ELASTIC, 2167., 2, 1.E-3
YOUNGS MODULUS = 72.4E9
POISSONS RATIO = .33
END
MATERIAL, 5, ELASTIC, 2167., 2, 1.2E-3
YOUNGS MODULUS = 72.4E9
POISSONS RATIO = .33
END
EXIT
```

Information Only

Initial Stress Subroutine For The Heated WIPP Benchmark II Problem

This section presents a listing of the INITST subroutine that was used in SANTOS to specify the initial stresses for the Benchmark II heated drift analysis.

Information Only

```
      SUBROUTINE INITST( SIG,COORD,LINK,DATMAT,KONMAT,SCREL )
C
C
*****************************************************************************
C
C   DESCRIPTION:
C     THIS ROUTINE PROVIDES AN INITIAL STRESS STATE TO SANTOS
C
C   FORMAL PARAMETERS:
C     SIG       REAL          ELEMENT STRESS ARRAY WHICH MUST BE RETURNED
C                             WITH THE REQUIRED STRESS VALUES
C     COORD     REAL          GLOBAL NODAL COORDINATE ARRAY
C     LINK      INTEGER       CONNECTIVITY ARRAY
C     DATMAT    REAL          MATERIAL PROPERTIES ARRAY
C     KONMAT    INTEGER       MATERIAL PROPERTIES INTEGER ARRAY
C
C   CALLED BY: INIT
C
C
*****************************************************************************
C
      INCLUDE 'params.blk'
      INCLUDE 'psize.blk'
      INCLUDE 'contrl.blk'
      INCLUDE 'bsize.blk'
      INCLUDE 'timer.blk'
C
      DIMENSION LINK(NELNS,NUMEL),KONMAT(10,NEMBLK),COORD(NNOD,NSPC),
     *          SIG(NSYMM,NUMEL),DATMAT(MCONS,*),SCREL(NEBLK,*)
C
      DO 1000 I = 1,NEMBLK
         MATID = KONMAT(1,I)
         MKIND = KONMAT(2,I)
         ISTRT = KONMAT(3,I)
         IEND = KONMAT(4,I)
            DO 500 J = ISTRT,IEND
               II = LINK( 1,J )
               JJ = LINK( 2,J )
               KK = LINK( 3,J )
               LL = LINK( 4,J )
               ZAVG = 0.25 * ( COORD(II,2) + COORD(JJ,2) + COORD(KK,2) +
     *                 COORD(LL,2) )
               STRESS = 21252. * ( ZAVG )
               SIG(1,J) = STRESS
               SIG(2,J) = STRESS
               SIG(3,J) = STRESS
               SIG(4,J) = 0.0
  500       CONTINUE
 1000 CONTINUE
      RETURN
      END
```

Information Only

SANTOS Output For The Heated WIPP Benchmark II Problem

The following section presents a portion of the SANTOS printed output for the Benchmark II heated drift analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

```
 SSSSSS   AAAAA   N    NN  TTTTTT   OOOOO   SSSSSS
SS       AA   AA  NN   NN    TT    OO   OO SS
SS       AA   AA  NNN  NN    TT    OO   OO SS
 SSSSS   AAAAAAA  NN N NN    TT    OO   OO  SSSSS
     SS  AA   AA  NN  NNN    TT    OO   OO      SS
     SS  AA   AA  NN   NN    TT    OO   OO      SS
SSSSSS   AA   AA  NN    N    TT     OOOOO  SSSSSS




                  VERSION 2.0.0
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                 PROGRAMMED BY:

                CHARLES M. STONE
           ENGINEERING SCIENCES CENTER
          SANDIA NATIONAL LABORATORIES
          ALBUQUERQUE, NEW MEXICO 87185

            DERIVED FROM PRONTO2D BY
      LEE M. TAYLOR AND DENNIS P. FLANAGAN



           RUN ON 03/06/96 AT 15:45:32
         RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

```
                              INPUT STREAM IMAGES
LINE -------------------------------------------------------------------------------
  1: TITLE
  2:   BENCHMARK II HEATED PROBLEM - SANTOS VERIFICATION (1/17/95)
  3: RESIDUAL TOLERANCE = .50
  4: MAXIMUM ITERATIONS = 10000
  5: INTERMEDIATE PRINT = 100
  6: MAXIMUM TOLERANCE = 5.
  7: THERMAL STRESS, EXTERNAL
  8: PLANE STRAIN
  9: TIME STEP SCALE = .10
 10: PREDICTOR SCALE FACTOR = 3
 11: EFFECTIVE MODULUS = VARIABLE
 12: INITIAL STRESS = USER
 13: GRAVITY = 1 = 0. = -9.8066 = 0.
 14: STEP CONTROL
 15:  1000 3.157E8
 16: END
 17: PLOT TIME
 18:  10 3.157E8
 19: END
 20: OUTPUT TIME
 21:  10 3.157E8
 22: END
 23: PLOT NODAL DISPLACEMENT, REACTION, RESIDUAL
 24: PLOT ELEMENT STRESS, VONMISES, TEMPERATURE, EFFMOD
 25: PLOT STATE EQCS
 26: NO DISPLACEMENT X, 1
 27: NO DISPLACEMENT X, 12
 28: NO DISPLACEMENT Y, 12
 29: FUNCTION = 1
 30: 0. 1.
 31: 4.E8 1.
 32: END
 33: FUNCTION = 2
 34: 299.,-.02
```

Information Only

```
350.,1.
END
FUNCTION = 3
0. 0.
4.E8 0.
END
PRESSURE, 13, 1, 12.71E6
PRESSURE, 14, 1, 15.01E6
CONTACT SURFACE, 8, 9, 0., .02, 1.E40
CONTACT SURFACE, 11, 10, 0., .02, 1.E40
CONTACT SURFACE, 15, 16, 0., .02, 1.E40
CONTACT SURFACE, 18, 17, 0., .02, 1.E40
MATERIAL, 1, POWER LAW CREEP, 2167., 2, 2.25E-3
TWO MU = 19.84E9
BULK MODULUS = 16.53E9
CREEP CONSTANT = 5.79E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 6039.
END
MATERIAL, 2, POWER LAW CREEP, 2167., 2, 2.E-3
TWO MU = 19.84E9
BULK MODULUS = 16.53E9
CREEP CONSTANT = 1.74E-35
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 6039.
END
MATERIAL, 3, POWER LAW CREEP, 2167., 2, 2.135E-3
TWO MU = 21.2E9
BULK MODULUS = 17.66E9
CREEP CONSTANT = 5.21E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 6039.
END
MATERIAL, 4, ELASTIC, 2167., 2, 1.E-3
YOUNGS MODULUS = 72.4E9
POISSONS RATIO = .33
```

Information Only

```
71: END
72: MATERIAL, 5, ELASTIC, 2167., 2, 1.2E-3
73: YOUNGS MODULUS = 72.4E9
74: POISSONS RATIO = .33
75: END
76: EXIT
    ---------------------------------------------------------------------------
```

Information Only

```
                P R O B L E M   T I T L E

  BENCHMARK II HEATED PROBLEM - SANTOS VERIFICATION (1/17/95)



                  P R O B L E M   D E F I N I T I O N

  NUMBER OF ELEMENTS .........................         798
  NUMBER OF NODES ............................         926
  NUMBER OF MATERIALS ........................           5
  NUMBER OF FUNCTIONS ........................           3
  NUMBER OF CONTACT SURFACES .................           4
  NUMBER OF RIGID SURFACES ...................           0
  NUMBER OF MATERIAL POINTS MONITORED ........           0
  ANALYSIS TYPE ..............................  PLANE STRAIN
  GLOBAL CONVERGENCE MEASURE .................
  RESIDUAL TOLERANCE .........................   5.000E-01
  MAXIMUM NUMBER OF ITERATIONS ...............       10000
  ITERATIONS FOR INTERMEDIATE PRINT ..........         100
  MAXIMUM RESIDUAL TOLERANCE .................   5.000E+00
  PREDICTOR SCALE FACTOR FUNCTION ............           3
  MINIMUM DAMPING FACTOR .....................   2.000E-01
  EFFECTIVE MODULUS STATUS ...................  VARIABLE
  THERMAL STRESS ANALYSIS PERFORMED ..........  EXTERNAL
     THERMAL FORCE MAGNITUDE .................   0.000E+00
  INITIAL STRESS DISTRIBUTION APPLIED ........
  GRAVITY LOADS APPLIED ......................
  SCALE FACTOR APPLIED TO TIME STEP ..........   1.000E-01
  STRAIN SOFTENING SCALE FACTOR ..............   1.000E+00
  HOURGLASS STIFFNESS FACTOR .................   5.000E-02
  HOURGLASS VISCOSITY FACTOR .................   0.000E+00
```

Information Only

Information Only

```
          L O A D   S T E P   D E F I N I T I O N S

  TIME           NO. OF STEPS          TIME
0.000E+00           1000            3.157E+08



          P R I N T E D   O U T P U T   F R E Q U E N C Y

  TIME      STEPS BETWEEN PRINTS         TIME
0.000E+00            10             3.157E+08



          P L O T T E D   O U T P U T   F R E Q U E N C Y

  TIME      STEPS BETWEEN PLOTS          TIME
0.000E+00            10             3.157E+08



          M A T E R I A L   D E F I N I T I O N S

 MATERIAL TYPE ........................POWER LAW CREEP
 MATERIAL ID ..........................          1
 DENSITY ..............................  2.167E+03
 THERMAL STRAIN ID ....................          2
 THERMAL STRAIN SCALE FACTOR ..........  2.250E-03
```

```
MATERIAL PROPERTIES:
        TWO MU                 =     1.984E+10
        BULK MODULUS           =     1.653E+10
        CREEP CONSTANT         =     5.790E-36
        STRESS EXPONENT        =     4.900E+00
        THERMAL CONSTANT       =     6.039E+03


MATERIAL TYPE .........................ELASTIC
MATERIAL ID ..........................          4
DENSITY ..............................  2.167E+03
THERMAL STRAIN ID ....................          2
THERMAL STRAIN SCALE FACTOR ..........  1.000E-03
MATERIAL PROPERTIES:
        YOUNGS MODULUS         =     7.240E+10
        POISSONS RATIO         =     3.300E-01


MATERIAL TYPE .........................POWER LAW CREEP
MATERIAL ID ..........................          3
DENSITY ..............................  2.167E+03
THERMAL STRAIN ID ....................          2
THERMAL STRAIN SCALE FACTOR ..........  2.135E-03
MATERIAL PROPERTIES:
        TWO MU                 =     2.120E+10
        BULK MODULUS           =     1.766E+10
        CREEP CONSTANT         =     5.210E-36
        STRESS EXPONENT        =     4.900E+00
        THERMAL CONSTANT       =     6.039E+03


MATERIAL TYPE .........................ELASTIC
MATERIAL ID ..........................          5
DENSITY ..............................  2.167E+03
THERMAL STRAIN ID ....................          2
THERMAL STRAIN SCALE FACTOR ..........  1.200E-03
```

Information Only

```
MATERIAL PROPERTIES:
       YOUNGS MODULUS          =     7.240E+10
       POISSONS RATIO          =     3.300E-01


MATERIAL TYPE ........................POWER LAW CREEP
MATERIAL ID ..........................          2
DENSITY ..............................  2.167E+03
THERMAL STRAIN ID ....................          2
THERMAL STRAIN SCALE FACTOR ..........  2.000E-03
MATERIAL PROPERTIES:
       TWO MU                  =     1.984E+10
       BULK MODULUS            =     1.653E+10
       CREEP CONSTANT          =     1.740E-35
       STRESS EXPONENT         =     4.900E+00
       THERMAL CONSTANT        =     6.039E+03



     F U N C T I O N   D E F I N I T I O N S


FUNCTION ID .........      1     NUMBER OF POINTS ....      2

              N       S          F(S)
              1    0.000E+00   1.000E+00
              2    4.000E+08   1.000E+00


FUNCTION ID .........      2     NUMBER OF POINTS ....      2

              N       S          F(S)
              1    2.990E+02  -2.000E-02
              2    3.500E+02   1.000E+00
```

Information Only

Information Only

```
     FUNCTION ID .........       3     NUMBER OF POINTS ....       2

                N         S          F(S)
                1     0.000E+00   0.000E+00
                2     4.000E+08   0.000E+00


   NO DISPLACEMENT BOUNDARY CONDITIONS

              NODE SET FLAG      DIRECTION
                    1                X
                   12                X
                   12                Y


              CONTACT SURFACES

   SURFACE  SURFACE 1  SURFACE 2  PENALTY   COEFFICIENT  PENETRATION   TENSION
   NUMBER     FLAG       FLAG     FACTOR    OF FRICTION  MULTIPLIER    RELEASE
      1         8          9     0.000E+00   0.000E+00   2.000E-02   1.000E+40
      2        11         10     0.000E+00   0.000E+00   2.000E-02   1.000E+40
      3        15         16     0.000E+00   0.000E+00   2.000E-02   1.000E+40
      4        18         17     0.000E+00   0.000E+00   2.000E-02   1.000E+40


   PRESSURE BOUNDARY CONDITONS
```

Information Only

```
SURFACE       FUNCTION      SCALE
 FLAG          NUMBER       FACTOR
   13             1       1.271E+07
   14             1       1.501E+07



        E N D   O F   D A T A   I N P U T   P H A S E
              3.340E-01 CPU SECONDS USED
                    110 WORDS ALLOCATED



E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
              2.434E-02 CPU SECONDS USED
                    926 WORDS ALLOCATED



   V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

              NODAL         ELEMENT       GLOBAL
              -----         -------       ------
              DISPLX        SIGXX         FX
              DISPLY        SIGYY         FY
              RESIDX        SIGZZ         RX
              RESIDY        TAUXY         RY
              RESID         TEMP          ITER
              REACTX        VONMISES      RMAG
              REACTY        EFFMOD
                            EQCS
```

Information Only

```
**** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****

STEP      TIME      TIME      DAMPING    APPLIED    RESIDUAL    PERCENT   TOTAL
                    STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE  STEPS
  100  3.157E+05  3.157E+05  9.590E-01  1.223E+08  2.386E+07     19.51      100
  200  3.157E+05  3.157E+05  9.817E-01  1.223E+08  1.872E+07     15.31      200
  300  3.157E+05  3.156E+05  9.841E-01  1.223E+08  1.529E+07     12.50      300
  400  3.157E+05  3.156E+05  9.882E-01  1.223E+08  1.219E+07      9.97      400
  500  3.157E+05  3.156E+05  9.886E-01  1.223E+08  9.575E+06      7.83      500
  600  3.157E+05  3.156E+05  9.886E-01  1.223E+08  7.681E+06      6.28      600
  700  3.157E+05  3.156E+05  9.849E-01  1.223E+08  6.502E+06      5.32      700
  800  3.157E+05  3.156E+05  9.978E-01  1.223E+08  5.743E+06      4.70      800
  900  3.157E+05  3.156E+05  9.932E-01  1.223E+08  4.859E+06      3.97      900
 1000  3.157E+05  3.156E+05  9.928E-01  1.223E+08  4.076E+06      3.33     1000
 1100  3.157E+05  3.156E+05  9.930E-01  1.223E+08  3.456E+06      2.83     1100
 1200  3.157E+05  3.156E+05  9.917E-01  1.223E+08  2.972E+06      2.43     1200
 1300  3.157E+05  3.156E+05  9.944E-01  1.223E+08  2.614E+06      2.14     1300
 1400  3.157E+05  3.156E+05  9.944E-01  1.223E+08  2.362E+06      1.93     1400
 1500  3.157E+05  3.156E+05  9.994E-01  1.223E+08  2.182E+06      1.78     1500
 1600  3.157E+05  3.156E+05  9.932E-01  1.223E+08  2.066E+06      1.69     1600
 1700  3.157E+05  3.156E+05  9.828E-01  1.223E+08  1.991E+06      1.63     1700
 1800  3.157E+05  3.156E+05  1.000E+00  1.223E+08  1.942E+06      1.59     1800
 1900  3.157E+05  3.156E+05  9.964E-01  1.223E+08  1.896E+06      1.55     1900
 2000  3.157E+05  3.156E+05  9.962E-01  1.223E+08  1.871E+06      1.53     2000
 2100  3.157E+05  3.156E+05  9.942E-01  1.223E+08  1.820E+06      1.49     2100
 2200  3.157E+05  3.156E+05  9.952E-01  1.223E+08  1.900E+06      1.55     2200
 2300  3.157E+05  3.156E+05  9.975E-01  1.223E+08  2.385E+06      1.95     2300
 2400  3.157E+05  3.156E+05  9.960E-01  1.223E+08  3.142E+06      2.57     2400
 2500  3.157E+05  3.156E+05  9.900E-01  1.223E+08  2.314E+06      1.89     2500
 2600  3.157E+05  3.156E+05  9.938E-01  1.223E+08  2.250E+06      1.84     2600
 2700  3.157E+05  3.156E+05  9.984E-01  1.223E+08  2.717E+06      2.22     2700
```

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2800	3.157E+05	3.156E+05	9.995E-01	1.223E+08	5.520E+06	4.51	2800
2900	3.157E+05	3.156E+05	1.000E+00	1.223E+08	1.402E+07	11.46	2900
3000	3.157E+05	3.156E+05	1.000E+00	1.223E+08	2.850E+07	23.30	3000
3100	3.157E+05	3.156E+05	9.120E-01	1.223E+08	1.291E+07	10.56	3100
3200	3.157E+05	3.156E+05	1.000E+00	1.223E+08	2.370E+06	1.94	3200
3300	3.157E+05	3.156E+05	9.999E-01	1.223E+08	3.343E+06	2.73	3300
3400	3.157E+05	3.156E+05	9.998E-01	1.223E+08	3.094E+06	2.53	3400
3500	3.157E+05	3.156E+05	9.998E-01	1.223E+08	6.366E+06	5.21	3500
3600	3.157E+05	3.156E+05	1.000E+00	1.223E+08	2.134E+07	17.45	3600
3700	3.157E+05	3.156E+05	9.755E-01	1.223E+08	3.015E+06	2.47	3700
3800	3.157E+05	3.156E+05	9.845E-01	1.223E+08	2.550E+06	2.08	3800
3900	3.157E+05	3.156E+05	1.000E+00	1.223E+08	2.041E+06	1.67	3900
4000	3.157E+05	3.156E+05	1.000E+00	1.223E+08	3.602E+06	2.95	4000
4100	3.157E+05	3.156E+05	9.991E-01	1.223E+08	1.357E+07	11.10	4100
4200	3.157E+05	3.156E+05	9.429E-01	1.223E+08	3.998E+06	3.27	4200
4300	3.157E+05	3.156E+05	1.000E+00	1.223E+08	1.859E+06	1.52	4300
4400	3.157E+05	3.156E+05	1.000E+00	1.223E+08	2.990E+06	2.44	4400
4500	3.157E+05	3.156E+05	9.998E-01	1.223E+08	3.718E+06	3.04	4500
4600	3.157E+05	3.156E+05	1.000E+00	1.223E+08	3.385E+06	2.77	4600
4700	3.157E+05	3.156E+05	1.000E+00	1.223E+08	1.566E+07	12.80	4700
4800	3.157E+05	3.156E+05	9.655E-01	1.223E+08	1.031E+07	8.43	4800
4900	3.157E+05	3.156E+05	9.873E-01	1.223E+08	1.265E+06	1.03	4900
5000	3.157E+05	3.156E+05	9.990E-01	1.223E+08	1.731E+06	1.42	5000
5100	3.157E+05	3.156E+05	1.000E+00	1.223E+08	2.277E+06	1.86	5100
5200	3.157E+05	3.156E+05	1.000E+00	1.223E+08	3.906E+06	3.19	5200
5300	3.157E+05	3.156E+05	1.000E+00	1.223E+08	1.067E+07	8.72	5300
5400	3.157E+05	3.156E+05	1.000E+00	1.223E+08	2.466E+07	20.17	5400
5500	3.157E+05	3.156E+05	9.610E-01	1.223E+08	1.068E+06	0.87	5500
5600	3.157E+05	3.156E+05	1.000E+00	1.223E+08	1.085E+06	0.89	5600
5700	3.157E+05	3.156E+05	9.998E-01	1.223E+08	1.295E+06	1.06	5700
5800	3.157E+05	3.156E+05	1.000E+00	1.223E+08	9.212E+05	0.75	5800
5900	3.157E+05	3.156E+05	1.000E+00	1.223E+08	3.149E+06	2.58	5900
6000	3.157E+05	3.156E+05	1.000E+00	1.223E+08	1.127E+07	9.21	6000
6100	3.157E+05	3.156E+05	1.000E+00	1.223E+08	2.352E+07	19.24	6100
6200	3.157E+05	3.156E+05	9.710E-01	1.223E+08	2.685E+06	2.20	6200
6300	3.157E+05	3.156E+05	1.000E+00	1.223E+08	1.036E+06	0.85	6300

```
6400  3.157E+05  3.156E+05  1.000E+00  1.223E+08  1.046E+06    0.86   6400
6500  3.157E+05  3.156E+05  1.000E+00  1.223E+08  2.495E+06    2.04   6500
6600  3.157E+05  3.156E+05  1.000E+00  1.223E+08  7.326E+06    5.99   6600
6700  3.157E+05  3.156E+05  1.000E+00  1.223E+08  1.418E+07   11.60   6700
6800  3.157E+05  3.156E+05  9.321E-01  1.223E+08  9.488E+05    0.78   6800
6900  3.157E+05  3.156E+05  1.000E+00  1.223E+08  7.654E+05    0.63   6900
7000  3.157E+05  3.156E+05  1.000E+00  1.223E+08  1.284E+06    1.05   7000
7100  3.157E+05  3.156E+05  1.000E+00  1.223E+08  3.462E+06    2.83   7100
7200  3.157E+05  3.156E+05  1.000E+00  1.223E+08  6.868E+06    5.62   7200
7300  3.157E+05  3.156E+05  1.000E+00  1.223E+08  9.688E+06    7.92   7300
7400  3.157E+05  3.156E+05  9.144E-01  1.223E+08  1.146E+06    0.94   7400
7500  3.157E+05  3.156E+05  1.000E+00  1.223E+08  7.395E+05    0.60   7500
7600  3.157E+05  3.156E+05  1.000E+00  1.223E+08  1.873E+06    1.53   7600

STEP     TIME       TIME     DAMPING     APPLIED   RESIDUAL    PERCENT    TOTAL
                    STEP      FACTOR   LOAD NORM  LOAD NORM  IMBALANCE    STEPS
 100  6.314E+05  3.157E+05  9.680E-01  1.223E+08  5.367E+06    4.39   7711
 200  6.314E+05  3.157E+05  9.728E-01  1.223E+08  2.989E+06    2.44   7811
 300  6.314E+05  3.157E+05  9.352E-01  1.223E+08  2.241E+06    1.83   7911
 400  6.314E+05  3.157E+05  9.978E-01  1.223E+08  2.041E+06    1.67   8011
 500  6.314E+05  3.157E+05  9.879E-01  1.223E+08  1.697E+06    1.39   8111
 600  6.314E+05  3.157E+05  9.941E-01  1.223E+08  1.420E+06    1.16   8211
 700  6.314E+05  3.157E+05  9.925E-01  1.223E+08  1.159E+06    0.95   8311
 800  6.314E+05  3.157E+05  9.842E-01  1.223E+08  8.730E+05    0.71   8411
 900  6.314E+05  3.157E+05  9.993E-01  1.223E+08  6.891E+05    0.56   8511

STEP     TIME       TIME     DAMPING     APPLIED   RESIDUAL    PERCENT    TOTAL
                    STEP      FACTOR   LOAD NORM  LOAD NORM  IMBALANCE    STEPS
 100  9.471E+05  3.157E+05  9.983E-01  1.223E+08  4.606E+06    3.77   8673
 200  9.471E+05  3.157E+05  9.823E-01  1.223E+08  2.551E+06    2.09   8773
 300  9.471E+05  3.157E+05  8.538E-01  1.223E+08  1.755E+06    1.44   8873
 400  9.471E+05  3.157E+05  9.902E-01  1.223E+08  1.615E+06    1.32   8973
 500  9.471E+05  3.157E+05  9.964E-01  1.223E+08  1.354E+06    1.11   9073
 600  9.471E+05  3.157E+05  9.957E-01  1.223E+08  1.016E+06    0.83   9173
```

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```
   700   9.471E+05  3.157E+05  9.836E-01  1.223E+08  7.586E+05       0.62      9273

 STEP       TIME       TIME     DAMPING    APPLIED   RESIDUAL     PERCENT    TOTAL
                       STEP     FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
   100   1.263E+06  3.157E+05  9.841E-01  1.223E+08  3.743E+06       3.06      9465
   200   1.263E+06  3.157E+05  9.987E-01  1.223E+08  2.182E+06       1.78      9565
   300   1.263E+06  3.157E+05  9.127E-01  1.223E+08  1.638E+06       1.34      9665
   400   1.263E+06  3.157E+05  9.690E-01  1.223E+08  1.382E+06       1.13      9765
   500   1.263E+06  3.157E+05  9.947E-01  1.223E+08  1.096E+06       0.90      9865
   600   1.263E+06  3.157E+05  9.843E-01  1.223E+08  8.060E+05       0.66      9965
   700   1.263E+06  3.157E+05  9.770E-01  1.223E+08  6.400E+05       0.52     10065

 STEP       TIME       TIME     DAMPING    APPLIED   RESIDUAL     PERCENT    TOTAL
                       STEP     FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
   100   1.578E+06  3.157E+05  9.678E-01  1.223E+08  3.412E+06       2.79     10193
   200   1.578E+06  3.157E+05  9.999E-01  1.223E+08  1.825E+06       1.49     10293
   300   1.578E+06  3.157E+05  9.920E-01  1.223E+08  1.443E+06       1.18     10393
   400   1.578E+06  3.157E+05  9.989E-01  1.223E+08  1.239E+06       1.01     10493
   500   1.578E+06  3.157E+05  9.997E-01  1.223E+08  9.860E+05       0.81     10593
   600   1.578E+06  3.157E+05  9.960E-01  1.223E+08  7.126E+05       0.58     10693

 STEP       TIME       TIME     DAMPING    APPLIED   RESIDUAL     PERCENT    TOTAL
                       STEP     FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
   100   1.894E+06  3.157E+05  9.986E-01  1.223E+08  3.303E+06       2.70     10854
   200   1.894E+06  3.157E+05  9.915E-01  1.223E+08  1.737E+06       1.42     10954
   300   1.894E+06  3.157E+05  1.000E+00  1.223E+08  1.322E+06       1.08     11054
   400   1.894E+06  3.157E+05  9.869E-01  1.223E+08  1.104E+06       0.90     11154
   500   1.894E+06  3.157E+05  9.817E-01  1.223E+08  7.668E+05       0.63     11254

 STEP       TIME       TIME     DAMPING    APPLIED   RESIDUAL     PERCENT    TOTAL
                       STEP     FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
   100   2.210E+06  3.157E+05  9.590E-01  1.223E+08  2.874E+06       2.35     11444
```

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```
  200  2.210E+06  3.157E+05  9.730E-01  1.223E+08  1.576E+06     1.29     11544
  300  2.210E+06  3.157E+05  9.798E-01  1.223E+08  1.281E+06     1.05     11644
  400  2.210E+06  3.157E+05  9.875E-01  1.223E+08  1.065E+06     0.87     11744
  500  2.210E+06  3.157E+05  9.744E-01  1.223E+08  8.680E+05     0.71     11844
  600  2.210E+06  3.157E+05  9.958E-01  1.223E+08  7.068E+05     0.58     11944

STEP     TIME      TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                   STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  100  2.526E+06  3.157E+05  9.570E-01  1.223E+08  2.878E+06     2.35     12106
  200  2.526E+06  3.157E+05  9.776E-01  1.223E+08  1.550E+06     1.27     12206
  300  2.526E+06  3.157E+05  9.986E-01  1.223E+08  1.191E+06     0.97     12306
  400  2.526E+06  3.157E+05  9.909E-01  1.223E+08  9.425E+05     0.77     12406
  500  2.526E+06  3.157E+05  9.495E-01  1.223E+08  7.843E+05     0.64     12506
  600  2.526E+06  3.157E+05  9.999E-01  1.223E+08  6.937E+05     0.57     12606

STEP     TIME      TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                   STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  100  2.841E+06  3.157E+05  9.849E-01  1.223E+08  2.599E+06     2.13     12767
  200  2.841E+06  3.157E+05  9.421E-01  1.223E+08  1.530E+06     1.25     12867
  300  2.841E+06  3.157E+05  9.720E-01  1.223E+08  1.162E+06     0.95     12967
  400  2.841E+06  3.157E+05  9.798E-01  1.223E+08  9.116E+05     0.75     13067
  500  2.841E+06  3.157E+05  9.815E-01  1.223E+08  7.265E+05     0.59     13167

STEP     TIME      TIME      DAMPING    APPLIED    RESIDUAL    PERCENT    TOTAL
                   STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE   STEPS
  100  3.157E+06  3.157E+05  9.824E-01  1.223E+08  2.497E+06     2.04     13358
  200  3.157E+06  3.157E+05  9.990E-01  1.223E+08  1.418E+06     1.16     13458
  300  3.157E+06  3.157E+05  9.987E-01  1.223E+08  1.057E+06     0.86     13558
  400  3.157E+06  3.157E+05  9.459E-01  1.223E+08  8.478E+05     0.69     13658
  500  3.157E+06  3.157E+05  9.989E-01  1.223E+08  6.270E+05     0.51     13758
```

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 15:45:32
  BENCHMARK II HEATED PROBLEM - SANTOS VERIFICATION (1/17/95)

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER    10, TIME = 3.157E+06
NUMBER OF ITERATIONS =       514, TOTAL NUMBER OF ITERATIONS =     13772
FINAL CONVERGENCE TOLERANCE = 4.994E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION =-8.137E+03
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.997E+04
SUM OF REACTION FORCES IN X-DIRECTION = 3.874E+06
SUM OF REACTION FORCES IN Y-DIRECTION = 6.377E+06
*********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 3.157E+06  STEP NUMBER    10 ****
```

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```
SANTOS, VERSION 2.0.0    ,RUN ON 03/06/96 ,AT 15:45:32
 BENCHMARK II HEATED PROBLEM - SANTOS VERIFICATION (1/17/95)

************************************************************************
SUMMARY OF DATA AT STEP NUMBER  1000, TIME = 3.157E+08
NUMBER OF ITERATIONS =       424, TOTAL NUMBER OF ITERATIONS =    438727
FINAL CONVERGENCE TOLERANCE = 4.998E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION =-5.607E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.997E+04
SUM OF REACTION FORCES IN X-DIRECTION = 1.243E+06
SUM OF REACTION FORCES IN Y-DIRECTION = 1.052E+07
************************************************************************


**** PLOT TAPE WRITTEN AT TIME = 3.157E+08  STEP NUMBER  1000 ****




          100 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


                  E N D  O F  S O L U T I O N  P H A S E
                      8.878E+03 CPU SECONDS USED
                           926 WORDS ALLOCATED
```

APPENDIX T

Input/Output Data For Problem 20 – Isothermal WIPP Parallel Calculation

The following three sections present the input data, the initial stress subroutine, and the formatted output, respectively, for the Isothermal WIPP Parallel Calculation verification problem.

FASTQ and SANTOS Input Data For The Isothermal WIPP Parallel Calculation

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the Parallel Calculation isothermal drift problem.

Information Only

```
TITLE
     ISOTHERMAL REFERENCE CALCULATION
POINT      1      0.0000000E+00       5.2869999E+01
POINT      2      0.0000000E+00       4.9380001E+01
POINT      3      0.0000000E+00       3.1860001E+01
POINT      4      0.0000000E+00       2.8299999E+01
POINT      5      0.0000000E+00       1.3580000E+01
POINT      6      0.0000000E+00       1.0670000E+01
POINT      7      0.0000000E+00       9.3500004E+00
POINT      8      0.0000000E+00       9.1599998E+00
POINT      9      0.0000000E+00       7.7700000E+00
POINT     10      0.0000000E+00       6.7100000E+00
POINT     11      0.0000000E+00       4.2700000E+00
POINT     12      0.0000000E+00       2.3099999E+00
POINT     13      0.0000000E+00       2.0999999E+00
POINT     14      0.0000000E+00       0.0000000E+00
POINT     15      0.0000000E+00      -2.4360001E+00
POINT     16      0.0000000E+00      -6.3979998E+00
POINT     17      0.0000000E+00      -7.7700000E+00
POINT     18      0.0000000E+00      -8.6300001E+00
POINT     19      0.0000000E+00      -1.1370000E+01
POINT     20      0.0000000E+00      -1.4020000E+01
POINT     21      0.0000000E+00      -1.6330000E+01
POINT     22      0.0000000E+00      -1.6410000E+01
POINT     23      0.0000000E+00      -2.6209999E+01
POINT     24      0.0000000E+00      -3.0600000E+01
POINT     25      0.0000000E+00      -4.9990002E+01
POINT     26      0.0000000E+00      -5.4189999E+01
POINT     27      5.0300002E+00       1.3580000E+01
POINT     28      5.0300002E+00       1.0670000E+01
POINT     29      5.0300002E+00       9.3500004E+00
POINT     30      5.0300002E+00       9.1599998E+00
POINT     31      5.0300002E+00       9.1599998E+00
POINT     32      5.0300002E+00       7.7700000E+00
POINT     33      5.0300002E+00       6.7100000E+00
POINT     34      5.0300002E+00       6.7100000E+00
POINT     35      5.0300002E+00       4.2700000E+00
POINT     36      5.0300002E+00       4.2700000E+00
POINT     37      5.0300002E+00       2.3099999E+00
POINT     38      5.0300002E+00       2.0999999E+00
POINT     39      5.0300002E+00       2.0999999E+00
POINT     40      5.0300002E+00       0.0000000E+00
POINT     41      5.0300002E+00       0.0000000E+00
POINT     42      5.0300002E+00      -2.4360001E+00
POINT     43      5.0300002E+00      -2.9000001E+00
POINT     44      5.0279999E+00      -2.9000001E+00
POINT     45      5.0300002E+00      -3.7200000E+00
POINT     46      5.0300002E+00      -6.3979998E+00
POINT     47      5.0300002E+00      -7.7700000E+00
POINT     48      5.0300002E+00      -8.6300001E+00
POINT     49      5.0300002E+00      -8.6300001E+00
POINT     50      5.0300002E+00      -1.1370000E+01
POINT     51      5.0300002E+00      -1.1370000E+01
POINT     52      5.0300002E+00      -1.4020000E+01
```

Information Only

```
POINT     53       2.0270000E+01       5.2869999E+01
POINT     54       2.0270000E+01       4.9380001E+01
POINT     55       2.0270000E+01       3.1860001E+01
POINT     56       2.0270000E+01       2.8299999E+01
POINT     57       2.0270000E+01       1.3580000E+01
POINT     58       2.0270000E+01       1.0670000E+01
POINT     59       2.0270000E+01       9.3500004E+00
POINT     60       2.0270000E+01       9.1599998E+00
POINT     61       2.0270000E+01       7.7700000E+00
POINT     62       2.0270000E+01       6.7100000E+00
POINT     63       2.0270000E+01       4.2700000E+00
POINT     64       2.0270000E+01       2.3099999E+00
POINT     65       2.0270000E+01       2.0999999E+00
POINT     66       2.0270000E+01       0.0000000E+00
POINT     67       2.0270000E+01      -2.4360001E+00
POINT     68       2.0270000E+01      -2.9000001E+00
POINT     69       2.0270000E+01      -3.7200000E+00
POINT     70       2.0270000E+01      -6.3979998E+00
POINT     71       2.0270000E+01      -7.7700000E+00
POINT     72       2.0270000E+01      -8.6300001E+00
POINT     73       2.0270000E+01      -1.1370000E+01
POINT     74       2.0270000E+01      -1.4020000E+01
POINT     75       2.0270000E+01      -1.6330000E+01
POINT     76       2.0270000E+01      -1.6410000E+01
POINT     77       2.0270000E+01      -2.6209999E+01
POINT     78       2.0270000E+01      -3.0600000E+01
POINT     79       2.0270000E+01      -4.9990002E+01
POINT     80       2.0270000E+01      -5.4189999E+01
POINT     81       5.0300002E+00      -1.6330000E+01
POINT     82       5.0300002E+00      -1.6410000E+01
POINT     84       5.0300002E+00      -1.4020000E+01
POINT     86       5.0300002E+00       1.3580000E+01
POINT     87       5.0300002E+00       2.8299999E+01
POINT     88       5.0300002E+00       3.1860001E+01
POINT     89       5.0300002E+00       4.9380001E+01
POINT     90       5.0300002E+00       5.2869999E+01
POINT     91       5.0300002E+00      -1.6410000E+01
POINT     92       5.0300002E+00      -2.6209999E+01
POINT     93       5.0300002E+00      -3.0600000E+01
POINT     94       5.0300002E+00      -4.9990002E+01
POINT     95       5.0300002E+00      -5.4189999E+01
POINT     96       5.0300002E+00      -5.8109999E+00
POINT     97       2.0270000E+01      -5.8109999E+00
LINE       1    STR      1      2      0      2     0.000000
LINEBC     1     1
LINE       2    STR      2      3      0      9     0.000000
LINEBC     1     2
LINE       3    STR      3      4      0      2     0.000000
LINEBC     1     3
LINE       4    STR      4      5      0      9     0.970000
LINEBC     1     4
LINE       5    STR      5      6      0      2     0.000000
LINEBC     1     5
LINE       6    STR      6      7      0      2     0.000000
```

Information Only

```
LINEBC     1      6
LINE       7     STR     7      8      0      1      0.000000
LINEBC     1      7
LINE       8     STR     8      9      0      2      0.000000
LINEBC     1      8
LINE       9     STR     9     10      0      2      0.000000
LINEBC     1      9
LINE      10     STR    10     11      0      3      0.000000
LINEBC     1     10
LINE      11     STR    11     12      0      3      0.000000
LINEBC     1     11
LINE      12     STR    12     13      0      1      0.000000
LINEBC     1     12
LINE      13     STR    13     14      0      3      0.000000
LINEBC     1     13
LINE      14     STR    14     15      0      4      0.000000
LINEBC     1     14
LINE      15     STR    16     17      0      3      0.000000
LINEBC     1     15
LINE      16     STR    17     18      0      2      0.000000
LINEBC     1     16
LINE      17     STR    18     19      0      4      0.000000
LINEBC     1     17
LINE      18     STR    19     20      0      3      0.000000
LINEBC     1     18
LINE      19     STR    20     21      0      3      0.000000
LINEBC     1     19
LINE      20     STR    21     22      0      1      0.000000
LINEBC     1     20
LINE      21     STR    22     23      0      6      1.050000
LINEBC     1     21
LINE      22     STR    23     24      0      3      0.000000
LINEBC     1     22
LINE      23     STR    24     25      0      9      0.000000
LINEBC     1     23
LINE      24     STR    25     26      0      2      0.000000
LINEBC     1     24
LINE      25     STR    42     43      0      2      0.000000
LINE      26     STR    44     45      0      2      0.000000
LINE      27     STR    45     96      0      3      0.000000
LINE      28     STR    53     54      0      2      0.000000
LINEBC     2     28
LINE      29     STR    54     55      0      9      0.000000
LINEBC     1     29
LINE      30     STR    55     56      0      2      0.000000
LINEBC     1     30
LINE      31     STR    56     57      0      9      0.970000
LINEBC     1     31
LINE      32     STR    57     58      0      2      0.000000
LINEBC     1     32
LINE      33     STR    58     59      0      2      0.000000
LINEBC     1     33
LINE      34     STR    59     60      0      1      0.000000
LINEBC     1     34
```

Information Only

```
LINE      35    STR     60    61     0     2    0.000000
LINEBC     1     35
LINE      36    STR     61    62     0     2    0.000000
LINEBC     1     36
LINE      37    STR     62    63     0     3    0.000000
LINEBC     1     37
LINE      38    STR     63    64     0     3    0.000000
LINEBC     1     38
LINE      39    STR     64    65     0     1    0.000000
LINEBC     1     39
LINE      40    STR     65    66     0     3    0.000000
LINEBC     1     40
LINE      41    STR     66    67     0     4    0.000000
LINEBC     1     41
LINE      42    STR     67    68     0     2    0.000000
LINEBC     1     42
LINE      43    STR     68    69     0     2    0.000000
LINEBC     1     43
LINE      44    STR     69    97     0     3    0.000000
LINEBC     1     44
LINE      45    STR     70    71     0     3    0.000000
LINEBC     1     45
LINE      46    STR     71    72     0     2    0.000000
LINEBC     1     46
LINE      47    STR     72    73     0     4    0.000000
LINEBC     1     47
LINE      48    STR     73    74     0     3    0.000000
LINEBC     1     48
LINE      49    STR     74    75     0     3    0.000000
LINEBC     1     49
LINE      50    STR     75    76     0     1    0.000000
LINEBC     1     50
LINE      51    STR     76    77     0     6    1.050000
LINEBC     1     51
LINE      52    STR     77    78     0     3    0.000000
LINEBC     1     52
LINE      53    STR     78    79     0     9    0.000000
LINEBC     1     53
LINE      54    STR     79    80     0     2    0.000000
LINEBC     1     54
LINE      55    STR      1    90     0     6    0.900000
SIDEBC     3     55
LINE      56    STR      2    89     0     6    0.900000
LINE      57    STR      3    88     0     6    0.900000
LINE      58    STR      4    87     0     6    0.900000
LINE      59    STR      5    86     0     6    0.900000
SIDEBC   105     59
LINE      60    STR      5    27     0     6    0.900000
SIDEBC   106     60
LINE      61    STR     27    57     0    11    1.150000
SIDEBC   106     61
LINE      62    STR      6    28     0     6    0.900000
LINE      63    STR     28    58     0    11    1.150000
LINE      64    STR      7    29     0     6    0.900000
```

Information Only

```
LINE      65    STR    29    59     0    11    1.150000
LINE      66    STR     8    30     0     6    0.900000
SIDEBC   107     66
LINE      67    STR    30    60     0    11    1.150000
SIDEBC   107     67
LINE      68    STR     8    31     0     6    0.900000
SIDEBC   108     68
LINE      69    STR    31    60     0    11    1.150000
SIDEBC   108     69
LINE      70    STR     9    32     0     6    0.900000
LINE      71    STR    32    61     0    11    1.150000
LINE      72    STR    10    33     0     6    0.900000
SIDEBC   109     72
LINE      73    STR    33    62     0    11    1.150000
SIDEBC   109     73
LINE      74    STR    10    34     0     6    0.900000
SIDEBC   110     74
LINE      75    STR    34    62     0    11    1.150000
SIDEBC   110     75
LINE      76    STR    11    35     0     6    0.900000
SIDEBC   111     76
LINE      77    STR    35    63     0    11    1.150000
SIDEBC   111     77
LINE      78    STR    11    36     0     6    0.900000
SIDEBC   112     78
LINE      79    STR    36    63     0    11    1.150000
SIDEBC   112     79
LINE      80    STR    12    37     0     6    0.900000
LINE      81    STR    37    64     0    11    1.150000
LINE      82    STR    13    38     0     6    0.900000
SIDEBC   113     82
LINE      83    STR    38    65     0    11    1.150000
SIDEBC   113     83
LINE      84    STR    13    39     0     6    0.900000
SIDEBC   114     84
LINE      85    STR    39    65     0    11    1.150000
SIDEBC   114     85
LINE      86    STR    14    40     0     6    0.900000
SIDEBC   115     86
LINE      87    STR    40    66     0    11    1.150000
SIDEBC   115     87
LINE      88    STR    14    41     0     6    0.900000
SIDEBC   116     88
LINE      89    STR    41    66     0    11    1.150000
SIDEBC   116     89
LINE      90    STR    15    42     0     6    0.900000
LINE      91    STR    42    67     0    11    1.150000
LINE      92    STR    43    68     0    11    1.150000
SIDEBC   117     92
LINE      93    STR    44    68     0    11    1.150000
SIDEBC   118     93
LINE      94    STR    45    69     0    11    1.150000
LINE      95    STR    46    70     0    11    1.150000
LINE      96    STR    17    47     0     6    0.900000
```

Information Only

```
LINE      97   STR    47    71     0    11    1.150000
LINE      98   STR    18    48     0     6    0.900000
SIDEBC   119    98
LINE      99   STR    48    72     0    11    1.150000
SIDEBC   119    99
LINE     100   STR    18    49     0     6    0.900000
SIDEBC   120   100
LINE     101   STR    49    72     0    11    1.150000
SIDEBC   120   101
LINE     102   STR    19    50     0     6    0.900000
SIDEBC   121   102
LINE     103   STR    50    73     0    11    1.150000
SIDEBC   121   103
LINE     104   STR    19    51     0     6    0.900000
SIDEBC   122   104
LINE     105   STR    51    73     0    11    1.150000
SIDEBC   122   105
LINE     106   STR    20    52     0     6    0.900000
SIDEBC   123   106
LINE     107   STR    52    74     0    11    1.150000
SIDEBC   123   107
LINE     108   STR    20    84     0     6    0.900000
SIDEBC   124   108
LINE     109   STR    21    81     0     6    0.900000
LINE     110   STR    22    82     0     6    0.900000
SIDEBC   125   110
LINE     111   STR    23    92     0     6    0.900000
LINE     112   STR    24    93     0     6    0.900000
LINE     113   STR    25    94     0     6    0.900000
LINE     114   STR    26    95     0     6    0.900000
SIDEBC     4   114
LINE     115   STR    16    46     0     6    0.900000
LINE     116   STR    81    75     0    11    1.150000
LINE     117   STR    82    76     0    11    1.150000
SIDEBC   125   117
LINE     118   STR    91    76     0    11    1.150000
SIDEBC   126   118
LINE     120   STR    84    74     0    11    1.150000
SIDEBC   124   120
LINE     121   STR    86    57     0    11    1.150000
SIDEBC   105   121
LINE     122   STR    87    56     0    11    1.150000
LINE     123   STR    88    55     0    11    1.150000
LINE     124   STR    89    54     0    11    1.150000
LINE     125   STR    90    53     0    11    1.150000
SIDEBC     3   125
LINE     126   STR    95    80     0    11    1.150000
SIDEBC     4   126
LINE     127   STR    94    79     0    11    1.150000
LINE     128   STR    93    78     0    11    1.150000
LINE     129   STR    92    77     0    11    1.150000
LINE     130   STR    22    91     0     6    0.900000
SIDEBC   126   130
LINE     131   STR    96    46     0     2    0.000000
```

Information Only

```
LINE      132   STR    97    70     0     2    0.000000
LINEBC      1   132
SIDE        1    60    61
SIDE        2    62    63
SIDE        3    64    65
SIDE        4    66    67
SIDE        5    68    69
SIDE        6    70    71
SIDE        7    72    73
SIDE        8    74    75
SIDE        9    76    77
SIDE       10    78    79
SIDE       11    80    81
SIDE       12    82    83
SIDE       13    84    85
SIDE       14    86    87
SIDE       15    88    89
SIDE       16    90    91
SIDE       17   115    95
SIDE       18    96    97
SIDE       19    98    99
SIDE       20   100   101
SIDE       21   102   103
SIDE       22   104   105
SIDE       23   106   107
SIDE       24   108   120
SIDE       25   109   116
SIDE       26   110   117
SIDE       27    59   121
SIDE       28    58   122
SIDE       29    57   123
SIDE       30    56   124
SIDE       31    55   125
SIDE       32   130   118
SIDE       33   111   129
SIDE       34   112   128
SIDE       35   113   127
SIDE       36   114   126
SIDE       37    27   131
SIDE       38    44   132
REGION      1     3    31    -1    30   -28
REGION      2     1    30    -2    29   -29
REGION      3     3    29    -3    28   -30
REGION      4     1    28    -4    27   -31
REGION      5     2     1    -5     2   -32
REGION      6     1     2    -6     3   -33
REGION      7     3     3    -7     4   -34
REGION      8     2     5    -8     6   -35
REGION      9     1     6    -9     7   -36
REGION     10     1     8   -10     9   -37
REGION     11     1    10   -11    11   -38
REGION     12     3    11   -12    12   -39
REGION     13     1    13   -13    14   -40
REGION     14     1    15   -14    16   -41
```

Information Only

```
REGION  15     1   -91   -25   -92   -42
REGION  16     2   -93   -26   -94   -43
REGION  17     1   -94    37   -95    38
REGION  18     1    17   -15    18   -45
REGION  19     3    18   -16    19   -46
REGION  20     1    20   -17    21   -47
REGION  21     1    22   -18    23   -48
REGION  22     1    24   -19    25   -49
REGION  23     3    25   -20    26   -50
REGION  24     1    32   -21    33   -51
REGION  25     3    33   -22    34   -52
REGION  26     1    34   -23    35   -53
REGION  27     4    35   -24    36   -54
SCHEME   0
EXIT
```

Information Only

```
TITLE
 REFERENCE PARALLEL ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/24/95)
RESIDUAL TOLERANCE = .5
MAXIMUM ITERATIONS = 20000
INTERMEDIATE PRINT = 100
MAXIMUM TOLERANCE = 5.
PLANE STRAIN
TIME STEP SCALE = 0.7
PREDICTOR SCALE FACTOR = 2
EFFECTIVE MODULUS = VARIABLE
INITIAL STRESS = USER
GRAVITY = 1 = 0. = -9.790 = 0.
STEP CONTROL
 400 3.157E8
END
PLOT TIME
 1 3.157E8
END
OUTPUT TIME
 100 3.157E8
END
PLOT NODAL DISPLACEMENT, REACTION, RESIDUAL
PLOT ELEMENT STRESS, VONMISES, EFFMOD
PLOT STATE EQCS
NO DISPLACEMENT X, 1
NO DISPLACEMENT X, 2
NO DISPLACEMENT Y, 2
FUNCTION = 1
0. 1.
4.E8 1.
END
FUNCTION = 2
0. 0.
4.E8 0.
END
PRESSURE, 3, 1, 13.57E6
PRESSURE, 4, 1, 15.96E6
CONTACT SURFACE, 105, 106, FIXED,
CONTACT SURFACE, 107, 108, FIXED,
CONTACT SURFACE, 109, 110, 0.4,
CONTACT SURFACE, 111, 112, 0.4,
CONTACT SURFACE, 113, 114, 0.4,
CONTACT SURFACE, 115, 116, 0.4,
CONTACT SURFACE, 118, 117, 0.4,
CONTACT SURFACE, 119, 120, 0.4,
CONTACT SURFACE, 121, 122, 0.4,
CONTACT SURFACE, 123, 124, FIXED,
CONTACT SURFACE, 125, 126, FIXED,
MATERIAL,1,POWER LAW CREEP,2300.   $  HALITE
TWO MU = 24.8E9
BULK MODULUS = 20.7E9
CREEP CONSTANT = 5.79E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 20.13
```

Information Only

```
END
MATERIAL,2,POWER LAW CREEP,2300.    $  ARGILLACEOUS HALITE
TWO MU = 24.8E9
BULK MODULUS = 20.7E9
CREEP CONSTANT = 1.74E-35
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 20.13
END
MATERIAL,3,ELASTIC,2300.    $  ANHYDRITE
YOUNGS MODULUS = 75.1E9
POISSONS RATIO = .35
END
MATERIAL,4,ELASTIC,2300.    $  POLYHALITE
YOUNGS MODULUS = 55.3E9
POISSONS RATIO = .36
END
EXIT
```

Information Only

Initial Stress Subroutine For The Isothermal WIPP Parallel Calculation

This section presents a listing of the INITST subroutine that was used in SANTOS to specify the initial stresses for the Parallel Calculation isothermal drift analysis.

Information Only

```
      SUBROUTINE INITST( SIG,COORD,LINK,DATMAT,KONMAT,SCREL )
C
C
************************************************************************
C
C   DESCRIPTION:
C     THIS ROUTINE PROVIDES AN INITIAL STRESS STATE TO SANTOS
C
C   FORMAL PARAMETERS:
C     SIG       REAL         ELEMENT STRESS ARRAY WHICH MUST BE RETURNED
C                            WITH THE REQUIRED STRESS VALUES
C     COORD     REAL         GLOBAL NODAL COORDINATE ARRAY
C     LINK      INTEGER      CONNECTIVITY ARRAY
C     DATMAT    REAL         MATERIAL PROPERTIES ARRAY
C     KONMAT    INTEGER      MATERIAL PROPERTIES INTEGER ARRAY
C
C   CALLED BY: INIT
C
C
************************************************************************
C
      INCLUDE 'params.blk'
      INCLUDE 'psize.blk'
      INCLUDE 'contrl.blk'
      INCLUDE 'bsize.blk'
      INCLUDE 'timer.blk'
C
      DIMENSION LINK(NELNS,NUMEL),KONMAT(10,NEMBLK),COORD(NNOD,NSPC),
     *          SIG(NSYMM,NUMEL),DATMAT(MCONS,*),SCREL(NEBLK,*)
C
      DO 1000 I = 1,NEMBLK
         MATID = KONMAT(1,I)
         MKIND = KONMAT(2,I)
         ISTRT = KONMAT(3,I)
         IEND = KONMAT(4,I)
            DO 500 J = ISTRT,IEND
               II = LINK( 1,J )
               JJ = LINK( 2,J )
               KK = LINK( 3,J )
               LL = LINK( 4,J )
               ZAVG = 0.25 * ( COORD(II,2) + COORD(JJ,2) + COORD(KK,2) +
     *                COORD(LL,2) )
               STRESS = - 2.256E4 * ( 655. - ZAVG )
               SIG(1,J) = STRESS
               SIG(2,J) = STRESS
               SIG(3,J) = STRESS
               SIG(4,J) = 0.0
  500       CONTINUE
 1000 CONTINUE
      RETURN
      END
```

Information Only

SANTOS Output For The Isothermal WIPP Parallel Calculation

The following section presents a portion of the SANTOS printed output for the Parallel Calculation isothermal drift analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

Information Only

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS



                    VERSION 2.0.0
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                   PROGRAMMED BY:

                  CHARLES M. STONE
             ENGINEERING SCIENCES CENTER
            SANDIA NATIONAL LABORATORIES
            ALBUQUERQUE, NEW MEXICO 87185

               DERIVED FROM PRONTO2D BY
          LEE M. TAYLOR AND DENNIS P. FLANAGAN



             RUN ON 03/08/96 AT 15:37:49
           RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

```
                              INPUT STREAM IMAGES
LINE -----------------------------------------------------------------------
  1: TITLE
  2:   REFERENCE PARALLEL ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/24/95)
  3: RESIDUAL TOLERANCE = .5
  4: MAXIMUM ITERATIONS = 20000
  5: INTERMEDIATE PRINT = 100
  6: MAXIMUM TOLERANCE = 5.
  7: PLANE STRAIN
  8: TIME STEP SCALE = 0.7
  9: PREDICTOR SCALE FACTOR = 2
 10: EFFECTIVE MODULUS = VARIABLE
 11: INITIAL STRESS = USER
 12: GRAVITY = 1 = 0. = -9.790 = 0.
 13: STEP CONTROL
 14:  400 3.157E8
 15: END
 16: PLOT TIME
 17:  1 3.157E8
 18: END
 19: OUTPUT TIME
 20:  100 3.157E8
 21: END
 22: PLOT NODAL DISPLACEMENT, REACTION, RESIDUAL
 23: PLOT ELEMENT STRESS, VONMISES, EFFMOD
 24: PLOT STATE EQCS
 25: NO DISPLACEMENT X, 1
 26: NO DISPLACEMENT X, 2
 27: NO DISPLACEMENT Y, 2
 28: FUNCTION = 1
 29: 0. 1.
 30: 4.E8 1.
 31: END
 32: FUNCTION = 2
 33: 0. 0.
 34: 4.E8 0.
```

```
35: END
36: PRESSURE, 3, 1, 13.57E6
37: PRESSURE, 4, 1, 15.96E6
38: CONTACT SURFACE, 105, 106, FIXED,
39: CONTACT SURFACE, 107, 108, FIXED,
40: CONTACT SURFACE, 109, 110, 0.4,
41: CONTACT SURFACE, 111, 112, 0.4,
42: CONTACT SURFACE, 113, 114, 0.4,
43: CONTACT SURFACE, 115, 116, 0.4,
44: CONTACT SURFACE, 118, 117, 0.4,
45: CONTACT SURFACE, 119, 120, 0.4,
46: CONTACT SURFACE, 121, 122, 0.4,
47: CONTACT SURFACE, 123, 124, FIXED,
48: CONTACT SURFACE, 125, 126, FIXED,
49: MATERIAL,1,POWER LAW CREEP,2300.   $  HALITE
50: TWO MU = 24.8E9
51: BULK MODULUS = 20.7E9
52: CREEP CONSTANT = 5.79E-36
53: STRESS EXPONENT = 4.9
54: THERMAL CONSTANT = 20.13
55: END
56: MATERIAL,2,POWER LAW CREEP,2300.   $  ARGILLACEOUS HALITE
57: TWO MU = 24.8E9
58: BULK MODULUS = 20.7E9
59: CREEP CONSTANT = 1.74E-35
60: STRESS EXPONENT = 4.9
61: THERMAL CONSTANT = 20.13
62: END
63: MATERIAL,3,ELASTIC,2300.    $  ANHYDRITE
64: YOUNGS MODULUS = 75.1E9
65: POISSONS RATIO = .35
66: END
67: MATERIAL,4,ELASTIC,2300.    $  POLYHALITE
68: YOUNGS MODULUS = 55.3E9
69: POISSONS RATIO = .36
70: END
```

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71: EXIT

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PROBLEM TITLE

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REFERENCE PARALLEL ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/24/95)
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PROBLEM DEFINITION

```
NUMBER OF ELEMENTS .......................       1476
NUMBER OF NODES ..........................       1761
NUMBER OF MATERIALS ......................          4
NUMBER OF FUNCTIONS ......................          2
NUMBER OF CONTACT SURFACES ...............         11
NUMBER OF RIGID SURFACES .................          0
NUMBER OF MATERIAL POINTS MONITORED .....           0
ANALYSIS TYPE ............................ PLANE STRAIN
GLOBAL CONVERGENCE MEASURE ...............
RESIDUAL TOLERANCE .......................  5.000E-01
MAXIMUM NUMBER OF ITERATIONS ............       20000
ITERATIONS FOR INTERMEDIATE PRINT .......         100
MAXIMUM RESIDUAL TOLERANCE ...............  5.000E+00
PREDICTOR SCALE FACTOR FUNCTION .........           2
MINIMUM DAMPING FACTOR ...................  2.000E-01
EFFECTIVE MODULUS STATUS ................. VARIABLE
INITIAL STRESS DISTRIBUTION APPLIED .....
GRAVITY LOADS APPLIED ...................
SCALE FACTOR APPLIED TO TIME STEP .......   7.000E-01
STRAIN SOFTENING SCALE FACTOR ...........   1.000E+00
HOURGLASS STIFFNESS FACTOR ..............   5.000E-02
HOURGLASS VISCOSITY FACTOR ..............   0.000E+00
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        L O A D   S T E P   D E F I N I T I O N S


  TIME               NO. OF STEPS              TIME
0.000E+00                400                3.157E+08



        P R I N T E D   O U T P U T   F R E Q U E N C Y


  TIME      STEPS BETWEEN PRINTS              TIME
0.000E+00            100                    3.157E+08



        P L O T T E D   O U T P U T   F R E Q U E N C Y


  TIME      STEPS BETWEEN PLOTS               TIME
0.000E+00             1                     3.157E+08



        M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE ........................ELASTIC
  MATERIAL ID .........................           3
  DENSITY .............................  2.300E+03
  MATERIAL PROPERTIES:
          YOUNGS MODULUS         =     7.510E+10
          POISSONS RATIO         =     3.500E-01
```

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```
MATERIAL TYPE ........................POWER LAW CREEP
MATERIAL ID ..........................         1
DENSITY ..............................  2.300E+03
MATERIAL PROPERTIES:
       TWO MU                   =     2.480E+10
       BULK MODULUS             =     2.070E+10
       CREEP CONSTANT           =     5.790E-36
       STRESS EXPONENT          =     4.900E+00
       THERMAL CONSTANT         =     2.013E+01


MATERIAL TYPE ........................POWER LAW CREEP
MATERIAL ID ..........................         2
DENSITY ..............................  2.300E+03
MATERIAL PROPERTIES:
       TWO MU                   =     2.480E+10
       BULK MODULUS             =     2.070E+10
       CREEP CONSTANT           =     1.740E-35
       STRESS EXPONENT          =     4.900E+00
       THERMAL CONSTANT         =     2.013E+01


MATERIAL TYPE ........................ELASTIC
MATERIAL ID ..........................         4
DENSITY ..............................  2.300E+03
MATERIAL PROPERTIES:
       YOUNGS MODULUS           =     5.530E+10
       POISSONS RATIO           =     3.600E-01



     F U N C T I O N   D E F I N I T I O N S
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     FUNCTION ID .........       1     NUMBER OF POINTS ....       2

                    N         S            F(S)
                    1    0.000E+00     1.000E+00
                    2    4.000E+08     1.000E+00


     FUNCTION ID .........       2     NUMBER OF POINTS ....       2

                    N         S            F(S)
                    1    0.000E+00     0.000E+00
                    2    4.000E+08     0.000E+00




 N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

                NODE SET FLAG     DIRECTION
                      1               X
                      2               X
                      2               Y



                C O N T A C T   S U R F A C E S

 SURFACE   SURFACE 1   SURFACE 2  PENALTY   COEFFICIENT  PENETRATION   TENSION
 NUMBER      FLAG        FLAG      FACTOR   OF FRICTION  MULTIPLIER    RELEASE
    1         105         106    0.000E+00     FIXED    1.000E-02   1.000E+40
    2         107         108    0.000E+00     FIXED    1.000E-02   1.000E+40
    3         109         110    0.000E+00   4.000E-01   1.000E-02   1.000E+40
    4         111         112    0.000E+00   4.000E-01   1.000E-02   1.000E+40
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   5       113         114   0.000E+00   4.000E-01   1.000E-02   1.000E+40
   6       115         116   0.000E+00   4.000E-01   1.000E-02   1.000E+40
   7       118         117   0.000E+00   4.000E-01   1.000E-02   1.000E+40
   8       119         120   0.000E+00   4.000E-01   1.000E-02   1.000E+40
   9       121         122   0.000E+00   4.000E-01   1.000E-02   1.000E+40
  10       123         124   0.000E+00     FIXED   1.000E-02   1.000E+40
  11       125         126   0.000E+00     FIXED   1.000E-02   1.000E+40



P R E S S U R E   B O U N D A R Y   C O N D T I O N S

           SURFACE      FUNCTION     SCALE
            FLAG         NUMBER      FACTOR
              3             1      1.357E+07
              4             1      1.596E+07



                E N D   O F   D A T A   I N P U T   P H A S E
                       3.417E-01 CPU SECONDS USED
                             175 WORDS ALLOCATED



      E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
                       2.111E-02 CPU SECONDS USED
                            1761 WORDS ALLOCATED
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      V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                    NODAL         ELEMENT       GLOBAL
                    -----         -------       ------
                    DISPLX        SIGXX         FX
                    DISPLY        SIGYY         FY
                    RESIDX        SIGZZ         RX
                    RESIDY        TAUXY         RY
                    RESID         VONMISES      ITER
                    REACTX        EFFMOD        RMAG
                    REACTY        EQCS


   **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****



 STEP      TIME       TIME      DAMPING    APPLIED    RESIDUAL    PERCENT     TOTAL
                      STEP      FACTOR    LOAD NORM  LOAD NORM   IMBALANCE    STEPS
   100  7.892E+05  7.891E+05  9.875E-01  1.097E+08  1.343E+08    122.42        100
   200  7.892E+05  7.890E+05  6.771E-01  1.097E+08  1.513E+08    137.96        200
   300  7.892E+05  7.890E+05  8.533E-01  1.097E+08  8.340E+07     76.03        300
   400  7.892E+05  7.890E+05  8.579E-01  1.097E+08  6.276E+07     57.22        400
   500  7.892E+05  7.890E+05  8.066E-01  1.097E+08  7.449E+07     67.91        500
   600  7.892E+05  7.890E+05  4.195E-01  1.097E+08  1.770E+07     16.14        600
   700  7.892E+05  7.890E+05  8.244E-01  1.097E+08  3.513E+07     32.03        700
   800  7.892E+05  7.890E+05  7.527E-01  1.097E+08  6.115E+07     55.75        800
   900  7.892E+05  7.890E+05  7.745E-01  1.097E+08  1.144E+08    104.27        900
  1000  7.892E+05  7.890E+05  9.599E-01  1.097E+08  2.193E+07     19.99       1000
  1100  7.892E+05  7.890E+05  8.344E-01  1.097E+08  6.107E+07     55.68       1100
  1200  7.892E+05  7.890E+05  7.863E-01  1.097E+08  3.329E+07     30.35       1200
  1300  7.892E+05  7.890E+05  6.610E-01  1.097E+08  1.648E+07     15.02       1300
  1400  7.892E+05  7.890E+05  8.955E-01  1.097E+08  3.108E+07     28.33       1400
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1500	7.892E+05	7.890E+05	8.779E-01	1.097E+08	2.796E+07	25.49	1500
1600	7.892E+05	7.890E+05	8.885E-01	1.097E+08	1.920E+07	17.50	1600
1700	7.892E+05	7.890E+05	8.048E-01	1.097E+08	2.243E+07	20.44	1700
1800	7.892E+05	7.890E+05	9.231E-01	1.097E+08	1.464E+07	13.35	1800
1900	7.892E+05	7.890E+05	9.997E-01	1.097E+08	9.839E+06	8.97	1900
2000	7.892E+05	7.890E+05	7.635E-01	1.097E+08	1.360E+07	12.40	2000
2100	7.892E+05	7.890E+05	8.982E-01	1.097E+08	8.017E+06	7.31	2100
2200	7.892E+05	7.890E+05	8.775E-01	1.097E+08	6.166E+07	56.22	2200
2300	7.892E+05	7.890E+05	8.181E-01	1.097E+08	1.393E+07	12.70	2300
2400	7.892E+05	7.890E+05	8.495E-01	1.097E+08	2.088E+07	19.03	2400
2500	7.892E+05	7.890E+05	6.538E-01	1.097E+08	1.458E+07	13.30	2500
2600	7.892E+05	7.890E+05	9.162E-01	1.097E+08	1.223E+07	11.15	2600
2700	7.892E+05	7.890E+05	7.969E-01	1.097E+08	1.392E+07	12.69	2700
2800	7.892E+05	7.890E+05	8.277E-01	1.097E+08	1.393E+07	12.70	2800
2900	7.892E+05	7.890E+05	9.944E-01	1.097E+08	6.596E+06	6.01	2900
3000	7.892E+05	7.890E+05	7.157E-01	1.097E+08	1.466E+07	13.36	3000
3100	7.892E+05	7.890E+05	9.580E-01	1.097E+08	6.113E+06	5.57	3100
3200	7.892E+05	7.890E+05	9.979E-01	1.097E+08	1.687E+07	15.38	3200
3300	7.892E+05	7.890E+05	6.032E-01	1.097E+08	1.182E+07	10.77	3300
3400	7.892E+05	7.890E+05	8.895E-01	1.097E+08	9.190E+06	8.38	3400
3500	7.892E+05	7.890E+05	9.998E-01	1.097E+08	1.495E+07	13.63	3500
3600	7.892E+05	7.890E+05	9.676E-01	1.097E+08	8.492E+06	7.74	3600
3700	7.892E+05	7.890E+05	9.054E-01	1.097E+08	7.498E+06	6.84	3700
3800	7.892E+05	7.890E+05	8.755E-01	1.097E+08	1.232E+07	11.24	3800
3900	7.892E+05	7.890E+05	6.622E-01	1.097E+08	1.321E+07	12.04	3900
4000	7.892E+05	7.890E+05	9.999E-01	1.097E+08	8.387E+06	7.65	4000
4100	7.892E+05	7.890E+05	7.485E-01	1.097E+08	7.013E+06	6.39	4100
4200	7.892E+05	7.889E+05	7.151E-01	1.097E+08	5.387E+06	4.91	4200
4300	7.892E+05	7.889E+05	5.118E-01	1.097E+08	5.652E+06	5.15	4300
4400	7.892E+05	7.889E+05	5.041E-01	1.097E+08	5.857E+06	5.34	4400
4500	7.892E+05	7.889E+05	8.106E-01	1.097E+08	8.192E+06	7.47	4500
4600	7.892E+05	7.889E+05	7.407E-01	1.097E+08	6.266E+06	5.71	4600
4700	7.892E+05	7.889E+05	8.921E-01	1.097E+08	4.848E+06	4.42	4700
4800	7.892E+05	7.889E+05	8.548E-01	1.097E+08	1.028E+07	9.37	4800
4900	7.892E+05	7.889E+05	9.959E-01	1.097E+08	8.634E+06	7.87	4900
5000	7.892E+05	7.889E+05	8.455E-01	1.097E+08	9.438E+06	8.60	5000

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5100	7.892E+05	7.889E+05	7.958E-01	1.097E+08	8.736E+06	7.96	5100
5200	7.892E+05	7.889E+05	7.879E-01	1.097E+08	1.757E+07	16.02	5200
5300	7.892E+05	7.889E+05	9.361E-01	1.097E+08	7.657E+06	6.98	5300
5400	7.892E+05	7.889E+05	9.281E-01	1.097E+08	1.870E+07	17.05	5400
5500	7.892E+05	7.889E+05	9.810E-01	1.097E+08	6.328E+06	5.77	5500
5600	7.892E+05	7.889E+05	8.907E-01	1.097E+08	4.715E+06	4.30	5600
5700	7.892E+05	7.889E+05	9.999E-01	1.097E+08	4.491E+06	4.09	5700
5800	7.892E+05	7.889E+05	8.468E-01	1.097E+08	4.133E+06	3.77	5800
5900	7.892E+05	7.889E+05	6.579E-01	1.097E+08	8.706E+06	7.94	5900
6000	7.892E+05	7.889E+05	8.213E-01	1.097E+08	9.726E+06	8.87	6000
6100	7.892E+05	7.889E+05	7.589E-01	1.097E+08	6.486E+06	5.91	6100
6200	7.892E+05	7.889E+05	9.064E-01	1.097E+08	4.232E+06	3.86	6200
6300	7.892E+05	7.889E+05	8.889E-01	1.097E+08	1.075E+07	9.80	6300
6400	7.892E+05	7.889E+05	9.095E-01	1.097E+08	5.394E+06	4.92	6400
6500	7.892E+05	7.889E+05	9.049E-01	1.097E+08	7.306E+06	6.66	6500
6600	7.892E+05	7.889E+05	8.470E-01	1.097E+08	4.062E+06	3.70	6600
6700	7.892E+05	7.889E+05	9.966E-01	1.097E+08	4.646E+06	4.24	6700
6800	7.892E+05	7.889E+05	8.289E-01	1.097E+08	4.146E+06	3.78	6800
6900	7.892E+05	7.889E+05	6.946E-01	1.097E+08	3.729E+06	3.40	6900
7000	7.892E+05	7.889E+05	9.939E-01	1.097E+08	7.250E+06	6.61	7000
7100	7.892E+05	7.889E+05	8.438E-01	1.097E+08	3.685E+06	3.36	7100
7200	7.892E+05	7.889E+05	5.176E-01	1.097E+08	8.641E+06	7.88	7200
7300	7.892E+05	7.889E+05	8.825E-01	1.097E+08	9.979E+06	9.10	7300
7400	7.892E+05	7.889E+05	9.029E-01	1.097E+08	6.160E+06	5.62	7400
7500	7.892E+05	7.889E+05	9.550E-01	1.097E+08	3.376E+06	3.08	7500
7600	7.892E+05	7.889E+05	9.946E-01	1.097E+08	4.520E+06	4.12	7600
7700	7.892E+05	7.889E+05	9.075E-01	1.097E+08	4.163E+06	3.80	7700
7800	7.892E+05	7.889E+05	9.563E-01	1.097E+08	3.289E+06	3.00	7800
7900	7.892E+05	7.889E+05	9.765E-01	1.097E+08	9.184E+06	8.37	7900
8000	7.892E+05	7.889E+05	8.182E-01	1.097E+08	3.589E+06	3.27	8000
8100	7.892E+05	7.889E+05	7.872E-01	1.097E+08	3.405E+06	3.10	8100
8200	7.892E+05	7.889E+05	7.382E-01	1.097E+08	4.018E+06	3.66	8200
8300	7.892E+05	7.889E+05	8.541E-01	1.097E+08	2.921E+06	2.66	8300
8400	7.892E+05	7.889E+05	9.636E-01	1.097E+08	2.940E+06	2.68	8400
8500	7.892E+05	7.889E+05	7.834E-01	1.097E+08	5.626E+06	5.13	8500
8600	7.892E+05	7.889E+05	6.755E-01	1.097E+08	5.697E+06	5.19	8600

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8700	7.892E+05	7.889E+05	9.237E-01	1.097E+08	5.022E+06	4.58	8700
8800	7.892E+05	7.889E+05	9.641E-01	1.097E+08	5.877E+06	5.36	8800
8900	7.892E+05	7.889E+05	8.495E-01	1.097E+08	2.772E+06	2.53	8900
9000	7.892E+05	7.889E+05	9.917E-01	1.097E+08	6.123E+06	5.58	9000
9100	7.892E+05	7.889E+05	6.859E-01	1.097E+08	1.227E+07	11.18	9100
9200	7.892E+05	7.889E+05	6.909E-01	1.097E+08	3.266E+06	2.98	9200
9300	7.892E+05	7.889E+05	9.230E-01	1.097E+08	4.091E+06	3.73	9300
9400	7.892E+05	7.889E+05	8.625E-01	1.097E+08	3.101E+06	2.83	9400
9500	7.892E+05	7.889E+05	9.109E-01	1.097E+08	2.607E+06	2.38	9500
9600	7.892E+05	7.889E+05	6.761E-01	1.097E+08	3.031E+06	2.76	9600
9700	7.892E+05	7.889E+05	9.012E-01	1.097E+08	2.615E+06	2.38	9700
9800	7.892E+05	7.889E+05	9.744E-01	1.097E+08	2.943E+06	2.68	9800
9900	7.892E+05	7.889E+05	9.988E-01	1.097E+08	4.861E+06	4.43	9900
10000	7.892E+05	7.889E+05	6.348E-01	1.097E+08	5.942E+06	5.42	10000
10100	7.892E+05	7.889E+05	8.881E-01	1.097E+08	2.884E+06	2.63	10100
10200	7.892E+05	7.889E+05	7.794E-01	1.097E+08	2.818E+06	2.57	10200
10300	7.892E+05	7.889E+05	1.000E+00	1.097E+08	2.967E+06	2.70	10300
10400	7.892E+05	7.889E+05	5.496E-01	1.097E+08	2.489E+06	2.27	10400
10500	7.892E+05	7.889E+05	6.853E-01	1.097E+08	3.140E+06	2.86	10500
10600	7.892E+05	7.889E+05	9.567E-01	1.097E+08	2.260E+06	2.06	10600
10700	7.892E+05	7.889E+05	6.546E-01	1.097E+08	2.694E+06	2.46	10700
10800	7.892E+05	7.889E+05	8.003E-01	1.097E+08	3.053E+06	2.78	10800
10900	7.892E+05	7.889E+05	4.441E-01	1.097E+08	2.318E+06	2.11	10900
11000	7.892E+05	7.889E+05	8.487E-01	1.097E+08	8.190E+06	7.47	11000
11100	7.892E+05	7.889E+05	9.335E-01	1.097E+08	2.280E+06	2.08	11100
11200	7.892E+05	7.889E+05	8.846E-01	1.097E+08	4.786E+06	4.36	11200
11300	7.892E+05	7.889E+05	5.766E-01	1.097E+08	2.978E+06	2.72	11300
11400	7.892E+05	7.889E+05	8.964E-01	1.097E+08	2.315E+06	2.11	11400
11500	7.892E+05	7.889E+05	8.935E-01	1.097E+08	2.465E+06	2.25	11500
11600	7.892E+05	7.889E+05	9.387E-01	1.097E+08	3.200E+06	2.92	11600
11700	7.892E+05	7.889E+05	5.694E-01	1.097E+08	2.915E+06	2.66	11700
11800	7.892E+05	7.889E+05	9.510E-01	1.097E+08	2.755E+06	2.51	11800
11900	7.892E+05	7.889E+05	7.342E-01	1.097E+08	2.212E+06	2.02	11900
12000	7.892E+05	7.889E+05	9.988E-01	1.097E+08	9.615E+06	8.77	12000
12100	7.892E+05	7.889E+05	8.461E-01	1.097E+08	2.402E+06	2.19	12100
12200	7.892E+05	7.889E+05	8.187E-01	1.097E+08	2.277E+06	2.08	12200

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12300	7.892E+05	7.889E+05	8.315E-01	1.097E+08	4.287E+06	3.91	12300
12400	7.892E+05	7.889E+05	8.498E-01	1.097E+08	3.271E+06	2.98	12400
12500	7.892E+05	7.889E+05	7.743E-01	1.097E+08	2.760E+06	2.52	12500
12600	7.892E+05	7.889E+05	6.507E-01	1.097E+08	2.644E+06	2.41	12600
12700	7.892E+05	7.889E+05	9.483E-01	1.097E+08	1.787E+06	1.63	12700
12800	7.892E+05	7.889E+05	7.794E-01	1.097E+08	3.436E+06	3.13	12800
12900	7.892E+05	7.889E+05	9.247E-01	1.097E+08	2.340E+06	2.13	12900
13000	7.892E+05	7.889E+05	6.157E-01	1.097E+08	1.808E+06	1.65	13000
13100	7.892E+05	7.889E+05	9.607E-01	1.097E+08	2.361E+06	2.15	13100
13200	7.892E+05	7.889E+05	9.831E-01	1.097E+08	1.980E+06	1.81	13200
13300	7.892E+05	7.889E+05	9.448E-01	1.097E+08	1.778E+06	1.62	13300
13400	7.892E+05	7.889E+05	9.953E-01	1.097E+08	2.176E+06	1.98	13400
13500	7.892E+05	7.889E+05	8.680E-01	1.097E+08	2.190E+06	2.00	13500
13600	7.892E+05	7.889E+05	9.150E-01	1.097E+08	1.795E+06	1.64	13600
13700	7.892E+05	7.889E+05	9.394E-01	1.097E+08	1.730E+06	1.58	13700
13800	7.892E+05	7.889E+05	8.039E-01	1.097E+08	1.697E+06	1.55	13800
13900	7.892E+05	7.889E+05	7.839E-01	1.097E+08	3.698E+06	3.37	13900
14000	7.892E+05	7.889E+05	8.491E-01	1.097E+08	1.767E+06	1.61	14000
14100	7.892E+05	7.889E+05	9.001E-01	1.097E+08	1.712E+06	1.56	14100
14200	7.892E+05	7.889E+05	9.999E-01	1.097E+08	1.467E+06	1.34	14200
14300	7.892E+05	7.889E+05	5.805E-01	1.097E+08	1.551E+06	1.41	14300
14400	7.892E+05	7.889E+05	7.399E-01	1.097E+08	1.876E+06	1.71	14400
14500	7.892E+05	7.889E+05	9.999E-01	1.097E+08	1.498E+06	1.37	14500
14600	7.892E+05	7.889E+05	8.168E-01	1.097E+08	1.504E+06	1.37	14600
14700	7.892E+05	7.889E+05	8.311E-01	1.097E+08	2.123E+06	1.94	14700
14800	7.892E+05	7.889E+05	9.783E-01	1.097E+08	1.691E+06	1.54	14800
14900	7.892E+05	7.889E+05	8.514E-01	1.097E+08	1.460E+06	1.33	14900
15000	7.892E+05	7.889E+05	7.471E-01	1.097E+08	2.854E+06	2.60	15000
15100	7.892E+05	7.889E+05	8.191E-01	1.097E+08	1.431E+06	1.30	15100
15200	7.892E+05	7.889E+05	7.573E-01	1.097E+08	1.283E+06	1.17	15200
15300	7.892E+05	7.889E+05	7.555E-01	1.097E+08	1.474E+06	1.34	15300
15400	7.892E+05	7.889E+05	9.472E-01	1.097E+08	1.641E+06	1.50	15400
15500	7.892E+05	7.889E+05	8.699E-01	1.097E+08	2.391E+06	2.18	15500
15600	7.892E+05	7.889E+05	9.984E-01	1.097E+08	1.809E+06	1.65	15600
15700	7.892E+05	7.889E+05	8.882E-01	1.097E+08	1.796E+06	1.64	15700
15800	7.892E+05	7.889E+05	9.967E-01	1.097E+08	2.906E+06	2.65	15800

15900	7.892E+05	7.889E+05	7.640E-01	1.097E+08	1.590E+06	1.45	15900
16000	7.892E+05	7.889E+05	9.000E-01	1.097E+08	1.542E+06	1.41	16000
16100	7.892E+05	7.889E+05	9.563E-01	1.097E+08	1.481E+06	1.35	16100
16200	7.892E+05	7.889E+05	9.899E-01	1.097E+08	1.135E+06	1.03	16200
16300	7.892E+05	7.889E+05	9.673E-01	1.097E+08	1.724E+06	1.57	16300
16400	7.892E+05	7.889E+05	8.374E-01	1.097E+08	1.322E+06	1.21	16400
16500	7.892E+05	7.889E+05	9.204E-01	1.097E+08	1.605E+06	1.46	16500
16600	7.892E+05	7.889E+05	9.867E-01	1.097E+08	1.432E+06	1.31	16600
16700	7.892E+05	7.889E+05	9.686E-01	1.097E+08	1.790E+06	1.63	16700
16800	7.892E+05	7.889E+05	6.690E-01	1.097E+08	1.289E+06	1.18	16800
16900	7.892E+05	7.889E+05	9.939E-01	1.097E+08	1.205E+06	1.10	16900
17000	7.892E+05	7.889E+05	6.361E-01	1.097E+08	1.579E+06	1.44	17000
17100	7.892E+05	7.889E+05	8.673E-01	1.097E+08	2.289E+06	2.09	17100
17200	7.892E+05	7.889E+05	9.995E-01	1.097E+08	1.050E+06	0.96	17200
17300	7.892E+05	7.889E+05	1.000E+00	1.097E+08	2.268E+06	2.07	17300
17400	7.892E+05	7.889E+05	7.918E-01	1.097E+08	1.764E+06	1.61	17400
17500	7.892E+05	7.889E+05	8.053E-01	1.097E+08	1.035E+06	0.94	17500
17600	7.892E+05	7.889E+05	9.255E-01	1.097E+08	1.052E+06	0.96	17600
17700	7.892E+05	7.889E+05	7.042E-01	1.097E+08	1.002E+06	0.91	17700
17800	7.892E+05	7.889E+05	9.309E-01	1.097E+08	1.473E+06	1.34	17800
17900	7.892E+05	7.889E+05	9.715E-01	1.097E+08	1.220E+06	1.11	17900
18000	7.892E+05	7.889E+05	9.967E-01	1.097E+08	9.974E+05	0.91	18000
18100	7.892E+05	7.889E+05	7.379E-01	1.097E+08	1.507E+06	1.37	18100
18200	7.892E+05	7.889E+05	9.965E-01	1.097E+08	1.236E+06	1.13	18200
18300	7.892E+05	7.889E+05	8.750E-01	1.097E+08	1.383E+06	1.26	18300
18400	7.892E+05	7.889E+05	7.999E-01	1.097E+08	1.132E+06	1.03	18400
18500	7.892E+05	7.889E+05	5.627E-01	1.097E+08	1.553E+06	1.42	18500
18600	7.892E+05	7.889E+05	9.469E-01	1.097E+08	1.972E+06	1.80	18600
18700	7.892E+05	7.889E+05	5.846E-01	1.097E+08	1.037E+06	0.95	18700
18800	7.892E+05	7.889E+05	6.438E-01	1.097E+08	1.374E+06	1.25	18800
18900	7.892E+05	7.889E+05	6.926E-01	1.097E+08	1.737E+06	1.58	18900
19000	7.892E+05	7.889E+05	6.226E-01	1.097E+08	1.123E+06	1.02	19000
19100	7.892E+05	7.889E+05	7.623E-01	1.097E+08	1.689E+06	1.54	19100
19200	7.892E+05	7.889E+05	6.412E-01	1.097E+08	1.112E+06	1.01	19200
19300	7.892E+05	7.889E+05	8.124E-01	1.097E+08	8.103E+05	0.74	19300
19400	7.892E+05	7.889E+05	9.997E-01	1.097E+08	8.660E+05	0.79	19400

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```
19500  7.892E+05  7.889E+05  8.424E-01  1.097E+08  8.221E+05     0.75     19500
19600  7.892E+05  7.889E+05  9.989E-01  1.097E+08  8.115E+05     0.74     19600
19700  7.892E+05  7.889E+05  8.686E-01  1.097E+08  1.259E+06     1.15     19700
19800  7.892E+05  7.889E+05  9.971E-01  1.097E+08  7.358E+05     0.67     19800
19900  7.892E+05  7.889E+05  8.817E-01  1.097E+08  1.132E+06     1.03     19900

   **** PLOT TAPE WRITTEN AT TIME = 7.892E+05  STEP NUMBER     1 ****
.
.
.
```

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```
 SANTOS, VERSION 2.0.0     ,RUN ON 03/08/96 ,AT 15:37:49
  REFERENCE PARALLEL ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/24/95)

***********************************************************************
SUMMARY OF DATA AT STEP NUMBER   400, TIME = 3.157E+08
NUMBER OF ITERATIONS =       1223, TOTAL NUMBER OF ITERATIONS =     636310
FINAL CONVERGENCE TOLERANCE = 4.987E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 4.222E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 2.974E+04
SUM OF REACTION FORCES IN X-DIRECTION = 1.233E+05
SUM OF REACTION FORCES IN Y-DIRECTION =-1.022E+07
***********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 3.157E+08  STEP NUMBER   400 ****




   400 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


         E N D  O F  S O L U T I O N  P H A S E
              2.923E+04 CPU SECONDS USED
                   1761 WORDS ALLOCATED
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APPENDIX U

Input/Output Data For Problem 21 – Heated WIPP Parallel Calculation

The following three sections present the input data, the initial stress subroutine, and the formatted output, respectively, for the Heated Parallel Calculation verification problem.

FASTQ and SANTOS Input Data For The Heated WIPP Parallel Calculation

This section presents a listing of the FASTQ and SANTOS input data files that were used for the mesh generation and analysis of the Parallel Calculation heated drift problem.

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```
TITLE
     REFERENCE PARALLEL HEATED CACULATION (Structural - 1/19/95)
POINT      1      0.0000000E+00       -5.4189999E+01
POINT      2      2.7500000E+00       -5.4189999E+01
POINT      3      1.1750000E+01       -5.4189999E+01
POINT      4      0.0000000E+00       -4.9990002E+01
POINT      5      2.7500000E+00       -4.9990002E+01
POINT      6      1.1750000E+01       -4.9990002E+01
POINT      7      0.0000000E+00       -3.0600000E+01
POINT      8      2.7500000E+00       -3.0600000E+01
POINT      9      1.1750000E+01       -3.0600000E+01
POINT     10      2.7500000E+00       -3.0600000E+01
POINT     11      0.0000000E+00       -2.6209999E+01
POINT     12      2.7500000E+00       -2.6209999E+01
POINT     13      1.1750000E+01       -2.6209999E+01
POINT     14      0.0000000E+00       -1.6410000E+01
POINT     15      2.7500000E+00       -1.6410000E+01
POINT     16      1.1750000E+01       -1.6410000E+01
POINT     17      2.7500000E+00       -1.6410000E+01
POINT     18      0.0000000E+00       -1.6330000E+01
POINT     19      2.7500000E+00       -1.6330000E+01
POINT     20      1.1750000E+01       -1.6330000E+01
POINT     21      0.0000000E+00       -1.1370000E+01
POINT     22      2.7500000E+00       -1.1370000E+01
POINT     23      1.1750000E+01       -1.1370000E+01
POINT     24      2.7500000E+00       -1.1370000E+01
POINT     25      0.0000000E+00       -8.6300001E+00
POINT     26      2.7500000E+00       -8.6300001E+00
POINT     27      1.1750000E+01       -8.6300001E+00
POINT     28      2.7500000E+00       -8.6300001E+00
POINT     29      0.0000000E+00       -7.7700000E+00
POINT     30      2.7500000E+00       -7.7700000E+00
POINT     31      1.1750000E+01       -7.7700000E+00
POINT     32      0.0000000E+00       -3.7200000E+00
POINT     33      2.7500000E+00       -3.7200000E+00
POINT     34      1.1750000E+01       -3.7200000E+00
POINT     35      0.0000000E+00       -2.9000001E+00
POINT     36      2.7500000E+00       -2.9000001E+00
POINT     37      1.1750000E+01       -2.9000001E+00
POINT     38      2.7500000E+00       -2.9000001E+00
POINT     39      0.0000000E+00       -1.0800000E+00
POINT     40      2.7500000E+00       -1.0800000E+00
POINT     41      1.1750000E+01       -1.0800000E+00
POINT     42      2.7500000E+00        0.0000000E+00
POINT     43      2.7500000E+00        0.0000000E+00
POINT     44      1.1750000E+01        0.0000000E+00
POINT     45      2.7500000E+00        2.0999999E+00
POINT     46      2.7200000E+00        2.0999999E+00
POINT     47      1.1750000E+01        2.0999999E+00
POINT     48      2.7500000E+00        2.3099999E+00
POINT     49      1.1750000E+01        2.3099999E+00
POINT     50      2.7500000E+00        4.2700000E+00
POINT     51      2.7000000E+00        4.2700000E+00
POINT     52      1.1750000E+01        4.2700000E+00
```

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```
POINT      53        2.7500000E+00       4.4200001E+00
POINT      54        1.1750000E+01       4.4200001E+00
POINT      55        0.0000000E+00       4.4200001E+00
POINT      56        0.0000000E+00       6.7100000E+00
POINT      57        2.7500000E+00       6.7100000E+00
POINT      58        1.1750000E+01       6.7100000E+00
POINT      59        2.7500000E+00       6.7100000E+00
POINT      60        0.0000000E+00       7.7700000E+00
POINT      61        2.7500000E+00       7.7700000E+00
POINT      62        1.1750000E+01       7.7700000E+00
POINT      63        0.0000000E+00       9.1599998E+00
POINT      64        2.7500000E+00       9.1599998E+00
POINT      65        1.1750000E+01       9.1599998E+00
POINT      66        2.7500000E+00       9.1599998E+00
POINT      67        0.0000000E+00       9.3500004E+00
POINT      68        2.7500000E+00       9.3500004E+00
POINT      69        1.1750000E+01       9.3500004E+00
POINT      70        0.0000000E+00       1.0670000E+01
POINT      71        2.7500000E+00       1.0670000E+01
POINT      72        1.1750000E+01       1.0670000E+01
POINT      73        0.0000000E+00       1.3580000E+01
POINT      74        2.7500000E+00       1.3580000E+01
POINT      75        1.1750000E+01       1.3580000E+01
POINT      76        2.7500000E+00       1.3580000E+01
POINT      77        0.0000000E+00       2.8299999E+01
POINT      78        2.7500000E+00       2.8299999E+01
POINT      79        1.1750000E+01       2.8299999E+01
POINT      80        2.7500000E+00       2.8299999E+01
POINT      81        0.0000000E+00       3.1860001E+01
POINT      82        2.7500000E+00       3.1860001E+01
POINT      83        1.1750000E+01       3.1860001E+01
POINT      84        0.0000000E+00       4.9380001E+01
POINT      85        2.7500000E+00       4.9380001E+01
POINT      86        1.1750000E+01       4.9380001E+01
POINT      87        0.0000000E+00       5.2869999E+01
POINT      88        2.7500000E+00       5.2869999E+01
POINT      89        1.1750000E+01       5.2869999E+01
LINE        1   STR      1       2       0       6      0.000000
SIDEBC      1     1
LINE        2   STR      2       3       0      10      1.100000
SIDEBC      1     2
LINE        3   STR      1       4       0       1      0.000000
LINEBC      2     3
LINE        4   STR      2       5       0       1      0.000000
LINE        5   STR      3       6       0       1      0.000000
LINEBC      2     5
LINE        6   STR      4       5       0       6      0.000000
LINE        7   STR      5       6       0      10      1.100000
LINE        8   STR      4       7       0       5      0.000000
LINEBC      2     8
LINE        9   STR      5       8       0       5      0.000000
LINE       10   STR      6       9       0       5      0.000000
LINEBC      2    10
LINE       11   STR      7       8       0       6      0.000000
```

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```
SIDEBC 1011     11
LINE      12    STR      8      9      0     10     1.100000
SIDEBC 1011     12
LINE      13    STR      7     10      0      6     0.000000
SIDEBC 1013     13
LINE      14    STR     10      9      0     10     1.100000
SIDEBC 1013     14
LINE      15    STR      7     11      0      3     0.000000
LINEBC     2    15
LINE      16    STR     10     12      0      3     0.000000
LINE      17    STR      9     13      0      3     0.000000
LINEBC     2    17
LINE      18    STR     11     12      0      6     0.000000
LINE      19    STR     12     13      0     10     1.100000
LINE      20    STR     11     14      0      8     0.000000
LINEBC     2    20
LINE      21    STR     12     15      0      8     0.000000
LINE      22    STR     13     16      0      8     0.000000
LINEBC     2    22
LINE      23    STR     14     15      0      6     0.000000
SIDEBC 1023     23
LINE      24    STR     15     16      0     10     1.100000
SIDEBC 1023     24
LINE      25    STR     14     17      0      6     0.000000
SIDEBC 1025     25
LINE      26    STR     17     16      0     10     1.100000
SIDEBC 1025     26
LINE      27    STR     14     18      0      1     0.000000
LINEBC     2    27
LINE      28    STR     17     19      0      1     0.000000
LINE      29    STR     16     20      0      1     0.000000
LINEBC     2    29
LINE      30    STR     18     19      0      6     0.000000
LINE      31    STR     19     20      0     10     1.100000
LINE      32    STR     18     21      0      7     0.000000
LINEBC     2    32
LINE      33    STR     19     22      0      7     0.000000
LINE      34    STR     20     23      0      7     0.000000
LINEBC     2    34
LINE      35    STR     21     22      0      6     0.000000
SIDEBC 1035     35
LINE      36    STR     22     23      0     10     1.100000
SIDEBC 1035     36
LINE      37    STR     21     24      0      6     0.000000
SIDEBC 1037     37
LINE      38    STR     24     23      0     10     1.100000
SIDEBC 1037     38
LINE      39    STR     21     25      0      5     0.000000
LINEBC     2    39
LINE      40    STR     24     26      0      5     0.000000
LINE      41    STR     23     27      0      5     0.000000
LINEBC     2    41
LINE      42    STR     25     26      0      6     0.000000
SIDEBC 1042     42
```

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```
LINE      43    STR     26     27     0    10    1.100000
SIDEBC 1042      43
LINE      44    STR     25     28     0     6    0.000000
SIDEBC 1044      44
LINE      45    STR     28     27     0    10    1.100000
SIDEBC 1044      45
LINE      46    STR     25     29     0     2    0.000000
LINEBC     2     46
LINE      47    STR     28     30     0     2    0.000000
LINE      48    STR     27     31     0     2    0.000000
LINEBC     2     48
LINE      49    STR     29     30     0     6    0.000000
LINE      50    STR     30     31     0    10    1.100000
LINE      51    STR     29     32     0     8    0.000000
LINEBC     2     51
LINE      52    STR     30     33     0     8    0.000000
LINE      53    STR     31     34     0     8    0.000000
LINEBC     2     53
LINE      54    STR     32     33     0     6    0.000000
LINE      55    STR     33     34     0    10    1.100000
LINE      56    STR     32     35     0     2    0.000000
LINEBC     2     56
LINE      57    STR     33     36     0     2    0.000000
LINE      58    STR     34     37     0     2    0.000000
LINEBC     2     58
LINE      59    STR     35     36     0     6    0.000000
SIDEBC 1059      59
LINE      60    STR     36     37     0    10    1.100000
SIDEBC 1059      60
LINE      61    STR     35     38     0     6    0.000000
SIDEBC 1061      61
LINE      62    STR     38     37     0    10    1.100000
SIDEBC 1061      62
LINE      63    STR     35     39     0     5    0.000000
LINEBC     2     63
LINE      64    STR     38     40     0     5    0.000000
LINE      65    STR     37     41     0     5    0.000000
LINEBC     2     65
LINE      66    STR     39     40     0     6    0.000000
LINE      67    STR     40     41     0    10    1.100000
LINE      68    STR     40     42     0     2    0.000000
LINE      69    STR     41     44     0     2    0.000000
LINEBC     2     69
LINE      70    STR     42     44     0    10    1.100000
SIDEBC 1070      70
LINE      71    STR     43     44     0    10    1.100000
SIDEBC 1071      71
LINE      72    STR     43     45     0     3    0.000000
LINE      73    STR     44     47     0     3    0.000000
LINEBC     2     73
LINE      74    STR     45     47     0    10    1.100000
SIDEBC 1074      74
LINE      75    STR     46     47     0    10    1.100000
SIDEBC 1075      75
```

Information Only

```
LINE      76   STR   46   48    0    1   0.000000
LINE      77   STR   47   49    0    1   0.000000
LINEBC     2    77
LINE      78   STR   48   49    0   10   1.100000
LINE      79   STR   48   50    0    3   0.000000
LINE      80   STR   49   52    0    3   0.000000
LINEBC     2    80
LINE      81   STR   50   52    0   10   1.100000
SIDEBC  1081    81
LINE      82   STR   51   52    0   10   1.100000
SIDEBC  1082    82
LINE      83   STR   51   53    0    1   0.000000
LINE      84   STR   52   54    0    1   0.000000
LINEBC     2    84
LINE      85   STR   55   53    0    6   0.000000
LINE     185   STR   53   54    0   10   1.100000
LINE      86   STR   55   56    0    4   0.000000
LINEBC     2    86
LINE      87   STR   53   57    0    4   0.000000
LINE      88   STR   54   58    0    4   0.000000
LINEBC     2    88
LINE      89   STR   56   57    0    6   0.000000
SIDEBC  1089    89
LINE      90   STR   57   58    0   10   1.100000
SIDEBC  1089    90
LINE      91   STR   56   59    0    6   0.000000
SIDEBC  1091    91
LINE      92   STR   59   58    0   10   1.100000
SIDEBC  1091    92
LINE      93   STR   56   60    0    2   0.000000
LINEBC     2    93
LINE      94   STR   59   61    0    2   0.000000
LINE      95   STR   58   62    0    2   0.000000
LINEBC     2    95
LINE      96   STR   60   61    0    6   0.000000
LINE      97   STR   61   62    0   10   1.100000
LINE      98   STR   60   63    0    3   0.000000
LINEBC     2    98
LINE      99   STR   61   64    0    3   0.000000
LINE     100   STR   62   65    0    3   0.000000
LINEBC     2   100
LINE     101   STR   63   64    0    6   0.000000
SIDEBC  1101   101
LINE     102   STR   64   65    0   10   1.100000
SIDEBC  1101   102
LINE     103   STR   63   66    0    6   0.000000
SIDEBC  1103   103
LINE     104   STR   66   65    0   10   1.100000
SIDEBC  1103   104
LINE     105   STR   63   67    0    1   0.000000
LINEBC     2   105
LINE     106   STR   66   68    0    1   0.000000
LINE     107   STR   65   69    0    1   0.000000
LINEBC     2   107
```

Information Only

```
LINE     108    STR    67    68    0    6    0.000000
LINE     109    STR    68    69    0   10    1.100000
LINE     110    STR    67    70    0    3    0.000000
LINEBC     2    110
LINE     111    STR    68    71    0    3    0.000000
LINE     112    STR    69    72    0    3    0.000000
LINEBC     2    112
LINE     113    STR    70    71    0    6    0.000000
LINE     114    STR    71    72    0   10    1.100000
LINE     115    STR    70    73    0    5    0.000000
LINEBC     2    115
LINE     116    STR    71    74    0    5    0.000000
LINE     117    STR    72    75    0    5    0.000000
LINEBC     2    117
LINE     118    STR    73    74    0    6    0.000000
SIDEBC  1118    118
LINE     119    STR    74    75    0   10    1.100000
SIDEBC  1118    119
LINE     120    STR    73    76    0    6    0.000000
SIDEBC  1120    120
LINE     121    STR    76    75    0   10    1.100000
SIDEBC  1120    121
LINE     122    STR    73    77    0    7    0.000000
LINEBC     2    122
LINE     123    STR    76    78    0    7    0.000000
LINE     124    STR    75    79    0    7    0.000000
LINEBC     2    124
LINE     125    STR    77    78    0    6    0.000000
SIDEBC  1125    125
LINE     126    STR    78    79    0   10    1.100000
SIDEBC  1125    126
LINE     127    STR    77    80    0    6    0.000000
SIDEBC  1127    127
LINE     128    STR    80    79    0   10    1.100000
SIDEBC  1127    128
LINE     129    STR    77    81    0    2    0.000000
LINEBC     2    129
LINE     130    STR    80    82    0    2    0.000000
LINE     131    STR    79    83    0    2    0.000000
LINEBC     2    131
LINE     132    STR    81    82    0    6    0.000000
LINE     133    STR    82    83    0   10    1.100000
LINE     134    STR    81    84    0    5    0.000000
LINEBC     2    134
LINE     135    STR    82    85    0    5    0.000000
LINE     136    STR    83    86    0    5    0.000000
LINEBC     2    136
LINE     137    STR    84    85    0    6    0.000000
LINE     138    STR    85    86    0   10    1.100000
LINE     139    STR    84    87    0    2    0.000000
LINEBC     2    139
LINE     140    STR    85    88    0    2    0.000000
LINE     141    STR    86    89    0    2    0.000000
LINEBC     4    141
```

Information Only

```
LINE      142    STR     87     88      0      6    0.000000
SIDEBC      3    142
LINE      143    STR     88     89      0     10    1.100000
SIDEBC      3    143
SIDE      201      1      2
SIDE      202      6      7
SIDE      203     11     12
SIDE      204     13     14
SIDE      205     18     19
SIDE      206     23     24
SIDE      207     25     26
SIDE      208     30     31
SIDE      209     35     36
SIDE      210     37     38
SIDE      211     42     43
SIDE      212     44     45
SIDE      213     49     50
SIDE      214     54     55
SIDE      215     59     60
SIDE      216     61     62
SIDE      217     66     67
SIDE      218     85    185
SIDE      219     89     90
SIDE      220     91     92
SIDE      221     96     97
SIDE      222    101    102
SIDE      223    103    104
SIDE      224    108    109
SIDE      225    113    114
SIDE      226    118    119
SIDE      227    120    121
SIDE      228    125    126
SIDE      229    127    128
SIDE      230    132    133
SIDE      231    137    138
SIDE      232    142    143
REGION      1      4    201     -5    202     -3
REGION      2      1    202    -10    203     -8
REGION      3      3    204    -17    205    -15
REGION      4      1    205    -22    206    -20
REGION      5      3    207    -29    208    -27
REGION      6      1    208    -34    209    -32
REGION      7      1    210    -41    211    -39
REGION      8      3    212    -48    213    -46
REGION      9      1    213    -53    214    -51
REGION     10      2    214    -58    215    -56
REGION     11      1    216    -65    217    -63
REGION     12      1    -67    -69    -70    -68
REGION     13      1    -71    -73    -74    -72
REGION     14      3    -75    -77    -78    -76
REGION     15      1    -78    -80    -81    -79
REGION     16      1    -82    -84   -185    -83
REGION     17      1    218    -88    219    -86
REGION     18      1    220    -95    221    -93
```

Information Only

```
REGION    19    2    221   -100    222    -98
REGION    20    3    223   -107    224   -105
REGION    21    1    224   -112    225   -110
REGION    22    2    225   -117    226   -115
REGION    23    1    227   -124    228   -122
REGION    24    3    229   -131    230   -129
REGION    25    1    230   -136    231   -134
REGION    26    3    231   -141    232   -139
SCHEME     0
EXIT
```

Information Only

```
TITLE
 REFERENCE PARALLEL HEATED PROBLEM - SANTOS VERIFICATION (1/27/95)
RESIDUAL TOLERANCE = .5
MAXIMUM ITERATIONS = 20000
INTERMEDIATE PRINT = 100
MAXIMUM TOLERANCE = 5.
THERMAL STRESS, EXTERNAL
PLANE STRAIN
TIME STEP SCALE = .50
PREDICTOR SCALE FACTOR = 3
EFFECTIVE MODULUS = VARIABLE
INITIAL STRESS = USER
GRAVITY = 1 = 0. = -9.790 = 0.
STEP CONTROL
 400 1.5785E8
END
PLOT TIME
 4 1.5785E8
END
OUTPUT TIME
 10 1.5785E8
END
PLOT NODAL DISPLACEMENT, REACTION, RESIDUAL
PLOT ELEMENT STRESS, VONMISES, TEMPERATURE, EFFMOD, PRESSURE
PLOT STATE EQCS, EVMAX, EVFRAC, EV, NUM
NO DISPLACEMENT X, 2
NO DISPLACEMENT X, 4
NO DISPLACEMENT Y, 4
FUNCTION = 1
0. 1.
4.E8 1.
END
FUNCTION = 2
299 -.01
400 1.
END
FUNCTION = 3
0. 0.
4.E8 0.
END
PRESSURE, 3, 1, 13.57E6
PRESSURE, 1, 1, 15.95E6
CONTACT SURFACE, 1013, 1011, FIXED,
CONTACT SURFACE, 1025, 1023, FIXED,
CONTACT SURFACE, 1037, 1035, 0.4
CONTACT SURFACE, 1044, 1042, 0.4
CONTACT SURFACE, 1061, 1059, 0.4
CONTACT SURFACE, 1071, 1070, 0.4
CONTACT SURFACE, 1075, 1074, 0.4
CONTACT SURFACE, 1082, 1081, 0.4
CONTACT SURFACE, 1091, 1089, 0.4
CONTACT SURFACE, 1103, 1101, 0.4
CONTACT SURFACE, 1120, 1118, 0.4
CONTACT SURFACE, 1127, 1125, FIXED,
```

Information Only

```
MATERIAL, 1, POWER LAW CREEP, 2300., 2, 4.5E-3  $  HALITE
TWO MU = 24.8E9
BULK MODULUS = 20.7E9
CREEP CONSTANT = 5.79E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 6039.
END
MATERIAL, 2, POWER LAW CREEP, 2300., 2, 4.E-3   $  ARGILLACEOUS
HALITE
TWO MU = 24.8E9
BULK MODULUS = 20.7E9
CREEP CONSTANT = 1.74E-35
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 6039.
END
MATERIAL, 3, SOIL N FOAMS, 2300., 2, 2.E-3      $ ANHYDRITE
TWO MU = 55.630E9
BULK MODULUS = 83.444E9
A0 = 2.3383E6
A1 = 2.3383
A2 = 0.0
PRESSURE CUTOFF = -1.0E6
FUNCTION ID = 0
END
MATERIAL, 4, SOIL N FOAMS, 2300., 2, 2.4E-3     $ POLYHALITE
TWO MU = 40.662E9
BULK MODULUS = 65.833E9
A0 = 2.4595E6
A1 = 2.4578
A2 = 0.0
PRESSURE CUTOFF = -1.0E6
FUNCTION ID = 0
END
EXIT
```

Information Only

Initial Stress Subroutine For The Heated WIPP Parallel Calculation

This section presents a listing of the INITST subroutine that was used in SANTOS to specify the initial stresses for the Parallel Calculation heated drift analysis.

Information Only

```
      SUBROUTINE INITST( SIG,COORD,LINK,DATMAT,KONMAT,SCREL )
C
C
*********************************************************************
C
C   DESCRIPTION:
C     THIS ROUTINE PROVIDES AN INITIAL STRESS STATE TO SANTOS
C
C   FORMAL PARAMETERS:
C     SIG       REAL         ELEMENT STRESS ARRAY WHICH MUST BE RETURNED
C                            WITH THE REQUIRED STRESS VALUES
C     COORD     REAL         GLOBAL NODAL COORDINATE ARRAY
C     LINK      INTEGER      CONNECTIVITY ARRAY
C     DATMAT    REAL         MATERIAL PROPERTIES ARRAY
C     KONMAT    INTEGER      MATERIAL PROPERTIES INTEGER ARRAY
C
C   CALLED BY: INIT
C
C
*********************************************************************
C
      INCLUDE 'params.blk'
      INCLUDE 'psize.blk'
      INCLUDE 'contrl.blk'
      INCLUDE 'bsize.blk'
      INCLUDE 'timer.blk'
C
      DIMENSION LINK(NELNS,NUMEL),KONMAT(10,NEMBLK),COORD(NNOD,NSPC),
     *          SIG(NSYMM,NUMEL),DATMAT(MCONS,*),SCREL(NEBLK,*)
C
      DO 1000 I = 1,NEMBLK
         MATID = KONMAT(1,I)
         MKIND = KONMAT(2,I)
         ISTRT = KONMAT(3,I)
         IEND = KONMAT(4,I)
            DO 500 J = ISTRT,IEND
               II = LINK( 1,J )
               JJ = LINK( 2,J )
               KK = LINK( 3,J )
               LL = LINK( 4,J )
               ZAVG = 0.25 * ( COORD(II,2) + COORD(JJ,2) + COORD(KK,2) +
     *                   COORD(LL,2) )
               STRESS = - 2.256E4 * ( 655. - ZAVG )
               SIG(1,J) = STRESS
               SIG(2,J) = STRESS
               SIG(3,J) = STRESS
               SIG(4,J) = 0.0
  500       CONTINUE
 1000 CONTINUE
      RETURN
      END
```

Information Only

SANTOS Output For The Heated WIPP Parallel Calculation

The following section presents a portion of the SANTOS printed output for the Parallel Calculation heated drift analysis. Because all pertinent information and results from the analysis are written to the plot file for post-processing, the printed output file simply echoes input data and problem–descriptive information at the beginning, followed by information that tracks the convergence behavior of the solution, and a summary of CPU usage at the end. For this reason, only a partial listing, consisting of approximately the first 500 lines of output and the last 100 lines of output, is provided.

Information Only

```
 SSSSSS   AAAAA   N    NN  TTTTTT    OOOOO    SSSSSS
SS       AA   AA  NN   NN    TT     OO   OO  SS
SS       AA   AA  NNN  NN    TT     OO   OO  SS
 SSSSS   AAAAAAA  NN N NN    TT     OO   OO   SSSSS
     SS  AA   AA  NN  NNN    TT     OO   OO       SS
     SS  AA   AA  NN   NN    TT     OO   OO       SS
SSSSSS   AA   AA  NN    N    TT      OOOOO   SSSSSS


                 VERSION 2.0.0
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                PROGRAMMED BY:

               CHARLES M. STONE
          ENGINEERING SCIENCES CENTER
         SANDIA NATIONAL LABORATORIES
         ALBUQUERQUE, NEW MEXICO 87185

          DERIVED FROM PRONTO2D BY
     LEE M. TAYLOR AND DENNIS P. FLANAGAN


          RUN ON 03/11/96 AT 10:04:21
        RUN ON A Cray0J90 UNDER UniCo8.0
```

Information Only

Information Only

```
                                   INPUT STREAM IMAGES
LINE -------------------------------------------------------------------------------------
  1: TITLE
  2:   REFERENCE PARALLEL HEATED PROBLEM - SANTOS VERIFICATION (1/27/95)
  3: RESIDUAL TOLERANCE = .5
  4: MAXIMUM ITERATIONS = 20000
  5: INTERMEDIATE PRINT = 100
  6: MAXIMUM TOLERANCE = 5.
  7: THERMAL STRESS, EXTERNAL
  8: PLANE STRAIN
  9: TIME STEP SCALE = .50
 10: PREDICTOR SCALE FACTOR = 3
 11: EFFECTIVE MODULUS = VARIABLE
 12: INITIAL STRESS = USER
 13: GRAVITY = 1 = 0. = -9.790 = 0.
 14: STEP CONTROL
 15:  400 1.5785E8
 16: END
 17: PLOT TIME
 18:  4 1.5785E8
 19: END
 20: OUTPUT TIME
 21:  10 1.5785E8
 22: END
 23: PLOT NODAL DISPLACEMENT, REACTION, RESIDUAL
 24: PLOT ELEMENT STRESS, VONMISES, TEMPERATURE, EFFMOD, PRESSURE
 25: PLOT STATE EQCS, EVMAX, EVFRAC, EV, NUM
 26: NO DISPLACEMENT X, 2
 27: NO DISPLACEMENT X, 4
 28: NO DISPLACEMENT Y, 4
 29: FUNCTION = 1
 30: 0. 1.
 31: 4.E8 1.
 32: END
 33: FUNCTION = 2
```

Information Only

```
299 -.01
400 1.
END
FUNCTION = 3
0. 0.
4.E8 0.
END
PRESSURE, 3, 1, 13.57E6
PRESSURE, 1, 1, 15.95E6
CONTACT SURFACE, 1013, 1011, FIXED,
CONTACT SURFACE, 1025, 1023, FIXED,
CONTACT SURFACE, 1037, 1035, 0.4
CONTACT SURFACE, 1044, 1042, 0.4
CONTACT SURFACE, 1061, 1059, 0.4
CONTACT SURFACE, 1071, 1070, 0.4
CONTACT SURFACE, 1075, 1074, 0.4
CONTACT SURFACE, 1082, 1081, 0.4
CONTACT SURFACE, 1091, 1089, 0.4
CONTACT SURFACE, 1103, 1101, 0.4
CONTACT SURFACE, 1120, 1118, 0.4
CONTACT SURFACE, 1127, 1125, FIXED,
MATERIAL, 1, POWER LAW CREEP, 2300., 2, 4.5E-3  $  HALITE
TWO MU = 24.8E9
BULK MODULUS = 20.7E9
CREEP CONSTANT = 5.79E-36
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 6039.
END
MATERIAL, 2, POWER LAW CREEP, 2300., 2, 4.E-3   $  ARGILLACEOUS HALITE
TWO MU = 24.8E9
BULK MODULUS = 20.7E9
CREEP CONSTANT = 1.74E-35
STRESS EXPONENT = 4.9
THERMAL CONSTANT = 6039.
END
MATERIAL, 3, SOIL N FOAMS, 2300., 2, 2.E-3      $ ANHYDRITE
```

Information Only

```
70: TWO MU = 55.630E9
71: BULK MODULUS = 83.444E9
72: A0 = 2.3383E6
73: A1 = 2.3383
74: A2 = 0.0
75: PRESSURE CUTOFF = -1.0E6
76: FUNCTION ID = 0
77: END
78: MATERIAL, 4, SOIL N FOAMS, 2300., 2, 2.4E-3     $ POLYHALITE
79: TWO MU = 40.662E9
80: BULK MODULUS = 65.833E9
81: A0 = 2.4595E6
82: A1 = 2.4578
83: A2 = 0.0
84: PRESSURE CUTOFF = -1.0E6
85: FUNCTION ID = 0
86: END
87: EXIT
    -----------------------------------------------------------------------
```

```
                    P R O B L E M   T I T L E

     REFERENCE PARALLEL HEATED PROBLEM - SANTOS VERIFICATION (1/27/95)


                   P R O B L E M   D E F I N I T I O N

      NUMBER OF ELEMENTS .......................        1396
      NUMBER OF NODES ..........................        1675
      NUMBER OF MATERIALS ......................           4
      NUMBER OF FUNCTIONS ......................           3
      NUMBER OF CONTACT SURFACES ...............          12
      NUMBER OF RIGID SURFACES .................           0
      NUMBER OF MATERIAL POINTS MONITORED ......           0
      ANALYSIS TYPE ............................ PLANE STRAIN
      GLOBAL CONVERGENCE MEASURE ...............
      RESIDUAL TOLERANCE .......................   5.000E-01
      MAXIMUM NUMBER OF ITERATIONS .............       20000
      ITERATIONS FOR INTERMEDIATE PRINT ........         100
      MAXIMUM RESIDUAL TOLERANCE ...............   5.000E+00
      PREDICTOR SCALE FACTOR FUNCTION ..........           3
      MINIMUM DAMPING FACTOR ...................   2.000E-01
      EFFECTIVE MODULUS STATUS ................. VARIABLE
      THERMAL STRESS ANALYSIS PERFORMED ........ EXTERNAL
         THERMAL FORCE MAGNITUDE ...............   0.000E+00
      INITIAL STRESS DISTRIBUTION APPLIED ......
      GRAVITY LOADS APPLIED ....................
      SCALE FACTOR APPLIED TO TIME STEP ........   5.000E-01
      STRAIN SOFTENING SCALE FACTOR ............   1.000E+00
      HOURGLASS STIFFNESS FACTOR ...............   5.000E-02
      HOURGLASS VISCOSITY FACTOR ...............   0.000E+00
```

Information Only

Information Only

```
          L O A D   S T E P   D E F I N I T I O N S


   TIME             NO. OF STEPS            TIME
 0.000E+00              400              1.579E+08



          P R I N T E D   O U T P U T   F R E Q U E N C Y


   TIME       STEPS BETWEEN PRINTS            TIME
 0.000E+00             10                  1.579E+08



          P L O T T E D   O U T P U T   F R E Q U E N C Y


   TIME       STEPS BETWEEN PLOTS             TIME
 0.000E+00             4                   1.579E+08



          M A T E R I A L   D E F I N I T I O N S


  MATERIAL TYPE ........................SOIL N FOAMS
  MATERIAL ID ..........................         4
  DENSITY ..............................  2.300E+03
  THERMAL STRAIN ID ....................         2
```

Information Only

```
THERMAL STRAIN SCALE FACTOR ..........  2.400E-03
MATERIAL PROPERTIES:
       TWO MU                   =     4.066E+10
       BULK MODULUS             =     6.583E+10
       A0                       =     2.460E+06
       A1                       =     2.458E+00
       A2                       =     0.000E+00
       FUNCTION ID              =     0.000E+00
       PRESSURE CUTOFF          =    -1.000E+06
CONICAL YIELD SURFACE
MAXIMUM TENSILE PRESSURE  -1.000E+06
PEAK PRESSURE USED FOR
QUADRATIC PRESSURE YIELD   6.583E+12


MATERIAL TYPE .......................POWER LAW CREEP
MATERIAL ID .........................          1
DENSITY .............................  2.300E+03
THERMAL STRAIN ID ...................          2
THERMAL STRAIN SCALE FACTOR ..........  4.500E-03
MATERIAL PROPERTIES:
       TWO MU                   =     2.480E+10
       BULK MODULUS             =     2.070E+10
       CREEP CONSTANT           =     5.790E-36
       STRESS EXPONENT          =     4.900E+00
       THERMAL CONSTANT         =     6.039E+03


MATERIAL TYPE .......................SOIL N FOAMS
MATERIAL ID .........................          3
DENSITY .............................  2.300E+03
THERMAL STRAIN ID ...................          2
THERMAL STRAIN SCALE FACTOR ..........  2.000E-03
MATERIAL PROPERTIES:
       TWO MU                   =     5.563E+10
       BULK MODULUS             =     8.344E+10
```

Information Only

```
               A0                       =    2.338E+06
               A1                       =    2.338E+00
               A2                       =    0.000E+00
               FUNCTION ID              =    0.000E+00
               PRESSURE CUTOFF          =   -1.000E+06
        CONICAL YIELD SURFACE
        MAXIMUM TENSILE PRESSURE DETERMINED FROM
        YIELD SURFACE IS LESS THAN THE USER
        SUPPLIED PRESSURE CUTOFF. COMPUTED VALUE
        WILL BE USED:
        MAXIMUM TENSILE PRESSURE  -1.000E+06
        PEAK PRESSURE USED FOR
        QUADRATIC PRESSURE YIELD   8.344E+12


        MATERIAL TYPE ........................POWER LAW CREEP
        MATERIAL ID ..........................          2
        DENSITY ..............................  2.300E+03
        THERMAL STRAIN ID ....................          2
        THERMAL STRAIN SCALE FACTOR ..........  4.000E-03
        MATERIAL PROPERTIES:
               TWO MU                   =    2.480E+10
               BULK MODULUS             =    2.070E+10
               CREEP CONSTANT           =    1.740E-35
               STRESS EXPONENT          =    4.900E+00
               THERMAL CONSTANT         =    6.039E+03



             F U N C T I O N   D E F I N I T I O N S


    FUNCTION ID .........      1     NUMBER OF POINTS ....      2

               N        S          F(S)
```

```
                1     0.000E+00     1.000E+00
                2     4.000E+08     1.000E+00


      FUNCTION ID .........      2     NUMBER OF POINTS ....      2

                N          S             F(S)
                1     2.990E+02    -1.000E-02
                2     4.000E+02     1.000E+00


      FUNCTION ID .........      3     NUMBER OF POINTS ....      2

                N          S             F(S)
                1     0.000E+00     0.000E+00
                2     4.000E+08     0.000E+00




   N O   D I S P L A C E M E N T   B O U N D A R Y   C O N D I T I O N S

             NODE SET FLAG      DIRECTION
                   2                X
                   4                X
                   4                Y



             C O N T A C T   S U R F A C E S

   SURFACE  SURFACE 1  SURFACE 2  PENALTY  COEFFICIENT  PENETRATION  TENSION
   NUMBER     FLAG       FLAG     FACTOR   OF FRICTION  MULTIPLIER   RELEASE
      1       1013       1011   0.000E+00     FIXED     1.000E-02  1.000E+40
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 2     1025       1023   0.000E+00     FIXED    1.000E-02    1.000E+40
 3     1037       1035   0.000E+00   4.000E-01   1.000E-02    1.000E+40
 4     1044       1042   0.000E+00   4.000E-01   1.000E-02    1.000E+40
 5     1061       1059   0.000E+00   4.000E-01   1.000E-02    1.000E+40
 6     1071       1070   0.000E+00   4.000E-01   1.000E-02    1.000E+40
 7     1075       1074   0.000E+00   4.000E-01   1.000E-02    1.000E+40
 8     1082       1081   0.000E+00   4.000E-01   1.000E-02    1.000E+40
 9     1091       1089   0.000E+00   4.000E-01   1.000E-02    1.000E+40
10     1103       1101   0.000E+00   4.000E-01   1.000E-02    1.000E+40
11     1120       1118   0.000E+00   4.000E-01   1.000E-02    1.000E+40
12     1127       1125   0.000E+00     FIXED    1.000E-02    1.000E+40


P R E S S U R E   B O U N D A R Y   C O N D T I O N S

        SURFACE       FUNCTION     SCALE
         FLAG          NUMBER      FACTOR
           3             1       1.357E+07
           1             1       1.595E+07


                  E N D   O F   D A T A   I N P U T   P H A S E
                        4.057E-01 CPU SECONDS USED
                             176 WORDS ALLOCATED


      E N D   O F   D A T A   I N I T I A L I Z A T I O N   P H A S E
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                    3.079E-02 CPU SECONDS USED
                         1675 WORDS ALLOCATED



        V A R I A B L E S   O N   P L O T T I N G   D A T A   B A S E

                    NODAL          ELEMENT        GLOBAL
                    -----          -------        ------
                    DISPLX         SIGXX          FX
                    DISPLY         SIGYY          FY
                    RESIDX         SIGZZ          RX
                    RESIDY         TAUXY          RY
                    RESID          TEMP           ITER
                    REACTX         PRESSURE       RMAG
                    REACTY         VONMISES
                                   EFFMOD
                                   EQCS
                                   EVMAX
                                   EVFRAC
                                   EV
                                   NUM


  **** PLOT TAPE WRITTEN FOR THE INITIAL STATE AT TIME = 0.000E+00 ****


STEP        TIME         TIME       DAMPING     APPLIED     RESIDUAL     PERCENT     TOTAL
                         STEP       FACTOR     LOAD NORM    LOAD NORM   IMBALANCE    STEPS
   100   3.946E+05   3.946E+05   9.560E-01   6.428E+07   2.295E+07     35.70        100
   200   3.946E+05   3.946E+05   9.781E-01   6.428E+07   1.519E+07     23.62        200
   300   3.946E+05   3.945E+05   9.836E-01   6.429E+07   1.089E+07     16.94        300
   400   3.946E+05   3.945E+05   9.892E-01   6.429E+07   8.741E+06     13.60        400
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500	3.946E+05	3.945E+05	9.985E-01	6.429E+07	3.204E+07	49.84	500
600	3.946E+05	3.945E+05	9.673E-01	6.429E+07	1.750E+07	27.23	600
700	3.946E+05	3.944E+05	8.600E-01	6.429E+07	1.410E+07	21.94	700
800	3.946E+05	3.944E+05	9.860E-01	6.429E+07	1.612E+07	25.08	800
900	3.946E+05	3.944E+05	8.607E-01	6.429E+07	1.412E+07	21.96	900
1000	3.946E+05	3.944E+05	9.462E-01	6.429E+07	1.224E+07	19.04	1000
1100	3.946E+05	3.944E+05	9.451E-01	6.429E+07	1.554E+07	24.18	1100
1200	3.946E+05	3.944E+05	9.786E-01	6.429E+07	2.150E+07	33.45	1200
1300	3.946E+05	3.944E+05	9.397E-01	6.429E+07	7.567E+06	11.77	1300
1400	3.946E+05	3.944E+05	9.068E-01	6.429E+07	1.026E+07	15.96	1400
1500	3.946E+05	3.944E+05	9.246E-01	6.429E+07	9.157E+06	14.24	1500
1600	3.946E+05	3.944E+05	9.704E-01	6.429E+07	1.163E+07	18.08	1600
1700	3.946E+05	3.944E+05	9.829E-01	6.429E+07	8.852E+06	13.77	1700
1800	3.946E+05	3.944E+05	9.539E-01	6.429E+07	7.839E+06	12.19	1800
1900	3.946E+05	3.944E+05	9.729E-01	6.429E+07	8.601E+06	13.38	1900
2000	3.946E+05	3.944E+05	9.657E-01	6.429E+07	5.986E+06	9.31	2000
2100	3.946E+05	3.944E+05	9.996E-01	6.429E+07	8.561E+06	13.32	2100
2200	3.946E+05	3.944E+05	9.148E-01	6.429E+07	5.565E+06	8.66	2200
2300	3.946E+05	3.944E+05	9.952E-01	6.429E+07	1.016E+07	15.81	2300
2400	3.946E+05	3.944E+05	7.274E-01	6.429E+07	8.028E+06	12.49	2400
2500	3.946E+05	3.944E+05	8.954E-01	6.429E+07	5.615E+06	8.73	2500
2600	3.946E+05	3.944E+05	8.630E-01	6.429E+07	3.714E+06	5.78	2600
2700	3.946E+05	3.945E+05	8.958E-01	6.429E+07	7.712E+06	12.00	2700
2800	3.946E+05	3.945E+05	9.650E-01	6.429E+07	3.829E+06	5.96	2800
2900	3.946E+05	3.945E+05	9.773E-01	6.429E+07	5.722E+06	8.90	2900
3000	3.946E+05	3.945E+05	9.971E-01	6.429E+07	7.477E+06	11.63	3000
3100	3.946E+05	3.945E+05	7.685E-01	6.429E+07	4.733E+06	7.36	3100
3200	3.946E+05	3.945E+05	9.578E-01	6.429E+07	6.459E+06	10.05	3200
3300	3.946E+05	3.945E+05	8.165E-01	6.429E+07	6.093E+06	9.48	3300
3400	3.946E+05	3.945E+05	9.563E-01	6.429E+07	7.460E+06	11.60	3400
3500	3.946E+05	3.945E+05	9.255E-01	6.429E+07	3.296E+06	5.13	3500
3600	3.946E+05	3.945E+05	9.983E-01	6.429E+07	4.473E+06	6.96	3600
3700	3.946E+05	3.945E+05	8.579E-01	6.429E+07	1.137E+07	17.69	3700
3800	3.946E+05	3.945E+05	8.789E-01	6.429E+07	4.200E+06	6.53	3800
3900	3.946E+05	3.945E+05	9.967E-01	6.429E+07	5.564E+06	8.65	3900
4000	3.946E+05	3.945E+05	9.759E-01	6.429E+07	4.150E+06	6.46	4000

4100	3.946E+05	3.945E+05	9.356E-01	6.429E+07	6.883E+06	10.71	4100
4200	3.946E+05	3.945E+05	9.970E-01	6.429E+07	4.971E+06	7.73	4200
4300	3.946E+05	3.945E+05	9.998E-01	6.429E+07	3.753E+06	5.84	4300
4400	3.946E+05	3.945E+05	8.574E-01	6.429E+07	3.787E+06	5.89	4400
4500	3.946E+05	3.945E+05	1.000E+00	6.429E+07	2.926E+06	4.55	4500
4600	3.946E+05	3.945E+05	9.547E-01	6.429E+07	3.185E+06	4.96	4600
4700	3.946E+05	3.945E+05	9.322E-01	6.429E+07	4.997E+06	7.77	4700
4800	3.946E+05	3.945E+05	9.166E-01	6.429E+07	3.201E+06	4.98	4800
4900	3.946E+05	3.945E+05	9.989E-01	6.429E+07	3.264E+06	5.08	4900
5000	3.946E+05	3.945E+05	8.928E-01	6.429E+07	8.955E+06	13.93	5000
5100	3.946E+05	3.945E+05	9.923E-01	6.429E+07	3.581E+06	5.57	5100
5200	3.946E+05	3.945E+05	1.000E+00	6.429E+07	3.809E+06	5.93	5200
5300	3.946E+05	3.945E+05	8.921E-01	6.429E+07	3.698E+06	5.75	5300
5400	3.946E+05	3.945E+05	7.988E-01	6.429E+07	3.112E+06	4.84	5400
5500	3.946E+05	3.945E+05	9.831E-01	6.429E+07	4.447E+06	6.92	5500
5600	3.946E+05	3.945E+05	9.744E-01	6.429E+07	2.484E+06	3.86	5600
5700	3.946E+05	3.945E+05	9.997E-01	6.429E+07	2.406E+06	3.74	5700
5800	3.946E+05	3.945E+05	8.826E-01	6.429E+07	4.290E+06	6.67	5800
5900	3.946E+05	3.945E+05	9.991E-01	6.429E+07	2.643E+06	4.11	5900
6000	3.946E+05	3.945E+05	9.704E-01	6.429E+07	4.904E+06	7.63	6000
6100	3.946E+05	3.945E+05	9.928E-01	6.429E+07	2.652E+06	4.13	6100
6200	3.946E+05	3.945E+05	9.611E-01	6.429E+07	4.227E+06	6.58	6200
6300	3.946E+05	3.945E+05	1.000E+00	6.429E+07	3.310E+06	5.15	6300
6400	3.946E+05	3.945E+05	9.524E-01	6.429E+07	2.778E+06	4.32	6400
6500	3.946E+05	3.945E+05	1.000E+00	6.429E+07	3.568E+06	5.55	6500
6600	3.946E+05	3.945E+05	9.997E-01	6.429E+07	3.612E+06	5.62	6600
6700	3.946E+05	3.945E+05	9.991E-01	6.429E+07	3.887E+06	6.05	6700
6800	3.946E+05	3.945E+05	1.000E+00	6.429E+07	3.357E+06	5.22	6800
6900	3.946E+05	3.945E+05	9.665E-01	6.429E+07	3.941E+06	6.13	6900
7000	3.946E+05	3.945E+05	9.536E-01	6.429E+07	2.985E+06	4.64	7000
7100	3.946E+05	3.945E+05	9.365E-01	6.429E+07	2.606E+06	4.05	7100
7200	3.946E+05	3.945E+05	9.946E-01	6.429E+07	2.369E+06	3.69	7200
7300	3.946E+05	3.945E+05	9.835E-01	6.429E+07	3.112E+06	4.84	7300
7400	3.946E+05	3.945E+05	9.185E-01	6.429E+07	3.711E+06	5.77	7400
7500	3.946E+05	3.945E+05	1.000E+00	6.429E+07	4.156E+06	6.46	7500
7600	3.946E+05	3.945E+05	9.435E-01	6.429E+07	2.389E+06	3.72	7600

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7700	3.946E+05	3.945E+05	1.000E+00	6.429E+07	5.808E+06	9.03	7700
7800	3.946E+05	3.945E+05	9.949E-01	6.429E+07	5.559E+06	8.65	7800
7900	3.946E+05	3.945E+05	9.937E-01	6.429E+07	2.185E+06	3.40	7900
8000	3.946E+05	3.945E+05	9.998E-01	6.429E+07	3.497E+06	5.44	8000
8100	3.946E+05	3.945E+05	9.047E-01	6.429E+07	2.647E+06	4.12	8100
8200	3.946E+05	3.945E+05	8.729E-01	6.429E+07	3.498E+06	5.44	8200
8300	3.946E+05	3.945E+05	9.297E-01	6.429E+07	3.631E+06	5.65	8300
8400	3.946E+05	3.945E+05	9.917E-01	6.429E+07	7.144E+06	11.11	8400
8500	3.946E+05	3.945E+05	9.962E-01	6.429E+07	2.360E+06	3.67	8500
8600	3.946E+05	3.945E+05	8.701E-01	6.429E+07	2.067E+06	3.21	8600
8700	3.946E+05	3.945E+05	9.691E-01	6.429E+07	2.728E+06	4.24	8700
8800	3.946E+05	3.945E+05	9.074E-01	6.429E+07	3.738E+06	5.81	8800
8900	3.946E+05	3.945E+05	8.566E-01	6.429E+07	2.283E+06	3.55	8900
9000	3.946E+05	3.945E+05	9.991E-01	6.429E+07	6.613E+06	10.29	9000
9100	3.946E+05	3.945E+05	8.903E-01	6.429E+07	2.151E+06	3.35	9100
9200	3.946E+05	3.945E+05	9.119E-01	6.429E+07	3.058E+06	4.76	9200
9300	3.946E+05	3.945E+05	1.000E+00	6.429E+07	2.115E+06	3.29	9300
9400	3.946E+05	3.945E+05	8.829E-01	6.429E+07	2.048E+06	3.19	9400
9500	3.946E+05	3.945E+05	9.859E-01	6.429E+07	2.855E+06	4.44	9500
9600	3.946E+05	3.945E+05	9.224E-01	6.429E+07	4.506E+06	7.01	9600
9700	3.946E+05	3.945E+05	9.623E-01	6.429E+07	3.155E+06	4.91	9700
9800	3.946E+05	3.945E+05	9.563E-01	6.429E+07	2.256E+06	3.51	9800
9900	3.946E+05	3.945E+05	8.184E-01	6.429E+07	2.000E+06	3.11	9900
10000	3.946E+05	3.945E+05	8.987E-01	6.429E+07	2.194E+06	3.41	10000
10100	3.946E+05	3.945E+05	9.857E-01	6.429E+07	2.712E+06	4.22	10100
10200	3.946E+05	3.945E+05	9.992E-01	6.429E+07	4.625E+06	7.19	10200
10300	3.946E+05	3.945E+05	9.998E-01	6.429E+07	1.971E+06	3.07	10300
10400	3.946E+05	3.945E+05	8.033E-01	6.429E+07	2.175E+06	3.38	10400
10500	3.946E+05	3.945E+05	1.000E+00	6.429E+07	1.620E+06	2.52	10500
10600	3.946E+05	3.945E+05	1.000E+00	6.429E+07	1.084E+07	16.87	10600
10700	3.946E+05	3.945E+05	1.000E+00	6.429E+07	1.930E+06	3.00	10700
10800	3.946E+05	3.945E+05	9.847E-01	6.429E+07	1.926E+06	3.00	10800
10900	3.946E+05	3.945E+05	9.899E-01	6.429E+07	1.667E+06	2.59	10900
11000	3.946E+05	3.945E+05	9.099E-01	6.429E+07	7.575E+06	11.78	11000
11100	3.946E+05	3.945E+05	9.241E-01	6.429E+07	2.694E+06	4.19	11100
11200	3.946E+05	3.945E+05	9.969E-01	6.429E+07	1.970E+06	3.07	11200

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11300	3.946E+05	3.945E+05	6.381E-01	6.429E+07	2.264E+06	3.52	11300
11400	3.946E+05	3.945E+05	9.995E-01	6.429E+07	1.624E+06	2.53	11400
11500	3.946E+05	3.945E+05	9.406E-01	6.429E+07	1.441E+06	2.24	11500
11600	3.946E+05	3.945E+05	9.051E-01	6.429E+07	5.092E+06	7.92	11600
11700	3.946E+05	3.945E+05	9.914E-01	6.429E+07	1.696E+06	2.64	11700
11800	3.946E+05	3.945E+05	8.485E-01	6.429E+07	1.812E+06	2.82	11800
11900	3.946E+05	3.945E+05	9.320E-01	6.429E+07	1.542E+06	2.40	11900
12000	3.946E+05	3.945E+05	8.955E-01	6.429E+07	1.904E+06	2.96	12000
12100	3.946E+05	3.945E+05	9.999E-01	6.429E+07	1.580E+06	2.46	12100
12200	3.946E+05	3.945E+05	9.943E-01	6.429E+07	1.483E+06	2.31	12200
12300	3.946E+05	3.945E+05	1.000E+00	6.429E+07	1.380E+06	2.15	12300
12400	3.946E+05	3.945E+05	8.537E-01	6.429E+07	2.128E+06	3.31	12400
12500	3.946E+05	3.945E+05	9.972E-01	6.429E+07	1.996E+06	3.10	12500
12600	3.946E+05	3.945E+05	9.802E-01	6.429E+07	1.516E+06	2.36	12600
12700	3.946E+05	3.945E+05	9.932E-01	6.429E+07	3.761E+06	5.85	12700
12800	3.946E+05	3.945E+05	9.994E-01	6.429E+07	1.649E+06	2.57	12800
12900	3.946E+05	3.945E+05	9.119E-01	6.429E+07	1.808E+06	2.81	12900
13000	3.946E+05	3.945E+05	9.000E-01	6.429E+07	2.220E+06	3.45	13000
13100	3.946E+05	3.945E+05	1.000E+00	6.429E+07	2.519E+06	3.92	13100
13200	3.946E+05	3.945E+05	1.000E+00	6.429E+07	2.512E+06	3.91	13200
13300	3.946E+05	3.945E+05	9.930E-01	6.429E+07	1.513E+06	2.35	13300
13400	3.946E+05	3.945E+05	1.000E+00	6.429E+07	1.251E+06	1.95	13400
13500	3.946E+05	3.945E+05	9.996E-01	6.429E+07	1.207E+06	1.88	13500
13600	3.946E+05	3.945E+05	9.790E-01	6.429E+07	3.659E+06	5.69	13600
13700	3.946E+05	3.945E+05	9.959E-01	6.429E+07	2.224E+06	3.46	13700
13800	3.946E+05	3.945E+05	9.998E-01	6.429E+07	2.871E+06	4.47	13800
13900	3.946E+05	3.945E+05	1.000E+00	6.429E+07	1.950E+06	3.03	13900
14000	3.946E+05	3.945E+05	9.853E-01	6.429E+07	1.532E+06	2.38	14000
14100	3.946E+05	3.945E+05	1.000E+00	6.429E+07	1.286E+06	2.00	14100
14200	3.946E+05	3.945E+05	9.877E-01	6.429E+07	1.106E+06	1.72	14200
14300	3.946E+05	3.945E+05	9.964E-01	6.429E+07	6.693E+06	10.41	14300
14400	3.946E+05	3.945E+05	1.000E+00	6.429E+07	1.705E+06	2.65	14400
14500	3.946E+05	3.945E+05	9.964E-01	6.429E+07	1.242E+06	1.93	14500
14600	3.946E+05	3.945E+05	1.000E+00	6.429E+07	1.256E+06	1.95	14600
14700	3.946E+05	3.945E+05	9.777E-01	6.429E+07	1.071E+06	1.67	14700
14800	3.946E+05	3.945E+05	9.687E-01	6.429E+07	1.115E+06	1.73	14800

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14900	3.946E+05	3.945E+05	9.976E-01	6.429E+07	1.091E+06	1.70	14900
15000	3.946E+05	3.945E+05	9.095E-01	6.429E+07	1.807E+06	2.81	15000
15100	3.946E+05	3.945E+05	9.621E-01	6.429E+07	1.213E+06	1.89	15100
15200	3.946E+05	3.945E+05	5.766E-01	6.429E+07	1.006E+06	1.56	15200
15300	3.946E+05	3.945E+05	8.249E-01	6.429E+07	3.170E+06	4.93	15300
15400	3.946E+05	3.945E+05	9.937E-01	6.429E+07	1.214E+06	1.89	15400
15500	3.946E+05	3.945E+05	9.888E-01	6.429E+07	1.336E+06	2.08	15500
15600	3.946E+05	3.945E+05	9.671E-01	6.429E+07	1.427E+06	2.22	15600
15700	3.946E+05	3.945E+05	9.964E-01	6.429E+07	1.978E+06	3.08	15700
15800	3.946E+05	3.945E+05	1.000E+00	6.429E+07	9.876E+05	1.54	15800
15900	3.946E+05	3.945E+05	9.980E-01	6.429E+07	8.881E+05	1.38	15900
16000	3.946E+05	3.945E+05	8.559E-01	6.429E+07	6.044E+06	9.40	16000
16100	3.946E+05	3.945E+05	9.888E-01	6.429E+07.	1.433E+06	2.23	16100
16200	3.946E+05	3.945E+05	1.000E+00	6.429E+07	9.917E+05	1.54	16200
16300	3.946E+05	3.945E+05	9.906E-01	6.429E+07	8.287E+05	1.29	16300
16400	3.946E+05	3.945E+05	9.946E-01	6.429E+07	8.672E+05	1.35	16400
16500	3.946E+05	3.945E+05	9.750E-01	6.429E+07	8.210E+05	1.28	16500
16600	3.946E+05	3.945E+05	7.741E-01	6.429E+07	8.977E+05	1.40	16600
16700	3.946E+05	3.945E+05	9.664E-01	6.429E+07	2.193E+06	3.41	16700
16800	3.946E+05	3.945E+05	9.846E-01	6.429E+07	1.238E+06	1.93	16800
16900	3.946E+05	3.945E+05	7.595E-01	6.429E+07	1.556E+06	2.42	16900
17000	3.946E+05	3.945E+05	8.792E-01	6.429E+07	1.715E+06	2.67	17000
17100	3.946E+05	3.945E+05	9.767E-01	6.429E+07	8.506E+05	1.32	17100
17200	3.946E+05	3.945E+05	1.000E+00	6.429E+07	7.314E+05	1.14	17200
17300	3.946E+05	3.945E+05	9.755E-01	6.429E+07	7.221E+05	1.12	17300
17400	3.946E+05	3.945E+05	4.730E-01	6.429E+07	8.625E+05	1.34	17400
17500	3.946E+05	3.945E+05	9.506E-01	6.429E+07	6.846E+05	1.06	17500
17600	3.946E+05	3.945E+05	9.953E-01	6.429E+07	7.278E+05	1.13	17600
17700	3.946E+05	3.945E+05	8.447E-01	6.429E+07	7.257E+05	1.13	17700
17800	3.946E+05	3.945E+05	8.661E-01	6.429E+07	1.173E+06	1.83	17800
17900	3.946E+05	3.945E+05	9.212E-01	6.429E+07	7.285E+05	1.13	17900
18000	3.946E+05	3.945E+05	9.949E-01	6.429E+07	8.430E+05	1.31	18000
18100	3.946E+05	3.945E+05	8.812E-01	6.429E+07	7.933E+05	1.23	18100
18200	3.946E+05	3.945E+05	1.000E+00	6.429E+07	6.528E+05	1.02	18200
18300	3.946E+05	3.945E+05	1.000E+00	6.429E+07	7.082E+05	1.10	18300
18400	3.946E+05	3.945E+05	8.373E-01	6.429E+07	6.998E+05	1.09	18400

18500	3.946E+05	3.945E+05	9.444E-01	6.429E+07	1.982E+06	3.08	18500
18600	3.946E+05	3.945E+05	9.600E-01	6.429E+07	6.926E+05	1.08	18600
18700	3.946E+05	3.945E+05	8.719E-01	6.429E+07	6.331E+05	0.98	18700
18800	3.946E+05	3.945E+05	9.905E-01	6.429E+07	7.303E+05	1.14	18800
18900	3.946E+05	3.945E+05	8.973E-01	6.429E+07	8.313E+05	1.29	18900
19000	3.946E+05	3.945E+05	9.484E-01	6.429E+07	7.206E+05	1.12	19000
19100	3.946E+05	3.945E+05	1.000E+00	6.429E+07	5.795E+05	0.90	19100
19200	3.946E+05	3.945E+05	9.054E-01	6.429E+07	5.767E+05	0.90	19200
19300	3.946E+05	3.945E+05	9.998E-01	6.429E+07	5.521E+05	0.86	19300
19400	3.946E+05	3.945E+05	9.794E-01	6.429E+07	6.321E+05	0.98	19400
19500	3.946E+05	3.945E+05	6.253E-01	6.429E+07	5.023E+05	0.78	19500
19600	3.946E+05	3.945E+05	8.188E-01	6.429E+07	9.315E+05	1.45	19600
19700	3.946E+05	3.945E+05	1.000E+00	6.429E+07	1.747E+06	2.72	19700
19800	3.946E+05	3.945E+05	8.111E-01	6.429E+07	6.852E+05	1.07	19800
19900	3.946E+05	3.945E+05	9.990E-01	6.429E+07	9.233E+05	1.44	19900

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	7.892E+05	3.945E+05	9.848E-01	6.429E+07	3.379E+06	5.26	20100
200	7.892E+05	3.945E+05	9.676E-01	6.429E+07	2.350E+06	3.66	20200
300	7.892E+05	3.945E+05	9.999E-01	6.429E+07	2.037E+06	3.17	20300
400	7.892E+05	3.945E+05	9.985E-01	6.429E+07	1.745E+06	2.71	20400
500	7.892E+05	3.945E+05	7.726E-01	6.429E+07	1.465E+06	2.28	20500
600	7.892E+05	3.944E+05	9.860E-01	6.429E+07	1.748E+06	2.72	20600
700	7.892E+05	3.944E+05	9.526E-01	6.429E+07	1.325E+06	2.06	20700
800	7.892E+05	3.944E+05	8.751E-01	6.429E+07	2.838E+06	4.41	20800
900	7.892E+05	3.944E+05	9.837E-01	6.429E+07	5.651E+06	8.79	20900
1000	7.892E+05	3.944E+05	7.872E-01	6.429E+07	1.382E+07	21.50	21000
1100	7.892E+05	3.944E+05	9.994E-01	6.429E+07	5.312E+07	82.64	21100
1200	7.892E+05	3.944E+05	9.992E-01	6.429E+07	1.077E+07	16.75	21200
1300	7.892E+05	3.944E+05	9.659E-01	6.429E+07	1.291E+07	20.08	21300
1400	7.892E+05	3.944E+05	9.563E-01	6.429E+07	4.055E+07	63.08	21400
1500	7.892E+05	3.944E+05	9.653E-01	6.429E+07	1.122E+08	174.53	21500
1600	7.892E+05	3.944E+05	9.694E-01	6.429E+07	6.964E+07	108.34	21600
1700	7.892E+05	3.944E+05	9.797E-01	6.429E+07	2.302E+08	358.13	21700

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1800	7.892E+05	3.944E+05	1.000E+00	6.429E+07	3.017E+07	46.94	21800
1900	7.892E+05	3.944E+05	9.888E-01	6.429E+07	2.714E+07	42.22	21900
2000	7.892E+05	3.944E+05	9.612E-01	6.429E+07	1.030E+07	16.03	22000
2100	7.892E+05	3.944E+05	7.757E-01	6.429E+07	1.594E+08	247.89	22100
2200	7.892E+05	3.944E+05	5.701E-01	6.429E+07	8.770E+07	136.42	22200
2300	7.892E+05	3.944E+05	5.675E-01	6.429E+07	1.348E+08	209.66	22300
2400	7.892E+05	3.944E+05	9.928E-01	6.429E+07	1.548E+08	240.72	22400
2500	7.892E+05	3.944E+05	1.000E+00	6.429E+07	4.429E+07	68.89	22500
2600	7.892E+05	3.944E+05	9.999E-01	6.429E+07	1.222E+07	19.01	22600
2700	7.892E+05	3.944E+05	9.208E-01	6.429E+07	1.097E+07	17.06	22700
2800	7.892E+05	3.944E+05	1.000E+00	6.429E+07	1.345E+08	209.29	22800
2900	7.892E+05	3.944E+05	1.000E+00	6.429E+07	1.527E+07	23.76	22900
3000	7.892E+05	3.944E+05	9.654E-01	6.429E+07	5.073E+07	78.92	23000
3100	7.892E+05	3.944E+05	9.000E-01	6.429E+07	7.558E+07	117.56	23100
3200	7.892E+05	3.944E+05	1.000E+00	6.429E+07	6.249E+07	97.20	23200
3300	7.892E+05	3.944E+05	1.000E+00	6.429E+07	7.776E+06	12.10	23300
3400	7.892E+05	3.944E+05	8.070E-01	6.429E+07	9.134E+07	142.08	23400
3500	7.892E+05	3.944E+05	1.000E+00	6.429E+07	9.425E+07	146.61	23500
3600	7.892E+05	3.944E+05	1.000E+00	6.429E+07	7.042E+06	10.95	23600
3700	7.892E+05	3.944E+05	8.743E-01	6.429E+07	4.848E+07	75.41	23700
3800	7.892E+05	3.944E+05	1.000E+00	6.429E+07	1.133E+07	17.63	23800
3900	7.892E+05	3.944E+05	5.235E-01	6.429E+07	6.774E+07	105.37	23900
4000	7.892E+05	3.944E+05	5.926E-01	6.429E+07	1.904E+08	296.24	24000
4100	7.892E+05	3.944E+05	1.000E+00	6.429E+07	1.144E+08	177.96	24100
4200	7.892E+05	3.944E+05	1.000E+00	6.429E+07	8.463E+06	13.17	24200
4300	7.892E+05	3.944E+05	6.282E-01	6.429E+07	7.066E+07	109.92	24300
4400	7.892E+05	3.944E+05	9.402E-01	6.429E+07	1.607E+08	249.96	24400
4500	7.892E+05	3.944E+05	1.000E+00	6.429E+07	3.835E+07	59.66	24500
4600	7.892E+05	3.944E+05	1.000E+00	6.429E+07	3.607E+07	56.11	24600
4700	7.892E+05	3.944E+05	9.418E-01	6.429E+07	1.343E+07	20.90	24700
4800	7.892E+05	3.944E+05	9.959E-01	6.429E+07	1.948E+07	30.30	24800
4900	7.892E+05	3.944E+05	9.931E-01	6.429E+07	9.510E+06	14.79	24900
5000	7.892E+05	3.944E+05	4.254E-01	6.429E+07	1.871E+06	2.91	25000
5100	7.892E+05	3.944E+05	1.000E+00	6.429E+07	2.238E+07	34.82	25100
5200	7.892E+05	3.944E+05	9.200E-01	6.429E+07	9.901E+05	1.54	25200
5300	7.892E+05	3.944E+05	1.000E+00	6.429E+07	3.264E+07	50.77	25300

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5400	7.892E+05	3.944E+05	8.774E-01	6.429E+07	1.777E+06	2.76	25400
5500	7.892E+05	3.944E+05	1.000E+00	6.429E+07	1.541E+07	23.97	25500
5600	7.892E+05	3.944E+05	9.967E-01	6.429E+07	4.205E+06	6.54	25600
5700	7.892E+05	3.944E+05	7.571E-01	6.429E+07	1.217E+08	189.36	25700
5800	7.892E+05	3.943E+05	1.000E+00	6.429E+07	9.140E+06	14.22	25800
5900	7.892E+05	3.943E+05	9.460E-01	6.429E+07	4.654E+06	7.24	25900
6000	7.892E+05	3.943E+05	8.382E-01	6.429E+07	1.651E+08	256.81	26000
6100	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.458E+07	22.68	26100
6200	7.892E+05	3.943E+05	9.258E-01	6.429E+07	1.833E+06	2.85	26200
6300	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.115E+08	173.49	26300
6400	7.892E+05	3.943E+05	1.000E+00	6.429E+07	6.262E+06	9.74	26400
6500	7.892E+05	3.943E+05	9.355E-01	6.429E+07	7.771E+06	12.09	26500
6600	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.262E+08	196.24	26600
6700	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.640E+07	25.51	26700
6800	7.892E+05	3.943E+05	1.000E+00	6.429E+07	6.745E+06	10.49	26800
6900	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.213E+08	188.67	26900
7000	7.892E+05	3.943E+05	1.000E+00	6.429E+07	3.423E+07	53.25	27000
7100	7.892E+05	3.943E+05	1.000E+00	6.429E+07	3.693E+06	5.74	27100
7200	7.892E+05	3.943E+05	8.750E-01	6.429E+07	1.024E+08	159.22	27200
7300	7.892E+05	3.943E+05	1.000E+00	6.429E+07	2.179E+07	33.90	27300
7400	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.487E+06	2.31	27400
7500	7.892E+05	3.943E+05	1.000E+00	6.429E+07	6.241E+07	97.08	27500
7600	7.892E+05	3.943E+05	1.000E+00	6.429E+07	5.902E+05	0.92	27600
7700	7.892E+05	3.943E+05	1.000E+00	6.429E+07	8.366E+07	130.14	27700
7800	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.462E+07	22.74	27800
7900	7.892E+05	3.943E+05	6.908E-01	6.429E+07	4.320E+06	6.72	27900
8000	7.892E+05	3.943E+05	9.100E-01	6.429E+07	1.517E+07	23.59	28000
8100	7.892E+05	3.943E+05	9.042E-01	6.429E+07	5.280E+06	8.21	28100
8200	7.892E+05	3.943E+05	9.924E-01	6.429E+07	1.232E+06	1.92	28200
8300	7.892E+05	3.943E+05	1.000E+00	6.429E+07	3.436E+07	53.45	28300
8400	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.461E+07	22.73	28400
8500	7.892E+05	3.943E+05	9.856E-01	6.429E+07	4.941E+06	7.69	28500
8600	7.892E+05	3.943E+05	9.468E-01	6.429E+07	2.328E+06	3.62	28600
8700	7.892E+05	3.943E+05	9.819E-01	6.429E+07	7.824E+07	121.70	28700
8800	7.892E+05	3.943E+05	1.000E+00	6.429E+07	8.877E+06	13.81	28800
8900	7.892E+05	3.943E+05	9.443E-01	6.429E+07	8.339E+05	1.30	28900

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9000	7.892E+05	3.943E+05	1.000E+00	6.429E+07	9.045E+07	140.71	29000
9100	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.154E+07	17.94	29100
9200	7.892E+05	3.943E+05	1.000E+00	6.429E+07	9.488E+06	14.76	29200
9300	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.299E+06	2.02	29300
9400	7.892E+05	3.943E+05	7.328E-01	6.429E+07	3.811E+07	59.28	29400
9500	7.892E+05	3.943E+05	1.000E+00	6.429E+07	3.747E+07	58.29	29500
9600	7.892E+05	3.943E+05	1.000E+00	6.429E+07	4.478E+07	69.66	29600
9700	7.892E+05	3.943E+05	7.665E-01	6.429E+07	1.266E+07	19.69	29700
9800	7.892E+05	3.943E+05	1.000E+00	6.429E+07	3.234E+07	50.30	29800
9900	7.892E+05	3.943E+05	1.000E+00	6.429E+07	1.078E+07	16.77	29900
10000	7.892E+05	3.943E+05	9.998E-01	6.429E+07	1.086E+06	1.69	30000
10100	7.892E+05	3.943E+05	1.000E+00	6.429E+07	4.377E+07	68.09	30100
10200	7.892E+05	3.943E+05	1.000E+00	6.429E+07	6.119E+06	9.52	30200
10300	7.892E+05	3.943E+05	6.881E-01	6.429E+07	9.446E+05	1.47	30300

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	1.184E+06	3.946E+05	9.957E-01	6.429E+07	2.103E+06	3.27	30424
200	1.184E+06	3.945E+05	8.430E-01	6.429E+07	1.624E+06	2.53	30524
300	1.184E+06	3.945E+05	9.996E-01	6.429E+07	1.201E+06	1.87	30624
400	1.184E+06	3.945E+05	8.835E-01	6.429E+07	1.043E+06	1.62	30724
500	1.184E+06	3.945E+05	9.518E-01	6.429E+07	9.956E+05	1.55	30824
600	1.184E+06	3.945E+05	9.695E-01	6.429E+07	9.826E+05	1.53	30924
700	1.184E+06	3.945E+05	9.966E-01	6.429E+07	8.729E+05	1.36	31024
800	1.184E+06	3.945E+05	9.992E-01	6.429E+07	8.411E+05	1.31	31124
900	1.184E+06	3.945E+05	8.702E-01	6.429E+07	7.944E+05	1.24	31224
1000	1.184E+06	3.945E+05	9.442E-01	6.429E+07	7.582E+05	1.18	31324
1100	1.184E+06	3.945E+05	9.988E-01	6.429E+07	7.700E+05	1.20	31424
1200	1.184E+06	3.945E+05	9.930E-01	6.429E+07	8.982E+05	1.40	31524
1300	1.184E+06	3.945E+05	9.272E-01	6.429E+07	9.129E+05	1.42	31624
1400	1.184E+06	3.945E+05	9.817E-01	6.429E+07	7.502E+05	1.17	31724
1500	1.184E+06	3.945E+05	9.744E-01	6.429E+07	6.934E+05	1.08	31824
1600	1.184E+06	3.945E+05	8.788E-01	6.429E+07	8.492E+05	1.32	31924
1700	1.184E+06	3.945E+05	1.000E+00	6.429E+07	6.822E+05	1.06	32024
1800	1.184E+06	3.945E+05	9.913E-01	6.429E+07	6.296E+05	0.98	32124

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1900	1.184E+06	3.945E+05	8.975E-01	6.429E+07	6.237E+05	0.97	32224
2000	1.184E+06	3.945E+05	9.963E-01	6.429E+07	5.709E+05	0.89	32324
2100	1.184E+06	3.945E+05	9.338E-01	6.429E+07	9.130E+05	1.42	32424
2200	1.184E+06	3.945E+05	9.987E-01	6.429E+07	8.698E+05	1.35	32524
2300	1.184E+06	3.945E+05	9.995E-01	6.429E+07	5.258E+05	0.82	32624
2400	1.184E+06	3.945E+05	6.176E-01	6.429E+07	5.669E+05	0.88	32724
2500	1.184E+06	3.945E+05	9.361E-01	6.429E+07	1.006E+06	1.56	32824
2600	1.184E+06	3.945E+05	9.853E-01	6.429E+07	5.369E+05	0.84	32924
2700	1.184E+06	3.945E+05	7.637E-01	6.429E+07	5.886E+05	0.92	33024
2800	1.184E+06	3.945E+05	8.502E-01	6.429E+07	5.074E+05	0.79	33124
2900	1.184E+06	3.945E+05	9.625E-01	6.429E+07	7.411E+05	1.15	33224
3000	1.184E+06	3.945E+05	1.000E+00	6.429E+07	6.081E+05	0.95	33324
3100	1.184E+06	3.945E+05	9.701E-01	6.429E+07	6.738E+05	1.05	33424
3200	1.184E+06	3.945E+05	8.607E-01	6.429E+07	5.556E+05	0.86	33524
3300	1.184E+06	3.945E+05	9.986E-01	6.429E+07	6.677E+05	1.04	33624
3400	1.184E+06	3.945E+05	9.579E-01	6.429E+07	5.065E+05	0.79	33724
3500	1.184E+06	3.945E+05	8.336E-01	6.429E+07	7.288E+05	1.13	33824
3600	1.184E+06	3.945E+05	1.000E+00	6.429E+07	4.778E+05	0.74	33924
3700	1.184E+06	3.945E+05	9.112E-01	6.429E+07	4.969E+05	0.77	34024
3800	1.184E+06	3.945E+05	8.912E-01	6.429E+07	6.059E+05	0.94	34124
3900	1.184E+06	3.945E+05	9.775E-01	6.429E+07	4.590E+05	0.71	34224
4000	1.184E+06	3.945E+05	9.007E-01	6.429E+07	5.834E+05	0.91	34324
4100	1.184E+06	3.945E+05	9.722E-01	6.429E+07	4.170E+05	0.65	34424
4200	1.184E+06	3.945E+05	8.716E-01	6.429E+07	4.814E+05	0.75	34524
4300	1.184E+06	3.945E+05	8.924E-01	6.429E+07	4.372E+05	0.68	34624
4400	1.184E+06	3.945E+05	9.807E-01	6.429E+07	4.293E+05	0.67	34724
4500	1.184E+06	3.945E+05	8.678E-01	6.429E+07	5.912E+05	0.92	34824
4600	1.184E+06	3.945E+05	9.001E-01	6.429E+07	4.068E+05	0.63	34924
4700	1.184E+06	3.945E+05	9.258E-01	6.429E+07	4.069E+05	0.63	35024
4800	1.184E+06	3.945E+05	9.633E-01	6.429E+07	3.828E+05	0.60	35124
4900	1.184E+06	3.945E+05	9.492E-01	6.429E+07	4.537E+05	0.71	35224
5000	1.184E+06	3.945E+05	9.995E-01	6.429E+07	5.192E+05	0.81	35324
5100	1.184E+06	3.945E+05	8.801E-01	6.429E+07	5.483E+05	0.85	35424
5200	1.184E+06	3.945E+05	9.892E-01	6.429E+07	9.061E+05	1.41	35524
5300	1.184E+06	3.945E+05	8.092E-01	6.429E+07	4.101E+05	0.64	35624
5400	1.184E+06	3.945E+05	8.863E-01	6.429E+07	4.088E+05	0.64	35724

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5500	1.184E+06	3.945E+05	9.724E-01	6.429E+07	3.924E+05	0.61	35824
5600	1.184E+06	3.945E+05	7.650E-01	6.429E+07	4.412E+05	0.69	35924
5700	1.184E+06	3.945E+05	9.504E-01	6.429E+07	5.235E+05	0.81	36024
5800	1.184E+06	3.945E+05	9.912E-01	6.429E+07	3.867E+05	0.60	36124
5900	1.184E+06	3.945E+05	6.991E-01	6.429E+07	3.994E+05	0.62	36224
6000	1.184E+06	3.945E+05	5.263E-01	6.429E+07	4.740E+05	0.74	36324
6100	1.184E+06	3.945E+05	1.000E+00	6.429E+07	3.345E+05	0.52	36424
6200	1.184E+06	3.945E+05	7.135E-01	6.429E+07	3.737E+05	0.58	36524
6300	1.184E+06	3.945E+05	9.889E-01	6.429E+07	3.563E+05	0.55	36624

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	1.578E+06	3.946E+05	9.990E-01	6.429E+07	1.923E+06	2.99	36799
200	1.578E+06	3.945E+05	9.170E-01	6.429E+07	1.423E+06	2.21	36899
300	1.578E+06	3.945E+05	9.538E-01	6.429E+07	1.020E+06	1.59	36999
400	1.578E+06	3.945E+05	9.824E-01	6.429E+07	8.565E+05	1.33	37099
500	1.578E+06	3.945E+05	9.479E-01	6.429E+07	9.017E+05	1.40	37199
600	1.578E+06	3.945E+05	9.640E-01	6.429E+07	8.100E+05	1.26	37299
700	1.578E+06	3.945E+05	9.596E-01	6.429E+07	7.907E+05	1.23	37399
800	1.578E+06	3.945E+05	8.579E-01	6.429E+07	7.532E+05	1.17	37499
900	1.578E+06	3.945E+05	7.456E-01	6.429E+07	7.333E+05	1.14	37599
1000	1.578E+06	3.945E+05	8.185E-01	6.429E+07	8.585E+05	1.34	37699
1100	1.578E+06	3.945E+05	9.408E-01	6.429E+07	7.420E+05	1.15	37799
1200	1.578E+06	3.945E+05	8.882E-01	6.429E+07	6.273E+05	0.98	37899
1300	1.578E+06	3.945E+05	9.742E-01	6.429E+07	7.760E+05	1.21	37999
1400	1.578E+06	3.945E+05	7.975E-01	6.429E+07	7.116E+05	1.11	38099
1500	1.578E+06	3.945E+05	9.576E-01	6.429E+07	8.245E+05	1.28	38199
1600	1.578E+06	3.945E+05	9.207E-01	6.429E+07	6.199E+05	0.96	38299
1700	1.578E+06	3.945E+05	9.999E-01	6.429E+07	6.059E+05	0.94	38399
1800	1.578E+06	3.945E+05	9.338E-01	6.429E+07	6.143E+05	0.96	38499
1900	1.578E+06	3.945E+05	9.497E-01	6.429E+07	7.073E+05	1.10	38599
2000	1.578E+06	3.945E+05	8.809E-01	6.429E+07	6.911E+05	1.07	38699
2100	1.578E+06	3.945E+05	1.000E+00	6.429E+07	5.477E+05	0.85	38799
2200	1.578E+06	3.945E+05	8.142E-01	6.429E+07	5.124E+05	0.80	38899
2300	1.578E+06	3.945E+05	9.773E-01	6.429E+07	5.538E+05	0.86	38999

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2400	1.578E+06	3.945E+05	9.739E-01	6.429E+07	5.274E+05	0.82	39099
2500	1.578E+06	3.945E+05	9.922E-01	6.429E+07	6.698E+05	1.04	39199
2600	1.578E+06	3.945E+05	9.935E-01	6.429E+07	8.595E+05	1.34	39299
2700	1.578E+06	3.945E+05	8.310E-01	6.429E+07	6.793E+05	1.06	39399
2800	1.578E+06	3.945E+05	7.882E-01	6.429E+07	5.294E+05	0.82	39499
2900	1.578E+06	3.945E+05	6.475E-01	6.429E+07	7.758E+05	1.21	39599
3000	1.578E+06	3.945E+05	9.536E-01	6.429E+07	8.438E+05	1.31	39699
3100	1.578E+06	3.945E+05	8.057E-01	6.429E+07	4.656E+05	0.72	39799
3200	1.578E+06	3.945E+05	9.601E-01	6.429E+07	4.492E+05	0.70	39899
3300	1.578E+06	3.945E+05	9.566E-01	6.429E+07	7.118E+05	1.11	39999
3400	1.578E+06	3.945E+05	8.919E-01	6.429E+07	5.379E+05	0.84	40099
3500	1.578E+06	3.945E+05	8.801E-01	6.429E+07	4.621E+05	0.72	40199
3600	1.578E+06	3.945E+05	8.394E-01	6.429E+07	6.294E+05	0.98	40299
3700	1.578E+06	3.945E+05	9.805E-01	6.429E+07	8.283E+05	1.29	40399
3800	1.578E+06	3.945E+05	9.655E-01	6.429E+07	5.525E+05	0.86	40499
3900	1.578E+06	3.945E+05	9.580E-01	6.429E+07	5.201E+05	0.81	40599
4000	1.578E+06	3.945E+05	9.946E-01	6.429E+07	4.552E+05	0.71	40699
4100	1.578E+06	3.945E+05	7.816E-01	6.429E+07	8.543E+05	1.33	40799
4200	1.578E+06	3.945E+05	9.321E-01	6.429E+07	9.740E+05	1.52	40899
4300	1.578E+06	3.945E+05	8.286E-01	6.429E+07	5.688E+05	0.88	40999
4400	1.578E+06	3.945E+05	9.826E-01	6.429E+07	8.908E+05	1.39	41099
4500	1.578E+06	3.945E+05	8.725E-01	6.429E+07	4.680E+05	0.73	41199
4600	1.578E+06	3.945E+05	9.135E-01	6.429E+07	4.505E+05	0.70	41299
4700	1.578E+06	3.945E+05	9.992E-01	6.429E+07	4.767E+05	0.74	41399
4800	1.578E+06	3.945E+05	9.104E-01	6.429E+07	3.804E+05	0.59	41499
4900	1.578E+06	3.945E+05	9.741E-01	6.429E+07	6.864E+05	1.07	41599
5000	1.578E+06	3.945E+05	5.800E-01	6.429E+07	4.290E+05	0.67	41699
5100	1.578E+06	3.945E+05	9.807E-01	6.429E+07	3.913E+05	0.61	41799
5200	1.578E+06	3.945E+05	7.623E-01	6.429E+07	3.805E+05	0.59	41899
5300	1.578E+06	3.945E+05	7.971E-01	6.429E+07	3.656E+05	0.57	41999
5400	1.578E+06	3.945E+05	8.141E-01	6.429E+07	5.064E+05	0.79	42099
5500	1.578E+06	3.945E+05	9.664E-01	6.429E+07	1.005E+06	1.56	42199
5600	1.578E+06	3.945E+05	9.287E-01	6.429E+07	3.627E+05	0.56	42299
5700	1.578E+06	3.945E+05	7.091E-01	6.429E+07	3.568E+05	0.56	42399
5800	1.578E+06	3.945E+05	8.198E-01	6.429E+07	4.584E+05	0.71	42499
5900	1.578E+06	3.945E+05	9.792E-01	6.429E+07	4.129E+05	0.64	42599

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6000  1.578E+06  3.945E+05  9.512E-01  6.429E+07  4.389E+05      0.68      42699
6100  1.578E+06  3.945E+05  9.152E-01  6.429E+07  3.577E+05      0.56      42799
6200  1.578E+06  3.945E+05  9.307E-01  6.429E+07  3.539E+05      0.55      42899
6300  1.578E+06  3.945E+05  8.615E-01  6.429E+07  4.200E+05      0.65      42999
6400  1.578E+06  3.945E+05  9.383E-01  6.429E+07  3.875E+05      0.60      43099
6500  1.578E+06  3.945E+05  9.853E-01  6.429E+07  3.463E+05      0.54      43199
6600  1.578E+06  3.945E+05  6.630E-01  6.429E+07  3.508E+05      0.55      43299

  **** PLOT TAPE WRITTEN AT TIME = 1.578E+06  STEP NUMBER     4 ****
 .
 .
 .
```

```
 SANTOS, VERSION 2.0.0    ,RUN ON 03/11/96 ,AT 10:04:21
  REFERENCE PARALLEL HEATED PROBLEM - SANTOS VERIFICATION (1/27/95)

****************************************************************
SUMMARY OF DATA AT STEP NUMBER   400, TIME = 1.579E+08
NUMBER OF ITERATIONS =      4270, TOTAL NUMBER OF ITERATIONS =   1425723
FINAL CONVERGENCE TOLERANCE = 4.948E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.742E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-1.996E+04
SUM OF REACTION FORCES IN X-DIRECTION = 9.009E+04
SUM OF REACTION FORCES IN Y-DIRECTION =-7.401E+06
****************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.579E+08  STEP NUMBER   400 ****




         100 TIME STEPS WERE WRITTEN TO THE PLOTTING DATA BASE


               E N D  O F  S O L U T I O N  P H A S E
                  6.586E+04 CPU SECONDS USED
                     1675 WORDS ALLOCATED
```

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APPENDIX AA

Generation of SANTOS Executable for Calculations Run With A User Subroutine

When a calculation is run with SANTOS, a default executable is typically used. When the ACCESS system was created, the installation procedure included the compilation of the source code into an object library. This default object library was then linked to generate this default executable.

However, when a user subroutine, like an initial stress subroutine or an adaptive pressure subroutine, is used in a calculation, a new and slightly different executable is generated for use with that specific calculation. This new executable is used in lieu of the default executable that resides within the system. The new executable is generated by first compiling the user subroutine and generating an object file for it. The object file resulting from the compilation of the user subroutine is then linked with the default object to generate the new executable that will be used in the calculation. Thus, no changes are made to the default code and its integrity is maintained.

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