Appendix H

NUCLEAR WASTE MANAGEMENT PROGRAM Sandia National Laboratories	**Validation Document Criteria Form**	**Form Number: NP 19-1-7** **Page 1 of 1**

1. **Software Name:** SANTOS
2. **Software Version:** 2.1.7
3. **Document Version:** 1.20
4. **ERMS #:** 530091

Prior to sign-off of the VD, all items shall be appropriately addressed by the code sponsor so that "**Yes**" or "**N/A**" may be checked. Include this form as part of the VD.

5. **Is the following information included, where applicable?**

	Yes	N/A
(a) computer program and version tested	☒	☐
(b) computer hardware and operating system used	☒	☐
(c) test equipment and calibrations	☐	☒
(d) date of test	☒	☐
(e) tester or data recorder	☒	☐
(f) simulation models used,	☐	☒
(g) test problem input and output files	☒	☐
(h) results and acceptability	☒	☐
(I) action taken in connection with any deviations noted	☐	☒

6. **Test Result Validation**
   The test results were compared to the following (check one or more, where applicable as based on code functionality):

	Yes	N/A
- hand calculations,	☒	☐
- manual inspection,	☒	☐
- calculations using comparable proven problems,	☒	☐
- empirical data & information from confirmed published data and correlations and/or technical literature,	☐	☒
- other validated software of similar purpose,	☐	☒
- other independent software of similar purpose.	☒	☐

7. **Test Documentation Acceptability** ☒ Yes
   Do the tests meet the acceptance criteria identified in the approved VVP?
8. **Test Documentation Repeatability** ☒ Yes
   Are the tests documented in sufficient detail such that they can be repeated?
9. **Computer File Documentation** ☒ Yes
   Are the test case input and output files included in the Validation Document?
10. **Understandability of Documentation** ☒ Yes
    Are the validation methods, test data, results, and conclusions documented in a form that can be understood by an independent, technically competent individual?

11.	Byoung Yoon Park **Code Team/Sponsor** (*print*)	[signature] Signature	6/30/03 Date
12.	Janis Trone **Technical Reviewer** (*print*)	[signature] Signature	6/26/03 Date
13.	David Kessel **Responsible Manager** (*print*)	[signature] Signature	6/30/03 Date
14.	Jennifer Long **SCM Coordinator** (*print*)	[signature] Signature	6/30/03 Date

Key for check boxes above:

Check **Yes** for each item reviewed and found acceptable
Check **N/A** for items not applicable

Appendix D

NUCLEAR WASTE MANAGEMENT PROGRAM Sandia National Laboratories	**Verification and Validation Plan Criteria Form**	**Form Number: NP 19-1-3** **Page 1 of 1**

1. **Software Name:** SANTOS
2. **Software Version:** 2.1.7
3. **Document Version:** 1.20
4. **ERMS #:** 530091

Prior to sign-off of the VVP, all items shall be appropriately addressed by the code sponsor so that "**Yes**" or "**N/A**" may be checked. Include this form as part of the VVP.

5. **Sufficient Test Cases** — [X] Yes
   Does the VVP identify sufficient test cases and acceptance criteria to ensure the final software and end product satisfies the requirements of the approved RD? (Check Yes if peer review is identified to fulfill the validation requirements)
6. **Adequacy of Test Cases** — [X] Yes
   Do the test cases demonstrate that the code adequately performs all intended functions and produces valid results for problems encompassing the range of permitted usage?
7. **Operational Control** — [X] Yes
   If the software is used for operational control, do tests demonstrate required performance over the range of operation of the controlled function or process?
8. **Unintended Functions** — [X] Yes
   Do the test cases show that the code does not perform any unintended function that either by itself or in combination with other functions can degrade the intended outcomes of the software?
9. **Test Result Validation.** (check one or more, where applicable as based on code functionality)
   The test results will be compared to the following:

	Yes	N/A
- hand calculations,	[X] Yes	[ ] N/A
- manual inspection,	[X] Yes	[ ] N/A
- calculations using comparable proven problems,	[X] Yes	[ ] N/A
- empirical data and information from confirmed published data and correlation's and/or technical literature,	[ ] Yes	[X] N/A
- other validated software of similar purpose,	[ ] Yes	[X] N/A
- other independent software of similar purpose.	[X] Yes	[ ] N/A
A documented peer review will be performed.	[ ] Yes	[X] N/A
Do the test cases describe how the code results will be validated?	[X] Yes	

10. **Does the VVP specify the following, where applicable as based on code functionality?**

	Yes	N/A
(a) required tests and test sequence	[X] Yes	[ ] N/A
(b) required ranges of input parameters	[ ] Yes	[X] N/A
(c) identification of the stages at which testing is required	[ ] Yes	[X] N/A
(d) criteria for establishing test cases	[X] Yes	[ ] N/A
(e) requirements for testing logic branches	[ ] Yes	[X] N/A
(f) requirements for hardware integration	[ ] Yes	[X] N/A
(g) anticipated output values	[X] Yes	[ ] N/A
(h) acceptance criteria	[X] Yes	[ ] N/A

11. **Installation and Regression Testing** — [X] Yes
    Are test cases which are suitable for installation testing and regression testing identified in the set of verification and validation test cases?

	Name (print)	Signature	Date
12.	Byoung Yoon Park **Code Team/Sponsor's** Name (*print*)	Signature	6/30/03
13.	Janis Trone **Technical Reviewer's** Name (*print*)	Signature	6/26/03
14.	David Kessel **Responsible Manager's** Name (*print*)	Signature	6/30/03
15.	Jennifer Long **SCM Coordinator's** Name (*print*)	Signature	6/30/03

Key for check boxes above:
Check **Yes** for each item reviewed and found acceptable
Check **N/A** for items not applicable, where applicable as based on code functionality

Appendix A

NUCLEAR WASTE MANAGEMENT PROGRAM Sandia National Laboratories	**Document Review and Comment (DRC)**	**Form Number: NP 6-1-1** Page 1 of 2

REVIEW REQUESTER (e.g., author/Sandia contact)
Complete items 1-6.
Provide the DRC and review document to the reviewer.
REVIEWER:
Review the document applying the criteria specified below, and complete items 7 and 8.
Return DRC to review requester/delegate.
REVIEW REQUESTER/DELEGATE:
If there are comments requiring response, prepare response to each comment on following page(s); complete item 9, and return to reviewer.
REVIEWER:
Review responses to comments. Indicate acceptance or rejection on the DRC and complete item 10.
NOTE: REVIEWER AND REVIEW REQUESTER/DELEGATE are encouraged to discuss comments. If comment(s) cannot be resolved, refer the issue(s) to management.
Entries must be complete, legible, and in reproducible ink or completed electronically.

1.Document Title: VERIFICATION AND VALIDATION PLAN/VALIDATION DOCUMENT for SANTOS (Version 2.1.7)

2. Rev. # (if applicable): 1.2

3. Document Description: (e.g. abstract, procedure, SAND report): Software QA Document

4. Type of Review & Criteria

☐ Technical (Technical adequacy, accuracy, completeness)
-Are objectives clearly stated and fulfilled?
-Is the technical activity clearly described?
-Are equations/calculations accurate?
-Does logic lead to reasonable conclusions?
-Are the results drawn from the data supported by data presented?
-Data/tables/figures: Are they easily understood? Are legends complete?

☐ QA (Compliance and completeness)
-Are applicable QA requirements adequately cited/ incorporated and met (content, reviews)?
- Has the technical review been performed by someone who is "independent"? (see NP 6-1, Section 2.2)

☒ Management(Completeness and correctness)
-Is report consistent with policy?
-Is there consensus with other program documents?
-Does the document meet applicable criteria?

☐ Other type of review (please specify or leave blank if not applicable)

5. Additional criteria (if applicable)

6. Review Requester: Sean Dunagan (Printed Name) Date: 6/25/03

7. Review Prepared by: David Kessel (Reviewer's Printed Name) [signature] (Reviewer's Signature) 6821 (Org.) 6/26/03 (Date)

8. One of the following boxes must be checked: ☐ No comments ☒ Comments; record on following pages.

(This section to be left blank if there are no comments requiring a response)

9. Response to comments prepared by: Sean Dunagan (Review Requester's/Delegate's Printed Name) [signature] (Review Requester's/Delegate's Signature) 6821 (Org.) 6/26/03 (Date)

10. Response Concurrence: [signature] (Reviewer's Signature) 6/26/03 (Date)

Document Review and Comment (DRC)

Form Number:
NP 6-1-1
Page 2 **of** 2

Type of Review ☐ Technical ☐ QA ☒ Management ☐ Other

Document Title VERIFICATION AND VALIDATION PLAN/VALIDATION DOCUMENT for SANTOS (Version 2.1.7) Rev. # 1.2

Reviewer's Comments (Enter "LAST COMMENT" in row below last entry)				Review Requester's/Delegate's Response			Reviewer's Response	
Comment#	*	Location	Comment	Accept	Reject		Accept	Reject
1	N	TOC	Introduction is repeated	X		Corrected	DSW	
			Last comment					

* Mark Y (Yes) for comments requiring a response from the Review Requester/Delegate.
Mark N (No) for comments not requiring a response from the Review Requester/Delegate.

Appendix A

NUCLEAR WASTE MANAGEMENT PROGRAM Sandia National Laboratories	**Document Review and Comment (DRC)**	**Form Number: NP 6-1-1** Page 1 of 2

REVIEW REQUESTER (e.g., author/Sandia contact)
Complete items 1-6.
Provide the DRC and review document to the reviewer.
REVIEWER:
Review the document applying the criteria specified below, and complete items 7 and 8.
Return DRC to review requester/delegate.
REVIEW REQUESTER/DELEGATE:
If there are comments requiring response, prepare response to each comment on following page(s); complete item 9, and return to reviewer.
REVIEWER:
Review responses to comments. Indicate acceptance or rejection on the DRC and complete item 10.
NOTE: REVIEWER AND REVIEW REQUESTER/DELEGATE are encouraged to discuss comments. If comment(s) cannot be resolved, refer the issue(s) to management.
Entries must be complete, legible, and in reproducible ink or completed electronically.

1.Document Title: SANTOS, Version 2.1.7., Verification and Validation Plan/Validation Document
2. Rev. # (if applicable): 1.20
3. Document Description: (e.g. abstract, procedure, SAND report): software document

4. Type of Review & Criteria

☒ Technical (Technical adequacy, accuracy, completeness)
-Are objectives clearly stated and fulfilled?
-Is the technical activity clearly described?
-Are equations/calculations accurate?
-Does logic lead to reasonable conclusions?
-Are the results drawn from the data supported by data presented?
-Data/tables/figures: Are they easily understood? Are legends complete?

☐ QA (Compliance and completeness)
-Are applicable QA requirements adequately cited/ incorporated and met (content, reviews)?
- Has the technical review been performed by someone who is "independent"? (see NP 6-1, Section 2.2)

☐ Management(Completeness and correctness)
-Is report consistent with policy?
-Is there consensus with other program documents?
-Does the document meet applicable criteria?

☐ Other type of review (please specify or leave blank if not applicable)

5. Additional criteria (if applicable)
6. Review Requester: Sean Dunagan (Printed Name) Date: 6/24/03

7. Review Prepared by: Janis Trone (Reviewer's Printed Name) — [signature] (Reviewer's Signature) — 6821 (Org.) — 6/24/03 (Date)

8. One of the following boxes must be checked: ☐ No comments ☒ Comments; record on following pages.

(This section to be left blank if there are no comments requiring a response)

9. Response to comments prepared by: Sean Dunagan (Review Requester's/Delegate's Printed Name) — [signature] (Review Requester's/Delegate's Signature) — 6821 (Org.) — 6/25/03 (Date)

10. Response Concurrence: [signature] (Reviewer's Signature) — 6/26/03 (Date)

Document Review and Comment (DRC)

Form Number: NP 6-1-1
Page 2 of 2

Type of Review ☒ Technical ☐ QA ☐ Management ☐ Other

Document Title SANTOS, Version 2.1.7., Verification and Validation Plan/Validation Document Rev. # 1.20

Reviewer's Comments (Enter "LAST COMMENT" in row below last entry)				Review Requester's/Delegate's Response			Reviewer's Response	
Comment#	*	Location	Comment	Accept	Reject		Accept	Reject
Note	N	All	A review of the SANTOS –Verification and Qualification Plan was completed by Billy Joe Thorne on 5/9/96. The analytic solutions for the 21 test cases have not changed since the Thorne review, therefore this review will focus on the validation portion (comparison of results to the analytic solutions). I will not be re-verifying the analytic solutions.					
1	Y	6.1.2	Does figure show rotation of 90 degrees?		X	Figure shows how the cube moves to 90 degrees over 10 increments. It shows the cube at an incremental stage before 90 degrees.	X	
2	Y	Figure 6.3.3	Text states displacement increases from 0 to .216, but figure shows displacement decreasing from 0 to around -.21	X		Explained in 6.3.5.	X	
3	Y	Figures 6.4.3. and 6.4.4	Reverse the two figures to match the order of the text description.	X		Reversed	X	
4	Y	6.7.5	A conclusion of the codes adequacy is not stated.	X		Added	X	
5	Y	6.8.5	Text states that it appears SANTOS is working correctly. Suggest removing the word appears and state the conclusion more confidently.	X		Reworded	X	
6	Y	6.9.5, 6.15.5 and 6.19.5	A conclusion of the code adequacy is not stated.	X		Added	X	
			Last comment					

* Mark Y (Yes) for comments requiring a response from the Review Requester/Delegate.
Mark N (No) for comments not requiring a response from the Review Requester/Delegate.

WIPP PA

VERIFICATION AND VALIDATION PLAN/
VALIDATION DOCUMENT

for

SANTOS (Version 2.1.7)

Document Version 1.20

ERMS# 530091

June 2003

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

This document describes a suite of tests, which have been solved with the SANTOS finite element computer program, and, as such, the SANTOS theory and user's manual [1] is incorporated herewith as the primary reference for all of the tests described herein. They range from simple single-element tests that are used to verify specific features or constitutive model implementations in the code to the highly nonlinear, large deformation, complex geomechanics tests of previous benchmarking exercises. The range of tests solved is intended to thoroughly exercise SANTOS, and thus result in a code that has been extensively validated for WIPP applications. Each of the following tests is relatively self-contained. The test and specific aspects of the code that are exercised are first described. The analytic solution (for the case of verification tests) or solutions from other codes (for the regression tests) 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 test contains references for all other cited literature.

1.1 Software Identifier

Code name:	SANTOS
WIPP Prefix:	SANTOS
Version:	2.1.7

1.2 Points of Contact

Code Sponsors:	Byoung-Yoon Park, 505-234-0001
Code Consultant:	Charles M. Stone, 505-844-5116
Tester/Evaluator:	Jianjun Lin, 505-284-0088

1.3 Description

SANTOS is a finite element program designed to compute the quasistatic, large deformation, inelastic response of two-dimensional planar or axisymmetric solids or engineering structures. The code is derived from the transient dynamic code PRONTO 2D [2]. The solution strategy used to compute the equilibrium states is based on a self-adaptive dynamic relaxation solution scheme, which is based on explicit central difference pseudo-time integration and artificial mass proportional damping. The element used in SANTOS is a uniform strain 4-node quadrilateral element with an hourglass solution scheme to control the spurious deformation modes. Finite strain constitutive models for many common engineering materials are available. A robust master-slave contact algorithm for modeling sliding contact is implemented. An interface for coupling to an external code is also provided.

2.0 REQUIREMENTS DOCUMENT

The requirements of the SANTOS code are described in Sections 2.1 through 2.5. The requirements coverage by test case is shown in Table 2-1.

2.1 Functional Requirements

SANTOS is required to perform the following functions:

R.1 - Compute the quasistatic, inelastic response of two-dimensional plain strain or axisymmetric solids.

R.2 - Handle problems involving large deformations.

R.3 - Handle problems involving large strains.

R.4 and R.5- Model the inelastic response of materials, including:

R.4 - Consolidation of porous materials.

R.5 - Time-dependent deformation (creep) of geological media.

R.6 through R.10 - Handle the following types of boundary conditions:

R.6 - Kinematic boundary conditions.

R.7 - Traction boundary conditions.

R.8 - Thermal boundary conditions.

R.9 - Distributed load boundary conditions.

R.10 - Initial Stress boundary conditions.

R.11 - Handle multilayered media of large physical extent.

R.12 - Contain a provision for including the pressurization effects of gas or brine within cavities.

R.13 - Model contacts and separations of interfaces with zero tensile strength.

2.2 Performance Requirements

There are no performance requirements for SANTOS.

Design Constraints

SANTOS has already been developed; therefore, there are no design constraints.

Attribute Requirements

There are no attribute requirements for SANTOS

External Interface Requirements

SANTOS must satisfy the following external interface requirements:

R.14 - Read user supplied commands from an ASCII input file.

R.15 - Read finite element mesh data created by the FASTQ [3] code.

R.16 Read transient nodal temperature data from an external file (this data may be created by the COYOTE II [4] and interpolated to the nodes of the structural mesh by the MERLIN II [5] code).

R.17 - SANTOS uses routines from, and therefore must be linked with, the following machine-specific libraries: SUPES, SUPLIB, XHELP, PLT, and SVDI. These libraries are described in Reference [6].

R.18 - Include an interface for coupling to user-supplied subroutines which, could be used for defining an initial stress state or an adaptive pressure routine.

R.19 - Produce a binary plot file containing all pertinent results.

R.20 - Produce an ASCII output file that echoes the input data and descriptive information about the problem, provides convergence tracking information, and summarizes the CPU usage.

R.21- SANTOS is a part of the Sandia National Laboratories ACCESS system [7].

TABLE 2.1 Requirements Coverage By Test Case

Requirement		Test Cases*																				
Type	**Number**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Functional	R.1	X	X	X	X			X	X	X	X								X	X	X	X
	R.2	X						X										X	X			X
	R.3																	X				X
	R.4																					X
	R.5																X					
	R.6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	R.7	X						X	X	X	X	X	X			X	X		X	X	X	X
	R.8											X	X	X						X		X
	R.9		X				X	X											X	X	X	X
	R.10																X		X	X	X	X
	R.11										X					X			X	X	X	X
	R.12					X																
	R.13								X	X	X							X	X	X	X	X
External Interface	R.14	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	R.15	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	R.16																			X		X
	R.17	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	R.18					X											X		X	X	X	X
	R.19	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	R.20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	R.21	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

3.0 ADDITIONAL FUNCTIONALITY TO BE TESTED

There is no additional functionality to be tested.

4.0 FUNCTIONALITY NOT TESTED

All functionality will be tested.

5.0 TESTING ENVIRONMENT

Hardware Platform:	i686
Operating System Distribution:	Red Hat Linux release 7.2 (Enigma) Kernel 2.4.18-27.7
Compiler:	Lahey/Fujitsu Fortran 95 Compiler Release L6.10a
Host:	warthog.sandia.gov
Configuration Management	SMCS library WP$CMSROOT:[SANTOS]

6.0 FUNCTIONAL TESTING

The test set of SANTOS consists of 21 test cases. The cases have been designed to verify that SANTOS satisfies the requirement specified in section 2 of this document.

6.1 Test Case 1: Large Rotation

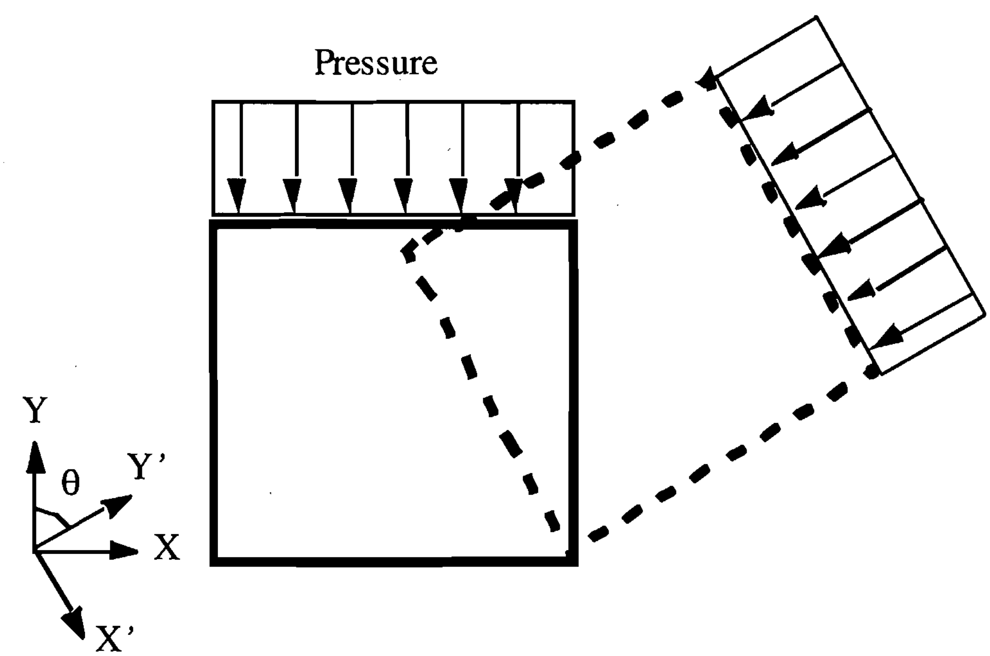
6.1.1 Test Objective

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

6.1.2 Test Procedure

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 6.1.1. The cube is rotated in ten increments from its original starting position.

Figure 6.1.1 Test Geometry and Boundary Conditions



6.1.3 Input/Output

Test 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 test information is given in APPENDIX A.

6.1.4 Acceptance Criteria

The two-dimensional stress state in the body can be expressed by the following equations taken from Fung [8].

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

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

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

where the unprimed stresses are those in the unrotated cube.

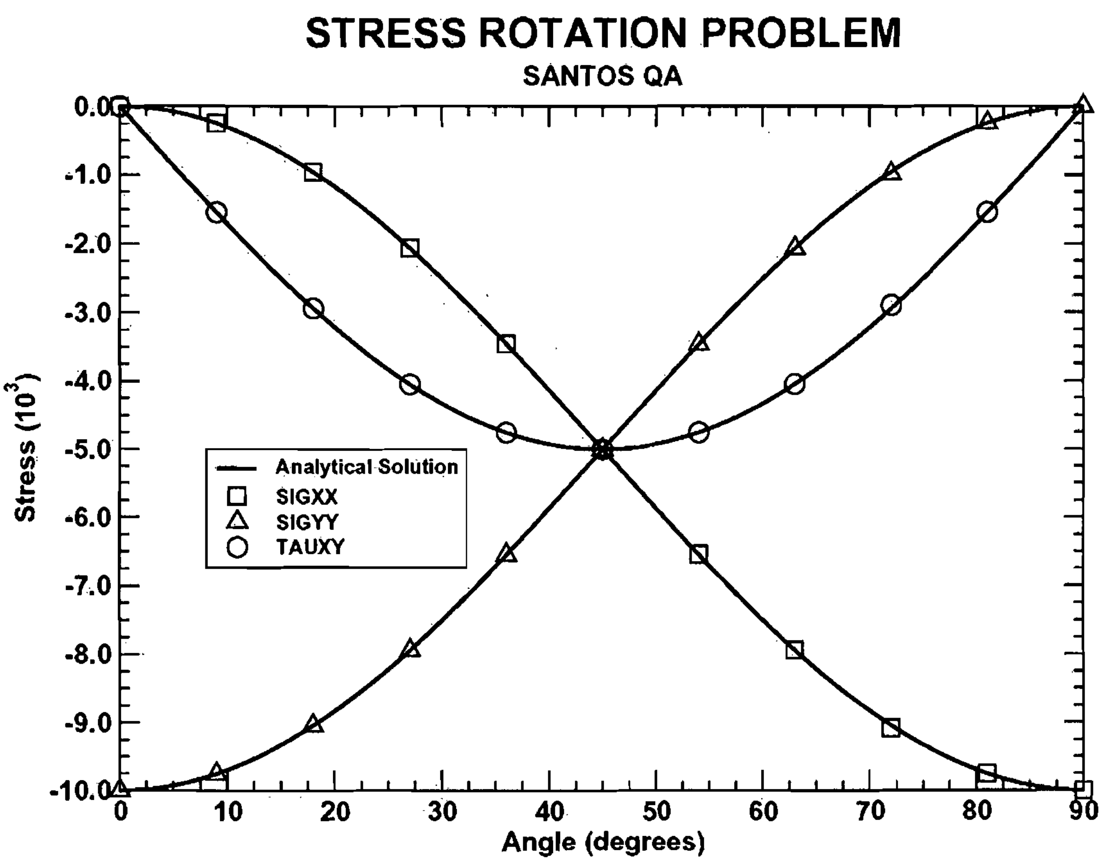
A value of 10,000 is used for the pressure in this specific example and the cube is treated as an elastic material with a Young's modulus of 1.0E6. Notice that, σ_{xx} and τ_{xy} are equal to zero, meaning that initially both the horizontal and the shear stresses in the system are zero. Because of the 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 $\theta = 90^\circ$.

6.1.5 Evaluation

A comparison of analytically-derived results and those predicted by SANTOS is shown in Figure 6.1.2. The SANTOS predictions are the same as the analytical ones, demonstrating that SANTOS correctly handles large rotation stress transformations.

Figure 6.1.2 Rotated Stress Plot



6.2 Test Case 2: Delete Material Option

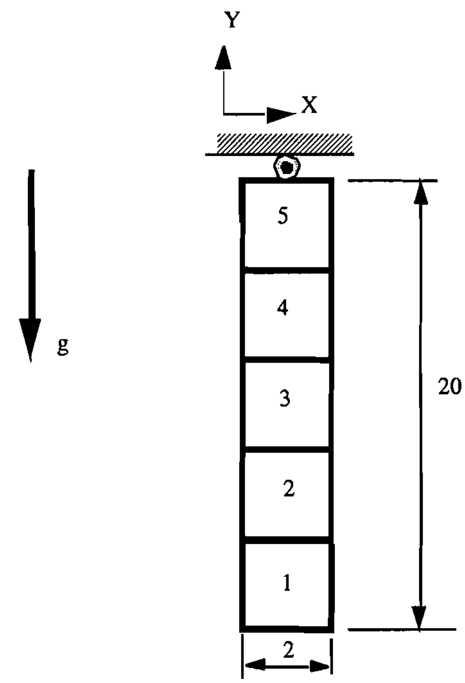
6.2.1 Test Objective

This test case 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.

6.2.2 Test Procedure

A linear, elastic isotropic rod is hanging from a pinned support in a constant gravity field, as shown in Figure 6.2.1. 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 6.2.1 Test Geometry and Boundary Conditions

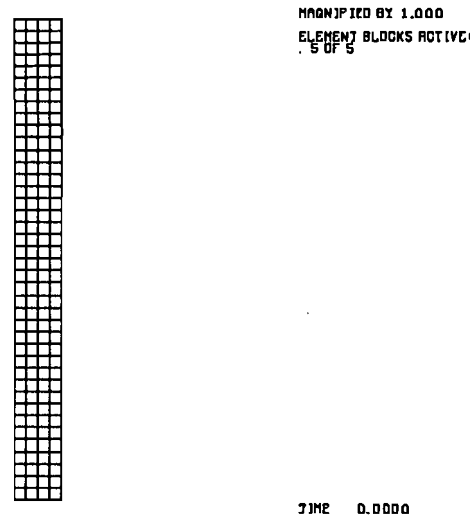


6.2.3 Input/Output

<u>**Test Discretization**</u>

A 160 element (4-node quadrilateral) mesh is used in the SANTOS calculations and is shown in Figure 6.2.2.

Figure 6.2.2 Finite Element Mesh



Input Data

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

Output Listing

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

6.2.4 Acceptance Criteria

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:

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

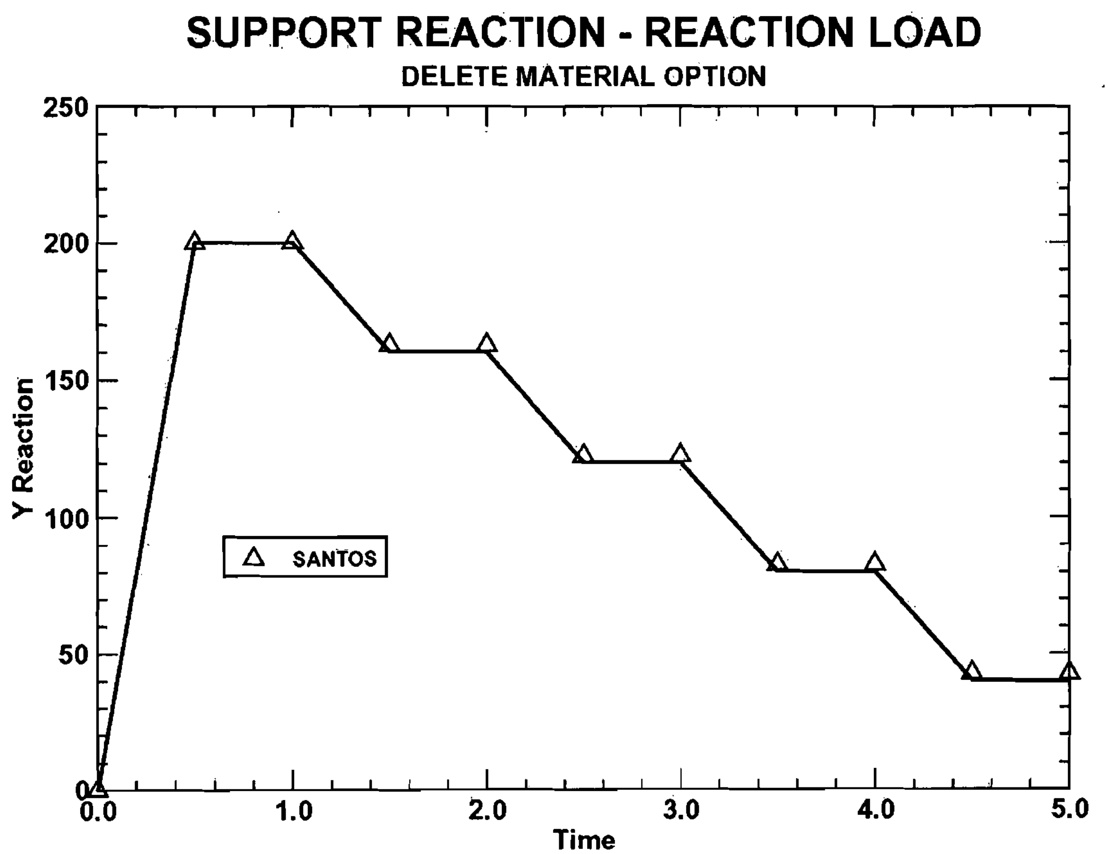
where N is the total number of material blocks and N^* is the number of material blocks removed. The above equation applies for $0 < N^* \leq N$.

Specific values used for this example were: $\rho = 1.0$; $g = 5.0$; and N=5. An elastic material with $E = 1.0X10^4$ 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.

6.2.5 Evaluation

The plot of computed reaction forces versus the analytical solution (the solid line) is shown in Figure 6.2.3. 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 6.2.3 Support Reaction Plot



6.3 Test Case 3: Prescribed Force Option

6.3.1 Test Objective

This test case tests the SANTOS prescribed force option.

6.3.2 Test Procedure

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.

6.3.3 Input/Output

<u>**Test Discretization**</u>

A 120 element (4-node quadrilateral) mesh is used in the SANTOS analysis and is shown in Figure 6.3.1.

Figure 6.3.1 Finite Element Mesh

<u>**Input Data**</u>

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

<u>**Output Listing**</u>

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

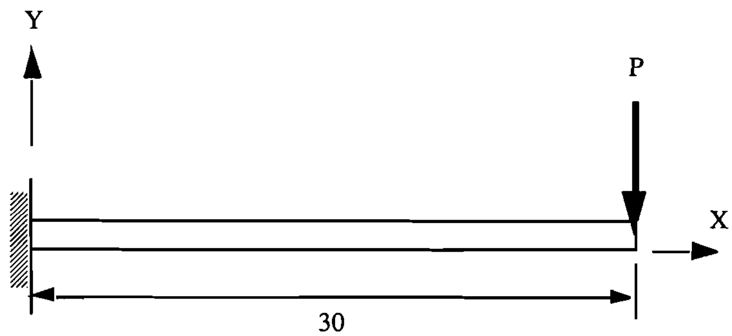
6.3.4 Acceptance Criteria

The model geometry and boundary conditions are shown in Figure 6.3.2. 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 [9]:

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

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 6.3.2 Concentrated Load



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

6.3.5 Evaluation

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 6.3.3 and Figure 6.3.4. 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. Because of the orientation of the y-axis in Figure 6.3.2 the displacement in Figure 6.3.3 is in the negative direction. Therefore direction and the magnitude of the displacement are as expected.

Figure 6.3.3 End-Point Displacement

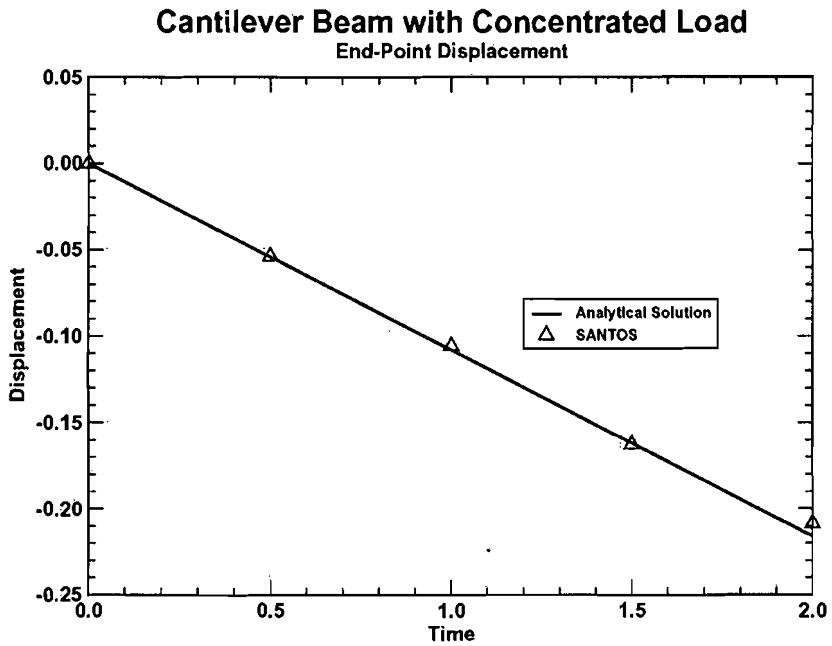
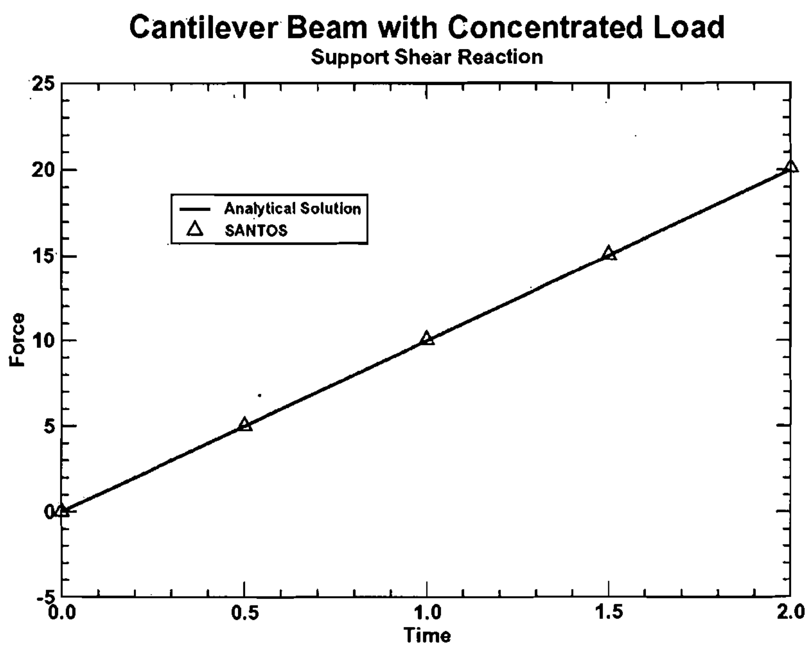


Figure 6.3.4 Support Shear Reaction



6.4 Test Case 4: Distributed Load Function

6.4.1 Test Objective

This test case verifies 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.

6.4.2 Test Procedure

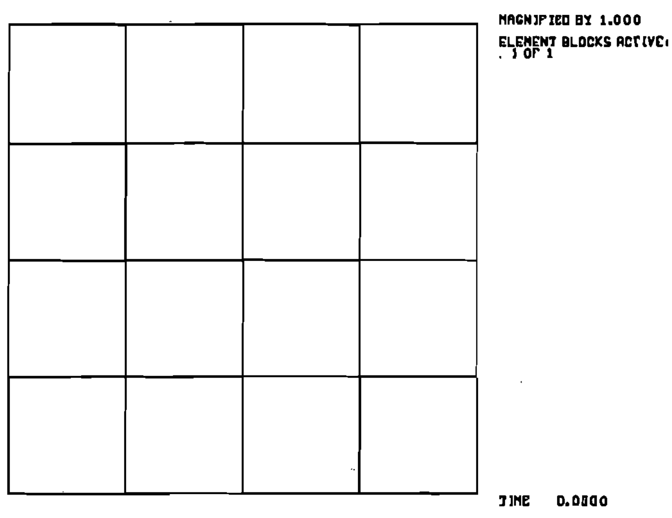
A two-dimensional cube of linear, elastic, isotropic material is loaded vertically with a uniformly distributed load that varies with time, i.e., the load starts off at zero and linearly increases with time to some final value. The vertical displacement and vertical reaction force of the cube are computed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

6.4.3 Input/Output

<u>Test Discretization</u>

A 16 element (4-node quadrilateral) mesh is used in the analysis and is shown in Figure 6.4.1.

Figure 6.4.1 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 DISTLF, written specifically for the verification test. DISTLF generates 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.

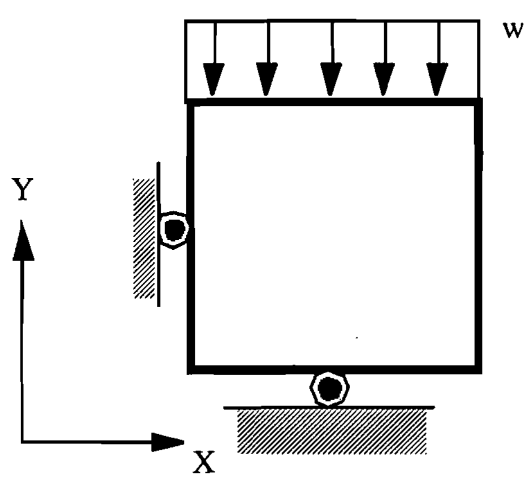
Output Listing

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

6.4.4 Acceptance Criteria

The model geometry and boundary conditions are shown in Figure 6.4.2. The reaction forces are computed by multiplying the area of the load surface by the distributed load.

Figure 6.4.2 Distributed Load



The vertical displacement of the top surface of the cube is computed with the following formula:

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

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.

Specific values used in this example were: L=4.0; $E = 1.0X10^7$; v=0 (Poisson's ratio, v, 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.

6.4.5 Evaluation

The plots of vertical displacement and reaction force are shown in Figure 6.4.3 and Figure 6.4.4., 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 6.4.3 Support Reaction Force

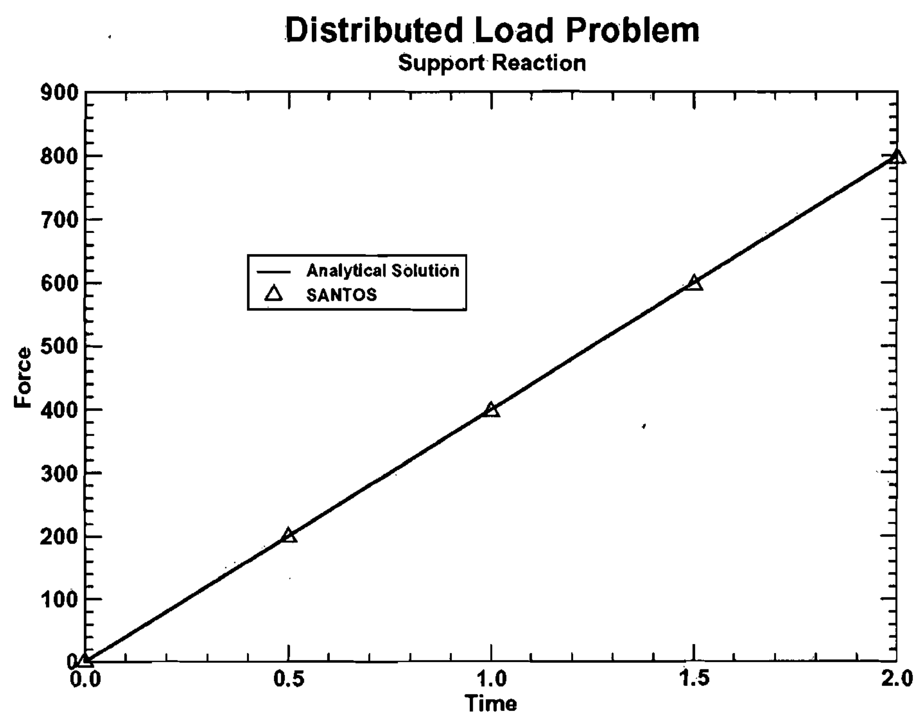
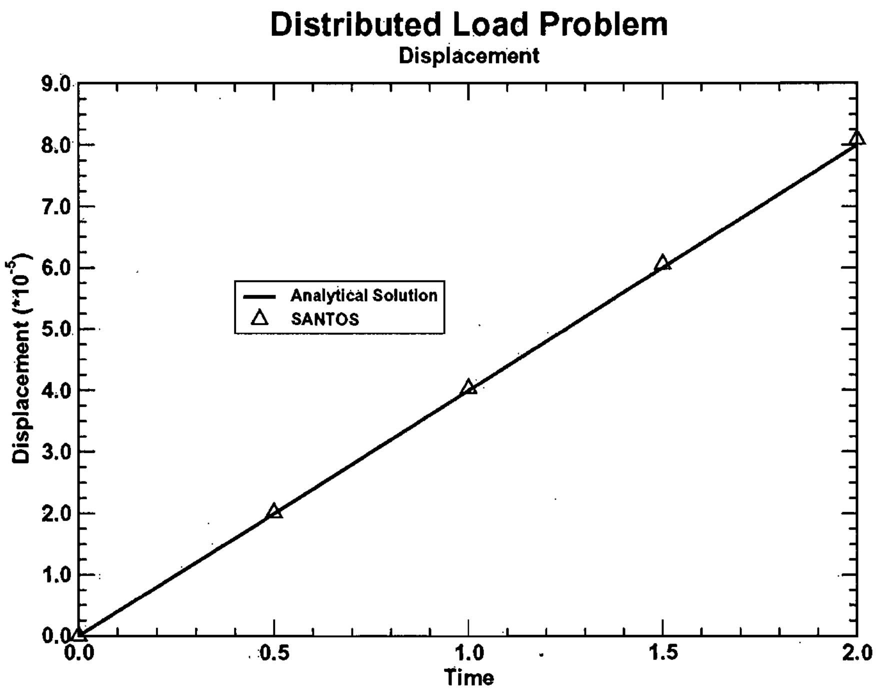


Figure 6.4.4 Axial Displacement



6.5 Test Case 5: Adaptive Pressure Option

6.5.1 Test Objective

This test 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.

6.5.2 Test Procedure

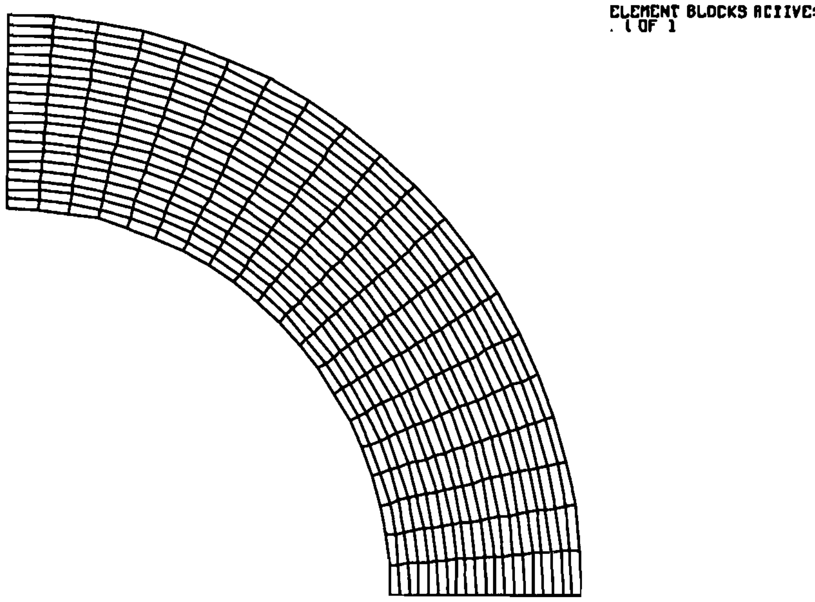
A linear elastic hollow sphere is initially pressurized with P_0, and the internal surface of the sphere expands radially outward increasing the volume of the cavity. Under adiabatic conditions the pressure of the gas will decrease in direct proportion to the volume expansion of the cavity.

6.5.3 Input/Output

<u>**Test Discretization**</u>

A 400 element mesh (4 node-quadrilaterals) is used in the SANTOS calculations and is shown in Figure 6.5.1.

Figure 6.5.1 Finite Element Mesh



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

Output Listing

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

6.5.4 Acceptance Criteria

The behavior of an ideal gas can be described by the following formula [10]:

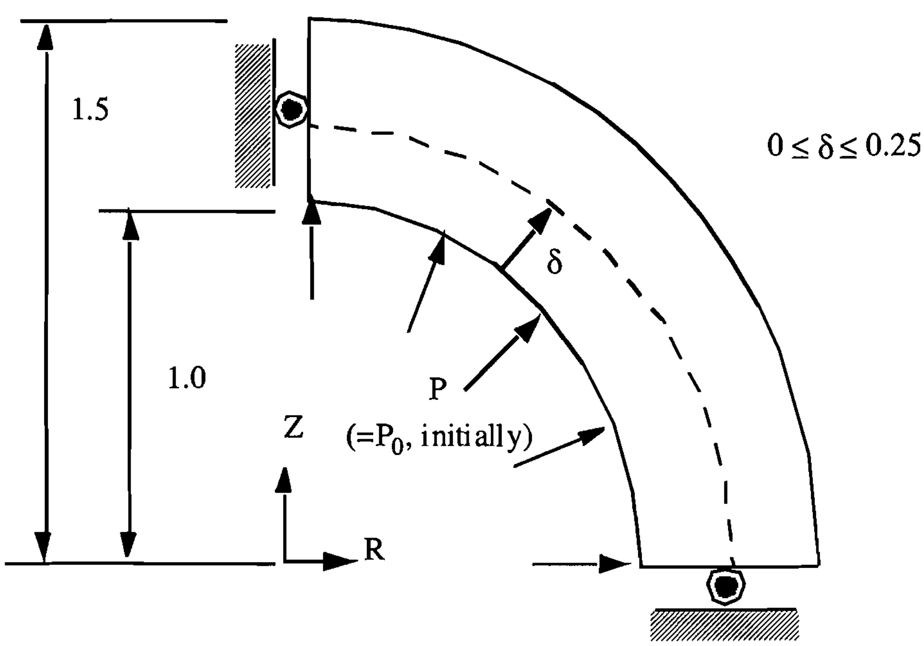
$$\frac{PV}{T} = K \qquad \textbf{(EQ 5.1)}$$

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 test, 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_0 and V_0 represent the initial pressure and initial volume, respectively. Figure 6.5.2 shows the specific geometry and boundary conditions of the test considered here. Also, the material properties used in this analysis correspond to those for an elastic material with: $E = 1X10^7$ and v=0.3.

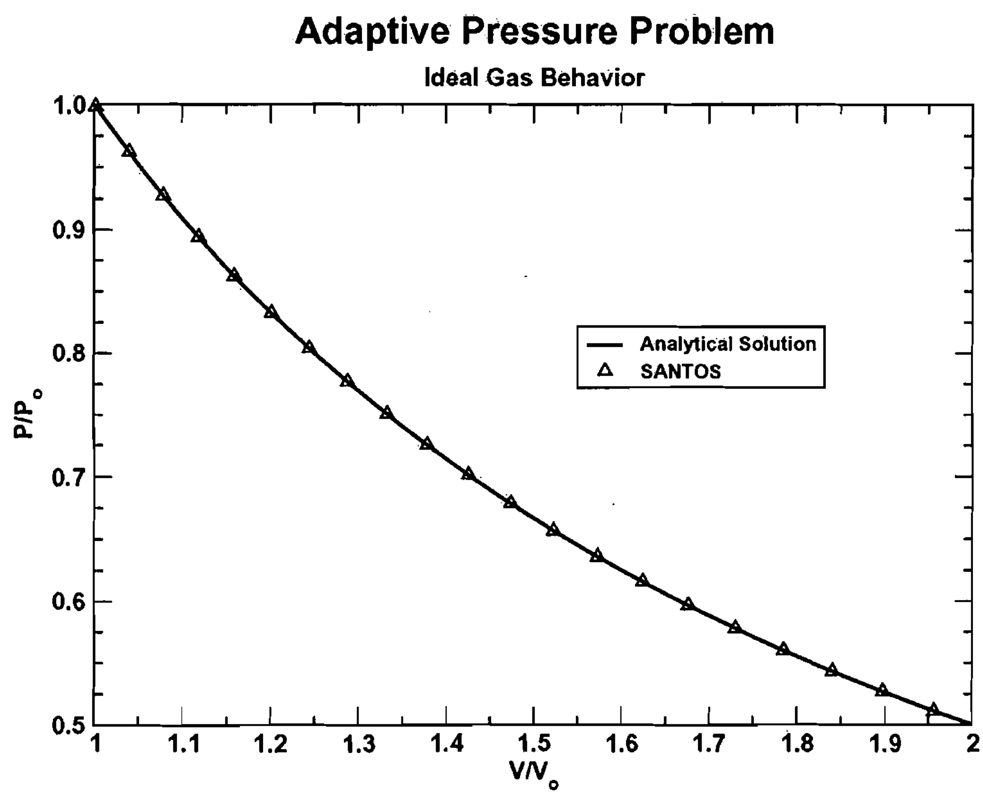
Figure 6.5.2 Geometry and Boundary Conditions



6.5.5 Evaluation

The comparison of the pressure versus volume predictions made with the analytic solution (the solid line) and SANTOS is shown in Figure 6.5.3. From the graph it can be seen that the SANTOS adaptive pressure option is working correctly.

Figure 6.5.3 Pressure Versus Volume



6.6 Test Case 6: Spinning Disk

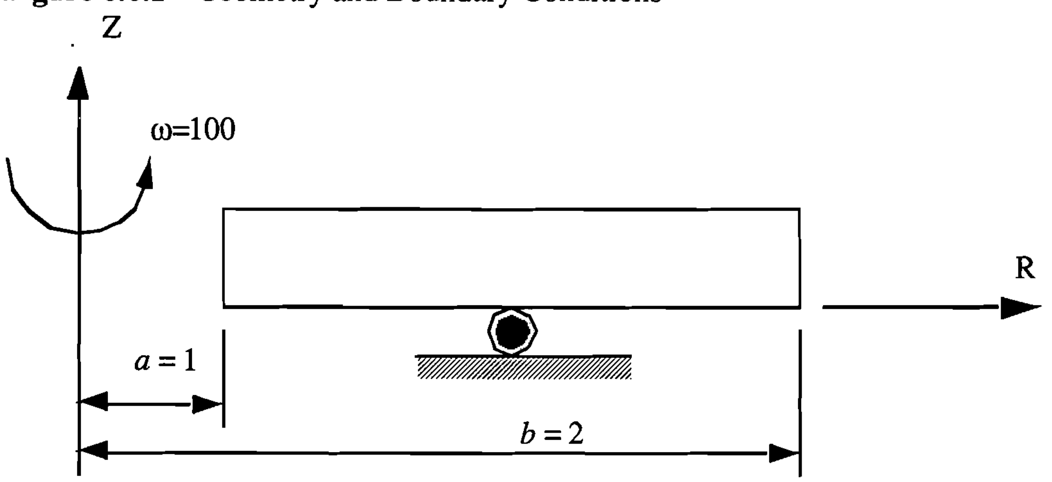
6.6.1 Test Objective

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.

6.6.2 Test Procedure

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 test and boundary conditions are shown in Figure 6.6.1.

Figure 6.6.1 Geometry and Boundary Conditions

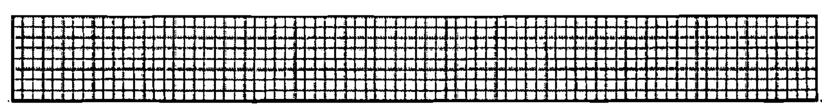


6.6.3 Input/Output

Test Discretization

The finite element mesh used in the SANTOS analysis is shown in Figure 6.6.2. It contains 640 four-node quadrilateral elements.

Figure 6.6.2 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 test information is given in APPENDIX F.

6.6.4 Acceptance Criteria

The radial displacement function for the spinning disk is taken from Timoshenko [11] 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:

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

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

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

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

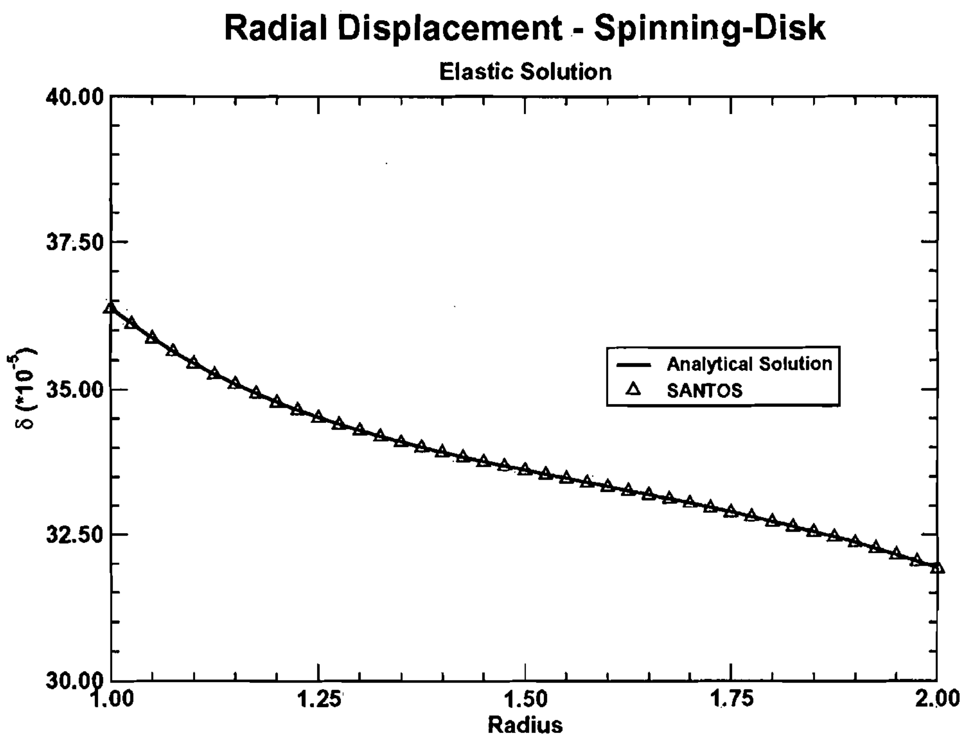
a = inner radius of the disk,
b = outer radius of the disk,
ν = Poisson's ratio,
E = Young's Modulus,
g = gravitational acceleration,
γ = weight density of the disk (Force/Length^3),
ω = angular velocity of the disk, and
r = radial distance $(a \le r \le b)$.

For specific comparisons between analytic and computed solutions, the following values were used in this example:
$a = 1.0;\ b = 2.0;\ \nu = 0.3;\ E = 2.07x10^{11};\ g = 9.8066;\ \gamma = 21250;\ and\ \omega = 100.$

6.6.5 Evaluation

A comparison of analytic results (shown as the solid line) and those predicted by SANTOS is shown in Figure 6.6.3. The SANTOS predictions are essentially the same as the analytical ones, demonstrating that SANTOS correctly analyzes axisymmetric centrifugal acceleration problems.

Figure 6.6.3 Elastic Solution



6.7 Test Case 7: Pressure and Gravity Loaded Beam

6.7.1 Test Objective

In this test 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.

6.7.2 Test Procedure

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 6.7.1, and is gravity-loaded in another case, as shown in Figure 6.7.2. 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 [12] and the SANTOS results are compared to Holden's solution.

Figure 6.7.1 Cantilever Bean With Pressure Load

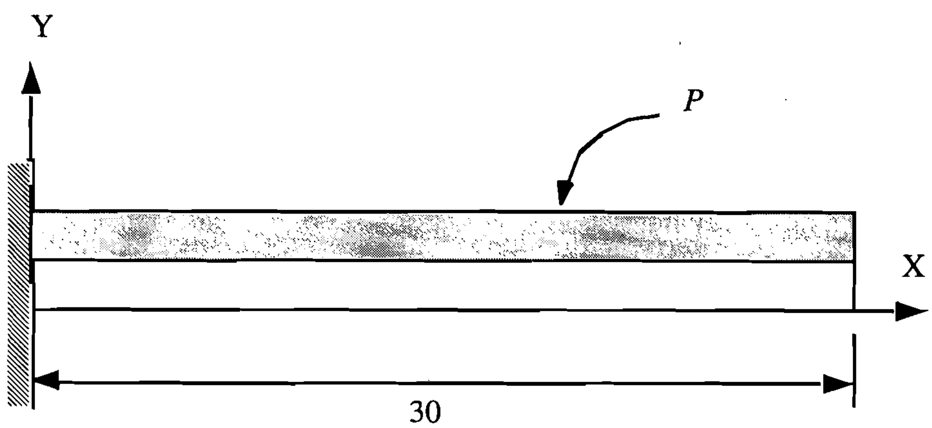
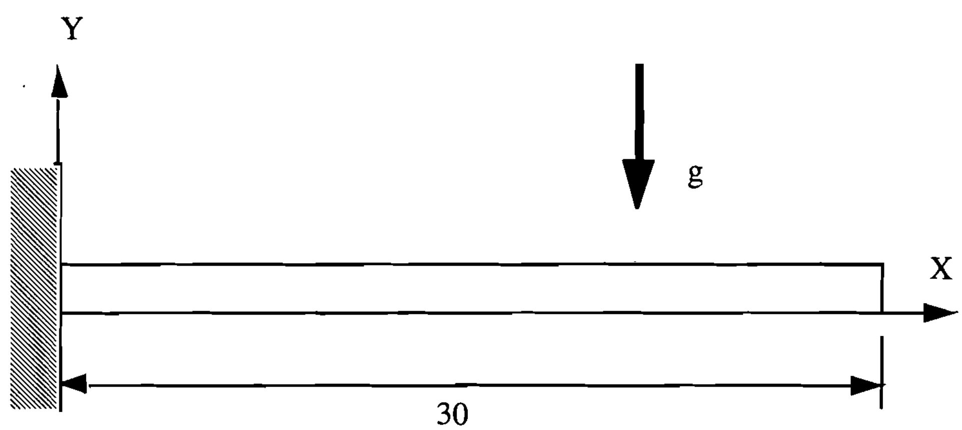


Figure 6.7.2 Cantilever Beam with Gravity Load



6.7.3 Input/Output

Test Discretization

A 102-element mesh was used for the SANTOS calculation and is shown in Figure 6.7.3. 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 [13].

Figure 6.7.3 Finite Element Mesh Underformed

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 test information is given in APPENDIX G.

6.7.4 Acceptance Criteria

For the gravity-loaded test 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,, 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:

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

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

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

To generate the analytic solution for the gravity-loaded beam, the following specific values were used in this example problem: $L = 30;\ I = 1/12;\ E = 1.0x10^7;\ \nu = 0;\ \rho = 400;\ and\ g$ 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:
$L = 30;\ I = 1/12;\ E = 1.0x10^7;\ \nu = 0;\ and\ P$ 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 Solution.

6.7.5 Evaluation

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 6.7.4, for the gravity-loaded case and in Figure 6.7.5, 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 test is also shown in Figure 6.7.6 for k equal to 6.5. From these calculations it can be seen that the hourglass algorithm in SANTOS is working correctly.

Figure 6.7.4 Gravity Beam and End-Point Displacements

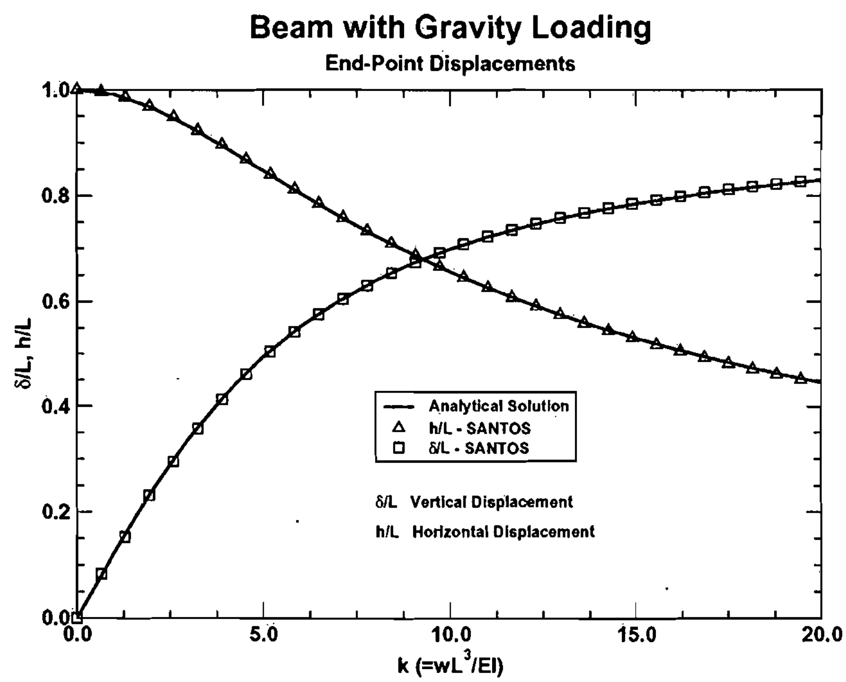
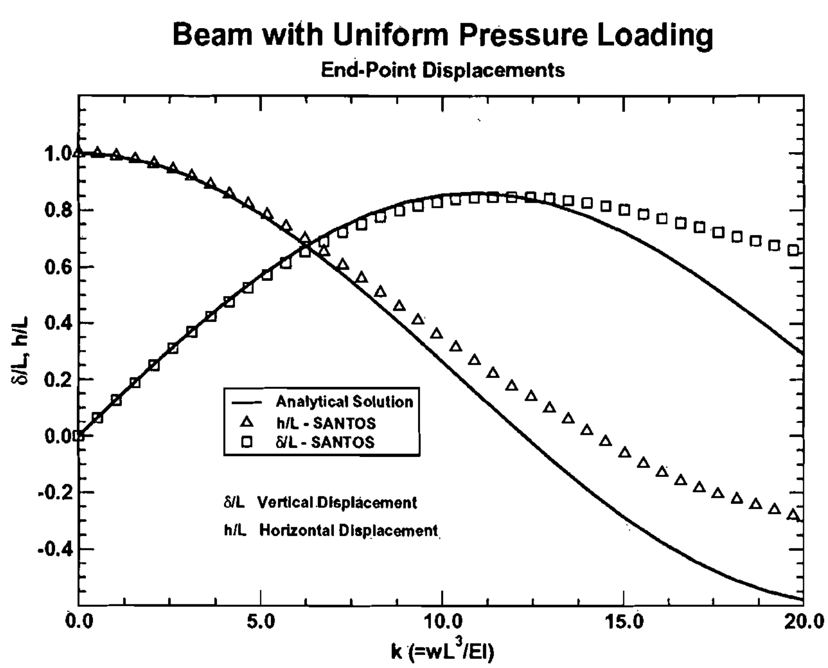
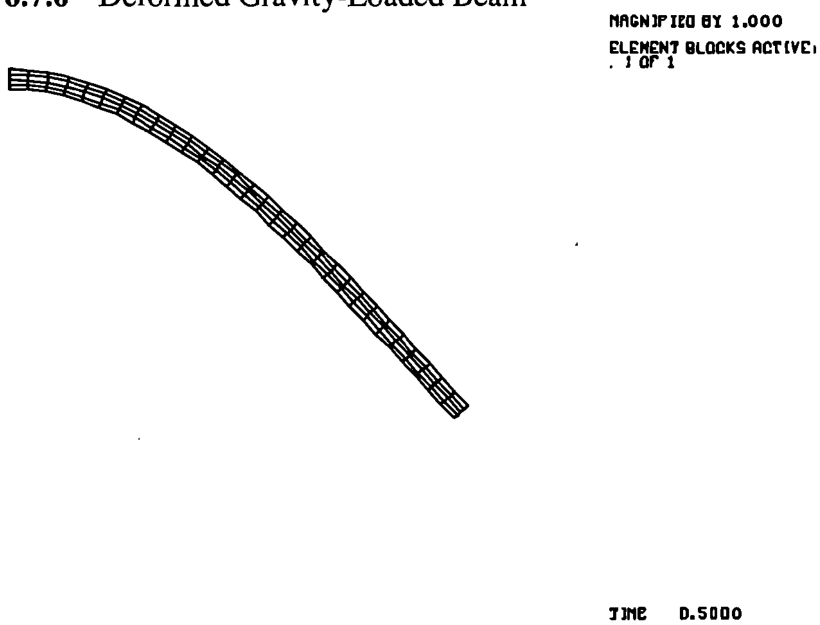


Figure 6.7.5 Pressure Beam End-Point Displacements



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 appear to be stiffer than the analytic results under higher loads. The JAC2D analysis of the same test produced the same results. Biffle and Blanford [13] 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.

Figure 6.7.6 Deformed Gravity-Loaded Beam



6.8 Test Case 8: Tension Releases Option

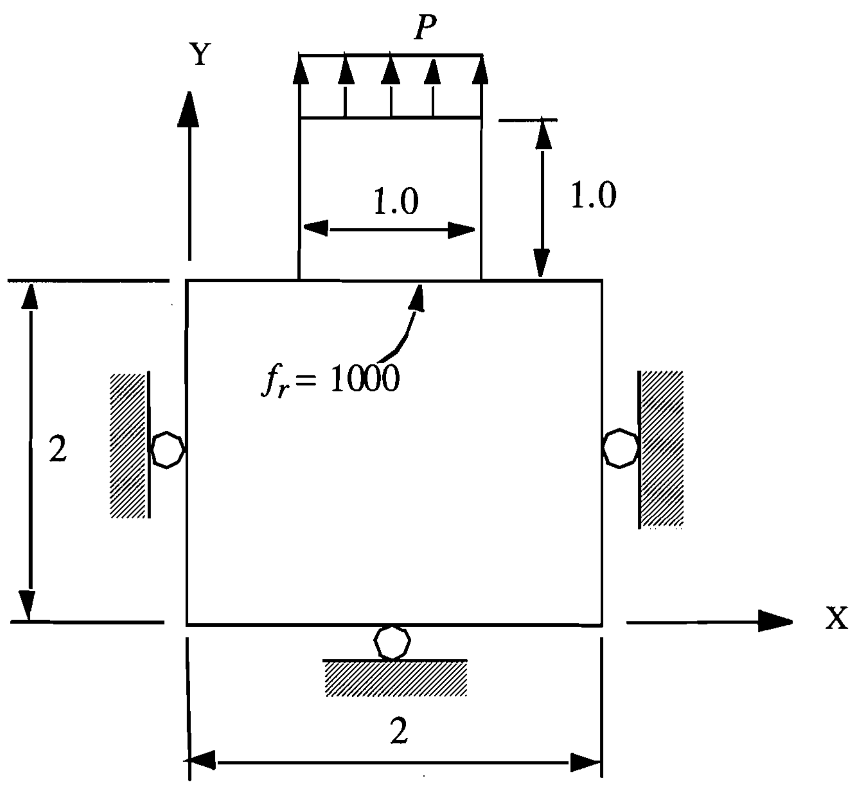
6.8.1 Test Objective

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

6.8.2 Test Procedure

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 6.8.1.

Figure 6.8.1 Problem Geometry and Boundary Conditions

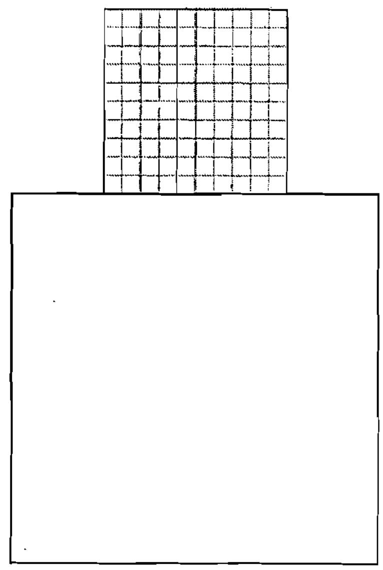


6.8.3 Input/Output

<u>Test Discretization</u>

The finite element mesh used in the SANTOS calculation is shown in Figure 6.8.2 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 6.8.2 Finite Element Mesh



<u>**Input Data**</u>

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

<u>**Output Listing**</u>

The output listing for the analysis is in APPENDIX H.

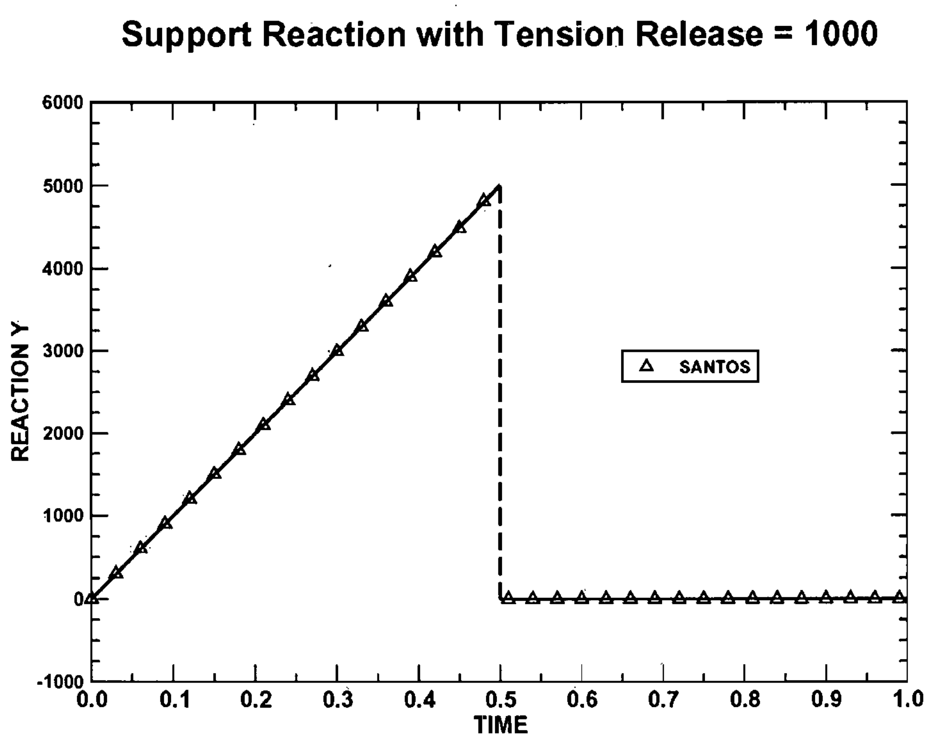
6.8.4 Acceptance Criteria

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 $E = 30x10^6$ and a Poisson's ratio of $\nu = 0.3$.

6.8.5 Evaluation

The support reaction predicted by the SANTOS analysis is plotted against the closed-form solution (dashed line) in Figure 6.8.3. 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 transferred 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 can be seen that the tensile release option of the contact surface algorithm in SANTOS is working correctly.

Figure 6.8.3 Plot of Vertical Support Reaction



6.9 Test Case 9: Rigid Sliding Surface Option

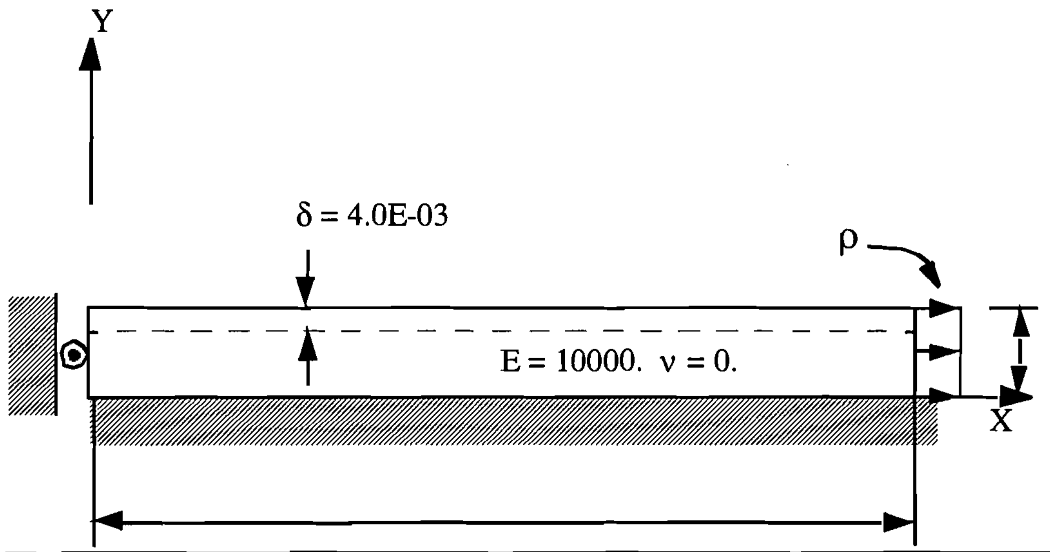
6.9.1 Test Objective

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.

6.9.2 Test Procedure

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 6.9.1 shows the geometry and boundary conditions of the problem.

Figure 6.9.1 Geometry and Boundary Conditions



6.9.3 Input/Output

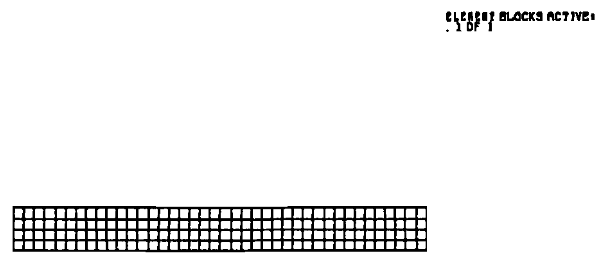
Test Discretization

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.

Figure 6.9.2 Finite Element Mesh



<u>Output Listing</u>

The output listings for the analyses are in APPENDIX I.

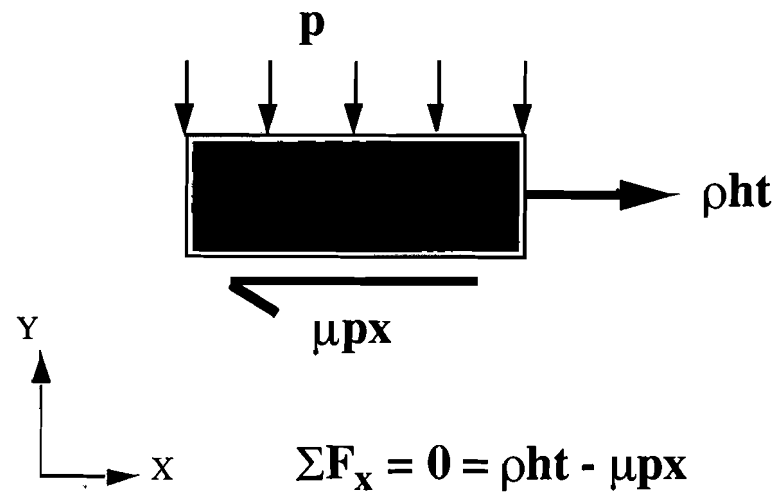
6.9.4 Acceptance Criteria

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

$$\Sigma F_x = 0 = \rho ht - \mu px \,. \qquad \textbf{(EQ 9.1)}$$

This is shown on the free body diagram in Figure 6.9.3, 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,

Figure 6.9.3 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:

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

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):

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

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:

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

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

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

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:

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

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:

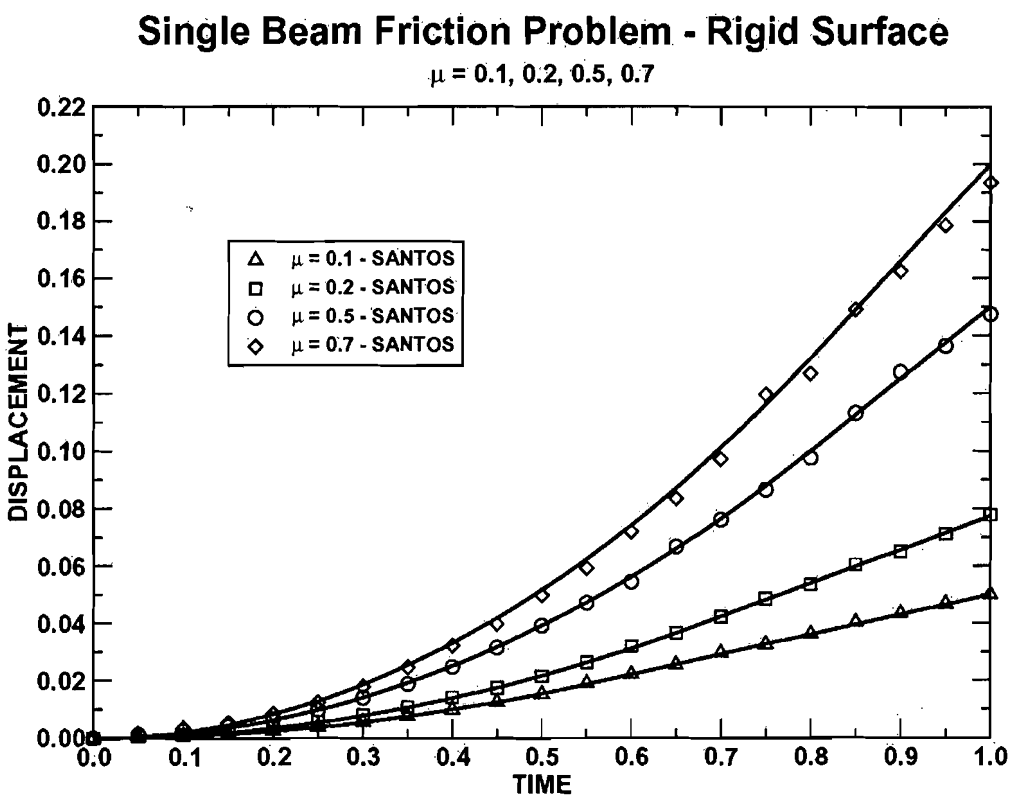
$$u(L) = \frac{\rho^2 h t^2}{2 \mu p E} . \qquad \textbf{(EQ 9.11)}$$

Specific values used in this example to generate values for comparison with the SANTOS predictions were: $E = 1.0x10^4$; $v = 0$ (Poisson's ratio, v, set to zero); $\delta = 4.0x10^{-3}$ (which corresponds to $p = 20$); $h = 2$; and $\mu = 0.1,\ 0.2,\ 0.5,\ 0.7$ with respectively corresponding maximum values of $\rho = 35,\ 58.75,\ 125,\ 170$.

6.9.5 Evaluation

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 ρ = 0 at time, *t* = 0, to a maximum of ρ = "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 that arise in the beam as the frictional stresses that 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 6.9.4. The figure shows excellent agreement between the SANTOS predictions of horizontal displacements and the analytic solutions (shown as the solid lines) and therefore SANTOS passes this test.

Figure 6.9.4 End-Point Horizontal Displacements



6.10 Test Case 10: Double Elastic Beam Contact Sliding Problem

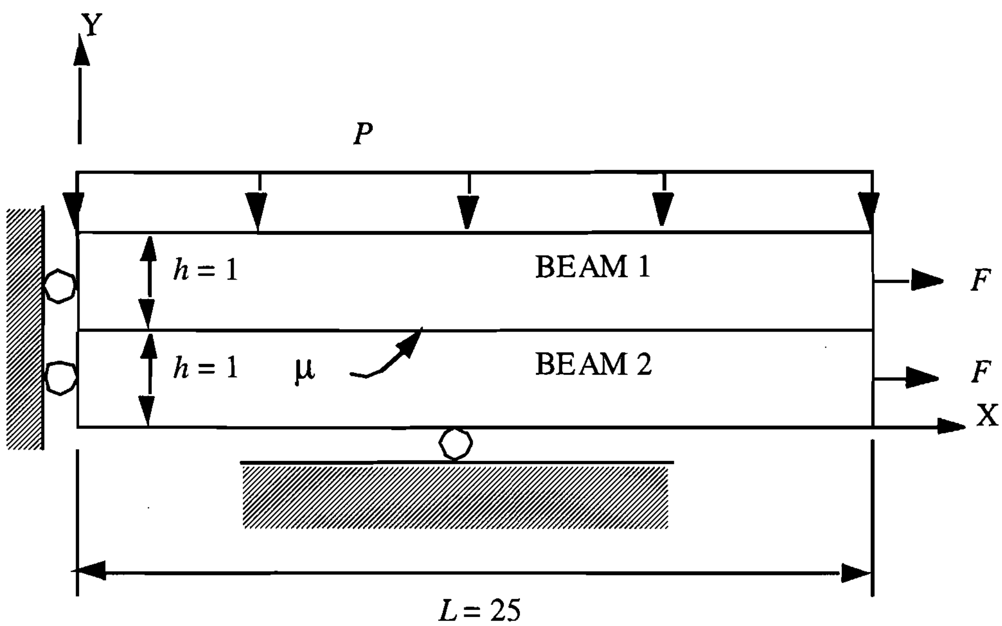
6.10.1 Test Objective

This test verifies 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.

6.10.2 Test Procedure

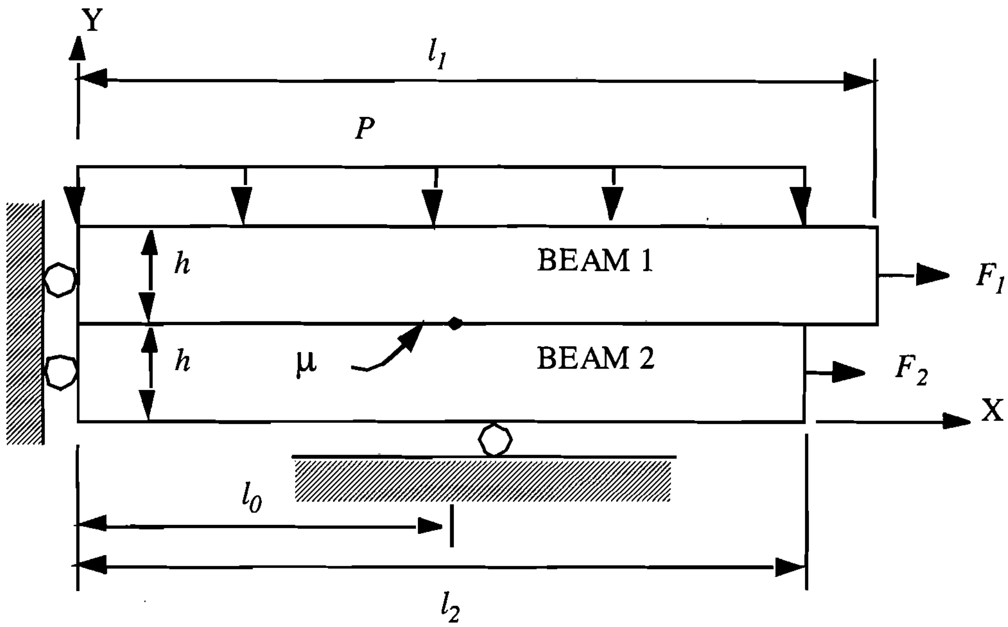
Two elastic beams of depth, h, and original length, L, and possessing different Young's moduli (E_1 for the top beam and E_2 for the bottom beam) are held in contact by a pressure, P, acting uniformly along their length as shown in Figure 6.10.1. The softer top beam is

Figure 6.10.1 Geometry and Boundary Conditions



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 6.10.1. 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 6.10.2. 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 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.

Figure 6.10.2 Deformed Geometry

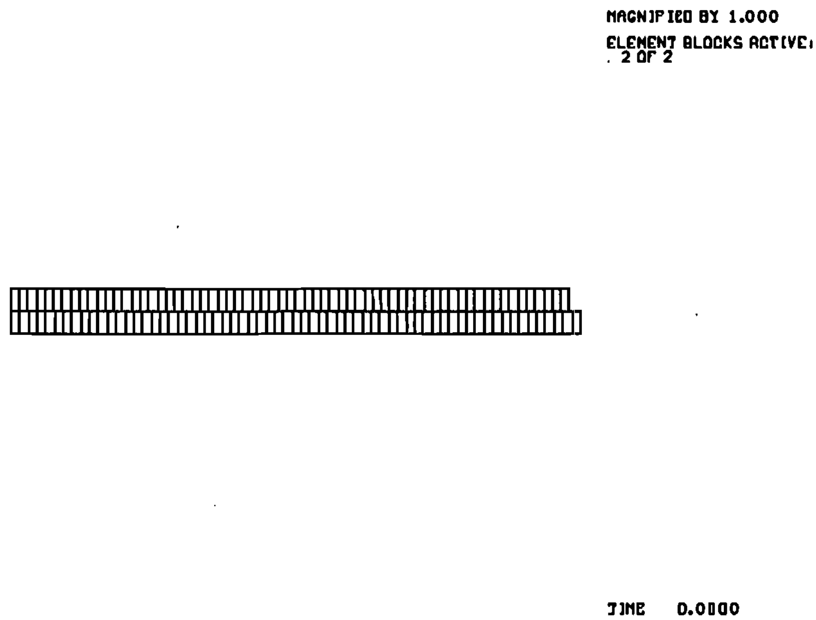


6.10.3 Input/Output

Test Discretization

The finite element mesh is shown in Figure 6.10.3 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 6.10.3 Finite Element Mesh



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.

6.10.4 Acceptance Criteria

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).

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:

$$l_0 = u_0 + L, \qquad \textbf{(EQ 10.4)}$$

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

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), $u_1^{l_1}$ 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:

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

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 6.10.4 for details):

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

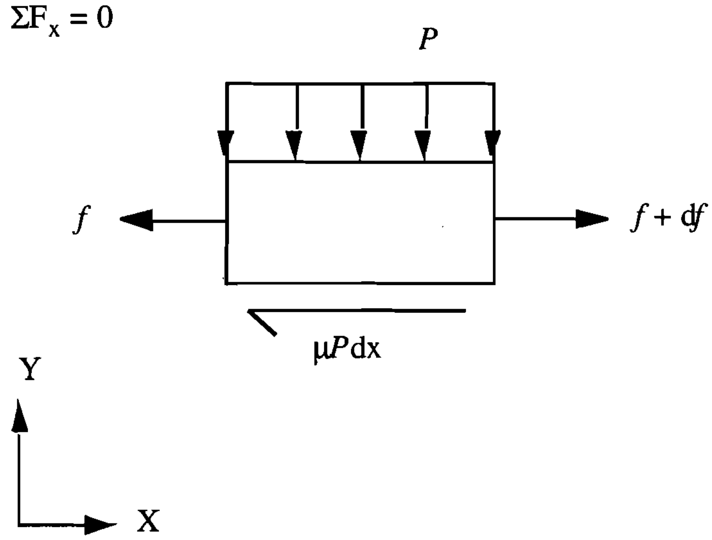
Integrating both sides of the equation yields the following:

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

and

$$f_1^e - f_1^x = \mu P(l_2 - x) \qquad \textbf{(EQ 10.12)}$$

Figure 6.10.4 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:

$$E_1 h \int_{u_0}^{u_1^x} du_1 = \int_0^x \left[f_1^e - \mu P(l_2 - x)\right] dx\text{, or} \qquad \textbf{(EQ 10.16)}$$

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

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:

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

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

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

$$E_2 h\left(u_2^{l_2} - u_0\right) = (l_2 - l_0)\left[F_1 - \frac{\mu P}{2}(l_2 - l_0)\right]. \quad \textbf{(EQ 10.20)}$$

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 $l_1 \equiv l_2 \equiv L$. Furthermore, we also note that $F_1 = F_2 = F$; $\sigma_1^{l_0} = \sigma_2^{l_0}$; and $\sigma_2^{l_0} = \sigma_2^A$. The six equations thus become:

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

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

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

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

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

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

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:

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

$$u_1^L=u_0+\frac{F^2(E_2-E_1)}{\mu PhE_1(E_1+E_2)}\left[\frac{3E_1+E_2}{2(E_1+E_2)}\right], \qquad \textbf{(EQ 10.28)}$$

and $$u_2^L=u_0+\frac{F^2(E_2-E_1)}{\mu PhE_2(E_1+E_2)}\left[\frac{E_1+3E_2}{2(E_1+E_2)}\right]. \qquad \textbf{(EQ 10.29)}$$

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.

6.10.5 Evaluation

The end-point displacements predicted by the SANTOS analyses are plotted against the closed-form solutions in Figure 6.10.5, for the first case, and Figure 6.10.6, for the second case. The SANTOS results show excellent agreement with the analytic solution (shown as the solid lines in both figures), and it is concluded that the sliding part of the contact algorithm is working correctly in SANTOS.

Figure 6.10.5 End-Point Displacements for Case 1

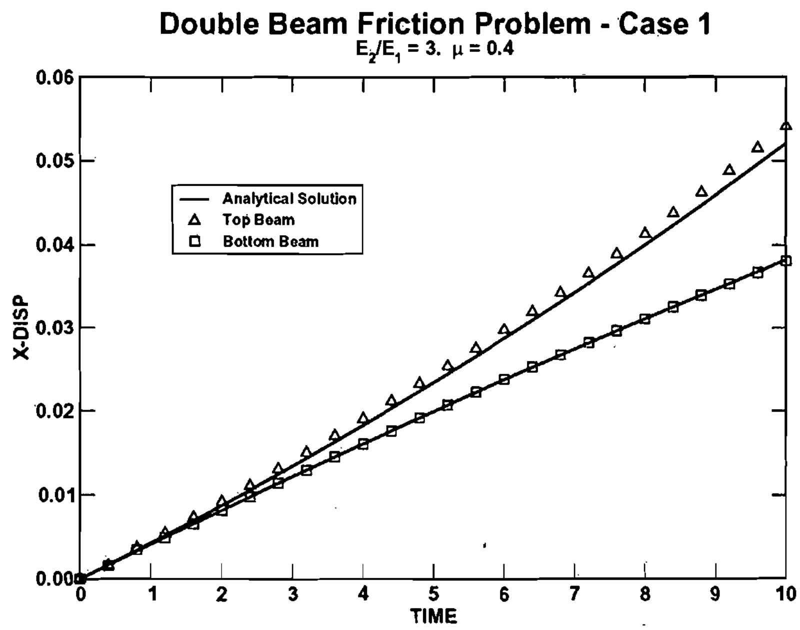
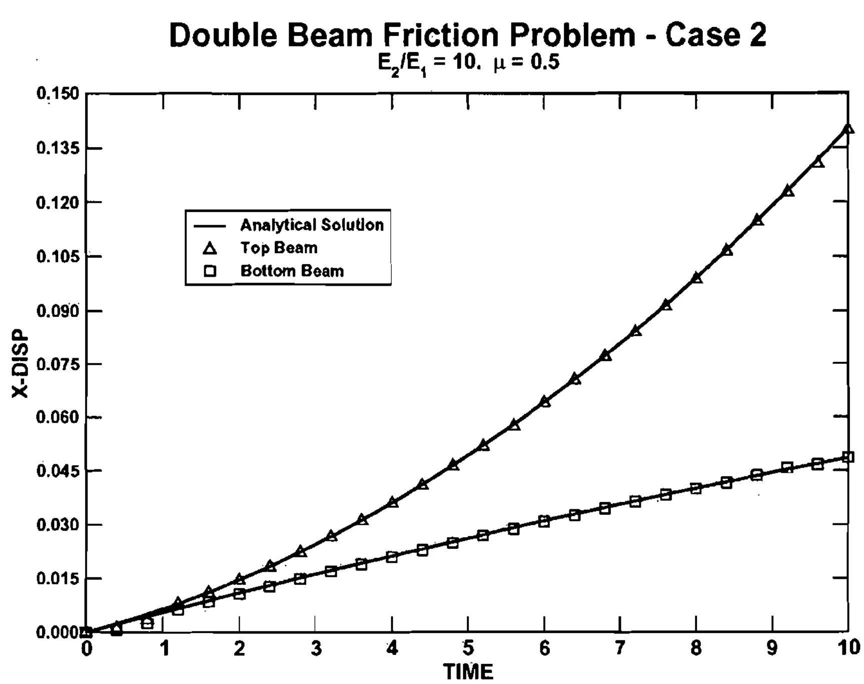


Figure 6.10.6 End-Point Displacements for Case 2



6.11 Test Case 11: Elastic/Plastic Analysis of a Thick-Walled Hollow Sphere

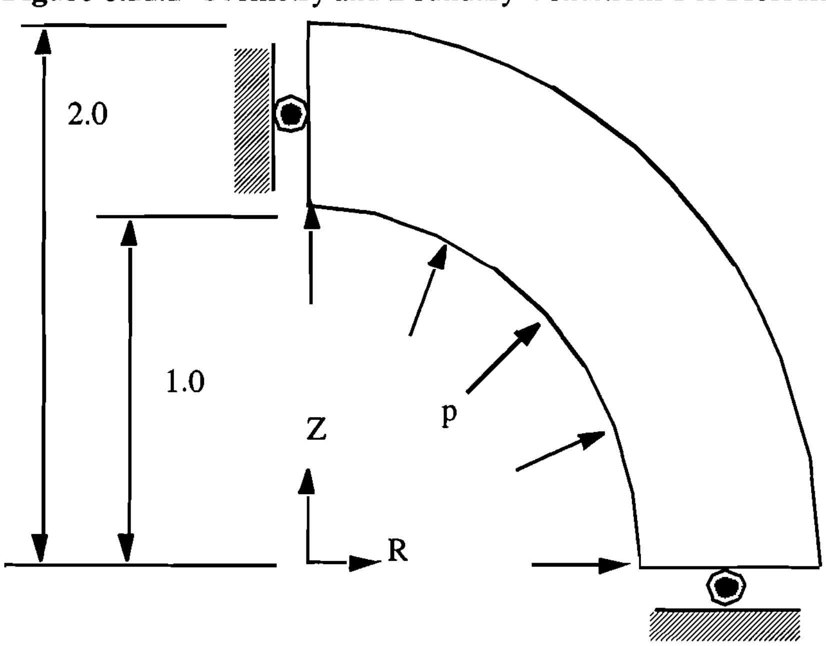
6.11.1 Test Objective

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.

6.11.2 Test Procedure

The sphere analyzed in all three cases has an internal radius of one and an outer radius of two, as shown in Figure 6.11.1. 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 6.11.1 Geometry and Boundary Conditions For Pressurized Cases



6.11.3 Input/Output

Test 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)

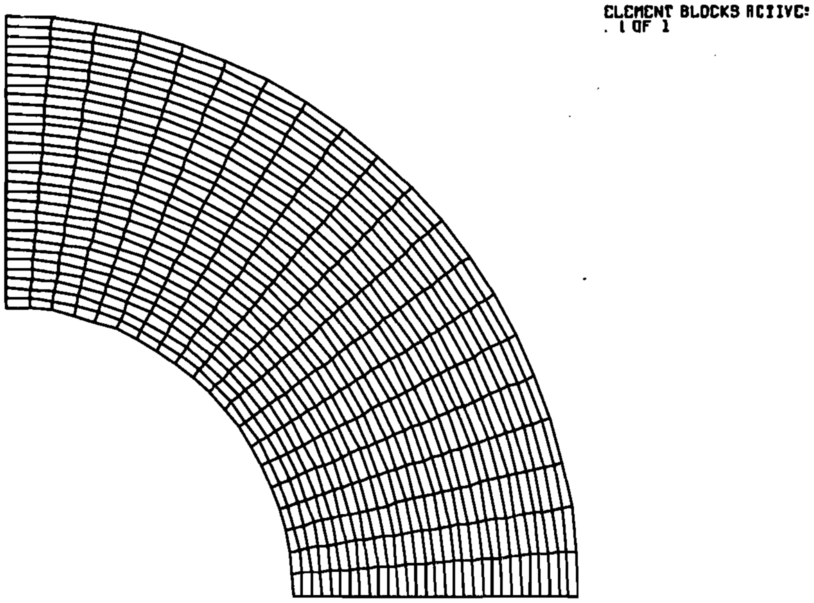
Input Data

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.

Figure 6.11.2 Finite Element Mesh



6.11.4 Acceptance Criteria

Pressure Loading Cases

The analytic solutions for these problems were derived by Mendelson [14]. For the isothermal pressurized loading cases the elastic/plastic interface expands radially outward 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 [14]. However, Biffle and Blanford [13] discovered that the effective stress function for the linear strain hardening material in Mendelson is incorrect, and the corrected equation from the JAC2D manual [13] is shown below. The expression:

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

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:

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

Specific values used in this example to generate a solution for comparison with computed results from SANTOS for the elastic/perfectly-plastic case are:
$\sigma_y = 1.0x10^4$; $a = 1.0$; $b = 2.0$; $E = 2.07x10^{11}$; and $\nu = 0.3$. The applied internal pressure used in the SANTOS analysis is shown in Table 6.11.1. 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.

Table 6.11.1 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

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:
$\sigma_y = 1.0x10^4$; $a = 1.0$; $b = 2.0$; $m = 0.1$; $E = 2.07x10^{11}$; and $\nu = 0.3$. The applied internal pressure used in the SANTOS analysis is shown in Table 6.11.2. 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 6.11.2 and Figure 6.11.3 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 6.11.2 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 6.11.3 Elastic/Perfectly Plastic Hollow Sphere

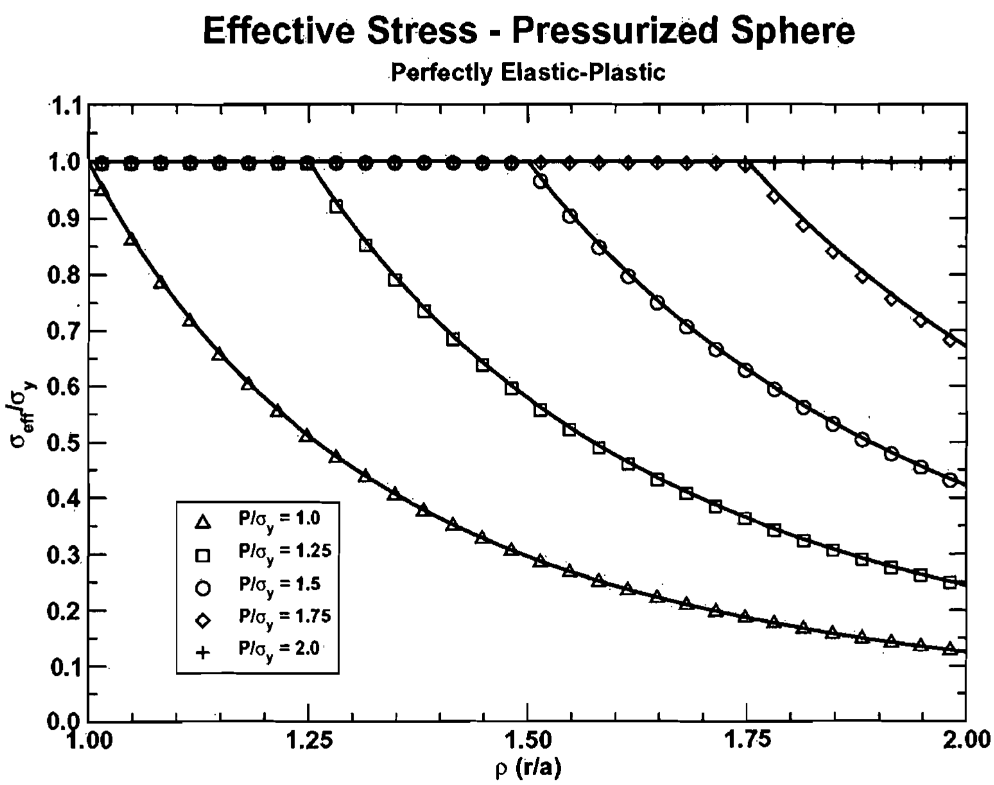
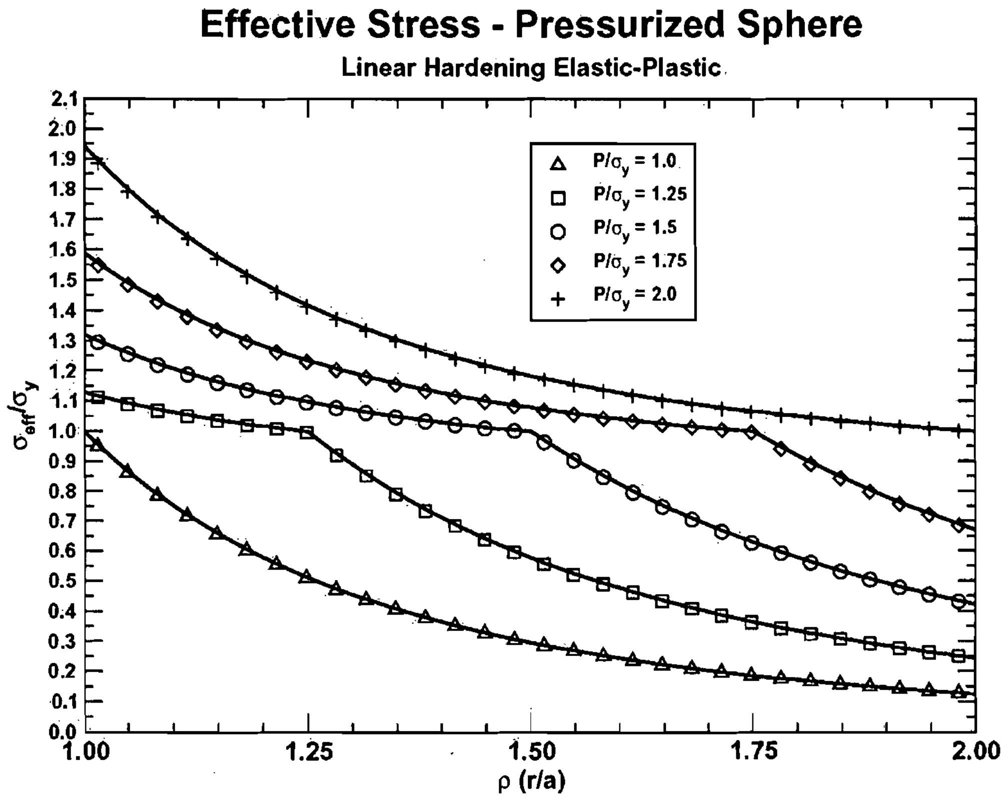


Figure 6.11.4 Elastic/Plastic Hollow Sphere with Linear Hardening



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_0 on the inner surface and zero temperature on the outer surface. The radial temperature gradient is given in Mendelson as:

$$T = \frac{T_0 a}{(b-a)}\left(\frac{b}{r} - 1\right) \qquad \textbf{(EQ 11.5)}$$

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 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:

$$\tau = \frac{E\alpha T_0}{\sigma_y(1-\nu)}, \qquad \textbf{(EQ 11.7)}$$

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

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

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: $\alpha = 1.0x10^{-5}$; $E = 1.0x10^7$; $\nu = 0.3$; $\sigma_y = 1.0x10^4$; $a = 1.0$; and $b = 2.0$. Using these values, the inner surface temperature, T_0, required to initiate yielding, at $r = a$, is $98°$.

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 [13]

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

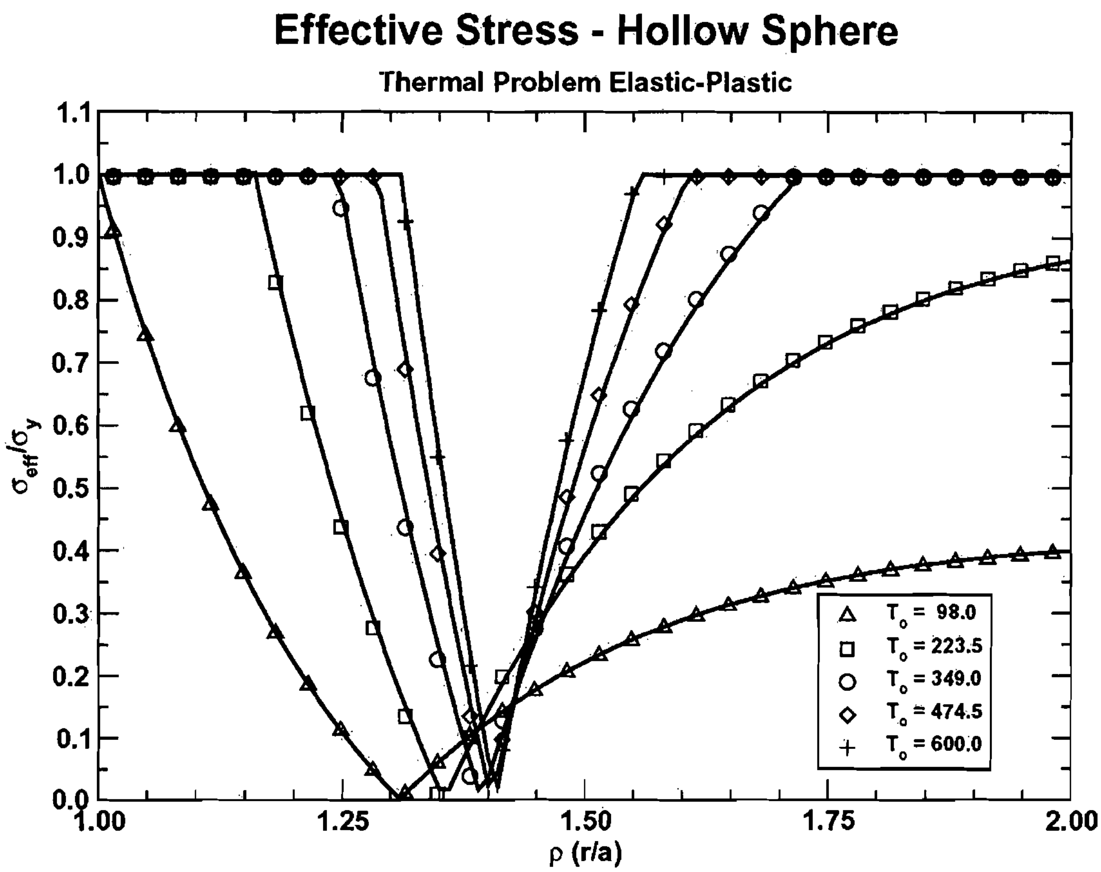
$$\ln\left(\frac{cd}{ab}\right) = \frac{2c}{3d}\left[\frac{d}{c} - 1\right]^2, \qquad \textbf{(EQ 11.13)}$$

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:

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

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 6.11.5 Elastic/Perfectly Plastic Hollow Sphere – Temperature Case



6.11.5 Evaluation

The results predicted by SANTOS are also shown in Figures 6.11.3 and 6.11.5. 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 6.11.3 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.

6.12 Test Case 12: Restart Option

6.12.1 Test Objective

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

6.12.2 Test Procedure

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 Test Case 11.

6.12.3 Input/Output

<u>**Test Discretization**</u>

The finite element mesh is shown in Figure 6.11.5 and is composed of 600 elements (4 node quadrilaterals)

<u>**Input Data**</u>

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

<u>**Output Listing**</u>

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

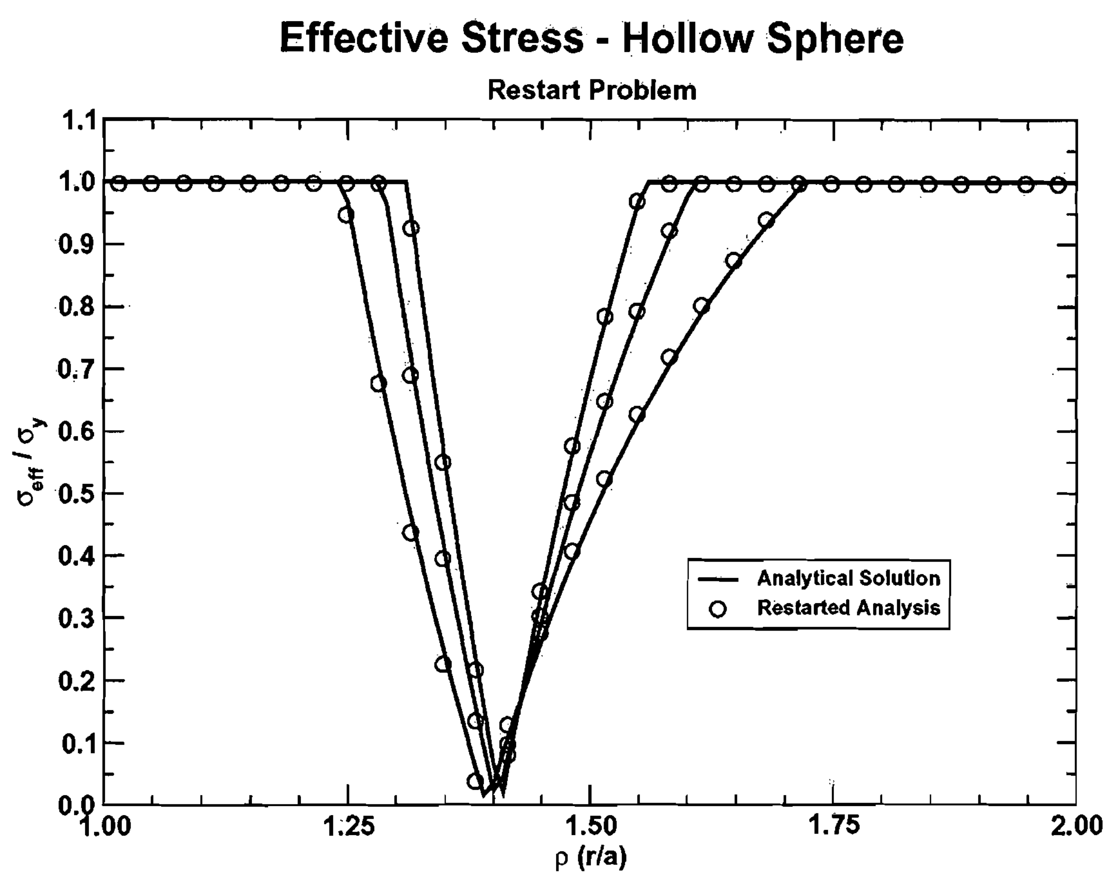
6.12.4 Acceptance Criteria

See Test Case 11 for the analytic solution and for specific material properties and geometric parameters used for this example.

6.12.5 Evaluation

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 6.12.1 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.

Figure 6.12.1 Effective Stress Comparison



6.13 Test Case 13: Sloping Roller Option

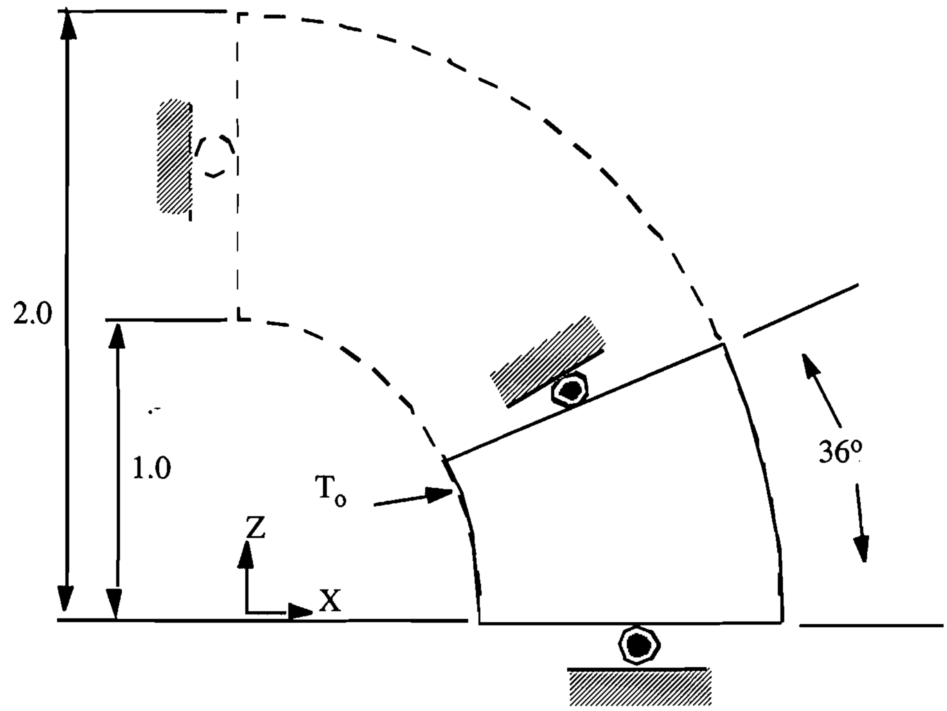
6.13.1 Test Objective

This test 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.

6.13.2 Test Procedure

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 test was analyzed in Test Case 11 using a hemispherical model of the sphere. In this calculation a 36^{o} wedge of the sphere is modeled using the sloping roller option. Figure 6.13.1 depicts the geometry and boundary conditions used in the sloping roller calculation.

Figure 6.13.1 Geometry and Boundary Conditions



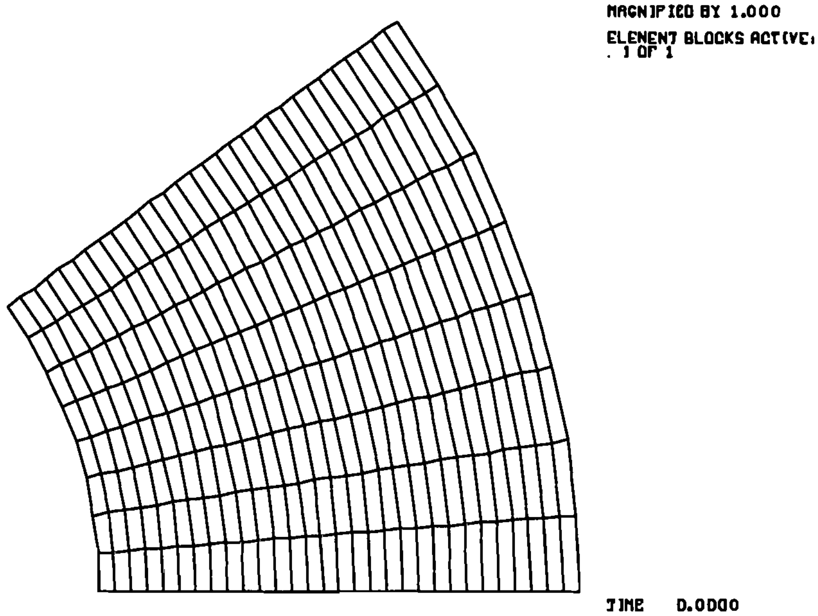
6.13.3 Input/Output

In this specific example, we use the same material and geometric parameters as for Problem 11: $\alpha = 1.0x10^{-5}$; $E = 1.0x10^{7}$; $\nu = 0.3$; $\sigma_y = 1.0x10^{4}$; $a = 1.0$; and $b = 2.0$.

Test Discretization

A 240 element mesh (4 node-quadrilateral) is used in the SANTOS calculation and is shown in Figure 6.13.2.

Figure 6.13.2 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 test information is given in APPENDIX M.

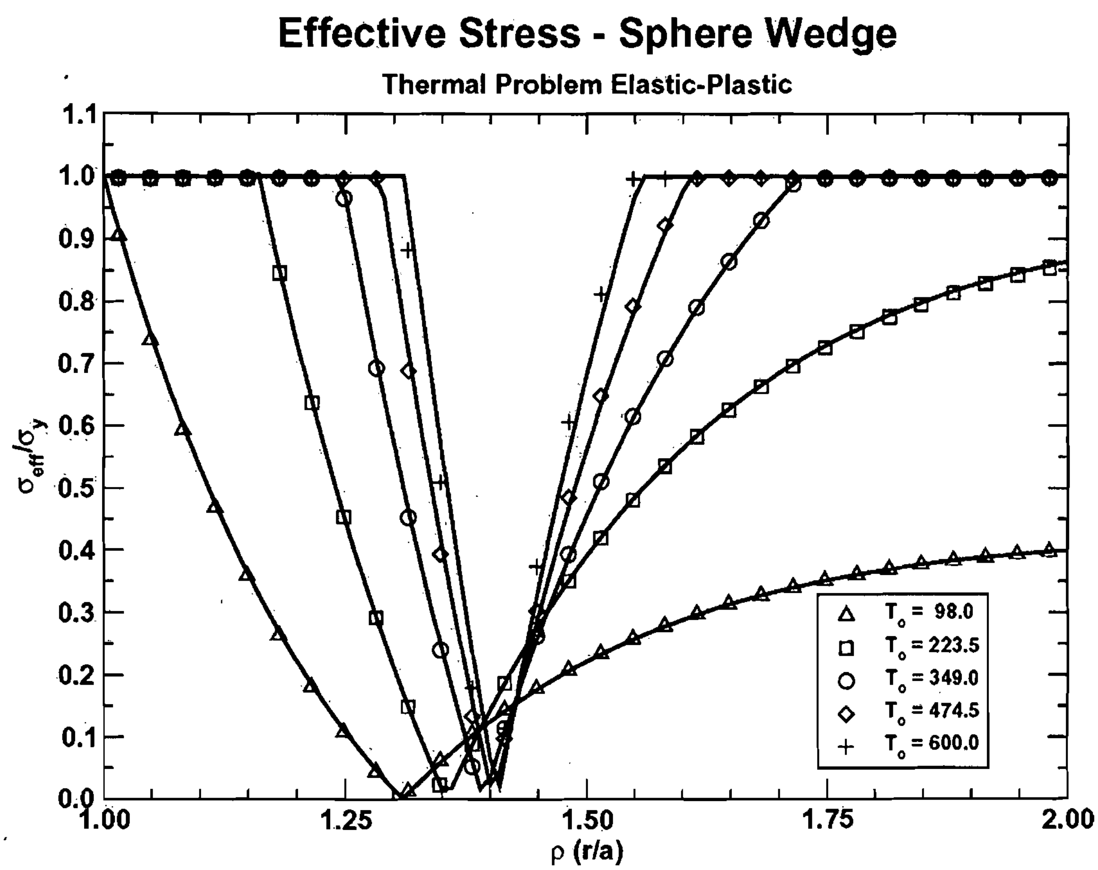
6.13.4 Acceptance Criteria

The analytical solution to this test was derived by Mendelson [14] and is discussed in greater detail in Test Case 11.

6.13.5 Evaluation

The calculation using the sloping roller option in SANTOS successfully recreated the effective stress profiles, as shown in Figure 6.13.3, that were plotted in Test Case 11. The sloping roller option is correctly working in SANTOS.

Figure 6.13.3 Effective Stress Plot



6.14 Test Case 14: Creep Relaxation

6.14.1 Test Objective

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

6.14.2 Test Procedure

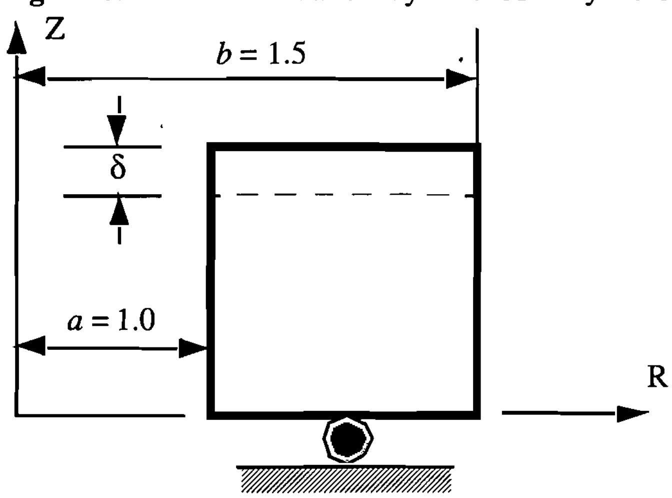
A stress-free, isotropic, and homogeneous hollow cylinder undergoes an axial displacement d at time zero. The calculation determines the axial creep stress relaxation in the cylinder over time when d is kept constant.

6.14.3 Input/Output

Test Discretization

A single element (4-mode quadrilateral) is used in the analysis and the problem geometry and boundary conditions are shown in Figure 6.14.1.

Figure 6.14.1 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.

6.14.4 Acceptance Criteria

This problem was used to verify the power law creep model in SANCHO [15]. The total strain rate can be decomposed into elastic and inelastic (creep) parts as follows:

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

The total strain rate is zero for the stress relaxation problem in question, after the displacement, d, 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:

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

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,
σ 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:

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

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, d.

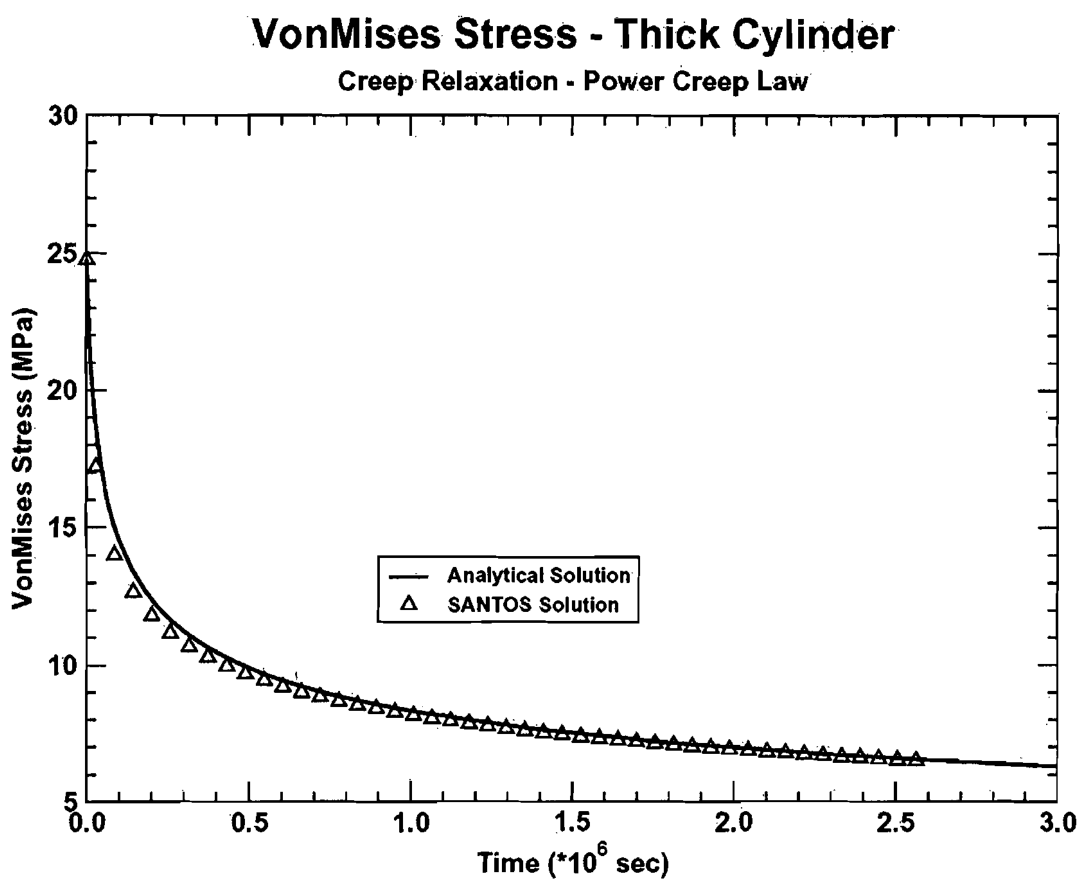
Specific values used in this example are as follows:

$\delta = 0.001$; $E = 24.75X10^9$; $\nu = 0$; $D = 5.79X10^{-36;}$ $n = 4.9$; and $Q/(RT) = 20.13$. Using these specific values, the elastic response induced by application of the displacement d 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.

6.14.5 Evaluation

A comparison of analytically derived Von Mises stresses with those predicted by SANTOS is shown in Figure 6.14.2. 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 6.14.2 Von Mises Stress Plot – Power Creep Law



6.15 Test Case 15: Linear Viscoelastic Constitutive Model Implementation

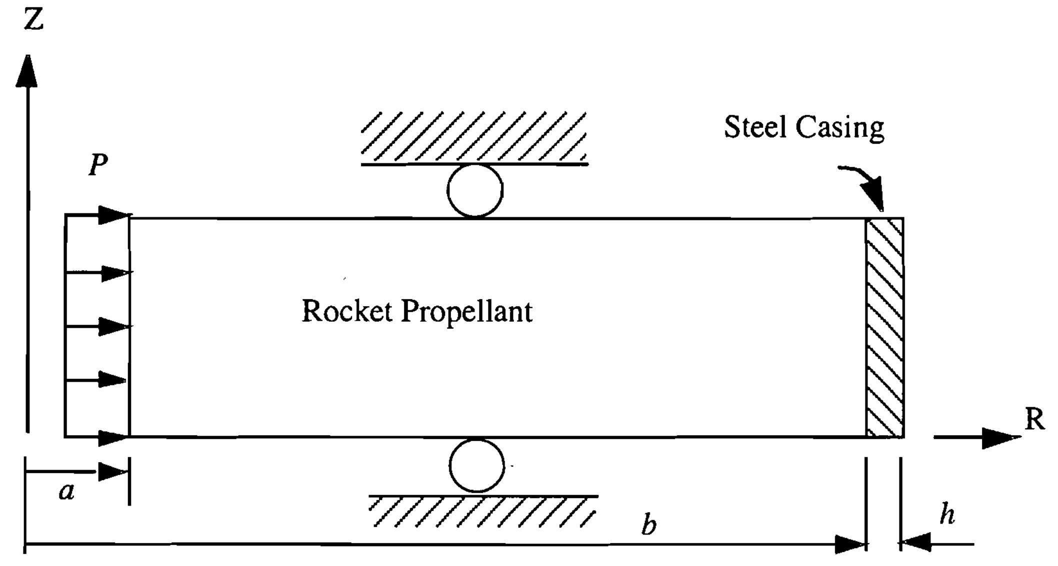
6.15.1 Test Objective

This test checks the implementation of a linear viscoelastic constitutive model [16] into SANTOS by analyzing an internally pressurized thick-walled cylinder.

6.15.2 Test Procedure

A thick-walled cylinder representing a rocket motor is subjected to an instantaneous pressure on its inner surface. The solid propellant is modeled 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 6.15.1 shows the problem geometry and boundary conditions.

Figure 6.15.1 Geometry and Boundary Conditions



6.15.3 Input/Output

Test Discretization

A 23 element mesh (4 node-quadrilateral) is used in the calculation and is shown in Figure 6.15.2.

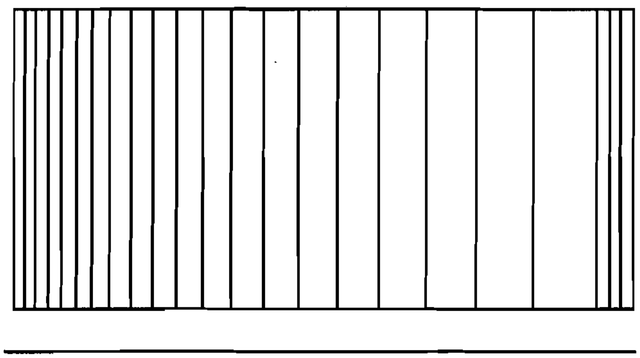
Input Data

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.

Figure 6.15.2 Finite Element Mesh



6.15.4 Acceptance Criteria

An analytical solution to this problem has been developed by Lee et al. [17] and Stone and Costin [16] used this problem to test their linear viscoelastic constitutive model implementation in the SANCHO finite element program [15]. Lee et al. make use of the Laplace transform to generate the following equation:

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

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

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

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:

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

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= 3.75×10^4; 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: $h = 1/8$; $E = 3\times10^7$; $\nu = 0.3015$; σ_y= 1×10^6; $H = 1\times10^6$; *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.

6.15.5 Evaluation

In Figure 6.15.3 and Figure 6.15.4 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 and therefore SANTOS passes this test.

Figure 6.15.3 Radial Stress Plot

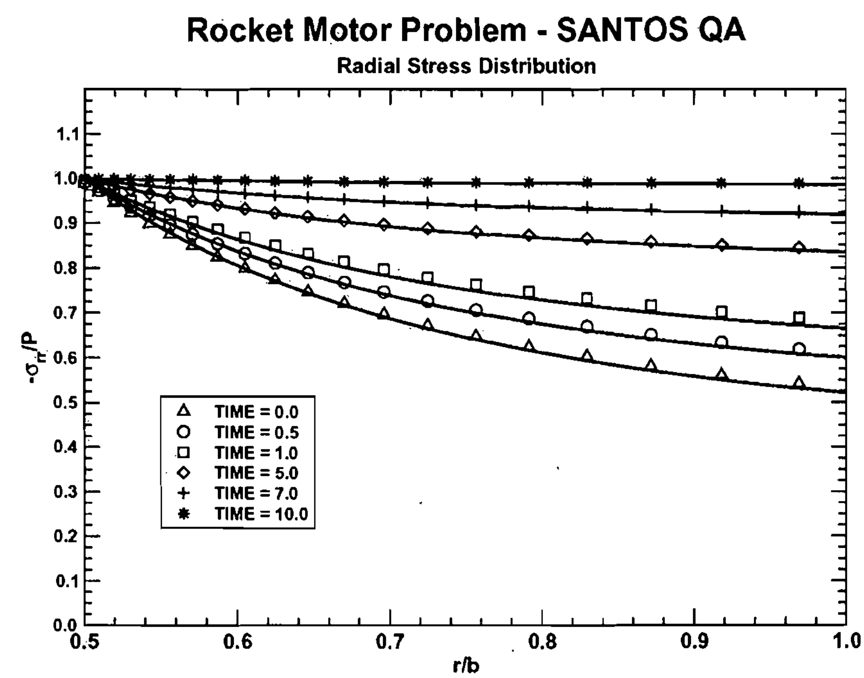
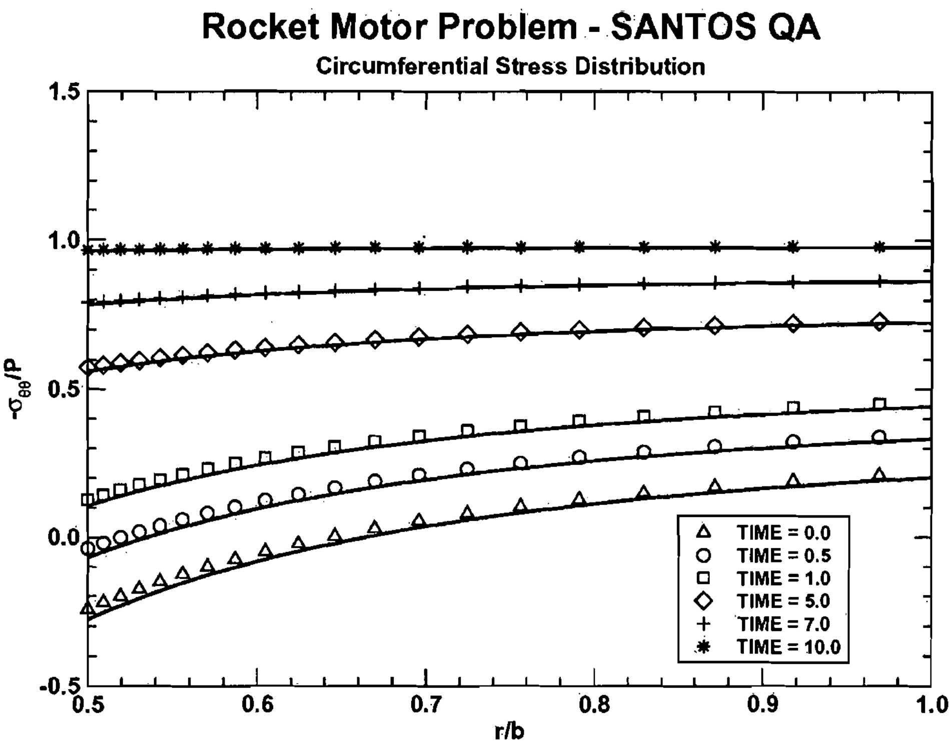


Figure 6.15.4 Circumferential Stress Plot



6.16 Test Case 16: M-D Constitutive Model Implementation

6.16.1 Test Objective

This test verifies the SANTOS implementation of the M-D constitutive model with a Tresca flow condition, as described by Munson et al. [18], on a shaft closure analysis. The SANTOS results are compared to those computed with the SPECTROM-32 code [19]. 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.

6.16.2 Test Procedure

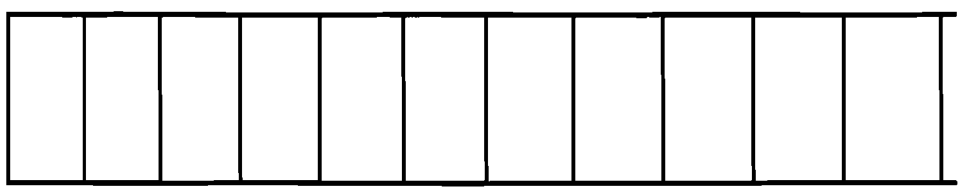
A vertical shaft of 6.5 m diameter is assumed to be excavated instantaneously at time zero at a depth of 655.3 m in bedded salt. The material at the depth of interest is subject to an in situ lithostatic stress of –15 MPa and immediately begins to close the shaft opening as it begins to creep. An analysis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

6.16.3 Input/Output

Test Discretization

A 128 element (4-node quadrilateral) mesh is used in the SANTOS analysis and is shown in Figure 6.16.1. The figure shows only a "close-up" of the mesh near the shaft opening, because the full mesh is very large.

Figure 6.16.1 Finite Element Mesh near the Shaft Opening



Input Data

A listing of the SANTOS input is in APPENDIX P.

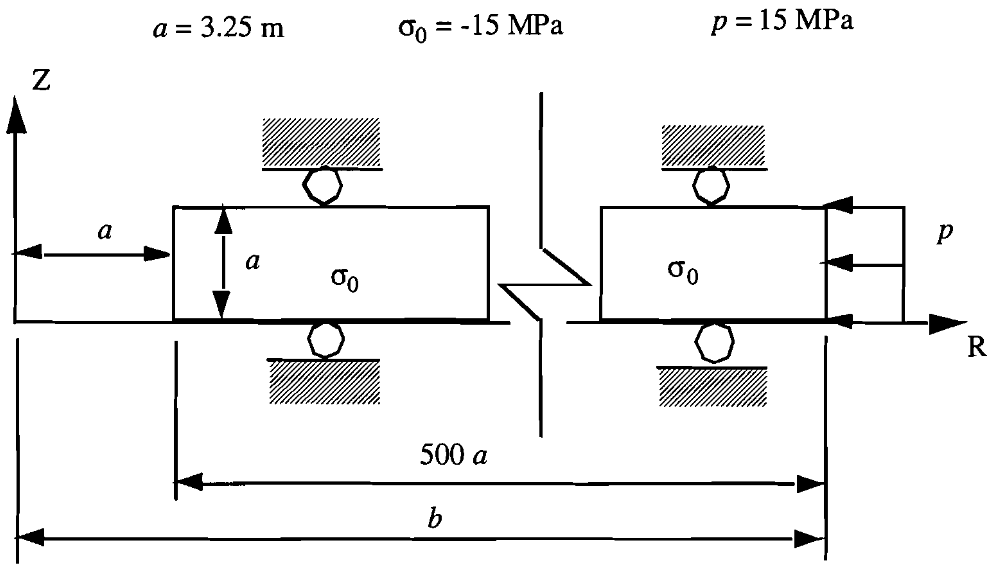
Output Listing

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

6.16.4 Acceptance Criteria (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. [20]. The results from that analysis were computed with SPECTROM-32. Figure 6.16.2 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), and applied pressure (*p*) used in the analysis are also shown on the figure.

Figure 6.16.2 Problem Geometry and Boundary Conditions



The elastic and creep properties used in this analysis are shown in Table 6.16.1 and Table 6.16.2, respectively. The creep parameters listed in the table are those given by Munson, et al. [18] for clean salt.

Table 6.16.1 Elastic Properties

G Mpa	E Mpa	ν
12,400	31,000	0.25

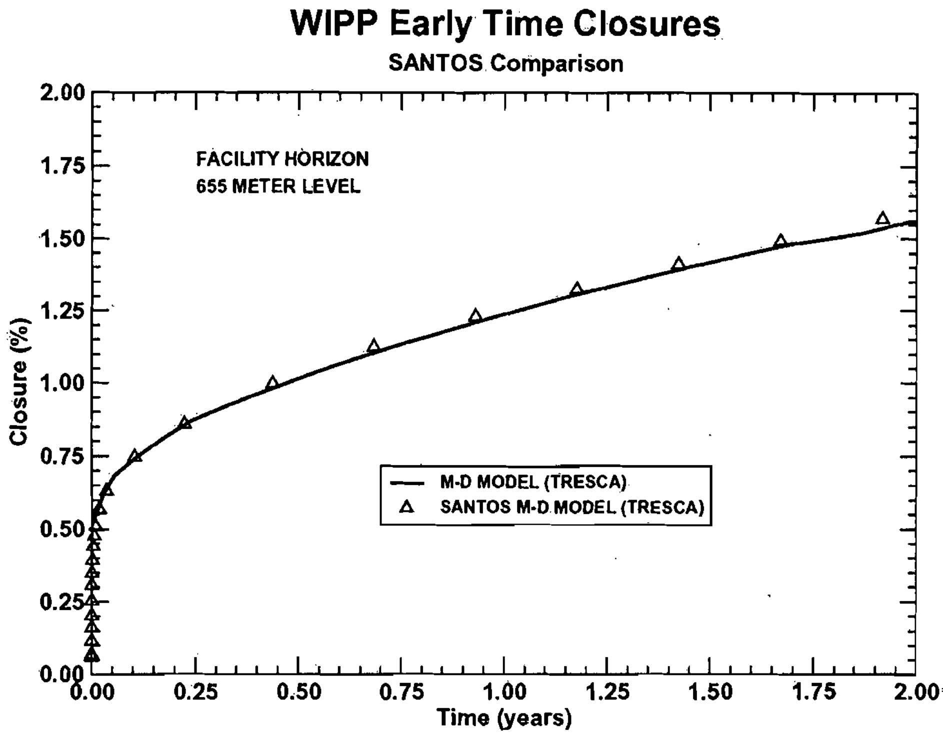
Table 6.16.2 Creep Properties

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
s_o (MPa)	20.57
q	5,335
M	3.0
K_o	6.275E5
c (/T)	9.198E-3
α	-17.37
ß	-7.738
δ	0.58

6.16.5 Evaluation

The SANTOS predictions of shaft closure are shown in Figure 6.16.3 and compare very well with the SPECTROM-32 results (shown as the solid line) that were presented in Munson et al. [20] 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.

Figure 6.16.3 Per-Cent Closure of Shaft SANTOS Results



6.17 Test Case 17: Upsetting of a Cylindrical Billet

6.17.1 Test Objective

This test case 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 [21]. The time history of the die force is to be compared to computational results by Taylor [22]. The die force is governed by large deformation, inelastic material behavior in conjunction with complex contact surface response.

6.17.2 Test Procedure

This test 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 [21]. 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.

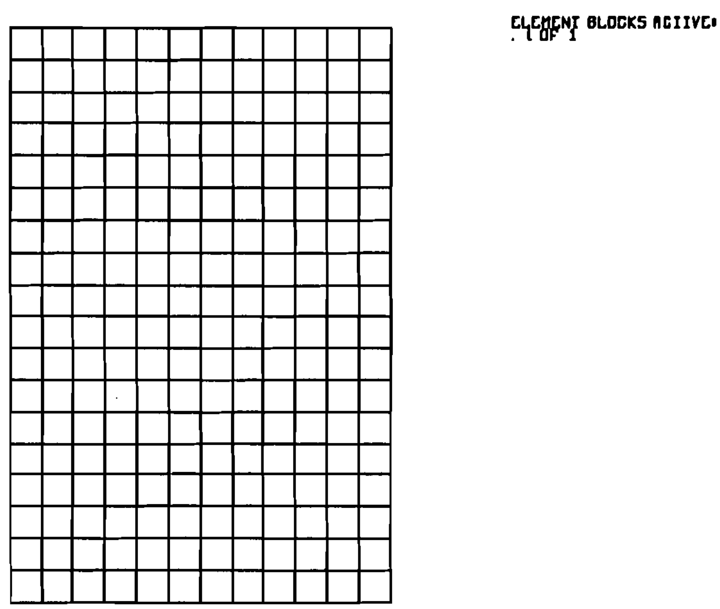
6.17.3 Input/Output

Test 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 6.17.1. Also shown on the figure are the applied boundary conditions. The mesh contains 247 nodes and 216 uniform strain, quadrilateral elements.

Figure 6.17.1 Mesh Discretization and Boundary Conditions



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 test is also provided as a section in APPENDIX Q.

6.17.4 Acceptance Criteria (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 [22].

6.17.5 Evaluation

Figure 6.17.2 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 6.17.3. Figure 6.17.4 shows a comparison of the upset force vs. die displacement with results taken from Taylor [22]. 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 rigid surface. This agreement of the SANTOS results with those of Taylor [22] suggests that SANTOS is adequate for performing metal-forming applications analyses.

Figure 6.17.2 Plots of the Deforming Billet at Various Times During the Upset

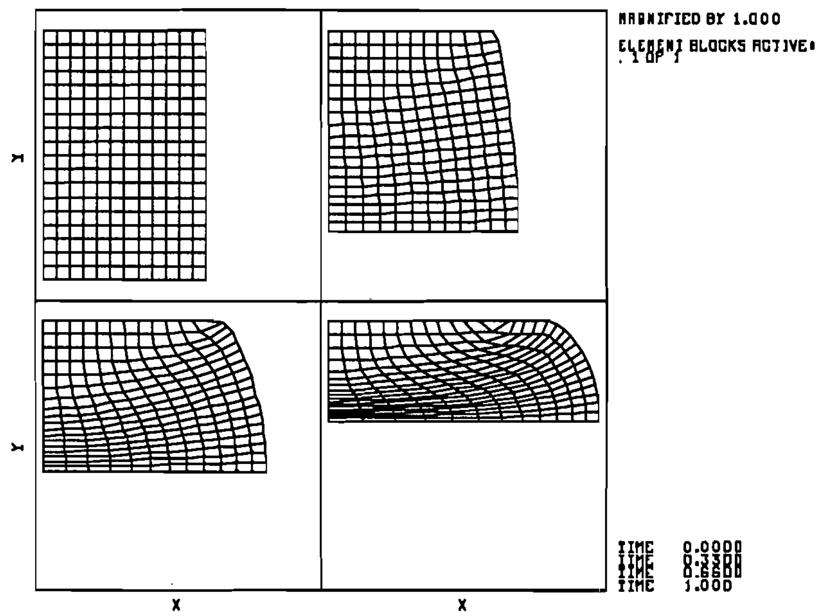


Figure 6.17.3 Final Deformed Shape of the Billet After 60% Upset

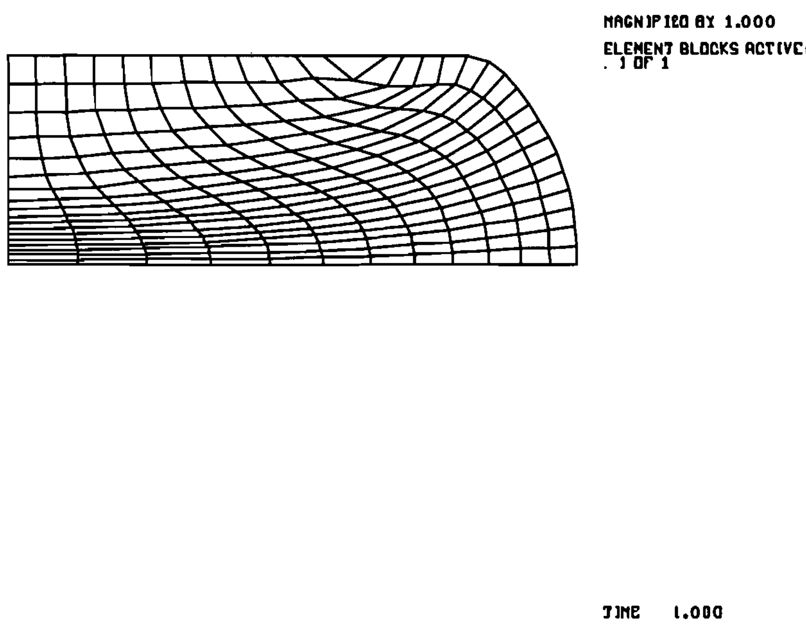
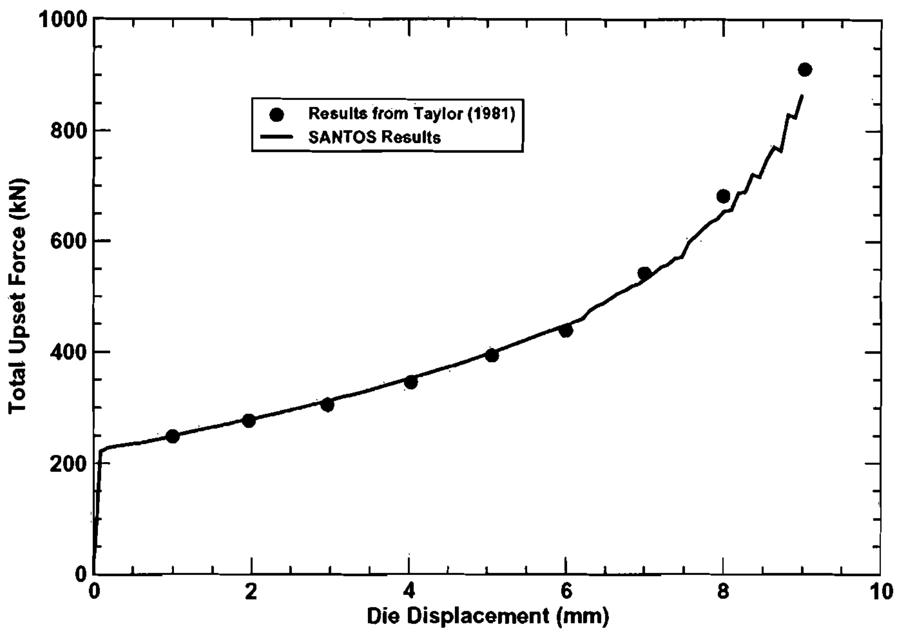


Figure 6.17.4 Comparison of SANTOS Calculation With Numerical Results Taken From Taylor [22] for the Upset of a Cylindrical Billet.



6.18 Test Case 18: Isothermal WIPP Benchmak II

6.18.1 Test Objective

This test is a geomechanics test 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 test 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 [23], 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.

6.18.2 Test Procedure

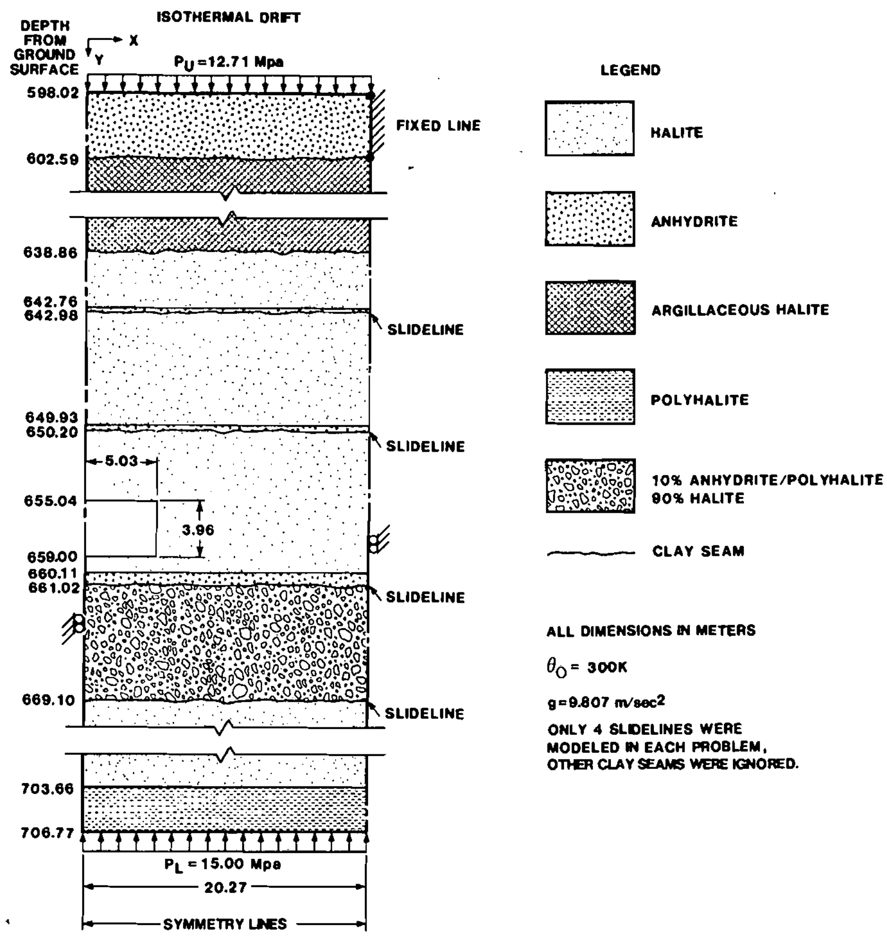
The problem geometry allows the use of a vertical plane of symmetry passing through the center of a drift and a symmetry plane between drifts to produce an equivalent single drift plane strain model. The boundary conditions and the layered stratigraphy are shown in Figure 6.18.1 [24]. The drift is rectangular 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. T he layers identified as halite, argillaceous halite, and 10% anhydrite/polyhalite–90% halite were modeled using an elastic–secondary creep model of the form:

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

Figure 6.18.1 Benchmark II Isothermal Drift Configuration [24]



where $\dot{\varepsilon}$ is the effective creep strain rate and σ is the effective stress ($\sigma = \sqrt{\frac{3}{2}\sigma'_{ij}\sigma'_{ij}}$), 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 6.18.1.

Table 6.18.1 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	2.48E+10	0.25	5.79E-36	4.9	12
Argillaceous Halite	2.48E+10	0.25	1.74E-35	4.9	12
10% A-P, 90% H	2.65E+10	0.25	5.21E-36	4.9	12
Anhydrite	7.24E+10	0.33			
Polyhalite	7.24E+10	0.33			

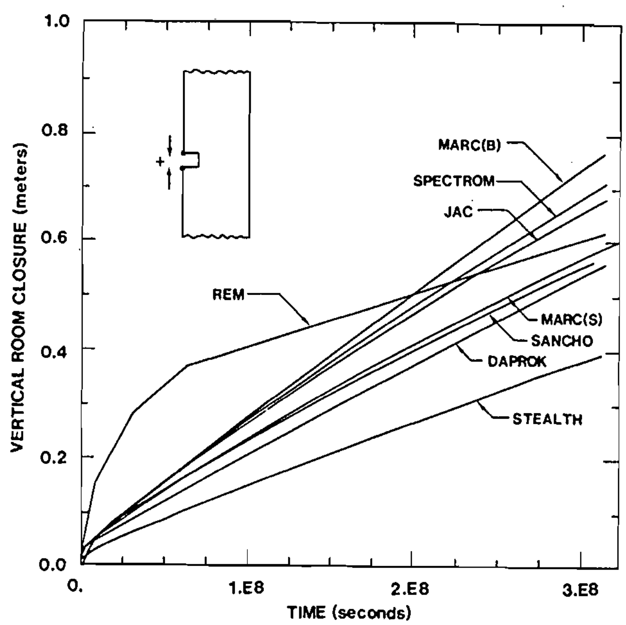
The initial stress state was assumed to be lithostatic with $\sigma_x = \sigma_{yy} = \sigma_{zz} = -21252y$, where y is the depth in meters and stresses are in pascals. The mechanical loads acting on the model consisted of the overburden uniform pressures specified along the top and bottom boundaries (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.

6.18.3 Input/Output

Test Discretization

The finite element mesh used in this analysis is shown in Figure 6.18.4. 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 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.

Figure 6.18.2 Vertical Closure History Results from Benchmark II Exercise – Isothermal Drift [24]



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 test is also provided as a section in APPENDIX R.

6.18.4 Acceptance Criteria (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 6.18.2 and Figure 6.18.3 show some results from a previous benchmark exercise [24] 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.

6.18.5 Evaluation

Figure 6.18.5 and Figure 6.18.6 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 6.18.2 for times of 1 year, 5 years, 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.

Figure 6.18.3 Midpillar Horizontal Displacement History Results from Benchmark II Exercise – Isothermal Drift [24]

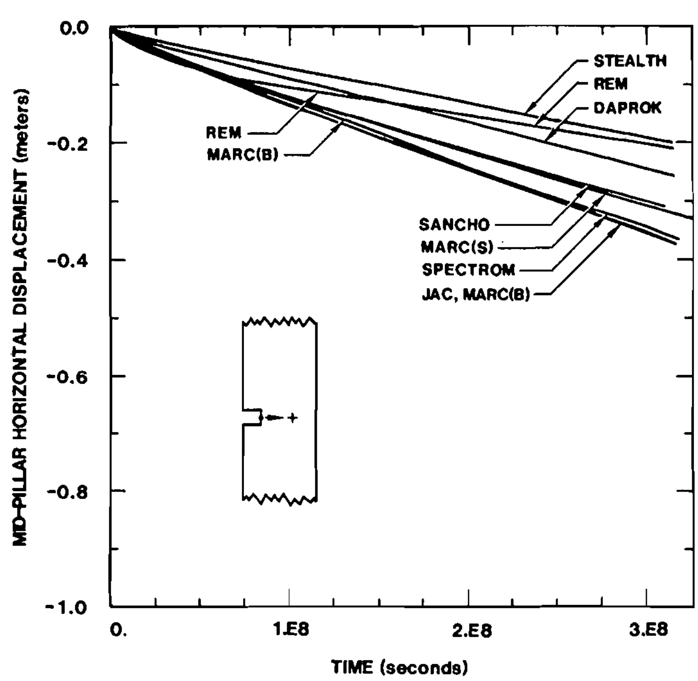


Table 18.2 Comparison of SANTOS Results For The Isothermal Problem With Those Computed In Benchmark II Exercise

Time (years)		Vertical Closure (meter)	Midpillar Horizontal Displacement (meters)
	Benchmark II Range	0.06 to 0.28	-0.03 to -0.06
1.0	SANTOS Value	0.099	-0.045
	Benchmark II Range	0.22 to 0.46	-0.11 to -0.21
5.0	SANTOS Value	0.346	-0.175
	Benchmark II Range	0.39 to 0.77	-0.21 to -0.38
10.0	SANTOS Value	0.617	-0.322

Figure 6.18.4 Santos Mesh Used For Benchmark II Isothermal Test

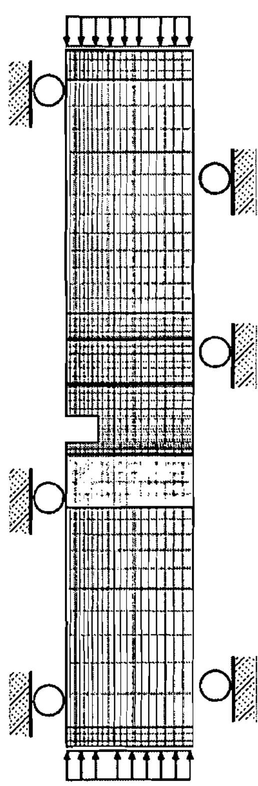


Figure 6.18.5 Vertical Closure History Computed With SANTOS for Benchmark II Isothermal Test

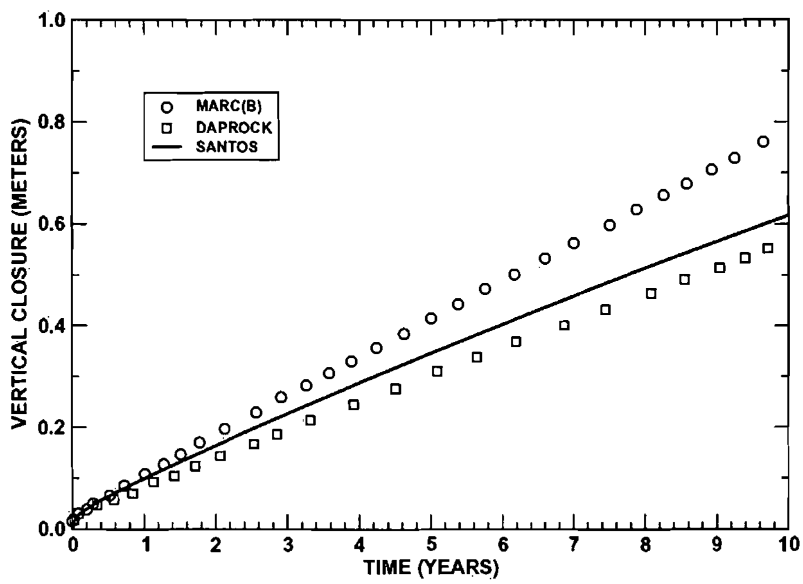
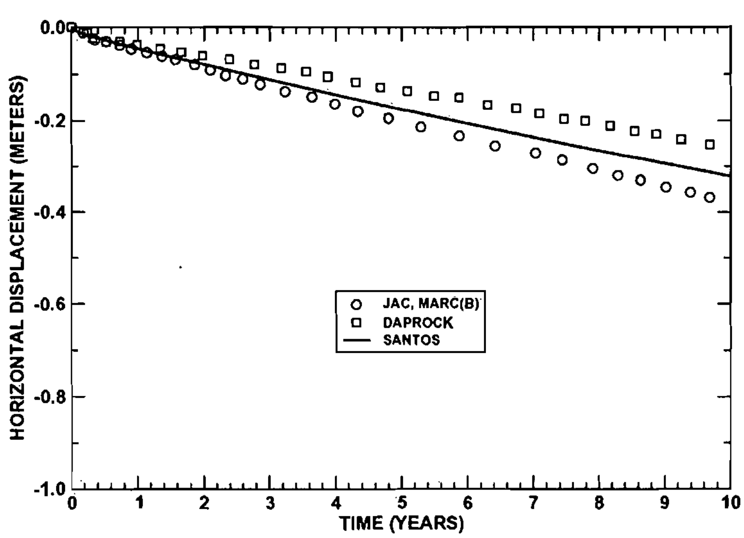


Figure 6.18.6 Midpillar Horizontal Displacement History Computed With SANTOS for Benchmark II Isothermal Test



6.19 Test Case 19: Heated WIPP Benchmark II

6.19.1 Test Objective

Again, as for the isothermal case of Test Case 18, this test models a repository horizon that 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 [23], 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.

6.19.2 Test Procedure

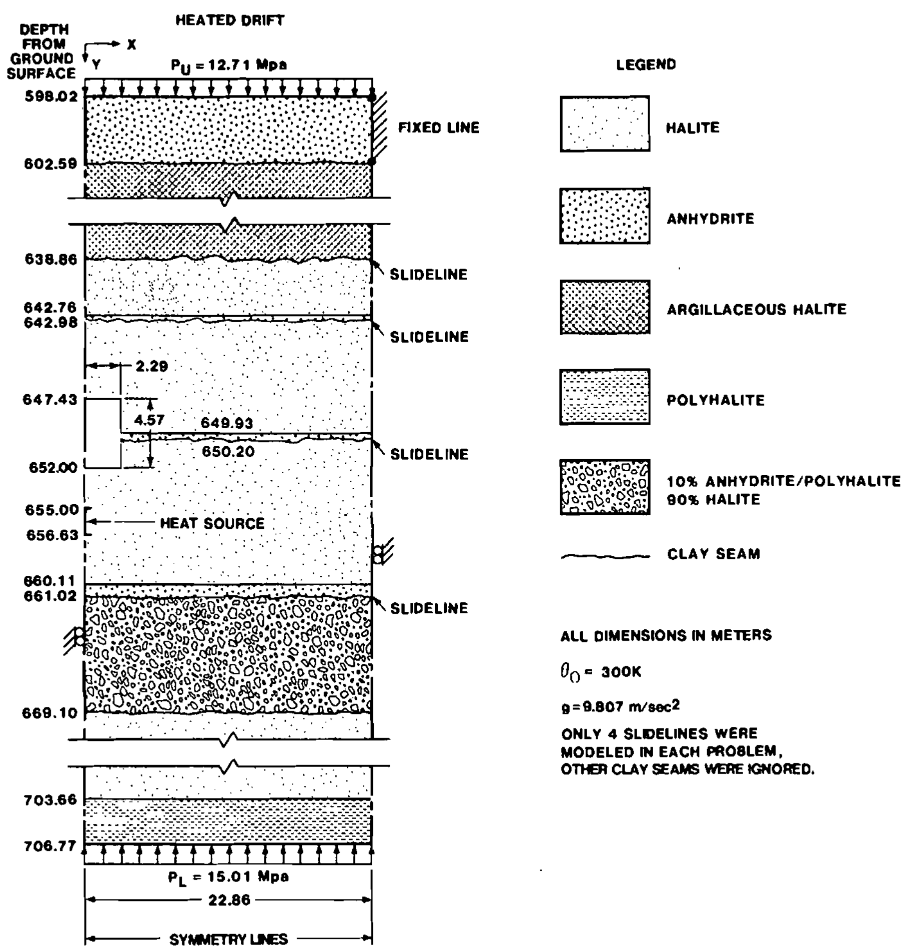
Two separate two-dimensional models were used for the heated Benchmark II analysis: a thermal model and a structural model. Only one-way coupling between the thermal and structural responses was considered, i.e., the thermal response was assumed to be unaffected by the structural deformations. The thermal model was used to compute temperatures in the configuration around the opening for the 5-year simulation period. The finite element code COYOTE II [25] 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 [26] 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 6.19.1. 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 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:

Figure 6.19.1 Benchmark II Heated Drift Configuration [24]



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

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 deviation from the Benchmark II definition for the thermal aspects of the heated problem but was appropriate because previous calculations [27] 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 that 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 6.19.2 and consists of four-node, isoparametric, quadrilateral elements.

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 6.19.1.

Figure 6.19.2 Thermal Mesh Used For Benchmark II Heated

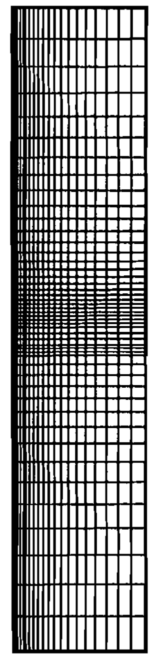


Table 6.19.1 Material Properties Used for Benchmark II Heated Problem – Thermal Analysis

Material	Density, p, 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 6.19.1. 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:

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

where $\dot{\varepsilon}$ is the effective creep strain rate and σ is the effective stress ($\sigma = \sqrt{\frac{3}{2}\sigma'_{ij}\sigma'_{ij}}$), 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 6.19.2.

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.

Table 6.19.2 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	2.48E+10	0.25	5.79E-36	4.9	12.0	45.0E-6
Argillaceous Halite	2.48E+10	0.25	1.74E-35	4.9	12.0	40.0E-6
10% A-P, 90% H	2.65E+10	0.25	5.21E-36	4.9	12.0	42.7E-6
Anhydrite	7.24E+10	0.33				20.0E-6
Polyhalite	7.24E+10	0.33				24.0E-6

6.19.3 Input/Output

Test Discretization

The finite element mesh used in this analysis is shown in Figure 6.19.5. 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.

Figure 6.19.3 Vertical Closure History Results from Benchmark II Exercise – Heated Drift [24]

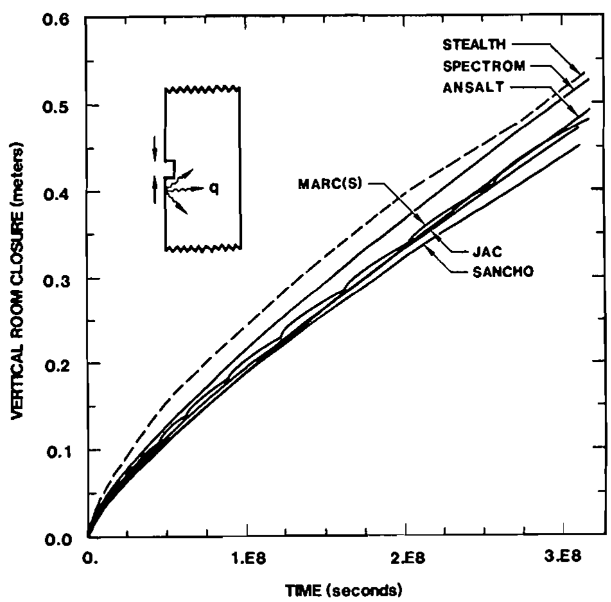


Figure 6.19.4 Midpillar Horizontal Displacement History Results from Benchmark II Exercise – Heated Drift [24]

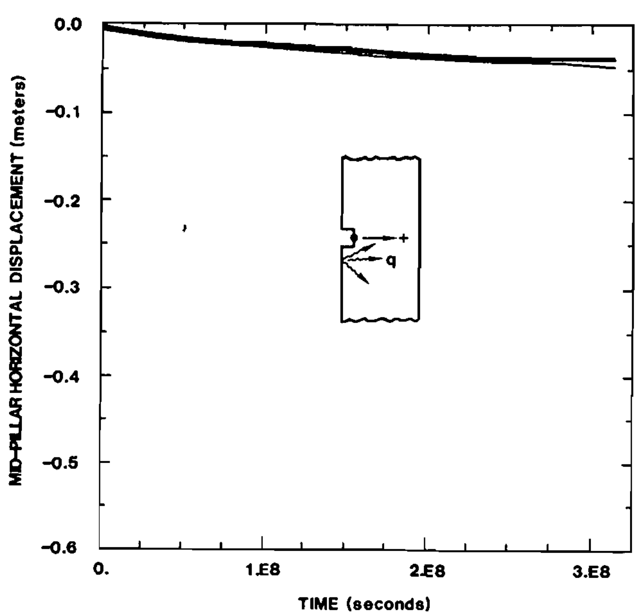
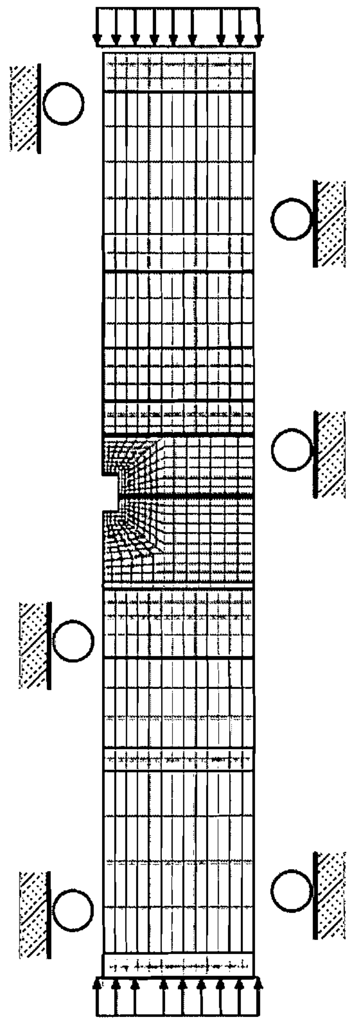


Figure 6.19.5 Santos Mesh Used For Benchmark II Heated Test



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.

6.19.4 Acceptance Criteria (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 6.19.3 and Figure 6.19.4 show some results from a previous benchmark exercise [24] 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.

6.19.5 Evaluation

Figure 6.19.6 and Figure 6.19.7 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 6.19.3 for times of 1 year, 3 years, and 10 years. Because the SANTOS results are very near the Benchmark II numbers this test is passed.

Figure 6.19.6 Vertical Closure History Computed With SANTOS for Benchmark II Heated Test

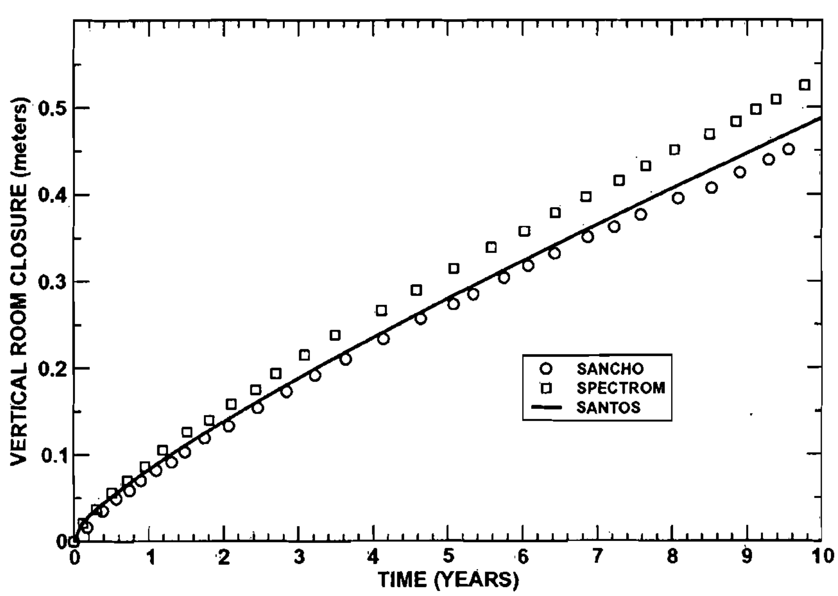


Figure 6.19.7 Midpillar Horizontal Displacement History Computed With SANTOS for Benchmark II Heated Test

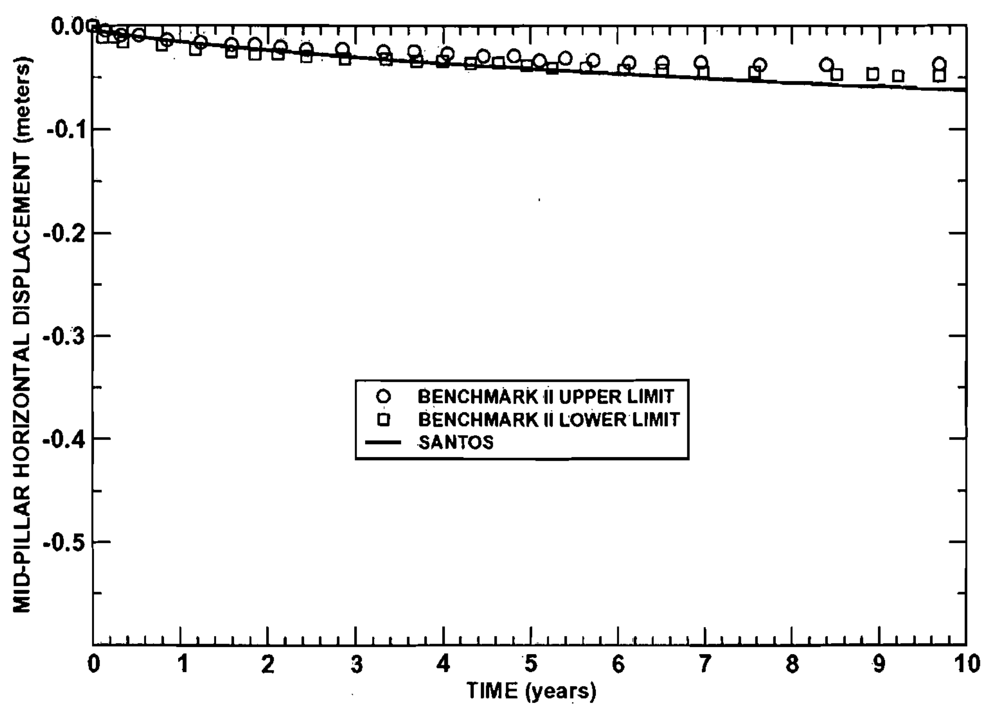


Table 6.19.3 Comparison of SANTOS Results For The Heated Problem With Those Computed In Benchmark II Exercise

Time (years)		Vertical Closure (meters)	Midpillar Horizontal Displacement (meter)
1.0	Benchmark II Range	0.07 to 0.11	~-0.02
	SANTOS Value	0.083	-0.013
3.0	Benchmark II Range	0.18 to 0.23	~-0.03
	SANTOS Value	0.188	-0.025
10.0	Benchmark II Range	0.45 to 0.53	-0.04 to –0.05
	SANTOS Value	0.488	-0.063

The 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.

6.20 Test Case 20: Isothermal WIPP Parallel Calculation

6.20.1 Test Objective

This test 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.

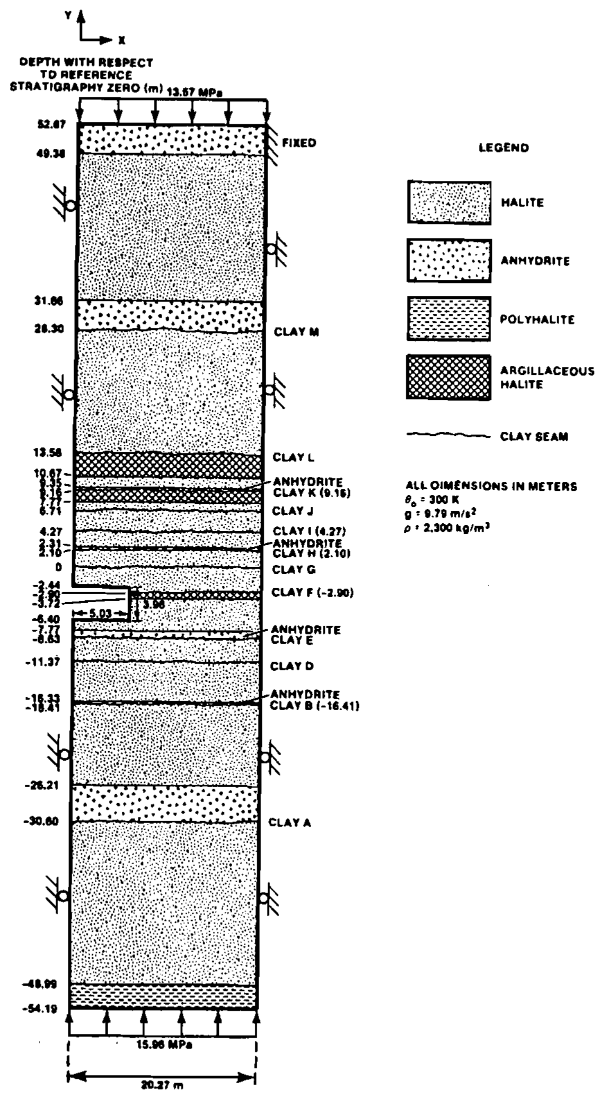
This problem again considers large displacements, large strains, and power law creep for an unheated drift configuration in a complicated stratigraphy. This problem was originally chosen [28] because it represented one of the proposed storage room configurations at the WIPP. This isothermal drift was 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.

6.20.2 Test Procedure

The two-dimensional planar configuration shown in Figure 6.20.1 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 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.

Figure 6.20.1 Parallel Calculation – Isothermal Drift Configuration [29]



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:

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

where $\dot{\varepsilon}$ is the effective creep strain rate and σ is the effective stress ($\sigma = \sqrt{\frac{3}{2}\sigma'_{ij}\sigma'_{ij}}$), 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 6.20.1.

Table 6.20.1 Material Properties Used for Parallel Calculation Isothermal Analysis

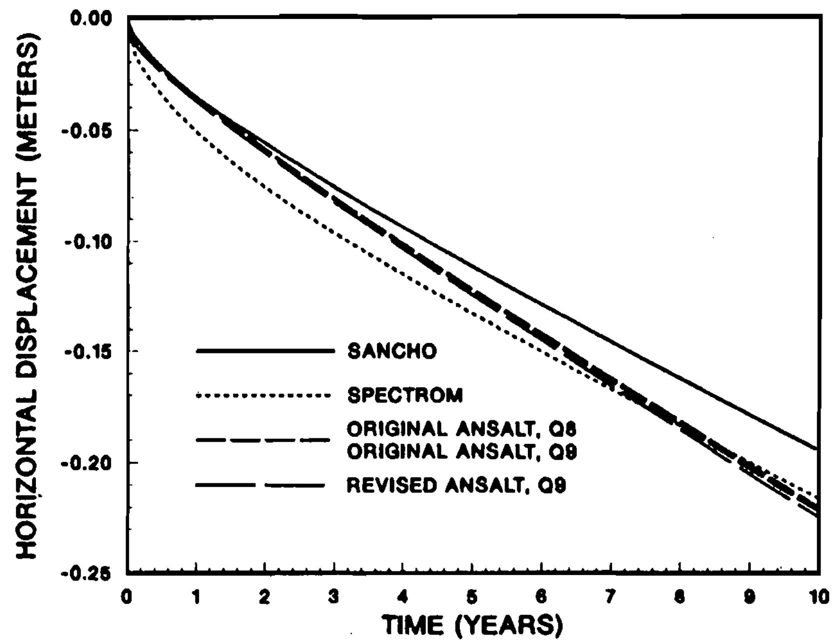
Material	Young's Modulus (Pa)	Poisson's Ratio	D (Pa $^{-4.9}$ sec^{-1})	n	Q (kcal/mole)
Halite	3.10E10	0.25	5.79E-36	4.9	12.0
Argillaceous Halite	3.10E10	0.25	1.74E-35	4.9	12.0
Anhydrite	7.51E10	0.35			
Polyhalite	5.53E10	0.36			

6.20.3 Input/Output

Test Discretization

The finite element mesh used in this analysis is shown in Figure 6.20.4. 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.

Figure 6.20.2 Midpillar Horizontal Displacement History Results from Parallel Calculation Exercise – Isothermal Drift [29]



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.

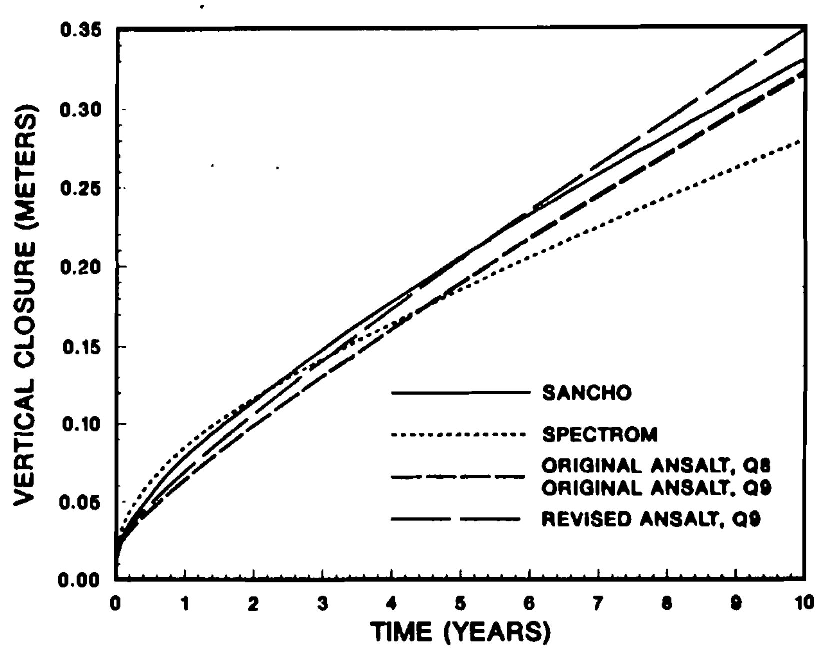
Output Listing

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

6.20.4 Acceptance Criteria (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 6.20.2 and Figure 6.20.3 show some results from a previous benchmark exercise [29] 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 6.20.3 Vertical Closure History Results for Parallel Calculation Exercise – Isothermal Drift [29]



6.20.5 Evaluation

Figure 6.20.5 and Figure 6.20.6 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 6.20.2 for times of 1 year, 5 years, and 10 years. The table shows that in all cases, the SANTOS results fall very close to the lower end of the Parallel Calculation exercise ranges, indicating that SANTOS gives comparable results for the isothermal drift problem.

Figure 6.20.4 Santos Mesh Used For Parallel Calculation Isothermal Test

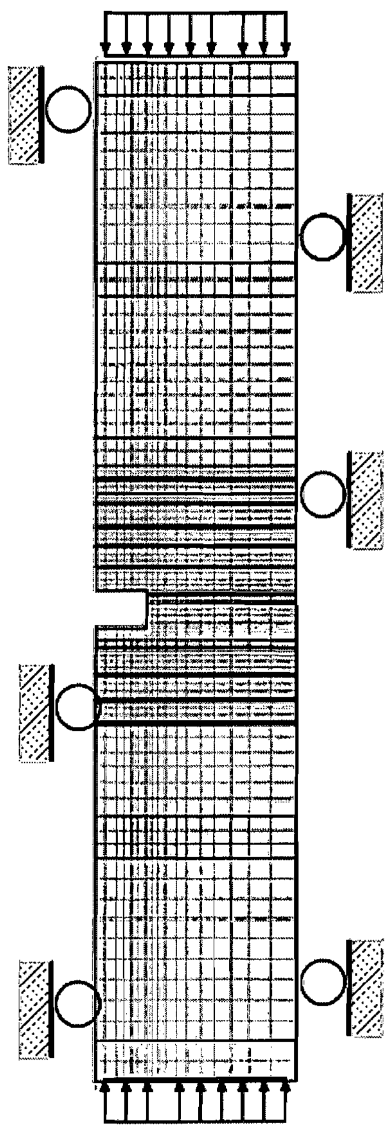


Figure 6.20.5 Vertical Closure History Computed With SANTOS for Parallel Calculation Isothermal Test

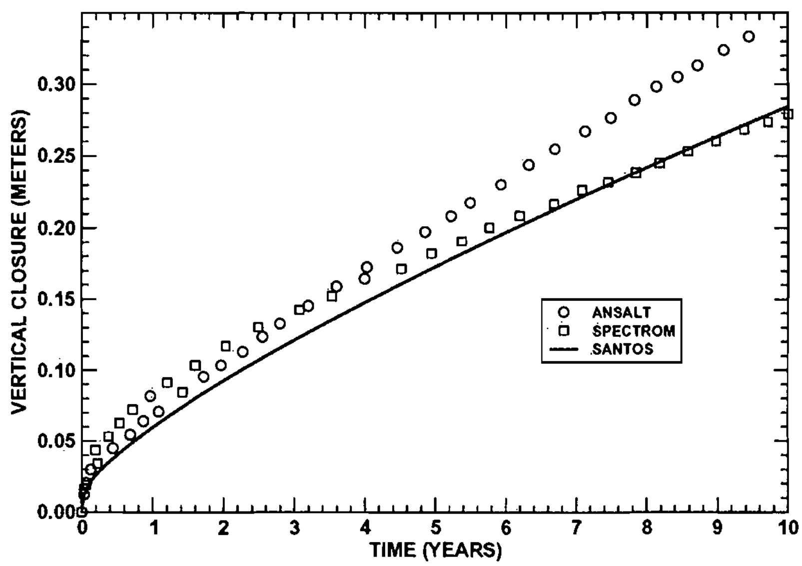


Figure 6.20.6 Midpillar Horizontal Displacement History Computed With SANTOS for Parallel Calculation Isothermal Test

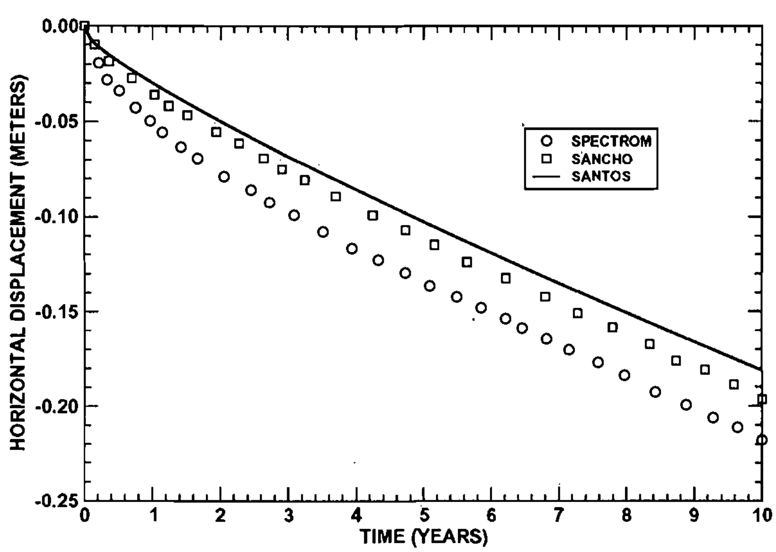


Table 6.20.2 Comparison of SANTOS Results For The Isothermal Problem With Those Computed in Parallel Calculation Exercise

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	0.060	-0.030
5.0	Parallel Calculation Exercise Range	0.18 to 0.20	-0.11 to –0.13
	SANTOS Value	0.173	-0.103
10.0	Parallel Calculation Exercise Range	0.28 to 0.35	-0.19 to –0.23
	SANTOS Value	0.285	-0.181

6.21 Test Case 21: Heated WIPP Parallel Calculation

6.21.1 Test Objective

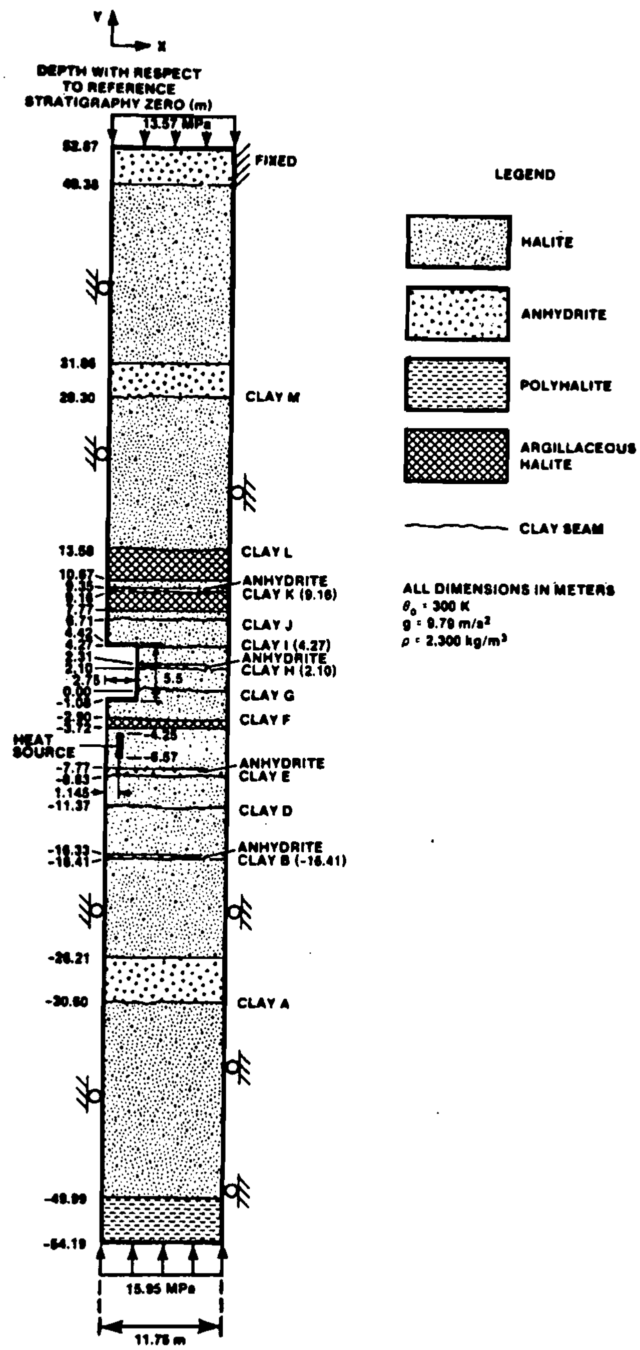
This test is another of the tests analyzed in the Parallel Calculation exercise and is the heated room companion to Test Case 20. Once again it models a repository horizon that consists of a long series of parallel drifts. It considers large displacements, large strains, and power law creep for a heated drift configuration in a complicated stratigraphy. This problem was originally chosen [28] 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 [30]. 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.

6.21.2 Test Procedure

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 [25] 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 [26] 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 6.21.1. 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 discrete heaters were approximated, in the calculation, as a continuous heat source in the out-of-plane direction.

Figure 6.21.1 Parallel Calculation – Heated Drift Configuration [29]



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 6.21.1. 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:

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

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 [27]. 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 that 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 6.21.1.

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 6.21.1. 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 15.95 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 strain condition could be assumed. The surfaces of the room were traction-free, and the room was assumed to appear instantaneously at time zero.

Figure 6.21.2 Thermal Mesh Used For Heated Parallel Calculation

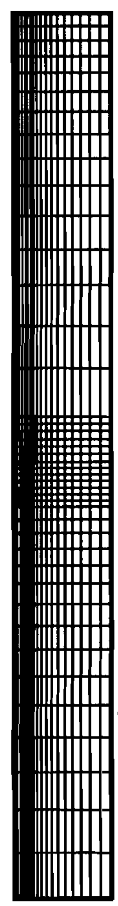


Table 6.21.1 Material Properties Used for Heated Parallel Calculation – Thermal Analysis

Material	Density, p, 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"	1.000	1000	50.0	0.00

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:

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

where $\dot{\varepsilon}$ is the effective creep strain rate and σ is the effective stress ($\sigma = \sqrt{\frac{3}{2}\sigma'_{ij}\sigma'_{ij}}$), 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 6.21.2.

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:

$$\sqrt{J_2'} = C - aJ_1 \,, \qquad \textbf{(EQ 21.4)}$$

where J'_2 is the second invariant of the deviatoric stress ($\sqrt{J_2'} = \sigma / \sqrt{3}$), 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 6.21.3

Table 6.21.2 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	3.10E+10	0.25	5.79E-36	4.9	12.0	45.0E-6
Argillaceous Halite	3.10E+10	0.25	1.74E-35	4.9	12.0	40.0E-6

Table 6.21.3 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	7.51E1+0	0.35	1.35	0.450	20.0E-6
Polyhalite	5.53^{E}+10	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.

6.21.3 Input/Output

Test 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 test is also provided as a section in APPENDIX U.

6.21.4 Acceptance Criteria (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 6.21.3 and Figure 6.21.4 show some results from a previous benchmark exercise [29] 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.

Figure 6.21.3 Vertical Closure History Results from Parallel Calculation Exercise – Heated Drift [29]

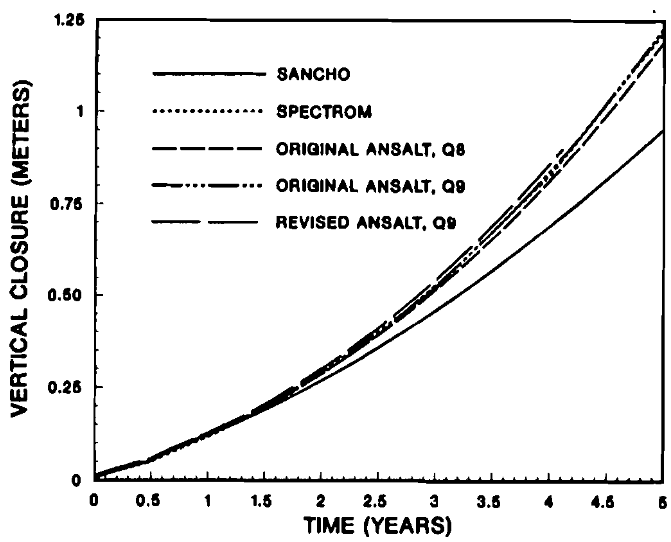
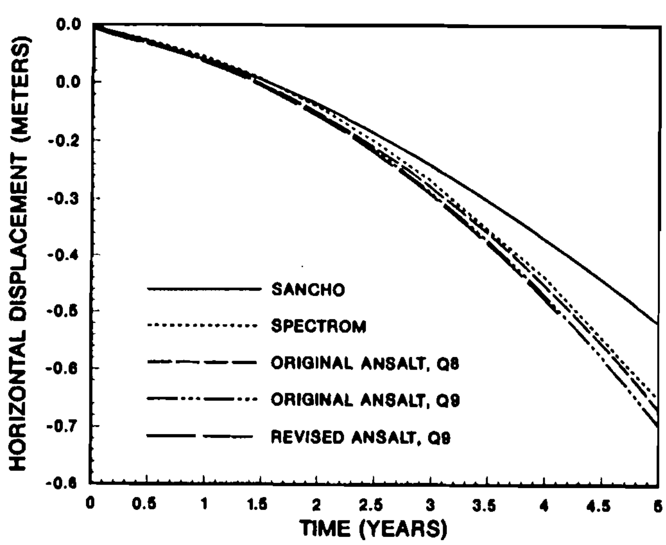


Figure 6.21.4 Midpillar Horizontal Displacement History Results from Parallel Calculation Exercise – Heated Drift [29]



6.21.5 Evaluation

Figure 6.21.6 and Figure 6.21.7 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 6.21.4 or 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, indicating that SANTOS gives comparable results for the heated drift problem.

Figure 6.21.5 SANTOS Mesh Used For Heated Parallel Calculation

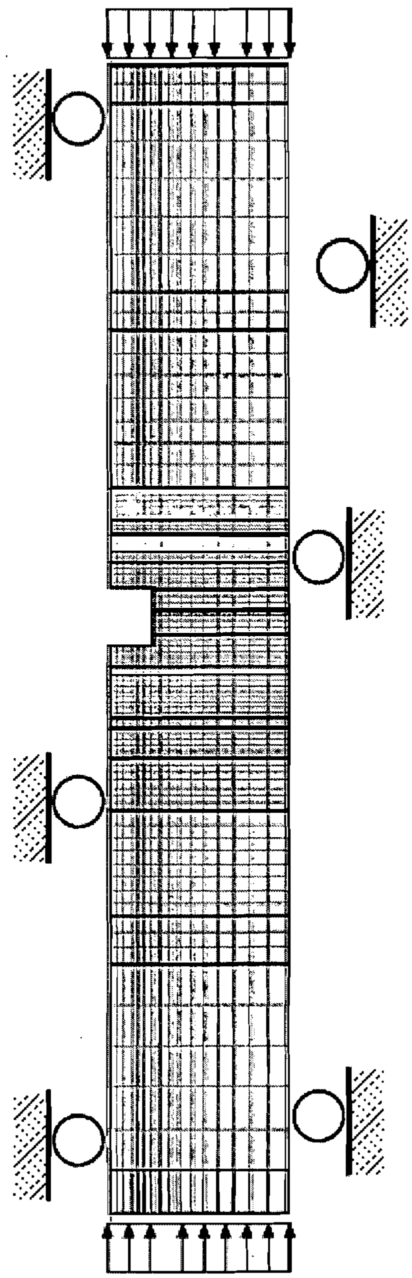


Figure 6.21.6 Vertical Closure History Computed With SANTOS for Parallel Calculation Heated Test

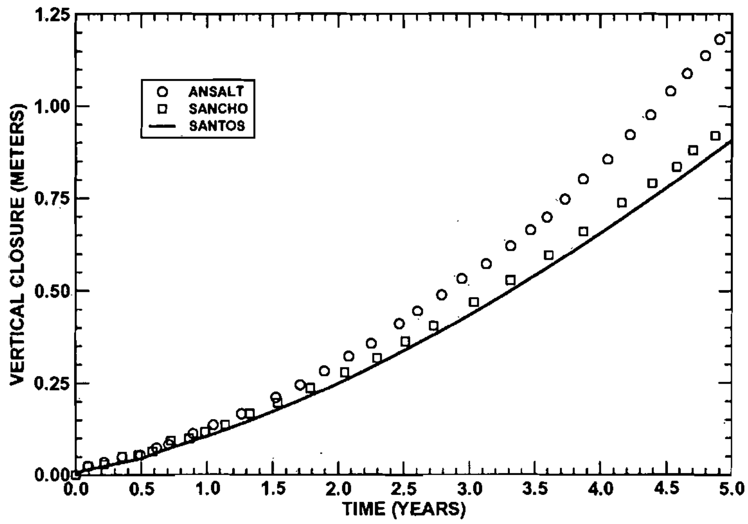


Figure 6.21.7 Midpillar Horizontal Displacement History Computed With SANTOS for Parallel Calculation Heated Test

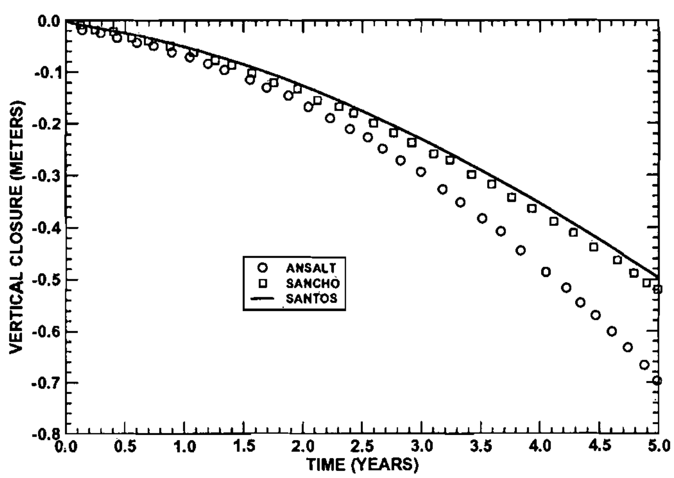


Table 6.21.4 Comparison of SANTOS Results For The Heated Problem With Those Computed In Parallel Calculation Exercise

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	-0.053
3.0	Parallel Calculation Exercise Range	0.45 to 0.55	-0.25 to -0.31
	SANTOS Value	0.435	-0.236
5.0	Parallel Calculation Exercise Range	0.95 to 1.25	-0.52 to -0.71
	SANTOS Value	0.909	-0.509

7.0 INSTALLATION AND REGRESSION TESTING

Test Cases 1-21 are suitable for installation and regression testing.

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APPENDIX A

Input/Output Data For Test Case 1

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

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.

sant_onerot.fsq

```
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
```

sant_onerot.i

```
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
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 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
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 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
```

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.

sant_onerot.o

```
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 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 2.1.7-DP
              COPYRIGHT 1995, SANDIA CORPORATION
```

```
                        PROGRAMMED BY:

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



                 RUN ON 20030610 AT 11:38:47
               RUN ON A     i686 UNDER Lx2.4.20

TITLE
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PLANE STRAIN
MAXIMUM ITERATIONS 600
RESIDUAL TOLERANCE .01
INITIAL STRESS,CONSTANT,0.,-10000.,0.,0.
MATERIAL,1,ELASTIC,1.
YOUNGS MODULUS 1.0E06
POISSONS RATIO 0.
END
FUNCTION,2
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 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
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FUNCTION,3
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 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.
```

```
   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
1                                       INPUT STREAM IMAGES
  LINE -----------------------------------------------------------------------
   55: TITLE
   56:   SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94
   57: PLANE STRAIN
   58: MAXIMUM ITERATIONS 600
   59: RESIDUAL TOLERANCE .01
   60: INITIAL STRESS,CONSTANT,0.,-10000.,0.,0.
   61: MATERIAL,1,ELASTIC,1.
   62: YOUNGS MODULUS 1.0E06
   63: POISSONS RATIO 0.
   64: END
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   66:  0.0000000, 0.0000000
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   70:  1.6000000, 0.1909835
   71:  2.0000000, 0.2928941
   72:  2.4000000, 0.4122159
   73:  2.8000000, 0.5460110
   74:  3.6000000, 0.8435554
   75:  4.0000000, 0.9999833
   76: END
   77: FUNCTION,3
   78:  0.0000000, 0.0000000
   79:  0.4000000, 0.1564346
   80:  0.8000000, 0.3090174
   81:  1.2000000, 0.4539911
   82:  1.6000000, 0.5877860
   83:  2.0000000, 0.7071076
   84:  2.4000000, 0.8090178
   85:  2.8000000, 0.8910072
   86:  3.2000000, 0.9510553
   87:  3.6000000, 0.9876868
   88:  4.0000000, 1.0000000
   89: END
   90: FUNCTION,4
   91:   0.  10000.
   92:   4.  10000.
   93: STEP CONTROL
   94:   10 4.
   95: END
   96: PLOT TIME
   97:   1 4.
   98: END
   99: OUTPUT TIME
  100:   1 4.
```

```
   101: END
   102: PRESCRIBED DISPLACEMENT X 4 2 1.
   103: PRESCRIBED DISPLACEMENT Y 4 3 1.
   104: NO DISPLACEMENT X 3
   105: NO DISPLACEMENT Y 3
   106: PRESSURE 5 4 1.
   107: EXIT
        ------------------------------------------------------------------------
1
                         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 ............        600
             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
```

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

NO DISPLACEMENT BOUNDARY CONDITIONS

NODE SET FLAG	DIRECTION
3	X
3	Y

PRESCRIBED DISPLACEMENT BOUNDARY CONDITIONS

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

PRESSURE BOUNDARY CONDTIONS

SURFACE FLAG	FUNCTION NUMBER	SCALE FACTOR
5	4	1.000E+00

END OF DATA INPUT PHASE
3.000E-02 CPU SECONDS USED
270 WORDS ALLOCATED

END OF DATA INITIALIZATION PHASE
0.000E+00 CPU SECONDS USED
13188 WORDS ALLOCATED

VARIABLES ON PLOTTING DATA BASE

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
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
400	4.000E-01	4.000E-01	8.000E-01	7.071E+03	6.464E+00	0.09	400
408	4.000E-01	4.000E-01	8.031E-01	7.071E+03	6.237E+00	0.09	408
416	4.000E-01	4.000E-01	8.000E-01	7.071E+03	4.806E+00	0.07	416
424	4.000E-01	4.000E-01	8.250E-01	7.071E+03	4.640E+00	0.07	424
432	4.000E-01	4.000E-01	8.001E-01	7.071E+03	3.574E+00	0.05	432
440	4.000E-01	4.000E-01	8.000E-01	7.071E+03	3.018E+00	0.04	440
448	4.000E-01	4.000E-01	8.008E-01	7.071E+03	2.658E+00	0.04	448
456	4.000E-01	4.000E-01	8.000E-01	7.071E+03	2.253E+00	0.03	456
464	4.000E-01	4.000E-01	8.063E-01	7.071E+03	1.972E+00	0.03	464
472	4.000E-01	4.000E-01	8.000E-01	7.071E+03	1.679E+00	0.02	472
480	4.000E-01	4.000E-01	8.000E-01	7.071E+03	1.332E+00	0.02	480
488	4.000E-01	4.000E-01	8.000E-01	7.071E+03	1.097E+00	0.02	488
496	4.000E-01	4.000E-01	8.016E-01	7.071E+03	9.990E-01	0.01	496
504	4.000E-01	4.000E-01	8.000E-01	7.071E+03	8.154E-01	0.01	504
512	4.000E-01	4.000E-01	8.125E-01	7.071E+03	7.337E-01	0.01	512

```
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030610, AT 11:38:47
        SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

      **********************************************************************
      SUMMARY OF DATA AT STEP NUMBER     1, TIME = 4.000E-01
      NUMBER OF ITERATIONS =       515, TOTAL NUMBER OF ITERATIONS =      515
      FINAL CONVERGENCE TOLERANCE = 9.755E-03
      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 =-7.826E+02
      SUM OF REACTION FORCES IN Y-DIRECTION =-4.939E+03
      **********************************************************************


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

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
8	8.000E-01	4.035E-01	8.008E-01	7.464E+03	4.567E+04	611.85	523
16	8.000E-01	4.037E-01	8.000E-01	7.089E+03	3.950E+04	557.24	531
24	8.000E-01	4.039E-01	9.250E-01	6.735E+03	2.959E+04	439.35	539
32	8.000E-01	4.041E-01	7.911E-01	7.019E+03	1.706E+04	243.01	547
40	8.000E-01	4.041E-01	8.000E-01	7.261E+03	1.408E+04	193.92	555
48	8.000E-01	4.041E-01	8.000E-01	7.100E+03	1.142E+04	160.81	563
56	8.000E-01	4.042E-01	8.250E-01	6.930E+03	1.040E+04	150.05	571
64	8.000E-01	4.042E-01	8.001E-01	7.074E+03	8.422E+03	119.05	579
72	8.000E-01	4.042E-01	8.000E-01	7.166E+03	6.726E+03	93.86	587
80	8.000E-01	4.042E-01	8.008E-01	7.057E+03	6.253E+03	88.60	595
88	8.000E-01	4.042E-01	8.000E-01	7.003E+03	5.016E+03	71.63	603
96	8.000E-01	4.042E-01	8.063E-01	7.094E+03	4.608E+03	64.95	611
104	8.000E-01	4.042E-01	8.000E-01	7.120E+03	3.746E+03	52.62	619

112	8.000E-01	4.042E-01	8.500E-01	7.048E+03	3.288E+03	46.65	627
120	8.000E-01	4.042E-01	8.002E-01	7.038E+03	2.801E+03	39.80	635
128	8.000E-01	4.042E-01	8.000E-01	7.090E+03	2.311E+03	32.60	643
136	8.000E-01	4.042E-01	8.016E-01	7.093E+03	2.088E+03	29.44	651
144	8.000E-01	4.042E-01	8.000E-01	7.054E+03	1.722E+03	24.41	659
152	8.000E-01	4.042E-01	8.125E-01	7.058E+03	1.532E+03	21.71	667
160	8.000E-01	4.042E-01	8.000E-01	7.086E+03	1.284E+03	18.12	675
168	8.000E-01	4.042E-01	9.000E-01	7.079E+03	1.033E+03	14.60	683
176	8.000E-01	4.042E-01	8.004E-01	7.059E+03	9.601E+02	13.60	691
184	8.000E-01	4.042E-01	8.000E-01	7.067E+03	7.743E+02	10.96	699
192	8.000E-01	4.042E-01	9.000E-01	7.079E+03	6.242E+02	8.82	707
200	8.000E-01	4.042E-01	8.004E-01	7.073E+03	5.879E+02	8.31	715
208	8.000E-01	4.042E-01	8.000E-01	7.065E+03	4.627E+02	6.55	723
216	8.000E-01	4.042E-01	8.031E-01	7.071E+03	4.445E+02	6.29	731
224	8.000E-01	4.042E-01	8.000E-01	7.076E+03	3.435E+02	4.86	739
232	8.000E-01	4.042E-01	8.250E-01	7.070E+03	3.311E+02	4.68	747
240	8.000E-01	4.042E-01	8.001E-01	7.068E+03	2.551E+02	3.61	755
248	8.000E-01	4.042E-01	8.000E-01	7.072E+03	2.155E+02	3.05	763
256	8.000E-01	4.042E-01	8.008E-01	7.074E+03	1.895E+02	2.68	771
264	8.000E-01	4.042E-01	8.000E-01	7.070E+03	1.611E+02	2.28	779
272	8.000E-01	4.042E-01	8.063E-01	7.069E+03	1.404E+02	1.99	787
280	8.000E-01	4.042E-01	8.000E-01	7.072E+03	1.202E+02	1.70	795
288	8.000E-01	4.042E-01	8.500E-01	7.072E+03	1.007E+02	1.42	803
296	8.000E-01	4.042E-01	8.002E-01	7.070E+03	8.943E+01	1.26	811
304	8.000E-01	4.042E-01	8.000E-01	7.070E+03	7.114E+01	1.01	819
312	8.000E-01	4.042E-01	8.016E-01	7.072E+03	6.618E+01	0.94	827
320	8.000E-01	4.042E-01	8.000E-01	7.071E+03	5.347E+01	0.76	835
328	8.000E-01	4.042E-01	8.125E-01	7.070E+03	4.817E+01	0.68	843
336	8.000E-01	4.042E-01	8.000E-01	7.071E+03	4.027E+01	0.57	851
344	8.000E-01	4.042E-01	9.000E-01	7.071E+03	3.225E+01	0.46	859
352	8.000E-01	4.042E-01	8.004E-01	7.071E+03	3.040E+01	0.43	867
360	8.000E-01	4.042E-01	8.000E-01	7.071E+03	2.395E+01	0.34	875
368	8.000E-01	4.042E-01	8.031E-01	7.071E+03	2.298E+01	0.33	883
376	8.000E-01	4.042E-01	8.000E-01	7.071E+03	1.778E+01	0.25	891
384	8.000E-01	4.042E-01	8.250E-01	7.071E+03	1.712E+01	0.24	899
392	8.000E-01	4.042E-01	8.001E-01	7.071E+03	1.320E+01	0.19	907
400	8.000E-01	4.042E-01	8.000E-01	7.071E+03	1.115E+01	0.16	915
408	8.000E-01	4.042E-01	8.008E-01	7.071E+03	9.799E+00	0.14	923
416	8.000E-01	4.042E-01	8.000E-01	7.071E+03	8.334E+00	0.12	931
424	8.000E-01	4.042E-01	8.000E-01	7.071E+03	6.546E+00	0.09	939
432	8.000E-01	4.042E-01	8.500E-01	7.071E+03	5.774E+00	0.08	947
440	8.000E-01	4.042E-01	8.002E-01	7.071E+03	4.924E+00	0.07	955
448	8.000E-01	4.042E-01	8.000E-01	7.071E+03	4.060E+00	0.06	963
456	8.000E-01	4.042E-01	8.016E-01	7.071E+03	3.673E+00	0.05	971
464	8.000E-01	4.042E-01	8.000E-01	7.071E+03	3.025E+00	0.04	979
472	8.000E-01	4.042E-01	8.125E-01	7.071E+03	2.696E+00	0.04	987
480	8.000E-01	4.042E-01	8.000E-01	7.071E+03	2.256E+00	0.03	995
488	8.000E-01	4.042E-01	9.000E-01	7.071E+03	1.819E+00	0.03	1003
496	8.000E-01	4.042E-01	8.004E-01	7.071E+03	1.687E+00	0.02	1011
504	8.000E-01	4.042E-01	8.000E-01	7.071E+03	1.363E+00	0.02	1019
512	8.000E-01	4.042E-01	8.031E-01	7.071E+03	1.265E+00	0.02	1027
520	8.000E-01	4.042E-01	8.000E-01	7.071E+03	1.020E+00	0.01	1035
528	8.000E-01	4.042E-01	8.250E-01	7.071E+03	9.374E-01	0.01	1043
536	8.000E-01	4.042E-01	8.001E-01	7.071E+03	7.608E-01	0.01	1051

1 SANTOS, VERSION 2.1.7-DP, RUN ON 20030610, AT 11:38:47
SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

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SUMMARY OF DATA AT STEP NUMBER      2, TIME = 8.000E-01
NUMBER OF ITERATIONS =        539, TOTAL NUMBER OF ITERATIONS =       1054
FINAL CONVERGENCE TOLERANCE = 9.957E-03
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
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**** PLOT TAPE WRITTEN AT TIME = 8.000E-01   STEP NUMBER      2 ****
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STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
8	1.200E+00	4.075E-01	8.008E-01	7.728E+03	6.520E+04	843.74	1062
16	1.200E+00	4.079E-01	8.000E-01	7.238E+03	5.604E+04	774.21	1070
24	1.200E+00	4.087E-01	7.544E-01	6.786E+03	2.649E+04	390.40	1078
32	1.200E+00	4.089E-01	7.248E-01	6.968E+03	1.388E+04	199.23	1086
40	1.200E+00	4.089E-01	8.997E-01	7.202E+03	1.169E+04	162.36	1094
48	1.200E+00	4.089E-01	8.004E-01	7.141E+03	1.042E+04	145.91	1102
56	1.200E+00	4.090E-01	8.000E-01	6.971E+03	8.371E+03	120.08	1110
64	1.200E+00	4.090E-01	8.031E-01	7.038E+03	7.914E+03	112.45	1118
72	1.200E+00	4.090E-01	8.000E-01	7.154E+03	6.185E+03	86.46	1126
80	1.200E+00	4.090E-01	8.250E-01	7.086E+03	5.904E+03	83.31	1134
88	1.200E+00	4.090E-01	8.001E-01	7.008E+03	4.579E+03	65.33	1142
96	1.200E+00	4.090E-01	8.000E-01	7.068E+03	3.837E+03	54.29	1150
104	1.200E+00	4.090E-01	8.000E-01	7.114E+03	3.029E+03	42.58	1158
112	1.200E+00	4.090E-01	7.987E-01	7.075E+03	2.071E+03	29.28	1166
120	1.200E+00	4.090E-01	8.000E-01	7.049E+03	1.571E+03	22.29	1174
128	1.200E+00	4.090E-01	8.008E-01	7.072E+03	1.475E+03	20.86	1182
136	1.200E+00	4.090E-01	8.000E-01	7.088E+03	1.184E+03	16.71	1190
144	1.200E+00	4.090E-01	8.063E-01	7.068E+03	1.089E+03	15.41	1198
152	1.200E+00	4.090E-01	8.000E-01	7.059E+03	8.853E+02	12.54	1206
160	1.200E+00	4.090E-01	8.500E-01	7.075E+03	7.781E+02	11.00	1214
168	1.200E+00	4.090E-01	8.002E-01	7.080E+03	6.614E+02	9.34	1222
176	1.200E+00	4.090E-01	6.500E-01	7.070E+03	4.908E+02	6.94	1230
184	1.200E+00	4.090E-01	7.994E-01	7.067E+03	2.713E+02	3.84	1238
192	1.200E+00	4.090E-01	8.000E-01	7.072E+03	2.388E+02	3.38	1246
200	1.200E+00	4.090E-01	7.823E-01	7.073E+03	1.414E+02	2.00	1254
208	1.200E+00	4.090E-01	7.999E-01	7.071E+03	1.011E+02	1.43	1262
216	1.200E+00	4.090E-01	8.000E-01	7.070E+03	8.267E+01	1.17	1270
224	1.200E+00	4.090E-01	8.063E-01	7.071E+03	7.571E+01	1.07	1278
232	1.200E+00	4.090E-01	8.563E-01	7.072E+03	7.244E+01	1.02	1286
240	1.200E+00	4.090E-01	8.002E-01	7.071E+03	6.630E+01	0.94	1294
248	1.200E+00	4.090E-01	8.000E-01	7.070E+03	5.200E+01	0.74	1302
256	1.200E+00	4.090E-01	8.016E-01	7.071E+03	4.903E+01	0.69	1310
264	1.200E+00	4.090E-01	8.000E-01	7.071E+03	3.905E+01	0.55	1318
272	1.200E+00	4.090E-01	8.125E-01	7.071E+03	3.571E+01	0.51	1326
280	1.200E+00	4.090E-01	8.000E-01	7.071E+03	2.939E+01	0.42	1334
288	1.200E+00	4.090E-01	9.000E-01	7.071E+03	2.392E+01	0.34	1342
296	1.200E+00	4.090E-01	8.004E-01	7.071E+03	2.220E+01	0.31	1350
304	1.200E+00	4.090E-01	8.000E-01	7.071E+03	1.775E+01	0.25	1358
312	1.200E+00	4.090E-01	8.031E-01	7.071E+03	1.680E+01	0.24	1366
320	1.200E+00	4.090E-01	8.000E-01	7.071E+03	1.316E+01	0.19	1374
328	1.200E+00	4.090E-01	8.000E-01	7.071E+03	1.089E+01	0.15	1382

336	1.200E+00	4.090E-01	7.563E-01	7.071E+03	6.601E+00	0.09	1390
344	1.200E+00	4.090E-01	7.998E-01	7.071E+03	5.743E+00	0.08	1398
352	1.200E+00	4.090E-01	8.250E-01	7.071E+03	5.135E+00	0.07	1406
360	1.200E+00	4.090E-01	8.001E-01	7.071E+03	4.180E+00	0.06	1414
368	1.200E+00	4.090E-01	8.000E-01	7.071E+03	3.355E+00	0.05	1422
376	1.200E+00	4.090E-01	8.008E-01	7.071E+03	3.108E+00	0.04	1430
384	1.200E+00	4.090E-01	8.000E-01	7.071E+03	2.504E+00	0.04	1438
392	1.200E+00	4.090E-01	7.984E-01	7.071E+03	1.646E+00	0.02	1446
400	1.200E+00	4.090E-01	7.995E-01	7.071E+03	1.153E+00	0.02	1454
408	1.200E+00	4.090E-01	8.008E-01	7.071E+03	1.071E+00	0.02	1462
416	1.200E+00	4.090E-01	8.070E-01	7.071E+03	1.067E+00	0.02	1470
424	1.200E+00	4.090E-01	8.000E-01	7.071E+03	9.292E-01	0.01	1478
432	1.200E+00	4.090E-01	8.500E-01	7.071E+03	7.707E-01	0.01	1486

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1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030610, AT 11:38:47
         SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER      3, TIME = 1.200E+00
     NUMBER OF ITERATIONS =        438, TOTAL NUMBER OF ITERATIONS =       1492
     FINAL CONVERGENCE TOLERANCE = 9.835E-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
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     **** PLOT TAPE WRITTEN AT TIME = 1.200E+00   STEP NUMBER      3 ****
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STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
8	1.600E+00	4.148E-01	7.914E-01	7.396E+03	3.759E+04	508.25	1500
16	1.600E+00	4.143E-01	9.000E-01	7.532E+03	5.104E+04	677.65	1508
24	1.600E+00	4.148E-01	9.004E-01	6.715E+03	3.751E+04	558.63	1516
32	1.600E+00	4.149E-01	8.004E-01	6.880E+03	3.455E+04	502.15	1524
40	1.600E+00	4.151E-01	8.000E-01	7.410E+03	2.652E+04	357.87	1532
48	1.600E+00	4.153E-01	7.906E-01	7.211E+03	1.329E+04	184.25	1540
56	1.600E+00	4.153E-01	8.000E-01	6.956E+03	1.143E+04	164.32	1548
64	1.600E+00	4.153E-01	8.000E-01	6.996E+03	8.950E+03	127.93	1556
72	1.600E+00	4.153E-01	8.000E-01	7.154E+03	7.324E+03	102.37	1564
80	1.600E+00	4.153E-01	8.000E-01	7.117E+03	5.910E+03	83.04	1572
88	1.600E+00	4.153E-01	8.031E-01	7.003E+03	5.531E+03	78.98	1580
96	1.600E+00	4.153E-01	8.000E-01	7.048E+03	4.403E+03	62.47	1588
104	1.600E+00	4.153E-01	8.250E-01	7.126E+03	4.088E+03	57.37	1596
112	1.600E+00	4.153E-01	8.001E-01	7.082E+03	3.288E+03	46.43	1604
120	1.600E+00	4.153E-01	8.000E-01	7.035E+03	2.654E+03	37.72	1612
128	1.600E+00	4.153E-01	8.008E-01	7.069E+03	2.448E+03	34.63	1620
136	1.600E+00	4.153E-01	8.000E-01	7.099E+03	1.977E+03	27.85	1628
144	1.600E+00	4.153E-01	8.063E-01	7.068E+03	1.814E+03	25.67	1636
152	1.600E+00	4.153E-01	8.000E-01	7.051E+03	1.476E+03	20.93	1644
160	1.600E+00	4.153E-01	8.500E-01	7.077E+03	1.297E+03	18.33	1652
168	1.600E+00	4.153E-01	8.002E-01	7.086E+03	1.101E+03	15.54	1660
176	1.600E+00	4.153E-01	8.000E-01	7.066E+03	9.141E+02	12.94	1668
184	1.600E+00	4.153E-01	8.016E-01	7.061E+03	8.197E+02	11.61	1676
192	1.600E+00	4.153E-01	8.000E-01	7.076E+03	6.822E+02	9.64	1684

200	1.600E+00	4.153E-01	8.125E-01	7.078E+03	6.009E+02	8.49	1692
208	1.600E+00	4.153E-01	8.000E-01	7.066E+03	5.095E+02	7.21	1700
216	1.600E+00	4.153E-01	9.000E-01	7.067E+03	4.050E+02	5.73	1708
224	1.600E+00	4.153E-01	5.004E-01	7.075E+03	3.811E+02	5.39	1716
232	1.600E+00	4.153E-01	7.988E-01	7.073E+03	1.960E+02	2.77	1724
240	1.600E+00	4.153E-01	8.000E-01	7.070E+03	1.649E+02	2.33	1732
248	1.600E+00	4.153E-01	8.000E-01	7.070E+03	1.305E+02	1.85	1740
256	1.600E+00	4.153E-01	8.000E-01	7.072E+03	1.077E+02	1.52	1748
264	1.600E+00	4.153E-01	6.959E-01	7.072E+03	8.615E+01	1.22	1756
272	1.600E+00	4.153E-01	8.996E-01	7.070E+03	6.107E+01	0.86	1764
280	1.600E+00	4.153E-01	9.004E-01	7.071E+03	5.683E+01	0.80	1772
288	1.600E+00	4.153E-01	8.035E-01	7.072E+03	6.011E+01	0.85	1780
296	1.600E+00	4.153E-01	8.000E-01	7.071E+03	4.757E+01	0.67	1788
304	1.600E+00	4.153E-01	8.250E-01	7.070E+03	4.431E+01	0.63	1796
312	1.600E+00	4.153E-01	8.001E-01	7.071E+03	3.559E+01	0.50	1804
320	1.600E+00	4.153E-01	8.000E-01	7.071E+03	2.874E+01	0.41	1812
328	1.600E+00	4.153E-01	8.008E-01	7.071E+03	2.653E+01	0.38	1820
336	1.600E+00	4.153E-01	8.000E-01	7.071E+03	2.143E+01	0.30	1828
344	1.600E+00	4.153E-01	8.063E-01	7.071E+03	1.966E+01	0.28	1836
352	1.600E+00	4.153E-01	8.000E-01	7.071E+03	1.599E+01	0.23	1844
360	1.600E+00	4.153E-01	8.500E-01	7.071E+03	1.406E+01	0.20	1852
368	1.600E+00	4.153E-01	8.002E-01	7.071E+03	1.194E+01	0.17	1860
376	1.600E+00	4.153E-01	8.000E-01	7.071E+03	9.907E+00	0.14	1868
384	1.600E+00	4.153E-01	8.016E-01	7.071E+03	8.884E+00	0.13	1876
392	1.600E+00	4.153E-01	8.000E-01	7.071E+03	7.395E+00	0.10	1884
400	1.600E+00	4.153E-01	8.125E-01	7.071E+03	6.512E+00	0.09	1892
408	1.600E+00	4.153E-01	7.625E-01	7.071E+03	3.686E+00	0.05	1900
416	1.600E+00	4.153E-01	7.999E-01	7.071E+03	2.889E+00	0.04	1908
424	1.600E+00	4.153E-01	8.000E-01	7.071E+03	2.387E+00	0.03	1916
432	1.600E+00	4.153E-01	8.000E-01	7.071E+03	1.890E+00	0.03	1924
440	1.600E+00	4.153E-01	8.000E-01	7.071E+03	1.568E+00	0.02	1932
448	1.600E+00	4.153E-01	7.820E-01	7.071E+03	1.044E+00	0.01	1940
456	1.600E+00	4.153E-01	7.999E-01	7.071E+03	8.472E-01	0.01	1948
464	1.600E+00	4.153E-01	8.125E-01	7.071E+03	7.483E-01	0.01	1956

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1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030610, AT 11:38:47
         SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER      4, TIME = 1.600E+00
     NUMBER OF ITERATIONS =        467, TOTAL NUMBER OF ITERATIONS =       1959
     FINAL CONVERGENCE TOLERANCE = 9.952E-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 =-2.939E+03
     SUM OF REACTION FORCES IN Y-DIRECTION =-4.045E+03
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     **** PLOT TAPE WRITTEN AT TIME = 1.600E+00   STEP NUMBER      4 ****
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STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
8	2.000E+00	4.216E-01	6.757E-01	7.885E+03	6.197E+04	785.94	1967
16	2.000E+00	4.216E-01	8.245E-01	7.605E+03	6.209E+04	816.47	1975
24	2.000E+00	4.229E-01	7.907E-01	6.903E+03	2.524E+04	365.57	1983

32	2.000E+00	4.230E-01	8.000E-01	6.876E+03	2.121E+04	308.46	1991
40	2.000E+00	4.231E-01	8.000E-01	7.232E+03	1.637E+04	226.30	1999
48	2.000E+00	4.231E-01	8.000E-01	7.202E+03	1.320E+04	183.35	2007
56	2.000E+00	4.231E-01	8.000E-01	6.964E+03	1.078E+04	154.79	2015
64	2.000E+00	4.231E-01	8.031E-01	6.996E+03	9.994E+03	142.84	2023
72	2.000E+00	4.231E-01	8.000E-01	7.165E+03	7.916E+03	110.48	2031
80	2.000E+00	4.231E-01	8.250E-01	7.116E+03	7.444E+03	104.61	2039
88	2.000E+00	4.231E-01	8.001E-01	6.997E+03	5.848E+03	83.58	2047
96	2.000E+00	4.231E-01	8.000E-01	7.050E+03	4.838E+03	68.63	2055
104	2.000E+00	4.232E-01	8.008E-01	7.130E+03	4.312E+03	60.47	2063
112	2.000E+00	4.232E-01	8.000E-01	7.080E+03	3.632E+03	51.30	2071
120	2.000E+00	4.232E-01	8.000E-01	7.031E+03	2.873E+03	40.85	2079
128	2.000E+00	4.232E-01	8.000E-01	7.069E+03	2.381E+03	33.69	2087
136	2.000E+00	4.232E-01	8.000E-01	7.098E+03	1.886E+03	26.57	2095
144	2.000E+00	4.232E-01	8.000E-01	7.071E+03	1.568E+03	22.18	2103
152	2.000E+00	4.232E-01	8.500E-01	7.053E+03	1.312E+03	18.60	2111
160	2.000E+00	4.232E-01	8.002E-01	7.074E+03	1.177E+03	16.64	2119
168	2.000E+00	4.232E-01	8.000E-01	7.084E+03	9.234E+02	13.04	2127
176	2.000E+00	4.232E-01	8.016E-01	7.067E+03	8.749E+02	12.38	2135
184	2.000E+00	4.232E-01	8.000E-01	7.062E+03	6.912E+02	9.79	2143
192	2.000E+00	4.232E-01	8.125E-01	7.075E+03	6.385E+02	9.02	2151
200	2.000E+00	4.232E-01	8.000E-01	7.077E+03	5.192E+02	7.34	2159
208	2.000E+00	4.232E-01	8.000E-01	7.068E+03	4.282E+02	6.06	2167
216	2.000E+00	4.232E-01	8.000E-01	7.067E+03	3.409E+02	4.82	2175
224	2.000E+00	4.232E-01	8.000E-01	7.074E+03	2.812E+02	3.98	2183
232	2.000E+00	4.232E-01	8.000E-01	7.073E+03	2.246E+02	3.18	2191
240	2.000E+00	4.232E-01	8.000E-01	7.069E+03	1.845E+02	2.61	2199
248	2.000E+00	4.232E-01	8.031E-01	7.070E+03	1.715E+02	2.43	2207
256	2.000E+00	4.232E-01	8.000E-01	7.073E+03	1.364E+02	1.93	2215
264	2.000E+00	4.232E-01	8.250E-01	7.072E+03	1.282E+02	1.81	2223
272	2.000E+00	4.232E-01	8.001E-01	7.070E+03	1.010E+02	1.43	2231
280	2.000E+00	4.232E-01	8.000E-01	7.071E+03	8.364E+01	1.18	2239
288	2.000E+00	4.232E-01	8.000E-01	7.072E+03	6.684E+01	0.95	2247
296	2.000E+00	4.232E-01	8.000E-01	7.071E+03	5.501E+01	0.78	2255
304	2.000E+00	4.232E-01	8.000E-01	7.070E+03	4.388E+01	0.62	2263
312	2.000E+00	4.232E-01	8.000E-01	7.071E+03	3.624E+01	0.51	2271
320	2.000E+00	4.232E-01	8.063E-01	7.072E+03	3.183E+01	0.45	2279
328	2.000E+00	4.232E-01	8.000E-01	7.071E+03	2.727E+01	0.39	2287
336	2.000E+00	4.232E-01	8.500E-01	7.071E+03	2.270E+01	0.32	2295
344	2.000E+00	4.232E-01	8.002E-01	7.071E+03	2.039E+01	0.29	2303
352	2.000E+00	4.232E-01	8.000E-01	7.071E+03	1.600E+01	0.23	2311
360	2.000E+00	4.232E-01	8.016E-01	7.071E+03	1.515E+01	0.21	2319
368	2.000E+00	4.232E-01	8.000E-01	7.071E+03	1.197E+01	0.17	2327
376	2.000E+00	4.232E-01	8.000E-01	7.071E+03	9.965E+00	0.14	2335
384	2.000E+00	4.232E-01	8.000E-01	7.071E+03	7.879E+00	0.11	2343
392	2.000E+00	4.232E-01	8.000E-01	7.071E+03	6.545E+00	0.09	2351
400	2.000E+00	4.232E-01	8.000E-01	7.071E+03	5.189E+00	0.07	2359
408	2.000E+00	4.232E-01	9.000E-01	7.071E+03	4.297E+00	0.06	2367
416	2.000E+00	4.232E-01	8.004E-01	7.071E+03	3.927E+00	0.06	2375
424	2.000E+00	4.232E-01	8.000E-01	7.071E+03	3.188E+00	0.05	2383
432	2.000E+00	4.232E-01	8.031E-01	7.071E+03	2.973E+00	0.04	2391
440	2.000E+00	4.232E-01	8.000E-01	7.071E+03	2.363E+00	0.03	2399
448	2.000E+00	4.232E-01	8.000E-01	7.071E+03	1.928E+00	0.03	2407
456	2.000E+00	4.232E-01	8.250E-01	7.071E+03	1.787E+00	0.03	2415
464	2.000E+00	4.232E-01	8.001E-01	7.071E+03	1.432E+00	0.02	2423
472	2.000E+00	4.232E-01	8.000E-01	7.071E+03	1.161E+00	0.02	2431
480	2.000E+00	4.232E-01	8.000E-01	7.071E+03	9.521E-01	0.01	2439
488	2.000E+00	4.232E-01	8.000E-01	7.071E+03	7.602E-01	0.01	2447

```
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030610, AT 11:38:47
        SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

      *********************************************************************
      SUMMARY OF DATA AT STEP NUMBER      5, TIME = 2.000E+00
      NUMBER OF ITERATIONS =         491, TOTAL NUMBER OF ITERATIONS =       2450
      FINAL CONVERGENCE TOLERANCE = 9.983E-03
      SUM OF EXTERNAL FORCES IN X-DIRECTION =-7.071E+03
      SUM OF EXTERNAL FORCES IN Y-DIRECTION =-7.071E+03
      SUM OF REACTION FORCES IN X-DIRECTION =-3.536E+03
      SUM OF REACTION FORCES IN Y-DIRECTION =-3.536E+03
      *********************************************************************


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

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
8	2.400E+00	4.256E-01	8.570E-01	9.402E+03	1.314E+05	1397.25	2458
16	2.400E+00	4.274E-01	8.002E-01	8.341E+03	1.116E+05	1337.70	2466
24	2.400E+00	4.321E-01	7.250E-01	6.916E+03	2.939E+04	424.91	2474
32	2.400E+00	4.322E-01	7.997E-01	6.797E+03	2.814E+04	413.97	2482
40	2.400E+00	4.323E-01	8.031E-01	7.315E+03	2.216E+04	302.94	2490
48	2.400E+00	4.324E-01	8.000E-01	7.243E+03	1.807E+04	249.54	2498
56	2.400E+00	4.324E-01	8.250E-01	6.881E+03	1.704E+04	247.59	2506
64	2.400E+00	4.324E-01	8.001E-01	6.983E+03	1.342E+04	192.11	2514
72	2.400E+00	4.324E-01	8.000E-01	7.208E+03	1.093E+04	151.60	2522
80	2.400E+00	4.325E-01	8.008E-01	7.120E+03	9.924E+03	139.37	2530
88	2.400E+00	4.325E-01	8.000E-01	6.966E+03	8.091E+03	116.16	2538
96	2.400E+00	4.325E-01	8.063E-01	7.057E+03	7.324E+03	103.79	2546
104	2.400E+00	4.325E-01	8.000E-01	7.155E+03	5.996E+03	83.81	2554
112	2.400E+00	4.325E-01	8.500E-01	7.071E+03	5.246E+03	74.19	2562
120	2.400E+00	4.325E-01	8.002E-01	7.009E+03	4.460E+03	63.63	2570
128	2.400E+00	4.325E-01	8.000E-01	7.076E+03	3.691E+03	52.16	2578
136	2.400E+00	4.325E-01	8.016E-01	7.117E+03	3.305E+03	46.44	2586
144	2.400E+00	4.325E-01	8.000E-01	7.062E+03	2.763E+03	39.13	2594
152	2.400E+00	4.325E-01	8.125E-01	7.039E+03	2.416E+03	34.32	2602
160	2.400E+00	4.325E-01	8.000E-01	7.083E+03	2.066E+03	29.17	2610
168	2.400E+00	4.325E-01	8.000E-01	7.091E+03	1.625E+03	22.91	2618
176	2.400E+00	4.325E-01	9.000E-01	7.062E+03	1.353E+03	19.16	2626
184	2.400E+00	4.325E-01	8.004E-01	7.058E+03	1.230E+03	17.42	2634
192	2.400E+00	4.325E-01	8.000E-01	7.080E+03	1.004E+03	14.18	2642
200	2.400E+00	4.325E-01	8.031E-01	7.080E+03	9.304E+02	13.14	2650
208	2.400E+00	4.325E-01	8.000E-01	7.063E+03	7.449E+02	10.55	2658
216	2.400E+00	4.325E-01	8.250E-01	7.066E+03	6.949E+02	9.83	2666
224	2.400E+00	4.325E-01	8.001E-01	7.078E+03	5.512E+02	7.79	2674
232	2.400E+00	4.325E-01	8.000E-01	7.074E+03	4.534E+02	6.41	2682
240	2.400E+00	4.325E-01	8.000E-01	7.066E+03	3.649E+02	5.16	2690
248	2.400E+00	4.325E-01	8.008E-01	7.070E+03	3.343E+02	4.73	2698
256	2.400E+00	4.325E-01	8.000E-01	7.075E+03	2.724E+02	3.85	2706
264	2.400E+00	4.325E-01	8.063E-01	7.071E+03	2.481E+02	3.51	2714
272	2.400E+00	4.325E-01	8.000E-01	7.068E+03	2.030E+02	2.87	2722
280	2.400E+00	4.325E-01	8.500E-01	7.071E+03	1.778E+02	2.51	2730
288	2.400E+00	4.325E-01	8.002E-01	7.073E+03	1.512E+02	2.14	2738
296	2.400E+00	4.325E-01	8.000E-01	7.071E+03	1.254E+02	1.77	2746

```
    304  2.400E+00  4.325E-01  8.016E-01  7.070E+03  1.123E+02      1.59      2754
    312  2.400E+00  4.325E-01  8.000E-01  7.071E+03  9.381E+01      1.33      2762
    320  2.400E+00  4.325E-01  8.125E-01  7.072E+03  8.213E+01      1.16      2770
    328  2.400E+00  4.325E-01  8.000E-01  7.071E+03  7.019E+01      0.99      2778
    336  2.400E+00  4.325E-01  9.000E-01  7.070E+03  5.527E+01      0.78      2786
    344  2.400E+00  4.325E-01  8.004E-01  7.072E+03  5.259E+01      0.74      2794
    352  2.400E+00  4.325E-01  8.000E-01  7.072E+03  4.136E+01      0.58      2802
    360  2.400E+00  4.325E-01  8.031E-01  7.071E+03  3.945E+01      0.56      2810
    368  2.400E+00  4.325E-01  8.000E-01  7.071E+03  3.095E+01      0.44      2818
    376  2.400E+00  4.325E-01  8.250E-01  7.071E+03  2.921E+01      0.41      2826
    384  2.400E+00  4.325E-01  8.001E-01  7.071E+03  2.314E+01      0.33      2834
    392  2.400E+00  4.325E-01  8.000E-01  7.071E+03  1.895E+01      0.27      2842
.
.
.
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030610, AT 11:38:47
        SANTOS QA PROBLEM - ONE ELEMENT ROTATION - 10/21/94

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER     10, TIME = 4.000E+00
     NUMBER OF ITERATIONS =       520, TOTAL NUMBER OF ITERATIONS =      5190
     FINAL CONVERGENCE TOLERANCE = 9.881E-03
     SUM OF EXTERNAL FORCES IN X-DIRECTION =-1.000E+04
     SUM OF EXTERNAL FORCES IN Y-DIRECTION = 2.856E+00
     SUM OF REACTION FORCES IN X-DIRECTION =-4.998E+03
     SUM OF REACTION FORCES IN Y-DIRECTION = 1.217E+00
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 4.000E+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
                           2.100E-01 CPU SECONDS USED
                               13298 WORDS ALLOCATED
```

APPENDIX B

Input/Output Data For Test Case 2

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

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.

sant_delete.fsq

```
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
```

sant_delete.i

```
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.
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
MATERIAL,5,ELASTIC,1.
YOUNGS MODULUS 10000.
POISSONS RATIO 0.
END
DELETE MATERIAL 1 1.001
DELETE MATERIAL 2 2.001
DELETE MATERIAL 3 3.001
DELETE MATERIAL 4 4.001
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
```

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.

sant_delete.o

```
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 2.1.7-DP
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                               PROGRAMMED BY:

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



                        RUN ON 20030612 AT 10:22:09
                      RUN ON A     i686 UNDER Lx2.4.20

     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 1.001
  27: DELETE MATERIAL 2 2.001
  28: DELETE MATERIAL 3 3.001
  29: DELETE MATERIAL 4 4.001
  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
1                                    INPUT STREAM IMAGES
 LINE ---------------------------------------------------------------------------
  48: TITLE
  49:  GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA
  50: PLANE STRAIN
  51: MAXIMUM ITERATIONS,1000
  52: RESIDUAL TOLERANCE 0.1
  53: MATERIAL,1,ELASTIC,1.
  54: YOUNGS MODULUS 10000.
  55: POISSONS RATIO 0.
  56: END
  57: MATERIAL,2,ELASTIC,1.
  58: YOUNGS MODULUS 10000.
  59: POISSONS RATIO 0.
  60: END
  61: MATERIAL,3,ELASTIC,1.
  62: YOUNGS MODULUS 10000.
  63: POISSONS RATIO 0.
  64: END
  65: MATERIAL,4,ELASTIC,1.
  66: YOUNGS MODULUS 10000.
  67: POISSONS RATIO 0.
  68: END
  69: MATERIAL,5,ELASTIC,1.
  70: YOUNGS MODULUS 10000.
  71: POISSONS RATIO 0.
  72: END
  73: DELETE MATERIAL 1 1.001
  74: DELETE MATERIAL 2 2.001
  75: DELETE MATERIAL 3 3.001
  76: DELETE MATERIAL 4 4.001
  77: FUNCTION,1
  78:   0.,1.
  79:   5.,1.
  80: END
  81: STEP CONTROL
  82:   10,5.
```

```
83: END
84: PLOT TIME
85:   1,5.
86: END
87: OUTPUT TIME
88:   2,5.
89: END
90: GRAVITY,1,0.,-5.,0.
91: NO DISPLACEMENT,X,1
92: NO DISPLACEMENT,Y,2
93: EXIT
    ------------------------------------------------------------------------
1
                    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

 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
```

E L E M E N T   M A T E R I A L   B L O C K   D E L E T I O N

MATERIAL ID	DELETION TIME
1	1.000E+01
2	4.001E+00
3	3.001E+00
4	2.001E+00
5	1.001E+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
3.000E-02 CPU SECONDS USED
1686 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
0.000E+00 CPU SECONDS USED
25340 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 ****

1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:22:09
      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 = 1.229E-15
     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 ****

1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:22:09
      GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER     4, TIME = 2.000E+00
     NUMBER OF ITERATIONS =       289, TOTAL NUMBER OF ITERATIONS =      1301
     FINAL CONVERGENCE TOLERANCE = 8.411E-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 = 2.877E-15
     SUM OF REACTION FORCES IN Y-DIRECTION =-1.625E+02
     *********************************************************************


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



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

```
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:22:09
       GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER      6, TIME = 3.000E+00
     NUMBER OF ITERATIONS =        230, TOTAL NUMBER OF ITERATIONS =       1733
     FINAL CONVERGENCE TOLERANCE = 9.728E-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 = 1.231E-15
     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 ****

1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:22:09
       GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER      8, TIME = 4.000E+00
     NUMBER OF ITERATIONS =        191, TOTAL NUMBER OF ITERATIONS =       2074
     FINAL CONVERGENCE TOLERANCE = 9.959E-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 =-7.392E-16
     SUM OF REACTION FORCES IN Y-DIRECTION =-8.261E+01
     **********************************************************************


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



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

1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:22:09
       GRAVITY LOAD PROBLEM - DELETE OPTION TEST - SANTOS QA

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER     10, TIME = 5.000E+00
     NUMBER OF ITERATIONS =         83, TOTAL NUMBER OF ITERATIONS =       2246
     FINAL CONVERGENCE TOLERANCE = 9.605E-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 =-1.500E-16
     SUM OF REACTION FORCES IN Y-DIRECTION =-4.258E+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
                     2.000E+00 CPU SECONDS USED
                         31810 WORDS ALLOCATED
```

APPENDIX C

Input/Output Data For Test Case 3

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.

beamf.fsq

```
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   OMP
REGION   1     1   -1   -2   -3   -4  -5
EXIT
```

sant_beamf.i

```
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
PRESCRIBED FORCE,Y,1,1,-1.
EXIT
```

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.

sant_beamf.o

```
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 2.1.7-DP
                           COPYRIGHT 1995, SANDIA CORPORATION

                                   PROGRAMMED BY:

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



                             RUN ON 20030612 AT 10:26:26
                           RUN ON A     i686 UNDER Lx2.4.20

    1: TITLE
    2:  30 TO 1 BEAM WITH CONCENTRATED FORCE - SANTOS QA - 11/30/94
    3: PLANE STRAIN
    4: MAXIMUM ITERATIONS, 20000
    5: MAXIMUM TOLERANCE, 1000
    6: NO DAMPING,120,20
```

```
    7: MATERIAL,1,ELASTIC,1.0
    8: YOUNGS MODULUS = 1.0E+7
    9: POISSONS RATIO = 0.0
   10: END
   11: FUNCTION, 1  $ FUNCTION USED TO DEFINE PRESCRIBED FORCE
   12:    0.   0.
   13:    2.  20.
   14: END
   15: STEP CONTROL
   16:   400,2.
   17: END
   18: PLOT TIME
   19:   100,2.
   20: END
   21: OUTPUT TIME
   22:   400,2.
   23: END
   24: NO DISPLACEMENT Y,2
   25: NO DISPLACEMENT X,2
   26: PRESCRIBED FORCE,Y,1,1,-1.
   27: EXIT
1                                    INPUT STREAM IMAGES
  LINE -----------------------------------------------------------------------
   29: TITLE
   30:  30 TO 1 BEAM WITH CONCENTRATED FORCE - SANTOS QA - 11/30/94
   31: PLANE STRAIN
   32: MAXIMUM ITERATIONS, 20000
   33: MAXIMUM TOLERANCE, 1000
   34: NO DAMPING,120,20
   35: MATERIAL,1,ELASTIC,1.0
   36: YOUNGS MODULUS = 1.0E+7
   37: POISSONS RATIO = 0.0
   38: END
   39: FUNCTION, 1  $ FUNCTION USED TO DEFINE PRESCRIBED FORCE
   40:    0.   0.
   41:    2.  20.
   42: END
   43: STEP CONTROL
   44:   400,2.
   45: END
   46: PLOT TIME
   47:   100,2.
   48: END
   49: OUTPUT TIME
   50:   400,2.
   51: END
   52: NO DISPLACEMENT Y,2
   53: NO DISPLACEMENT X,2
   54: PRESCRIBED FORCE,Y,1,1,-1.
   55: EXIT
       -----------------------------------------------------------------------
1
                         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 .....................  5.000E-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


        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
```

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

E N D   O F   D A T A   I N P U T   P H A S E
1.000E-02 CPU SECONDS USED
1222 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
0.000E+00 CPU SECONDS USED
21646 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
310	5.000E-03	5.000E-03	1.000E+00	5.000E-02	1.512E-02	30.25	310
620	5.000E-03	5.000E-03	9.915E-01	5.000E-02	1.119E-02	22.38	620
930	5.000E-03	5.000E-03	9.970E-01	5.000E-02	1.030E-02	20.60	930
1240	5.000E-03	5.000E-03	9.993E-01	5.000E-02	9.320E-03	18.64	1240
1550	5.000E-03	5.000E-03	9.969E-01	5.000E-02	8.638E-03	17.28	1550
1860	5.000E-03	5.000E-03	9.970E-01	5.000E-02	8.180E-03	16.36	1860
2170	5.000E-03	5.000E-03	1.000E+00	5.000E-02	8.042E-03	16.08	2170
2480	5.000E-03	5.000E-03	9.992E-01	5.000E-02	7.971E-03	15.94	2480
2790	5.000E-03	5.000E-03	9.995E-01	5.000E-02	7.915E-03	15.83	2790
3100	5.000E-03	5.000E-03	9.995E-01	5.000E-02	7.738E-03	15.48	3100
3410	5.000E-03	5.000E-03	9.997E-01	5.000E-02	7.553E-03	15.11	3410
3720	5.000E-03	5.000E-03	9.996E-01	5.000E-02	7.303E-03	14.61	3720
4030	5.000E-03	5.000E-03	9.996E-01	5.000E-02	7.028E-03	14.06	4030
4340	5.000E-03	5.000E-03	9.995E-01	5.000E-02	6.802E-03	13.60	4340
4650	5.000E-03	5.000E-03	9.995E-01	5.000E-02	6.514E-03	13.03	4650
4960	5.000E-03	5.000E-03	9.994E-01	5.000E-02	6.246E-03	12.49	4960
5270	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.983E-03	11.97	5270
5580	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.696E-03	11.39	5580
5890	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.447E-03	10.89	5890
6200	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.211E-03	10.42	6200
6510	5.000E-03	5.000E-03	9.994E-01	5.000E-02	4.967E-03	9.93	6510
6820	5.000E-03	5.000E-03	9.995E-01	5.000E-02	4.728E-03	9.46	6820
7130	5.000E-03	5.000E-03	9.995E-01	5.000E-02	4.480E-03	8.96	7130
7440	5.000E-03	5.000E-03	9.995E-01	5.000E-02	4.238E-03	8.48	7440
7750	5.000E-03	5.000E-03	9.995E-01	5.000E-02	4.013E-03	8.03	7750
8060	5.000E-03	5.000E-03	9.995E-01	5.000E-02	3.794E-03	7.59	8060
8370	5.000E-03	5.000E-03	9.995E-01	5.000E-02	3.587E-03	7.17	8370
8680	5.000E-03	5.000E-03	9.994E-01	5.000E-02	3.385E-03	6.77	8680
8990	5.000E-03	5.000E-03	9.994E-01	5.000E-02	3.196E-03	6.39	8990
9300	5.000E-03	5.000E-03	9.994E-01	5.000E-02	3.014E-03	6.03	9300
9610	5.000E-03	5.000E-03	9.994E-01	5.000E-02	2.841E-03	5.68	9610
9920	5.000E-03	5.000E-03	9.994E-01	5.000E-02	2.684E-03	5.37	9920
10230	5.000E-03	5.000E-03	9.994E-01	5.000E-02	2.527E-03	5.05	10230
10540	5.000E-03	5.000E-03	9.995E-01	5.000E-02	2.381E-03	4.76	10540
10850	5.000E-03	5.000E-03	9.995E-01	5.000E-02	2.235E-03	4.47	10850
11160	5.000E-03	5.000E-03	9.995E-01	5.000E-02	2.095E-03	4.19	11160
11470	5.000E-03	5.000E-03	9.995E-01	5.000E-02	1.969E-03	3.94	11470

11780	5.000E-03	5.000E-03	9.995E-01	5.000E-02	1.846E-03	3.69	11780
12090	5.000E-03	5.000E-03	9.994E-01	5.000E-02	1.730E-03	3.46	12090
12400	5.000E-03	5.000E-03	9.994E-01	5.000E-02	1.624E-03	3.25	12400
12710	5.000E-03	5.000E-03	9.994E-01	5.000E-02	1.520E-03	3.04	12710
13020	5.000E-03	5.000E-03	9.994E-01	5.000E-02	1.426E-03	2.85	13020
13330	5.000E-03	5.000E-03	9.994E-01	5.000E-02	1.337E-03	2.67	13330
13640	5.000E-03	5.000E-03	9.994E-01	5.000E-02	1.251E-03	2.50	13640
13950	5.000E-03	5.000E-03	9.994E-01	5.000E-02	1.174E-03	2.35	13950
14260	5.000E-03	5.000E-03	9.995E-01	5.000E-02	1.098E-03	2.20	14260
14570	5.000E-03	5.000E-03	9.995E-01	5.000E-02	1.025E-03	2.05	14570
14880	5.000E-03	5.000E-03	9.995E-01	5.000E-02	9.584E-04	1.92	14880
15190	5.000E-03	5.000E-03	9.995E-01	5.000E-02	8.937E-04	1.79	15190
15500	5.000E-03	5.000E-03	9.995E-01	5.000E-02	8.355E-04	1.67	15500
15810	5.000E-03	5.000E-03	9.994E-01	5.000E-02	7.803E-04	1.56	15810
16120	5.000E-03	5.000E-03	9.994E-01	5.000E-02	7.274E-04	1.45	16120
16430	5.000E-03	5.000E-03	9.994E-01	5.000E-02	6.798E-04	1.36	16430
16740	5.000E-03	5.000E-03	9.994E-01	5.000E-02	6.345E-04	1.27	16740
17050	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.919E-04	1.18	17050
17360	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.531E-04	1.11	17360
17670	5.000E-03	5.000E-03	9.994E-01	5.000E-02	5.157E-04	1.03	17670
17980	5.000E-03	5.000E-03	9.995E-01	5.000E-02	4.809E-04	0.96	17980
18290	5.000E-03	5.000E-03	9.995E-01	5.000E-02	4.482E-04	0.90	18290
18600	5.000E-03	5.000E-03	9.995E-01	5.000E-02	4.169E-04	0.83	18600
18910	5.000E-03	5.000E-03	9.995E-01	5.000E-02	3.885E-04	0.78	18910
19220	5.000E-03	5.000E-03	9.995E-01	5.000E-02	3.617E-04	0.72	19220
19530	5.000E-03	5.000E-03	9.994E-01	5.000E-02	3.367E-04	0.67	19530
19840	5.000E-03	5.000E-03	9.994E-01	5.000E-02	3.135E-04	0.63	19840

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.000E-02	5.000E-03	1.000E+00	1.000E-01	4.686E-03	4.69	20310
620	1.000E-02	5.000E-03	1.000E+00	1.000E-01	3.840E-03	3.84	20620
930	1.000E-02	5.000E-03	1.000E+00	1.000E-01	1.941E-03	1.94	20930
1240	1.000E-02	5.000E-03	1.000E+00	1.000E-01	1.344E-03	1.34	21240
1550	1.000E-02	5.000E-03	1.000E+00	1.000E-01	3.507E-03	3.51	21550
1860	1.000E-02	5.000E-03	1.000E+00	1.000E-01	4.757E-03	4.76	21860
2170	1.000E-02	5.000E-03	1.000E+00	1.000E-01	4.458E-03	4.46	22170
2480	1.000E-02	5.000E-03	1.000E+00	1.000E-01	2.762E-03	2.76	22480
2790	1.000E-02	5.000E-03	1.000E+00	1.000E-01	1.083E-03	1.08	22790
3100	1.000E-02	5.000E-03	1.000E+00	1.000E-01	2.751E-03	2.75	23100

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	5.000E-02	5.000E-03	1.000E+00	5.000E-01	1.265E-02	2.53	24820
620	5.000E-02	5.000E-03	1.000E+00	5.000E-01	8.421E-03	1.68	25130
930	5.000E-02	5.000E-03	9.758E-01	5.000E-01	9.238E-03	1.85	25440
1240	5.000E-02	5.000E-03	1.000E+00	5.000E-01	1.106E-02	2.21	25750
1550	5.000E-02	5.000E-03	1.000E+00	5.000E-01	1.270E-02	2.54	26060
1860	5.000E-02	5.000E-03	1.000E+00	5.000E-01	1.051E-02	2.10	26370
2170	5.000E-02	5.000E-03	1.000E+00	5.000E-01	8.155E-03	1.63	26680
2480	5.000E-02	5.000E-03	1.000E+00	5.000E-01	7.432E-03	1.49	26990
2790	5.000E-02	5.000E-03	1.000E+00	5.000E-01	9.770E-03	1.95	27300
3100	5.000E-02	5.000E-03	1.000E+00	5.000E-01	1.160E-02	2.32	27610
3410	5.000E-02	5.000E-03	1.000E+00	5.000E-01	1.207E-02	2.41	27920
3720	5.000E-02	5.000E-03	1.000E+00	5.000E-01	1.044E-02	2.09	28230
4030	5.000E-02	5.000E-03	1.000E+00	5.000E-01	7.204E-03	1.44	28540

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	9.000E-02	5.000E-03	1.000E+00	9.000E-01	2.420E-02	2.69	30177
620	9.000E-02	5.000E-03	1.000E+00	9.000E-01	2.911E-02	3.23	30487
930	9.000E-02	5.000E-03	1.000E+00	9.000E-01	4.337E-02	4.82	30797
1240	9.000E-02	5.000E-03	1.000E+00	9.000E-01	4.410E-02	4.90	31107
1550	9.000E-02	5.000E-03	1.000E+00	9.000E-01	3.155E-02	3.51	31417
1860	9.000E-02	5.000E-03	1.000E+00	9.000E-01	2.058E-02	2.29	31727
2170	9.000E-02	5.000E-03	1.000E+00	9.000E-01	3.645E-02	4.05	32037
2480	9.000E-02	5.000E-03	1.000E+00	9.000E-01	5.245E-02	5.83	32347
2790	9.000E-02	5.000E-03	1.000E+00	9.000E-01	5.637E-02	6.26	32657
3100	9.000E-02	5.000E-03	1.000E+00	9.000E-01	4.513E-02	5.01	32967
3410	9.000E-02	5.000E-03	1.000E+00	9.000E-01	2.600E-02	2.89	33277

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.750E-01	5.000E-03	1.000E+00	1.750E+00	2.108E-02	1.20	34705
620	1.750E-01	5.000E-03	9.999E-01	1.750E+00	1.205E-02	0.69	35015
930	1.750E-01	5.000E-03	1.000E+00	1.750E+00	1.434E-02	0.82	35325

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	2.000E-01	5.000E-03	1.000E+00	2.000E+00	3.017E-02	1.51	36216
620	2.000E-01	5.000E-03	1.000E+00	2.000E+00	1.286E-02	0.64	36526

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	2.150E-01	5.000E-03	1.000E+00	2.150E+00	2.754E-02	1.28	37142
620	2.150E-01	5.000E-03	1.000E+00	2.150E+00	1.388E-02	0.65	37452

**** PLOT TAPE WRITTEN AT TIME = 5.000E-01 STEP NUMBER 100 ****

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	7.350E-01	5.000E-03	1.000E+00	7.350E+00	7.627E-02	1.04	41011
620	7.350E-01	5.000E-03	1.000E+00	7.350E+00	5.694E-02	0.77	41321
930	7.350E-01	5.000E-03	1.000E+00	7.350E+00	6.723E-02	0.91	41631
1240	7.350E-01	5.000E-03	1.000E+00	7.350E+00	8.193E-02	1.11	41941
1550	7.350E-01	5.000E-03	1.000E+00	7.350E+00	6.455E-02	0.88	42251

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	7.400E-01	5.000E-03	1.000E+00	7.400E+00	5.409E-02	0.73	42836
620	7.400E-01	5.000E-03	1.000E+00	7.400E+00	8.156E-02	1.10	43146
930	7.400E-01	5.000E-03	1.000E+00	7.400E+00	7.488E-02	1.01	43456
1240	7.400E-01	5.000E-03	1.000E+00	7.400E+00	8.544E-02	1.15	43766
1550	7.400E-01	5.000E-03	1.000E+00	7.400E+00	8.341E-02	1.13	44076
1860	7.400E-01	5.000E-03	9.999E-01	7.400E+00	9.241E-02	1.25	44386

2170	7.400E-01	5.000E-03	9.986E-01	7.400E+00	8.286E-02	1.12	44696
2480	7.400E-01	5.000E-03	1.000E+00	7.400E+00	8.095E-02	1.09	45006
2790	7.400E-01	5.000E-03	1.000E+00	7.400E+00	8.610E-02	1.16	45316
3100	7.400E-01	5.000E-03	1.000E+00	7.400E+00	7.019E-02	0.95	45626
3410	7.400E-01	5.000E-03	1.000E+00	7.400E+00	6.198E-02	0.84	45936

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	7.700E-01	5.000E-03	9.997E-01	7.700E+00	4.450E-02	0.58	46646
620	7.700E-01	5.000E-03	1.000E+00	7.700E+00	4.265E-02	0.55	46956

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	7.750E-01	5.000E-03	1.000E+00	7.750E+00	6.642E-02	0.86	47527
620	7.750E-01	5.000E-03	1.000E+00	7.750E+00	7.396E-02	0.95	47837
930	7.750E-01	5.000E-03	1.000E+00	7.750E+00	6.622E-02	0.85	48147
1240	7.750E-01	5.000E-03	1.000E+00	7.750E+00	7.426E-02	0.96	48457
1550	7.750E-01	5.000E-03	9.998E-01	7.750E+00	6.917E-02	0.89	48767
1860	7.750E-01	5.000E-03	1.000E+00	7.750E+00	5.202E-02	0.67	49077
2170	7.750E-01	5.000E-03	1.000E+00	7.750E+00	5.476E-02	0.71	49387

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	7.800E-01	5.000E-03	1.000E+00	7.800E+00	9.836E-02	1.26	49836
620	7.800E-01	5.000E-03	1.000E+00	7.800E+00	9.414E-02	1.21	50146
930	7.800E-01	5.000E-03	1.000E+00	7.800E+00	7.683E-02	0.99	50456
1240	7.800E-01	5.000E-03	1.000E+00	7.800E+00	8.371E-02	1.07	50766
1550	7.800E-01	5.000E-03	1.000E+00	7.800E+00	6.146E-02	0.79	51076
1860	7.800E-01	5.000E-03	1.000E+00	7.800E+00	6.605E-02	0.85	51386
2170	7.800E-01	5.000E-03	1.000E+00	7.800E+00	9.970E-02	1.28	51696
2480	7.800E-01	5.000E-03	1.000E+00	7.800E+00	8.841E-02	1.13	52006

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	8.200E-01	5.000E-03	1.000E+00	8.200E+00	4.274E-02	0.52	52818

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	8.250E-01	5.000E-03	1.000E+00	8.250E+00	5.651E-02	0.69	53212
620	8.250E-01	5.000E-03	1.000E+00	8.250E+00	4.739E-02	0.57	53522
930	8.250E-01	5.000E-03	1.000E+00	8.250E+00	4.671E-02	0.57	53832
1240	8.250E-01	5.000E-03	9.983E-01	8.250E+00	4.674E-02	0.57	54142
1550	8.250E-01	5.000E-03	9.996E-01	8.250E+00	4.572E-02	0.55	54452
1860	8.250E-01	5.000E-03	9.996E-01	8.250E+00	4.416E-02	0.54	54762
2170	8.250E-01	5.000E-03	9.996E-01	8.250E+00	4.334E-02	0.53	55072
2480	8.250E-01	5.000E-03	9.995E-01	8.250E+00	4.239E-02	0.51	55382

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	8.300E-01	5.000E-03	1.000E+00	8.300E+00	6.544E-02	0.79	55779
620	8.300E-01	5.000E-03	1.000E+00	8.300E+00	7.876E-02	0.95	56089
930	8.300E-01	5.000E-03	9.993E-01	8.300E+00	7.682E-02	0.93	56399

1240	8.300E-01	5.000E-03	1.000E+00	8.300E+00	6.683E-02	0.81	56709
1550	8.300E-01	5.000E-03	1.000E+00	8.300E+00	5.380E-02	0.65	57019
1860	8.300E-01	5.000E-03	1.000E+00	8.300E+00	4.703E-02	0.57	57329

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	8.350E-01	5.000E-03	1.000E+00	8.350E+00	4.483E-02	0.54	57885

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	8.400E-01	5.000E-03	1.000E+00	8.400E+00	4.528E-02	0.54	58407

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	9.400E-01	5.000E-03	1.000E+00	9.400E+00	5.008E-02	0.53	60948
620	9.400E-01	5.000E-03	9.999E-01	9.400E+00	4.963E-02	0.53	61258

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	9.450E-01	5.000E-03	9.996E-01	9.450E+00	5.072E-02	0.54	61737
620	9.450E-01	5.000E-03	1.000E+00	9.450E+00	4.981E-02	0.53	62047
930	9.450E-01	5.000E-03	1.000E+00	9.450E+00	4.882E-02	0.52	62357
1240	9.450E-01	5.000E-03	9.996E-01	9.450E+00	4.831E-02	0.51	62667

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	9.500E-01	5.000E-03	1.000E+00	9.500E+00	6.120E-02	0.64	63161

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	9.550E-01	5.000E-03	1.000E+00	9.550E+00	1.070E-01	1.12	63738
620	9.550E-01	5.000E-03	1.000E+00	9.550E+00	9.719E-02	1.02	64048
930	9.550E-01	5.000E-03	1.000E+00	9.550E+00	8.582E-02	0.90	64358

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	9.600E-01	5.000E-03	1.000E+00	9.600E+00	6.178E-02	0.64	64906
620	9.600E-01	5.000E-03	1.000E+00	9.600E+00	1.139E-01	1.19	65216

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	9.650E-01	5.000E-03	1.000E+00	9.650E+00	6.040E-02	0.63	65797

**** PLOT TAPE WRITTEN AT TIME = 1.000E+00 STEP NUMBER 200 ****

STEP	TIME	TIME	DAMPING	APPLIED	RESIDUAL	PERCENT	TOTAL

		STEP	FACTOR	LOAD NORM	LOAD NORM	IMBALANCE	STEPS
310	1.065E+00	5.000E-03	1.000E+00	1.065E+01	8.974E-02	0.84	66886
620	1.065E+00	5.000E-03	9.950E-01	1.065E+01	9.388E-02	0.88	67196

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.070E+00	5.000E-03	1.000E+00	1.070E+01	1.585E-01	1.48	67814
620	1.070E+00	5.000E-03	1.000E+00	1.070E+01	1.832E-01	1.71	68124
930	1.070E+00	5.000E-03	1.000E+00	1.070E+01	1.414E-01	1.32	68434
1240	1.070E+00	5.000E-03	1.000E+00	1.070E+01	1.482E-01	1.39	68744
1550	1.070E+00	5.000E-03	9.999E-01	1.070E+01	1.559E-01	1.46	69054
1860	1.070E+00	5.000E-03	1.000E+00	1.070E+01	1.088E-01	1.02	69364
2170	1.070E+00	5.000E-03	1.000E+00	1.070E+01	1.830E-01	1.71	69674
2480	1.070E+00	5.000E-03	1.000E+00	1.070E+01	1.737E-01	1.62	69984
2790	1.070E+00	5.000E-03	1.000E+00	1.070E+01	1.343E-01	1.26	70294
3100	1.070E+00	5.000E-03	1.000E+00	1.070E+01	1.655E-01	1.55	70604
3410	1.070E+00	5.000E-03	9.995E-01	1.070E+01	7.469E-02	0.70	70914
3720	1.070E+00	5.000E-03	1.000E+00	1.070E+01	1.449E-01	1.35	71224

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.095E+00	5.000E-03	1.000E+00	1.095E+01	6.435E-02	0.59	71803
620	1.095E+00	5.000E-03	1.000E+00	1.095E+01	6.336E-02	0.58	72113
930	1.095E+00	5.000E-03	1.000E+00	1.095E+01	6.206E-02	0.57	72423
1240	1.095E+00	5.000E-03	9.997E-01	1.095E+01	6.096E-02	0.56	72733
1550	1.095E+00	5.000E-03	9.995E-01	1.095E+01	5.985E-02	0.55	73043
1860	1.095E+00	5.000E-03	9.994E-01	1.095E+01	5.896E-02	0.54	73353
2170	1.095E+00	5.000E-03	9.995E-01	1.095E+01	5.751E-02	0.53	73663
2480	1.095E+00	5.000E-03	9.995E-01	1.095E+01	5.498E-02	0.50	73973

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.100E+00	5.000E-03	1.000E+00	1.100E+01	7.057E-02	0.64	74316
620	1.100E+00	5.000E-03	1.000E+00	1.100E+01	6.369E-02	0.58	74626
930	1.100E+00	5.000E-03	1.000E+00	1.100E+01	6.261E-02	0.57	74936
1240	1.100E+00	5.000E-03	1.000E+00	1.100E+01	6.435E-02	0.59	75246
1550	1.100E+00	5.000E-03	1.000E+00	1.100E+01	6.175E-02	0.56	75556
1860	1.100E+00	5.000E-03	9.990E-01	1.100E+01	5.922E-02	0.54	75866
2170	1.100E+00	5.000E-03	9.996E-01	1.100E+01	5.786E-02	0.53	76176

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.105E+00	5.000E-03	1.000E+00	1.105E+01	6.293E-02	0.57	76620
620	1.105E+00	5.000E-03	1.000E+00	1.105E+01	5.724E-02	0.52	76930

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.110E+00	5.000E-03	1.000E+00	1.110E+01	5.724E-02	0.52	77433

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.435E+00	5.000E-03	1.000E+00	1.435E+01	9.762E-02	0.68	80006

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.445E+00	5.000E-03	9.988E-01	1.445E+01	9.182E-02	0.64	80648
620	1.445E+00	5.000E-03	1.000E+00	1.445E+01	1.310E-01	0.91	80958

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.465E+00	5.000E-03	9.997E-01	1.465E+01	8.078E-02	0.55	81671

```
**** PLOT TAPE WRITTEN AT TIME = 1.500E+00   STEP NUMBER   300 ****
```

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.805E+00	5.000E-03	1.000E+00	1.805E+01	1.325E-01	0.73	83609
620	1.805E+00	5.000E-03	1.000E+00	1.805E+01	2.079E-01	1.15	83919
930	1.805E+00	5.000E-03	1.000E+00	1.805E+01	3.305E-01	1.83	84229
1240	1.805E+00	5.000E-03	9.928E-01	1.805E+01	1.709E-01	0.95	84539

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
310	1.825E+00	5.000E-03	1.000E+00	1.825E+01	9.342E-02	0.51	84998

```
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:26:26
       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 =          22, TOTAL NUMBER OF ITERATIONS =      86282
     FINAL CONVERGENCE TOLERANCE = 4.997E-01
     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 = 2.259E-01
     SUM OF REACTION FORCES IN Y-DIRECTION =-1.908E+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
                           7.363E+01 CPU SECONDS USED
                               26226 WORDS ALLOCATED
```

APPENDIX D

Input/Output Data For Test Case 4

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

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. Test Case 4 also required sant_beandl.dist and sant_distl.dist as input files. These files are binary and can be found in LIBSANTOS in CMS.

sant_distl.fsq

```
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
```

sant_distl.i

```
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
```

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.

```
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),numnod,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,numnod
 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. numnod )
            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,numnod),(fy(m),m = 1,numnod)
c
c.....force check
c
         fsum = 0.
         n = 0
         do while ( n .lt. numnod)
            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
         write(13,40) (n,fy(n),n = 1,numnod)
 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
```

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.

sant_distl.o

```
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



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                                   PROGRAMMED BY:

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



                             RUN ON 20030618 AT 14:40:44
                           RUN ON A      i686 UNDER Lx2.4.20
    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
1                                  INPUT STREAM IMAGES
  LINE ---------------------------------------------------------------------------
   24: TITLE
   25:  DISTRIBUTED LOAD PROBLEM   - SANTOS QA - 12/4/94
   26: PLANE STRAIN
   27: MAXIMUM ITERATIONS, 10000
   28: MAXIMUM TOLERANCE, 1000
   29: MATERIAL,1,ELASTIC,1.0
   30: YOUNGS MODULUS = 1.0E+7
   31: POISSONS RATIO = 0.0
   32: END
   33: 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
------------------------------------------------------------------------
```

1

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



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
                  2.000E-02 CPU SECONDS USED
                        274 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
                  0.000E+00 CPU SECONDS USED
                      14198 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  4.506E-01  1.010E+02  5.966E-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 ****

1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030618, AT 14:40:44
       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 = 2.583E-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 = 6.557E-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
     2.000E-02 CPU SECONDS USED
         15380 WORDS ALLOCATED
```

APPENDIX E

Input/Output Data For Test Case 5

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

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.

sant_adapt_fine.fsq

```
TITLE
 HOLLOW SPHERE - SANTOS QA TEST PROBLEM - 03/27/03
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    38   1.0
LINE    2   STR   3    4    0    10   1.0
LINE    3   CIRC  5    4    1    38   1.0
LINE    4   STR   2    5    0    10   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
```

sant_adapt.i

```
TITLE
  SANTOS QA PROBLEM - ADAPTIVE PRESSURE PROBLEM - AXISYMMETRIC
AXISYMMETRIC
MAXIMUM ITERATIONS 80000
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
    15   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
```

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.

```
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)
c
      INCLUDE 'precision.blk'
c
c.....vol1 is taken from NUMBERS evaluation of Genesis file
c
      vol1 = 1.425
      po = 10.
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
      pgas = po*vol1/volume
c
c
      return
      end
```

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

sant_adapt.o

```
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
```

```
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                   PROGRAMMED BY:

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


              RUN ON 20030612 AT 10:40:26
            RUN ON A     i686 UNDER Lx2.4.20
```

```
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
```

```
   30: EXIT
1                                         INPUT STREAM IMAGES
  LINE ------------------------------------------------------------------------------
   32: TITLE
   33:   SANTOS QA PROBLEM - ADAPTIVE PRESSURE PROBLEM - AXISYMMETRIC
   34: AXISYMMETRIC
   35: MAXIMUM ITERATIONS 40000
   36: MATERIAL,1,ELASTIC,1.
   37: YOUNGS MODULUS, 1.E+7
   38: POISSONS RATIO, 0.3
   39: END
   40: FUNCTION 2  $ DISPLACEMENT FUNCTION
   41:    0.       0.
   42:    1.E-4    0.
   43:   10.       0.25
   44: END
   45: STEP CONTROL
   46:    1   1.E-4
   47:   20  10.
   48: END
   49: OUTPUT TIME
   50:    0   1.E-4
   51:    0  10.
   52: END
   53: PLOT TIME
   54:    1   1.E-4
   55:    1  10.
   56: END
   57: ADAPTIVE PRESSURE 3 0. 0.
   58: PRESCRIBED DISPLACEMENT RADIAL 4 2 1. 0. 0.
   59: NO DISPLACEMENT Y  2
   60: NO DISPLACEMENT X  1
   61: EXIT
       ------------------------------------------------------------------------
1
                          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 ......................        380
              NUMBER OF NODES .........................        429
              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 .......        858
              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

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

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 FLAG	REFERENCE 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

2.000E-02 CPU SECONDS USED
4074 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

1.000E-02 CPU SECONDS USED
39406 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 ****


**** 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 ****

1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:40:26
        SANTOS QA PROBLEM - ADAPTIVE PRESSURE PROBLEM - AXISYMMETRIC
```

```
**********************************************************************
SUMMARY OF DATA AT STEP NUMBER     21, TIME = 1.000E+01
NUMBER OF ITERATIONS =       225, TOTAL NUMBER OF ITERATIONS =       3857
FINAL CONVERGENCE TOLERANCE = 3.642E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 6.273E+00
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 3.995E+00
SUM OF REACTION FORCES IN X-DIRECTION =-1.818E+06
SUM OF REACTION FORCES IN Y-DIRECTION = 1.157E+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
                      1.151E+01 CPU SECONDS USED
                          52026 WORDS ALLOCATED
```

APPENDIX F

Input/Output Data For Test Case 6

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

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.

sant_spind.fsq

```
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
```

sant_spind.i

```
TITLE
  SANTOS QA PROBLEM - SPINNING DISK - 01/27/03
AXISYMMETRIC
MAXIMUM ITERATIONS,10000
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
```

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.

sant_spind.o

```
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



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                                              PROGRAMMED BY:

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



                                       RUN ON 20030612 AT 10:41:55
                                     RUN ON A     i686 UNDER Lx2.4.20

    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
1                                   INPUT STREAM IMAGES
  LINE ------------------------------------------------------------------------------
   29: TITLE
   30:   SANTOS QA PROBLEM - SPINNING DISK - 10/14/94
   31: AXISYMMETRIC
   32: MAXIMUM ITERATIONS,2000
   33: RESIDUAL TOLERANCE 0.1
   34: MATERIAL,1,ELASTIC,2.1669E+03
   35: YOUNGS MODULUS 2.07E+11
   36: POISSONS RATIO 0.3
   37: END
   38: FUNCTION,1
   39:   0.,1.
   40:   1.,1.
   41: END
   42: STEP CONTROL
   43:   1,1.
   44: END
   45: PLOT TIME
   46:  1,1.
   47: END
   48: OUTPUT TIME
   49:  1,1.
   50: END
   51: $ NO DISPLACEMENT,Y,1
   52: NO DISPLACEMENT,Y,2
   53: GRAVITY,1,0.,0.,100.
   54: GLOBAL CONVERGENCE,1.E-8
   55: EXIT
       ------------------------------------------------------------------------------
1
                          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


  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
```

```
          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
                       2.000E-02 CPU SECONDS USED
                            6050 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
                       1.000E-02 CPU SECONDS USED
                           56998 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
   1458  1.000E+00  1.000E+00  9.893E-01  2.057E+05  8.817E+02      0.43      1458
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:41:55
        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
                           8.840E+00 CPU SECONDS USED
                               80148 WORDS ALLOCATED
```

APPENDIX G

Input/Output Data For Test Case 7

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

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.

beam.fsq

```
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
```

Gravity Loaded Beam

beamg.i

```
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
```

Pressure Loaded Beam

beamp.i

```
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
```

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.

Gravity Loaded Beam

beamg.o

```
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 2.1.7-DP
                         COPYRIGHT 1995, SANDIA CORPORATION

                                 PROGRAMMED BY:

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


                          RUN ON 20030612 AT 10:43:46
                        RUN ON A     i686 UNDER Lx2.4.20

     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
1                                    INPUT STREAM IMAGES
  LINE -----------------------------------------------------------------------
   33: TITLE
   34:  30 TO 1 BEAM WITH GRAVITY LOADS - SANTOS QA PROBLEM
   35: RESIDUAL TOLERANCE, 0.5
   36: MAXIMUM ITERATIONS, 3000
   37: INTERMEDIATE PRINT, 100
   38: MAXIMUM TOLERANCE, 1000
   39: NO DAMPING, 100, 50
   40: PLANE STRAIN
   41: STEP CONTROL
   42:  310 1.55
   43:  END
   44: PLOT TIME
   45:  10 1.55
   46: END
   47: OUTPUT TIME
   48:  1 1.55
   49:  END
   50: PLOT NODAL DISPLACEMENT
   51: PLOT ELEMENT STRESS,VONMISES
   52: NO DISPLACEMENT Y, 4
   53: NO DISPLACEMENT X, 4
   54: GRAVITY,1,0.,1.,0.
   55: FUNCTION, 1  $ FUNCTION TO DEFINE GRAVITY LOADS
   56: 0.  0.
   57: 2.  -2.
   58: END
   59: MATERIAL, 1, ELASTIC, 400.
   60: YOUNGS MODULUS = 1.E7
   61: POISSONS RATIO = 0.0
   62: END
   63: EXIT
       -----------------------------------------------------------------------
1
                         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
```

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
       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

3.000E-02 CPU SECONDS USED
2330 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

0.000E+00 CPU SECONDS USED
22728 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 STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL 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
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

1 SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:43:46
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 STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	1.000E-02	5.000E-03	1.000E+00	1.016E+01	1.416E+02	1393.45	3100
200	1.000E-02	5.000E-03	9.992E-01	1.016E+01	2.950E+01	290.29	3200

```
    300  1.000E-02  5.000E-03  1.000E+00  1.016E+01  2.617E+01     257.58      3300
    400  1.000E-02  5.000E-03  1.000E+00  1.016E+01  2.984E+01     293.62      3400
    500  1.000E-02  5.000E-03  1.000E+00  1.016E+01  1.287E+01     126.65      3500
    600  1.000E-02  5.000E-03  1.000E+00  1.016E+01  2.746E+01     270.23      3600
.
.
.

1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:43:46
       30 TO 1 BEAM WITH GRAVITY LOADS - SANTOS QA PROBLEM

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER   310, TIME = 1.550E+00
     NUMBER OF ITERATIONS =       871, TOTAL NUMBER OF ITERATIONS =    238005
     FINAL CONVERGENCE TOLERANCE = 4.937E-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 =-5.824E+01
     SUM OF REACTION FORCES IN Y-DIRECTION =-1.863E+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
                           2.042E+02 CPU SECONDS USED
                               27346 WORDS ALLOCATED



                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
                           7.301E+02 CPU SECONDS USED
                                       14138 WORDS ALLOCATED
```

Pressure Loaded Beam

beamp.o

```
  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 2.1.7-DP
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                                       PROGRAMMED BY:

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




                                RUN ON 20030612 AT 10:47:48
                              RUN ON A     i686 UNDER Lx2.4.20

     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
1                                   INPUT STREAM IMAGES
  LINE ------------------------------------------------------------------------
```

```
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
------------------------------------------------------------------------
```

```
1
                         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
```

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
```

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

          SURFACE       FUNCTION      SCALE
           FLAG          NUMBER       FACTOR
            30             1       4.000E+02



               E N D   O F   D A T A   I N P U T   P H A S E
                     2.000E-02 CPU SECONDS USED
                          2336 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
                     1.000E-02 CPU SECONDS USED
                         22734 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 STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	1.000E-03	1.000E-03	1.000E+00	2.173E+00	4.084E+00	188.00	100
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	9.967E-01	2.173E+00	3.312E+00	152.44	2200
2300	1.000E-03	1.000E-03	9.651E-01	2.173E+00	1.523E+00	70.09	2300
2400	1.000E-03	1.000E-03	1.000E+00	2.173E+00	7.333E-01	33.75	2400
2500	1.000E-03	1.000E-03	1.000E+00	2.173E+00	7.212E-01	33.20	2500
2600	1.000E-03	1.000E-03	9.994E-01	2.173E+00	7.127E-01	32.80	2600
2700	1.000E-03	1.000E-03	9.998E-01	2.173E+00	7.064E-01	32.52	2700
2800	1.000E-03	1.000E-03	9.965E-01	2.173E+00	6.990E-01	32.17	2800
2900	1.000E-03	1.000E-03	9.955E-01	2.173E+00	6.897E-01	31.75	2900

```
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:47:48
       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 = 3.146E+01
      SUM OF EXTERNAL FORCES IN X-DIRECTION =-3.122E-03
      SUM OF EXTERNAL FORCES IN Y-DIRECTION =-1.200E+01
      SUM OF REACTION FORCES IN X-DIRECTION =-1.249E-03
      SUM OF REACTION FORCES IN Y-DIRECTION =-7.165E+00
      *********************************************************************
```

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	2.000E-03	1.000E-03	1.000E+00	4.345E+00	7.374E+00	169.70	3100
200	2.000E-03	1.000E-03	9.989E-01	4.345E+00	1.355E+00	31.19	3200
300	2.000E-03	1.000E-03	1.000E+00	4.345E+00	1.351E+00	31.09	3300
400	2.000E-03	1.000E-03	9.998E-01	4.345E+00	1.340E+00	30.84	3400
500	2.000E-03	1.000E-03	1.000E+00	4.345E+00	1.326E+00	30.51	3500
600	2.000E-03	1.000E-03	9.991E-01	4.345E+00	1.313E+00	30.22	3600

.
.
.

```
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:47:48
       30 TO 1 BEAM WITH APPLIED PRESSURE
```

```
**********************************************************************
SUMMARY OF DATA AT STEP NUMBER  1550, TIME = 1.550E+00
NUMBER OF ITERATIONS =        52, TOTAL NUMBER OF ITERATIONS =    281051
FINAL CONVERGENCE TOLERANCE = 4.970E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION =-1.258E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 5.360E+03
SUM OF REACTION FORCES IN X-DIRECTION =-1.259E+04
SUM OF REACTION FORCES IN Y-DIRECTION = 5.240E+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
                      2.434E+02 CPU SECONDS USED
                          27042 WORDS ALLOCATED
```

APPENDIX H

Input/Output Data For Test Case 8

The following two sections present the input data and the formatted output for the tension release option verification test.

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.

sant_tension.fsq

```
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
```

sant_tension.i

```
 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 PLASTIC,1.
YOUNGS MODULUS 10.e+6
POISSIONS RATIO 0.3
YIELD STRESS 1.0e+4
HARDENING MODULUS 17000.
BETA 0.
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, -20000.
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
```

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.

sant_tension.o

```
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 2.1.7-DP
                       COPYRIGHT 1995, SANDIA CORPORATION

                               PROGRAMMED BY:

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



                        RUN ON 20030612 AT 10:52:33
                      RUN ON A     i686 UNDER Lx2.4.20

  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
```

```
   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
1                                    INPUT STREAM IMAGES
  LINE ----------------------------------------------------------------------
   47: TITLE
   48:   SANTOS QA PROBLEM - TENSION RELEASE CHECK
   49: PLANE STRAIN
   50: MAXIMUM ITERATIONS 5000
   51: RESIDUAL TOLERANCE,1.
   52: INTERMEDIATE PRINT = 100
   53: MAXIMUM TOLERANCE = 100000.
   54: MATERIAL,1,ELASTIC,1.
   55: YOUNGS MODULUS 30.e+6
   56: POISSIONS RATIO 0.3
   57: END
   58: MATERIAL,2,ELASTIC PLASTIC,1.
   59: YOUNGS MODULUS 10.e+6
   60: POISSIONS RATIO 0.3
   61: YIELD STRESS 1.0e+4
   62: HARDENING MODULUS 17000.
   63: BETA 0.
   64: END
   65: PLOT,NODAL,DISPLACEMENTS,RESIDUALS
   66: PLOT,ELEMENT,STRESS
   67: PLOT,STATE,EQPS
   68: FUNCTION 1
   69:    0.,0.0
   70:    1.,1.
   71: END
   72: STEP CONTROL
   73:  100,1.
   74: END
   75: OUTPUT TIME
   76:   1,1.
   77: END
   78: PLOT TIME
   79:   1,1.
   80: END
   81: PRESSURE, 10, 1, -10000.
   82: NO DISPLACEMENT X 1
   83: NO DISPLACEMENT X 2
   84: NO DISPLACEMENT X 3
   85: NO DISPLACEMENT X 4
   86: NO DISPLACEMENT Y 1
   87: NO DISPLACEMENT Y 2
   88: NO DISPLACEMENT Y 3
   89: NO DISPLACEMENT Y 4
   90: CONTACT SURFACE 100 200 0. 1.e-6 1000.
   91: EXIT
```

```
 ------------------------------------------------------------------------
1

                    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


             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
        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


              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
                      3.000E-02 CPU SECONDS USED
                            768 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
                      0.000E+00 CPU SECONDS USED
                          18192 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 ****


1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:52:33
        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 = 9.036E-01
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.776E-13
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 ****


1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:52:33
       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 = 7.000E-01
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 3.375E-12
     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 ****


1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:52:33
       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 = 9.313E-01
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 2.398E-12
     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 ****


1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:52:33
       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 = 9.436E-01
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 8.171E-12
     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 ****
```

```
.
.
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:52:33
        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 =    255322
     FINAL CONVERGENCE TOLERANCE = 6.371E+01
     SUM OF EXTERNAL FORCES IN X-DIRECTION =-6.120E+03
     SUM OF EXTERNAL FORCES IN Y-DIRECTION = 7.226E+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
                          6.603E+01 CPU SECONDS USED
                              19320 WORDS ALLOCATED
```

APPENDIX I

Input/Output Data For Test Case 9

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.

sant_singd.fsq

```
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
```

Case of $\mu = 0.1$

sant_sing01.i

```
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
```

Case of $\mu = 0.2$

sant_sing02.i

```
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
```

Case of $\mu = 0.5$

sant_sing05.i

```
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
```

Case of $\mu = 0.7$

sant_sing07.i

```
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
```

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.

Case of $\mu = 0.1$

sant_sing01.o

```
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 2.1.7-DP
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                              PROGRAMMED BY:

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



                         RUN ON 20030612 AT 10:54:47
                       RUN ON A     i686 UNDER Lx2.4.20

    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
1                                   INPUT STREAM IMAGES
 LINE -----------------------------------------------------------------------
   34: TITLE
   35:   SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.1
   36: PLANE STRAIN
   37: MAXIMUM ITERATIONS,20000
   38: RESIDUAL TOLERANCE 0.1
   39: TIME STEP SCALE 1.0
   40: MATERIAL,1,ELASTIC,1.
   41: YOUNGS MODULUS 10000.
   42: POISSONS RATIO 0.
   43: END
   44: FUNCTION,1
   45:   0.,1.
   46:   1.,1.
   47: END
   48: FUNCTION,2
   49:    0.,0.
   50:    1.,1.
   51: END
   52: STEP CONTROL
   53:   1000.,1.
   54: END
   55: PLOT TIME
   56:  10.,1.
   57: END
   58: OUTPUT TIME
   59:  1000.,1.
   60: END
   61: NO DISPLACEMENT,X,1
   62: PRESCRIBED DISPLACEMENT Y 3 1 -4.E-3 0. 0.
   63: PRESSURE,4,2,-35.
   64: RIGID SURFACE,5,0.,0.,0.,1.,0.1
   65: EXIT
       -----------------------------------------------------------------------
```

1

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

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      -            -


                         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
                       2.000E-02 CPU SECONDS USED
                            2398 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
                       0.000E+00 CPU SECONDS USED
                           25312 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 ****


**** 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 ****

.
.
.
.
.

1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:54:47
       SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.1

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER  1000, TIME = 1.000E+00
     NUMBER OF ITERATIONS =        34, TOTAL NUMBER OF ITERATIONS =     27114
     FINAL CONVERGENCE TOLERANCE = 8.887E-02
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 6.986E+01
     SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.260E-02
     SUM OF REACTION FORCES IN X-DIRECTION = 6.984E+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
                           3.270E+01 CPU SECONDS USED
                               31196 WORDS ALLOCATED
```

Case of $\mu = 0.2$

sant_sing02.o

```
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
```

```
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                   ENGINEERING SCIENCES CENTER
                  SANDIA NATIONAL LABORATORIES
                  ALBUQUERQUE, NEW MEXICO 87185



                  RUN ON 20030612 AT 10:55:20
                RUN ON A     i686 UNDER Lx2.4.20

    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
1                                  INPUT STREAM IMAGES
  LINE ------------------------------------------------------------------------
   34: TITLE
   35:   SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.2
   36: PLANE STRAIN
   37: MAXIMUM ITERATIONS,20000
   38: RESIDUAL TOLERANCE 0.1
   39: TIME STEP SCALE 1.0
   40: 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
------------------------------------------------------------------------
```

```
1
                    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

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 FLAG	DIRECTION	FUNCTION ID	SCALE FACTOR	A0	B0
3	Y	1	-4.000E-03	-	-

R I G I D S U R F A C E S

SURFACE NUMBER	SIDE SET FLAG	COEFFICIENT OF FRICTION	X0	Y0	NX	NY
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 FLAG	FUNCTION NUMBER	SCALE 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
3.000E-02 CPU SECONDS USED
2398 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
0.000E+00 CPU SECONDS USED
25312 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 ****



 **** 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 ****
```

•
•
•
•

```
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:55:20
        SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.2

 *********************************************************************
 SUMMARY OF DATA AT STEP NUMBER  1000, TIME = 1.000E+00
 NUMBER OF ITERATIONS =        35, TOTAL NUMBER OF ITERATIONS =     26762
 FINAL CONVERGENCE TOLERANCE = 9.109E-02
 SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.173E+02
 SUM OF EXTERNAL FORCES IN Y-DIRECTION =-7.894E-02
 SUM OF REACTION FORCES IN X-DIRECTION = 1.174E+02
 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

E N D  O F  S O L U T I O N  P H A S E
3.215E+01 CPU SECONDS USED
31196 WORDS ALLOCATED
```

Case of μ = 0.5

sant_sing05.o

```
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


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                    PROGRAMMED BY:

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


              RUN ON 20030612 AT 10:55:53
            RUN ON A      i686 UNDER Lx2.4.20

 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
1                                   INPUT STREAM IMAGES
  LINE ---------------------------------------------------------------------
   34: TITLE
   35:   SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.5
   36: PLANE STRAIN
   37: MAXIMUM ITERATIONS,20000
   38: RESIDUAL TOLERANCE 0.1
   39: TIME STEP SCALE 1.05
   40: MATERIAL,1,ELASTIC,1.
   41: YOUNGS MODULUS 10000.
   42: POISSONS RATIO 0.
   43: END
   44: FUNCTION,1
   45:   0.,1.
   46:   1.,1.
   47: END
   48: FUNCTION,2
   49:    0.,0.
   50:    1.,1.
   51: END
   52: STEP CONTROL
   53:   1000.,1.
   54: END
   55: PLOT TIME
   56:  10.,1.
   57: END
   58: OUTPUT TIME
   59:  1000.,1.
   60: END
   61: NO DISPLACEMENT,X,1
   62: PRESCRIBED DISPLACEMENT Y 3 1 -4.E-3 0. 0.
   63: PRESSURE,4,2,-125.
   64: RIGID SURFACE,5,0.,0.,0.,1.,0.5
   65: EXIT
       ---------------------------------------------------------------------
1
                        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

  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 FLAG	DIRECTION	FUNCTION ID	SCALE FACTOR	A0	B0
3	Y	1	-4.000E-03	-	-

R I G I D   S U R F A C E S

SURFACE NUMBER	SIDE SET FLAG	COEFFICIENT OF FRICTION	X0	Y0	NX	NY
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
                      3.000E-02 CPU SECONDS USED
                           2398 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
                      0.000E+00 CPU SECONDS USED
                          25312 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 ****


**** 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 ****

.
.
.
.

1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:55:53
        SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.5

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER  1000, TIME = 1.000E+00
     NUMBER OF ITERATIONS =        28, TOTAL NUMBER OF ITERATIONS =     24748
     FINAL CONVERGENCE TOLERANCE = 8.813E-02
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 2.495E+02
     SUM OF EXTERNAL FORCES IN Y-DIRECTION =-5.938E-01
     SUM OF REACTION FORCES IN X-DIRECTION = 2.495E+02
     SUM OF REACTION FORCES IN Y-DIRECTION =-4.038E+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
                          2.981E+01 CPU SECONDS USED
                              31196 WORDS ALLOCATED
```

Case of $\mu = 0.7$

sant_sing07.o

```
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


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```

```
                              PROGRAMMED BY:

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




                       RUN ON 20030612 AT 10:56:23
                     RUN ON A     i686 UNDER Lx2.4.20

    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
1                                   INPUT STREAM IMAGES
  LINE -----------------------------------------------------------------------
   34: TITLE
   35:   SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.7
   36: PLANE STRAIN
   37: MAXIMUM ITERATIONS,20000
   38: RESIDUAL TOLERANCE 0.1
   39: TIME STEP SCALE 1.05
   40: MATERIAL,1,ELASTIC,1.
   41: YOUNGS MODULUS 10000.
   42: POISSONS RATIO 0.
   43: END
   44: 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
------------------------------------------------------------------------
```

1

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

```
   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 FLAG	DIRECTION	FUNCTION ID	SCALE FACTOR	A0	B0
3	Y	1	-4.000E-03	-	-

R I G I D   S U R F A C E S

SURFACE NUMBER	SIDE SET FLAG	COEFFICIENT OF FRICTION	X0	Y0	NX	NY
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 FLAG	FUNCTION NUMBER	SCALE 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
2.000E-02 CPU SECONDS USED
2398 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
0.000E+00 CPU SECONDS USED
25312 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 ****



 **** 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 ****

.
.
.
.

1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 10:56:23
       SANTOS QA PROBLEM - SINGLE BEAM FRICTION MU = 0.7

 *********************************************************************
 SUMMARY OF DATA AT STEP NUMBER  1000, TIME = 1.000E+00
 NUMBER OF ITERATIONS =        33, TOTAL NUMBER OF ITERATIONS =     24097
 FINAL CONVERGENCE TOLERANCE = 8.010E-02
 SUM OF EXTERNAL FORCES IN X-DIRECTION = 3.393E+02
 SUM OF EXTERNAL FORCES IN Y-DIRECTION =-1.417E+00
 SUM OF REACTION FORCES IN X-DIRECTION = 3.394E+02
 SUM OF REACTION FORCES IN Y-DIRECTION =-4.054E+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
     2.915E+01 CPU SECONDS USED
         31196 WORDS ALLOCATED
```

APPENDIX J

Input/Output Data For Test Case 10

The following two sections present the input data and the formatted output for the double elastic beam contact sliding verification test.

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.

sant_doublc.fsq

```
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
```

Case 1 Input

sant_doubl1.i

```
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 = 0.30
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
FUNCTION,3
  0.  1.
  5.  1.
  5.5 0.7
 10.  0.5
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
```

Case 2 Input

sant_doubl2.i

```
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
```

```
TIME STEP SCALE = 0.1
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
FUNCTION,3
  0.  0.7
  5.  0.7
  5.5 0.5
 10.  0.25
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
```

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.

Case 1 Output

sant_doubl1.o

```
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



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                                PROGRAMMED BY:

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



                         RUN ON 20030618 AT 14:49:31
                       RUN ON A     i686 UNDER Lx2.4.20

    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 = 0.30
   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: FUNCTION,3
   27:   0.  1.
   28:   5.  1.
   29:   5.5 0.7
   30:  10.  0.5
   31: END
   32: STEP CONTROL
   33:   100.,10.
   34: END
   35: PLOT TIME
   36:  1.,10.
   37: END
   38: OUTPUT TIME
   39:  10.,10.
   40: END
   41: PLOT NODAL,REACTION,RESIDUAL
   42: NO DISPLACEMENT,X,1
   43: NO DISPLACEMENT,X,8
   44: NO DISPLACEMENT,Y,2
   45: CONTACT SURFACE,6,5,0.4,1.E-3,1.E+40
   46: PRESSURE,3,1,1.
   47: PRESSURE,4,2,-10.
   48: PRESSURE,7,2,-10.
   49: EXIT
1                                    INPUT STREAM IMAGES
  LINE -------------------------------------------------------------------------
   51: TITLE
   52:  SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.4 - E2/E1 = 3
   53: PLANE STRAIN
   54: MAXIMUM ITERATIONS = 3000
   55: RESIDUAL TOLERANCE = 0.50
   56: MAXIMUM TOLERANCE =  1000.0
   57: ELASTIC SOLUTION
   58: $ PREDICTOR SCALE FACTOR = 3
   59: TIME STEP SCALE = 0.30
   60: MATERIAL,1,ELASTIC,1.
   61: YOUNGS MODULUS 3000.
   62: POISSONS RATIO 0.
   63: END
   64: MATERIAL,2,ELASTIC,1.
   65: YOUNGS MODULUS 9000.
   66: POISSONS RATIO 0.
   67: END
   68: FUNCTION,1
   69:   0.,1.
   70:  10.,1.
   71: END
   72: FUNCTION,2
   73:    0.,0.
   74:   10.,1.
   75: END
   76: FUNCTION,3
   77:   0.  1.
   78:   5.  1.
   79:   5.5 0.7
   80:  10.  0.5
   81: END
   82: 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
----------------------------------------------------------------------
```

```
1
                     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 ....................          3
          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 ........          0
          MINIMUM DAMPING FACTOR .................  2.000E-01
          EFFECTIVE MODULUS STATUS ............... CONSTANT
          ELASTIC SOLUTION REQUESTED .............
          SCALE FACTOR APPLIED TO TIME STEP ......  3.000E-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


           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

  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
```

FUNCTION ID .... 3 NUMBER OF POINTS 4

N	S	F(S)
1	0.000E+00	1.000E+00
2	5.000E+00	1.000E+00
3	5.500E+00	7.000E-01
4	1.000E+01	5.000E-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
1	X
8	X
2	Y

C O N T A C T S U R F A C E S

SURFACE NUMBER	SURFACE 1 FLAG	SURFACE 2 FLAG	PENALTY FACTOR	COEFFICIENT OF FRICTION	PENETRATION MULTIPLIER	TENSION RELEASE
1	6	5	0.000E+00	4.000E-01	1.000E-03	INF

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 FLAG	FUNCTION NUMBER	SCALE 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
3.000E-02 CPU SECONDS USED
5124 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
1.000E-02 CPU SECONDS USED
70366 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
```

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
528	0.000E+00	1.000E-01	6.252E-01	3.089E+00	6.135E-01	19.86	528
1056	0.000E+00	1.000E-01	3.926E-01	3.089E+00	5.851E-01	18.94	1056
1584	0.000E+00	1.000E-01	9.073E-01	3.089E+00	5.710E-01	18.48	1584
2112	0.000E+00	1.000E-01	6.549E-01	3.089E+00	3.351E-01	10.85	2112
2640	0.000E+00	1.000E-01	4.684E-01	3.089E+00	2.507E-01	8.12	2640

```
1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030618, AT 14:49:31
      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 =       3000, TOTAL NUMBER OF ITERATIONS =       3000
     FINAL CONVERGENCE TOLERANCE = 1.303E+01
     SUM OF EXTERNAL FORCES IN X-DIRECTION =-2.604E-05
     SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.500E+01
     SUM OF REACTION FORCES IN X-DIRECTION = 3.293E-04
     SUM OF REACTION FORCES IN Y-DIRECTION =-2.421E+01
     *********************************************************************

     **** PLOT TAPE WRITTEN AT TIME = 0.000E+00   STEP NUMBER      0 ****
```

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
528	1.000E-01	9.998E-02	7.086E-01	3.091E+00	5.630E-01	18.22	3528
1056	1.000E-01	9.998E-02	5.674E-01	3.091E+00	3.124E-01	10.11	4056
1584	1.000E-01	9.998E-02	6.467E-01	3.091E+00	3.506E-01	11.34	4584
2112	1.000E-01	9.998E-02	6.403E-01	3.091E+00	3.376E-01	10.92	5112
2640	1.000E-01	9.998E-02	6.986E-01	3.091E+00	3.110E-01	10.06	5640

```
     **** PLOT TAPE WRITTEN AT TIME = 1.000E-01   STEP NUMBER      1 ****
```

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS

528	2.000E-01	1.000E-01	9.359E-01	3.095E+00	5.227E-01	16.89	6528
1056	2.000E-01	1.000E-01	7.148E-01	3.095E+00	3.253E-01	10.51	7056
1584	2.000E-01	1.000E-01	9.678E-01	3.095E+00	4.591E-01	14.83	7584
2112	2.000E-01	1.000E-01	6.143E-01	3.095E+00	3.441E-01	11.12	8112
2640	2.000E-01	1.000E-01	5.672E-01	3.095E+00	9.053E-01	29.25	8640

**** PLOT TAPE WRITTEN AT TIME = 2.000E-01 STEP NUMBER 2 ****

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
528	3.000E-01	1.000E-01	5.150E-01	3.104E+00	5.953E-01	19.18	9528
1056	3.000E-01	1.000E-01	4.768E-01	3.104E+00	3.285E-01	10.58	10056
1584	3.000E-01	1.000E-01	3.559E-01	3.104E+00	3.570E-01	11.50	10584
2112	3.000E-01	1.000E-01	8.879E-01	3.104E+00	5.935E-01	19.12	11112
2640	3.000E-01	1.000E-01	8.734E-01	3.104E+00	3.028E-01	9.76	11640

**** PLOT TAPE WRITTEN AT TIME = 3.000E-01 STEP NUMBER 3 ****

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
528	4.000E-01	1.000E-01	8.472E-01	3.115E+00	3.876E-01	12.44	12528
1056	4.000E-01	1.000E-01	9.708E-01	3.115E+00	6.258E-01	20.09	13056
1584	4.000E-01	1.000E-01	7.061E-01	3.115E+00	3.067E-01	9.85	13584
2112	4.000E-01	1.000E-01	7.387E-01	3.115E+00	9.108E-01	29.24	14112
2640	4.000E-01	1.000E-01	6.617E-01	3.115E+00	2.972E-01	9.54	14640

**** PLOT TAPE WRITTEN AT TIME = 4.000E-01 STEP NUMBER 4 ****

.
.
.
.

```
1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030618, AT 14:49:31
      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 =      3000, TOTAL NUMBER OF ITERATIONS =    303000
     FINAL CONVERGENCE TOLERANCE = 6.511E+00
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 2.000E+01
     SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.505E+01
     SUM OF REACTION FORCES IN X-DIRECTION = 1.992E+01
     SUM OF REACTION FORCES IN Y-DIRECTION =-2.413E+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
                      7.975E+02 CPU SECONDS USED
                          77230 WORDS ALLOCATED
```

Case 2 Output

sant_doubl2.o

```
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 2.1.7-DP
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                               PROGRAMMED BY:

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



                        RUN ON 20030618 AT 15:12:27
                      RUN ON A     i686 UNDER Lx2.4.20

    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: TIME STEP SCALE = 0.1
   11: MATERIAL,1,ELASTIC,1.
   12: YOUNGS MODULUS 800.
   13: POISSONS RATIO 0.
   14: END
```

```
   15: MATERIAL,2,ELASTIC,1.
   16: YOUNGS MODULUS 8000.
   17: POISSONS RATIO 0.
   18: END
   19: FUNCTION,1
   20:    0.,1.
   21:   10.,1.
   22: END
   23: FUNCTION,2
   24:    0.,0.
   25:   10.,1.
   26: END
   27: FUNCTION,3
   28:   0.  0.7
   29:   5.  0.7
   30:   5.5 0.5
   31:  10.  0.25
   32: END
   33: STEP CONTROL
   34:   100.,10.
   35: END
   36: PLOT TIME
   37:  1.,10.
   38: END
   39: OUTPUT TIME
   40:  10.,10.
   41: END
   42: PLOT NODAL,REACTION,RESIDUAL
   43: NO DISPLACEMENT,X,1
   44: NO DISPLACEMENT,X,8
   45: NO DISPLACEMENT,Y,2
   46: CONTACT SURFACE,6,5,0.5,1.E-3,1.E+40
   47: PRESSURE,3,1,1.
   48: PRESSURE,4,2,-10.
   49: PRESSURE,7,2,-10.
   50: EXIT
1                                       INPUT STREAM IMAGES
  LINE -----------------------------------------------------------------------
   52: TITLE
   53:  SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.5 - E2/E1 = 10
   54: PLANE STRAIN
   55: MAXIMUM ITERATIONS = 3000
   56: RESIDUAL TOLERANCE = 0.50
   57: MAXIMUM TOLERANCE =  1000.0
   58: ELASTIC SOLUTION
   59: PREDICTOR SCALE FACTOR = 3
   60: $ TIME STEP SCALE = 0.70
   61: TIME STEP SCALE = 0.1
   62: MATERIAL,1,ELASTIC,1.
   63: YOUNGS MODULUS 800.
   64: POISSONS RATIO 0.
   65: END
   66: MATERIAL,2,ELASTIC,1.
   67: YOUNGS MODULUS 8000.
   68: POISSONS RATIO 0.
   69: END
   70: FUNCTION,1
   71:    0.,1.
```

```
  10.,1.
END
FUNCTION,2
   0.,0.
  10.,1.
END
FUNCTION,3
  0.  0.7
  5.  0.7
  5.5 0.5
 10.  0.25
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
------------------------------------------------------------------------
```

1

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

     SANTOS QA PROBLEM - DOUBLE BEAM FRICTION - MU = 0.5 - E2/E1 = 10



                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 .....................          3
     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 .......  1.000E-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

```
  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

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

FUNCTION ID .... 3 NUMBER OF POINTS 4

N	S	F(S)
1	0.000E+00	7.000E-01
2	5.000E+00	7.000E-01
3	5.500E+00	5.000E-01
4	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
1	X
8	X
2	Y

C O N T A C T S U R F A C E S

SURFACE NUMBER	SURFACE 1 FLAG	SURFACE 2 FLAG	PENALTY FACTOR	COEFFICIENT OF FRICTION	PENETRATION MULTIPLIER	TENSION RELEASE
1	6	5	0.000E+00	5.000E-01	1.000E-03	INF

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 FLAG	FUNCTION NUMBER	SCALE 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
                      3.000E-02 CPU SECONDS USED
                           5124 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
                      1.000E-02 CPU SECONDS USED
                          70366 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

 STEP      TIME      TIME      DAMPING    APPLIED   RESIDUAL    PERCENT    TOTAL
                     STEP      FACTOR    LOAD NORM  LOAD NORM  IMBALANCE   STEPS
   528  0.000E+00  1.000E-01  4.815E-01  3.089E+00  7.956E-01    25.76      528
  1056  0.000E+00  1.000E-01  7.883E-01  3.089E+00  6.394E-01    20.70     1056
  1584  0.000E+00  1.000E-01  9.090E-01  3.089E+00  3.434E-01    11.12     1584
  2112  0.000E+00  1.000E-01  7.556E-01  3.089E+00  7.714E-01    24.97     2112
  2640  0.000E+00  1.000E-01  6.106E-01  3.089E+00  3.508E-01    11.36     2640
1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030618, AT 15:12:27
      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 =       3000, TOTAL NUMBER OF ITERATIONS =      3000
     FINAL CONVERGENCE TOLERANCE = 3.026E+01
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 5.944E-06
     SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.500E+01
     SUM OF REACTION FORCES IN X-DIRECTION =-2.301E-05
     SUM OF REACTION FORCES IN Y-DIRECTION =-2.409E+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  9.996E-02  6.783E-01  3.091E+00  4.045E-01    13.09     3528
```

1056	1.000E-01	9.996E-02	6.530E-01	3.091E+00	9.218E-01	29.83	4056
1584	1.000E-01	9.996E-02	8.244E-01	3.091E+00	4.039E-01	13.07	4584
2112	1.000E-01	9.996E-02	7.125E-01	3.091E+00	7.720E-01	24.98	5112
2640	1.000E-01	9.996E-02	6.926E-01	3.091E+00	4.135E-01	13.38	5640

**** PLOT TAPE WRITTEN AT TIME = 1.000E-01 STEP NUMBER 1 ****

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
528	2.000E-01	1.000E-01	4.869E-01	3.095E+00	6.601E-01	21.33	6528
1056	2.000E-01	1.000E-01	3.706E-01	3.095E+00	4.205E-01	13.58	7056
1584	2.000E-01	1.000E-01	5.422E-01	3.095E+00	6.284E-01	20.30	7584
2112	2.000E-01	1.000E-01	6.986E-01	3.095E+00	3.976E-01	12.84	8112
2640	2.000E-01	1.000E-01	7.943E-01	3.095E+00	5.770E-01	18.64	8640

**** PLOT TAPE WRITTEN AT TIME = 2.000E-01 STEP NUMBER 2 ****

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
528	3.000E-01	1.000E-01	7.528E-01	3.104E+00	6.147E-01	19.81	9528
1056	3.000E-01	1.000E-01	8.930E-01	3.104E+00	1.029E+00	33.16	10056
1584	3.000E-01	1.000E-01	5.660E-01	3.104E+00	9.387E-01	30.25	10584
2112	3.000E-01	1.000E-01	5.320E-01	3.104E+00	4.133E-01	13.32	11112
2640	3.000E-01	1.000E-01	8.658E-01	3.104E+00	6.997E-01	22.54	11640

**** PLOT TAPE WRITTEN AT TIME = 3.000E-01 STEP NUMBER 3 ****

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
528	4.000E-01	1.000E-01	9.547E-01	3.115E+00	7.350E-01	23.60	12528
1056	4.000E-01	1.000E-01	5.894E-01	3.115E+00	6.188E-01	19.87	13056
1584	4.000E-01	1.000E-01	7.598E-01	3.115E+00	5.648E-01	18.13	13584
2112	4.000E-01	1.000E-01	8.047E-01	3.115E+00	4.151E-01	13.33	14112
2640	4.000E-01	1.000E-01	6.995E-01	3.115E+00	6.552E-01	21.04	14640

**** PLOT TAPE WRITTEN AT TIME = 4.000E-01 STEP NUMBER 4 ****

.
.
.

1 SANTOS, VERSION 2.1.7-DP, RUN ON 20030618, AT 15:12:27
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 =      3000, TOTAL NUMBER OF ITERATIONS =    303000
FINAL CONVERGENCE TOLERANCE = 5.815E+00
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.998E+01
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.514E+01
SUM OF REACTION FORCES IN X-DIRECTION = 1.965E+01
SUM OF REACTION FORCES IN Y-DIRECTION =-2.408E+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
                      7.915E+02 CPU SECONDS USED
                          77230 WORDS ALLOCATED
```

APPENDIX K

Input/Output Data For Test Case 11

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. The binary file sant_temp.th is an input file for Test Case 11 that can be found in LIBSANTOS in CMS.

sant_plastic.fsq

```
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
```

Elastic/Perfectly-Plastic

sant_plastic.i

```
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
```

Elastic/Plastic with Hardening

sant_hard.i

```
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
```

Elastic/Perfectly-Plastic with Temperature

sant_temp.i

```
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 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
  4,1.
  4,2.
```

```
  4,3.
  4,4.
  4,5.
END
NO DISPLACEMENT,X,1
NO DISPLACEMENT,Y,2
EXIT
```

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.

Elastic/Perfectly-Plastic

sant_plastic.o

```
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 2.1.7-DP
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                             PROGRAMMED BY:

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



                        RUN ON 20030612 AT 11:11:30
                      RUN ON A     i686 UNDER Lx2.4.20

    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
   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
1                                   INPUT STREAM IMAGES
  LINE ---------------------------------------------------------------------
   47: TITLE
   48:   SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95
   49: AXISYMMETRIC
   50: MAXIMUM ITERATIONS 20000
   51: RESIDUAL TOLERANCE .01
   52: MATERIAL,1,ELASTIC PLASTIC,1.0
   53: YOUNGS MODULUS 2.07E+11
   54: POISSONS RATIO 0.3
   55: YIELD STRESS 10000.
   56: HARDENING MODULUS 0.
   57: BETA 0.
   58: END
   59: FUNCTION,1
   60:   0.        0.
   61:   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
------------------------------------------------------------------------
```

```
1
                    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

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

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
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 FLAG	FUNCTION NUMBER	SCALE 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
3.000E-02 CPU SECONDS USED
5666 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
1.000E-02 CPU SECONDS USED
60576 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 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:11:30
        SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER      1, TIME = 1.000E+00
     NUMBER OF ITERATIONS =        900, TOTAL NUMBER OF ITERATIONS =       900
     FINAL CONVERGENCE TOLERANCE = 9.611E-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 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:11:30
        SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER      2, TIME = 1.250E+00
     NUMBER OF ITERATIONS =        401, TOTAL NUMBER OF ITERATIONS =      1301
     FINAL CONVERGENCE TOLERANCE = 9.916E-03
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 7.455E+03
     SUM OF EXTERNAL FORCES IN Y-DIRECTION = 4.751E+03
     SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
     SUM OF REACTION FORCES IN Y-DIRECTION = 4.749E+03
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 1.250E+00  STEP NUMBER     2 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:11:30
        SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER      3, TIME = 1.500E+00
     NUMBER OF ITERATIONS =        568, TOTAL NUMBER OF ITERATIONS =      1869
     FINAL CONVERGENCE TOLERANCE = 9.906E-03
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 9.386E+03
     SUM OF EXTERNAL FORCES IN Y-DIRECTION = 5.982E+03
     SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
     SUM OF REACTION FORCES IN Y-DIRECTION = 5.985E+03
```

```
**********************************************************************


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


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:11:30
         SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      4, TIME = 1.750E+00
NUMBER OF ITERATIONS =        534, TOTAL NUMBER OF ITERATIONS =       2403
FINAL CONVERGENCE TOLERANCE = 9.556E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.051E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 6.696E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 6.693E+03
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.750E+00   STEP NUMBER      4 ****
```

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
1302	2.000E+00	2.500E-01	9.986E-01	3.405E+03	2.574E+00	0.08	3705
2604	2.000E+00	2.500E-01	9.991E-01	3.405E+03	2.535E+00	0.07	5007
3906	2.000E+00	2.500E-01	1.000E+00	3.405E+03	1.104E+00	0.03	6309
5208	2.000E+00	2.500E-01	1.000E+00	3.405E+03	9.098E-01	0.03	7611
6510	2.000E+00	2.500E-01	1.000E+00	3.405E+03	8.857E-01	0.03	8913
7812	2.000E+00	2.500E-01	1.000E+00	3.405E+03	5.340E-01	0.02	10215
9114	2.000E+00	2.500E-01	1.000E+00	3.405E+03	4.475E-01	0.01	11517

```
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:11:30
         SANTOS QA PROBLEM - HOLLOW SPHERE - 9/18/95

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      5, TIME = 2.000E+00
NUMBER OF ITERATIONS =       9981, TOTAL NUMBER OF ITERATIONS =      12384
FINAL CONVERGENCE TOLERANCE = 9.333E-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
                         6.085E+01 CPU SECONDS USED
                            79924 WORDS ALLOCATED
```

Elastic/Plastic with Hardening

sant_hard.o

```
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 2.1.7-DP
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                                PROGRAMMED BY:

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



                        RUN ON 20030612 AT 11:12:31
                      RUN ON A     i686 UNDER Lx2.4.20

    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
   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
1                                    INPUT STREAM IMAGES
  LINE ---------------------------------------------------------------------
   47: TITLE
   48:   SANTOS QA PROBLEM - HOLLOW SPHERE - 10/26/94 - HARDENING M = 0.1
   49: AXISYMMETRIC
   50: MAXIMUM ITERATIONS 20000
   51: RESIDUAL TOLERANCE .01
   52: MATERIAL,1,ELASTIC PLASTIC,1.0
   53: YOUNGS MODULUS 2.07E+11
   54: POISSONS RATIO 0.3
   55: YIELD STRESS 10000.
   56: HARDENING MODULUS 2.07E+10
   57: BETA 0.
   58: END
   59: FUNCTION,1
   60:   0.        0.
   61:   1.     5833.
   62:   1.25   9756.5
   63:   1.5   13003.2
   64:   1.75  15798.4
   65:   2.    18278.8
   66: END
   67: STEP CONTROL
   68:   1,1.
   69:   1,1.25
   70:   1,1.50
   71:   1,1.75
   72:   1,2.0
   73: END
   74: PLOT TIME
   75:  1,1.
   76:  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
----------------------------------------------------------------------
```

1

```
                 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

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	9.756E+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
                          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
                            3.000E-02 CPU SECONDS USED
                                 5666 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
                            0.000E+00 CPU SECONDS USED
                                60576 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 ****

1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:12:31
        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 =        640, TOTAL NUMBER OF ITERATIONS =       640
FINAL CONVERGENCE TOLERANCE = 9.987E-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 = 2.918E+03
**********************************************************************


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


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:12:31
        SANTOS QA PROBLEM - HOLLOW SPHERE - 10/26/94 - HARDENING M = 0.1

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      2, TIME = 1.250E+00
NUMBER OF ITERATIONS =        499, TOTAL NUMBER OF ITERATIONS =      1139
FINAL CONVERGENCE TOLERANCE = 9.886E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION = 7.655E+03
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 4.878E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 4.876E+03
**********************************************************************


**** PLOT TAPE WRITTEN AT TIME = 1.250E+00   STEP NUMBER      2 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:12:31
        SANTOS QA PROBLEM - HOLLOW SPHERE - 10/26/94 - HARDENING M = 0.1

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      3, TIME = 1.500E+00
NUMBER OF ITERATIONS =        324, TOTAL NUMBER OF ITERATIONS =      1463
FINAL CONVERGENCE TOLERANCE = 9.830E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.020E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 6.502E+03
SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
SUM OF REACTION FORCES IN Y-DIRECTION = 6.499E+03
**********************************************************************


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


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:12:31
        SANTOS QA PROBLEM - HOLLOW SPHERE - 10/26/94 - HARDENING M = 0.1

**********************************************************************
SUMMARY OF DATA AT STEP NUMBER      4, TIME = 1.750E+00
NUMBER OF ITERATIONS =        385, TOTAL NUMBER OF ITERATIONS =      1848
FINAL CONVERGENCE TOLERANCE = 9.661E-03
SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.240E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION = 7.899E+03
```

```
     SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
     SUM OF REACTION FORCES IN Y-DIRECTION = 7.897E+03
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 1.750E+00  STEP NUMBER     4 ****


1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:12:31
       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 =        571, TOTAL NUMBER OF ITERATIONS =      2419
     FINAL CONVERGENCE TOLERANCE = 9.939E-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 = 9.145E+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
                           1.204E+01 CPU SECONDS USED
                               79924 WORDS ALLOCATED
```

Elastic/Perfectly-Plastic with Temperature

sant_temp.o

```
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 2.1.7-DP
                    COPYRIGHT 1995, SANDIA CORPORATION
```

```
                              PROGRAMMED BY:

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



                       RUN ON 20030612 AT 11:12:43
                     RUN ON A     i686 UNDER Lx2.4.20

    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
1                                   INPUT STREAM IMAGES
  LINE ---------------------------------------------------------------------
   44: 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 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
  4,1.
  4,2.
  4,3.
  4,4.
  4,5.
END
NO DISPLACEMENT,X,1
NO DISPLACEMENT,Y,2
EXIT
------------------------------------------------------------------------
```

1

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

```
          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
                  1                X
                  2                Y




              E N D   O F   D A T A   I N P U T   P H A S E
                    2.000E-02 CPU SECONDS USED
                         5644 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
                    1.000E-02 CPU SECONDS USED
                        60554 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 ****

1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:12:43
       SANTOS QA PROBLEM - HOLLOW SPHERE - 12/14/94 - TEMPERATURE PROBLEM

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER     4, TIME = 1.000E+00
     NUMBER OF ITERATIONS =        48, TOTAL NUMBER OF ITERATIONS =       793
     FINAL CONVERGENCE TOLERANCE = 4.621E-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 =-3.843E+01
     **********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     4 ****

1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:12:43
       SANTOS QA PROBLEM - HOLLOW SPHERE - 12/14/94 - TEMPERATURE PROBLEM

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER     8, TIME = 2.000E+00
     NUMBER OF ITERATIONS =        96, TOTAL NUMBER OF ITERATIONS =      1235
     FINAL CONVERGENCE TOLERANCE = 4.923E-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 = 5.319E+01
     **********************************************************************
```

```
     **** PLOT TAPE WRITTEN AT TIME = 2.000E+00   STEP NUMBER      8 ****


1       SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:12:43
         SANTOS QA PROBLEM - HOLLOW SPHERE - 12/14/94 - TEMPERATURE PROBLEM

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER     12, TIME = 3.000E+00
     NUMBER OF ITERATIONS =         523, TOTAL NUMBER OF ITERATIONS =       1975
     FINAL CONVERGENCE TOLERANCE = 4.848E-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 = 5.199E+01
     **********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 3.000E+00   STEP NUMBER     12 ****


1       SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:12:43
         SANTOS QA PROBLEM - HOLLOW SPHERE - 12/14/94 - TEMPERATURE PROBLEM

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER     16, TIME = 4.000E+00
     NUMBER OF ITERATIONS =         464, TOTAL NUMBER OF ITERATIONS =       3839
     FINAL CONVERGENCE TOLERANCE = 4.617E-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 =-2.340E+01
     **********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 4.000E+00   STEP NUMBER     16 ****


1       SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:12:43
         SANTOS QA PROBLEM - HOLLOW SPHERE - 12/14/94 - TEMPERATURE PROBLEM

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER     20, TIME = 5.000E+00
     NUMBER OF ITERATIONS =          32, TOTAL NUMBER OF ITERATIONS =       4227
     FINAL CONVERGENCE TOLERANCE = 4.983E-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 =-5.381E+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
          2.204E+01 CPU SECONDS USED
              87408 WORDS ALLOCATED
```

APPENDIX L

Input/Output Data For Test Case 12

The following two sections present the input data and the formatted output for the restart option verification test.

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. The binary file sant_temp.th is an input file for Test Case 11 that can be found in LIBSANTOS in CMS.

sant_plastic.fsq

```
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
```

Restart Write

sant_rsout.i

```
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
```

Restart Read

sant_rsin.i

```
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
```

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.

Restart Write

sant_rsout.o

```
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



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                         ENGINEERING SCIENCES CENTER
                        SANDIA NATIONAL LABORATORIES
                        ALBUQUERQUE, NEW MEXICO 87185



                         RUN ON 20030612 AT 11:14:56
                       RUN ON A      i686 UNDER Lx2.4.20

    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
   35: NO DISPLACEMENT,X,1
   36: NO DISPLACEMENT,Y,2
   37: EXIT
1                                   INPUT STREAM IMAGES
  LINE ---------------------------------------------------------------------
   39: TITLE
   40:   SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART WRITE
   41: AXISYMMETRIC
   42: MAXIMUM ITERATIONS 20000
   43: RESIDUAL TOLERANCE .5
   44: MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
   45: YOUNGS MODULUS 1.E+7
   46: POISSONS RATIO 0.3
   47: YIELD STRESS 10000.
   48: HARDENING MODULUS 0.
   49: BETA 0.
   50: END
   51: THERMAL STRESS EXTERNAL 1000.
   52: PLOT ELEMENT STRESS TEMPERATURE
   53: FUNCTION 1  $ THERMAL STRAIN FOR ALPHA = 1.E-5
   54:      0.     0.
   55:   1000.    1.E-2
   56: END
   57: STEP CONTROL
   58:   4,1.
   59:   4,2,
   60:   4,3.
   61: END
   62: PLOT TIME
   63:   1,1.
   64:   4,2.
   65:   4,3.
   66: END
   67: OUTPUT TIME
   68:   4,1.
```

```
  4,2.
  4,3.
END
WRITE RESTART 1
NO DISPLACEMENT,X,1
NO DISPLACEMENT,Y,2
EXIT
-----------------------------------------------------------------------
```

1

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
```

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

```
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

```
                  E N D   O F   D A T A   I N P U T   P H A S E
                         2.000E-02 CPU SECONDS USED
                              5614 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
                         1.000E-02 CPU SECONDS USED
                             60524 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 ****
1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:14:56
       SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART WRITE

 ***********************************************************************
```

```
SUMMARY OF DATA AT STEP NUMBER     4, TIME = 1.000E+00
NUMBER OF ITERATIONS =         48, TOTAL NUMBER OF ITERATIONS =       793
FINAL CONVERGENCE TOLERANCE = 4.621E-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 =-3.843E+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 ****
1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:14:56
       SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART WRITE

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER     8, TIME = 2.000E+00
NUMBER OF ITERATIONS =         96, TOTAL NUMBER OF ITERATIONS =      1235
FINAL CONVERGENCE TOLERANCE = 4.923E-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 = 5.319E+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 ****
1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:14:56
       SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART WRITE

*********************************************************************
SUMMARY OF DATA AT STEP NUMBER    12, TIME = 3.000E+00
NUMBER OF ITERATIONS =        523, TOTAL NUMBER OF ITERATIONS =      1975
FINAL CONVERGENCE TOLERANCE = 4.848E-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 = 5.199E+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
                        1.030E+01 CPU SECONDS USED
                            87378 WORDS ALLOCATED
```

Restart Read

sant_rsin.o

```
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


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                       ENGINEERING SCIENCES CENTER
                      SANDIA NATIONAL LABORATORIES
                      ALBUQUERQUE, NEW MEXICO 87185


                      RUN ON 20030612 AT 11:15:06
                    RUN ON A     i686 UNDER Lx2.4.20

    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
1                                    INPUT STREAM IMAGES
  LINE -----------------------------------------------------------------------------
   39: TITLE
   40:   SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART READ
   41: AXISYMMETRIC
   42: MAXIMUM ITERATIONS 20000
   43: RESIDUAL TOLERANCE .5
   44: MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
   45: YOUNGS MODULUS 1.E+7
   46: POISSONS RATIO 0.3
   47: YIELD STRESS 10000.
   48: HARDENING MODULUS 0.
   49: BETA 0.
   50: END
   51: THERMAL STRESS EXTERNAL 1000.
   52: PLOT ELEMENT STRESS TEMPERATURE
   53: FUNCTION 1  $ THERMAL STRAIN FOR ALPHA = 1.E-5
   54:      0.     0.
   55:   1000.     1.E-2
   56: END
   57: STEP CONTROL
   58:   4,3.
   59:   4,4.
   60:   4,5.
   61: END
   62: 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
----------------------------------------------------------------------
```

1

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

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

```
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



                 E N D   O F   D A T A   I N P U T   P H A S E
                       2.000E-02 CPU SECONDS USED
                            5614 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
                       1.000E-02 CPU SECONDS USED
                           60524 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 ****
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:15:06
        SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART READ

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER      16, TIME = 4.000E+00
     NUMBER OF ITERATIONS =       464, TOTAL NUMBER OF ITERATIONS =       3839
     FINAL CONVERGENCE TOLERANCE = 4.617E-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 =-2.340E+01
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 4.000E+00   STEP NUMBER     16 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:15:06
        SANTOS QA PROBLEM - HOLLOW SPHERE - TEMPERATURE PROBLEM - RESTART READ

     *********************************************************************
```

```
SUMMARY OF DATA AT STEP NUMBER    20, TIME = 5.000E+00
NUMBER OF ITERATIONS =       32, TOTAL NUMBER OF ITERATIONS =      4227
FINAL CONVERGENCE TOLERANCE = 4.983E-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 =-5.381E+01
*********************************************************************


**** 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
                      1.161E+01 CPU SECONDS USED
                          87378 WORDS ALLOCATED
```

APPENDIX M

Input/Output Data For Test Case 13

The following two sections present the input data and the formatted output for the sloping roller option verification test.

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. The binary file sant_qtemp.th is an input file for Test Case 11 that can be found in LIBSANTOS in CMS.

sant_qtempf.fsq

```
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
```

sant_qtempf.i

```
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
```

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.

sant_qtempf.o

```
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



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                                 PROGRAMMED BY:

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

```
                                RUN ON 20030612 AT 11:15:26
                              RUN ON A     i686 UNDER Lx2.4.20

    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
1                                   INPUT STREAM IMAGES
  LINE -----------------------------------------------------------------------
   44: TITLE
   45:   SANTOS QA PROBLEM - HOLLOW SPHERE - 11/1/94 - QUADRANT TEMPERATURE PROBLEM
   46: AXISYMMETRIC
   47: MAXIMUM ITERATIONS 20000
   48: RESIDUAL TOLERANCE .5
   49: MATERIAL,1,ELASTIC PLASTIC,1.0,1,1.
   50: 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
-----------------------------------------------------------------------
```

```
1
                    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

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
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 FLAG	DIRECTION	FUNCTION ID	SCALE FACTOR	A0	B0
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
3.000E-02 CPU SECONDS USED
2570 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
0.000E+00 CPU SECONDS USED
32688 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 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:15:26
        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 =       519, TOTAL NUMBER OF ITERATIONS =       519
     FINAL CONVERGENCE TOLERANCE = 4.338E-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 =-1.969E+01
     SUM OF REACTION FORCES IN Y-DIRECTION =-4.142E+01
     **********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 2.500E-01   STEP NUMBER     1 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:15:26
        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 =        50, TOTAL NUMBER OF ITERATIONS =       569
     FINAL CONVERGENCE TOLERANCE = 4.991E-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 =-2.185E+00
     SUM OF REACTION FORCES IN Y-DIRECTION =-4.615E+00
     **********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 5.000E-01   STEP NUMBER     2 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:15:26
        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 =        39, TOTAL NUMBER OF ITERATIONS =       608
     FINAL CONVERGENCE TOLERANCE = 4.382E-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 = 7.926E+00
     SUM OF REACTION FORCES IN Y-DIRECTION = 1.664E+01
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 7.500E-01  STEP NUMBER     3 ****


1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:15:26
       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 =         52, TOTAL NUMBER OF ITERATIONS =       660
     FINAL CONVERGENCE TOLERANCE = 4.860E-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 = 4.793E+00
     SUM OF REACTION FORCES IN Y-DIRECTION = 1.004E+01
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 1.000E+00  STEP NUMBER     4 ****


1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:15:26
       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 =        187, TOTAL NUMBER OF ITERATIONS =      1095
     FINAL CONVERGENCE TOLERANCE = 4.835E-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 =-2.810E+01
     SUM OF REACTION FORCES IN Y-DIRECTION =-5.918E+01
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 2.000E+00  STEP NUMBER     8 ****


1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:15:26
       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 =         37, TOTAL NUMBER OF ITERATIONS =      1430
     FINAL CONVERGENCE TOLERANCE = 3.727E-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 =-1.906E+01
     SUM OF REACTION FORCES IN Y-DIRECTION =-4.018E+01
     *********************************************************************
```

```
     **** PLOT TAPE WRITTEN AT TIME = 3.000E+00   STEP NUMBER     12 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:15:26
        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 =        465, TOTAL NUMBER OF ITERATIONS =      2459
     FINAL CONVERGENCE TOLERANCE = 4.648E-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 =-8.319E+00
     SUM OF REACTION FORCES IN Y-DIRECTION =-1.761E+01
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 4.000E+00   STEP NUMBER     16 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:15:26
        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 =         11, TOTAL NUMBER OF ITERATIONS =      2549
     FINAL CONVERGENCE TOLERANCE = 4.806E-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 = 4.511E+01
     SUM OF REACTION FORCES IN Y-DIRECTION = 9.473E+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
                           5.160E+00 CPU SECONDS USED
                               44062 WORDS ALLOCATED
```

APPENDIX N

Input/Output Data For Test Case 14

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.

sant_crelax.fsq

```
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
```

sant_crelax.i

```
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
```

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.

sant_crelax.o

```
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 2.1.7-DP
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                               PROGRAMMED BY:

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



                        RUN ON 20030612 AT 11:17:03
                      RUN ON A     i686 UNDER Lx2.4.20

    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
1                                    INPUT STREAM IMAGES
  LINE ---------------------------------------------------------------------
    34: TITLE
    35:   SANTOS QA PROBLEM - CREEP RELAXATION PROBLEM - AXISYMMETRIC - 11/9/94
    36: AXISYMMETRIC
    37: ELASTIC SOLUTION
    38: MAXIMUM ITERATIONS 40000
    39: MATERIAL,1,POWER LAW CREEP,1.
    40: TWO MU 24.75E+9
    41: BULK MODULUS 8.25E+9
    42: CREEP CONSTANT 5.79E-36
    43: STRESS EXPONENT 4.9
    44: THERMAL CONSTANT 20.13
    45: END
    46: FUNCTION 1  $ PRESCRIBED DISPLACEMENT FUNCTION
    47:    0.        -0.001
    48:    2.592E+6 -0.001
    49: END
    50: STEP CONTROL
    51:    1  1.
    52:   90  2.592E+6
    53: END
    54: OUTPUT TIME
    55:    0  1.
    56:    0  2.592E+6
    57: END
    58: PLOT TIME
    59:    1  1.
    60:    1  2.592E+6
    61: END
```

```
62: PRESCRIBED DISPLACEMENT Y 3 1 1.0
63: NO DISPLACEMENT Y  2
64: PLOT ELEMENT STRESS VONMISES
65: EXIT
    ------------------------------------------------------------------------
1
                    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


       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
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 FLAG	DIRECTION	FUNCTION ID	SCALE FACTOR	A0	B0
3	Y	1	1.000E+00	-	-

```
                 E N D   O F   D A T A   I N P U T   P H A S E
                          2.000E-02 CPU SECONDS USED
                                152 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
                          0.000E+00 CPU SECONDS USED
                              13082 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
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:17:03
        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 = 3.975E-06
    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  2.881E+04  8.012E-01  7.679E+06  2.784E+06      36.25        14
    16  2.880E+04  2.881E+04  8.250E-01  7.795E+06  7.954E+05      10.20        22

    **** 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  2.881E+04  8.552E-01  6.820E+06  4.323E+06     63.39         38
   16  5.760E+04  2.881E+04  8.002E-01  6.822E+06  1.702E+06     24.94         46
   24  5.760E+04  2.881E+04  7.723E-01  6.821E+06  4.579E+05      6.71         54
   32  5.760E+04  2.881E+04  8.520E-01  6.821E+06  1.538E+05      2.25         62

   **** 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  2.881E+04  8.567E-01  6.311E+06  8.249E+05     13.07         74
   16  8.640E+04  2.881E+04  8.002E-01  6.311E+06  3.243E+05      5.14         82
   24  8.640E+04  2.881E+04  5.180E-01  6.311E+06  1.050E+05      1.66         90

   **** PLOT TAPE WRITTEN AT TIME = 8.640E+04  STEP NUMBER      4 ****
.
.
.
1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:17:03
       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 =       393
   FINAL CONVERGENCE TOLERANCE = 9.969E-02
   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

                     E N D  O F  S O L U T I O N  P H A S E
                        8.000E-02 CPU SECONDS USED
                          13196 WORDS ALLOCATED
```

APPENDIX O

Input/Output Data For Test Case 15

The following two sections present the input data and the formatted output for the linear viscoelastic constitutive model implementation verification test.

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.

sant_rocket.fsq

```
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  0MP
REGION  1   1   -1  -2  -7  -6
REGION  2   2   -3  -4  -5  -7
END
```

sant_rocket.i

```
TITLE
 SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY
AXISYMMETRIC
ELASTIC SOLUTION
RESIDUAL TOLERANCE 0.5
MAXIMUM ITERATIONS  10000
MAXIMUM TOLERANCE 0.5
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.
TEMP0 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
```

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.

sant_rocket.o

```
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 2.1.7-DP
                      COPYRIGHT 1995, SANDIA CORPORATION

                               PROGRAMMED BY:

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

                        RUN ON 20030612 AT 11:17:47
                      RUN ON A     i686 UNDER Lx2.4.20

  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: TEMP0 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
 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
1                                    INPUT STREAM IMAGES
 LINE ------------------------------------------------------------------------
  54: TITLE
  55:  SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY
  56: AXISYMMETRIC
  57: ELASTIC SOLUTION
  58: RESIDUAL TOLERANCE 0.5
  59: MAXIMUM ITERATIONS  5000
  60: MAXIMUM TOLERANCE 0.5
  61: INTERMEDIATE PRINT 10
  62: MATERIAL,1,LINEAR VISCOELASTIC,15.6   $ ROCKET PROPELLANT
  63: BULK 1.E+05
  64: BULK INF 1.E+05
  65: BULK RELAX 1.
  66: SHEAR INF 0.
  67: SHEAR ONE 3.75E+04
  68: SHEAR TWO 0.
  69: SHEAR THREE 0.
  70: RELAX ONE 1.
  71: RELAX TWO 1.
  72: RELAX THREE 1.
  73: C1 7.6
  74: C2 277.
  75: TEMPO 373.
  76: END
  77: MATERIAL,2,ELASTIC PLASTIC,98.   $ STEEL OUTER CASING
  78: YOUNGS MODULUS 3.E+07
  79: POISSONS RATIO 0.3015
  80: YIELD STRESS 1.E+06
  81: HARDENING MODULUS 1.E+06
  82: BETA 1
  83: END
  84: FUNCTION 1   $ PRESSURE HISTORY
  85:   0.,1000.
  86:  10.,1000.
  87: END
  88: STEP CONTROL
  89:   10,1.
  90:    9,10.
  91: END
  92: 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
------------------------------------------------------------------------
```

```
1
                    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

          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
       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
                      3.000E-02 CPU SECONDS USED
                            662 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
                      0.000E+00 CPU SECONDS USED
                          16124 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         EPSXX         ITER
                                EPSYY         RMAG
                                EPSZZ
                                EPSXY
                                BLKDECAY
```

DECAYX1
DECAYY1
DECAYZ1
DECAYX2
DECAYY2
DECAYZ2

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL 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	9.547E-01	8.891E+01	5.040E+01	56.69	120
130	0.000E+00	9.952E-02	9.992E-01	8.891E+01	5.001E+01	56.24	130
140	0.000E+00	9.951E-02	1.000E+00	8.892E+01	4.927E+01	55.41	140
150	0.000E+00	9.952E-02	1.000E+00	8.892E+01	4.789E+01	53.85	150
160	0.000E+00	9.951E-02	1.000E+00	8.892E+01	4.594E+01	51.67	160
170	0.000E+00	9.951E-02	1.000E+00	8.893E+01	4.390E+01	49.36	170
180	0.000E+00	9.951E-02	1.000E+00	8.893E+01	4.147E+01	46.63	180
190	0.000E+00	9.951E-02	1.000E+00	8.894E+01	3.831E+01	43.08	190
200	0.000E+00	9.951E-02	1.000E+00	8.895E+01	3.509E+01	39.45	200
210	0.000E+00	9.950E-02	1.000E+00	8.895E+01	3.176E+01	35.71	210
220	0.000E+00	9.951E-02	9.999E-01	8.896E+01	2.780E+01	31.25	220
230	0.000E+00	9.950E-02	1.000E+00	8.897E+01	2.368E+01	26.61	230
240	0.000E+00	9.950E-02	1.000E+00	8.898E+01	1.974E+01	22.18	240
250	0.000E+00	9.949E-02	1.000E+00	8.899E+01	1.542E+01	17.33	250
260	0.000E+00	9.950E-02	9.995E-01	8.900E+01	1.071E+01	12.04	260
270	0.000E+00	9.949E-02	1.000E+00	8.901E+01	6.405E+00	7.20	270
280	0.000E+00	9.949E-02	1.000E+00	8.902E+01	2.947E+00	3.31	280
290	0.000E+00	9.948E-02	1.000E+00	8.903E+01	4.274E+00	4.80	290
300	0.000E+00	9.948E-02	9.968E-01	8.904E+01	8.651E+00	9.72	300
310	0.000E+00	9.948E-02	9.923E-01	8.905E+01	1.272E+01	14.28	310
320	0.000E+00	9.948E-02	1.000E+00	8.905E+01	1.709E+01	19.19	320
330	0.000E+00	9.948E-02	1.000E+00	8.906E+01	2.153E+01	24.17	330
340	0.000E+00	9.947E-02	1.000E+00	8.907E+01	2.523E+01	28.32	340
350	0.000E+00	9.947E-02	1.000E+00	8.908E+01	2.872E+01	32.25	350
360	0.000E+00	9.947E-02	1.000E+00	8.909E+01	3.233E+01	36.29	360
370	0.000E+00	9.947E-02	1.000E+00	8.909E+01	3.535E+01	39.67	370
380	0.000E+00	9.946E-02	9.999E-01	8.910E+01	3.778E+01	42.40	380
390	0.000E+00	9.947E-02	9.997E-01	8.910E+01	4.014E+01	45.05	390
400	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.227E+01	47.43	400
410	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.358E+01	48.91	410
420	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.458E+01	50.03	420
430	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.553E+01	51.09	430
440	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.578E+01	51.38	440
450	0.000E+00	9.946E-02	5.406E-01	8.911E+01	4.565E+01	51.23	450
460	0.000E+00	9.946E-02	9.972E-01	8.911E+01	4.548E+01	51.04	460
470	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.494E+01	50.43	470
480	0.000E+00	9.946E-02	9.990E-01	8.911E+01	4.401E+01	49.38	480

490	0.000E+00	9.946E-02	1.000E+00	8.911E+01	4.264E+01	47.86	490
500	0.000E+00	9.946E-02	9.987E-01	8.910E+01	4.090E+01	45.90	500
510	0.000E+00	9.946E-02	9.911E-01	8.910E+01	3.882E+01	43.56	510
520	0.000E+00	9.947E-02	1.000E+00	8.909E+01	3.640E+01	40.86	520
530	0.000E+00	9.947E-02	1.000E+00	8.909E+01	3.368E+01	37.80	530
540	0.000E+00	9.947E-02	1.000E+00	8.908E+01	3.073E+01	34.50	540
550	0.000E+00	9.947E-02	1.000E+00	8.908E+01	2.755E+01	30.93	550
560	0.000E+00	9.947E-02	9.999E-01	8.907E+01	2.416E+01	27.12	560
570	0.000E+00	9.947E-02	9.999E-01	8.906E+01	2.063E+01	23.17	570
580	0.000E+00	9.948E-02	9.999E-01	8.905E+01	1.700E+01	19.09	580
590	0.000E+00	9.948E-02	9.996E-01	8.905E+01	1.327E+01	14.91	590
600	0.000E+00	9.948E-02	9.993E-01	8.904E+01	9.559E+00	10.74	600
610	0.000E+00	9.948E-02	9.994E-01	8.903E+01	5.874E+00	6.60	610
620	0.000E+00	9.949E-02	9.987E-01	8.902E+01	2.289E+00	2.57	620

```
1       SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:17:47
        SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY

      *********************************************************************
      SUMMARY OF DATA AT STEP NUMBER      0, TIME = 0.000E+00
      NUMBER OF ITERATIONS =        626, TOTAL NUMBER OF ITERATIONS =       626
      FINAL CONVERGENCE TOLERANCE = 3.514E-01
      SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.259E+02
      SUM OF EXTERNAL FORCES IN Y-DIRECTION = 5.591E-14
      SUM OF REACTION FORCES IN X-DIRECTION = 0.000E+00
      SUM OF REACTION FORCES IN Y-DIRECTION = 5.980E-14
      *********************************************************************


      **** PLOT TAPE WRITTEN AT TIME = 0.000E+00  STEP NUMBER     0 ****
```

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
10	1.000E-01	1.000E-01	9.148E-01	8.957E+01	1.081E+02	120.69	636
20	1.000E-01	1.000E-01	7.872E-01	8.949E+01	5.979E+01	66.81	646
30	1.000E-01	1.000E-01	9.998E-01	8.940E+01	7.418E+01	82.97	656
40	1.000E-01	1.000E-01	1.000E+00	8.924E+01	6.636E+01	74.36	666
50	1.000E-01	1.000E-01	1.000E+00	8.906E+01	8.584E+01	96.39	676
60	1.000E-01	1.000E-01	1.000E+00	8.891E+01	1.100E+02	123.77	686
70	1.000E-01	1.000E-01	9.603E-01	8.883E+01	9.567E+01	107.69	696
80	1.000E-01	1.000E-01	9.588E-01	8.885E+01	8.825E+01	99.33	706
90	1.000E-01	1.000E-01	9.326E-01	8.891E+01	7.907E+01	88.93	716
100	1.000E-01	1.000E-01	9.228E-01	8.899E+01	6.763E+01	76.00	726
110	1.000E-01	1.000E-01	9.355E-01	8.906E+01	5.865E+01	65.86	736
120	1.000E-01	1.000E-01	9.360E-01	8.911E+01	4.996E+01	56.07	746
130	1.000E-01	1.000E-01	9.434E-01	8.915E+01	4.370E+01	49.02	756
140	1.000E-01	1.000E-01	9.706E-01	8.917E+01	4.037E+01	45.27	766
150	1.000E-01	1.000E-01	9.888E-01	8.917E+01	3.908E+01	43.83	776
160	1.000E-01	1.000E-01	9.998E-01	8.917E+01	3.823E+01	42.87	786
170	1.000E-01	1.000E-01	9.820E-01	8.916E+01	3.837E+01	43.04	796
180	1.000E-01	1.000E-01	9.678E-01	8.914E+01	3.874E+01	43.46	806
190	1.000E-01	1.000E-01	9.736E-01	8.913E+01	3.890E+01	43.64	816
200	1.000E-01	1.000E-01	9.971E-01	8.912E+01	3.855E+01	43.26	826
210	1.000E-01	1.000E-01	9.998E-01	8.911E+01	3.744E+01	42.01	836
220	1.000E-01	1.000E-01	9.000E-01	8.911E+01	3.533E+01	39.65	846
230	1.000E-01	1.000E-01	9.288E-01	8.911E+01	3.387E+01	38.00	856

240	1.000E-01	1.000E-01	9.438E-01	8.912E+01	3.283E+01	36.84	866
250	1.000E-01	1.000E-01	9.733E-01	8.912E+01	3.181E+01	35.69	876
260	1.000E-01	1.000E-01	9.255E-01	8.912E+01	3.105E+01	34.84	886
270	1.000E-01	1.000E-01	9.717E-01	8.912E+01	3.055E+01	34.28	896
280	1.000E-01	1.000E-01	1.000E+00	8.912E+01	3.010E+01	33.78	906
290	1.000E-01	1.000E-01	1.000E+00	8.912E+01	2.941E+01	33.00	916
300	1.000E-01	1.000E-01	9.967E-01	8.912E+01	2.846E+01	31.93	926
310	1.000E-01	1.000E-01	9.828E-01	8.911E+01	2.739E+01	30.73	936
320	1.000E-01	1.000E-01	9.752E-01	8.911E+01	2.628E+01	29.49	946
330	1.000E-01	1.000E-01	9.781E-01	8.911E+01	2.522E+01	28.31	956
340	1.000E-01	1.000E-01	9.789E-01	8.911E+01	2.415E+01	27.11	966
350	1.000E-01	1.000E-01	9.790E-01	8.910E+01	2.307E+01	25.89	976
360	1.000E-01	1.000E-01	9.866E-01	8.910E+01	2.201E+01	24.70	986
370	1.000E-01	1.000E-01	9.856E-01	8.910E+01	2.088E+01	23.43	996
380	1.000E-01	1.000E-01	9.868E-01	8.910E+01	1.968E+01	22.09	1006
390	1.000E-01	1.000E-01	9.920E-01	8.909E+01	1.847E+01	20.74	1016
400	1.000E-01	1.000E-01	9.837E-01	8.909E+01	1.723E+01	19.33	1026
410	1.000E-01	1.000E-01	9.821E-01	8.909E+01	1.602E+01	17.98	1036
420	1.000E-01	1.000E-01	9.806E-01	8.909E+01	1.490E+01	16.72	1046
430	1.000E-01	1.000E-01	9.774E-01	8.908E+01	1.386E+01	15.55	1056
440	1.000E-01	1.000E-01	9.787E-01	8.908E+01	1.291E+01	14.49	1066
450	1.000E-01	1.000E-01	9.785E-01	8.908E+01	1.206E+01	13.54	1076
460	1.000E-01	1.000E-01	9.779E-01	8.908E+01	1.126E+01	12.64	1086
470	1.000E-01	1.000E-01	9.832E-01	8.908E+01	1.052E+01	11.81	1096
480	1.000E-01	1.000E-01	9.829E-01	8.908E+01	9.819E+00	11.02	1106
490	1.000E-01	1.000E-01	9.835E-01	8.907E+01	9.141E+00	10.26	1116
500	1.000E-01	1.000E-01	9.864E-01	8.907E+01	8.478E+00	9.52	1126
510	1.000E-01	1.000E-01	9.837E-01	8.907E+01	7.830E+00	8.79	1136
520	1.000E-01	1.000E-01	9.832E-01	8.907E+01	7.216E+00	8.10	1146
530	1.000E-01	1.000E-01	9.826E-01	8.907E+01	6.642E+00	7.46	1156
540	1.000E-01	1.000E-01	9.788E-01	8.907E+01	6.106E+00	6.85	1166
550	1.000E-01	1.000E-01	9.792E-01	8.907E+01	5.627E+00	6.32	1176
560	1.000E-01	1.000E-01	9.784E-01	8.907E+01	5.198E+00	5.84	1186
570	1.000E-01	1.000E-01	9.776E-01	8.907E+01	4.807E+00	5.40	1196
580	1.000E-01	1.000E-01	9.803E-01	8.906E+01	4.454E+00	5.00	1206
590	1.000E-01	1.000E-01	9.812E-01	8.906E+01	4.129E+00	4.64	1216
600	1.000E-01	1.000E-01	9.830E-01	8.906E+01	3.822E+00	4.29	1226
610	1.000E-01	1.000E-01	9.861E-01	8.906E+01	3.532E+00	3.97	1236
620	1.000E-01	1.000E-01	9.834E-01	8.906E+01	3.250E+00	3.65	1246
630	1.000E-01	1.000E-01	9.833E-01	8.906E+01	2.983E+00	3.35	1256
640	1.000E-01	1.000E-01	9.828E-01	8.906E+01	2.733E+00	3.07	1266
650	1.000E-01	1.000E-01	9.798E-01	8.906E+01	2.501E+00	2.81	1276
660	1.000E-01	1.000E-01	9.798E-01	8.906E+01	2.291E+00	2.57	1286
670	1.000E-01	1.000E-01	9.792E-01	8.906E+01	2.103E+00	2.36	1296
680	1.000E-01	1.000E-01	9.779E-01	8.906E+01	1.933E+00	2.17	1306
690	1.000E-01	1.000E-01	9.795E-01	8.906E+01	1.782E+00	2.00	1316
700	1.000E-01	1.000E-01	9.799E-01	8.906E+01	1.644E+00	1.85	1326
710	1.000E-01	1.000E-01	9.810E-01	8.906E+01	1.516E+00	1.70	1336
720	1.000E-01	1.000E-01	9.840E-01	8.906E+01	1.399E+00	1.57	1346
730	1.000E-01	1.000E-01	9.837E-01	8.906E+01	1.286E+00	1.44	1356
740	1.000E-01	1.000E-01	9.835E-01	8.906E+01	1.179E+00	1.32	1366
750	1.000E-01	1.000E-01	9.838E-01	8.906E+01	1.079E+00	1.21	1376
760	1.000E-01	1.000E-01	9.808E-01	8.906E+01	9.857E-01	1.11	1386
770	1.000E-01	1.000E-01	9.801E-01	8.906E+01	9.001E-01	1.01	1396
780	1.000E-01	1.000E-01	9.798E-01	8.906E+01	8.232E-01	0.92	1406
790	1.000E-01	1.000E-01	9.780E-01	8.906E+01	7.539E-01	0.85	1416
800	1.000E-01	1.000E-01	9.793E-01	8.906E+01	6.922E-01	0.78	1426
810	1.000E-01	1.000E-01	9.796E-01	8.906E+01	6.365E-01	0.71	1436

```
    820  1.000E-01  1.000E-01  9.795E-01  8.906E+01  5.858E-01      0.66      1446
    830  1.000E-01  1.000E-01  9.829E-01  8.906E+01  5.394E-01      0.61      1456
    840  1.000E-01  1.000E-01  9.828E-01  8.906E+01  4.959E-01      0.56      1466
    850  1.000E-01  1.000E-01  9.829E-01  8.906E+01  4.549E-01      0.51      1476
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:17:47
       SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY

      *********************************************************************
      SUMMARY OF DATA AT STEP NUMBER      1, TIME = 1.000E-01
      NUMBER OF ITERATIONS =        853, TOTAL NUMBER OF ITERATIONS =       1479
      FINAL CONVERGENCE TOLERANCE = 4.975E-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 = 3.162E-14
      *********************************************************************


      **** PLOT TAPE WRITTEN AT TIME = 1.000E-01  STEP NUMBER     1 ****

.
.
.
.
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:17:47
       SANTOS VERIFICATION - ROCKET MOTOR PROBLEM - LINEAR VISCOSITY

      *********************************************************************
      SUMMARY OF DATA AT STEP NUMBER     19, TIME = 1.000E+01
      NUMBER OF ITERATIONS =        286, TOTAL NUMBER OF ITERATIONS =       9452
      FINAL CONVERGENCE TOLERANCE = 4.969E-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 =-5.611E-14
      *********************************************************************


      **** 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
                           2.890E+00 CPU SECONDS USED
                               17510 WORDS ALLOCATED
```

APPENDIX P

Input/Output Data For Test Case 16

The following two sections present the input data and the formatted output for the M-D constitutive model implementation test.

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.

shaft.fsq

```
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
```

shaft.i

```
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
```

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.

shaft.o

```
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 2.1.7-DP
                      COPYRIGHT 1995, SANDIA CORPORATION


                               PROGRAMMED BY:

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



                        RUN ON 20030612 AT 11:18:30
                      RUN ON A     i686 UNDER Lx2.4.20

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
```

```
   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
1                                    INPUT STREAM IMAGES
 LINE -----------------------------------------------------------------------
   55: TITLE
   56:      SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)
   57: AXISYM
   58: STEP CONTROL
   59:  3650 3.1536E8
   60: END
   61: OUTPUT TIME
   62:   1 3.1536E8
   63: END
   64: PLOT TIME
   65:  1 3.1536E8
   66: END
   67: ELASTIC SOLUTION
   68: RESIDUAL TOLERANCE = .01
   69: MAXIMUM ITERATIONS = 5000
   70: INTERMEDIATE PRINT = 100
   71: MAXIMUM TOLERANCE = 100.
   72: MINIMUM DAMPING FACTOR = .2
   73: INITIAL STRESS = CONSTANT = -15.E6 = -15.E6 = -15.0E6 = 0.
   74: HOURGLASS STIFFENING = .005
   75: AUTO STEP 0.02 2.592e6 NOREDUCE 1.E-3
   76: PLOT NODAL DISPLACEMENT
   77: PLOT ELEMENT STRESS
   78: PLOT STATE EQCS
   79: FUNCTION 1
   80:  0. 1.
   81: 7.22E8 1.
   82: END
   83: PRESSURE, 3, 1, 15.0E6
   84: NO DISPLACEMENT, Y, 2
   85: MATERIAL, 1, M-D CREEP MODEL, 2300.
   86: TWO MU = 24.8E9
   87: BULK MODULUS = 20.66E9
   88: A1 = 8.386E22
   89: Q1/R = 41.94
   90: N1 = 5.5
   91: B1 = 6.086E6
   92: A2 = 9.672E12
```

```
 93: Q2/R = 16.776
 94: N2 = 5.0
 95: B2 = 3.034E-2
 96: SIG0 = 20.57E6
 97: QLC = 5335.
 98: M = 3.0
 99: K0 = 6.275E5
100: C = 2.759
101: ALPHA = -17.37
102: BETA = -7.738
103: DELTLC = 0.58
104: RN3 = 2.0
105: AMULT = 0.95
106: END
107: EXIT
     ------------------------------------------------------------------------
1
```

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

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
```

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

                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
                            4.000E-02 CPU SECONDS USED
                                 5882 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
                            0.000E+00 CPU SECONDS USED
                                30478 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
                                  EQCS           ITER
                                                 RMAG
1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:18:30
          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 = 9.441E-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 = 2.747E-03
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 0.000E+00  STEP NUMBER      0 ****

1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:18:30
          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 = 2.747E-03
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 1.000E-03  STEP NUMBER      1 ****

1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:18:30
          SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER      2, TIME = 2.000E-03
     NUMBER OF ITERATIONS =           8, TOTAL NUMBER OF ITERATIONS =       115
     FINAL CONVERGENCE TOLERANCE = 9.653E-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 =-5.066E-03
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 2.000E-03  STEP NUMBER      2 ****

1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:18:30
          SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER      3, TIME = 3.000E-03
     NUMBER OF ITERATIONS =          15, TOTAL NUMBER OF ITERATIONS =       130
     FINAL CONVERGENCE TOLERANCE = 9.796E-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 = 6.653E-03
     *********************************************************************
```

```
     **** PLOT TAPE WRITTEN AT TIME = 3.000E-03  STEP NUMBER     3 ****


1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:18:30
           SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER     4, TIME = 4.000E-03
     NUMBER OF ITERATIONS =         16, TOTAL NUMBER OF ITERATIONS =       146
     FINAL CONVERGENCE TOLERANCE = 9.857E-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 =-1.160E-03
     *********************************************************************


             **** PLOT TAPE WRITTEN AT TIME = 4.000E-03  STEP NUMBER     4 ****

.
.
.
.

1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:18:30
           SHAFT M-D CREEP SANTOS VERIFICATION CALCULATION (2/13/95)

     *********************************************************************
     SUMMARY OF DATA AT STEP NUMBER   204, TIME = 3.154E+08
     NUMBER OF ITERATIONS =          3, TOTAL NUMBER OF ITERATIONS =     32607
     FINAL CONVERGENCE TOLERANCE = 9.630E-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 = 1.322E-02
     *********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 3.154E+08  STEP NUMBER   204 ****




               205 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
                          2.320E+02 CPU SECONDS USED
                              36926 WORDS ALLOCATED
```

APPENDIX Q

Input/Output Data For Test Case 17

The following sections present the input data and the formatted output for the upsetting of a cylindrical billet test.

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.

billet17.fsq

```
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
```

billet17.i

```
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
```

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.

billet17.o

```
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 2.1.7-DP
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                                 PROGRAMMED BY:

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



                            RUN ON 20030612 AT 11:18:59
                           RUN ON A     i686 UNDER Lx2.4.20
```

```
    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
1                                   INPUT STREAM IMAGES
  LINE ---------------------------------------------------------------------
   33: TITLE
   34:   UPSETTING OF A CYLINDRICAL BILLET
   35: AXISYMMETRIC
   36: STEP CONTROL
   37: 100,1
   38: END
   39: INTERMEDIATE PRINT= 100
   40: MAXIMUM ITERATIONS = 3000
   41: RESIDUAL TOLERANCE = 0.5
   42: MAXIMUM TOLERANCE =  100.0
   43: OUTPUT TIME
   44: 5,1
   45: END
   46: PLOT TIME
   47: 1,1
   48: END
   49: PLOT NODAL = DISPLACEMENT,REACTION,RESIDUAL
   50: PLOT ELEMENT = VONMISES,PRESSURE
   51: PLOT STATE = EQPS
   52: NO DISPLACEMENT,X = 4
   53: PRESCRIBED DISPLACMENT,Y = 1,1,9.
   54: FUNCTION = 1
   55: 0,0
   56: 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
------------------------------------------------------------------------
```

1

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

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
```

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 FLAG	DIRECTION	FUNCTION ID	SCALE FACTOR	A0	B0
1	Y	1	9.000E+00	-	-

R I G I D   S U R F A C E S

SURFACE NUMBER	SIDE SET FLAG	COEFFICIENT OF FRICTION	X0	Y0	NX	NY
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
3.000E-02 CPU SECONDS USED
3474 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
0.000E+00 CPU SECONDS USED
31726 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		

**** 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
100	1.000E-02	9.999E-03	8.930E-01	1.146E+01	5.317E-01	4.64	100
200	1.000E-02	9.999E-03	9.331E-01	1.137E+01	1.011E-01	0.89	200

**** PLOT TAPE WRITTEN AT TIME = 1.000E-02   STEP NUMBER   1 ****

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	2.000E-02	1.000E-02	8.881E-01	1.155E+01	1.862E-01	1.61	327

```
 **** 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  9.573E-01  1.164E+01  6.329E-02       0.54        509

 **** PLOT TAPE WRITTEN AT TIME = 3.000E-02   STEP NUMBER      3 ****


 **** 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  1.000E+00  5.568E-03  8.008E-01  4.874E+01  1.012E+00       2.08      18672
1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:18:59
       UPSETTING OF A CYLINDRICAL BILLET

 *********************************************************************
 SUMMARY OF DATA AT STEP NUMBER   100, TIME = 1.000E+00
 NUMBER OF ITERATIONS =        118, TOTAL NUMBER OF ITERATIONS =      18690
 FINAL CONVERGENCE TOLERANCE = 4.704E-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 = 5.399E+01
 SUM OF REACTION FORCES IN Y-DIRECTION = 1.378E+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
                       3.563E+01 CPU SECONDS USED
                           38714 WORDS ALLOCATED
```

APPENDIX R

Input/Output Data For Test Case 18

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.

bm2isonew.fsq

```
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
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
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
SIDEBC     8     54     55
SIDEBC     9     56     57
SIDEBC    10     61     62
SIDEBC    11     63     64
SIDEBC    22     73     74
EXIT
```

bm2isonew.i

```
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
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
```

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.

```
      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
```

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.

bm2isonew.i

```
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 2.1.7-DP
                       COPYRIGHT 1995, SANDIA CORPORATION

                               PROGRAMMED BY:

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

```
                         RUN ON 20030612 AT 11:20:43
                       RUN ON A     i686 UNDER Lx2.4.20

TITLE
  BENCHMARK II ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/9/95)
RESIDUAL TOLERANCE = .5
MAXIMUM ITERATIONS = 50000
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
```

```
   53: CREEP CONSTANT = 1.74E-35
   54: STRESS EXPONENT = 4.9
   55: THERMAL CONSTANT = 20.13
   56: END
   57: MATERIAL,3,POWER LAW CREEP,2167.
   58: TWO MU = 21.2E9
   59: BULK MODULUS = 17.66E9
   60: CREEP CONSTANT = 5.21E-36
   61: STRESS EXPONENT = 4.9
   62: THERMAL CONSTANT = 20.13
   63: END
   64: MATERIAL,4,ELASTIC,2167.
   65: YOUNGS MODULUS = 72.4E9
   66: POISSONS RATIO = .33
   67: END
   68: EXIT
1                                    INPUT STREAM IMAGES
 LINE ---------------------------------------------------------------------------
   70: TITLE
   71:   BENCHMARK II ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/9/95)
   72: RESIDUAL TOLERANCE = .5
   73: MAXIMUM ITERATIONS = 50000
   74: INTERMEDIATE PRINT = 100
   75: MAXIMUM TOLERANCE = 5.
   76: PLANE STRAIN
   77: TIME STEP SCALE = 0.4
   78: PREDICTOR SCALE FACTOR = 2
   79: $HOURGLASS STIFFENING = 0.0005
   80: EFFECTIVE MODULUS = VARIABLE
   81: INITIAL STRESS = USER
   82: GRAVITY = 1 = 0. = -9.8066 = 0.
   83: STEP CONTROL
   84:  400 3.157E8
   85: END
   86: PLOT TIME
   87:  1 3.157E8
   88: END
   89: OUTPUT TIME
   90:  100 3.157E8
   91: END
   92: PLOT NODAL DISPLACEMENT, RESIDUAL
   93: PLOT ELEMENT STRESS, VONMISES, EFFMOD
   94: PLOT STATE EQCS
   95: NO DISPLACEMENT X, 3
   96: NO DISPLACEMENT X, 2
   97: NO DISPLACEMENT Y, 2
   98: FUNCTION = 1
   99: 0. 1.
  100: 4.E8 1.
  101: END
  102: FUNCTION = 2
  103: 0. 0.
  104: 4.E8 0.
  105: END
  106: PRESSURE, 1, 1, 12.71E6
  107: PRESSURE, 22, 1, 15.00E6
  108: CONTACT SURFACE, 4, 5, 0., .02, 1.E40
  109: CONTACT SURFACE, 7, 6, 0., .02, 1.E40
```

```
110: CONTACT SURFACE, 9, 8, 0., .02, 1.E40
111: CONTACT SURFACE, 10, 11, 0., .02, 1.E40
112: MATERIAL,1,POWER LAW CREEP,2167.
113: TWO MU = 19.84E9
114: BULK MODULUS = 16.53E9
115: CREEP CONSTANT = 5.79E-36
116: STRESS EXPONENT = 4.9
117: THERMAL CONSTANT = 20.13
118: END
119: MATERIAL,2,POWER LAW CREEP,2167.
120: TWO MU = 19.84E9
121: BULK MODULUS = 16.53E9
122: CREEP CONSTANT = 1.74E-35
123: STRESS EXPONENT = 4.9
124: THERMAL CONSTANT = 20.13
125: END
126: MATERIAL,3,POWER LAW CREEP,2167.
127: TWO MU = 21.2E9
128: BULK MODULUS = 17.66E9
129: CREEP CONSTANT = 5.21E-36
130: STRESS EXPONENT = 4.9
131: THERMAL CONSTANT = 20.13
132: END
133: MATERIAL,4,ELASTIC,2167.
134: YOUNGS MODULUS = 72.4E9
135: POISSONS RATIO = .33
136: END
137: EXIT
     ------------------------------------------------------------------------
1
                         P R O B L E M   T I T L E

        BENCHMARK II ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/9/95)



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

          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 ............        50000
          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


      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 .........................          4
DENSITY .............................  2.167E+03
MATERIAL PROPERTIES:
       YOUNGS MODULUS       =    7.240E+10
       POISSONS RATIO       =    3.300E-01

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
```

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 NUMBER	SURFACE 1 FLAG	SURFACE 2 FLAG	PENALTY FACTOR	COEFFICIENT OF FRICTION	PENETRATION MULTIPLIER	TENSION RELEASE
1	4	5	0.000E+00	0.000E+00	2.000E-02	INF
2	7	6	0.000E+00	0.000E+00	2.000E-02	INF

3	9	8	0.000E+00	0.000E+00	2.000E-02	INF
4	10	11	0.000E+00	0.000E+00	2.000E-02	INF

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 FLAG	FUNCTION NUMBER	SCALE 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
5.000E-02 CPU SECONDS USED
16384 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
1.000E-02 CPU SECONDS USED
155982 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	VONMISES	ITER
	EFFMOD	RMAG
	EQCS	

**** 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
100	7.892E+05	7.891E+05	9.416E-01	9.083E+07	1.123E+07	12.36	100
200	7.892E+05	7.891E+05	8.288E-01	9.083E+07	4.254E+07	46.84	200
300	7.892E+05	7.890E+05	7.480E-01	9.083E+07	1.583E+07	17.43	300
400	7.892E+05	7.890E+05	9.566E-01	9.083E+07	8.889E+07	97.87	400
500	7.892E+05	7.890E+05	8.052E-01	9.083E+07	1.975E+07	21.74	500

600	7.892E+05	7.890E+05	8.592E-01	9.083E+07	1.484E+07	16.34	600
700	7.892E+05	7.890E+05	7.473E-01	9.083E+07	1.862E+08	205.01	700
800	7.892E+05	7.890E+05	8.567E-01	9.083E+07	1.371E+08	150.89	800
900	7.892E+05	7.890E+05	9.334E-01	9.083E+07	5.117E+07	56.33	900
1000	7.892E+05	7.890E+05	9.343E-01	9.083E+07	6.483E+08	713.82	1000
1100	7.892E+05	7.890E+05	6.362E-01	9.083E+07	2.427E+07	26.72	1100
1200	7.892E+05	7.890E+05	6.959E-01	9.083E+07	3.582E+07	39.43	1200
1300	7.892E+05	7.890E+05	9.662E-01	9.083E+07	3.534E+08	389.13	1300
1400	7.892E+05	7.890E+05	8.168E-01	9.083E+07	4.245E+07	46.74	1400
1500	7.892E+05	7.890E+05	9.140E-01	9.083E+07	7.774E+07	85.59	1500
1600	7.892E+05	7.890E+05	8.435E-01	9.083E+07	2.690E+07	29.62	1600
1700	7.892E+05	7.890E+05	9.949E-01	9.083E+07	5.582E+07	61.45	1700
1800	7.892E+05	7.890E+05	8.813E-01	9.083E+07	1.263E+08	139.02	1800
1900	7.892E+05	7.890E+05	7.849E-01	9.083E+07	4.581E+07	50.43	1900
2000	7.892E+05	7.890E+05	8.453E-01	9.083E+07	1.038E+08	114.32	2000
2100	7.892E+05	7.890E+05	7.702E-01	9.083E+07	7.210E+07	79.38	2100
2200	7.892E+05	7.890E+05	7.341E-01	9.083E+07	3.678E+07	40.49	2200
2300	7.892E+05	7.890E+05	7.640E-01	9.083E+07	1.238E+07	13.63	2300
2400	7.892E+05	7.890E+05	7.889E-01	9.083E+07	4.765E+07	52.46	2400
2500	7.892E+05	7.890E+05	7.783E-01	9.083E+07	7.985E+07	87.91	2500
2600	7.892E+05	7.890E+05	8.071E-01	9.083E+07	4.304E+07	47.38	2600
2700	7.892E+05	7.890E+05	8.108E-01	9.083E+07	3.052E+07	33.60	2700
2800	7.892E+05	7.890E+05	9.151E-01	9.083E+07	2.390E+07	26.32	2800
2900	7.892E+05	7.890E+05	7.884E-01	9.083E+07	8.108E+07	89.27	2900
3000	7.892E+05	7.890E+05	9.326E-01	9.083E+07	9.185E+06	10.11	3000
3100	7.892E+05	7.890E+05	6.958E-01	9.083E+07	1.392E+07	15.32	3100
3200	7.892E+05	7.890E+05	9.154E-01	9.083E+07	2.750E+07	30.27	3200
3300	7.892E+05	7.890E+05	9.150E-01	9.083E+07	8.809E+06	9.70	3300
3400	7.892E+05	7.890E+05	8.212E-01	9.083E+07	3.100E+07	34.13	3400
3500	7.892E+05	7.890E+05	8.399E-01	9.083E+07	3.377E+07	37.18	3500
3600	7.892E+05	7.890E+05	6.786E-01	9.083E+07	1.869E+07	20.58	3600
3700	7.892E+05	7.890E+05	8.845E-01	9.083E+07	1.125E+07	12.38	3700
3800	7.892E+05	7.890E+05	8.912E-01	9.083E+07	1.279E+07	14.08	3800
3900	7.892E+05	7.890E+05	7.943E-01	9.083E+07	3.241E+07	35.68	3900
4000	7.892E+05	7.890E+05	8.841E-01	9.083E+07	2.815E+07	31.00	4000
4100	7.892E+05	7.890E+05	6.534E-01	9.083E+07	2.820E+07	31.05	4100
4200	7.892E+05	7.890E+05	7.311E-01	9.083E+07	2.143E+07	23.59	4200
4300	7.892E+05	7.889E+05	8.000E-01	9.083E+07	8.187E+06	9.01	4300
4400	7.892E+05	7.889E+05	9.058E-01	9.083E+07	4.344E+07	47.83	4400
4500	7.892E+05	7.889E+05	8.020E-01	9.083E+07	1.376E+07	15.15	4500
4600	7.892E+05	7.889E+05	9.526E-01	9.083E+07	1.130E+07	12.44	4600
4700	7.892E+05	7.889E+05	8.428E-01	9.083E+07	1.611E+06	1.77	4700
4800	7.892E+05	7.889E+05	9.604E-01	9.083E+07	1.963E+06	2.16	4800
4900	7.892E+05	7.889E+05	9.551E-01	9.083E+07	3.280E+06	3.61	4900
5000	7.892E+05	7.889E+05	8.109E-01	9.083E+07	2.427E+06	2.67	5000
5100	7.892E+05	7.889E+05	9.077E-01	9.083E+07	1.136E+06	1.25	5100
5200	7.892E+05	7.889E+05	8.874E-01	9.083E+07	1.594E+06	1.75	5200
5300	7.892E+05	7.889E+05	7.935E-01	9.083E+07	3.198E+06	3.52	5300
5400	7.892E+05	7.889E+05	6.660E-01	9.083E+07	1.622E+06	1.79	5400
5500	7.892E+05	7.889E+05	6.857E-01	9.083E+07	9.636E+05	1.06	5500
5600	7.892E+05	7.889E+05	8.114E-01	9.083E+07	1.054E+06	1.16	5600
5700	7.892E+05	7.889E+05	9.102E-01	9.083E+07	3.445E+06	3.79	5700
5800	7.892E+05	7.889E+05	6.683E-01	9.083E+07	3.688E+06	4.06	5800
5900	7.892E+05	7.889E+05	9.095E-01	9.083E+07	4.269E+06	4.70	5900
6000	7.892E+05	7.889E+05	8.357E-01	9.083E+07	1.557E+07	17.14	6000
6100	7.892E+05	7.889E+05	8.491E-01	9.083E+07	6.926E+05	0.76	6100
6200	7.892E+05	7.889E+05	8.362E-01	9.083E+07	1.145E+06	1.26	6200
6300	7.892E+05	7.889E+05	6.950E-01	9.083E+07	4.620E+06	5.09	6300

6400	7.892E+05	7.889E+05	8.987E-01	9.083E+07	1.271E+06	1.40	6400
6500	7.892E+05	7.889E+05	9.971E-01	9.083E+07	1.500E+06	1.65	6500
6600	7.892E+05	7.889E+05	9.916E-01	9.083E+07	5.790E+05	0.64	6600
6700	7.892E+05	7.889E+05	9.261E-01	9.083E+07	6.100E+05	0.67	6700
6800	7.892E+05	7.889E+05	8.226E-01	9.083E+07	1.591E+06	1.75	6800
6900	7.892E+05	7.889E+05	8.830E-01	9.083E+07	4.416E+06	4.86	6900
7000	7.892E+05	7.889E+05	7.058E-01	9.083E+07	2.082E+06	2.29	7000
7100	7.892E+05	7.889E+05	9.508E-01	9.083E+07	7.819E+06	8.61	7100
7200	7.892E+05	7.889E+05	9.776E-01	9.083E+07	1.156E+07	12.73	7200
7300	7.892E+05	7.889E+05	7.684E-01	9.083E+07	6.565E+06	7.23	7300
7400	7.892E+05	7.889E+05	9.508E-01	9.083E+07	1.938E+07	21.34	7400
7500	7.892E+05	7.889E+05	7.753E-01	9.083E+07	1.357E+07	14.94	7500
7600	7.892E+05	7.889E+05	7.159E-01	9.083E+07	2.278E+07	25.08	7600
7700	7.892E+05	7.889E+05	9.153E-01	9.083E+07	3.600E+07	39.64	7700
7800	7.892E+05	7.889E+05	6.958E-01	9.083E+07	9.122E+06	10.04	7800
7900	7.892E+05	7.889E+05	8.957E-01	9.083E+07	2.531E+07	27.87	7900
8000	7.892E+05	7.889E+05	7.213E-01	9.083E+07	2.008E+07	22.11	8000
8100	7.892E+05	7.889E+05	8.283E-01	9.083E+07	1.748E+07	19.24	8100
8200	7.892E+05	7.889E+05	6.411E-01	9.083E+07	1.399E+07	15.41	8200
8300	7.892E+05	7.889E+05	7.362E-01	9.083E+07	5.251E+07	57.81	8300
8400	7.892E+05	7.889E+05	7.475E-01	9.083E+07	2.484E+07	27.35	8400
8500	7.892E+05	7.889E+05	7.011E-01	9.083E+07	3.175E+07	34.96	8500
8600	7.892E+05	7.889E+05	7.202E-01	9.083E+07	2.637E+07	29.03	8600
8700	7.892E+05	7.889E+05	7.419E-01	9.083E+07	2.723E+07	29.98	8700
8800	7.892E+05	7.889E+05	7.906E-01	9.083E+07	5.225E+07	57.53	8800
8900	7.892E+05	7.889E+05	8.957E-01	9.083E+07	1.185E+07	13.05	8900
9000	7.892E+05	7.889E+05	7.529E-01	9.083E+07	8.862E+06	9.76	9000
9100	7.892E+05	7.889E+05	9.225E-01	9.083E+07	1.381E+07	15.20	9100
9200	7.892E+05	7.889E+05	8.843E-01	9.083E+07	8.863E+07	97.58	9200
9300	7.892E+05	7.889E+05	8.003E-01	9.083E+07	3.700E+07	40.74	9300
9400	7.892E+05	7.889E+05	9.319E-01	9.083E+07	8.303E+06	9.14	9400
9500	7.892E+05	7.889E+05	9.355E-01	9.083E+07	2.274E+07	25.04	9500
9600	7.892E+05	7.889E+05	5.604E-01	9.083E+07	2.170E+07	23.89	9600
9700	7.892E+05	7.889E+05	8.595E-01	9.083E+07	3.081E+07	33.92	9700
9800	7.892E+05	7.889E+05	8.474E-01	9.083E+07	9.328E+06	10.27	9800
9900	7.892E+05	7.889E+05	6.999E-01	9.083E+07	1.332E+07	14.66	9900
10000	7.892E+05	7.889E+05	8.850E-01	9.083E+07	6.796E+06	7.48	10000
10100	7.892E+05	7.889E+05	8.313E-01	9.083E+07	8.703E+06	9.58	10100
10200	7.892E+05	7.889E+05	8.097E-01	9.083E+07	2.653E+07	29.21	10200
10300	7.892E+05	7.889E+05	7.645E-01	9.083E+07	1.319E+07	14.52	10300
10400	7.892E+05	7.889E+05	8.309E-01	9.083E+07	1.199E+07	13.20	10400
10500	7.892E+05	7.889E+05	8.723E-01	9.083E+07	7.501E+06	8.26	10500
10600	7.892E+05	7.889E+05	8.442E-01	9.083E+07	1.387E+07	15.27	10600
10700	7.892E+05	7.889E+05	7.675E-01	9.083E+07	1.992E+07	21.93	10700
10800	7.892E+05	7.889E+05	9.759E-01	9.083E+07	1.119E+07	12.32	10800
10900	7.892E+05	7.889E+05	7.667E-01	9.083E+07	5.962E+07	65.64	10900
11000	7.892E+05	7.889E+05	7.950E-01	9.083E+07	4.545E+07	50.04	11000
11100	7.892E+05	7.889E+05	6.797E-01	9.083E+07	5.514E+07	60.71	11100
11200	7.892E+05	7.889E+05	7.220E-01	9.083E+07	4.658E+07	51.29	11200
11300	7.892E+05	7.889E+05	7.312E-01	9.083E+07	2.915E+07	32.09	11300
11400	7.892E+05	7.889E+05	7.996E-01	9.083E+07	2.337E+07	25.72	11400
11500	7.892E+05	7.889E+05	9.751E-01	9.083E+07	1.446E+07	15.92	11500
11600	7.892E+05	7.889E+05	8.800E-01	9.083E+07	2.969E+07	32.69	11600
11700	7.892E+05	7.889E+05	7.921E-01	9.083E+07	2.184E+07	24.05	11700
11800	7.892E+05	7.889E+05	8.956E-01	9.083E+07	2.917E+07	32.12	11800
11900	7.892E+05	7.889E+05	8.715E-01	9.083E+07	4.975E+06	5.48	11900
12000	7.892E+05	7.889E+05	9.593E-01	9.083E+07	1.358E+07	14.95	12000
12100	7.892E+05	7.889E+05	8.423E-01	9.083E+07	1.188E+07	13.08	12100

12200	7.892E+05	7.889E+05	8.872E-01	9.083E+07	2.263E+07	24.91	12200
12300	7.892E+05	7.889E+05	5.651E-01	9.083E+07	4.529E+07	49.86	12300
12400	7.892E+05	7.889E+05	9.070E-01	9.083E+07	1.637E+07	18.02	12400
12500	7.892E+05	7.889E+05	9.708E-01	9.083E+07	6.228E+06	6.86	12500
12600	7.892E+05	7.889E+05	5.412E-01	9.083E+07	2.141E+07	23.58	12600
12700	7.892E+05	7.889E+05	8.223E-01	9.083E+07	7.652E+07	84.25	12700
12800	7.892E+05	7.889E+05	9.804E-01	9.083E+07	4.275E+07	47.07	12800
12900	7.892E+05	7.889E+05	8.122E-01	9.083E+07	6.301E+06	6.94	12900
13000	7.892E+05	7.889E+05	7.705E-01	9.083E+07	3.496E+07	38.49	13000
13100	7.892E+05	7.889E+05	7.950E-01	9.083E+07	5.550E+07	61.11	13100
13200	7.892E+05	7.889E+05	8.423E-01	9.083E+07	3.156E+07	34.75	13200
13300	7.892E+05	7.889E+05	9.557E-01	9.083E+07	6.090E+07	67.05	13300
13400	7.892E+05	7.889E+05	8.101E-01	9.083E+07	4.076E+07	44.88	13400
13500	7.892E+05	7.889E+05	7.546E-01	9.083E+07	1.791E+08	197.19	13500
13600	7.892E+05	7.889E+05	7.155E-01	9.083E+07	6.763E+07	74.46	13600
13700	7.892E+05	7.889E+05	9.531E-01	9.083E+07	4.462E+07	49.13	13700
13800	7.892E+05	7.889E+05	6.895E-01	9.083E+07	4.244E+07	46.73	13800
13900	7.892E+05	7.889E+05	5.039E-01	9.083E+07	6.910E+07	76.07	13900
14000	7.892E+05	7.889E+05	8.299E-01	9.083E+07	1.904E+07	20.96	14000
14100	7.892E+05	7.889E+05	7.637E-01	9.083E+07	3.283E+07	36.15	14100
14200	7.892E+05	7.889E+05	5.104E-01	9.083E+07	1.407E+07	15.49	14200
14300	7.892E+05	7.889E+05	8.895E-01	9.083E+07	5.394E+06	5.94	14300
14400	7.892E+05	7.889E+05	9.661E-01	9.083E+07	1.082E+07	11.91	14400
14500	7.892E+05	7.889E+05	9.826E-01	9.083E+07	2.289E+07	25.20	14500
14600	7.892E+05	7.889E+05	9.934E-01	9.083E+07	8.891E+06	9.79	14600
14700	7.892E+05	7.889E+05	8.430E-01	9.083E+07	1.135E+07	12.49	14700
14800	7.892E+05	7.889E+05	9.366E-01	9.083E+07	2.410E+06	2.65	14800
14900	7.892E+05	7.889E+05	8.511E-01	9.083E+07	4.828E+07	53.15	14900
15000	7.892E+05	7.889E+05	8.018E-01	9.083E+07	7.790E+06	8.58	15000
15100	7.892E+05	7.889E+05	7.655E-01	9.083E+07	1.862E+06	2.05	15100
15200	7.892E+05	7.889E+05	4.962E-01	9.083E+07	1.338E+07	14.73	15200
15300	7.892E+05	7.889E+05	9.013E-01	9.083E+07	7.392E+06	8.14	15300
15400	7.892E+05	7.889E+05	8.932E-01	9.083E+07	8.606E+06	9.47	15400
15500	7.892E+05	7.889E+05	6.949E-01	9.083E+07	9.113E+06	10.03	15500
15600	7.892E+05	7.889E+05	7.619E-01	9.083E+07	2.789E+07	30.70	15600
15700	7.892E+05	7.889E+05	7.860E-01	9.083E+07	5.890E+06	6.48	15700
15800	7.892E+05	7.889E+05	8.713E-01	9.083E+07	6.957E+07	76.59	15800
15900	7.892E+05	7.889E+05	7.440E-01	9.083E+07	4.471E+07	49.22	15900
16000	7.892E+05	7.889E+05	6.235E-01	9.083E+07	2.768E+07	30.47	16000
16100	7.892E+05	7.889E+05	7.473E-01	9.083E+07	1.853E+07	20.40	16100
16200	7.892E+05	7.889E+05	6.294E-01	9.083E+07	1.650E+07	18.17	16200
16300	7.892E+05	7.889E+05	8.784E-01	9.083E+07	2.843E+07	31.30	16300
16400	7.892E+05	7.889E+05	9.033E-01	9.083E+07	2.814E+07	30.98	16400
16500	7.892E+05	7.889E+05	7.278E-01	9.083E+07	1.576E+07	17.35	16500
16600	7.892E+05	7.889E+05	7.703E-01	9.083E+07	8.906E+06	9.81	16600
16700	7.892E+05	7.889E+05	5.991E-01	9.083E+07	3.606E+06	3.97	16700
16800	7.892E+05	7.889E+05	8.908E-01	9.083E+07	2.387E+07	26.28	16800
16900	7.892E+05	7.889E+05	7.623E-01	9.083E+07	7.964E+06	8.77	16900
17000	7.892E+05	7.889E+05	7.710E-01	9.083E+07	1.947E+07	21.43	17000
17100	7.892E+05	7.889E+05	6.896E-01	9.083E+07	5.191E+07	57.15	17100
17200	7.892E+05	7.889E+05	9.185E-01	9.083E+07	1.703E+07	18.75	17200
17300	7.892E+05	7.889E+05	6.384E-01	9.083E+07	2.190E+07	24.11	17300
17400	7.892E+05	7.889E+05	6.742E-01	9.083E+07	1.725E+07	19.00	17400
17500	7.892E+05	7.889E+05	9.583E-01	9.083E+07	6.963E+06	7.67	17500
17600	7.892E+05	7.889E+05	7.236E-01	9.083E+07	1.212E+07	13.35	17600
17700	7.892E+05	7.889E+05	9.548E-01	9.083E+07	1.206E+07	13.28	17700
17800	7.892E+05	7.889E+05	7.379E-01	9.083E+07	3.813E+07	41.98	17800
17900	7.892E+05	7.889E+05	8.005E-01	9.083E+07	1.545E+07	17.01	17900

18000	7.892E+05	7.889E+05	6.676E-01	9.083E+07	5.571E+07	61.34	18000
18100	7.892E+05	7.889E+05	9.161E-01	9.083E+07	1.253E+06	1.38	18100
18200	7.892E+05	7.889E+05	8.557E-01	9.083E+07	1.485E+07	16.35	18200
18300	7.892E+05	7.889E+05	8.646E-01	9.083E+07	1.614E+07	17.77	18300
18400	7.892E+05	7.889E+05	7.416E-01	9.083E+07	4.095E+07	45.09	18400
18500	7.892E+05	7.889E+05	8.722E-01	9.083E+07	7.622E+07	83.92	18500
18600	7.892E+05	7.889E+05	6.663E-01	9.083E+07	4.782E+07	52.65	18600
18700	7.892E+05	7.889E+05	8.965E-01	9.083E+07	2.030E+07	22.35	18700
18800	7.892E+05	7.889E+05	9.344E-01	9.083E+07	2.485E+07	27.36	18800
18900	7.892E+05	7.889E+05	6.641E-01	9.083E+07	2.376E+07	26.16	18900
19000	7.892E+05	7.889E+05	7.295E-01	9.083E+07	2.379E+07	26.19	19000
19100	7.892E+05	7.889E+05	8.123E-01	9.083E+07	1.160E+07	12.77	19100
19200	7.892E+05	7.889E+05	7.836E-01	9.083E+07	2.013E+07	22.16	19200
19300	7.892E+05	7.889E+05	9.502E-01	9.083E+07	1.173E+07	12.92	19300
19400	7.892E+05	7.889E+05	7.974E-01	9.083E+07	2.175E+07	23.95	19400
19500	7.892E+05	7.889E+05	7.302E-01	9.083E+07	8.591E+06	9.46	19500
19600	7.892E+05	7.889E+05	7.601E-01	9.083E+07	1.037E+07	11.42	19600
19700	7.892E+05	7.889E+05	9.553E-01	9.083E+07	4.533E+06	4.99	19700
19800	7.892E+05	7.889E+05	8.805E-01	9.083E+07	2.979E+06	3.28	19800
19900	7.892E+05	7.889E+05	8.365E-01	9.083E+07	2.590E+06	2.85	19900
20000	7.892E+05	7.889E+05	6.210E-01	9.083E+07	5.998E+06	6.60	20000
20100	7.892E+05	7.889E+05	9.028E-01	9.083E+07	3.515E+06	3.87	20100
20200	7.892E+05	7.889E+05	7.136E-01	9.083E+07	6.840E+06	7.53	20200
20300	7.892E+05	7.889E+05	7.401E-01	9.083E+07	3.469E+06	3.82	20300
20400	7.892E+05	7.889E+05	9.059E-01	9.083E+07	1.113E+07	12.25	20400
20500	7.892E+05	7.889E+05	7.796E-01	9.083E+07	9.581E+06	10.55	20500
20600	7.892E+05	7.889E+05	8.722E-01	9.083E+07	2.748E+06	3.03	20600
20700	7.892E+05	7.889E+05	7.583E-01	9.083E+07	1.468E+07	16.17	20700
20800	7.892E+05	7.889E+05	7.636E-01	9.083E+07	1.618E+07	17.82	20800
20900	7.892E+05	7.889E+05	7.560E-01	9.083E+07	2.988E+07	32.90	20900
21000	7.892E+05	7.889E+05	7.158E-01	9.083E+07	5.407E+06	5.95	21000
21100	7.892E+05	7.889E+05	7.835E-01	9.083E+07	2.565E+07	28.24	21100
21200	7.892E+05	7.889E+05	8.988E-01	9.083E+07	1.958E+07	21.56	21200
21300	7.892E+05	7.889E+05	7.905E-01	9.083E+07	1.627E+07	17.91	21300
21400	7.892E+05	7.889E+05	6.587E-01	9.083E+07	1.608E+07	17.71	21400
21500	7.892E+05	7.889E+05	7.007E-01	9.083E+07	3.410E+07	37.54	21500
21600	7.892E+05	7.889E+05	8.326E-01	9.083E+07	2.763E+07	30.42	21600
21700	7.892E+05	7.889E+05	8.421E-01	9.083E+07	3.765E+07	41.45	21700
21800	7.892E+05	7.889E+05	9.591E-01	9.083E+07	1.031E+08	113.48	21800
21900	7.892E+05	7.889E+05	9.113E-01	9.083E+07	3.749E+07	41.28	21900
22000	7.892E+05	7.889E+05	9.096E-01	9.083E+07	2.888E+07	31.79	22000
22100	7.892E+05	7.889E+05	7.178E-01	9.083E+07	6.045E+06	6.66	22100
22200	7.892E+05	7.889E+05	7.788E-01	9.083E+07	1.253E+07	13.80	22200
22300	7.892E+05	7.889E+05	7.175E-01	9.083E+07	4.698E+06	5.17	22300
22400	7.892E+05	7.889E+05	6.856E-01	9.083E+07	1.735E+07	19.10	22400
22500	7.892E+05	7.889E+05	8.563E-01	9.083E+07	2.866E+07	31.55	22500
22600	7.892E+05	7.889E+05	8.579E-01	9.083E+07	1.035E+07	11.39	22600
22700	7.892E+05	7.889E+05	8.522E-01	9.083E+07	1.009E+07	11.11	22700
22800	7.892E+05	7.889E+05	7.618E-01	9.083E+07	7.605E+06	8.37	22800
22900	7.892E+05	7.889E+05	8.279E-01	9.083E+07	1.628E+07	17.92	22900
23000	7.892E+05	7.889E+05	9.578E-01	9.083E+07	1.296E+07	14.27	23000
23100	7.892E+05	7.889E+05	8.108E-01	9.083E+07	1.072E+08	118.02	23100
23200	7.892E+05	7.889E+05	8.118E-01	9.083E+07	1.350E+08	148.59	23200
23300	7.892E+05	7.889E+05	7.885E-01	9.083E+07	1.086E+07	11.96	23300
23400	7.892E+05	7.889E+05	9.176E-01	9.083E+07	3.846E+06	4.23	23400
23500	7.892E+05	7.889E+05	8.864E-01	9.083E+07	7.522E+06	8.28	23500
23600	7.892E+05	7.889E+05	8.449E-01	9.083E+07	1.090E+07	12.00	23600
23700	7.892E+05	7.889E+05	6.061E-01	9.083E+07	1.456E+07	16.03	23700

23800	7.892E+05	7.889E+05	7.991E-01	9.083E+07	1.431E+07	15.75	23800
23900	7.892E+05	7.889E+05	7.044E-01	9.083E+07	3.252E+07	35.80	23900
24000	7.892E+05	7.889E+05	6.721E-01	9.083E+07	5.113E+07	56.29	24000
24100	7.892E+05	7.889E+05	8.488E-01	9.083E+07	1.969E+07	21.68	24100
24200	7.892E+05	7.889E+05	8.825E-01	9.083E+07	4.576E+07	50.39	24200
24300	7.892E+05	7.889E+05	8.121E-01	9.083E+07	1.036E+08	114.05	24300
24400	7.892E+05	7.889E+05	7.390E-01	9.083E+07	9.305E+07	102.45	24400
24500	7.892E+05	7.889E+05	8.512E-01	9.083E+07	7.842E+07	86.34	24500
24600	7.892E+05	7.889E+05	8.474E-01	9.083E+07	6.832E+07	75.22	24600
24700	7.892E+05	7.889E+05	8.489E-01	9.083E+07	6.976E+07	76.81	24700
24800	7.892E+05	7.889E+05	9.260E-01	9.083E+07	2.816E+07	31.00	24800
24900	7.892E+05	7.889E+05	7.957E-01	9.083E+07	1.482E+07	16.32	24900
25000	7.892E+05	7.889E+05	9.554E-01	9.083E+07	1.076E+07	11.85	25000
25100	7.892E+05	7.889E+05	8.771E-01	9.083E+07	1.201E+07	13.22	25100
25200	7.892E+05	7.889E+05	9.014E-01	9.083E+07	2.012E+07	22.15	25200
25300	7.892E+05	7.889E+05	6.184E-01	9.083E+07	5.119E+07	56.36	25300
25400	7.892E+05	7.889E+05	7.195E-01	9.083E+07	5.266E+07	57.98	25400
25500	7.892E+05	7.889E+05	8.986E-01	9.083E+07	4.829E+07	53.17	25500
25600	7.892E+05	7.889E+05	7.459E-01	9.083E+07	9.216E+06	10.15	25600
25700	7.892E+05	7.889E+05	7.932E-01	9.083E+07	6.265E+06	6.90	25700
25800	7.892E+05	7.889E+05	8.857E-01	9.083E+07	5.650E+07	62.20	25800
25900	7.892E+05	7.889E+05	8.112E-01	9.083E+07	3.101E+07	34.14	25900
26000	7.892E+05	7.889E+05	9.450E-01	9.083E+07	2.095E+07	23.07	26000
26100	7.892E+05	7.889E+05	8.364E-01	9.083E+07	4.240E+07	46.69	26100
26200	7.892E+05	7.889E+05	8.868E-01	9.083E+07	2.219E+07	24.43	26200
26300	7.892E+05	7.889E+05	8.928E-01	9.083E+07	3.158E+07	34.77	26300
26400	7.892E+05	7.889E+05	8.230E-01	9.083E+07	1.387E+07	15.27	26400
26500	7.892E+05	7.889E+05	9.850E-01	9.083E+07	1.204E+07	13.26	26500
26600	7.892E+05	7.889E+05	7.314E-01	9.083E+07	2.663E+06	2.93	26600
26700	7.892E+05	7.889E+05	8.755E-01	9.083E+07	1.117E+07	12.30	26700
26800	7.892E+05	7.889E+05	8.228E-01	9.083E+07	9.015E+06	9.93	26800
26900	7.892E+05	7.889E+05	7.607E-01	9.083E+07	1.447E+07	15.93	26900
27000	7.892E+05	7.889E+05	7.104E-01	9.083E+07	9.331E+06	10.27	27000
27100	7.892E+05	7.889E+05	9.256E-01	9.083E+07	6.553E+06	7.21	27100
27200	7.892E+05	7.889E+05	8.944E-01	9.083E+07	1.520E+07	16.73	27200
27300	7.892E+05	7.889E+05	8.251E-01	9.083E+07	3.130E+07	34.46	27300
27400	7.892E+05	7.889E+05	8.891E-01	9.083E+07	9.912E+06	10.91	27400
27500	7.892E+05	7.889E+05	8.864E-01	9.083E+07	1.180E+07	12.99	27500
27600	7.892E+05	7.889E+05	8.075E-01	9.083E+07	2.555E+07	28.13	27600
27700	7.892E+05	7.889E+05	8.521E-01	9.083E+07	5.460E+07	60.11	27700
27800	7.892E+05	7.889E+05	7.686E-01	9.083E+07	1.123E+08	123.63	27800
27900	7.892E+05	7.889E+05	7.428E-01	9.083E+07	6.793E+07	74.79	27900
28000	7.892E+05	7.889E+05	8.571E-01	9.083E+07	2.332E+07	25.67	28000
28100	7.892E+05	7.889E+05	8.681E-01	9.083E+07	1.300E+07	14.31	28100
28200	7.892E+05	7.889E+05	8.015E-01	9.083E+07	1.660E+07	18.27	28200
28300	7.892E+05	7.889E+05	7.183E-01	9.083E+07	1.508E+07	16.60	28300
28400	7.892E+05	7.889E+05	6.730E-01	9.083E+07	1.429E+07	15.73	28400
28500	7.892E+05	7.889E+05	7.041E-01	9.083E+07	1.105E+07	12.17	28500
28600	7.892E+05	7.889E+05	9.023E-01	9.083E+07	1.581E+07	17.40	28600
28700	7.892E+05	7.889E+05	6.807E-01	9.083E+07	2.370E+07	26.09	28700
28800	7.892E+05	7.889E+05	9.533E-01	9.083E+07	2.609E+07	28.72	28800
28900	7.892E+05	7.889E+05	8.751E-01	9.083E+07	2.353E+07	25.91	28900
29000	7.892E+05	7.889E+05	7.935E-01	9.083E+07	6.448E+06	7.10	29000
29100	7.892E+05	7.889E+05	7.765E-01	9.083E+07	1.407E+07	15.50	29100
29200	7.892E+05	7.889E+05	9.648E-01	9.083E+07	8.536E+06	9.40	29200
29300	7.892E+05	7.889E+05	7.407E-01	9.083E+07	1.553E+08	171.04	29300
29400	7.892E+05	7.889E+05	7.991E-01	9.083E+07	5.254E+07	57.84	29400
29500	7.892E+05	7.889E+05	8.244E-01	9.083E+07	2.794E+07	30.77	29500

```
  29600   7.892E+05   7.889E+05   8.141E-01   9.083E+07   1.034E+07      11.38      29600
  29700   7.892E+05   7.889E+05   8.904E-01   9.083E+07   1.089E+07      11.99      29700
  29800   7.892E+05   7.889E+05   6.707E-01   9.083E+07   8.050E+06       8.86      29800
  29900   7.892E+05   7.889E+05   6.488E-01   9.083E+07   2.158E+06       2.38      29900
  30000   7.892E+05   7.889E+05   7.780E-01   9.083E+07   1.317E+07      14.50      30000
  30100   7.892E+05   7.889E+05   8.133E-01   9.083E+07   3.045E+06       3.35      30100
  30200   7.892E+05   7.889E+05   7.465E-01   9.083E+07   6.432E+06       7.08      30200
  30300   7.892E+05   7.889E+05   9.026E-01   9.083E+07   4.272E+07      47.03      30300
  30400   7.892E+05   7.889E+05   6.692E-01   9.083E+07   2.433E+07      26.79      30400
  30500   7.892E+05   7.889E+05   7.945E-01   9.083E+07   5.795E+07      63.80      30500
  30600   7.892E+05   7.889E+05   7.847E-01   9.083E+07   6.820E+06       7.51      30600
  30700   7.892E+05   7.889E+05   5.548E-01   9.083E+07   4.790E+06       5.27      30700
  30800   7.892E+05   7.889E+05   9.381E-01   9.083E+07   3.122E+06       3.44      30800
  30900   7.892E+05   7.889E+05   7.979E-01   9.083E+07   9.293E+06      10.23      30900
  31000   7.892E+05   7.889E+05   6.388E-01   9.083E+07   6.796E+06       7.48      31000
  31100   7.892E+05   7.889E+05   8.504E-01   9.083E+07   4.544E+06       5.00      31100
  31200   7.892E+05   7.889E+05   7.908E-01   9.083E+07   1.066E+07      11.74      31200
  31300   7.892E+05   7.889E+05   6.008E-01   9.083E+07   7.612E+06       8.38      31300
  31400   7.892E+05   7.889E+05   8.440E-01   9.083E+07   1.317E+07      14.50      31400
  31500   7.892E+05   7.889E+05   7.860E-01   9.083E+07   5.231E+06       5.76      31500
  31600   7.892E+05   7.889E+05   7.600E-01   9.083E+07   1.765E+07      19.43      31600
  31700   7.892E+05   7.889E+05   9.272E-01   9.083E+07   2.523E+07      27.77      31700
  31800   7.892E+05   7.889E+05   8.439E-01   9.083E+07   2.732E+07      30.08      31800
  31900   7.892E+05   7.889E+05   4.924E-01   9.083E+07   2.441E+07      26.88      31900
  32000   7.892E+05   7.889E+05   9.006E-01   9.083E+07   4.366E+06       4.81      32000
  32100   7.892E+05   7.889E+05   9.113E-01   9.083E+07   1.794E+06       1.98      32100
  32200   7.892E+05   7.889E+05   6.154E-01   9.083E+07   5.684E+06       6.26      32200
  32300   7.892E+05   7.889E+05   9.522E-01   9.083E+07   1.764E+07      19.42      32300
  32400   7.892E+05   7.889E+05   7.394E-01   9.083E+07   2.445E+07      26.92      32400
  32500   7.892E+05   7.889E+05   7.800E-01   9.083E+07   5.628E+05       0.62      32500


     **** PLOT TAPE WRITTEN AT TIME = 7.892E+05   STEP NUMBER      1 ****
.
.
.
.
.
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:20:43
        BENCHMARK II ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/9/95)

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER    400, TIME = 3.157E+08
     NUMBER OF ITERATIONS =       2502, TOTAL NUMBER OF ITERATIONS =    1988050
     FINAL CONVERGENCE TOLERANCE = 4.996E-01
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.611E+04
     SUM OF EXTERNAL FORCES IN Y-DIRECTION =-3.095E+03
     SUM OF REACTION FORCES IN X-DIRECTION =-1.573E+04
     SUM OF REACTION FORCES IN Y-DIRECTION =-9.436E+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
            3.477E+04 CPU SECONDS USED
               198720 WORDS ALLOCATED
```

APPENDIX S

Input/Output Data For Test Case 19

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. The binary file struct.th is an input file for Test Case 11 that can be found in LIBSANTOS in CMS.

bm2struct.fsq

```
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
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
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
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
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
```

struct.i

```
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
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
```

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.

```
      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
```

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.

struct.o

```
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 2.1.7-DP
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                               PROGRAMMED BY:

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



                         RUN ON 20030612 AT 11:21:51
                       RUN ON A     i686 UNDER Lx2.4.20

    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
```

```
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
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
```

```
   74: POISSONS RATIO = .33
   75: END
   76: EXIT
1                                    INPUT STREAM IMAGES
  LINE ---------------------------------------------------------------------------
   78: TITLE
   79:   BENCHMARK II HEATED PROBLEM - SANTOS VERIFICATION (1/17/95)
   80: RESIDUAL TOLERANCE = .50
   81: MAXIMUM ITERATIONS = 10000
   82: INTERMEDIATE PRINT = 100
   83: MAXIMUM TOLERANCE = 5.
   84: THERMAL STRESS, EXTERNAL
   85: PLANE STRAIN
   86: TIME STEP SCALE = .10
   87: PREDICTOR SCALE FACTOR = 3
   88: EFFECTIVE MODULUS = VARIABLE
   89: INITIAL STRESS = USER
   90: GRAVITY = 1 = 0. = -9.8066 = 0.
   91: STEP CONTROL
   92:   1000 3.157E8
   93: END
   94: PLOT TIME
   95:  10 3.157E8
   96: END
   97: OUTPUT TIME
   98:  10 3.157E8
   99: END
  100: PLOT NODAL DISPLACEMENT, REACTION, RESIDUAL
  101: PLOT ELEMENT STRESS, VONMISES, TEMPERATURE, EFFMOD
  102: PLOT STATE EQCS
  103: NO DISPLACEMENT X, 1
  104: NO DISPLACEMENT X, 12
  105: NO DISPLACEMENT Y, 12
  106: FUNCTION = 1
  107: 0. 1.
  108: 4.E8 1.
  109: END
  110: FUNCTION = 2
  111: 299.,-.02
  112: 350.,1.
  113: END
  114: FUNCTION = 3
  115: 0. 0.
  116: 4.E8 0.
  117: END
  118: PRESSURE, 13, 1, 12.71E6
  119: PRESSURE, 14, 1, 15.01E6
  120: CONTACT SURFACE, 8, 9, 0., .02, 1.E40
  121: CONTACT SURFACE, 11, 10, 0., .02, 1.E40
  122: CONTACT SURFACE, 15, 16, 0., .02, 1.E40
  123: CONTACT SURFACE, 18, 17, 0., .02, 1.E40
  124: MATERIAL, 1, POWER LAW CREEP, 2167., 2, 2.25E-3
  125: TWO MU = 19.84E9
  126: BULK MODULUS = 16.53E9
  127: CREEP CONSTANT = 5.79E-36
  128: STRESS EXPONENT = 4.9
  129: THERMAL CONSTANT = 6039.
  130: END
```

```
 131: MATERIAL, 2, POWER LAW CREEP, 2167., 2, 2.E-3
 132: TWO MU = 19.84E9
 133: BULK MODULUS = 16.53E9
 134: CREEP CONSTANT = 1.74E-35
 135: STRESS EXPONENT = 4.9
 136: THERMAL CONSTANT = 6039.
 137: END
 138: MATERIAL, 3, POWER LAW CREEP, 2167., 2, 2.135E-3
 139: TWO MU = 21.2E9
 140: BULK MODULUS = 17.66E9
 141: CREEP CONSTANT = 5.21E-36
 142: STRESS EXPONENT = 4.9
 143: THERMAL CONSTANT = 6039.
 144: END
 145: MATERIAL, 4, ELASTIC, 2167., 2, 1.E-3
 146: YOUNGS MODULUS = 72.4E9
 147: POISSONS RATIO = .33
 148: END
 149: MATERIAL, 5, ELASTIC, 2167., 2, 1.2E-3
 150: YOUNGS MODULUS = 72.4E9
 151: POISSONS RATIO = .33
 152: END
 153: EXIT
      ------------------------------------------------------------------------
1
                        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
```

```
        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
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


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
1	X
12	X
12	Y

C O N T A C T   S U R F A C E S

SURFACE NUMBER	SURFACE 1 FLAG	SURFACE 2 FLAG	PENALTY FACTOR	COEFFICIENT OF FRICTION	PENETRATION MULTIPLIER	TENSION RELEASE
1	8	9	0.000E+00	0.000E+00	2.000E-02	INF
2	11	10	0.000E+00	0.000E+00	2.000E-02	INF
3	15	16	0.000E+00	0.000E+00	2.000E-02	INF
4	18	17	0.000E+00	0.000E+00	2.000E-02	INF

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 FLAG	FUNCTION NUMBER	SCALE 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
9.000E-02 CPU SECONDS USED
11620 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
3.000E-02 CPU SECONDS USED
110968 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
```

**** 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
100	3.157E+05	3.157E+05	9.484E-01	1.223E+08	1.303E+07	10.66	100
200	3.157E+05	3.157E+05	9.700E-01	1.223E+08	9.171E+06	7.50	200
300	3.157E+05	3.157E+05	9.801E-01	1.223E+08	7.326E+06	5.99	300
400	3.157E+05	3.157E+05	9.823E-01	1.223E+08	5.850E+06	4.78	400
500	3.157E+05	3.157E+05	9.847E-01	1.223E+08	4.561E+06	3.73	500
600	3.157E+05	3.156E+05	9.862E-01	1.223E+08	3.411E+06	2.79	600
700	3.157E+05	3.156E+05	9.867E-01	1.223E+08	2.494E+06	2.04	700
800	3.157E+05	3.156E+05	9.865E-01	1.223E+08	1.859E+06	1.52	800
900	3.157E+05	3.156E+05	9.912E-01	1.223E+08	1.457E+06	1.19	900
1000	3.157E+05	3.156E+05	9.883E-01	1.223E+08	1.172E+06	0.96	1000
1100	3.157E+05	3.156E+05	9.872E-01	1.223E+08	9.596E+05	0.78	1100
1200	3.157E+05	3.156E+05	9.877E-01	1.223E+08	8.028E+05	0.66	1200
1300	3.157E+05	3.156E+05	9.771E-01	1.223E+08	6.925E+05	0.57	1300

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	6.314E+05	1.512E+04	9.938E-01	1.223E+08	1.695E+07	13.86	1484
200	6.314E+05	3.673E+04	9.950E-01	1.223E+08	1.380E+07	11.29	1584
300	6.314E+05	8.081E+04	9.915E-01	1.223E+08	9.325E+06	7.63	1684
400	6.314E+05	1.441E+05	9.998E-01	1.223E+08	6.020E+06	4.92	1784
500	6.314E+05	1.938E+05	9.659E-01	1.223E+08	4.187E+06	3.42	1884
600	6.314E+05	2.253E+05	9.933E-01	1.223E+08	3.062E+06	2.50	1984
700	6.314E+05	2.616E+05	9.896E-01	1.223E+08	2.299E+06	1.88	2084
800	6.314E+05	2.768E+05	9.883E-01	1.223E+08	1.875E+06	1.53	2184
900	6.314E+05	2.819E+05	9.905E-01	1.223E+08	1.555E+06	1.27	2284
1000	6.314E+05	2.838E+05	9.903E-01	1.223E+08	1.252E+06	1.02	2384
1100	6.314E+05	2.841E+05	9.895E-01	1.223E+08	9.710E+05	0.79	2484
1200	6.314E+05	2.840E+05	9.924E-01	1.223E+08	7.626E+05	0.62	2584

.
.
.
.

```
1     SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:21:51
       BENCHMARK II HEATED PROBLEM - SANTOS VERIFICATION (1/17/95)

      *******************************************************************
      SUMMARY OF DATA AT STEP NUMBER  1000, TIME = 3.157E+08
      NUMBER OF ITERATIONS =       3577, TOTAL NUMBER OF ITERATIONS =   2951435
      FINAL CONVERGENCE TOLERANCE = 4.997E-01
```

```
SUM OF EXTERNAL FORCES IN X-DIRECTION =-4.262E+04
SUM OF EXTERNAL FORCES IN Y-DIRECTION =-2.997E+04
SUM OF REACTION FORCES IN X-DIRECTION = 1.378E+06
SUM OF REACTION FORCES IN Y-DIRECTION = 1.027E+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
                      3.403E+04 CPU SECONDS USED
                         150040 WORDS ALLOCATED
```

APPENDIX T

Input/Output Data For Test Case 20

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.

reference.fsq

```
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
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
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
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
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
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
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
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
```

refiso.i

```
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
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
```

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.

```
      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
```

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.

refiso.o

```
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 2.1.7-DP
                         COPYRIGHT 1995, SANDIA CORPORATION

                                 PROGRAMMED BY:

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

```
                         RUN ON 20030612 AT 11:22:54
                       RUN ON A     i686 UNDER Lx2.4.20

 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
   71: EXIT
1                                    INPUT STREAM IMAGES
  LINE ---------------------------------------------------------------------------------
   73: TITLE
   74:   REFERENCE PARALLEL ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/24/95)
   75: RESIDUAL TOLERANCE = .5
   76: MAXIMUM ITERATIONS = 20000
   77: INTERMEDIATE PRINT = 100
   78: MAXIMUM TOLERANCE = 5.
   79: PLANE STRAIN
   80: TIME STEP SCALE = 0.7
   81: PREDICTOR SCALE FACTOR = 2
   82: EFFECTIVE MODULUS = VARIABLE
   83: INITIAL STRESS = USER
   84: GRAVITY = 1 = 0. = -9.790 = 0.
   85: STEP CONTROL
   86:  400 3.157E8
   87: END
   88: PLOT TIME
   89:  1 3.157E8
   90: END
   91: OUTPUT TIME
   92:  100 3.157E8
   93: END
   94: PLOT NODAL DISPLACEMENT, REACTION, RESIDUAL
   95: PLOT ELEMENT STRESS, VONMISES, EFFMOD
   96: PLOT STATE EQCS
   97: NO DISPLACEMENT X, 1
   98: NO DISPLACEMENT X, 2
   99: NO DISPLACEMENT Y, 2
  100: FUNCTION = 1
  101: 0. 1.
  102: 4.E8 1.
  103: END
  104: FUNCTION = 2
  105: 0. 0.
  106: 4.E8 0.
  107: END
  108: PRESSURE, 3, 1, 13.57E6
  109: PRESSURE, 4, 1, 15.96E6
  110: CONTACT SURFACE, 105, 106, FIXED,
  111: CONTACT SURFACE, 107, 108, FIXED,
```

```
  112: CONTACT SURFACE, 109, 110, 0.4,
  113: CONTACT SURFACE, 111, 112, 0.4,
  114: CONTACT SURFACE, 113, 114, 0.4,
  115: CONTACT SURFACE, 115, 116, 0.4,
  116: CONTACT SURFACE, 118, 117, 0.4,
  117: CONTACT SURFACE, 119, 120, 0.4,
  118: CONTACT SURFACE, 121, 122, 0.4,
  119: CONTACT SURFACE, 123, 124, FIXED,
  120: CONTACT SURFACE, 125, 126, FIXED,
  121: MATERIAL,1,POWER LAW CREEP,2300.   $  HALITE
  122: TWO MU = 24.8E9
  123: BULK MODULUS = 20.7E9
  124: CREEP CONSTANT = 5.79E-36
  125: STRESS EXPONENT = 4.9
  126: THERMAL CONSTANT = 20.13
  127: END
  128: MATERIAL,2,POWER LAW CREEP,2300.   $  ARGILLACEOUS HALITE
  129: TWO MU = 24.8E9
  130: BULK MODULUS = 20.7E9
  131: CREEP CONSTANT = 1.74E-35
  132: STRESS EXPONENT = 4.9
  133: THERMAL CONSTANT = 20.13
  134: END
  135: MATERIAL,3,ELASTIC,2300.    $  ANHYDRITE
  136: YOUNGS MODULUS = 75.1E9
  137: POISSONS RATIO = .35
  138: END
  139: MATERIAL,4,ELASTIC,2300.    $  POLYHALITE
  140: YOUNGS MODULUS = 55.3E9
  141: POISSONS RATIO = .36
  142: END
  143: EXIT
       ----------------------------------------------------------------------
1
                         P R O B L E M   T I T L E

          REFERENCE PARALLEL ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/24/95)



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

             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



      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

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

```
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 NUMBER	SURFACE 1 FLAG	SURFACE 2 FLAG	PENALTY FACTOR	COEFFICIENT OF FRICTION	PENETRATION MULTIPLIER	TENSION RELEASE
1	105	106	0.000E+00	FIXED	1.000E-02	1.000E+30

2	107	108	0.000E+00	FIXED	1.000E-02	1.000E+30
3	109	110	0.000E+00	4.000E-01	1.000E-02	1.000E+30
4	111	112	0.000E+00	4.000E-01	1.000E-02	1.000E+30
5	113	114	0.000E+00	4.000E-01	1.000E-02	1.000E+30
6	115	116	0.000E+00	4.000E-01	1.000E-02	1.000E+30
7	118	117	0.000E+00	4.000E-01	1.000E-02	1.000E+30
8	119	120	0.000E+00	4.000E-01	1.000E-02	1.000E+30
9	121	122	0.000E+00	4.000E-01	1.000E-02	1.000E+30
10	123	124	0.000E+00	FIXED	1.000E-02	1.000E+30
11	125	126	0.000E+00	FIXED	1.000E-02	1.000E+30

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 FLAG	FUNCTION NUMBER	SCALE 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
1.200E-01 CPU SECONDS USED
22772 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
2.000E-02 CPU SECONDS USED
249420 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	VONMISES	ITER
REACTX	EFFMOD	RMAG
REACTY	EQCS	

**** 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
100	7.892E+05	7.890E+05	8.078E-01	1.097E+08	2.346E+07	21.39	100
200	7.892E+05	7.890E+05	9.398E-01	1.097E+08	2.140E+07	19.51	200
300	7.892E+05	7.890E+05	8.960E-01	1.097E+08	8.387E+06	7.65	300
400	7.892E+05	7.889E+05	6.396E-01	1.097E+08	3.863E+06	3.52	400
500	7.892E+05	7.889E+05	9.509E-01	1.097E+08	4.651E+06	4.24	500
600	7.892E+05	7.889E+05	8.724E-01	1.097E+08	1.006E+07	9.17	600
700	7.892E+05	7.889E+05	9.353E-01	1.097E+08	6.387E+06	5.82	700
800	7.892E+05	7.889E+05	7.465E-01	1.097E+08	1.519E+07	13.85	800
900	7.892E+05	7.889E+05	9.632E-01	1.097E+08	2.753E+06	2.51	900
1000	7.892E+05	7.889E+05	5.406E-01	1.097E+08	2.683E+06	2.45	1000
1100	7.892E+05	7.889E+05	8.111E-01	1.097E+08	1.740E+06	1.59	1100
1200	7.892E+05	7.889E+05	8.503E-01	1.097E+08	9.304E+05	0.85	1200
1300	7.892E+05	7.889E+05	8.525E-01	1.097E+08	8.692E+05	0.79	1300
1400	7.892E+05	7.889E+05	7.870E-01	1.097E+08	7.771E+05	0.71	1400
1500	7.892E+05	7.889E+05	8.492E-01	1.097E+08	6.929E+05	0.63	1500
1600	7.892E+05	7.889E+05	8.063E-01	1.097E+08	6.355E+05	0.58	1600
1700	7.892E+05	7.889E+05	9.865E-01	1.097E+08	5.933E+05	0.54	1700
1800	7.892E+05	7.889E+05	9.084E-01	1.097E+08	7.023E+05	0.64	1800

**** PLOT TAPE WRITTEN AT TIME = 7.892E+05 STEP NUMBER 1 ****

problems may exist in tracking for slave node 947

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	1.578E+06	2.184E+05	9.714E-01	1.097E+08	7.981E+06	7.28	1979
200	1.578E+06	2.030E+05	9.870E-01	1.097E+08	4.273E+06	3.90	2079
300	1.578E+06	6.799E+05	7.774E-01	1.097E+08	3.109E+06	2.83	2179
400	1.578E+06	6.762E+05	8.328E-01	1.097E+08	2.654E+06	2.42	2279
500	1.578E+06	6.735E+05	8.639E-01	1.097E+08	1.760E+06	1.60	2379
600	1.578E+06	6.515E+05	9.700E-01	1.097E+08	2.837E+06	2.59	2479
700	1.578E+06	6.379E+05	6.311E-01	1.097E+08	2.986E+06	2.72	2579
800	1.578E+06	6.291E+05	7.290E-01	1.097E+08	2.429E+06	2.21	2679
900	1.578E+06	6.236E+05	8.732E-01	1.097E+08	1.353E+06	1.23	2779
1000	1.578E+06	6.186E+05	8.593E-01	1.097E+08	1.149E+06	1.05	2879
1100	1.578E+06	6.150E+05	8.931E-01	1.097E+08	9.910E+05	0.90	2979
1200	1.578E+06	6.126E+05	8.820E-01	1.097E+08	9.424E+05	0.86	3079
1300	1.578E+06	6.108E+05	8.481E-01	1.097E+08	8.640E+05	0.79	3179
1400	1.578E+06	6.099E+05	9.839E-01	1.097E+08	8.151E+05	0.74	3279
1500	1.578E+06	6.092E+05	9.372E-01	1.097E+08	7.917E+05	0.72	3379
1600	1.578E+06	6.089E+05	9.963E-01	1.097E+08	1.441E+06	1.31	3479
1700	1.578E+06	6.088E+05	9.712E-01	1.097E+08	6.873E+05	0.63	3579
1800	1.578E+06	6.088E+05	9.878E-01	1.097E+08	6.873E+05	0.63	3679
1900	1.578E+06	6.089E+05	9.844E-01	1.097E+08	6.454E+05	0.59	3779
2000	1.578E+06	6.092E+05	9.939E-01	1.097E+08	8.108E+05	0.74	3879
2100	1.578E+06	6.099E+05	9.709E-01	1.097E+08	7.223E+05	0.66	3979
2200	1.578E+06	6.103E+05	9.608E-01	1.097E+08	9.296E+05	0.85	4079
2300	1.578E+06	6.106E+05	9.848E-01	1.097E+08	9.467E+05	0.86	4179
2400	1.578E+06	6.109E+05	8.948E-01	1.097E+08	9.494E+05	0.87	4279
2500	1.578E+06	6.111E+05	8.926E-01	1.097E+08	8.902E+05	0.81	4379
2600	1.578E+06	6.113E+05	9.476E-01	1.097E+08	1.288E+06	1.17	4479
2700	1.578E+06	6.115E+05	9.835E-01	1.097E+08	6.398E+05	0.58	4579

```
  2800  1.578E+06  6.118E+05  9.777E-01  1.097E+08  5.710E+05       0.52       4679


    **** PLOT TAPE WRITTEN AT TIME = 1.578E+06   STEP NUMBER      2 ****
```

STEP	TIME	TIME STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	2.368E+06	1.375E+05	8.760E-01	1.097E+08	6.609E+06	6.03	4823
200	2.368E+06	2.941E+05	9.515E-01	1.097E+08	3.240E+06	2.95	4923
300	2.368E+06	3.144E+05	9.976E-01	1.097E+08	2.089E+06	1.90	5023
400	2.368E+06	6.733E+05	8.730E-01	1.097E+08	1.409E+06	1.28	5123
500	2.368E+06	6.721E+05	9.230E-01	1.097E+08	1.036E+06	0.94	5223
600	2.368E+06	6.762E+05	9.434E-01	1.097E+08	9.323E+05	0.85	5323
700	2.368E+06	6.810E+05	8.104E-01	1.097E+08	8.781E+05	0.80	5423
800	2.368E+06	6.867E+05	7.438E-01	1.097E+08	9.046E+05	0.82	5523
900	2.368E+06	6.909E+05	8.272E-01	1.097E+08	7.764E+05	0.71	5623
1000	2.368E+06	6.950E+05	9.612E-01	1.097E+08	7.432E+05	0.68	5723
1100	2.368E+06	6.993E+05	7.450E-01	1.097E+08	7.104E+05	0.65	5823
1200	2.368E+06	7.026E+05	9.949E-01	1.097E+08	6.855E+05	0.62	5923
1300	2.368E+06	7.066E+05	9.627E-01	1.097E+08	6.791E+05	0.62	6023
1400	2.368E+06	7.100E+05	8.482E-01	1.097E+08	7.080E+05	0.65	6123
1500	2.368E+06	7.123E+05	6.345E-01	1.097E+08	6.318E+05	0.58	6223
1600	2.368E+06	7.147E+05	8.903E-01	1.097E+08	6.207E+05	0.57	6323
1700	2.368E+06	7.168E+05	9.592E-01	1.097E+08	6.022E+05	0.55	6423
1800	2.368E+06	7.193E+05	8.114E-01	1.097E+08	6.257E+05	0.57	6523
1900	2.368E+06	7.211E+05	9.042E-01	1.097E+08	5.965E+05	0.54	6623
2000	2.368E+06	7.229E+05	8.011E-01	1.097E+08	5.731E+05	0.52	6723
2100	2.368E+06	7.248E+05	7.413E-01	1.097E+08	6.717E+05	0.61	6823

```
    **** PLOT TAPE WRITTEN AT TIME = 2.368E+06   STEP NUMBER      3 ****
 .
 .
 .
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:22:54
        REFERENCE PARALLEL ISOTHERMAL PROBLEM - SANTOS VERIFICATION (1/24/95)

    **********************************************************************
    SUMMARY OF DATA AT STEP NUMBER    400, TIME = 3.157E+08
    NUMBER OF ITERATIONS =       1283, TOTAL NUMBER OF ITERATIONS =     582447
    FINAL CONVERGENCE TOLERANCE = 4.999E-01
    SUM OF EXTERNAL FORCES IN X-DIRECTION = 1.672E+04
    SUM OF EXTERNAL FORCES IN Y-DIRECTION = 2.974E+04
    SUM OF REACTION FORCES IN X-DIRECTION = 8.938E+04
    SUM OF REACTION FORCES IN Y-DIRECTION =-1.023E+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
            1.414E+04 CPU SECONDS USED
               303618 WORDS ALLOCATED
```

APPENDIX U

Input/Output Data For Test Case 21

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. The binary file struct.th is an input file for Test Case 11 that can be found in LIBSANTOS in CMS.

refheated.fsq

```
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
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
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
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
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
```

```
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
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
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
```

struct.i

```
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,
```

```
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
```

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.

```
      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
```

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.

struct.o

```
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 2.1.7-DP
```

PROGRAMMED BY:

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

RUN ON 20030612 AT 11:26:16
RUN ON A   i686 UNDER Lx2.4.20

```
TITLE
  REFERENCE PARALLEL HEATED PROBLEM - SANTOS VERIFICATION (1/27/95)
RESIDUAL TOLERANCE = .5
MAXIMUM ITERATIONS = 10000
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
```

```
   43: CONTACT SURFACE, 1013, 1011, FIXED,
   44: CONTACT SURFACE, 1025, 1023, FIXED,
   45: CONTACT SURFACE, 1037, 1035, 0.4
   46: CONTACT SURFACE, 1044, 1042, 0.4
   47: CONTACT SURFACE, 1061, 1059, 0.4
   48: CONTACT SURFACE, 1071, 1070, 0.4
   49: CONTACT SURFACE, 1075, 1074, 0.4
   50: CONTACT SURFACE, 1082, 1081, 0.4
   51: CONTACT SURFACE, 1091, 1089, 0.4
   52: CONTACT SURFACE, 1103, 1101, 0.4
   53: CONTACT SURFACE, 1120, 1118, 0.4
   54: CONTACT SURFACE, 1127, 1125, FIXED,
   55: MATERIAL, 1, POWER LAW CREEP, 2300., 2, 4.5E-3  $  HALITE
   56: TWO MU = 24.8E9
   57: BULK MODULUS = 20.7E9
   58: CREEP CONSTANT = 5.79E-36
   59: STRESS EXPONENT = 4.9
   60: THERMAL CONSTANT = 6039.
   61: END
   62: MATERIAL, 2, POWER LAW CREEP, 2300., 2, 4.E-3   $  ARGILLACEOUS HALITE
   63: TWO MU = 24.8E9
   64: BULK MODULUS = 20.7E9
   65: CREEP CONSTANT = 1.74E-35
   66: STRESS EXPONENT = 4.9
   67: THERMAL CONSTANT = 6039.
   68: END
   69: MATERIAL, 3, SOIL N FOAMS, 2300., 2, 2.E-3      $ ANHYDRITE
   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
1                                    INPUT STREAM IMAGES
  LINE ------------------------------------------------------------------------
   89: TITLE
   90:   REFERENCE PARALLEL HEATED PROBLEM - SANTOS VERIFICATION (1/27/95)
   91: RESIDUAL TOLERANCE = .5
   92: MAXIMUM ITERATIONS = 10000
   93: INTERMEDIATE PRINT = 100
   94: MAXIMUM TOLERANCE = 5.
   95: THERMAL STRESS, EXTERNAL
   96: PLANE STRAIN
   97: TIME STEP SCALE = .50
   98: PREDICTOR SCALE FACTOR = 3
   99: 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,
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
```

```
158: TWO MU = 55.630E9
159: BULK MODULUS = 83.444E9
160: A0 = 2.3383E6
161: A1 = 2.3383
162: A2 = 0.0
163: PRESSURE CUTOFF = -1.0E6
164: FUNCTION ID = 0
165: END
166: MATERIAL, 4, SOIL N FOAMS, 2300., 2, 2.4E-3     $ POLYHALITE
167: TWO MU = 40.662E9
168: BULK MODULUS = 65.833E9
169: A0 = 2.4595E6
170: A1 = 2.4578
171: A2 = 0.0
172: PRESSURE CUTOFF = -1.0E6
173: FUNCTION ID = 0
174: END
175: EXIT
     -----------------------------------------------------------------------
1
```

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	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	5.000E-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

```
  TIME           NO. OF STEPS          TIME
0.000E+00            400            1.578E+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             1.578E+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             1.578E+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
 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
          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  -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 NUMBER	SURFACE 1 FLAG	SURFACE 2 FLAG	PENALTY FACTOR	COEFFICIENT OF FRICTION	PENETRATION MULTIPLIER	TENSION RELEASE
1	1013	1011	0.000E+00	FIXED	1.000E-02	1.000E+30
2	1025	1023	0.000E+00	FIXED	1.000E-02	1.000E+30
3	1037	1035	0.000E+00	4.000E-01	1.000E-02	1.000E+30
4	1044	1042	0.000E+00	4.000E-01	1.000E-02	1.000E+30
5	1061	1059	0.000E+00	4.000E-01	1.000E-02	1.000E+30
6	1071	1070	0.000E+00	4.000E-01	1.000E-02	1.000E+30
7	1075	1074	0.000E+00	4.000E-01	1.000E-02	1.000E+30
8	1082	1081	0.000E+00	4.000E-01	1.000E-02	1.000E+30
9	1091	1089	0.000E+00	4.000E-01	1.000E-02	1.000E+30
10	1103	1101	0.000E+00	4.000E-01	1.000E-02	1.000E+30
11	1120	1118	0.000E+00	4.000E-01	1.000E-02	1.000E+30
12	1127	1125	0.000E+00	FIXED	1.000E-02	1.000E+30

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 FLAG	FUNCTION NUMBER	SCALE 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
1.000E-01 CPU SECONDS USED
21824 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
1.000E-02 CPU SECONDS USED

241570 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 STEP	DAMPING FACTOR	APPLIED LOAD NORM	RESIDUAL LOAD NORM	PERCENT IMBALANCE	TOTAL STEPS
100	3.946E+05	3.944E+05	9.292E-01	6.429E+07	4.314E+06	6.71	100
200	3.946E+05	3.944E+05	9.549E-01	6.429E+07	2.015E+06	3.13	200
300	3.946E+05	3.944E+05	8.681E-01	6.429E+07	1.546E+06	2.41	300
400	3.946E+05	3.944E+05	9.554E-01	6.429E+07	1.372E+06	2.13	400
500	3.946E+05	3.944E+05	9.141E-01	6.429E+07	1.072E+06	1.67	500
600	3.946E+05	3.944E+05	8.801E-01	6.429E+07	9.493E+05	1.48	600
700	3.946E+05	3.944E+05	9.746E-01	6.429E+07	8.961E+05	1.39	700
800	3.946E+05	3.944E+05	9.594E-01	6.429E+07	8.304E+05	1.29	800
900	3.946E+05	3.944E+05	8.429E-01	6.429E+07	7.809E+05	1.21	900
1000	3.946E+05	3.944E+05	8.737E-01	6.429E+07	7.303E+05	1.14	1000
1100	3.946E+05	3.944E+05	9.708E-01	6.429E+07	6.918E+05	1.08	1100
1200	3.946E+05	3.944E+05	9.803E-01	6.429E+07	5.617E+05	0.87	1200
1300	3.946E+05	3.944E+05	9.601E-01	6.429E+07	4.945E+05	0.77	1300
1400	3.946E+05	3.944E+05	1.000E+00	6.429E+07	4.598E+05	0.72	1400
1500	3.946E+05	3.944E+05	9.730E-01	6.429E+07	4.357E+05	0.68	1500
1600	3.946E+05	3.944E+05	8.802E-01	6.429E+07	4.152E+05	0.65	1600
1700	3.946E+05	3.944E+05	9.774E-01	6.429E+07	3.994E+05	0.62	1700
1800	3.946E+05	3.944E+05	9.977E-01	6.429E+07	3.860E+05	0.60	1800
1900	3.946E+05	3.944E+05	9.196E-01	6.429E+07	3.709E+05	0.58	1900
2000	3.946E+05	3.944E+05	8.722E-01	6.429E+07	3.624E+05	0.56	2000
2100	3.946E+05	3.944E+05	8.716E-01	6.429E+07	3.567E+05	0.55	2100
2200	3.946E+05	3.944E+05	8.414E-01	6.429E+07	3.526E+05	0.55	2200
2300	3.946E+05	3.944E+05	1.000E+00	6.429E+07	3.476E+05	0.54	2300
2400	3.946E+05	3.944E+05	1.000E+00	6.429E+07	3.222E+05	0.50	2400

STEP TIME TIME DAMPING APPLIED RESIDUAL PERCENT TOTAL

		STEP	FACTOR	LOAD NORM	LOAD NORM	IMBALANCE	STEPS
100	7.892E+05	1.456E+05	9.743E-01	6.429E+07	4.540E+06	7.06	2503
200	7.892E+05	2.479E+05	9.499E-01	6.429E+07	2.097E+06	3.26	2603
300	7.892E+05	3.356E+05	9.927E-01	6.429E+07	1.268E+06	1.97	2703
400	7.892E+05	3.396E+05	9.718E-01	6.429E+07	8.266E+05	1.29	2803
500	7.892E+05	3.396E+05	9.915E-01	6.429E+07	6.825E+05	1.06	2903
600	7.892E+05	3.396E+05	9.170E-01	6.429E+07	5.760E+05	0.90	3003
700	7.892E+05	3.396E+05	9.287E-01	6.429E+07	5.255E+05	0.82	3103
800	7.892E+05	3.396E+05	9.591E-01	6.429E+07	4.896E+05	0.76	3203
900	7.892E+05	3.396E+05	9.675E-01	6.429E+07	4.589E+05	0.71	3303
1000	7.892E+05	3.396E+05	9.390E-01	6.429E+07	4.463E+05	0.69	3403
1100	7.892E+05	3.396E+05	9.970E-01	6.429E+07	4.187E+05	0.65	3503
1200	7.892E+05	3.396E+05	9.618E-01	6.429E+07	4.085E+05	0.64	3603
1300	7.892E+05	3.396E+05	9.558E-01	6.429E+07	5.794E+05	0.90	3703
1400	7.892E+05	3.396E+05	9.722E-01	6.429E+07	3.929E+05	0.61	3803
1500	7.892E+05	3.396E+05	8.803E-01	6.429E+07	6.230E+05	0.97	3903
1600	7.892E+05	3.396E+05	9.961E-01	6.429E+07	6.944E+05	1.08	4003
1700	7.892E+05	3.396E+05	9.305E-01	6.429E+07	3.596E+05	0.56	4103
1800	7.892E+05	3.396E+05	9.946E-01	6.429E+07	3.845E+05	0.60	4203
1900	7.892E+05	3.396E+05	8.254E-01	6.429E+07	3.760E+05	0.58	4303
2000	7.892E+05	3.396E+05	9.954E-01	6.429E+07	3.494E+05	0.54	4403
2100	7.892E+05	3.396E+05	9.992E-01	6.429E+07	5.311E+05	0.83	4503
2200	7.892E+05	3.396E+05	9.068E-01	6.429E+07	4.934E+05	0.77	4603
2300	7.892E+05	3.396E+05	8.137E-01	6.429E+07	5.438E+05	0.85	4703

```
.
.
.
1      SANTOS, VERSION 2.1.7-DP, RUN ON 20030612, AT 11:26:16
        REFERENCE PARALLEL HEATED PROBLEM - SANTOS VERIFICATION (1/27/95)

     **********************************************************************
     SUMMARY OF DATA AT STEP NUMBER   400, TIME = 1.578E+08
     NUMBER OF ITERATIONS =      7838, TOTAL NUMBER OF ITERATIONS =   1531091
     FINAL CONVERGENCE TOLERANCE = 4.920E-01
     SUM OF EXTERNAL FORCES IN X-DIRECTION = 5.388E+03
     SUM OF EXTERNAL FORCES IN Y-DIRECTION =-1.996E+04
     SUM OF REACTION FORCES IN X-DIRECTION = 6.332E+04
     SUM OF REACTION FORCES IN Y-DIRECTION =-6.889E+06
     **********************************************************************


     **** PLOT TAPE WRITTEN AT TIME = 1.578E+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
                            3.812E+04 CPU SECONDS USED
                               311518 WORDS ALLOCATED
```

```
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
```

APPENDIX AA

Generation of SANTOS Executables

Normally, SANTOS runs using the default executable. When the ACCESS system is installed, the source code for SANTOS is compiled into an object library. This object library is linked to create the default SANTOS executable.

Some test cases in this validation document require the use of user subroutines in addition to the SANTOS code. For these test cases, the SANTOS object library is linked with the compiled user subroutine to create a "local" executable for that test case. The re-linking of SANTOS does not alter the object files in the SANTOS library. Thus, the SANTOS subroutines are identical in both the default and the local executables.

Table AA.1 lists the executable used for each test case, its path, its size and the date the executable was created.

Table AA.1 Executables used in SANTOS validation tests

Test Case	Executable Name	Path	Size and Date
1	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
2	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
3	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
4	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
5	santos (local)	/home/jialin/santos-2.1.7_test/test_05	884934 (6/12/03 10:40)
6	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
7	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
8	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
9	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
10	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
11	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
12	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
13	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
14	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
15	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
16	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
17	santos	/data/ACCESS/bin	885509 (6/9/03 12:46)
18	santos (local)	/home/jialin/santos-2.1.7_test/test_18	885581 (6/12/03 11:20)
19	santos (local)	/home/jialin/santos-2.1.7_test/test_19	885851 (6/12/03 11:21)
20	santos (local)	/home/jialin/santos-2.1.7_test/test_20	885613 (6/12/03 11:22)
21	santos (local)	/home/jialin/santos-2.1.7_test/test_21	885851 (6/12/03 11:26)

(local) indicates that the executable was created in a local directory

The subroutine, fpres.f, was used in Test Case 5. Its path is /home/jialin/santos-2.1.7_test/test_05.

fpres.f

```
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)
c
      INCLUDE 'precision.blk'
c
c.....vol1 is taken from NUMBERS evaluation of Genesis file
c
      vol1 = 1.425
      po = 10.
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
      pgas = po*vol1/volume
c
c
      return
      end
```

The subroutine, initst.f, was used in Test Case 18. Its path is /home/jialin/santos-2.1.7_test/test_18.

initst.f

```
      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 'precision.blk'
      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 )
CCC               STRESS = -14.8E6
CCC               IF( MATID .NE. 1 )THEN
CCC                  STRESS = 0.
CCC               END IF
               SIG(1,J) = STRESS
               SIG(2,J) = STRESS
               SIG(3,J) = STRESS
               SIG(4,J) = 0.0

  500       CONTINUE
 1000 CONTINUE
      RETURN
      END
```

The subroutine, initst.f, was used in Test Case 19. Its path is /home/jialin/santos-2.1.7_test/test_19.

initst.f

```
      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 'precision.blk'
      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
      RL = -5.980200E+02 + 7.067700E+02
      BL = -7.067700E+02
      P1 = -12.71E+06
      P2 = -15.01E+06
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) )
               S = (ZAVG - BL)/RL
               STRESS = P1*S + P2*(1. - S)
c
               SIG(1,J) = STRESS
               SIG(2,J) = STRESS
               SIG(3,J) = STRESS
               SIG(4,J) = 0.0

  500       CONTINUE
 1000 CONTINUE
      RETURN
      END
```

The subroutine, initst.f, was used in Test Case 20. Its path is /home/jialin/santos-2.1.7_test/test_20.

initst.f

```
      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 'precision.blk'
      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
```

The subroutine, initst.f, was used in Test Case 21. Its path is /home/jialin/santos-2.1.7_test/test_21.

initst.f

```
      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 'precision.blk'
      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
      RL =  52.87 + 54.19
      BL = -54.19
      P1 = -13.57E+06
      P2 = -15.95E+06
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) )
               S = (ZAVG - BL)/RL
               STRESS = P1*S + P2*(1. - S)
C
               SIG(1,J) = STRESS
               SIG(2,J) = STRESS
               SIG(3,J) = STRESS
               SIG(4,J) = 0.0

  500       CONTINUE
 1000 CONTINUE
      RETURN
      END
```