OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

1. QA: QA

Complete Only Applicable Items

Page: 1 of: 1

This is a placeholder page for records that cannot be scanned or microfilmed

2. Record Date

~~09/23/99~~ 09/22/98 9/14/99

3. Accession Number

MOL. 19981014. 0002

4. Author Name(s)

Ming Lin/Dwayne Kicker

5. Author Organization

M&O

6. Title

Deformation Monitoring Analysis

7. Document Number(s)

BABEE0000-01717-5705-00005

8. Version

00

9. Document Type

DESIGN DOCUMENT

10. Medium

PAPER OPTIC

11. Access Control Code

PUB

12. Traceability Designator

BABEE0000-01717-5705-00005

13. Comments

THIS ONE OF A KIND COLOR
DOCUMENT CAN BE LOCATED
THROUGH THE RECORDS
PROCESSING CENTER

ESF DESIGN CONFIRMATION
TASK 4

MOL.19981014.0002

PERMANENT

TECHNICAL DOCUMENT TITLE

DEFORMATION MONITORING ANALYSIS

DOCUMENT IDENTIFIER (Including Rev. No.)

BABEE0000-01717-5705-00005 REV 00

DATE

September 1998

Preparers:

MING LIN
Geotechnical Engineer

Date:

9/22/98

DWAYNE C. KICKER
Geotechnical Engineer

Date:

9/22/98

Approvals:

JOHN H. PYE
Lead Geotechnical Engineer

Date:

9/22/98

WILLIAM R. KENNEDY
Responsible Manager

Date:

9/23/98

Checker
Concurrence:
DAVID H. TANG
Repository Subsurface Design

Date:

9/22/98

WILLIAM C. FRENCH
PCG Compliance Check

Date:

9/22/98

REMARKS:

TBV-403 applies to this design confirmation document.

TABLE OF CONTENTS

	Page
LIST OF FIGURES	3
LIST OF TABLES	5
1.0 INTRODUCTION	6
1.1 SCOPE	6
1.2 BACKGROUND	7
1.3 REPORT ORGANIZATION	7
2.0 QUALITY ASSURANCE	8
3.0 METHOD	8
4.0 DATA AND INFORMATION	8
4.1 DESIGN CONFIRMATION PARAMETERS	8
4.2 DESIGN CONFIRMATION CRITERIA	9
4.3 ASSUMPTIONS	10
5.0 REFERENCES	10
6.0 COMPUTER SOFTWARE	13
6.1 QUALIFIED COMPUTER SOFTWARE	14
6.2 NON-QUALIFIED SOFTWARE	14
7.0 DESIGN CONFIRMATION ANALYSIS	15
7.1 INTRODUCTION	15
7.2 SUMMARY OF ESF TUNNEL CONVERGENCE DATA	16
7.2.1 Summary of Tape Extensometer Convergence Data	16
7.2.2 Summary of Borehole Extensometer Deformation Data	28
7.2.3 Comparison of the Deformation Data from Tape Extensometers and Borehole Extensometers	29
7.3 ANALYSIS OF CONVERGENCE DATA	32
7.3.1 Interpretation of Convergence Measurements — The Convergence Solution	32
7.3.1.1 Background	32
7.3.1.2 Convergence Solution Analysis of Selected Borehole Extensometer Data	34
7.3.2 Correlation of Tunnel Deformation and Rock Mass Quality	36
7.3.3 Comparison of Monitored Deformation Data to Design Analysis Results	37
7.4 DETERMINATION OF ROCK MASS MODULUS OF DEFORMATION FROM CONVERGENCE MONITORING DATA	38
8.0 CONCLUSIONS AND RECOMMENDATIONS	39
8.1 CONCLUSIONS	40
8.2 RECOMMENDATIONS	41
9.0 ATTACHMENTS	42

LIST OF FIGURES

	Page
Figure 1. Schematic Layout of the Measurement Chord for Tape Extensometer (Looking at the Face)	43
Figure 2. Tape Extensometer Convergence Data Monitored in TCw Unit with Ground Support Class 4	44
Figure 3. Tape Extensometer Convergence Data Monitored in UO Unit with Ground Support Class 4	45
Figure 4. Tape Extensometer Convergence Data Monitored in PTn Unit with Ground Support Class 1	46
Figure 5. Tape Extensometer Convergence Data Monitored in TSw1 Unit with Ground Support Class 1	47
Figure 6. Tape Extensometer Convergence Data Monitored in TSw2 Unit with Ground Support Class 1	48
Figure 7. Schematic Layout of a Station with Borehole Extensometer (Looking at the Face)	49
Figure 8. Borehole Extensometer Deformation Data and Convergence Rate, Station 04+13	50
Figure 9. Borehole Extensometer Deformation Data and Convergence Rate, Station 09+75	51
Figure 10. Borehole Extensometer Deformation Data, Station 18+30	52
Figure 11. Borehole Extensometer Deformation Data and Convergence Rate, Station 21+34	53
Figure 12. Borehole Extensometer Deformation Data and Convergence Rate, Station 27+70	54
Figure 13. Borehole Extensometer Deformation Data and Convergence Rate, Station 28+28	55
Figure 14. Borehole Extensometer Deformation Data and Convergence Rate, Station 31+02	56
Figure 15. Borehole Extensometer Deformation Data and Convergence Rate, Station 34+01	57
Figure 16. Borehole Extensometer Deformation Data and Convergence Rate, Station 37+37	58
Figure 17. Borehole Extensometer Deformation Data and Convergence Rate, Station 42+47	59
Figure 18. Borehole Extensometer Deformation Data and Convergence Rate, Station 47+06	60
Figure 19. Borehole Extensometer Deformation Data and Convergence Rate, Station 50+64	61
Figure 20. Borehole Extensometer Deformation Data and Convergence Rate, Station 55+71	62

Figure 21. Borehole Extensometer Deformation Data and Convergence Rate, Station 60+55	63
Figure 22. Borehole Extensometer Deformation Data and Convergence Rate, Station 63+06	64
Figure 23. Borehole Extensometer Deformation Data and Convergence Rate, Station 67+95	65
Figure 24. Borehole Extensometer Deformation Data and Convergence Rate, Station 72+48	66
Figure 25. Deformation in the Rock Mass, Station 21+34	67
Figure 26. Deformation in the Rock Mass, Station 28+28	68
Figure 27. Comparison of the Instrumentation Results from the Tape Extensometers and Borehole Extensometer	69
Figure 28. Radial Convergence along the Tunnel Axis (for Time-independent Rock Mass Response)... ..	73
Figure 29. Estimated Complete Convergence Curve and its Comparison with the Instrumentation Data, Station 21+34	74
Figure 30. Estimated Complete Convergence Curve and its Comparison with the Instrumentation Data, Station 27+70	75
Figure 31. Estimated Complete Convergence Curve and its Comparison with the Instrumentation Data, Station 31+02	76
Figure 32. Estimated Complete Convergence Curve and its Comparison with the Instrumentation Data, Station 55+71	77
Figure 33. Estimated Complete Convergence Curve and its Comparison with the Instrumentation Data, Station 60+55	78
Figure 34. Estimated Complete Convergence Curve and its Comparison with the Instrumentation Data, Station 67+95	79
Figure 35. Predicted Long Term Roof Deformation for the Six Stations	80
Figure 36. Correlation of Tunnel Convergence with Q/Span, TCw Unit	81
Figure 37. Correlation of Tunnel Convergence with Q/Span, UO Unit	82
Figure 38. Correlation of Tunnel Convergence with Q/Span, PTn Unit	83
Figure 39. Correlation of Tunnel Convergence with Q/Span, TSw1 Unit	84
Figure 40. Correlation of Tunnel Convergence with Q/Span, TSw2 Unit	85
Figure 41. Correlation of MPBX Roof Convergence with Q/Span	86
Figure 42. Correlation of Estimated Convergence from Convergence Solution (Reference 5.2) with Q/Span	87
Figure 43. Comparison of Vertical Displacement Magnitudes in the ESF	88
Figure 44. Comparison of Horizontal Displacement Magnitudes in the ESF	88
Figure 45. Comparison of Rock Mass Modulus Assessment Methods	89

LIST OF TABLES

	Page
Table 1. Design Confirmation Parameters	9
Table 2. Summary of Tape Extensometer Convergence Data	18
Table 3. ESF Main Loop Recommended Ground Support Classes (Reference 5.10)	26
Table 4. Descriptive Statistics of the Maximum Convergence Data from Tape Extensometers	27
Table 5. Summary of Borehole Extensometer Deformation Data in ESF Main Loop	30
Table 6. Descriptive Statistics of the Maximum Deformation from Borehole Extensometer	32
Table 7. Curve-Fit Results Using Convergence Solution (Reference 5.2)	36
Table 8. Estimated Deformation and the Percentage of Relaxation at Ground Support Installation	36
Table 9. Predicted Convergence Rate at 5 Years after Excavation and the Ultimate Convergence	36
Table 10. Back Calculation of Rock Mass Modulus of Deformation from Convergence Data (Reference 5.1)	39

1.0 INTRODUCTION

The purpose of this Exploratory Studies Facility (ESF) design confirmation analysis is to satisfy the requirements of 10 CFR 60.141 (Reference 5.34), "Confirmation of Geotechnical and Design Parameters," as it relates to ESF ground support and opening design. The specific objectives for this analysis include the following:

- Correlate tunnel convergence rates and magnitudes as a function of thermal mechanical unit and the associated rock mass properties (10 CFR 60.141(c)).
- Confirm the design assumption that limited displacements (50% to 60% of the total displacement) will occur prior to ground support installation (10 CFR 60.141(b), (d)).
- Conduct a regression analysis of displacement data to address future potential displacement anomalies (10 CFR 60.141(e)).
- Predict long-term tunnel displacement and convergence rates (10 CFR 60.141(e)).
- Compare tunnel closure and closure rates in the ESF to the U.S. Department of Energy (DOE) Site Characterization Plan tentative goals (10 CFR 60.141(b)).
- Assess long-term tunnel stability based on predicted long-term tunnel displacement and convergence rates (10 CFR 60.141(e)).
- Back calculate the rock mass modulus of deformation from the convergence data (10 CFR 60.141(c)).

The results from this analysis may assist in ground support reconciliation and provide a baseline for ongoing inspection, up-grading and maintenance during the Operations and Maintenance (O&M) phase of the ESF operations. The results from this activity may also support Repository Design data and information needs.

The instrumentation data monitored in ESF tunnel were obtained under ambient condition. The predictions of long-term tunnel displacement based on the ESF monitored data are therefore not directly applicable to those underground openings which will be subjected to thermal loads.

1.1 SCOPE

This report presents an analysis of tunnel deformation in the ESF based on convergence monitoring data. Displacement data from 94 tape extensometer stations and 18 borehole extensometer stations along the ESF Main Loop (i.e., the North Ramp, Main Drift, and South Ramp) were evaluated as part of this analysis. A semi-empirical convergence solution has been applied to interpret the convergence measurements to estimate ground behavior prior to installation of the convergence monitoring station and to predict long-term tunnel displacement. An analytical solution that relates convergence to elastic modulus was applied to estimate rock mass modulus.

This analysis completes Task 4 of the ESF Design Confirmation activities. Additional design confirmation analyses that are either currently underway or are completed include:

- Task 1 — Key ESF Design/Geomechanics Parameters Confirmation (Reference 5.12)
- Task 2 — ESF Ground Support Confirmation (Reference 5.13)
- Task 3 — Confirmation of Empirical Design Methodologies (Reference 5.14)
- Task 5 — Key Block Analyses (in progress)
- Task 6 — Steel Set Loads Analysis (in progress)
- Task 7 — Geology of the Exploratory Studies Facility Topopah Spring Main Loop (Reference 5.15)
- Task 8 — Controlled Drilling and Blasting Design Confirmation Analysis (Reference 5.16).

1.2 BACKGROUND

ESF design confirmation activities are part of the baseline phase of performance confirmation (Reference 5.35, p. 8.3.5.16-3) as required by 10 CFR 60.140(b) and 10 CFR 60.140 (c). The purpose of the ESF design confirmation is to address the 10 CFR 60.141 requirements with specific reference to confirmation of geotechnical parameters used in rock support design. The range of the rock mass property values used in the design of the ESF ground support system was originally based on North Ramp geotechnical (NRG) borehole data. Scanline data, full peripheral mapping, tunnel convergence measurements and ground support instrumentation have provided a substantial volume of data and information that have been used to confirm key ESF design parameters and hence the original basis for design. The acquired data and information also serve to confirm the empirical and analytical design methodologies used in the design of the ESF ground support systems. Any significant variance between the actual and predicted performance of the installed ground support system will be resolved as part of the ground support confirmation program. This data and information will be incorporated into the performance confirmation baseline and will serve as the technical basis for ongoing assessments of the ESF including periodic inspection and maintenance of the facility openings and ground support.

Because of Corrective Action Report (CAR) YM-97-C-004 regarding procurement and QA issues with the manufacturer (Geokon), the instrumentation data are considered "indeterminate". TBV-403 is applied to all the Geokon instrumentation related data. It is anticipated that the data will be qualified upon resolution of the QA issues.

1.3 REPORT ORGANIZATION

The format of this document follows the general guidelines of the Technical Document Preparation Plan (TDPP) for design confirmation analyses (Reference 5.7). Section 1 describes the purpose of this analysis, how it relates to the ESF design and how it supports the design confirmation process. Section 2 indicates the applicability of the Quality Assurance (QA) program. An outline of the analytical methods used in this design confirmation analysis is presented in Section 3. The source of all data and information is identified and documented in Section 4, and listed in Section 5 together with supplemental references that support this analysis.

Section 6 includes a list of software used to support the design confirmation analysis that is subject to the requirements of the Quality Assurance Requirements and Description (QARD). The design confirmation analysis is presented in Section 7, and the conclusions and recommendations based on the results of the analysis are presented in Section 8. Finally, a list of attachments that provides supporting documentation for this analysis is included in Section 9.

2.0 QUALITY ASSURANCE

A QAP-2-0 activity evaluation was performed for the preparation of this report, which showed that this analysis activity is subject to the controls of a Quality Assurance (QA) program. Ground support systems in the ESF Main Loop are classified by QAP-2-3 as QA-1 and QA-5. The ESF main access openings are classified as QA-2 (References 5.8 and 5.9).

All software used in this analysis is identified in Section 6 and is controlled by appropriate software QA procedures. There are no NLP-2-0 Determination of Importance Evaluations (DIEs) applicable to the development of this document.

3.0 METHOD

This design confirmation analysis was developed using both empirical and analytical methods. Scientific publications, project documents, and data obtained from the technical database were reviewed for use in this analysis. Various software tools (see Section 6) were used to analyze and interpret convergence data. A semi-empirical approach known as the Convergence Solution (Reference 5.2) was applied to interpret convergence measurements and evaluate the ground response to excavation activity. The empirical relationship between rock mass quality and deformation from Barton et al. (Reference 5.4) was evaluated using available rock mass quality and deformation data from the ESF. An analytical approach was also used to relate tunnel convergence to elastic rock mass modulus. These methods are discussed in detail in Section 7.

4.0 DATA AND INFORMATION

4.1 DESIGN CONFIRMATION PARAMETERS

A list of design confirmation parameters and their sources is provided in Table 1. The design confirmation parameters include data and information collected either by field monitoring and testing or by laboratory testing. All design confirmation parameters are qualified unless otherwise noted in Table 1.

Table 1. Design Confirmation Parameters

Design Confirmation Parameter	Source
Tunnel Convergence Data	Convergence monitoring in the ESF (Reference 5.21) (Tunnel convergence data are considered "indeterminate" until Corrective Action Report YM-97-C-004 is resolved, TBV-403)
Rock Mass Quality, Q	Full-peripheral field mapping data (References 5.22 to 5.32)
Rock Mass Rating, RMR	Full-peripheral field mapping data (References 5.22 to 5.32)
Modified Rock Mass Quality, Q_{modified}	Task 3 design confirmation analysis (Reference 5.14)
TBM field data	Daily construction field activities reports (Reference 5.6) (TBM construction records are unqualified)
Lithostratigraphic and thermal mechanical contacts in the ESF Main Loop	Task 7 design confirmation analysis (Reference 5.15)
Poisson's ratio for each thermal mechanical unit in the ESF Main Loop	Laboratory test data (Reference 5.11)
Vertical stress along the ESF tunnel alignment	Task 7 design confirmation analysis (Reference 5.15)
Principal field stress ratio	Hydraulic fracturing in situ stress measurements in the ESF (Reference 5.20)

4.2 DESIGN CONFIRMATION CRITERIA

The following ESF design criteria that specifically require ground support monitoring, including deformation monitoring, were developed to respond to the ESFDR (Reference 5.33). Requirements from the ESFDR are cited for each criteria statement.

- 4.2.1 A sampling of the ground support components will be instrumented and monitored. The data collected will allow evaluation of the continued functioning of the ground support system (ESFDR 3.7.3.1.F).
- 4.2.2 The need for specific types of ground support is determined using a combination of analysis (empirical and analytical) and observation and monitoring during construction. The ESF Main Loop ground support system is designed such that it provides flexibility to

accommodate specific site conditions identified through in situ monitoring, testing, or excavation (ESFDR 3.7.3.1.J, 3.7.3.1.K, F.2.79).

- 4.2.3** ESF Main Loop ground support system is designed using empirical and analytical methods and by monitoring and observation during and after construction to reduce the potential for deleterious rock movement at the test alcove and alcove/ramp (ESFDR 3.7.3.1.G, F.2.64).

4.3 ASSUMPTIONS

The following assumptions have been used in this design confirmation analysis.

- 4.3.1** It is assumed that a plastic yield zone does not develop around the opening in the welded tuff units. This assumption was made to facilitate curve-fit of the Convergence Solution due to the lack of the data in the beginning portion of the convergence curve. This is considered reasonable judging from the high strength/stress ratio in the welded tuff units at site.
- 4.3.2** No rock movement is assumed for the deep anchor point (7.4 m, Reference 5.21) in the multiple point borehole extensometer (MPBX) station. Measurements from the measurement rods which connect the deep anchor point and the borehole collar are therefore the true deformation at roof.

5.0 REFERENCES

The following is a complete list of references used in this design confirmation analysis. Data tracking numbers (DTNs), Record Processing Center accession numbers (ACCs), and Technical Information Center (TIC) catalog numbers are noted where appropriate.

- 5.1** Amini, A. and Hill, J. L. III. 1989. Determination of Rock Mass Modulus of Deformation from Field Measurements During Excavation. *Rock Mechanics as a Guide for Efficient Utilization of Natural Resources: Proceedings of the 30th U.S. Symposium*, Khair, A. W. (ed.), 793–800. Rotterdam, Netherlands: Balkema. TIC: 238735.
- 5.2** Barlow, J. P. 1986. *Interpretation of Tunnel Convergence Measurements*. M.S. Thesis, The University of Alberta, Department of Civil Engineering. Edmonton, Alberta: The University of Alberta. TIC: 233843.
- 5.3** Barton, N.; Løset, F.; Lien, R.; and Lunde, J. 1980. Application of Q-System In Design Decisions Concerning Dimensions and Appropriate Support for Underground

Installations. *Proceedings, International Conference on Subsurface Space, Rockstore, 2*, 553–561. Stockholm, Sweden: Pergamon Press. TIC: 226221.

- 5.4 Barton, N.; Lien, R.; and Lunde, J. 1974. Engineering Classification of Rock Masses for Design of Tunnel Support. *Rock Mechanics*, 6, 4, 189–236. New York, New York: Springer-Verlag. TIC: 219995.

- 5.5 Bieniawski, Z. T. 1979. The Geomechanics Classification in Rock Engineering Applications. *Proceedings of the Fourth International Congress on Rock Mechanics*, 2, 41–48. Rotterdam, Netherlands: Balkema. TIC: 226224.

- 5.6 CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1996. *Job Package 95-17 Records – CMO Field Activities Reports, January 1995 through December 1995*. Las Vegas, Nevada: CRWMS M&O. ACC: DRC.19961022.0169.

CRWMS M&O 1997. *Job Package 96-01 Records – CMO Field Activities Reports, November 1995 through December 1996*. Las Vegas, Nevada: CRWMS M&O. ACC: DRC.19970128.0048.

CRWMS M&O 1997. *Job Package 96-01 Records – CMO Field Activities Reports, January 1997*. Las Vegas, Nevada: CRWMS M&O. ACC: DRC.19970218.0066.

CRWMS M&O 1997. *Job Package 96-01 Records – CMO Field Activities Reports, February 1997 and March 1997*. Las Vegas, Nevada: CRWMS M&O. ACC: DRC.19970414.0010.

CRWMS M&O 1997. *Job Package 95-17 Records – CMO Field Activities Reports, April 1997 through June 1997*. Las Vegas, Nevada: CRWMS M&O. ACC: DRC.19970714.0009.

- 5.7 CRWMS M&O 1997. *Technical Document Preparation Plan for Design Confirmation Analyses*. BAB000000-01717-2200-00148 REV 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971218.0945.

- 5.8 CRWMS M&O 1996. *QA Classification Analysis of Ground Support Systems*. BABEE0000-01717-2200-00001 REV 05. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970508.0371.

- 5.9 CRWMS M&O 1997. *QA Classification Analysis of Main Access Openings*. BABEAD000-01717-2200-00002 REV 04. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980210.0154.

- 5.10 CRWMS M&O 1995. *ESF Ground Support Design Analysis*. BABEE0000-01717-0200-00002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19960409.0355.
- 5.11 CRWMS M&O 1997. *Yucca Mountain Site Geotechnical Report*. B000000000-01717-5705-00043 REV 01. Las Vegas, Nevada: CRWMS M&O. ACCs: MOL.19971017.0736 and MOL.19971017.0737.
- 5.12 CRWMS M&O 1997. *Key ESF Design/Geomechanics Parameters Confirmation*. BABEE0000-01717-5705-00001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971021.0552.
- 5.13 CRWMS M&O 1998. *ESF Ground Support Confirmation*. BABEE0000-01717-5705-00003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980727.0308.
- 5.14 CRWMS M&O 1997. *Confirmation of Empirical Design Methodologies*. BABEE0000-01717-5705-00002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980219.0104.
- 5.15 CRWMS M&O 1998. *Geology of the Exploratory Studies Facility Topopah Spring Loop*. BAB000000-01717-0200-00002 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980415.0283.
- 5.16 CRWMS M&O 1997. *Controlled Drilling and Blasting Design Confirmation Analysis*. BABE000000-01717-0200-00005 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971218.0650.
- 5.17 CRWMS M&O 1997. *Software Qualification Report for Fast Lagrangian Analysis of Continua (FLAC) Version: 3.30 Computer Software*. CSCI: 30022 V3.3, DI: 30022-2003 Rev. 0, MI: 30022-M04-001 & 30022-M04-002. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980123.0651.
- 5.18 CRWMS M&O 1998. *Software Routine Report for CONRATE V.01*, CSCI: 30071 V.01, DI: 30071-2999 Rev. 00, MI: 30071-M04-001. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981116.0241.
- 5.19 CRWMS M&O 1998. *Cross Drift Geotechnical Predictive Report: Geotechnical Baseline Report*. BABEA0000-01717-5705-00002 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980806.0219.
- 5.20 SNL (Sandia National Laboratories) 1997. *Hydraulic Fracturing Stress Measurements in Test Hole ESF-AOD-HDFR1, Thermal Test Facility, Exploratory Studies Facility*. TDIF 305878. Albuquerque, New Mexico: SNL. DTN: SNF37100195002.001. ACC: MOL.19970717.0008.

-
- 5.21 SNL 1997. *Tunnel Convergence Data*. TDIF 306296. Albuquerque, New Mexico: SNL. DTN: SNF33120393002.009. ACC: MOL.19980209.0397. (TBV-403)
- 5.22 USBR/USGS (U. S. Bureau of Reclamation/U. S. Geological Survey) 1996. Geologic Mapping of the ESF, Station 00+60 to 04+00, Revision 0. Denver, Colorado: USBR. DTN: GS950508314224.003.
- 5.23 USBR/USGS 1996. Geologic Mapping of the ESF, Station 04+00 to 26+00, Revision 1. Denver, Colorado: USBR. DTN: GS960908314224.020.
- 5.24 USBR/USGS 1996. Geologic Mapping of the ESF, Station 26+00 to 30+00, Revision 0. Denver, Colorado: USBR. DTN: GS960808314224.012.
- 5.25 USBR/USGS 1996. Geologic Mapping of the ESF, Station 30+00 to 40+00, Revision 0. Denver, Colorado: USBR. DTN: GS960908314224.015.
- 5.26 USBR/USGS 1996. Geologic Mapping of the ESF, Station 40+00 to 50+00, Revision 0. Denver, Colorado: USBR. DTN: GS960908314224.016.
- 5.27 USBR/USGS 1996. Geologic Mapping of the ESF, Station 50+00 to 55+00, Revision 0. Denver, Colorado: USBR. DTN: GS960908314224.017.
- 5.28 USBR/USGS 1997. Geologic Mapping of the ESF, Station 55+00 to 60+00, Revision 0. Denver, Colorado: USBR. DTN: GS970108314224.002.
- 5.29 USBR/USGS 1997. Geologic Mapping of the ESF, Station 60+00 to 65+00, Revision 0. Denver, Colorado: USBR. DTN: GS970208314224.004.
- 5.30 USBR/USGS 1997. Geologic Mapping of the ESF, Station 65+00 to 70+00, Revision 0. Denver, Colorado: USBR. DTN: GS970808314224.009.
- 5.31 USBR/USGS 1997. Geologic Mapping of the ESF, Station 70+00 to 75+00, Revision 0. Denver, Colorado: USBR. DTN: GS970808314224.011.
- 5.32 USBR/USGS 1997. Geologic Mapping of the ESF, Station 75+00 to 78+77, Revision 0. Denver, Colorado: USBR. DTN: GS970808314224.013.
- 5.33 DOE (U. S. Department of Energy) 1997. *Exploratory Studies Facility Design Requirements*, YMP/CM-0019, Rev. 2, ICN 1. Las Vegas, Nevada: DOE Office of Civilian Radioactive Waste Management. ACC: MOL.19980107.0544.
- 5.34 10 CFR 60 (Title 10, Code of Federal Regulations, Part 60) 1998. Energy: Disposal of High-Level Radioactive Wastes in Geologic Repositories. *Federal Register*. Washington, D.C.: U.S. Government Printing Office. TICs: 239475, 240902, and 240903.

-
- 5.35 DOE 1988. Performance Confirmation. *Site Characterization Plan*, Volume VII, Part B, Chapter 8, Section 8.3.5.16. DOE/RW-0199. Washington, D.C.: DOE Office of Civilian Radioactive Waste Management. ACC: HQS.19880517.2992.
- 5.36 Digital Equipment Corporation 1997. *Digital Fortran Language Reference Manual*. Maynard, Massachusetts: Digital Equipment Corporation. TIC: 238454.
- 5.37 SNL 1997. *Goodman Jack Measurements in the Single Heater Test Block From 08/26/96 to 5/5/97 (Thermal Testing in the Exploratory Studies Facility, Borehole ESF-TMA-B-J-1)*. TDIF: 306115. Albuquerque, New Mexico: SNL. DTN: SNF35110695001.005. ACC: MOL.19971120.0022.
- 5.38 Serafim, J. L. and Pereira, J. P. 1983. Considerations on the Geomechanical Classification of Bieniawski. *Proceedings, International Symposium on Engineering Geology and Underground Construction*, II, II.33-II.42. Lisbon, Portugal: Laboratorio Nacional Engenharia Civil. TIC: 226267.
- 5.39 Hoek, E. and Brown, E. T. 1980. *Underground Excavations in Rock*. London, England: Institute of Mining and Metallurgy. TIC: 217420.
- 5.40 SNL 1998. *Drift Scale Test Status Report #1: Evaluation and Comparative Analysis of the Drift Scale Test Thermal and Thermomechanical Data (Results of 12/3/1997 through 5/31/1998)*. TDIF 306910. Albuquerque, New Mexico: SNL. DTN: SNF39012298002.002. ACC: MOL.19980908.0435.

6.0 COMPUTER SOFTWARE

6.1 QUALIFIED COMPUTER SOFTWARE

The following qualified computer software items were used in parts of this design confirmation analysis.

- 6.1.1 Fast Lagrangian Analysis of Continua (FLAC), Version 3.30 (Reference 5.17) was used to calculate the geometry factor for the back calculation of the rock mass modulus of deformation. The analyses were performed on a computer with a Pentium microprocessor. FLAC software is appropriate for the applications used in this design confirmation analysis. FLAC was obtained from the Software Configuration Management (SCM) in accordance with the applicable M&O procedures. FLAC software was used only within the range of validation as specified in the software qualification documentation (Reference 5.17). A complete listing of input files used in this analysis is provided in Attachment V. The outputs are presented and described in Section 7. Detailed description of FLAC and its fields of application are presented in Reference 5.17.

6.1.2 Convergence monitoring data were analyzed using the software routine, CONRATE V.01 (Reference 5.18). The source code of the software routine was written in FORTRAN by John P. Barlow and listed in Reference 5.2. This software routine is used to calculate tunnel convergence versus time and normalized convergence rate versus time curves according to the semi-empirical Convergence Solution presented in Reference 5.2. Compilation of CONRATE was completed using DIGITAL Visual FORTRAN compiler (Reference 5.36). The executable program performs the calculations in the MS-DOS environment under Microsoft Windows 95 operating system. The routine was originally developed and qualified to perform the specific calculations for which it was used. CONRATE was used only within the range of validation as described in Reference 5.18 and is the appropriate software for the described application. CONRATE was obtained from the SCM in accordance with appropriate procedures.

6.2 NON-QUALIFIED SOFTWARE

In addition to the above listed items, *Microsoft Excel 97* was also used. This software item was used to perform support activities and is not the controlled source of information in this design confirmation analysis, and thus not subject to qualification per QAP-SI-0.

Excel is a commercial spreadsheet program designed to assist in routine calculations. The program provides built-in mathematical functions together with user-defined formulas to automate the calculation process. Output formulas are automatically updated as input data are added or changed. *Excel* also includes a graphical package to assist in data presentation. *Excel* was used to assist in the summary of the deformation and graphical presentation of the convergence curves.

7.0 DESIGN CONFIRMATION ANALYSIS

7.1 INTRODUCTION

This analysis provides an assessment of the tunnel deformation monitoring data in the ESF. The tunnel deformation data were measured using both a tape extensometer and borehole extensometers (Reference 5.21). Periods of data acquisition reported are 06/10/93 to 07/28/97 for the tape extensometer stations and 12/14/96 to 07/23/97 for the borehole extensometers (Reference 5.21). No recent data (after 07/1997) have been released at the time of this analysis. This analysis focuses on the data obtained from the monitoring stations located in the ESF Main Loop. Data monitored in the alcoves and in the North Ramp Starter Tunnel are not included.

Deformation has been considered as the most effective means of monitoring rock mass behavior during and after the construction of an underground excavation (Reference 5.39). Convergence data has been used in many tunneling projects to provide information that is used to check the validity of the design or to permit the completion of the on-going design work (Reference 5.2). Convergence data has also been used to back calculate the deformation modulus of rock mass based on analytical solutions which relate radial convergence to the deformation modulus. (Reference 5.1).

The approach toward this design confirmation analysis involves the following:

1. The ESF Main Loop deformation data has been summarized and descriptive statistics have been provided.
2. A semi-empirical approach, named the Convergence Solution and developed by Barlow (Reference 5.2) has been applied to interpret the convergence measurements to estimate ground behavior to predict long-term tunnel displacement.
3. An analytical solution proposed by Amini and Hill (Reference 5.1) that relates convergence to elastic modulus was applied to estimate rock mass modulus of deformation.

7.2 SUMMARY OF ESF TUNNEL CONVERGENCE DATA

7.2.1 Summary of Tape Extensometer Convergence Data

The tape extensometer (Geokon Model 1600) measures the change of distance between two convergence points. Six sets of chord positions, referred to as H, L, R, V, RF, and LF, were included in tape extensometer measurements. The chord positions are illustrated in Figure 1. Among the six chords, H, L, R, and V are the most common chord measurements. The mechanical accuracy of the tape extensometers is ± 0.127 mm (0.005 inch) (Reference 5.21).

A summary of the convergence data measured from the tape extensometer stations in the ESF Main Loop is presented in Table 2. The table includes the relevant station and chord information, the maximum convergence in millimeters (mm), and the calculated convergence rate based on the last two readings. In order to evaluate the impact of ground support to convergence, the installed ground support class (References 5.22 to 5.32) is included in Table 2. The descriptions for the ground support classes are provided in Table 3. Also included in Table 2 are the excavation date for the monitoring station (Reference 5.6), and the distance between the excavation face and the monitoring station at the first instrumentation reading.

As presented in Table 2, the time lag between the first convergence readings and the excavation date ranges from several days to more than half a year. Distance between the monitoring station and the excavation face spreads from tens to thousands of meters at the time of first reading. The maximum convergences to date for most of the welded tuff units are within 2.0 mm. As expected, higher convergence was monitored for the non-welded tuff units. The maximum convergences for most of non-welded tuff units are less than 5.0 mm. The cells are shaded for stations with the maximum convergence greater than 5.0 mm. The maximum convergence for the welded tuff units is 5.8 mm monitored at Chord L of Station 28+24. The maximum convergence for the non-welded tuff units is 15.55 mm monitored at Chord V of Station 10+00. The actual convergence should be greater than the monitored values since the starting of the monitoring was days after the excavation. In fact, the delay in the start of instrumentation precludes the measurements of the initial and important portion of convergence curve. For stations with long

delay, the monitored data is projected to be in the asymptotic range of the convergence curve with little deformation increment. The actual deformation increment monitored in this range may be overridden by human/measurement errors.

The calculated convergence rates based on the last two readings are presented in the last column of Table 2. The cells are shaded for stations with the convergence rate greater than 2 mm/yr. Convergence rate ranges from -15 mm/yr (Station 28+32, V Chord) to 44 mm/yr (Station 50+59, HB Chord) with the median value of approximately 0.4 mm/yr. The wide range of the calculated convergence rates is caused mainly by the fluctuation of the instrumentation results. The calculation results for convergence rate may not represent the actual convergence rate due to the limitation of the accuracy from the tape measurement. More discussion on this is provided in Section 7.2.3.

Summary statistics for the maximum convergence data is presented in Table 4. Measurements are grouped based on the thermal mechanical unit, measurement chord, and the installed ground support class. The magnitudes of the convergence in PTn unit with ground support class 1 stands out among all the groups. This is consistent with the laboratory test results on the rock deformational properties (Reference 5.11). The average Young's modulus measured for PTn unit is approximately one tenth of those for the welded tuff units.

The effect of ground support to convergence is revealed in Table 4. For purpose of comparison, convergence of the steel set is assumed to be fully coupled with the rock mass. The effect of ground support is most apparent in the PTn unit. The median value of the convergence measured in the vertical chord with support class 1 is 3.909 mm, whereas the median value of the convergence with support class 4 is less than 1 mm. The effect of ground support on convergence for the welded tuff units is, however, not as apparent as in the PTn unit. Convergence in the welded tuff units is in general small. The median value of the convergence is in the range of 0.3 mm to 1 mm, regardless of the support class. Standard deviation of the convergence is in general about the same magnitude as the average value of convergence. This indicate that a wide range distribution for the convergence in all units.

Convergence curves were also grouped and plotted against the time based on thermal mechanical unit, measurement chord, and the installed ground support class. Figures 2 to 6 show the convergence curves for the five thermal mechanical units respectively. The reference time is the excavation date for the monitoring station in these figures. Notice that these figures do not include all the convergence curves measured in ESF Main Loop, only the H, L, R, and V chords for the predominant support class are presented. Attachment I contains a complete set of figures which include all the convergence data. As shown in Figures 2 to 6, most of the convergence curves measured from the tape extensometer fluctuate with time and a consistent trend within each unit is difficult to define. The convergence curves do reveal a trend of continuous increase of the convergence at time well after excavation. Rock displacement was monitored 200 to 300 days after excavation for most of the stations. Since the time-independent convergence should occur within the first 10 to 20 days after the excavation, the displacements monitored at time well after excavation should be time-dependent convergence. Time-dependent behavior is especially clear in Figure 4 for PTn unit.

Table 2. Summary of Tape Extensometer Convergence Data

Monitoring Station Location (ESF Location) ¹	Thermal Mechanical Unit	Station Instrumentation Type ²	Installed Ground Support Class ³	Excavation Date	Measurement Chord ⁴	Number of Reading	First Instrumentation Reading		Date of Last Instrumentation Reading	Maximum Convergence (mm)	Convergence Rate at Last Reading (mm/yr)
							Date	Distance to Excavation Face (m)			
00+63	TCw	S	4	10/15/94	H	10	6/2/95	846.96	5/29/97	1.706	-2.404
					L	12	5/9/95	624.26	5/1/97	1.204	0.183
					R	12	5/9/95	624.26	5/1/97	0.749	1.485
00+70	TCw	S	4	10/29/94	H	11	6/2/95	839.96	5/29/97	0.574	-9.458
					L	12	5/9/95	617.26	5/1/97	1.130	2.875
					R	12	5/9/95	617.26	5/1/97	0.909	0.914
00+75	TCw	S	4	11/7/94	V	11	5/9/95	617.26	5/1/97	1.232	1.859
					H	11	6/2/95	834.96	5/29/97	1.084	-0.641
					L	12	5/9/95	612.26	5/1/97	0.567	1.316
00+81	TCw	S	4	11/15/94	R	12	4/28/95	546.5	5/1/97	3.562	3.467
					V	10	5/9/95	612.26	5/1/97	0.909	0.180
					H	11	6/2/95	828.96	5/29/97	1.467	-1.271
01+00	TCw	S	4	12/28/94	L	10	5/9/95	606.26	5/1/97	1.158	1.436
					R	12	5/9/95	606.26	5/1/97	1.396	0.286
					V	11	5/9/95	606.26	5/1/97	1.200	1.541
01+12	TCw	S	4	1/4/95	H	11	5/23/95	697.56	5/29/97	0.413	-1.147
					L	10	5/4/95	564.62	5/1/97	0.381	-0.055
					R	11	4/28/95	521.5	5/1/97	0.648	0.023
01+21	TCw	S	4	1/4/95	V	11	4/28/95	521.5	5/1/97	0.793	-0.006
					H	11	5/23/95	685.56	5/29/97	0.889	-2.380
					L	11	5/4/95	552.62	5/1/97	0.989	0.951
01+36	TCw	S	4	1/10/95	R	11	4/28/95	509.5	5/1/97	1.154	0.766
					V	11	4/28/95	509.5	5/1/97	0.825	0.713
					H	11	6/5/95	804.71	5/29/97	1.238	-0.213
01+56	TCw	S	4	1/18/95	L	9	5/4/95	543.62	5/1/97	1.170	1.131
					R	10	4/28/95	500.5	5/1/97	1.614	2.736
					V	10	4/28/95	500.5	5/1/97	1.428	-0.138
01+67	TCw	S	4	1/18/95	H	11	6/2/95	773.96	5/29/97	0.631	-1.464
					L	10	5/4/95	528.62	5/1/97	0.415	1.304
					R	11	5/4/95	528.62	5/1/97	0.767	1.926
01+74	TCw	S	4	1/18/95	V	10	5/4/95	528.62	5/1/97	0.933	0.935
					H	11	4/25/95	435.45	5/29/97	0.888	1.261
					L	11	5/4/95	508.62	5/1/97	1.197	0.596
01+79	TCw	S	4	1/24/95	R	11	4/25/95	435.45	5/1/97	0.953	1.907
					V	11	4/25/95	435.45	5/1/97	0.809	0.387
					H	14	5/22/95	616.97	5/29/97	0.000	-4.761
01+90	TCw	S	4	1/27/95	L	12	5/23/95	630.56	5/1/97	0.291	0.949
					R	13	5/23/95	630.56	5/1/97	0.136	1.784
					V	12	5/23/95	630.56	5/1/97	1.118	1.537
01+90	TCw	S	4	1/27/95	H	14	5/22/95	609.97	5/29/97	0.000	-4.027
					L	15	5/3/95	483.5	5/1/97	1.864	1.831
					R	15	4/28/95	447.5	5/1/97	2.334	-0.141
01+90	TCw	S	4	1/27/95	V	14	5/22/95	609.97	5/1/97	3.269	1.631
					H	12	4/25/95	412.45	5/29/97	0.968	-3.365
					L	12	1/30/95	9.2	5/1/97	2.943	6.341
01+90	TCw	S	4	1/27/95	R	12	1/30/95	9.2	5/1/97	1.690	1.992
					V	10	4/25/95	412.45	5/1/97	1.138	0.067
					H	11	6/6/95	739.4	5/29/97	0.882	-1.276
01+90	TCw	S	4	1/27/95	L	11	2/9/95	11.9	5/1/97	0.384	-0.059
					R	13	2/9/95	11.9	5/1/97	0.755	1.713
					V	11	4/25/95	401.45	5/1/97	1.314	0.502

Table 2. Summary of Tape Extensometer Convergence Data (continued)

Monitoring Station Location (ESF Location) ¹	Thermal Mechanical Unit	Station Instrumentation Type ²	Installed Ground Support Class ³	Excavation Date	Measurement Chord ⁴	Number of Reading	First Instrumentation Reading		Date of Last Instrumentation Reading	Maximum Convergence (mm)	Convergence Rate at Last Reading (mm/yr)
							Date	Distance to Excavation Face (m)			
01+94	TCw	S	4	1/27/95	H	12	6/2/95	715.96	5/29/97	0.027	-10.696
					L	12	5/4/95	470.62	5/1/97	2.233	-0.165
					R	12	5/4/95	470.62	5/1/97	1.193	0.100
					V	11	4/28/95	427.5	5/1/97	2.384	-0.566
01+96	TCw	S	4	1/27/95	H	13	6/2/95	713.96	5/29/97	0.287	1.429
					L	12	5/4/95	468.62	5/1/97	0.148	0.133
					R	11	5/4/95	468.62	5/1/97	1.348	1.043
					V	10	4/28/95	425.5	5/1/97	2.506	1.993
02+00	UO	S	4	1/31/95	H	12	6/2/95	709.96	5/29/97	0.176	-0.318
					L	11	5/2/95	448.14	5/1/97	1.023	0.491
					R	10	4/28/95	421.5	5/1/97	1.453	0.447
					V	11	4/28/95	421.5	5/1/97	1.431	1.425
02+15	UO	S	4	2/14/95	H	10	9/27/95	1698.09	5/29/97	0.891	-1.411
					L	12	2/15/95	19.45	5/1/97	5.769	0.831
					R	12	2/15/95	19.45	5/1/97	2.882	1.285
					V	11	4/15/95	339.24	5/1/97	1.623	0.897
02+33	UO	S	4	2/15/95	H	11	4/15/95	321.24	5/29/97	0.559	-0.729
					L	9	4/15/95	321.24	5/1/97	0.000	0.595
					R	10	4/15/95	321.24	5/1/97	0.705	1.473
					V	9	4/15/95	321.24	5/1/97	0.214	0.892
02+50	UO	S	4	2/16/95	H	10	4/15/95	304.24	5/29/97	0.000	0.150
					L	14	2/18/95	17.26	5/1/97	5.202	1.321
					R	14	2/18/95	17.26	5/1/97	1.375	0.570
					V	11	4/15/95	304.24	5/1/97	2.932	3.056
02+70	UO	S	4	2/18/95	H	10	4/15/95	284.24	5/29/97	0.281	-3.118
					L	13	2/22/95	20.94	5/1/97	2.214	2.868
					R	11	2/22/95	20.94	5/1/97	1.865	2.151
					V	12	4/15/95	284.24	5/1/97	1.537	2.432
03+18	UO	A	1	2/24/95	H	11	4/15/95	236.24	5/29/97	1.010	1.987
					L	12	4/25/95	273.45	5/1/97	1.068	1.143
					R	11	4/28/95	303.5	11/14/96	1.336	-2.003
					V	12	4/28/95	303.5	5/1/97	4.576	1.603
03+48	UO	S	4	2/28/95	H	8	4/15/95	206.24	2/19/97	0.000	-0.161
					L	12	4/28/95	273.5	5/1/97	0.456	1.253
					R	11	4/15/95	206.24	11/14/96	1.083	-2.793
					V	12	4/28/95	273.5	5/1/97	1.941	1.989
03+61	TCw	S	4	3/2/95	H	11	4/25/95	230.45	5/29/97	0.000	-3.609
					L	12	4/27/95	257.77	5/8/97	0.386	1.184
					R	13	4/27/95	257.77	5/8/97	1.172	1.162
					V	12	4/27/95	257.77	5/8/97	0.000	1.346
04+13	TCw	B	1	3/13/95	H	10	9/27/95	1500.09	5/29/97	1.575	0.970
					L	6	1/24/96	3481.51	11/14/96	0.078	-2.005
					R	7	1/24/96	3481.51	5/8/97	0.014	0.582
					V	7	1/24/96	3481.51	5/8/97	0.112	0.641
04+43	TCw	S	4	3/15/95	H	8	6/2/95	466.96	5/29/97	0.413	3.454
					L	12	5/10/95	254.12	5/8/97	0.870	0.853
					R	13	5/10/95	254.12	5/8/97	0.551	0.879
					V	11	5/10/95	254.12	5/8/97	0.614	0.412
04+84	TCw	S	4	3/21/95	H	11	6/2/95	425.96	5/29/97	1.377	-3.923
					L	12	5/10/95	213.12	5/8/97	1.542	1.378
					R	12	5/10/95	213.12	5/8/97	0.531	2.118
					V	12	5/10/95	213.12	5/8/97	0.455	-0.389

Table 2. Summary of Tape Extensometer Convergence Data (continued)

Monitoring Station Location (ESF Location) ¹	Thermal Mechanical Unit	Station Instrumentation Type ²	Installed Ground Support Class ³	Excavation Date	Measurement Chord ⁴	Number of Reading	First Instrumentation Reading		Date of Last Instrumentation Reading	Maximum Convergence (mm)	Convergence Rate at Last Reading (mm/yr)
							Date	Distance to Excavation Face (m)			
05+05	TCw	S	4	3/23/95	H	11	6/2/95	404.96	5/29/97	1.117	-3.033
					L	11	5/10/95	192.12	5/8/97	0.934	-1.610
					R	11	5/10/95	192.12	5/8/97	0.868	3.401
					V	12	5/10/95	192.12	5/8/97	0.749	1.505
05+47	TCw	S	4	3/30/95	H	10	9/27/95	1366.09	5/29/97	2.186	-7.103
					L	11	10/3/95	1514.97	5/8/97	0.074	-0.347
					R	11	9/15/95	1141.45	5/8/97	1.273	0.432
					V	11	9/15/95	1141.45	5/8/97	0.266	-0.298
07+53	PTn	A	1	5/16/95	H	14	8/17/95	508.77	5/29/97	1.242	-6.858
					L	13	8/19/95	508.77	11/14/96	1.440	-1.155
					R	17	8/17/95	508.77	5/8/97	2.276	1.486
					V	17	8/17/95	508.77	5/8/97	3.391	0.410
07+56	PTn	A	1	5/16/95	L	18	8/17/95	505.77	5/8/97	4.097	2.692
					R	13	8/17/95	505.77	5/8/97	2.638	2.796
					RF	16	8/18/95	505.77	5/8/97	4.631	1.790
					V	17	8/18/95	505.77	5/8/97	6.038	5.313
07+59	PTn	A	1	5/16/95	H	15	8/17/95	502.77	5/29/97	2.285	2.391
					L	18	8/17/95	502.77	5/8/97	2.443	1.422
					R	18	8/17/95	502.77	5/8/97	4.054	1.293
					V	18	8/17/95	502.77	5/8/97	3.909	1.540
08+98	PTn	S	4	6/1/95	H	10	9/29/95	1090.43	9/18/96	0.000	1.292
					L	12	10/3/95	1163.97	5/8/97	0.452	0.281
					R	11	10/16/95	1352.9	5/8/97	0.744	0.278
					V	13	10/3/95	1163.97	5/8/97	0.895	1.179
09+75	PTn	B	1	6/12/95	L	12	9/15/95	713.45	5/8/97	0.792	0.982
					R	14	9/15/95	713.45	5/8/97	1.375	3.065
					V	14	9/15/95	713.45	5/8/97	1.144	0.630
10+00	PTn	A	1	6/13/95	H	14	9/15/95	688.45	5/29/97	6.611	22.136
					L	17	9/15/95	688.45	5/8/97	7.873	4.378
					R	18	9/5/95	477.82	5/8/97	11.111	5.060
					V	17	9/15/95	688.45	5/8/97	15.546	5.544
10+24	PTn	A	1	6/14/95	H	15	10/9/95	1099.73	6/9/97	4.682	0.505
					L	22	10/9/95	1099.73	5/8/97	2.861	1.980
					R	22	10/9/95	1099.73	5/8/97	3.392	1.254
					V	20	10/9/95	1099.73	5/8/97	3.731	0.671
10+27	PTn	A	1	6/14/95	L	22	10/9/95	1096.73	5/8/97	5.452	0.698
					R	22	10/9/95	1096.73	5/8/97	5.203	1.224
					RF	21	10/11/95	1147.82	5/8/97	6.661	1.092
					V	20	10/9/95	1096.73	5/8/97	5.095	1.300
10+31	PTn	A	1	6/14/95	H	16	10/9/95	1092.73	6/9/97	1.569	-0.335
					L	18	10/9/95	1092.73	5/8/97	2.200	1.422
					R	21	10/9/95	1092.73	5/8/97	4.101	0.368
					V	22	10/9/95	1092.73	5/8/97	3.638	0.375
11+23	TSw1	S	4	6/24/95	H	12	9/15/95	565.45	10/28/96	0.000	20.550
					L	16	9/15/95	565.45	5/8/97	1.320	0.731
					R	18	9/5/95	354.82	5/8/97	1.123	1.483
					V	13	9/28/95	816.49	5/8/97	1.118	0.208
11+55	TSw1	S	4	7/19/95	H	13	10/24/95	1219.84	6/9/97	0.000	-2.557
					L	13	10/23/95	1219.84	5/8/97	0.846	1.510
					R	14	10/23/95	1219.84	5/8/97	0.387	0.466
					V	15	10/23/95	1219.84	5/8/97	0.453	-0.354

Table 2. Summary of Tape Extensometer Convergence Data (continued)

Monitoring Station Location (ESF Location) ¹	Thermal Mechanical Unit	Station Instrumentation Type ²	Installed Ground Support Class ³	Excavation Date	Measurement Chord ⁴	Number of Reading	First Instrumentation Reading		Date of Last Instrumentation Reading	Maximum Convergence (mm)	Convergence Rate at Last Reading (mm/yr)
							Date	Distance to Excavation Face (m)			
11+56	TSw1	S	4	7/19/95	H	12	11/13/95	1586	6/9/97	0.641	-0.623
					L	15	10/23/95	1218.84	5/8/97	1.624	1.501
					R	16	10/23/95	1218.84	5/8/97	0.594	0.752
					V	10	1/24/96	2738.51	5/8/97	0.890	0.773
12+31	TSw1	A	1	8/8/95	H	5	1/23/96	2663.51	6/9/97	0.708	-2.948
					L	8	2/8/96	2913.29	5/6/97	0.982	-0.280
					R	10	1/22/96	2663.51	5/6/97	0.715	0.199
					V	10	1/22/96	2663.51	5/6/97	1.174	0.830
13+05	TSw1	S	4	8/24/95	H	13	11/16/95	1529.75	6/9/97	1.114	-0.714
					L	11	1/11/96	2505.46	5/6/97	0.608	-0.349
					R	11	1/11/96	2505.46	5/6/97	1.009	0.170
					V	10	1/11/96	2505.46	5/6/97	1.206	0.398
15+26	TSw1	A	1	9/6/95	H	9	1/23/96	2368.51	6/9/97	1.118	0.261
					L	11	1/22/96	2368.51	5/6/97	0.697	0.914
					R	11	1/22/96	2368.51	5/6/97	1.228	0.592
					V	11	1/22/96	2368.51	5/6/97	1.444	0.211
16+43	TSw1	A	1	9/13/95	H	9	1/23/96	2251.51	6/9/97	1.379	-1.048
					L	11	1/22/96	2251.51	5/6/97	0.562	0.179
					R	8	1/22/96	2251.51	10/29/96	1.042	-2.607
					V	10	1/22/96	2251.51	5/6/97	1.620	-0.169
18+30	TSw1	B	1	9/22/95	H	9	1/23/96	2064.51	6/9/97	2.430	0.007
					L	10	1/22/96	2064.51	5/6/97	0.988	0.960
					R	11	1/22/96	2064.51	5/6/97	1.665	1.978
					V	10	1/22/96	2064.51	5/6/97	2.057	0.295
20+35	TSw1	A	1	10/2/95	H	9	1/23/96	1859.51	6/9/97	1.458	-3.463
					L	11	1/22/96	1859.51	5/6/97	0.908	-3.149
					R	11	1/22/96	1859.51	5/6/97	1.108	1.565
					V	10	1/22/96	1859.51	5/6/97	1.826	1.061
21+34	TSw1	B	1	10/9/95	H	10	1/23/96	1760.51	6/9/97	1.272	0.865
					L	11	1/22/96	1760.51	5/6/97	0.944	0.241
					R	11	1/22/96	1760.51	5/6/97	0.833	0.301
					V	11	1/22/96	1760.51	5/6/97	1.573	-0.189
23+20	TSw1	A	1	10/18/95	H	10	1/23/96	1574.51	6/9/97	1.907	1.197
					L	11	1/22/96	1574.51	5/6/97	1.480	0.842
					R	9	1/22/96	1574.51	5/6/97	2.059	0.525
					V	10	2/6/96	1767.89	5/6/97	2.633	-0.072
24+97	TSw1	A	1	10/30/95	H	12	11/13/95	245	6/9/97	2.032	1.695
					L	14	11/8/95	207.33	5/6/97	1.263	0.772
					R	14	11/8/95	207.33	5/6/97	1.354	0.773
					V	13	11/8/95	207.33	5/6/97	2.213	-0.265
27+70	TSw2	B	1	11/14/95	H	9	1/18/96	1124.51	6/9/97	2.639	0.437
					L	12	1/8/96	940.11	5/6/97	1.477	1.133
					R	10	1/8/96	940.11	9/24/96	4.355	-2.721
					V	11	1/8/96	940.11	5/6/97	1.293	0.516
28+24	TSw2	A	1	11/16/95	H	5	1/30/96	1182.88	6/9/97	2.627	2.518
					L	15	1/12/96	1011.61	6/24/97	5.815	-2.154
					R	12	1/16/96	1056.01	6/24/97	1.941	-0.005
					V	16	1/16/96	1056.01	6/24/97	4.234	0.959
28+28	TSw2	B	1	11/16/95	L	1	1/16/96	1052.01	1/16/96	0.000	NA
					LF	12	1/12/96	1007.61	6/24/97	5.461	-1.302
					R	15	1/16/96	1052.01	6/24/97	2.451	0.230
					V	14	1/16/96	1052.01	3/10/97	3.873	0.078

Table 2. Summary of Tape Extensometer Convergence Data (continued)

Monitoring Station Location (ESF Location) ¹	Thermal Mechanical Unit	Station Instrumentation Type ²	Installed Ground Support Class ³	Excavation Date	Measurement Chord ⁴	Number of Reading	First Instrumentation Reading		Date of Last Instrumentation Reading	Maximum Convergence (mm)	Convergence Rate at Last Reading (mm/yr)
							Date	Distance to Excavation Face (m)			
28+32	TSw2	A	1	11/16/95	H	12	1/25/96	1088.19	6/9/97	0.795	-0.631
					L	16	1/12/96	1003.61	6/24/97	4.213	-8.556
					R	15	1/12/96	1003.61	6/24/97	3.681	-4.009
					V	15	1/25/96	1088.19	6/24/97	2.599	-15.340
29+50	TSw2	A	1	11/22/95	H	9	2/8/96	1194.29	6/9/97	1.234	4.451
					L	11	2/6/96	1137.89	6/24/97	0.625	-3.547
					R	8	2/6/96	1137.89	6/24/97	1.253	-2.936
					V	11	2/6/96	1137.89	6/24/97	1.372	-0.801
31+02	TSw2	B	1	11/30/95	H	10	1/18/96	792.51	6/9/97	1.004	3.922
					L	11	1/8/96	608.11	6/24/97	1.626	-1.572
					R	11	1/8/96	608.11	3/10/97	1.732	1.299
					V	12	1/8/96	608.11	6/24/97	2.887	-0.572
32+52	TSw2	A	1	12/13/95	H	9	1/18/96	642.51	6/9/97	0.827	2.232
					L	13	1/8/96	458.11	6/24/97	0.917	-1.226
					R	13	1/8/96	458.11	6/24/97	1.368	-0.990
					V	13	1/8/96	458.11	6/24/97	1.893	-1.683
34+01	TSw2	B	1	12/20/95	H	9	1/18/96	493.51	3/25/97	2.311	4.798
					L	11	1/16/96	479.01	6/24/97	0.701	0.444
					R	12	1/16/96	479.01	6/24/97	0.970	-1.246
					V	12	1/16/96	479.01	6/24/97	1.592	-0.286
35+96	TSw2	A	1	1/3/96	H	6	5/13/96	1674.79	3/25/97	0.882	-1.542
					L	8	5/24/96	1868.78	6/24/97	1.019	-1.352
					R	7	5/24/96	1868.78	3/10/97	0.818	1.212
					V	8	5/24/96	1868.78	6/24/97	3.246	-2.687
37+30	TSw2	A	1	1/9/96	H	8	4/24/96	1176.61	6/9/97	0.000	1.517
					L	9	4/24/96	1176.61	7/2/97	1.483	-2.351
					R	9	4/24/96	1176.61	7/2/97	1.117	-12.082
					V	8	4/24/96	1176.61	3/10/97	2.394	0.776
37+37	TSw2	B	1	1/9/96	L	7	4/24/96	1169.61	7/2/97	2.964	-0.274
					LF	1	4/24/96	1169.61	4/24/96	0.000	NA
					R	9	4/24/96	1169.61	7/2/97	1.615	-1.446
					V	8	5/24/96	1727.78	7/2/97	0.556	-0.405
37+43	TSw2	A	1	1/9/96	H	8	4/24/96	1163.61	6/9/97	0.017	0.750
					L	8	4/24/96	1163.61	7/2/97	1.888	1.600
					R	7	4/24/96	1163.61	7/2/97	0.977	-0.283
					V	8	4/24/96	1163.61	7/2/97	1.313	0.300
39+51	TSw2	A	1	1/26/96	H	8	3/5/96	458.11	6/9/97	1.734	6.146
					L	10	3/12/96	521.61	6/24/97	1.243	1.127
					R	10	3/12/96	521.61	6/24/97	1.130	-1.756
					V	8	3/12/96	521.61	6/24/97	4.690	0.532
41+00	TSw2	A	1	2/7/96	H	8	3/5/96	309.11	6/9/97	1.216	4.187
					L	7	4/10/96	734.39	6/24/97	0.610	-1.507
					R	6	4/10/96	734.39	6/24/97	1.317	1.025
					V	7	4/10/96	734.39	6/24/97	0.807	-1.118
41+41	TSw2	S	4	2/8/96	H	8	3/5/96	268.11	7/2/97	0.378	-13.213
					L	10	3/12/96	331.61	6/24/97	0.894	-0.142
					R	9	3/12/96	331.61	6/24/97	0.875	0.497
					V	9	3/12/96	331.61	6/24/97	0.825	-0.457
42+47	TSw2	B	1	2/21/96	H	7	3/12/96	225.61	7/2/97	1.283	-5.132
					L	10	3/12/96	225.61	6/24/97	1.457	0.874
					R	10	3/12/96	225.61	6/24/97	0.916	0.174
					V	8	3/12/96	225.61	6/24/97	1.841	-10.306

Table 2. Summary of Tape Extensometer Convergence Data (continued)

Monitoring Station Location (ESF Location) ¹	Thermal Mechanical Unit	Station Instrumentation Type ²	Installed Ground Support Class ³	Excavation Date	Measurement Chord ⁴	Number of Reading	First Instrumentation Reading		Date of Last Instrumentation Reading	Maximum Convergence (mm)	Convergence Rate at Last Reading (mm/yr)
							Date	Distance to Excavation Face (m)			
43+42	TSw2	S	4	2/28/96	H	7	4/15/96	524.11	7/2/97	0.220	-13.566
					L	8	5/28/96	1147.32	6/24/97	0.214	2.187
					R	8	5/28/96	1147.32	6/24/97	0.266	1.764
					V	3	8/19/96	1890.75	6/24/97	0.020	0.658
45+50	TSw2	A	4	3/18/96	H	7	4/15/96	316.11	6/26/97	1.011	1.249
					L	9	4/15/96	316.11	6/24/97	1.181	-0.188
					R	7	4/15/96	316.11	6/24/97	0.446	-0.262
					V	8	4/15/96	316.11	6/24/97	1.575	0.551
47+06	TSw2	B	1	4/3/96	H	6	7/9/96	1255.28	6/26/97	1.728	2.121
					L	8	6/18/96	1003.64	6/24/97	0.208	1.417
					R	7	6/18/96	1003.64	6/24/97	0.383	-0.013
					V	5	6/18/96	1003.64	6/24/97	0.377	-0.880
48+50	TSw2	A	4	4/11/96	H	6	5/29/96	666.05	6/26/97	0.478	1.055
					L	9	5/28/96	639.32	6/24/97	0.527	0.655
					R	9	5/28/96	639.32	6/24/97	0.380	0.962
					V	6	5/28/96	639.32	6/24/97	3.465	0.262
50+01	TSw2	A	1	4/29/96	H	6	5/29/96	515.05	6/26/97	0.220	0.330
					L	9	5/28/96	488.32	6/24/97	0.770	-0.634
					R	9	5/28/96	488.32	6/24/97	0.455	0.733
					V	7	5/28/96	488.32	6/24/97	0.950	0.048
50+59	TSw2	A	1	5/1/96	HB	5	10/14/96	1575.78	6/26/97	0.501	44.928
					HT	2	10/14/96	1575.78	11/19/96	0.412	4.182
					L	4	10/14/96	1575.78	6/24/97	2.741	0.473
					R	4	10/14/96	1575.78	6/24/97	1.537	3.941
					V	1	10/14/96	1575.78	10/14/96	0.000	NA
50+63	TSw2	B	1	5/1/96	L	5	10/14/96	1571.78	6/24/97	4.213	4.042
					LF	3	10/14/96	1571.78	6/24/97	2.627	-0.558
					R	5	10/14/96	1571.78	6/24/97	3.031	1.332
					V	4	10/14/96	1571.78	6/24/97	3.462	5.190
50+70	TSw2	A	1	5/1/96	HB	2	10/14/96	1564.78	11/19/96	0.000	-1.354
					HT	3	10/14/96	1564.78	6/26/97	0.551	1.268
					L	3	10/14/96	1564.78	6/24/97	1.724	0.195
					R	3	10/14/96	1564.78	6/24/97	1.669	2.270
					V	3	10/14/96	1564.78	6/24/97	2.437	2.549
53+00	TSw2	A	4	5/14/96	H	5	7/9/96	661.28	6/26/97	2.526	-1.231
					L	6	6/18/96	409.64	6/24/97	1.161	0.759
					R	8	6/18/96	409.64	6/24/97	0.226	1.206
					V	8	6/18/96	409.64	6/24/97	0.360	-0.491
54+50	TSw2	A	1	5/23/96	H	6	7/9/96	511.28	6/26/97	3.073	-2.285
					L	8	6/18/96	259.64	3/13/97	0.073	-1.433
					R	9	6/18/96	259.64	6/23/97	0.000	1.691
					V	8	6/18/96	259.64	6/23/97	0.429	-0.464
55+71	TSw2	B	1	5/31/96	H	6	7/9/96	390.28	6/26/97	2.151	-0.924
					L	5	7/23/96	474.58	6/23/97	0.000	0.148
					R	9	7/23/96	474.58	6/23/97	0.000	1.570
					V	8	7/23/96	474.58	6/23/97	0.030	-0.890
57+48	TSw2	A	1	6/20/96	H	4	8/28/96	569.47	6/26/97	1.469	5.985
					L	5	7/23/96	297.58	6/23/97	1.031	-1.960
					R	6	7/23/96	297.58	6/23/97	0.566	1.698
					V	9	7/23/96	297.58	6/23/97	0.911	-0.773
59+02	TSw2	A	1	7/2/96	H	4	8/28/96	415.47	6/26/97	0.269	-0.184
					L	8	8/19/96	330.75	6/23/97	0.294	2.753
					R	7	8/19/96	330.75	6/23/97	0.827	1.843
					V	8	8/19/96	330.75	6/23/97	1.504	0.237

Table 2. Summary of Tape Extensometer Convergence Data (continued)

Monitoring Station Location (ESF Location) ¹	Thermal Mechanical Unit	Station Instrumentation Type ²	Installed Ground Support Class ³	Excavation Date	Measurement Chord ⁴	Number of Reading	First Instrumentation Reading		Date of Last Instrumentation Reading	Maximum Convergence (mm)	Convergence Rate at Last Reading (mm/yr)
							Date	Distance to Excavation Face (m)			
60+55	TSw2	B	1	7/25/96	H	4	8/28/96	262.47	3/26/97	0.181	3.101
					L	7	9/9/96	292.06	6/23/97	2.924	-0.381
					R	7	9/9/96	292.06	6/23/97	0.183	2.094
					V	6	9/9/96	292.06	6/23/97	3.215	-1.124
62+00	TSw2	A	3a	8/13/96	H	3	1/28/97	945.64	6/26/97	0.488	-0.112
					L	5	10/14/96	434.78	6/23/97	0.368	1.358
					R	5	10/14/96	434.78	6/23/97	0.240	0.551
					V	6	10/14/96	434.78	6/23/97	0.585	-1.814
63+05	TSw2	B	1	8/27/96	H	3	1/28/97	840.64	6/26/97	3.673	-0.408
					L	6	10/14/96	329.78	6/23/97	0.563	-0.571
					R	4	10/14/96	329.78	6/23/97	0.730	0.749
					V	5	10/14/96	329.78	6/23/97	0.000	-0.155
65+06	TSw1	A	1	10/8/96	H	5	11/19/96	471.07	6/26/97	0.146	-0.414
					L	6	11/19/96	471.07	6/23/97	0.801	1.096
					R	6	11/19/96	471.07	6/23/97	0.355	0.819
					V	6	11/19/96	471.07	6/23/97	0.316	0.337
66+50	PTn	A	1	10/15/96	H	4	11/19/96	327.07	6/26/97	2.150	0.279
					L	6	11/19/96	327.07	6/23/97	1.654	0.087
					R	5	11/19/96	327.07	3/19/97	1.824	4.526
					V	6	11/19/96	327.07	6/23/97	8.787	5.700
67+95	TSw1	B	1	10/31/96	H	4	1/28/97	350.64	6/26/97	1.296	-2.798
					L	5	12/20/96	335.06	6/23/97	0.633	-0.341
					R	5	12/20/96	335.06	6/23/97	1.165	0.007
					V	4	12/20/96	335.06	3/19/97	0.928	-1.245
69+51	TSw1	A	1	11/15/96	H	4	1/28/97	194.64	6/26/97	0.423	1.535
					L	5	12/20/96	179.06	6/23/97	0.000	0.585
					R	3	12/20/96	179.06	6/23/97	0.283	0.792
					V	5	12/20/96	179.06	6/23/97	0.516	0.545
69+87	TSw1	A	1	11/20/96	H	4	2/19/97	357.51	6/26/97	0.599	-0.965
					L	5	2/12/97	298.1	6/23/97	0.656	-2.029
					R	5	2/12/97	298.1	6/23/97	0.887	-3.583
					V	5	2/12/97	298.1	6/23/97	0.913	2.378
69+94	TSw1	S	3a	11/20/96	H	4	2/19/97	350.51	6/26/97	0.112	-0.818
					L	5	2/12/97	291.1	6/23/97	2.918	2.955
					R	5	2/12/97	291.1	6/23/97	0.464	0.277
					V	5	2/12/97	291.1	6/23/97	0.177	-0.352
70+04	PTn	S	3a	11/21/96	H	4	2/19/97	340.51	6/26/97	0.012	2.820
					L	4	2/12/97	281.1	6/23/97	1.028	-1.821
					R	5	2/12/97	281.1	6/23/97	0.349	-0.445
					V	5	2/12/97	281.1	6/23/97	0.891	2.791
70+59	TSw2	S	3a	11/25/96	H	4	2/19/97	285.51	6/26/97	0.262	-0.362
					L	5	2/19/97	285.51	6/23/97	0.248	-0.470
					R	5	2/19/97	285.51	6/23/97	0.108	1.246
					V	5	2/19/97	285.51	6/23/97	0.251	0.388
72+52	TSw1	B	1	2/7/97	H	3	3/26/97	487.45	6/26/97	0.543	0.885
					L	4	3/19/97	467.97	6/23/97	0.629	-0.405
					R	4	3/19/97	467.97	6/23/97	0.924	-2.627
					V	4	3/19/97	467.97	6/23/97	0.895	4.031
73+95	TSw1	A	1	2/21/97	H	3	3/26/97	344.45	6/26/97	0.000	0.281
					L	4	3/19/97	324.97	6/23/97	0.910	-6.019
					R	4	3/19/97	324.97	6/23/97	1.049	-2.546
					V	4	3/19/97	324.97	6/23/97	0.243	-0.445

Table 2. Summary of Tape Extensometer Convergence Data (continued)

Monitoring Station Location (ESF Location) ¹	Thermal Mechanical Unit	Station Instrumentation Type ²	Installed Ground Support Class ³	Excavation Date	Measurement Chord ⁴	Number of Reading	First Instrumentation Reading		Date of Last Instrumentation Reading	Maximum Convergence (mm)	Convergence Rate at Last Reading (mm/yr)
							Date	Distance to Excavation Face (m)			
75+02	PTn	S	2a	2/26/97	H	3	3/26/97	237.45	6/26/97	0.000	0.552
					L	4	3/19/97	217.97	6/23/97	0.918	-2.101
					R	2	3/19/97	217.97	4/22/97	0.389	4.181
					V	4	3/19/97	217.97	6/23/97	0.773	0.551
75+16	TCw	S	4	2/27/97	L	4	3/19/97	203.97	6/23/97	0.932	-0.518
					R	4	3/19/97	203.97	6/23/97	0.716	1.850
					V	4	3/19/97	203.97	6/23/97	0.287	-0.175
75+59	TCw	A	1	3/4/97	H	3	3/26/97	180.45	6/26/97	0.130	0.070
					L	4	3/26/97	180.45	6/23/97	0.509	-6.281
					R	4	3/26/97	180.45	6/23/97	0.094	0.998
					V	3	3/26/97	180.45	4/30/97	0.195	-7.746

¹ ESF Station refers to the distance from the North Portal measured in meters (i.e., 28+24 indicates 2,824 m from the portal).

² The Typical type A station consists of 6 convergence pins. The typical type B station consists of one MPBX (crown), two SPBX (springline), and 6 convergence pins. The typical type S station consists of 6 convergence pins mounted on a steel set.

³ Description of Ground Support Class is provided in Table 3.

⁴ Measurement chords are defined in Figure 1. Where two horizontal chords are installed the higher horizontal chord is named as HT and the lower horizontal chord is name as HB.

Table 3. ESF Main Loop Recommended Ground Support Classes (Reference 5.10)

Ground Support Class	ESF Ground Support Recommendation
1	Rock bolts square pattern installed on 1.5x1.5m c/c w/welded wire mesh (WWF). Spot bolt as necessary. (Pins and channel may be used to secure mesh as needed)
1a	Light (W6x20) steel sets spaced 1.22 - 1.8 m w/WWF
2	Rock bolts square pattern installed on 1.0x1.0m c/c w/WWF. Spot bolt as necessary. (Pins and channel may be used to secure mesh as needed)
2a	Light (W6x20) steel sets spaced 1.22 m w/welded wire fabric (WWF)
3	Rock bolts nominal 1.0x1.0m c/c w/WWF (Spot bolt as necessary) plus 100 - 150 mm shotcrete.
3a	Light (W6x20) steel sets spaced 1.22 m w/WWF and partial lagging as required.
4	Medium (W8x31) steel sets spaced 0.61 - 1.22 m w/WWF and crown lagging as necessary.
5	Medium (W8x31) steel sets spaced 0.61 m w/full lagging

Table 4. Descriptive Statistics of the Maximum Convergence Data from Tape Extensometers

Thermal Mechanical Unit	Measurement Chord*	Installed Ground Support Class	Total Number of Chord	Highest Value of Maximum Convergence (mm)	Lowest Value of Maximum Convergence (mm)	Average Value of Maximum Convergence (mm)	Median Value of Maximum Convergence (mm)	Standard Deviation (mm)
TCw	H	1	2	1.575	0.130	0.853	0.853	1.021
	L	1	2	0.509	0.078	0.294	0.294	0.305
	R	1	2	0.094	0.014	0.054	0.054	0.056
	V	1	2	0.195	0.112	0.153	0.153	0.058
	H	4	20	2.186	0.000	0.807	0.885	0.611
	L	4	21	2.943	0.074	0.991	0.934	0.716
	R	4	21	3.562	0.136	1.158	0.953	0.731
	V	4	20	3.269	0.000	1.112	0.921	0.800
	H	2a	3	0.338	0.000	0.113	0.000	0.195
PTn	LF & RF	1	2	6.661	4.631	5.646	5.646	1.435
	H	1	5	6.611	1.569	3.459	2.285	2.127
	L	1	9	7.873	0.792	3.201	2.443	2.255
	R	1	9	11.111	1.375	3.997	3.392	2.934
	V	1	9	15.546	1.144	5.475	3.909	4.117
	H	4	1	0.000	0.000	0.000	0.000	NA
	L	4	1	0.452	0.452	0.452	0.452	NA
	R	4	1	0.744	0.744	0.744	0.744	NA
	V	4	1	0.895	0.895	0.895	0.895	NA
	H	2a	2	0.012	0.000	0.006	0.006	0.008
	L	2a	2	1.028	0.918	0.973	0.973	0.078
	R	2a	2	0.389	0.349	0.369	0.369	0.029
	V	2a	2	0.891	0.773	0.832	0.832	0.083
	H	1	1	1.010	1.010	1.010	1.010	NA
UO	L	1	1	1.068	1.068	1.068	1.068	NA
	R	1	1	1.336	1.336	1.336	1.336	NA
	V	1	1	4.576	4.576	4.576	4.576	NA
	H	4	6	0.891	0.000	0.318	0.229	0.349
	L	4	6	5.709	0.000	2.434	1.619	2.460
	R	4	6	2.882	0.705	1.560	1.414	0.754
	V	4	6	2.932	0.214	1.613	1.580	0.877
TSw1	H	1	14	2.430	0.000	1.094	1.195	0.726
	L	1	14	1.480	0.000	0.818	0.855	0.347
	R	1	14	2.059	0.283	1.048	1.046	0.465
	V	1	14	2.633	0.243	1.311	1.309	0.725
	H	4	4	1.114	0.000	0.439	0.320	0.542
	L	4	4	1.624	0.608	1.099	1.083	0.458
	R	4	4	1.123	0.387	0.778	0.801	0.346
	V	4	4	1.206	0.453	0.917	1.004	0.336
	H	3a	1	0.112	0.112	0.112	0.112	NA
	L	3a	1	2.918	2.918	2.918	2.918	NA
	R	3a	1	0.464	0.464	0.464	0.464	NA
	V	3a	1	0.177	0.177	0.177	0.177	NA
TSw2	HB	1	2	0.501	0.000	0.251	0.251	0.354
	LF & RF	1	3	5.461	0.000	2.696	2.627	2.731
	H	1	21	3.673	0.000	1.397	1.234	1.045
	L	1	26	5.815	0.000	1.561	1.137	1.460
	R	1	26	4.355	0.000	1.347	1.124	1.060
	HT	1	2	0.551	0.412	0.482	0.482	0.098
	V	1	26	4.690	0.000	1.842	1.548	1.362
	H	4	5	2.526	0.220	0.923	0.478	0.944
	L	4	5	1.181	0.214	0.795	0.894	0.419
	R	4	5	0.875	0.226	0.439	0.380	0.259
	V	4	5	3.465	0.020	1.249	0.825	1.369
	H	3a	2	0.488	0.262	0.375	0.375	0.160
	L	3a	2	0.368	0.248	0.308	0.308	0.085
	R	3a	2	0.240	0.108	0.174	0.174	0.093
	V	3a	2	0.585	0.251	0.418	0.418	0.236

* Measurement chords are defined in Figure 1. Where two horizontal chords are installed the higher horizontal chord is named as HT and the lower horizontal chord is name as HB.

7.2.2 Summary of Borehole Extensometer Deformation Data

Borehole extensometers include both the multiple point borehole extensometer (MPBX) with two to five anchor points and the single point borehole extensometer (SPBX). The borehole extensometer (Geokon Model A-5) consists of inflatable hydraulic anchors, stainless steel measurement rods, and vibrating wire displacement transducer. The resolution of the displacement transducer is 0.025% of the full scale reading (i.e., for 10 mm deformation reading, the accuracy is 0.0025 mm). A typical MPBX station consists of three anchor points. The anchor depths for the three anchor points are typically located 7.4, 2.7, and 1.3 m from the surface into the rock. For the SPBX, the anchor point is set at 2.7 m from the borehole collar to rock. Deformation was measured from extension or contraction of the measurement rod that connects the borehole collar and the anchor point. The deformation measurement accounts for only a portion of the convergence. To convert the deformation data to convergence data, the deformation measurements were multiplied by a factor of 2 assuming that the rock mass is homogeneous and isotropic. A schematic layout of a borehole extensometer monitoring station is shown in Figure 7. A total of 18 borehole monitoring stations was set up in the ESF Main Loop.

Figures 8 to 24 presents the deformation curves for each monitoring station except Station 79+96 for lack of data at this time. The deformation curves resemble the asymptotic characteristics of a typical deformation curve around an opening. Deformation with respect to both time and distance are included. The reference time is the excavation date for the monitoring station in these figures. Distance is measured from the excavation face position to the monitoring station. Also included in the figures are the deformation rates calculated from the measurements of the deep anchor points (with the exception of Station 18+30 for lack of data). The deformation curves also show continuous increase of the convergence well after days of excavation. This confirms the observation of the time-dependent characteristics of the rock response from the tape extensometer data.

Summary of the borehole extensometer deformation data in the ESF Main Loop is provided in Table 5. Information included in Table 5 is similar to those in Table 2 for the summary of the tape extensometer data. The table contains the station excavation date, time of first instrumentation reading, distance between the station and the excavation face at first instrumentation reading, maximum convergence, and the calculated convergence rate based on the last two readings. Most of the borehole extensometer monitoring stations are installed in the region with ground support class 1. Similar to the tape extensometer data, the time lag between the first deformation readings and the excavation date ranges from several days to several months. Distance between the monitoring station and the excavation face also spreads from tens to thousands of meters at the time of first reading. The maximum deformation monitored for most of the stations is within 1.0 mm. The maximum deformation among all stations is 4.3 mm monitored at the SPBX of Spring-Line-Right (SLR) of Station 28+28. The actual deformation should be greater than the listed values since the start of the monitoring was days after the excavation.

The calculated deformation rates based on the last two readings are presented in the last column of Table 5. Deformation rate ranges from approximately -0.7 mm/yr to 2.0 mm/yr with the median value approximately 0.06 mm/yr. The calculated deformation rates appear to be more consistent than the convergence rates calculated based on the tape extensometers data. Summary statistics for the maximum deformation measured from the deep anchor point (7.4 m in most station) of MPBX is presented in Table 6. Measurements are grouped based on the thermal mechanical unit. Most of the MPBX stations are located in TSw2 units. The median values of the maximum deformation are 0.283 mm and 0.485 mm for TSw1 and TSw2 respectively. The highest value of deformation at roof among all stations is 3.825 mm, measured at Station 27+70.

Since the deformation data is measured from extension or contraction of the measurement rod, the measurement is actually the relative displacement between the anchor point and the borehole collar. The surrounding rock movement due to excavation normally extends from the perimeter of the opening to the rock about the distance of one to two diameters of the opening. The deformation measured from the deepest anchor point is therefore the closest to the actual displacement at the excavation surface. Although the deformation measurements from the intermediate anchor points located in 1.3 and 2.7 m are the relative displacements, the actual displacements at these points can be calculated from subtracting the measured value from the deep anchor measurements. The actual displacements at the intermediate anchor points provide the information of the displacement field in the surrounding rock mass. Figures 25 and 26 present the displacements in the rock mass for Station 21+34 and Station 28+28. A linear trend of displacement within 4.3 m of the rock at Station 21+34 is shown in Figure 25. Station 28+28 is located at the intersection between the Main Loop and the thermal test alcove. A deep anchor point located at 13.77 m, approximately two diameters away from the opening, is installed in this station. Figure 26 shows movement of 0.6 to 0.8 mm at depth of 7.67 m in the first six month of the excavation and then no movement afterward. The movement observed at the depth of 7.67 m indicates that the deformation measured from the typical deep anchor point (7.4 m) for most of the station may be less than the actual movement.

7.2.3 Comparison of the Deformation Data from Tape Extensometers and Borehole Extensometers

Comparison of the instrumentation results from the tape extensometers and borehole extensometers is summarized in Figure 27. The comparison focuses on the vertical convergence at 16 type B stations. The convergence values for the borehole extensometers were calculated by multiplying the roof deformation measurements by a factor of 2 assuming the surrounding rock mass is homogeneous and isotropic. The convergence curves from borehole extensometers resemble the asymptotic characteristics of a typical convergence curve, while most of the convergence curves from the tape extensometer fluctuate with time. Only two stations show good agreement (Stations 28+28 and 31+02). Convergence measurements from tape extensometers in 7 out of 16 stations include negative values, while the measurements from the borehole extensometers consistently indicate closure in the vertical direction.

A similar and important attribute is observed for the measurements in the two stations that show good agreement between the data from the tape extensometer and borehole extensometer, that is, convergences are all relatively large compared to other stations. This indicates that the tape extensometer performed well in conditions with large convergence. The problem of aberrant measurements using the tape extensometers may result from the limitation of accuracy for the tape extensometer.

Table 5. Summary of Borehole Extensometer Deformation Data in ESF Main Loop

Monitoring Station Location (ESF Station) ¹	Thermal Mechanical Unit	Gage Location	Gage Depth (m)	Number of Reading	Installed Ground Support Class	First Instrumentation Reading		Maximum Deformation (mm)	Deformation Rate at Last Reading (mm/yr)
						Days after Excavation	Distance after Excavation Face (m)		
04+13	TCw	CROWN	6.1	26	1	16	123	0.615	-0.043
		CROWN	3.05	26	1	16	123	0.356	-0.333
		CROWN	1.52	26	1	16	123	0.098	-0.085
		SLL ²	3.05	26	1	16	123	0.402	-0.398
09+75	PTn	CROWN	7.37	25	1	95	698	0.289	0.131
		CROWN	6.1	25	1	95	698	0.253	0.114
		CROWN	3.05	25	1	95	698	0.173	-0.058
		SLL ²	2.74	25	1	95	698	0.259	0.144
		SLR ²	3.08	25	1	95	698	0.242	0.131
18+30	TSw1	CROWN	7.38	13	1	133	2232	0.000	NA
		CROWN	2.81	13	1	133	2232	1.514	0.269
		SLL ²	2.78	13	1	133	2232	0.298	-0.083
		SLR ²	2.78	13	1	133	2232	0.157	-0.010
21+34	TSw1	CROWN	1.27	23	1	4	80	0.143	0.010
		CROWN	4.32	23	1	4	80	0.340	-0.091
		CROWN	7.37	23	1	4	80	0.489	-0.030
		SLL ²	3.05	23	1	4	80	0.459	-0.052
		SLR ²	3.05	23	1	4	80	0.405	0.062
27+70	TSw2	CROWN	7.38	18	1	7	124	3.825	1.158
		CROWN	2.81	18	1	7	124	1.198	2.030
		SLL ²	2.74	18	1	7	124	0.275	0.010
		SLR ²	2.74	18	1	7	124	0.612	-0.115
28+28	TSw2	CROWN	13.77	15	1	57	982	2.171	0.031
		CROWN	7.67	15	1	57	982	2.140	0.062
		CROWN	3.09	15	1	57	982	0.539	-0.031
		SLR ²	13.77	15	1	57	982	0.000	-0.094
		SLR ²	7.67	15	1	57	982	4.349	0.064
31+02	TSw2	SLR ²	3.09	15	1	57	982	0.064	-0.052
		CROWN	7.38	18	1	12	79	1.501	0.183
		CROWN	2.81	18	1	12	79	1.273	0.363
		SLL ²	2.74	18	1	12	79	0.197	-0.115
34+01	TSw2	SLR ²	2.74	18	1	12	79	0.408	0.140
		CROWN	7.38	11	1	92	1184	2.878	1.164
		CROWN	2.81	11	1	92	1184	0.215	0.579
		SLL ²	3.03	11	1	92	1184	0.019	-0.020
37+37	TSw2	SLR ²	2.72	11	1	92	1184	0.260	-0.111
		CROWN	1.25	12	1	101	1129	0.057	-0.024
		CROWN	3.08	12	1	101	1129	0.163	0.079
		CROWN	7.35	12	1	101	1129	1.012	0.230
42+47	TSw2	SLR ²	2.72	12	1	101	1129	0.127	0.215
		CROWN	1.25	11	1	70	779	0.023	0.022
		CROWN	3.08	11	1	70	779	0.139	0.101
		CROWN	7.35	11	1	70	779	0.352	0.190
		SLL ²	2.72	11	1	70	779	0.007	-0.091
		SLR ²	2.72	11	1	70	779	0.005	-0.072

Table 5. Summary of Borehole Extensometer Deformation Data in ESF Main Loop (continued)

Monitoring Station Location (ESF Station) ¹	Thermal Mechanical Unit	Gage Location	Gage Depth (m)	Number of Reading	Installed Ground Support Class	First Instrumentation Reading		Maximum Deformation (mm)	Deformation Rate at Last Reading (mm/yr)
						Days after Excavation	Distance after Excavation Face (m)		
47+06	TSw2	CROWN	1.27	7	1	114	1353	0.098	0.163
		CROWN	2.8	7	1	114	1353	0.057	-0.716
		CROWN	7.37	7	1	114	1353	0.049	-0.359
		SLL ²	2.72	7	1	114	1353	0.080	-0.060
		SLR ²	2.72	7	1	114	1353	0.000	-0.148
50+64	TSw2	CROWN	1.27	5	1	170	1652	0.048	0.031
		CROWN	2.79	5	1	170	1652	0.069	0.083
		CROWN	7.39	5	1	170	1652	0.148	0.228
		SLR ²	2.72	5	1	170	1652	0.457	0.788
55+71	TSw2	CROWN	1.27	8	1	12	88	0.044	-0.060
		CROWN	2.8	8	1	12	88	0.226	0.142
		CROWN	7.37	8	1	12	88	0.469	0.151
		SLL ²	2.72	8	1	12	88	0.278	-0.020
		SLR ²	2.72	8	1	12	88	0.087	-0.369
60+55	TSw2	CROWN	1.26	7	1	16	129	0.048	-0.030
		CROWN	2.79	7	1	16	129	0.062	-0.021
		CROWN	7.36	7	1	16	129	0.374	0.152
		SLL ²	2.72	7	1	16	129	0.116	0.039
		SLR ²	2.72	7	1	16	129	0.122	-0.239
63+06	TSw2	CROWN	1.27	5	3a	48	329	0.094	-0.010
		CROWN	2.79	5	3a	48	329	0.108	0.000
		CROWN	7.36	5	3a	48	329	0.349	0.288
		SLL ²	2.72	5	3a	48	329	0.267	0.050
		SLR ²	2.72	5	3a	48	329	0.090	0.020
67+95	TSw1	CROWN	1.27	6	1	5	93	0.240	0.644
		CROWN	2.79	6	1	5	93	0.397	0.273
		CROWN	7.36	6	1	5	93	0.501	0.293
		SLL ²	2.72	6	1	5	93	0.489	0.366
		SLR ²	2.72	6	1	5	93	0.594	0.251
72+48	TSw1	CROWN	1.27	3	1	12	97	0.092	0.156
		CROWN	2.79	3	1	12	97	0.119	0.156
		CROWN	7.36	3	1	12	97	0.078	0.253
		SLL ²	2.72	3	1	12	97	0.192	0.192
		SLR ²	2.72	3	1	12	97	0.682	1.121
76+96	TCw	CROWN	1.27	1	2a	25	50	0.000	NA
		CROWN	2.79	1	2a	25	50	0.000	NA
		CROWN	7.36	1	2a	25	50	0.000	NA
		SLL ²	2.72	2	2a	25	50	0.096	0.438
		SLR ²	2.72	2	2a	25	50	0.152	0.696

¹ ESF Station refers to the distance from the North Portal measured in meters (i.e., 28+24 indicates 2,824 m from the portal).

² SLL – Spring-Line-Left of SPBX, SLR – Spring-Line-Right of SPBX

Table 6. Descriptive Statistics of the Maximum Roof Deformation from Borehole Extensometer

<i>Thermal Mechanical Unit</i>	<i>Number of Data Sets</i>	<i>Highest Value of Maximum Deformation (mm)</i>	<i>Lowest Value of Maximum Deformation (mm)</i>	<i>Average Value of Maximum Deformation (mm)</i>	<i>Median Value of Maximum Deformation (mm)</i>	<i>Standard Deviation (mm)</i>
TCw	2	0.615	0.000	0.307	NA	NA
PTn	1	0.289	0.289	0.289	NA	NA
TSw1	4	0.501	0.000	0.267	0.283	0.265
TSw2	11	3.825	0.049	1.136	0.485	1.218

7.3 ANALYSIS OF CONVERGENCE DATA

7.3.1 Interpretation of Convergence Measurements — The Convergence Solution

7.3.1.1 Background

Tunnel convergence is caused by stress redistribution around the periphery of an opening during excavation. The stress redistribution and deformation occurs both in cross-sections through the plane of tunnel radius and the plane of the tunnel axis. Figure 28 shows the magnitude of the radial convergence as a function of the distance from the tunnel face. The figure demonstrates that deformation occurs ahead of the excavation face. The portion of the deformation ahead of excavation face is called pre-face deformation.

The Convergence Solution was derived from the general form of the convergence equation proposed by Guenot et al. (Reference 5.2). The equation was developed based on finite-element analyses with field measurements. In this approach, a semi-empirical equation is fitted to the convergence measurements by adjusting parameters which characterize the response of the rock. These parameters are related to important physical quantities, such as the extent of the yield zone and the time-dependent properties of the rock. The Guenot et al. (Reference 5.2) equation is presented as follows:

$$C(x, t) = C_1(x) \{C_{\infty} + AC_2(t)\} \quad (\text{Eqn. 1})$$

where x = the distance along the tunnel from a reference point;

t = time;

$C_1(x)$ = time-independent, or loading function;

$C_2(t)$ = time-dependent;

C_{∞} = ultimate time-independent convergence (elastic + plastic);

A = ultimate time-dependent convergence; and

$(C_{\infty} + A)$ = total ultimate convergence.

$C_1(x)$ represents the proportion of the ultimate stress change that has been transferred to the rock at a distance x from the face. The time-independent convergence is given by the product $C_1(x) \times C_{\infty}$, and the time-dependent convergence is given by $C_1(x) \times A \times C_2(t)$.

The form of convergence function for the time-independent portion is described in the following:

$$C_1(x) = C_{\infty} \left\{ 1 - \left[\frac{1}{1 + \frac{x}{X}} \right]^2 \right\} \quad (\text{Eqn. 2})$$

where $X = 0.84 R$ and R is the radius of the plastic zone.

The form of convergence function for the time-dependent portion is described in the following:

$$C_2(t) = 1 - \left[\frac{1}{1 + \frac{t}{T}} \right]^{0.3} \quad (\text{Eqn. 3})$$

where T = parameter reflecting the shape of the time-dependent curve for a particular rock..

Barlow (Reference 5.2) pointed out two major limitations of the approach by Guenot et al. (Reference 5.2). The first limitation is that pre-face deformation is not accounted in the equation. The second limitation is that the effect of a tunnel support is not considered. The Convergence Solution proposed by Barlow (Reference 5.2) extends Guenot's approach to include the pre-face portion of convergence and the consideration of a supported tunnel. The extended equations by Barlow (Reference 5.2) are included in Attachment II.

The main assumption for the basis of the Convergence Solution is that the behavior of the rock mass can be characterized by the shape of the convergence curve. This is normally achieved by normalizing the convergence to the ultimate convergence. However, ultimate convergence is usually an unknown during the observational design stage. Barlow (Reference 5.2) proposed a solution of using the convergence rates, instead of the actual convergence, in the curve-fitting process to circumvent the problem of unknown ultimate convergence. The maximum convergence rate is used to normalize the convergence rates to characterize the response of the rock. The maximum convergence rate is observed at or near the face and can be monitored in the early stage of the excavation monitoring. The convergence rate equations are also included in Attachment II.

A computer program CONRATE written in FORTRAN language, provided in Reference 5.2, has been qualified to use for the design monitoring tasks (Section 6.1.2). This program calculates the convergence vs time curve, and the normalized convergence rate vs time curve according to the

equations of the Convergence Solution (listed in Attachment II). Three parameters X , T and A^* are required for input to CONRATE. The first parameter X is related to the size of the yield zone around the tunnel. The second parameter T reflects the shape of the creep curve for the rock mass. The third parameter A^* is the ratio of time-dependent convergence to the time-independent convergence (A/C_{∞}). As stated by Barlow (Reference 5.2), it is possible to obtain independent estimates of the three parameters, because each parameter influences a different portion of the convergence rate curve.

7.3.1.2 Convergence Solution Analysis of Selected Borehole Extensometer Data

As presented in Section 7.2.1, most of the tape extensometer data were measured with a long delay between the excavation date and the first instrumentation reading. The monitored data is projected to be in the asymptotic range of the convergence curve with a relatively small increment. The projected monitored range combined with human/measurement errors causes the convergence curves to fluctuate with time (Figures 2 to 6) and hence exaggerate the calculated convergence rate. As described in Section 7.3.1.1, accurate convergence rate data collected from monitoring stations installed close to the excavation face are required for the Convergence Solution analysis. The data from tape extensometers were therefore considered inadequate for the Convergence Solution analysis.

The deformation measurements from borehole extensometer were used for the Convergence Solution analysis. Stations with relatively early instrumentation reading data were selected for the analysis. A total of six monitoring stations were selected: Station 21+34, Station 27+70, Station 31+02, Station 55+71, Station 60+55, and Station 67+95. The first instrumentation reading for these stations ranges from 4 to 16 days after the excavation.

To curve-fit the convergence data to the Convergence Solution equations, convergence rates were first calculated and normalized to the maximum convergence rate. Negative convergence rates were eliminated from the normalized convergence curves before the curve-fit.

The best-fit process consists of determining the value of X , T , and A^* that best describe the shapes of the convergence curve and convergence rate curve. The parameter X has a dominant influence on the beginning portion of the convergence curve because it reflects the time-independent behavior of the rock. Due to the lack of the data in this portion of the curve, an assumption that no yield zone was formed around the excavation was made. The value of X was therefore fixed as 3.192 m (0.84×3.8 m) in the analysis. This is considered reasonable judging from the high strength/stress ratio in the welded tuff units at site.

Best fit of the measured data was determined by adjusting the values of T and A^* to approximate the shapes of both the convergence curve and normalized convergence rate curve. The CONRATE input files, output files, and best-fit curves are presented in Attachment III. The results of best fit are summarized in Table 7. Best-fit curves for each selected station are presented in Figures III-1 to III-12 sequentially. Notice that the objective of the best fit is to approximate the shape of the normalized convergence rate curve but not the magnitude of the

actual convergence rate. The results indicate high values for parameter A^* , which represents the ratio of time-dependent convergence to the time-independent convergence ($A/C_{x\infty}$). A^* value ranges from 10 to 80. The best-fit results confirm the observation of the time-dependent behavior of the rock response described in Sections 7.2.1 and 7.2.2.

The complete convergence was calculated based on the best-fit parameters. The calculation was completed using numerical integration of the convergence rates. Convergence rate was first obtained from multiplying the normalized convergence rate to the monitored maximum convergence rate. Numerical integration was conducted in an EXCEL spreadsheet. The process of calculating the complete convergence is illustrated by the example of Station 31+02, as presented in Attachment IV. Figures 29 to 34 show the estimated complete convergence curve and its comparison with the instrumentation data for each station respectively. As predicted in Sections 7.2.1 and 7.2.2, the convergence occurred before monitoring is quite substantial.

Once the complete convergence curve is obtained, the estimated deformation for the monitoring station at a certain time of interest is available (Attachment IV, Table IV-1). The estimated deformations at the time of ground support installation and at 300 days after excavation are tabulated in Table 8. The time of ground support installation is approximated to be the time when the excavation face is 10 m from the monitoring station, or a day after the excavation. Also included in Table 8 is the calculated percentage of relaxation at ground support installation based on the estimated deformations. The percentage of relaxation was calculated as the ratio of the estimated deformation at the time of ground support installation to the estimated deformation at 300 days after excavation. The relaxation percentage ranges from 18% to 61 %. The percentage of relaxation appears to be strongly related to parameter A^* .

Long-term tunnel displacement can be predicted based on the best-fit parameters and the Convergence Solution equations. As described in Attachment III, an initial estimate of ultimate time-independent convergence is required for the input of program CONRATE. This estimate does not affect the outcome of the normalized convergence rate but does have an effect on the magnitude of convergence result. Once the actual convergence is calculated using the numerical integration (described in Attachment IV), the ultimate time-independent convergence can be determined based on the ratio of the actual convergence and the initial convergence estimation from CONRATE. With the best fit parameter A^* (ratio of ultimate time-independent convergence to the ultimate time-dependent convergence) and the value of ultimate time-independent convergence, the ultimate time-dependent convergence can also be calculated. Table 9 lists the predicted values for the ultimate time-independent convergence, the ultimate time-dependent convergence, and the ultimate total convergence. The predictive convergence rate after 5 years of excavation is also included in Table 9. This value is obtained directly from the CONRATE output based on the similar input file listed in Attachment III but with time expanded to 5 years. Both the predictive total convergence and convergence rate are lower than the tentative goals set by the DOE Site Characterization Plan (70 mm total displacement for 100 years and 1 mm/yr convergence rate, Reference 5.33). The predicted roof displacements up to 5 years for the six stations are presented in Figure 35.

7.3.2 Correlation of Tunnel Deformation and Rock Mass Quality

Barton suggested that rock mass quality Q may have some influence on the deformation resulting from excavation (Reference 5.3). If a relationship could be established between the rock mass quality and rock deformation, the deformability of the host rock could be predicted based on the rock mass quality data. The results to correlate Q with the measured convergence are presented in this section.

Table 7. Curve-Fit Results Using Convergence Solution (Reference 5.2)

Station	Thermal mechanical Unit	X	T	A*
21+34	TSw1	3.192	2.5	20
27+70	TSw2	3.192	50	80
31+02	TSw2	3.192	10	25
55+71	TSw2	3.192	50	10
60+55	TSw2	3.192	20	10
67+95	TSw1	3.192	15	10

Table 8. Estimated Deformation and the Percentage of Relaxation at Ground Support Installation

Station	Thermal mechanical Unit	Estimated Deformation at Ground Support Installation (mm)	Estimated Deformation at 300 days after Excavation (mm)	Percentage of Relaxation at Ground Support Installation
21+34	TSw1	0.86	1.408	61%
27+70	TSw2	0.791	4.487	18%
31+02	TSw2	1.366	3.360	41%
55+71	TSw2	0.228	0.708	32%
60+55	TSw2	0.26	0.682	38%
67+95	TSw1	0.35	0.837	42%

Table 9. Predicted Convergence Rate at 5 Years after Excavation and the Ultimate Convergence

Station	Thermal mechanical Unit	Ultimate Time-independent Convergence (mm)	Ultimate Time-dependent Convergence (mm)	Ultimate Total Convergence (mm)	Convergence Rate at 5 years after Excavation (mm/yr)
21+34	TSw1	0.086	3.440	3.612	0.015
27+70	TSw2	0.122	19.520	19.764	0.207
31+02	TSw2	0.200	10.420	10.420	0.171
55+71	TSw2	0.130	2.869	2.869	0.027
60+55	TSw2	0.103	2.277	2.277	0.017
67+95	TSw1	0.123	2.696	2.696	0.018

The modified Q values from the full peripheral mapping data were used to correlate with the tunnel deformation. In order to account for the dimension of the opening, Q/span was used for correlation. Figures 36 to 40 present the results of correlation for the tape extensometer data in each thermal mechanical unit. Notice that the tape extensometer data are uncorrected and do not include the initial deformation before instrumentation. The suggested upper and lower bounds by Barton (Reference 5.3) are also included in these figures. The uncorrected deformation data in ESF appear to skew to Barton's lower bound in all units. The correlation between the uncorrected deformation from tape extensometer and Q/span is in general poor.

Correlation results for the uncorrected borehole extensometer data is shown in Figure 41. The trend is similar to that of tape extensometer data. About half of the data points fall outside of Barton's lower bound. The data Barton used to establish the bounds are mainly from well-instrumented underground power station projects with few tunnel data included. Barton also explicitly stated that there was a complete lack of data for small tunnels in good quality rock masses in his database.

One potential problem in the correlation is that the convergence measurements used are uncorrected and therefore do not represent the complete convergence as revealed in Figures 29 to 34. The estimated complete convergence at 300 days after excavation (see Figures 29 to 34) from Convergence Solution (Reference 5.2) was therefore used to correlate with Q/span . The results are shown in Figure 42. Barton's upper and lower bounds appear to be applicable to the estimated complete convergence obtained from the Convergence Solution. However, correlation of the complete convergence and Q/span is still poor with the convergence virtually independent of Q/span .

7.3.3 Comparison of Monitored Deformation Data to Design Analysis Results

The ESF Ground Support Design Analysis (Reference 5.10, p. 46) presented a series of calculated closures at various stations, which were based on Mohr-Coulomb plasticity analyses of unsupported tunnel openings. Both the in situ stress condition and the rock mass properties were varied to produce a range of vertical and horizontal closure curves for each thermal mechanical unit in the ESF. The maximum closure magnitudes from the ESF closure models are compared to actual displacement magnitudes from field measurements in Figures 43 and 44.

The actual (uncorrected) displacement magnitudes from field measurements are presented as an average of the maximum displacements occurring at each convergence monitoring station within a thermal mechanical unit. It is important to note that since the convergence monitoring stations were installed at some time after the opening was excavated, much of the initial deformation at each station was not measured. Field-measured displacement magnitudes are not therefore directly comparable to the closures of ESF Ground Support Analysis. To compensate for this problem, the results from the Convergence Solution are shown for the vertical displacements in Figure 43. The Convergence Solution values extrapolate the field-measured values to estimate the initial (unmeasured) deformation.

Based on the interpretation of the field measured convergence data using the Convergence Solution approach, the ESF ground support design analysis closure model is conservative, and actual displacements in the ESF Main Loop are less than projected.

7.4 DETERMINATION OF ROCK MASS MODULUS OF DEFORMATION FROM CONVERGENCE MONITORING DATA

A methodology for determining the modulus of deformation using monitored convergence data was developed by Amini and Hill under the sponsorship of Defense Nuclear Agency (DNA) (Reference 5.1). This method accounts elastic displacement and movement along joint and other anomalies in the surrounding rock mass as the cause of the tunnel convergence. The advantage of this method is that the calculated rock mass modulus of deformation represents the desired field scale. This method has been applied in the Nevada Test Site and was found to better describe the tunnel behavior than the empirical approaches.

The equation to calculate the rock mass modulus of deformation provided by Amini and Hill (Reference 5.1) is listed in the following:

$$E_{RM} = \frac{(1+\nu)(1+k)(\sigma_v)(a)}{2u_T} \times GF \quad (\text{Eqn. 4})$$

where ν is the Poisson's ratio,
 k is the ratio of horizontal to vertical stress,
 σ_v is the vertical component of the in situ stress,
 a is the effective radius of the opening,
 u_T is measured roof deformation, and
 GF is defined as geometry factor.

For a circular opening, GF is the ratio between the roof deformation and the average convergence around the periphery of the opening. The original elastic solution requires only the average convergence around the periphery of the opening. However, in order to obtain the average convergence around the periphery of the opening, one must monitor the deformation of the opening at several points around the periphery of the opening and average the results. To alleviate this problem so that only one convergence measurement and calculation is necessary, the equation was rearranged to include the roof deformation and GF .

The estimated complete convergence at 300 days after excavation (see Table 8) was used as the roof deformation in the calculation. The rest of the required properties in Equation 4, other than GF , were obtained from site related reference sources. Numerical analysis using the finite-difference code FLAC (Reference 5.17) was performed to calculate the geometry factor (GF).

The numerical analysis simulates the excavation of a circular opening with k value of 0.5. The detail description of the FLAC analysis is presented in Attachment V.

Table 10 summarizes the calculation results for rock mass modulus of deformation. The calculated rock mass modulus of deformation range from 1.23 GPa to 8.78 GPa. The results are presented graphically in Figure 45 and compared with the prediction from other empirical models. Also included in Figure 45 are the Cross Drift Prediction Model (CDPM, Reference 5.19), the reported in situ Goodman borehole jack test results (References 5.37 and 5.40), and the plate loading test results (Reference 5.40). All the field tests results presented in Figure 45 were conducted under ambient condition. Tests were also conducted for the heated environment, the modulus values are approximately two times of those for the ambient condition. The calculated rock mass modulus of deformation are in general agreement with CDPM, the in situ Goodman borehole jack test results, and the plate loading test results.

Table 10. Back Calculation of Rock Mass Modulus of Deformation from Convergence Data (Reference 5.1)

Station	Thermal mechanical unit	RMR ¹	Estimated Roof Deformation at 300 days after excavation(mm)	Estimated Convergence at 300 days after Excavation(u_T , mm)	In Situ Vertical Stress ² (MPa)	k	GF	Rock Mass Poisson's Ratio ³	Estimated Rock Mass Modulus (GPa)
21+34	TSw1	61	1.403	2.806	3.3	0.5	0.715	0.3	3.12
27+70	TSw2	63	4.439	8.878	4.4	0.5	0.715	0.21	1.22
31+02	TSw2	57	3.402	6.804	4.9	0.5	0.715	0.21	1.78
55+71	TSw2	70	0.708	1.416	5	0.5	0.715	0.21	8.71
60+55	TSw2	61	0.688	1.376	3.9	0.5	0.715	0.21	6.99
67+95	TSw1	40	0.856	1.712	2	0.5	0.715	0.3	3.09

¹ data source: Reference 5.14, ² data source: Reference 5.15, ³ data source: Reference 5.19

8.0 CONCLUSIONS AND RECOMMENDATIONS

This design confirmation analysis has provided the results to satisfy the requirements of 10 CFR 60.141 (Reference 5.34), "Confirmation of Geotechnical and Design Parameters". The following conclusions and recommendations have resulted from this analysis.

* Complete satisfaction of 10 CFR 60.141 will depend on the eventual resolution of TBV-403.

8.1 CONCLUSIONS

- Convergence measured from both tape extensometers and borehole extensometers are in general low in the ESF Main Loop. The maximum observed convergences to date for most of the welded tuff units are within 2.0 mm. As expected, higher convergence was monitored for the non-welded tuff units. The maximum observed convergences for most of non-welded tuff units are less than 5.0 mm. The maximum observed convergence among all the welded tuff units is 5.8 mm monitored at Chord L of Station 28+24 (Table 2). The maximum observed convergence among all the non-welded tuff units is 15.55 mm monitored at Chord V of Station 10+00 (Table 2). The first instrumentation dates for most stations were around one to two months after the excavation. The actual convergence should therefore be greater than the magnitudes of the monitored deformation. The delay in the start of instrumentation precludes the measurement of the initial and important portion of convergence curve. If the initial convergence is not measured, the monitored data is projected to be in the asymptotic range of the convergence curve with little deformation increment. The actual deformation increment may be overridden by human errors in tape measurements.
- The deformation curves show a consistent trend of time-dependent rock response to the excavation (Figures 8 to 24). The increase of deformation is observed well after 200 days of excavation. The Convergence Solution analysis confirms this observation (Section 7.3.1.2).
- Borehole extensometers provide better accuracy than the tape extensometers ($\pm 0.025\%$ of full scale reading for borehole extensometer versus ± 0.127 mm for tape extensometer) with less chance for human error for data acquisition. The comparison provided in Section 7.2.3 indicates a more consistent trend from the borehole extensometer measurements. Convergence measurements from tape extensometers include negative values (indicating the expansion of the opening) in several of the monitoring stations, while the measurements from the borehole extensometers consistently indicate closure in the vertical direction.
- A regression analysis of the selected deformation data based on the Convergence Solution (Reference 5.2) was conducted to estimate the long-term displacement and convergence rate. The predicted ultimate convergence magnitudes from Convergence Solution are all less than the SCP goals of 70 mm total displacement for 100 years (Table 9). The predicted convergence rates at 5 years after excavation are less than the closure rate criterion of 1 mm/year (Table 9). This design confirmation analysis indicates that tunnel displacement will not have an adverse effect on long-term tunnel stability.
- The percentage of relaxation at ground support installation was calculated based on the estimated deformation at 300 days after excavation. The relaxation percentage ranges from 18% to 61 % (Table 8). These values are in general lower than used in the ESF

Ground Support Analysis (Reference 5.10). The pronounced time-dependent rock response to excavation is the main cause for the low values.

- Correlation between the rock mass quality and the deformation data monitored in ESF Main Loop is in general poor (Section 7.3.2). Most of the uncorrected deformation data are less than Barton's projected lower bound from Q correlation (Figures 36 to 41).
- Based on the interpretation of the field measured convergence data using the Convergence Solution approach, the ESF ground support design analysis closure model is conservative, and actual displacements in the ESF Main Loop are less than projected.
- Rock mass modulus of deformation was back calculated from the convergence data. The calculated rock mass modulus of deformation ranges from 1.22 GPa to 8.71 GPa (Table 10). The results are presented graphically in Figure 45 and compared with the prediction from other empirical models. The calculated rock mass modulus of deformation values are in general agreement with the Cross Drift Prediction Model, the in situ Goodman borehole jack test results, and the plate loading test results.

8.2 RECOMMENDATIONS

- Although the magnitudes of convergence measured in the ESF Main Loop were in general small, time-dependent rock response is pronounced. Continuous monitoring is recommended to assess the impact of time-dependent characteristics on the ground support system.
- A monitoring program in which convergence measurements are collected immediately after the monitoring station has been excavated is recommended to obtain the complete convergence curves. Instrumentation set up should start as early as possible in order to acquire the initial deformation history of the rock mass.
- For long term deformation monitoring, the convergence increment will be too small to measure using tape extensometers. Borehole extensometers are recommended for long term deformation monitoring.
- The approach of obtaining the rock mass modulus of deformation from back calculation of the convergence data is promising. In addition to collecting early convergence data immediately after excavation, a program of in situ field tests, such as the Goodman borehole jack, is recommended to validate this approach.

9.0 ATTACHMENTS

Attachment I: Convergence Curves Based on Data from Tape Extensometer Measurements	Pages I-1 to I-59
Attachment II: Equations for the Convergence Solution	Pages II-1 to II-4
Attachment III: Best Fit of Deformation Data to the Convergence Solution	Pages III-1 to III-60
Attachment IV: Illustrative Calculation of Convergence Using Numerical Integration of Convergence Rates	Pages IV-1 to IV-12
Attachment V: FLAC Analysis to Obtain the GF Value	Pages V-1 to V-10

Figure 1. Schematic Layout of the Measurement Chord for Tape Extensometer (Looking at the Face)

Figure 2. Tape Extensometer Convergence Data Monitored in TCw Unit with Groud Support Class 4
 (Data Source: Reference 5.21)

Figure 3. Tape Extensometer Convergence Data Monitored in UO Unit with Ground Support Class 4
 (Data Source: Reference 5.21)

Figure 4. Tape Extensometer Convergence Data Monitored in PTn Unit with Ground Support Class 1
 (Data Source: Reference 5.21)

Figure 5. Tape Extensometer Convergence Data Monitored in TSw1 Unit with Ground Support Class 1
 (Data Source: Reference 5.21)

Figure 6. Tape Extensometer Convergence Data Monitored in TSw2 Unit with Ground Support Class 1
 (Data Source: Reference 5.21)

Figure 7. Schematic Layout of a Station with Borehole Extensometer
(Looking at the Face)

(a)

(b)

(c)

Figure 8. Borehole Extensometer Deformation Data, Station 04+13
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 9. Borehole Extensometer Deformation Data, Station 09+75
(Data Source: Reference 5.21)

(a)

(b)

Figure 10. Borehole Extensometer Deformation Data, Station 18+3
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 11. Borehole Extensometer Deformation Data, Station 21+34
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 12. Borehole Extensometer Deformation Data, Station 27+70
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 13. Borehole Extensometer Deformation Data, Station 28+28
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 14. Borehole Extensometer Deformation Data, Station 31+02
(Data Source: Reference 5.21)

(a)

(b)

Figure 15. Borehole Extensometer Deformation Data, Station 34+01
(Data Source: Reference 5.21)

(a)

(b)

Figure 16. Borehole Extensometer Deformation Data, Station 37+37
(Data Source: Reference 5.21)

(a)

(b)

Figure 17. Borehole Extensometer Deformation Data, Station 42+47
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 18. Borehole Extensometer Deformation Data, Station 47+06
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 19. Borehole Extensometer Deformation Data, Station 50+64
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 20. Borehole Extensometer Deformation Data, Station 55+71
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 21. Borehole Extensometer Deformation Data, Station 60+55
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 22. Borehole Extensometer Deformation Data, Station 63+06
(Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 23. Borehole Extensometer Deformation Data, Station 67+95
 (Data Source: Reference 5.21)

(a)

(b)

(c)

Figure 24. Borehole Extensometer Deformation Data, Station 72+48
(Data Source: Reference 5.21)

Figure 25. Deformation in the Rock Mass, Station 21+34 (Data Source: Reference 5.21)

Figure 26. Deformation in the Rock Mass, Station 28+28 (Data Source: Reference 5.21)

Figure 27. Comparison of the Instrumentation Results from the Tape Extensometers and Borehole Extensometers
 (Data Source: Reference 5.21)

(e)

(f)

(g)

(h)

Figure 27. Comparison of the Instrumentation Results from the Tape Extensometers and Borehole Extensometers (Continued)
 (Data Source: Reference 5.21)

(i)

(j)

(k)

(l)

Figure 27. Comparison of the Instrumentation Results from the Tape Extensometers and Borehole Extensometers (Continued)
 (Data Source: Reference 5.21)

(m)

(n)

(o)

(p)

Figure 27. Comparison of the Instrumentation Results from the Tape Extensometers and Borehole Extensometers (Concluded)
 (Data Source: Reference 5.21)

δ = Radial convergence at any distance from the tunnel face
 u_T = Ultimate Convergence

Figure 28. Radial Convergence along the Tunnel Axis

Figure 29. Estimated Complete Convergence and its Comparison with the Instrumentation Data, Station 21+34

Figure 30. Estimated Complete Convergence and its Comparison with the Instrumentation Data, Station 27+70

Figure 31. Estimated Complete Convergence and its Comparison with the Instrumentation Data, Station 31+02

Figure 32. Estimated Complete Convergence and its Comparison with the Instrumentation Data, Station 55+71

Figure 33. Estimated Complete Convergence and its Comparison with the Instrumentation Data, Station 60+55

Figure 34. Estimated Complete Convergence and its Comparison with the Instrumentation Data, Station 67+95

Figure 35. Predicted Long Term Roof Deformation for the Six Stations

Figure 36. Correlation of Tunnel Convergence with Q/Span, TCw Unit

Figure 37. Correlation of Tunnel Convergence with Q/Span, UO Unit

Figure 38. Correlation of Tunnel Convergence with Q/Span, PTn Unit

Figure 39. Correlation of Tunnel Convergence with Q/Span, TSw1 Unit

Figure 40. Correlation of Tunnel Convergence with Q/Span, TSw2 Unit

Figure 41. Correlation of MPBX Measured Convergence with $Q/Span$

Figure 42. Correlation of Estimated Convergence from the Convergence Solution (Reference 5.2) with Q/Span

Figure 43. Comparison of Vertical Displacement Magnitudes in the ESF

Figure 44. Comparison of Horizontal Displacement Magnitudes in the ESF

Figure 45. Comparison of Rock Mass Modulus Assessment Methods

ATTACHMENT I

CONVERGENCE CURVES FROM TAPE EXTENSOMETER MEASUREMENT

Figure I-1. Convergence Curves Measured from Chord H with Ground Support Class 1, TCw Unit (Data Source: Ref.5.21)

Figure I-2. Convergence Curves Measured from Chord L with Ground Support Class 1, TCw Unit (Data Source: Ref.5.21)

Figure I-3. Convergence Curves Measured from Chord R with Ground Support Class 1, TCw Unit (Data Source: Ref.5.21)

Figure I-4. Convergence Curves Measured from Chord V with Ground Support Class 1, TCw Unit (Data Source: Ref.5.21)

Figure I-5. Convergence Curves Measured from Chord H with Ground Support Class 4, TCw Unit (Data Source: Ref.5.21)

Figure I-6. Convergence Curves Measured from Chord L with Ground Support Class 4, TCw Unit (Data Source: Ref.5.21)

Figure I-7. Convergence Curves Measured from Chord R with Ground Support Class 4, TCw Unit (Data Source: Ref.5.21)

Figure I-8. Convergence Curves Measured from Chord V with Ground Support Class 4, TCw Unit (Data Source: Ref.5.21)

Figure I-9. Convergence Curves Measured from Chord H with Ground Support Class 1, UO Unit (Data Source: Ref.5.21)

Figure I-10. Convergence Curves Measured from Chord L with Ground Support Class 1, UO Unit (Data Source: Ref.5.21)

Figure I-11. Convergence Curves Measured from Chord R with Ground Support Class 1, UO Unit (Data Source: Ref.5.21)

Figure I-12. Convergence Curves Measured from Chord V with Ground Support Class 1, UO Unit (Data Source: Ref.5.21)

Figure I-13. Convergence Curves Measured from Chord H with Ground Support Class 4, UO Unit (Data Source: Ref.5.21)

Figure I-14. Convergence Curves Measured from Chord L with Ground Support Class 4, UO Unit (Data Source: Ref.5.21)

Figure I-15. Convergence Curves Measured from Chord R with Ground Support Class 4, UO Unit (Data Source: Ref.5.21)

Figure I-16. Convergence Curves Measured from Chord V with Ground Support Class 4, UO Unit (Data Source: Ref.5.21)

Figure I-17. Convergence Curves Measured from Chord H with Ground Support Class 1, PTn Unit (Data Source: Ref.5.21)

Figure I-18. Convergence Curves Measured from Chord L with Ground Support Class 1, PTn Unit (Data Source: Ref.5.21)

Figure I-19. Convergence Curves Measured from Chord R with Ground Support Class 1, PTn Unit (Data Source: Ref.5.21)

Figure I-20. Convergence Curves Measured from Chord V with Ground Support Class 1, PTn Unit (Data Source: Ref.5.21)

Figure I-21. Convergence Curves Measured from ChordS LF and RF with Ground Support Class 1, PTn Unit (Data Source: Ref.5.21)

Figure I-22. Convergence Curves Measured from Chord H with Ground Support Class 2a, PTn Unit (Data Source: Ref.5.21)

Figure I-23. Convergence Curves Measured from Chord L with Ground Support Class 2a, PTn Unit (Data Source: Ref.5.21)

Figure I-24. Convergence Curves Measured from Chord R with Ground Support Class 2a, PTn Unit (Data Source: Ref.5.21)

Figure I-25. Convergence Curves Measured from Chord V with Ground Support Class 2a, PTn Unit (Data Source: Ref.5.21)

Figure I-26. Convergence Curves Measured from Chord H with Ground Support Class 3a, PTn Unit (Data Source: Ref.5.21)

Figure I-27. Convergence Curves Measured from Chord L with Ground Support Class 3a, PTn Unit (Data Source: Ref.5.21)

Figure I-28. Convergence Curves Measured from Chord R with Ground Support Class 3a, PTn Unit (Data Source: Ref.5.21)

Figure I-29. Convergence Curves Measured from Chord V with Ground Support Class 3a, PTn Unit (Data Source: Ref.5.21)

Figure I-30. Convergence Curves Measured from Chord H with Ground Support Class 4, PTn Unit (Data Source: Ref.5.21)

Figure I-31. Convergence Curves Measured from Chord L with Ground Support Class 4, PTn Unit (Data Source: Ref.5.21)

Figure I-32. Convergence Curves Measured from Chord R with Ground Support Class 4, PTn Unit (Data Source: Ref.5.21)

Figure I-33. Convergence Curves Measured from Chord V with Ground Support Class 4, PTn Unit (Data Source: Ref.5.21)

Figure I-34. Convergence Curves Measured from Chord H with Ground Support Class 1, TSw1 Unit (Data Source: Ref.5.21)

Figure I-35. Convergence Curves Measured from Chord L with Ground Support Class 1, TSw1 Unit (Data Source: Ref.5.21)

Figure I-36. Convergence Curves Measured from Chord R with Ground Support Class 1, TSw1 Unit (Data Source: Ref.5.21)

Figure I-37. Convergence Curves Measured from Chord V with Ground Support Class 1, TSw1 Unit (Data Source: Ref.5.21)

Figure I-38. Convergence Curves Measured from Chord H with Ground Support Class 3a, TSw1 Unit (Data Source: Ref.5.21)

Figure I-39. Convergence Curves Measured from Chord L with Ground Support Class 3a, TSw1 Unit (Data Source: Ref.5.21)

Figure I-40. Convergence Curves Measured from Chord R with Ground Support Class 3a, TSw1 Unit (Data Source: Ref.5.21)

Figure I-41. Convergence Curves Measured from Chord V with Ground Support Class 3a, TSw1 Unit (Data Source: Ref.5.21)

Figure I-42. Convergence Curves Measured from Chord H with Ground Support Class 4, TSw1 Unit (Data Source: Ref.5.21)

Figure I-43. Convergence Curves Measured from Chord L with Ground Support Class 4, TSw1 Unit (Data Source: Ref.5.21)

Figure I-44. Convergence Curves Measured from Chord R with Ground Support Class 4, TSw1 Unit (Data Source: Ref.5.21)

Figure I-45. Convergence Curves Measured from Chord V with Ground Support Class 4, TSw1 Unit
 (Data Source: Ref.5.21)

Figure I-46. Convergence Curves Measured from Chord H with Ground Support Class 1, TSw2 Unit (Data Source: Ref.5.21)

Figure I-47. Convergence Curves Measured from Chord L with Ground Support Class 1, TSw2 Unit (Data Source: Ref.5.21)

Figure I-48. Convergence Curves Measured from Chord R with Ground Support Class 1, TSw2 Unit (Data Source: Ref.5.21)

Figure I-49. Convergence Curves Measured from Chord V with Ground Support Class 1, TSw2 Unit (Data Source: Ref.5.21)

Figure I-50. Convergence Curves Measured from Chords LF and RF with Ground Support Class 1, TSw2 Unit
(Data Source: Ref.5.21)

Figure I-51. Convergence Curves Measured from Chord H with Ground Support Class 3a, TSw2 Unit
(Data Source: Ref.5.21)

Figure I-52. Convergence Curves Measured from Chord L with Ground Support Class 3a, TSw2 Unit
(Data Source: Ref.5.21)

Figure I-53. Convergence Curves Measured from Chord R with Ground Support Class 3a, TSw2 Unit
(Data Source: Ref.5.21)

Figure I-54. Convergence Curves Measured from Chord V with Ground Support Class 3a, TSw2 Unit
(Data Source: Ref.5.21)

Figure I-55. Convergence Curves Measured from Chord H with Ground Support Class 4, TSw2 Unit
 (Data Source: Ref.5.21)

Figure I-56. Convergence Curves Measured from Chord L with Ground Support Class 4, TSw2 Unit
 (Data Source: Ref.5.21)

Figure I-57. Convergence Curves Measured from Chord R with Ground Support Class 4, TSw2 Unit
 (Data Source: Ref.5.21)

Figure I-58. Convergence Curves Measured from Chord V with Ground Support Class 4, TSw2 Unit
 (Data Source: Ref.5.21)

ATTACHMENT II

EQUATIONS FOR THE CONVERGENCE SOLUTION

The Convergence Solution was derived from the general form of the convergence equation proposed by Guenot et al. (Reference 5.2). The equation was extended to include the pre-face portion of convergence and the consideration of a supported tunnel by Barlow (Reference 5.2). This Attachment include the extended equations developed by by Barlow (Reference 5.2).

Three parameters X , T and A^* are used as input in order to best fit the Convergence Solution. The first parameter X is related to the size of the yield zone around the tunnel. The second parameter T reflects the shape of the creep curve for the rock mass. The third parameter is A^* is the ratio of time-dependent convergence to the time-independent convergence (A/C_{∞}). The extended equations are presented in two groups, without ground support and with ground support, as follows:

(1) Without Ground Support

(a) convergence, pre-face portion

$$C(x,t) = Q_1 C_{pf}(x) [C_{\infty} + AC_2(t)] \quad (\text{Eqn. I-1})$$

where Q_1 = proportion of the total stress change associated with excavation that occurs ahead of the face; and

$$C_{pf}(x) = \left[\frac{1}{1 + \left(\frac{x_f - x}{X} \right)} \right]^{1.2} \quad (\text{Eqn. I-2})$$

where x_f = value of x at tunnel face.

(b) convergence, post-face portion

$$C(x,t) = [Q_1 + Q_2 C_1(x)] [C_{\infty} + AC_2(t)] \quad (\text{Eqn. I-3})$$

where Q_2 = proportion of the total stress change associated with excavation that occurs after the face.

(2) With Ground Support

(a) convergence, pre-face portion

$$C(x,t) = [Q_1 C_{pf}(x) - Q_k P_{k+}(x)] [C_{\infty} + AC_2(t)] \quad (\text{Eqn. I-4})$$

where the parameter Q_k is the equivalent pressure, p_k , normalized to the total pressure P_o (i.e., $Q_k = p_k / p_o$). The function P_{k+} gradually increases from zero to a value of 1.0 at the point liner installation.

(b) convergence, post-face portion, before ground support installation

$$C(x, t) = [Q_1 + Q_2 C_1(x) - Q_k P_{k+}(x)] [C_{\infty} + A C_2(t)] \quad (\text{Eqn. I-5})$$

(c) convergence, post-face portion, after ground support installation

$$C(x, t) = [Q_1 + Q_2 C_1(x) - P_s(C(x, t)) - Q_k P_{k-}(x)] [C_{\infty} + A C_2(t)] \quad (\text{Eqn. I-6})$$

where $P_s(C(x, t))$ is the amount of pressure taken by the support and the term $Q_k P_{k-}(x)$ transfers the extra pressure p_k onto the lined portion of the tunnel as it decreases from a value of Q_k to zero. The function P_{k-} decreases from a value of 1.0 at the point liner installation to 0 at large x .

The Convergence Solution is difficult to use in the process of tunnel excavation since the ultimate convergence is still an unknown. Because the maximum convergence rate always occurs around the time the excavation passes through the instrumentation station, the convergence rate equations would be more useful in this situation. Barlow therefore derived the convergence rate equations for this purpose (Reference 5.2). These equations are normalized against the maximum convergence rate. These equations are presented in the following:

(1) Without Ground Support

(a) normalized convergence rate, pre-face portion

$$\frac{C'(t)}{C'_{\max}} = \frac{Q_1}{N} [C'_{PF}(t) + C'_{PF}(t) A^* C_2(t) + C_{PF}(t) A^* C'_2(t)] \quad (\text{Eqn. I-7})$$

(b) normalized convergence rate, post-face portion

$$\frac{C'(x, t)}{C'_{\max}} = \frac{Q_2}{N} [C'_1(t) + C'_1(t) A^* C_2(t) + C_1(t) A^* C'_2(t) + \frac{Q_1}{Q_2} A^* C'_2(t)] \quad (\text{Eqn. I-8})$$

where

$$N = \left[\frac{2Q_2 V}{X} + \frac{2Q_2 V}{X} A^* C_2(t) + Q_1 A^* C'_2(t) \right] \quad (\text{Eqn. I-9})$$

and V is the excavation rate.

(2) With Ground Support

(a) normalized convergence rate, pre-face portion

$$\frac{C'(t)}{C'_{\max}} = \frac{Q_1}{M} [C'_{pf}(t) + C'_{pf}(t)A^*C_2(t) + C'_{pf}(t)A^*C'_2(t) - \quad (\text{Eqn. I-10})$$

$$\frac{Q_k}{Q_1} P'_{k+}(t) - \frac{Q_k}{Q_1} P'_{k+}(t)A^*C_2(t) - \frac{Q_k}{Q_1} P'_{k+}(t)A^*C'_2(t)] \quad (\text{Eqn. I-11})$$

where

$$M = \left[\frac{2Q_2V}{X} + \frac{2Q_2V}{X} A^*C_2(t) + Q_1 A^*C'_2(t) - \frac{Q_k}{Q_2} P'_{k+}(t) - \frac{Q_k}{Q_2} P'_{k+}(t)A^*C_2(t) - \frac{Q_k}{Q_2} P'_{k+}(t)A^*C'_2(t) \right]$$

(b) normalized convergence rate, post-face portion, before ground support installation

$$\frac{C'(t)}{C'_{\max}} = \frac{Q_2}{M} \left[\frac{Q_1}{Q_2} A^*C'_2(t) + C'_1(t) + C'_1(t)A^*C_2(t) + C'_1(t)A^*C'_2(t) \right. \quad (\text{Eqn. I-12})$$

$$\left. - \frac{Q_k}{Q_2} P'_{k+}(t) - \frac{Q_k}{Q_2} P'_{k+}(t)A^*C_2(t) - \frac{Q_k}{Q_2} P'_{k+}(t)A^*C'_2(t) \right]$$

(c) normalized convergence rate, post-face portion, after ground support installation

$$\frac{C'(t)}{C'_{\max}} = \frac{Q_2}{M} \left[\frac{Q_1}{Q_2} A^*C'_2(t) + C'_1(t) + C'_1(t)A^*C'_2(t) + C'_1(t)A^*C_2(t) \right. \quad (\text{Eqn. I-13})$$

$$\left. + \frac{Q_k}{Q_2} P'_{k-}(t) - \frac{Q_k}{Q_2} P'_{k-}(t)A^*C'_2(t) + \frac{Q_k}{Q_2} P'_{k-}(t)A^*C_2(t) - \frac{K}{Q_2} C'(t)C_{\infty} \right.$$

$$\left. - \frac{K}{Q_2} C(t)A^*C'_2(t) - \frac{K}{Q_2} C'(t)A^*C_2(t) - \frac{K}{Q_2} A^*C'_2(t)C_s \right]$$

and K is the ground support stiffness.

The program CONRATE (Reference 5.18) incorporates all the equations presented in this Attachment.

ATTACHMENT III

BEST FIT OF DEFORMATION DATA TO THE CONVERGENCE SOLUTION

This attachment includes the input and output files for best fitting the Convergence Solution. Also included are the best-fit curves and their comparison with the instrumentation data.

The input for program CONRATE requires an initial estimate of the ultimate time-independent convergence (CXF). This estimate does not affect the outcome of the normalized convergence rate but does have an effect on the magnitude of convergence result. The calculated maximum convergence rate from the monitored data was used to normalize the convergence rate.

The input file format is listed as follows:

Line 1, NP, NS, NH, TOFF

NP – Number of parameter sets input (integer).
NS – Number of constant velocity intervals (integer).
NH – Number of headings in sequential excavation (integer).
TOFF – Offset of initial time (real).

Line 2, Q1, Q2, Q, TFACE, XFLACE, A, CXF

Q1 – Pre-face portion of convergence (real).
Q2 – Post-face portion of convergence (real).
Q – Ratio of time-independent convergence of 1st to other heading (real).
TFACE – Time at which face passes monitoring station (real).
XFACE – Position of the monitoring station along the tunnel axis (real).
A – Radius of tunnel (real).
CXF – Ultimate time-independent convergence (real).

Line 3, VA, TI, TF, TINC, RP, RPC

VA – Velocity of excavation (real).
TI – Time at beginning of constant excavation velocity section (real).
TF – Time at end of constant excavation velocity section (real).
TINC – Time increment (real).
RP – Ratio of propagated to non-propagated plastic radius (real).
RPC – Ratio of propagated to non-propagated plastic CXF (real).

Line 4, BIGXR, BIGT, ASTAR, TNORM, FKS, F, TSUP

BIGXR – $2R/a$ (real).
BIGT – T (real).
ASTAR – A^* (real).
TNORM – Convergence rate at this time used to normalize all other rates (real).
FKS – Support stiffness (real).
F – Numerical factor for supported tunnel calculation (real);
 F = 10. For $K < 0.002$
 F = 10. – 30. For $0.002 < K < 0.02$
 F = 30. For $K > 0.02$.
TSUP – Time of support installation (real).

Line 5, XSUP, QK

XSUP – Position along tunnel axis at which support is installed (real).
QK – Parameter Q_k (real).

The output files contain three columns: time, the estimated convergence, and the normalized convergence rate. Note that the estimated convergence listed in column 2 is not the real convergence since it is calculated based on an estimated ultimate time-independent convergence. The estimated convergence does provide the outcome of a convergence shape to compare with instrumentation data. All calculations start at 10 days before the excavation to include all the pre-face deformation. The excavation date is therefore the 10th day shown on the output listings.

Input File, Station 21+34, T=1, A*=0.5

1,1,1,0.0,
 0.27,0.73,1.0,10.0,106.0,3.8,0.4,
 10.6,0.0,600.0,5.0,1.0,1.0,
 1.0,1.0,0.5,19.5,0.0100,15.,1000.0,
 10600.0,0.050,

Output File, Station 21+34, T=1, A*=0.5

Calculation of Convergence Solution
 for the following parameters:

R/a = 1.000 T = 1.00 A* = 0.500

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00155	0.3300739
5.000	0.00417	0.7934114
10.000	0.13569	1942.4079590
15.000	0.51173	1.6609596
20.000	0.51943	0.9630016
25.000	0.52459	0.7072192
30.000	0.52852	0.5571001
35.000	0.53168	0.4566807
40.000	0.53431	0.3847564
45.000	0.53655	0.3308459
50.000	0.53849	0.2890594
55.000	0.54019	0.2558126
60.000	0.54171	0.2287967
65.000	0.54307	0.2064580
70.000	0.54431	0.1877136
75.000	0.54543	0.1717867
80.000	0.54647	0.1581062
85.000	0.54742	0.1462433
90.000	0.54831	0.1358701
95.000	0.54913	0.1267320
100.000	0.54990	0.1186282
105.000	0.55062	0.1113984
110.000	0.55130	0.1049136
115.000	0.55194	0.0990681
120.000	0.55254	0.0937753
125.000	0.55312	0.0889631
130.000	0.55366	0.0845712
135.000	0.55418	0.0805490
140.000	0.55467	0.0768532
145.000	0.55514	0.0734473

(~Continued)

Output File, Station 21+34, T=1, A*=0.5 (Continued)

150.000	0.55559	0.0702996
155.000	0.55602	0.0673829
160.000	0.55644	0.0646737
165.000	0.55684	0.0621514
170.000	0.55722	0.0597981
175.000	0.55759	0.0575979
180.000	0.55794	0.0555370
185.000	0.55828	0.0536030
190.000	0.55862	0.0517850
195.000	0.55893	0.0500734
200.000	0.55924	0.0484593
205.000	0.55954	0.0469350
210.000	0.55983	0.0454935
215.000	0.56011	0.0441285
220.000	0.56039	0.0428343
225.000	0.56065	0.0416057
230.000	0.56091	0.0404381
235.000	0.56116	0.0393272
240.000	0.56140	0.0382692
245.000	0.56164	0.0372605
250.000	0.56187	0.0362978
255.000	0.56210	0.0353783
260.000	0.56231	0.0344992
265.000	0.56253	0.0336579
270.000	0.56274	0.0328523
275.000	0.56294	0.0320801
280.000	0.56314	0.0313395
285.000	0.56333	0.0306285
290.000	0.56352	0.0299456
295.000	0.56371	0.0292891
300.000	0.56389	0.0286576
305.000	0.56407	0.0280498
310.000	0.56424	0.0274644
315.000	0.56441	0.0269002
320.000	0.56458	0.0263562
325.000	0.56474	0.0258314
330.000	0.56491	0.0253247
335.000	0.56506	0.0248353
340.000	0.56522	0.0243624
345.000	0.56537	0.0239051
350.000	0.56552	0.0234628
355.000	0.56566	0.0230347
360.000	0.56581	0.0226202
365.000	0.56595	0.0222188
370.000	0.56608	0.0218297
375.000	0.56622	0.0214524
380.000	0.56635	0.0210866
385.000	0.56649	0.0207316
390.000	0.56661	0.0203870
395.000	0.56674	0.0200523
400.000	0.56687	0.0197273
405.000	0.56699	0.0194114

(-continued)

Output File, Station 21+34, T=1, A*=0.5 (continued)

410.000	0.56711	0.0191043
415.000	0.56723	0.0188056
420.000	0.56735	0.0185151
425.000	0.56746	0.0182324
430.000	0.56757	0.0179573
435.000	0.56769	0.0176893
440.000	0.56780	0.0174283
445.000	0.56790	0.0171740
450.000	0.56801	0.0169262
455.000	0.56812	0.0166845
460.000	0.56822	0.0164489
465.000	0.56832	0.0162190
470.000	0.56842	0.0159948
475.000	0.56852	0.0157759
480.000	0.56862	0.0155622
485.000	0.56872	0.0153535
490.000	0.56882	0.0151497
495.000	0.56891	0.0149506
500.000	0.56900	0.0147560
505.000	0.56909	0.0145659
510.000	0.56919	0.0143799
515.000	0.56928	0.0141981
520.000	0.56936	0.0140202
525.000	0.56945	0.0138462
530.000	0.56954	0.0136759
535.000	0.56962	0.0135092
540.000	0.56971	0.0133461
545.000	0.56979	0.0131863
550.000	0.56987	0.0130298
555.000	0.56995	0.0128765
560.000	0.57003	0.0127263
565.000	0.57011	0.0125792
570.000	0.57019	0.0124349
575.000	0.57027	0.0122934
580.000	0.57035	0.0121547
585.000	0.57042	0.0120187
590.000	0.57050	0.0118853
595.000	0.57057	0.0117543
600.000	0.57064	0.0116259

Input File, Station 21+34, T=2.5, A*=20.0

1,1,1,0.0,
0.27,0.73,1.0,10.0,106.0,3.8,0.03,
10.6,0.0,600.0,5.0,1.0,1.0,
1.0,2.5,20.0,19.5,0.0100,15.,1000.0,
10600.0,0.050,

Output File, Station 21+34, T=2.5, A*=20.0

Calculation of Convergence Solution
for the following parameters:

R/a = 1.000 T = 2.50 A* = 20.0

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00012	0.0680766
5.000	0.00171	0.1248507
10.000	0.07014	293.2897339
15.000	0.29463	1.3912861
20.000	0.31943	0.9701895
25.000	0.33766	0.7436361
30.000	0.35199	0.5975055
35.000	0.36369	0.4957216
40.000	0.37351	0.4211208
45.000	0.38193	0.3643433
50.000	0.38927	0.3198456
55.000	0.39576	0.2841413
60.000	0.40154	0.2549329
65.000	0.40676	0.2306485
70.000	0.41150	0.2101779
75.000	0.41582	0.1927167
80.000	0.41980	0.1776680
85.000	0.42348	0.1645807
90.000	0.42690	0.1531075
95.000	0.43008	0.1429775
100.000	0.43306	0.1339758
105.000	0.43585	0.1259305
110.000	0.43848	0.1187023
115.000	0.44096	0.1121770
120.000	0.44331	0.1062606
125.000	0.44554	0.1008748
130.000	0.44766	0.0959537
135.000	0.44967	0.0914421
140.000	0.45159	0.0872926
145.000	0.45343	0.0834651

(-continued)

Output File, Station 21+34, T=2.5, A*=20.0 (Continued)

150.000	0.45519	0.0799247
155.000	0.45687	0.0766417
160.000	0.45849	0.0735899
165.000	0.46004	0.0707467
170.000	0.46153	0.0680923
175.000	0.46297	0.0656091
180.000	0.46435	0.0632817
185.000	0.46569	0.0610965
190.000	0.46698	0.0590414
195.000	0.46823	0.0571054
200.000	0.46944	0.0552790
205.000	0.47061	0.0535535
210.000	0.47175	0.0519210
215.000	0.47285	0.0503745
220.000	0.47391	0.0489077
225.000	0.47495	0.0475148
230.000	0.47596	0.0461906
235.000	0.47694	0.0449302
240.000	0.47789	0.0437295
245.000	0.47882	0.0425844
250.000	0.47973	0.0414913
255.000	0.48061	0.0404468
260.000	0.48147	0.0394480
265.000	0.48230	0.0384920
270.000	0.48312	0.0375762
275.000	0.48392	0.0366983
280.000	0.48470	0.0358560
285.000	0.48546	0.0350473
290.000	0.48621	0.0342703
295.000	0.48694	0.0335233
300.000	0.48765	0.0328046
305.000	0.48835	0.0321127
310.000	0.48903	0.0314463
315.000	0.48970	0.0308039
320.000	0.49036	0.0301843
325.000	0.49100	0.0295864
330.000	0.49163	0.0290092
335.000	0.49225	0.0284516
340.000	0.49286	0.0279127
345.000	0.49345	0.0273916
350.000	0.49404	0.0268874
355.000	0.49461	0.0263994
360.000	0.49517	0.0259269
365.000	0.49573	0.0254691
370.000	0.49627	0.0250254
375.000	0.49680	0.0245952
380.000	0.49733	0.0241779
385.000	0.49784	0.0237729
390.000	0.49835	0.0233798
395.000	0.49885	0.0229981
400.000	0.49934	0.0226272
405.000	0.49982	0.0222668

(-continued)

Output File, Station 21+34, T=2.5, A*=20.0 (Continued)

410.000	0.50030	0.0219164
415.000	0.50076	0.0215756
420.000	0.50123	0.0212441
425.000	0.50168	0.0209215
430.000	0.50213	0.0206074
435.000	0.50257	0.0203016
440.000	0.50300	0.0200037
445.000	0.50343	0.0197134
450.000	0.50385	0.0194305
455.000	0.50426	0.0191547
460.000	0.50467	0.0188857
465.000	0.50508	0.0186233
470.000	0.50547	0.0183673
475.000	0.50587	0.0181175
480.000	0.50625	0.0178736
485.000	0.50663	0.0176354
490.000	0.50701	0.0174028
495.000	0.50738	0.0171755
500.000	0.50775	0.0169534
505.000	0.50811	0.0167364
510.000	0.50847	0.0165242
515.000	0.50882	0.0163167
520.000	0.50917	0.0161137
525.000	0.50952	0.0159152
530.000	0.50986	0.0157209
535.000	0.51019	0.0155308
540.000	0.51053	0.0153446
545.000	0.51085	0.0151624
550.000	0.51118	0.0149840
555.000	0.51150	0.0148092
560.000	0.51182	0.0146380
565.000	0.51213	0.0144702
570.000	0.51244	0.0143058
575.000	0.51274	0.0141446
580.000	0.51305	0.0139866
585.000	0.51335	0.0138317
590.000	0.51364	0.0136798
595.000	0.51393	0.0135308
600.000	0.51422	0.0133846

Input File, Station 21+34, T=10.0, A*=0.5

1,1,1,0.0,
0.27,0.73,1.0,10.0,106.0,3.8,0.3,
10.6,0.0,600.0,5.0,1.0,1.0,
1.0,10.,0.5,19.5,0.0100,15.,1000.0,
10600.0,0.050,

Output File, Station 21+34, T=10.0, A*=0.5

Calculation of Convergence Solution
for the following parameters:

R/a = 1.000 T = 10.00 A* = 0.500

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00116	0.1335247
5.000	0.00274	0.5595385
10.000	0.08860	1384.0501709
15.000	0.33525	1.4460117
20.000	0.34190	0.9736172
25.000	0.34689	0.7787367
30.000	0.35098	0.6501715
35.000	0.35443	0.5562716
40.000	0.35741	0.4843638
45.000	0.36003	0.4275615
50.000	0.36235	0.3816329
55.000	0.36443	0.3437974
60.000	0.36632	0.3121440
65.000	0.36803	0.2853147
70.000	0.36960	0.2623175
75.000	0.37105	0.2424116
80.000	0.37240	0.2250329
85.000	0.37365	0.2097446
90.000	0.37481	0.1962035
95.000	0.37590	0.1841366
100.000	0.37693	0.1733238
105.000	0.37790	0.1635861
110.000	0.37881	0.1547765
115.000	0.37968	0.1467730
120.000	0.38050	0.1394738
125.000	0.38129	0.1327932
130.000	0.38203	0.1266587
135.000	0.38274	0.1210084
140.000	0.38342	0.1157893

(-Continued)

Output File, Station 21+34, T=10.0, A*=0.5 (Continued)

145.000	0.38408	0.1109557
150.000	0.38470	0.1064680
155.000	0.38530	0.1022917
160.000	0.38588	0.0983967
165.000	0.38643	0.0947567
170.000	0.38697	0.0913483
175.000	0.38748	0.0881509
180.000	0.38798	0.0851464
185.000	0.38846	0.0823183
190.000	0.38893	0.0796523
195.000	0.38938	0.0771354
200.000	0.38982	0.0747558
205.000	0.39024	0.0725030
210.000	0.39065	0.0703676
215.000	0.39105	0.0683410
220.000	0.39144	0.0664154
225.000	0.39181	0.0645837
230.000	0.39218	0.0628395
235.000	0.39254	0.0611770
240.000	0.39288	0.0595907
245.000	0.39322	0.0580757
250.000	0.39355	0.0566275
255.000	0.39387	0.0552420
260.000	0.39419	0.0539154
265.000	0.39449	0.0526440
270.000	0.39479	0.0514248
275.000	0.39508	0.0502546
280.000	0.39537	0.0491307
285.000	0.39565	0.0480504
290.000	0.39592	0.0470115
295.000	0.39619	0.0460117
300.000	0.39645	0.0450488
305.000	0.39671	0.0441210
310.000	0.39696	0.0432265
315.000	0.39720	0.0423635
320.000	0.39745	0.0415306
325.000	0.39768	0.0407261
330.000	0.39791	0.0399488
335.000	0.39814	0.0391974
340.000	0.39836	0.0384705
345.000	0.39858	0.0377672
350.000	0.39880	0.0370862
355.000	0.39901	0.0364267
360.000	0.39922	0.0357876
365.000	0.39942	0.0351681
370.000	0.39962	0.0345673
375.000	0.39982	0.0339843
380.000	0.40001	0.0334186
385.000	0.40020	0.0328692
390.000	0.40039	0.0323356
395.000	0.40058	0.0318171
400.000	0.40076	0.0313131

(-Continued)

Output File, Station 21+34, T=10.0, A*=0.5 (Continued)

405.000	0.40094	0.0308231
410.000	0.40111	0.0303464
415.000	0.40128	0.0298826
420.000	0.40145	0.0294311
425.000	0.40162	0.0289916
430.000	0.40179	0.0285635
435.000	0.40195	0.0281464
440.000	0.40211	0.0277400
445.000	0.40227	0.0273438
450.000	0.40243	0.0269575
455.000	0.40258	0.0265807
460.000	0.40273	0.0262130
465.000	0.40288	0.0258543
470.000	0.40303	0.0255041
475.000	0.40318	0.0251622
480.000	0.40332	0.0248283
485.000	0.40346	0.0245021
490.000	0.40360	0.0241834
495.000	0.40374	0.0238719
500.000	0.40388	0.0235674
505.000	0.40401	0.0232697
510.000	0.40414	0.0229785
515.000	0.40427	0.0226937
520.000	0.40440	0.0224150
525.000	0.40453	0.0221422
530.000	0.40466	0.0218753
535.000	0.40478	0.0216139
540.000	0.40491	0.0213580
545.000	0.40503	0.0211073
550.000	0.40515	0.0208618
555.000	0.40527	0.0206212
560.000	0.40539	0.0203854
565.000	0.40550	0.0201543
570.000	0.40562	0.0199277
575.000	0.40573	0.0197056
580.000	0.40585	0.0194877
585.000	0.40596	0.0192740
590.000	0.40607	0.0190644
595.000	0.40618	0.0188587
600.000	0.40628	0.0186568

Figure III-1. Curve Fit of the Normalized Deformation Rate Data, Station 21+34

Figure III-2. Curve Fit of the Deformation Data, Station 21+34

Input File, Station 27+70, T=50.0, A*=80.0

1,1,1,0.0,
0.27,0.73,1.0,10.0,106.0,3.8,0.14,
10.6,0.0,600.0,5.0,1.0,1.0,
1.0,50.0,80.0,76.6,0.0100,15.,1000.0,
10600.0,0.050,

Output File, Station 27+70, T=50.0, A*=80.0

Calculation of Convergence Solution
for the following parameters:

R/a = 1.000 T = 50.00 A* = 80.0

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00054	0.0161403
5.000	0.00393	0.0698866
10.000	0.19875	178.4097900
15.000	0.98540	2.4168952
20.000	1.21458	2.1662943
25.000	1.42234	1.9770473
30.000	1.61265	1.8170255
35.000	1.78803	1.6789689
40.000	1.95046	1.5585690
45.000	2.10156	1.4526937
50.000	2.24265	1.3589330
55.000	2.37485	1.2753831
60.000	2.49910	1.2005171
65.000	2.61622	1.1330932
70.000	2.72690	1.0720937
75.000	2.83174	1.0166742
80.000	2.93127	0.9661300
85.000	3.02594	0.9198684
90.000	3.11615	0.8773870
95.000	3.20227	0.8382577
100.000	3.28462	0.8021136
105.000	3.36347	0.7686383
110.000	3.43908	0.7375579
115.000	3.51169	0.7086341
120.000	3.58148	0.6816582
125.000	3.64866	0.6564475
130.000	3.71338	0.6328408
135.000	3.77581	0.6106955
140.000	3.83609	0.5898854
145.000	3.89434	0.5702978

(Continued)

Output File, Station 27+70, T=50.0, A*=80.0 (Continued)

150.000	3.95067	0.5518323
155.000	4.00521	0.5343989
160.000	4.05804	0.5179167
165.000	4.10926	0.5023131
170.000	4.15896	0.4875223
175.000	4.20721	0.4734850
180.000	4.25408	0.4601472
185.000	4.29965	0.4474601
190.000	4.34398	0.4353789
195.000	4.38712	0.4238631
200.000	4.42913	0.4128755
205.000	4.47006	0.4023819
210.000	4.50996	0.3923511
215.000	4.54888	0.3827543
220.000	4.58686	0.3735651
225.000	4.62393	0.3647592
230.000	4.66013	0.3563140
235.000	4.69551	0.3482086
240.000	4.73008	0.3404238
245.000	4.76389	0.3329418
250.000	4.79696	0.3257458
255.000	4.82933	0.3188204
260.000	4.86101	0.3121513
265.000	4.89203	0.3057251
270.000	4.92242	0.2995293
275.000	4.95220	0.2935523
280.000	4.98139	0.2877830
285.000	5.01001	0.2822113
290.000	5.03808	0.2768277
295.000	5.06562	0.2716231
300.000	5.09264	0.2665892
305.000	5.11917	0.2617180
310.000	5.14521	0.2570020
315.000	5.17079	0.2524343
320.000	5.19592	0.2480083
325.000	5.22061	0.2437178
330.000	5.24488	0.2395568
335.000	5.26873	0.2355198
340.000	5.29218	0.2316017
345.000	5.31525	0.2277974
350.000	5.33794	0.2241022
355.000	5.36027	0.2205118
360.000	5.38224	0.2170219
365.000	5.40386	0.2136285
370.000	5.42515	0.2103279
375.000	5.44611	0.2071164
380.000	5.46675	0.2039906
385.000	5.48708	0.2009473
390.000	5.50711	0.1979834
395.000	5.52685	0.1950960
400.000	5.54630	0.1922822
405.000	5.56547	0.1895394

(-Continued)

Output File, Station 27+70, T=50.0, A*=80.0 (Continued)

410.000	5.58437	0.1868651
415.000	5.60301	0.1842567
420.000	5.62138	0.1817121
425.000	5.63951	0.1792290
430.000	5.65739	0.1768052
435.000	5.67502	0.1744388
440.000	5.69242	0.1721279
445.000	5.70960	0.1698706
450.000	5.72654	0.1676650
455.000	5.74327	0.1655097
460.000	5.75979	0.1634028
465.000	5.77610	0.1613429
470.000	5.79220	0.1593285
475.000	5.80810	0.1573581
480.000	5.82380	0.1554303
485.000	5.83932	0.1535440
490.000	5.85465	0.1516977
495.000	5.86979	0.1498904
500.000	5.88475	0.1481207
505.000	5.89954	0.1463877
510.000	5.91416	0.1446901
515.000	5.92860	0.1430271
520.000	5.94289	0.1413975
525.000	5.95701	0.1398005
530.000	5.97097	0.1382350
535.000	5.98477	0.1367003
540.000	5.99842	0.1351954
545.000	6.01193	0.1337196
550.000	6.02528	0.1322719
555.000	6.03849	0.1308517
560.000	6.05157	0.1294583
565.000	6.06450	0.1280908
570.000	6.07729	0.1267486
575.000	6.08996	0.1254311
580.000	6.10249	0.1241375
585.000	6.11489	0.1228673
590.000	6.12717	0.1216199
595.000	6.13932	0.1203946
600.000	6.15135	0.1191910

Input File, Station 27+70, T=500.0, A*=1.0

1,1,1,0.0,
 0.27,0.73,1.0,10.0,106.0,3.8,3.0,
 10.6,0.0,600.0,5.0,1.0,1.0,
 1.0,500.0,1.0,76.6,0.0100,15.,1000.0,
 10600.0,0.050,

Output File, Station 27+70, T=500.0, A*=1.0

Calculation of Convergence Solution
 for the following parameters:

R/a = 1.000 T = 500.00 A* = 1.000

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.01164	0.9138349
5.000	0.02596	3.9428856
10.000	0.81476	9775.2138672
15.000	3.01931	2.9513755
20.000	3.03315	1.3876064
25.000	3.04268	1.2034261
30.000	3.05145	1.1468604
35.000	3.05991	1.1178479
40.000	3.06820	1.0976880
45.000	3.07635	1.0811806
50.000	3.08439	1.0664879
55.000	3.09232	1.0528452
60.000	3.10015	1.0398930
65.000	3.10789	1.0274448
70.000	3.11553	1.0153961
75.000	3.12309	1.0036839
80.000	3.13055	0.9922674
85.000	3.13794	0.9811190
90.000	3.14524	0.9702186
95.000	3.15246	0.9595510
100.000	3.15960	0.9491038
105.000	3.16667	0.9388674
110.000	3.17366	0.9288331
115.000	3.18057	0.9189934
120.000	3.18741	0.9093415
125.000	3.19418	0.8998715
130.000	3.20088	0.8905776
135.000	3.20751	0.8814547
140.000	3.21408	0.8724979

(-continued)

Output File, Station 27+70, T=500.0, A*=1.0 (Continued)

145.000	3.22057	0.8637024
150.000	3.22701	0.8550640
155.000	3.23337	0.8465782
160.000	3.23968	0.8382413
165.000	3.24592	0.8300492
170.000	3.25210	0.8219984
175.000	3.25823	0.8140853
180.000	3.26429	0.8063064
185.000	3.27029	0.7986583
190.000	3.27624	0.7911381
195.000	3.28214	0.7837424
200.000	3.28798	0.7764683
205.000	3.29376	0.7693130
210.000	3.29949	0.7622738
215.000	3.30517	0.7553478
220.000	3.31080	0.7485325
225.000	3.31637	0.7418255
230.000	3.32190	0.7352239
235.000	3.32738	0.7287257
240.000	3.33281	0.7223284
245.000	3.33819	0.7160300
250.000	3.34353	0.7098280
255.000	3.34882	0.7037204
260.000	3.35406	0.6977052
265.000	3.35926	0.6917804
270.000	3.36442	0.6859440
275.000	3.36953	0.6801941
280.000	3.37460	0.6745290
285.000	3.37962	0.6689467
290.000	3.38461	0.6634457
295.000	3.38955	0.6580242
300.000	3.39446	0.6526805
305.000	3.39932	0.6474131
310.000	3.40415	0.6422204
315.000	3.40894	0.6371009
320.000	3.41369	0.6320531
325.000	3.41840	0.6270756
330.000	3.42307	0.6221669
335.000	3.42771	0.6173257
340.000	3.43231	0.6125507
345.000	3.43688	0.6078408
350.000	3.44141	0.6031944
355.000	3.44591	0.5986102
360.000	3.45037	0.5940874
365.000	3.45480	0.5896247
370.000	3.45920	0.5852208
375.000	3.46356	0.5808747
380.000	3.46789	0.5765853
385.000	3.47219	0.5723515
390.000	3.47646	0.5681724
395.000	3.48070	0.5640468
400.000	3.48490	0.5599740

(-continued)

Input File, Station 27+70, T=500.0, A*=1.0 (Continued)

405.000	3.48908	0.5559526
410.000	3.49322	0.5519821
415.000	3.49734	0.5480613
420.000	3.50143	0.5441894
425.000	3.50549	0.5403655
430.000	3.50952	0.5365889
435.000	3.51352	0.5328586
440.000	3.51749	0.5291737
445.000	3.52144	0.5255336
450.000	3.52536	0.5219375
455.000	3.52925	0.5183846
460.000	3.53312	0.5148739
465.000	3.53696	0.5114052
470.000	3.54077	0.5079774
475.000	3.54456	0.5045899
480.000	3.54833	0.5012419
485.000	3.55206	0.4979330
490.000	3.55578	0.4946623
495.000	3.55947	0.4914294
500.000	3.56313	0.4882334
505.000	3.56678	0.4850739
510.000	3.57040	0.4819502
515.000	3.57399	0.4788617
520.000	3.57756	0.4758078
525.000	3.58111	0.4727881
530.000	3.58464	0.4698018
535.000	3.58815	0.4668487
540.000	3.59163	0.4639279
545.000	3.59509	0.4610391
550.000	3.59853	0.4581818
555.000	3.60195	0.4553553
560.000	3.60535	0.4525594
565.000	3.60872	0.4497934
570.000	3.61208	0.4470569
575.000	3.61541	0.4443494
580.000	3.61873	0.4416705
585.000	3.62202	0.4390198
590.000	3.62530	0.4363967
595.000	3.62856	0.4338010
600.000	3.63179	0.4312321

Input File, Station 27+70, T=10.0, A*=40.0

1,1,1,0.0,
0.27,0.73,1.0,10.0,106.0,3.8,0.14,
10.6,0.0,600.0,5.0,1.0,1.0,
1.0,10.0,40.0,76.6,0.0100,15.,1000.0,
10600.0,0.050,

Output File, Station 27+70, T=10.0, A*=40.0

Calculation of Convergence Solution
for the following parameters:

R/a = 1.000 T = 10.00 A* = 40.0

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00054	0.0704455
5.000	0.00674	0.2348396
10.000	0.32166	570.7634277
15.000	1.48239	5.1463609
20.000	1.71126	3.9850347
25.000	1.89380	3.2526631
30.000	2.04502	2.7320445
35.000	2.17339	2.3433199
40.000	2.28441	2.0429771
45.000	2.38185	1.8046930
50.000	2.46839	1.6115581
55.000	2.54603	1.4522220
60.000	2.61627	1.3187937
65.000	2.68026	1.2056258
70.000	2.73894	1.1085768
75.000	2.79303	1.0245441
80.000	2.84314	0.9511608
85.000	2.88975	0.8865914
90.000	2.93327	0.8293923
95.000	2.97406	0.7784135
100.000	3.01239	0.7327281
105.000	3.04852	0.6915815
110.000	3.08267	0.6543537
115.000	3.11502	0.6205302
120.000	3.14572	0.5896818
125.000	3.17493	0.5614465
130.000	3.20276	0.5355181
135.000	3.22933	0.5116355
140.000	3.25473	0.4895748

(-Continued)

Output File, Station 27+70, T=10.0, A*=40.0 (Continued)

145.000	3.27906	0.4691429
150.000	3.30239	0.4501727
155.000	3.32479	0.4325186
160.000	3.34632	0.4160535
165.000	3.36705	0.4006658
170.000	3.38701	0.3862570
175.000	3.40628	0.3727403
180.000	3.42487	0.3600385
185.000	3.44284	0.3480828
190.000	3.46022	0.3368121
195.000	3.47705	0.3261712
200.000	3.49335	0.3161111
205.000	3.50915	0.3065871
210.000	3.52448	0.2975592
215.000	3.53937	0.2889913
220.000	3.55383	0.2808503
225.000	3.56789	0.2731064
230.000	3.58156	0.2657324
235.000	3.59487	0.2587035
240.000	3.60783	0.2519970
245.000	3.62046	0.2455920
250.000	3.63277	0.2394694
255.000	3.64478	0.2336118
260.000	3.65649	0.2280030
265.000	3.66793	0.2226281
270.000	3.67910	0.2174733
275.000	3.69001	0.2125260
280.000	3.70068	0.2077743
285.000	3.71111	0.2032074
290.000	3.72131	0.1988152
295.000	3.73130	0.1945881
300.000	3.74107	0.1905174
305.000	3.75064	0.1865950
310.000	3.76002	0.1828132
315.000	3.76920	0.1791649
320.000	3.77821	0.1756434
325.000	3.78704	0.1722426
330.000	3.79570	0.1689565
335.000	3.80419	0.1657797
340.000	3.81253	0.1627070
345.000	3.82071	0.1597337
350.000	3.82875	0.1568551
355.000	3.83664	0.1540670
360.000	3.84439	0.1513654
365.000	3.85201	0.1487464
370.000	3.85949	0.1462066
375.000	3.86685	0.1437425
380.000	3.87409	0.1413508
385.000	3.88121	0.1390287
390.000	3.88821	0.1367731
395.000	3.89509	0.1345815
400.000	3.90187	0.1324512

(-continued)

Output File, Station 27+70, T=10.0, A*=40.0 (Continued)

405.000	3.90854	0.1303798
410.000	3.91511	0.1283651
415.000	3.92157	0.1264047
420.000	3.92794	0.1244967
425.000	3.93421	0.1226390
430.000	3.94039	0.1208297
435.000	3.94648	0.1190671
440.000	3.95248	0.1173495
445.000	3.95840	0.1156752
450.000	3.96423	0.1140426
455.000	3.96998	0.1124503
460.000	3.97564	0.1108970
465.000	3.98124	0.1093811
470.000	3.98675	0.1079015
475.000	3.99219	0.1064569
480.000	3.99756	0.1050461
485.000	4.00286	0.1036680
490.000	4.00808	0.1023216
495.000	4.01324	0.1010057
500.000	4.01834	0.0997194
505.000	4.02337	0.0984618
510.000	4.02834	0.0972320
515.000	4.03324	0.0960290
520.000	4.03809	0.0948520
525.000	4.04287	0.0937003
530.000	4.04760	0.0925731
535.000	4.05227	0.0914695
540.000	4.05689	0.0903890
545.000	4.06145	0.0893308
550.000	4.06596	0.0882943
555.000	4.07041	0.0872788
560.000	4.07482	0.0862837
565.000	4.07917	0.0853084
570.000	4.08348	0.0843524
575.000	4.08774	0.0834152
580.000	4.09195	0.0824961
585.000	4.09611	0.0815948
590.000	4.10023	0.0807106
595.000	4.10431	0.0798432
600.000	4.10834	0.0789921

Figure III-3. Curve Fit of the Normalized Deformation Rate Data, Station 27+70

Figure III-4. Curve Fit of the Deformation Data, Station 27+70

Input File, Station 31+02, T=2.5, A*=20.0

1,1,1,0.0,
 0.27,0.73,1.0,10.0,106.0,3.8,0.14,
 10.6,0.0,600.0,5.0,1.0,1.0,
 1.0,2.5,20.0,50.0,0.0100,15.,1000.0,
 10600.0,0.050,

Output File, Station 31+02, T=2.5, A*=20.0

Calculation of Convergence Solution
 for the following parameters:

R/a = 1.000 T = 2.50 A* = 20.0

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00054	0.2128421
5.000	0.00799	0.3903467
10.000	0.32731	916.9727173
15.000	1.37492	4.3498678
20.000	1.49066	3.0333054
25.000	1.57576	2.3249846
30.000	1.64261	1.8681056
35.000	1.69720	1.5498778
40.000	1.74304	1.3166375
45.000	1.78235	1.1391224
50.000	1.81661	1.0000000
55.000	1.84686	0.8883702
60.000	1.87388	0.7970499
65.000	1.89821	0.7211244
70.000	1.92031	0.6571230
75.000	1.94052	0.6025302
80.000	1.95909	0.5554805
85.000	1.97625	0.5145628
90.000	1.99219	0.4786920
95.000	2.00704	0.4470203
100.000	2.02093	0.4188764
105.000	2.03397	0.3937228
110.000	2.04625	0.3711236
115.000	2.05783	0.3507223
120.000	2.06879	0.3322246
125.000	2.07918	0.3153857
130.000	2.08906	0.3000002
135.000	2.09846	0.2858944
140.000	2.10743	0.2729211

(-continued)

Output File, Station 31+02, T=2.5, A*=20.0 (Continued)

145.000	2.11600	0.2609542
150.000	2.12420	0.2498854
155.000	2.13206	0.2396209
160.000	2.13960	0.2300795
165.000	2.14684	0.2211902
170.000	2.15381	0.2128911
175.000	2.16052	0.2051273
180.000	2.16699	0.1978508
185.000	2.17323	0.1910188
190.000	2.17926	0.1845933
195.000	2.18509	0.1785406
200.000	2.19073	0.1728304
205.000	2.19619	0.1674354
210.000	2.20149	0.1623314
215.000	2.20662	0.1574964
220.000	2.21160	0.1529104
225.000	2.21644	0.1485554
230.000	2.22115	0.1444152
235.000	2.22572	0.1404748
240.000	2.23017	0.1367206
245.000	2.23450	0.1331404
250.000	2.23872	0.1297228
255.000	2.24283	0.1264573
260.000	2.24684	0.1233345
265.000	2.25076	0.1203455
270.000	2.25457	0.1174823
275.000	2.25830	0.1147375
280.000	2.26194	0.1121041
285.000	2.26550	0.1095757
290.000	2.26898	0.1071465
295.000	2.27238	0.1048109
300.000	2.27571	0.1025639
305.000	2.27897	0.1004008
310.000	2.28216	0.0983170
315.000	2.28529	0.0963085
320.000	2.28835	0.0943715
325.000	2.29135	0.0925023
330.000	2.29429	0.0906976
335.000	2.29717	0.0889542
340.000	2.30000	0.0872693
345.000	2.30278	0.0856400
350.000	2.30550	0.0840637
355.000	2.30818	0.0825380
360.000	2.31080	0.0810606
365.000	2.31338	0.0796293
370.000	2.31592	0.0782421
375.000	2.31841	0.0768971
380.000	2.32086	0.0755924
385.000	2.32326	0.0743263
390.000	2.32563	0.0730973
395.000	2.32796	0.0719037
400.000	2.33025	0.0707442

(-continued)

Output File, Station 31+02, T=2.5, A*=20.0 (Continued)

405.000	2.33250	0.0696173
410.000	2.33472	0.0685217
415.000	2.33690	0.0674563
420.000	2.33905	0.0664198
425.000	2.34117	0.0654111
430.000	2.34325	0.0644292
435.000	2.34531	0.0634730
440.000	2.34733	0.0625416
445.000	2.34932	0.0616341
450.000	2.35129	0.0607496
455.000	2.35323	0.0598873
460.000	2.35513	0.0590463
465.000	2.35702	0.0582260
470.000	2.35887	0.0574256
475.000	2.36071	0.0566445
480.000	2.36251	0.0558819
485.000	2.36430	0.0551372
490.000	2.36605	0.0544099
495.000	2.36779	0.0536994
500.000	2.36950	0.0530050
505.000	2.37119	0.0523264
510.000	2.37286	0.0516629
515.000	2.37451	0.0510141
520.000	2.37614	0.0503796
525.000	2.37775	0.0497589
530.000	2.37934	0.0491515
535.000	2.38090	0.0485570
540.000	2.38245	0.0479751
545.000	2.38398	0.0474054
550.000	2.38550	0.0468475
555.000	2.38699	0.0463011
560.000	2.38847	0.0457657
565.000	2.38993	0.0452412
570.000	2.39138	0.0447272
575.000	2.39281	0.0442233
580.000	2.39422	0.0437293
585.000	2.39561	0.0432450
590.000	2.39699	0.0427700
595.000	2.39836	0.0423040
600.000	2.39971	0.0418469

Input File, Station 31+02, T=100.0, A*=10.0

1,1,1,0.0,
 0.27,0.73,1.0,10.0,106.0,3.8,0.2,
 10.6,0.0,600.0,5.0,1.0,1.0,
 1.0,100.0,10.0,50.0,0.0100,15.,1000.0,
 10600.0,0.050,

Output File, Station 31+02, T=100.0, A*=10.0

Calculation of Convergence Solution
 for the following parameters:

R/a = 1.000 T = 100.00 A* = 10.0

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00078	0.0321800
5.000	0.00198	0.1402098
10.000	0.06922	351.2839050
15.000	0.28145	1.4797378
20.000	0.30626	1.3459162
25.000	0.32940	1.2702857
30.000	0.35132	1.2055910
35.000	0.37215	1.1472989
40.000	0.39199	1.0940609
45.000	0.41093	1.0451380
50.000	0.42904	1.0000000
55.000	0.44638	0.9582214
60.000	0.46300	0.9194467
65.000	0.47897	0.8833708
70.000	0.49431	0.8497300
75.000	0.50908	0.8182939
80.000	0.52331	0.7888602
85.000	0.53704	0.7612503
90.000	0.55029	0.7353060
95.000	0.56310	0.7108868
100.000	0.57548	0.6878669
105.000	0.58747	0.6661341
110.000	0.59909	0.6455876
115.000	0.61035	0.6261364
120.000	0.62127	0.6076987
125.000	0.63188	0.5902004
130.000	0.64219	0.5735743
135.000	0.65220	0.5577593

(-continued)

Output File, Station 31+02, T=100.0, A*=10.0 (Continued)

140.000	0.66195	0.5426998
145.000	0.67143	0.5283451
150.000	0.68067	0.5146487
155.000	0.68967	0.5015683
160.000	0.69844	0.4890647
165.000	0.70700	0.4771023
170.000	0.71535	0.4656480
175.000	0.72350	0.4546714
180.000	0.73146	0.4441444
185.000	0.73923	0.4340410
190.000	0.74683	0.4243374
195.000	0.75427	0.4150110
200.000	0.76154	0.4060412
205.000	0.76865	0.3974088
210.000	0.77562	0.3890959
215.000	0.78244	0.3810857
220.000	0.78912	0.3733627
225.000	0.79567	0.3659124
230.000	0.80208	0.3587211
235.000	0.80838	0.3517761
240.000	0.81455	0.3450655
245.000	0.82060	0.3385781
250.000	0.82654	0.3323034
255.000	0.83237	0.3262315
260.000	0.83810	0.3203532
265.000	0.84372	0.3146597
270.000	0.84925	0.3091428
275.000	0.85468	0.3037947
280.000	0.86001	0.2986082
285.000	0.86526	0.2935762
290.000	0.87041	0.2886924
295.000	0.87548	0.2839504
300.000	0.88047	0.2793446
305.000	0.88538	0.2748693
310.000	0.89021	0.2705192
315.000	0.89496	0.2662895
320.000	0.89964	0.2621754
325.000	0.90425	0.2581724
330.000	0.90879	0.2542762
335.000	0.91326	0.2504829
340.000	0.91767	0.2467885
345.000	0.92200	0.2431895
350.000	0.92628	0.2396822
355.000	0.93050	0.2362635
360.000	0.93465	0.2329301
365.000	0.93875	0.2296789
370.000	0.94279	0.2265072
375.000	0.94677	0.2234122
380.000	0.95070	0.2203911
385.000	0.95458	0.2174416
390.000	0.95841	0.2145611
395.000	0.96218	0.2117475

(-continued)

Output File, Station 31+02, T=100.0, A*=10.0 (Continued)

400.000	0.96591	0.2089985
405.000	0.96959	0.2063120
410.000	0.97322	0.2036860
415.000	0.97680	0.2011185
420.000	0.98034	0.1986077
425.000	0.98384	0.1961518
430.000	0.98729	0.1937491
435.000	0.99070	0.1913980
440.000	0.99407	0.1890968
445.000	0.99740	0.1868441
450.000	1.00069	0.1846385
455.000	1.00394	0.1824785
460.000	1.00716	0.1803627
465.000	1.01033	0.1782900
470.000	1.01347	0.1762590
475.000	1.01658	0.1742685
480.000	1.01965	0.1723174
485.000	1.02268	0.1704047
490.000	1.02568	0.1685291
495.000	1.02865	0.1666898
500.000	1.03159	0.1648856
505.000	1.03449	0.1631157
510.000	1.03737	0.1613790
515.000	1.04021	0.1596748
520.000	1.04302	0.1580021
525.000	1.04581	0.1563601
530.000	1.04856	0.1547481
535.000	1.05129	0.1531652
540.000	1.05399	0.1516107
545.000	1.05666	0.1500838
550.000	1.05931	0.1485839
555.000	1.06192	0.1471102
560.000	1.06452	0.1456622
565.000	1.06708	0.1442392
570.000	1.06963	0.1428405
575.000	1.07214	0.1414656
580.000	1.07464	0.1401139
585.000	1.07711	0.1387848
590.000	1.07955	0.1374778
595.000	1.08198	0.1361924
600.000	1.08438	0.1349280

Input File, Station 31+02, T=10.0, A*=25.0

1,1,1,0.0,
 0.27,0.73,1.0,10.0,106.0,3.8,0.14,
 10.6,0.0,600.0,5.0,1.0,1.0,
 1.0,10.0,25.0,50.0,0.0100,15.,1000.0,
 10600.0,0.050,

Output File, Station 31+02, T=10.0, A*=25.0

Calculation of Convergence Solution
 for the following parameters:

R/a = 1.000 T = 10.00 A* = 25.0

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00054	0.0460411
5.000	0.00467	0.1557643
10.000	0.21521	379.0564880
15.000	0.97887	3.1979370
20.000	1.12200	2.4733803
25.000	1.23611	2.0185034
30.000	1.33063	1.6953452
35.000	1.41086	1.4540980
40.000	1.48025	1.2677145
45.000	1.54115	1.1198475
50.000	1.59524	1.0000000
55.000	1.64377	0.9011272
60.000	1.68766	0.8183314
65.000	1.72766	0.7481082
70.000	1.76434	0.6878873
75.000	1.79814	0.6357434
80.000	1.82946	0.5902078
85.000	1.85859	0.5501414
90.000	1.88579	0.5146484
95.000	1.91128	0.4830152
100.000	1.93524	0.4546667
105.000	1.95783	0.4291347
110.000	1.97917	0.4060344
115.000	1.99938	0.3850464
120.000	2.01857	0.3659045
125.000	2.03683	0.3483841
130.000	2.05422	0.3322953
135.000	2.07083	0.3174758
140.000	2.08671	0.3037868
145.000	2.10191	0.2911086

(-continued)

Output File, Station 31+02, T=10.0, A*=25.0 (Continued)

150.000	2.11649	0.2793373
155.000	2.13049	0.2683828
160.000	2.14395	0.2581659
165.000	2.15690	0.2486176
170.000	2.16938	0.2396768
175.000	2.18142	0.2312896
180.000	2.19304	0.2234079
185.000	2.20427	0.2159893
190.000	2.21514	0.2089956
195.000	2.22565	0.2023929
200.000	2.23584	0.1961504
205.000	2.24572	0.1902407
210.000	2.25530	0.1846388
215.000	2.26460	0.1793223
220.000	2.27364	0.1742707
225.000	2.28243	0.1694655
230.000	2.29097	0.1648899
235.000	2.29929	0.1605283
240.000	2.30739	0.1563668
245.000	2.31529	0.1523925
250.000	2.32298	0.1485934
255.000	2.33048	0.1449586
260.000	2.33781	0.1414783
265.000	2.34495	0.1381431
270.000	2.35194	0.1349445
275.000	2.35876	0.1318746
280.000	2.36542	0.1289262
285.000	2.37194	0.1260924
290.000	2.37832	0.1233669
295.000	2.38456	0.1207439
300.000	2.39067	0.1182180
305.000	2.39665	0.1157842
310.000	2.40251	0.1134375
315.000	2.40825	0.1111737
320.000	2.41388	0.1089886
325.000	2.41940	0.1068783
330.000	2.42481	0.1048392
335.000	2.43012	0.1028680
340.000	2.43533	0.1009614
345.000	2.44044	0.0991164
350.000	2.44547	0.0973302
355.000	2.45040	0.0956001
360.000	2.45524	0.0939237
365.000	2.46000	0.0922987
370.000	2.46468	0.0907227
375.000	2.46928	0.0891936
380.000	2.47380	0.0877096
385.000	2.47825	0.0862686
390.000	2.48263	0.0848690
395.000	2.48693	0.0835091
400.000	2.49117	0.0821873
405.000	2.49534	0.0809019

(-continued)

Output File, Station 31+02, T=10.0, A*=25.0 (Continued)

410.000	2.49944	0.0796518
415.000	2.50348	0.0784353
420.000	2.50746	0.0772513
425.000	2.51138	0.0760986
430.000	2.51524	0.0749760
435.000	2.51905	0.0738822
440.000	2.52280	0.0728164
445.000	2.52650	0.0717775
450.000	2.53014	0.0707645
455.000	2.53373	0.0697764
460.000	2.53728	0.0688125
465.000	2.54077	0.0678719
470.000	2.54422	0.0669538
475.000	2.54762	0.0660574
480.000	2.55097	0.0651820
485.000	2.55428	0.0643269
490.000	2.55755	0.0634914
495.000	2.56078	0.0626749
500.000	2.56396	0.0618767
505.000	2.56710	0.0610964
510.000	2.57021	0.0603332
515.000	2.57327	0.0595867
520.000	2.57630	0.0588564
525.000	2.57929	0.0581418
530.000	2.58225	0.0574423
535.000	2.58517	0.0567575
540.000	2.58805	0.0560870
545.000	2.59090	0.0554304
550.000	2.59372	0.0547872
555.000	2.59651	0.0541571
560.000	2.59926	0.0535396
565.000	2.60198	0.0529344
570.000	2.60467	0.0523412
575.000	2.60733	0.0517596
580.000	2.60997	0.0511893
585.000	2.61257	0.0506300
590.000	2.61514	0.0500814
595.000	2.61769	0.0495431
600.000	2.62021	0.0490150

Figure III-5. Curve Fit of the Normalized Deformation Rate Data, Station 31+02

Figure III-6. Curve Fit of the Deformation Data, Station 31+02

Input File, Station 55+71, T=50.0, A*=20.0

1,1,1,0.0,
 0.27,0.73,1.0,10.0,106.0,3.8,0.1717,
 10.6,0.0,400.0,5.0,1.0,1.0,
 1.0,50.0,20.0,49.5,0.0100,15.,1000.0,
 10600.0,0.050,

Output File, Station 55+71, T=50.0, A*=20.0

Calculation of Convergence Solution
 for the following parameters:

R/a = 1.000 T = 50.00 A* = 20.0

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00067	0.0187342
5.000	0.00232	0.0809982
10.000	0.09571	204.5469360
15.000	0.43060	1.7804964
20.000	0.50109	1.5855560
25.000	0.56484	1.4459175
30.000	0.62320	1.3286079
35.000	0.67698	1.2275623
40.000	0.72679	1.1394898
45.000	0.77312	1.0620612
50.000	0.81638	0.9935008
55.000	0.85691	0.9324112
60.000	0.89501	0.8776732
65.000	0.93092	0.8283780
70.000	0.96486	0.7837805
75.000	0.99700	0.7432632
80.000	1.02752	0.7063107
85.000	1.05655	0.6724892
90.000	1.08421	0.6414317
95.000	1.11061	0.6128250
100.000	1.13586	0.5864007
105.000	1.16004	0.5619276
110.000	1.18322	0.5392055
115.000	1.20548	0.5180600
120.000	1.22688	0.4983386
125.000	1.24748	0.4799076
130.000	1.26732	0.4626494
135.000	1.28646	0.4464596
140.000	1.30494	0.4312459
145.000	1.32280	0.4169260

(-continued)

Output File, Station 55+71, T=50.0, A*=20.0 (Continued)

150.000	1.34008	0.4034264
155.000	1.35680	0.3906814
160.000	1.37300	0.3786317
165.000	1.38870	0.3672244
170.000	1.40394	0.3564113
175.000	1.41873	0.3461490
180.000	1.43310	0.3363982
185.000	1.44708	0.3271230
190.000	1.46067	0.3182909
195.000	1.47389	0.3098720
200.000	1.48678	0.3018393
205.000	1.49933	0.2941677
210.000	1.51156	0.2868345
215.000	1.52349	0.2798186
220.000	1.53514	0.2731007
225.000	1.54650	0.2666630
230.000	1.55760	0.2604889
235.000	1.56845	0.2545634
240.000	1.57905	0.2488722
245.000	1.58942	0.2434023
250.000	1.59956	0.2381415
255.000	1.60948	0.2330786
260.000	1.61919	0.2282030
265.000	1.62870	0.2235050
270.000	1.63802	0.2189755
275.000	1.64715	0.2146058
280.000	1.65610	0.2103881
285.000	1.66488	0.2063148
290.000	1.67348	0.2023790
295.000	1.68193	0.1985741
300.000	1.69021	0.1948940
305.000	1.69835	0.1913328
310.000	1.70633	0.1878851
315.000	1.71417	0.1845458
320.000	1.72188	0.1813101
325.000	1.72945	0.1781734
330.000	1.73689	0.1751314
335.000	1.74420	0.1721801
340.000	1.75139	0.1693157
345.000	1.75847	0.1665345
350.000	1.76542	0.1638331
355.000	1.77227	0.1612083
360.000	1.77900	0.1586569
365.000	1.78563	0.1561761
370.000	1.79216	0.1537631
375.000	1.79859	0.1514153
380.000	1.80492	0.1491301
385.000	1.81115	0.1469053
390.000	1.81729	0.1447384
395.000	1.82334	0.1426275
400.000	1.82931	0.1405704

Input File, Station 55+71, T=50.0, A*=10.0

1,1,1,0.0,
0.27,0.73,1.0,10.0,106.0,3.8,0.14,
10.6,0.0,400.0,5.0,1.0,1.0,
1.0,50.0,10.0,49.5,0.0100,15.,1000.0,
10600.0,0.050,

Output File, Station 55+71, T=50.0, A*=10.0

Calculation of Convergence Solution
for the following parameters:

R/a = 1.000 T = 50.00 A* = 10.0

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00054	0.0279791
5.000	0.00155	0.1208685
10.000	0.05792	303.3574524
15.000	0.24538	1.7985342
20.000	0.27424	1.5879571
25.000	0.30026	1.4466090
30.000	0.32406	1.3288736
35.000	0.34599	1.2276765
40.000	0.36630	1.1395380
45.000	0.38519	1.0620772
50.000	0.40282	0.9934995
55.000	0.41935	0.9324003
60.000	0.43488	0.8776568
65.000	0.44952	0.8283585
70.000	0.46336	0.7837592
75.000	0.47646	0.7432410
80.000	0.48890	0.7062880
85.000	0.50074	0.6724667
90.000	0.51202	0.6414093
95.000	0.52278	0.6128029
100.000	0.53307	0.5863791
105.000	0.54293	0.5619065
110.000	0.55238	0.5391849
115.000	0.56146	0.5180399
120.000	0.57018	0.4983191
125.000	0.57858	0.4798886
130.000	0.58667	0.4626309
135.000	0.59447	0.4464416
140.000	0.60201	0.4312285
145.000	0.60929	0.4169090
150.000	0.61633	0.4034098

(-continued)

Output File, Station 55+71, T=50.0, A*=10.0 (Continued)

155.000	0.62315	0.3906652
160.000	0.62975	0.3786160
165.000	0.63616	0.3672091
170.000	0.64237	0.3563964
175.000	0.64840	0.3461345
180.000	0.65426	0.3363840
185.000	0.65995	0.3271092
190.000	0.66549	0.3182774
195.000	0.67089	0.3098588
200.000	0.67614	0.3018264
205.000	0.68126	0.2941551
210.000	0.68624	0.2868222
215.000	0.69111	0.2798066
220.000	0.69585	0.2730889
225.000	0.70049	0.2666515
230.000	0.70501	0.2604776
235.000	0.70944	0.2545523
240.000	0.71376	0.2488613
245.000	0.71798	0.2433916
250.000	0.72212	0.2381310
255.000	0.72616	0.2330683
260.000	0.73012	0.2281929
265.000	0.73400	0.2234952
270.000	0.73780	0.2189658
275.000	0.74152	0.2145963
280.000	0.74517	0.2103787
285.000	0.74875	0.2063056
290.000	0.75226	0.2023700
295.000	0.75570	0.1985652
300.000	0.75908	0.1948852
305.000	0.76239	0.1913241
310.000	0.76565	0.1878766
315.000	0.76885	0.1845374
320.000	0.77199	0.1813018
325.000	0.77507	0.1781653
330.000	0.77811	0.1751234
335.000	0.78109	0.1721722
340.000	0.78402	0.1693079
345.000	0.78690	0.1665268
350.000	0.78974	0.1638255
355.000	0.79253	0.1612007
360.000	0.79528	0.1586495
365.000	0.79798	0.1561688
370.000	0.80064	0.1537559
375.000	0.80326	0.1514081
380.000	0.80584	0.1491230
385.000	0.80838	0.1468983
390.000	0.81089	0.1447315
395.000	0.81335	0.1426207
400.000	0.81578	0.1405637

Input File, Station 55+71, T=20.0, A*=1.0

1,1,1,0.0,
 0.27,0.73,1.0,10.0,106.0,3.8,0.3,
 10.6,0.0,400.0,5.0,1.0,1.0,
 1.0,20.0,1.0,49.5,0.0100,15.,1000.0,
 10600.0,0.050,

Output File, Station 55+71, T=20.0, A*=1.0

Calculation of Convergence Solution
 for the following parameters:

R/a = 1.000 T = 20.00 A* = 1.000

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00116	0.1721399
5.000	0.00276	0.7331536
10.000	0.09027	1818.2546387
15.000	0.34554	2.7766659
20.000	0.35610	2.0960028
25.000	0.36468	1.7726271
30.000	0.37204	1.5393341
35.000	0.37848	1.3576618
40.000	0.38420	1.2114462
45.000	0.38933	1.0912114
50.000	0.39396	0.9907007
55.000	0.39819	0.9055382
60.000	0.40206	0.8325518
65.000	0.40563	0.7693810
70.000	0.40893	0.7142319
75.000	0.41201	0.6657166
80.000	0.41488	0.6227459
85.000	0.41757	0.5844526
90.000	0.42010	0.5501386
95.000	0.42248	0.5192360
100.000	0.42473	0.4912781
105.000	0.42687	0.4658781
110.000	0.42889	0.4427131
115.000	0.43082	0.4215110
120.000	0.43265	0.4020418
125.000	0.43441	0.3841092
130.000	0.43608	0.3675448
135.000	0.43769	0.3522037

(-continued)

Output File, Station 55+71, T=20.0, A*=1.0 (Continued)

140.000	0.43922	0.3379603
145.000	0.44070	0.3247053
150.000	0.44212	0.3123431
155.000	0.44349	0.3007899
160.000	0.44481	0.2899719
165.000	0.44608	0.2798236
170.000	0.44730	0.2702873
175.000	0.44849	0.2613112
180.000	0.44963	0.2528494
185.000	0.45074	0.2448605
190.000	0.45182	0.2373076
195.000	0.45286	0.2301573
200.000	0.45387	0.2233795
205.000	0.45485	0.2169470
210.000	0.45581	0.2108350
215.000	0.45674	0.2050212
220.000	0.45764	0.1994852
225.000	0.45852	0.1942082
230.000	0.45937	0.1891732
235.000	0.46020	0.1843646
240.000	0.46101	0.1797681
245.000	0.46181	0.1753704
250.000	0.46258	0.1711596
255.000	0.46333	0.1671244
260.000	0.46407	0.1632544
265.000	0.46479	0.1595402
270.000	0.46549	0.1559729
275.000	0.46618	0.1525443
280.000	0.46685	0.1492468
285.000	0.46751	0.1460733
290.000	0.46816	0.1430172
295.000	0.46879	0.1400724
300.000	0.46941	0.1372332
305.000	0.47001	0.1344942
310.000	0.47061	0.1318505
315.000	0.47119	0.1292973
320.000	0.47176	0.1268302
325.000	0.47232	0.1244452
330.000	0.47287	0.1221383
335.000	0.47341	0.1199061
340.000	0.47394	0.1177449
345.000	0.47446	0.1156517
350.000	0.47497	0.1136234
355.000	0.47547	0.1116572
360.000	0.47597	0.1097504
365.000	0.47645	0.1079003
370.000	0.47693	0.1061047
375.000	0.47740	0.1043613
380.000	0.47786	0.1026679
385.000	0.47832	0.1010224
390.000	0.47876	0.0994230
395.000	0.47920	0.0978679
400.000	0.47964	0.0963552

Figure III-7. Curve Fit of the Normalized Deformation Rate Data, Station 55+71

Figure III-8. Curve Fit of the Deformation Data, Station 55+71

Input File, Station 60+55, T=50.0, A*=10.0

1,1,1,0.0,
0.27,0.73,1.0,10.0,106.0,3.8,0.14,
10.6,0.0,400.0,5.0,1.0,1.0,
1.0,50.0,10.0,39.4,0.0100,15.,1000.0,
10600.0,0.050,

Output File, Station 60+55, T=50.0, A*=10.0

Calculation of Convergence Solution
for the following parameters:

R/a = 1.000 T = 50.00 A* = *****

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00054	0.0243400
5.000	0.00155	0.1051478
10.000	0.05792	263.9014587
15.000	0.24538	1.5646089
20.000	0.27424	1.3814205
25.000	0.30026	1.2584567
30.000	0.32406	1.1560345
35.000	0.34599	1.0679995
40.000	0.36630	0.9913248
45.000	0.38519	0.9239388
50.000	0.40282	0.8642806
55.000	0.41935	0.8111282
60.000	0.43488	0.7635049
65.000	0.44952	0.7206185
70.000	0.46336	0.6818200
75.000	0.47646	0.6465718
80.000	0.48890	0.6144252
85.000	0.50074	0.5850027
90.000	0.51202	0.5579848
95.000	0.52278	0.5330991
100.000	0.53307	0.5101121
105.000	0.54293	0.4888225
110.000	0.55238	0.4690562
115.000	0.56146	0.4506614
120.000	0.57018	0.4335055
125.000	0.57858	0.4174722
130.000	0.58667	0.4024591
135.000	0.59447	0.3883755
140.000	0.60201	0.3751410

(-continued)

Input File, Station 60+55, T=50.0, A*=10.0 (Continued)

145.000	0.60929	0.3626840
150.000	0.61633	0.3509406
155.000	0.62315	0.3398536
160.000	0.62975	0.3293715
165.000	0.63616	0.3194483
170.000	0.64237	0.3100419
175.000	0.64840	0.3011147
180.000	0.65426	0.2926324
185.000	0.65995	0.2845639
190.000	0.66549	0.2768808
195.000	0.67089	0.2695572
200.000	0.67614	0.2625695
205.000	0.68126	0.2558960
210.000	0.68624	0.2495169
215.000	0.69111	0.2434137
220.000	0.69585	0.2375698
225.000	0.70049	0.2319696
230.000	0.70501	0.2265988
235.000	0.70944	0.2214441
240.000	0.71376	0.2164933
245.000	0.71798	0.2117350
250.000	0.72212	0.2071587
255.000	0.72616	0.2027544
260.000	0.73012	0.1985132
265.000	0.73400	0.1944264
270.000	0.73780	0.1904861
275.000	0.74152	0.1866850
280.000	0.74517	0.1830159
285.000	0.74875	0.1794726
290.000	0.75226	0.1760488
295.000	0.75570	0.1727389
300.000	0.75908	0.1695376
305.000	0.76239	0.1664397
310.000	0.76565	0.1634405
315.000	0.76885	0.1605357
320.000	0.77199	0.1577209
325.000	0.77507	0.1549923
330.000	0.77811	0.1523461
335.000	0.78109	0.1497788
340.000	0.78402	0.1472870
345.000	0.78690	0.1448676
350.000	0.78974	0.1425176
355.000	0.79253	0.1402343
360.000	0.79528	0.1380149
365.000	0.79798	0.1358568
370.000	0.80064	0.1337577
375.000	0.80326	0.1317153
380.000	0.80584	0.1297275
385.000	0.80838	0.1277920
390.000	0.81089	0.1259071
395.000	0.81335	0.1240708
400.000	0.81578	0.1222814

Input File, Station 60+55, T=20.0, A*=10.0

1,1,1,0.0,
0.27,0.73,1.0,10.0,106.0,3.8,0.14,
10.6,0.0,400.0,5.0,1.0,1.0,
1.0,20.0,10.0,39.4,0.0100,15.,1000.0,
10600.0,0.050,

Output File, Station 60+55, T=20.0, A*=10.0

Calculation of Convergence Solution
for the following parameters:

R/a = 1.000 T = 20.00 A* = *****

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00054	0.0284086
5.000	0.00199	0.1149879
10.000	0.08109	286.0148926
15.000	0.35552	2.0454850
20.000	0.40259	1.6798002
25.000	0.44219	1.4368045
30.000	0.47640	1.2517265
35.000	0.50640	1.1054257
40.000	0.53304	0.9870016
45.000	0.55694	0.8893585
50.000	0.57856	0.8076159
55.000	0.59826	0.7382969
60.000	0.61632	0.6788570
65.000	0.63297	0.6273925
70.000	0.64839	0.5824518
75.000	0.66274	0.5429097
80.000	0.67613	0.5078820
85.000	0.68869	0.4766639
90.000	0.70048	0.4486875
95.000	0.71161	0.4234909
100.000	0.72212	0.4006940
105.000	0.73207	0.3799820
110.000	0.74152	0.3610918
115.000	0.75051	0.3438018
120.000	0.75908	0.3279246
125.000	0.76726	0.3133000
130.000	0.77507	0.2997912
135.000	0.78256	0.2872797

(-continued)

Output File, Station 60+55, T=20.0, A*=10.0 (Continued)

140.000	0.78974	0.2756633
145.000	0.79664	0.2648529
150.000	0.80326	0.2547705
155.000	0.80964	0.2453478
160.000	0.81579	0.2365247
165.000	0.82172	0.2282478
170.000	0.82744	0.2204698
175.000	0.83297	0.2131488
180.000	0.83832	0.2062473
185.000	0.84350	0.1997314
190.000	0.84852	0.1935711
195.000	0.85338	0.1877391
200.000	0.85810	0.1822109
205.000	0.86268	0.1769644
210.000	0.86713	0.1719793
215.000	0.87146	0.1672374
220.000	0.87567	0.1627220
225.000	0.87976	0.1584178
230.000	0.88375	0.1543111
235.000	0.88764	0.1503890
240.000	0.89143	0.1466399
245.000	0.89512	0.1430531
250.000	0.89873	0.1396185
255.000	0.90225	0.1363272
260.000	0.90569	0.1331708
265.000	0.90905	0.1301413
270.000	0.91233	0.1272317
275.000	0.91554	0.1244351
280.000	0.91868	0.1217456
285.000	0.92175	0.1191572
290.000	0.92476	0.1166645
295.000	0.92771	0.1142627
300.000	0.93059	0.1119469
305.000	0.93342	0.1097129
310.000	0.93619	0.1075566
315.000	0.93891	0.1054741
320.000	0.94158	0.1034619
325.000	0.94419	0.1015166
330.000	0.94676	0.0996351
335.000	0.94928	0.0978144
340.000	0.95175	0.0960517
345.000	0.95418	0.0943445
350.000	0.95656	0.0926902
355.000	0.95891	0.0910865
360.000	0.96121	0.0895313
365.000	0.96348	0.0880224
370.000	0.96570	0.0865579
375.000	0.96789	0.0851360
380.000	0.97005	0.0837548
385.000	0.97217	0.0824128
390.000	0.97426	0.0811084
395.000	0.97631	0.0798400
400.000	0.97833	0.0786064

Input File, Station 60+55, T=5.0, A*=1.0

1,1,1,0.0,
 0.27,0.73,1.0,10.0,106.0,3.8,0.3,
 10.6,0.0,400.0,5.0,1.0,1.0,
 1.0,5.0,1.0,39.4,0.0100,15.,1000.0,
 10600.0,0.050,

Output File, Station 60+55, T=5.0, A*=1.0

Calculation of Convergence Solution
 for the following parameters:

R/a = 1.000 T = 5.00 A* = 1.000

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00116	0.1951908
5.000	0.00307	0.7205783
10.000	0.10374	1767.0231934
15.000	0.40112	3.1463854
20.000	0.41462	2.1519673
25.000	0.42462	1.6757149
30.000	0.43259	1.3658930
35.000	0.43918	1.1462371
40.000	0.44478	0.9826199
45.000	0.44961	0.8563904
50.000	0.45386	0.7563366
55.000	0.45762	0.6752903
60.000	0.46101	0.6084557
65.000	0.46406	0.5525051
70.000	0.46685	0.5050611
75.000	0.46940	0.4643817
80.000	0.47176	0.4291629
85.000	0.47394	0.3984106
90.000	0.47597	0.3713542
95.000	0.47786	0.3473878
100.000	0.47964	0.3260289
105.000	0.48130	0.3068888
110.000	0.48288	0.2896509
115.000	0.48436	0.2740553
120.000	0.48577	0.2598864
125.000	0.48711	0.2469639
130.000	0.48838	0.2351365
135.000	0.48959	0.2242755

(-continued)

Output File, Station 60+55, T=5.0, A*=1.0 (Continued)

140.000	0.49074	0.2142717
145.000	0.49185	0.2050312
150.000	0.49291	0.1964730
155.000	0.49392	0.1885272
160.000	0.49490	0.1811328
165.000	0.49584	0.1742364
170.000	0.49674	0.1677913
175.000	0.49761	0.1617563
180.000	0.49844	0.1560950
185.000	0.49925	0.1507750
190.000	0.50004	0.1457676
195.000	0.50079	0.1410470
200.000	0.50152	0.1365903
205.000	0.50223	0.1323768
210.000	0.50292	0.1283879
215.000	0.50359	0.1246068
220.000	0.50424	0.1210183
225.000	0.50486	0.1176087
230.000	0.50548	0.1143654
235.000	0.50607	0.1112770
240.000	0.50665	0.1083331
245.000	0.50721	0.1055242
250.000	0.50776	0.1028416
255.000	0.50830	0.1002774
260.000	0.50882	0.0978241
265.000	0.50933	0.0954750
270.000	0.50983	0.0932238
275.000	0.51032	0.0910649
280.000	0.51079	0.0889928
285.000	0.51125	0.0870027
290.000	0.51171	0.0850900
295.000	0.51215	0.0832503
300.000	0.51259	0.0814799
305.000	0.51301	0.0797750
310.000	0.51343	0.0781322
315.000	0.51384	0.0765482
320.000	0.51424	0.0750201
325.000	0.51463	0.0735452
330.000	0.51501	0.0721208
335.000	0.51539	0.0707444
340.000	0.51576	0.0694139
345.000	0.51612	0.0681269
350.000	0.51648	0.0668815
355.000	0.51683	0.0656758
360.000	0.51717	0.0645080
365.000	0.51751	0.0633764
370.000	0.51784	0.0622794
375.000	0.51816	0.0612155
380.000	0.51848	0.0601834
385.000	0.51880	0.0591816
390.000	0.51911	0.0582088
395.000	0.51941	0.0572640
400.000	0.51971	0.0563460

Figure III-9. Curve Fit of the Normalized Deformation Rate Data, Station 60+55

Figure III-10. Curve Fit of the Deformation Data, Station 60+55

Input File, Station 67+95, T=1.0, A*=10.0

1,1,1,0.0,
 0.27,0.73,1.0,10.0,106.0,3.8,0.14,
 10.6,0.0,300.0,5.0,1.0,1.0,
 1.0,1.0,10.0,29.86,0.0100,15.,1000.0,
 10600.0,0.050,

Output File, Station 67+95, T=1.0, A*=10.0

Calculation of Convergence Solution
 for the following parameters:

R/a = 1.000 T = 1.00 A* = *****

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00054	0.3468459
5.000	0.00623	0.3617586
10.000	0.23168	853.5153809
15.000	0.92841	2.5051208
20.000	0.97773	1.6672626
25.000	1.01291	1.2527617
30.000	1.04011	0.9940869
35.000	1.06208	0.8175151
40.000	1.08040	0.6899231
45.000	1.09601	0.5938452
50.000	1.10955	0.5191733
55.000	1.12147	0.4596601
60.000	1.13208	0.4112445
65.000	1.14161	0.3711783
70.000	1.15024	0.3375387
75.000	1.15812	0.3089426
80.000	1.16535	0.2843712
85.000	1.17203	0.2630584
90.000	1.17821	0.2444179
95.000	1.18397	0.2279937
100.000	1.18935	0.2134263
105.000	1.19440	0.2004285
110.000	1.19915	0.1887687
115.000	1.20362	0.1782575
120.000	1.20785	0.1687393
125.000	1.21187	0.1600848
130.000	1.21567	0.1521859
135.000	1.21930	0.1449512
140.000	1.22275	0.1383036

(-continued)

Output File, Station 67+95, T=1.0, A*=10.0 (Continued)

145.000	1.22605	0.1321770
150.000	1.22921	0.1265146
155.000	1.23223	0.1212678
160.000	1.23513	0.1163940
165.000	1.23791	0.1118563
170.000	1.24059	0.1076225
175.000	1.24317	0.1036642
180.000	1.24565	0.0999563
185.000	1.24805	0.0964768
190.000	1.25036	0.0932060
195.000	1.25260	0.0901263
200.000	1.25476	0.0872222
205.000	1.25686	0.0844797
210.000	1.25889	0.0818861
215.000	1.26085	0.0794301
220.000	1.26276	0.0771014
225.000	1.26462	0.0748909
230.000	1.26642	0.0727900
235.000	1.26817	0.0707912
240.000	1.26987	0.0688875
245.000	1.27153	0.0670725
250.000	1.27315	0.0653404
255.000	1.27472	0.0636859
260.000	1.27626	0.0621040
265.000	1.27775	0.0605904
270.000	1.27921	0.0591408
275.000	1.28064	0.0577515
280.000	1.28203	0.0564188
285.000	1.28339	0.0551396
290.000	1.28473	0.0539108
295.000	1.28603	0.0527296
300.000	1.28730	0.0515934

Input File, Station 67+95, T=15.0, A*=10.0

```
1,1,1,0.0,
0.27,0.73,1.0,10.0,106.0,3.8,0.14,
10.6,0.0,300.0,5.0,1.0,1.0,
1.0,15.0,10.0,29.86,0.0100,15.,1000.0,
10600.0,0.050,
```

Output File, Station 67+95, T=15.0, A*=10.0

Calculation of Convergence Solution
for the following parameters:

R/a = 1.000 T = 15.00 A* = *****

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00054	0.0255095
5.000	0.00221	0.0987846
10.000	0.09150	244.1058350
15.000	0.40189	1.7343886
20.000	0.45395	1.3865526
25.000	0.49672	1.1618550
30.000	0.53299	0.9959410
35.000	0.56435	0.8681010
40.000	0.59186	0.7667742
45.000	0.61630	0.6846811
50.000	0.63822	0.6169686
55.000	0.65805	0.5602727
60.000	0.67612	0.5121892
65.000	0.69269	0.4709562
70.000	0.70796	0.4352545
75.000	0.72211	0.4040778
80.000	0.73527	0.3766461
85.000	0.74756	0.3523458
90.000	0.75907	0.3306883
95.000	0.76990	0.3112797
100.000	0.78010	0.2937995
105.000	0.78974	0.2779841
110.000	0.79887	0.2636150
115.000	0.80754	0.2505098
120.000	0.81579	0.2385147
125.000	0.82365	0.2274997
130.000	0.83115	0.2173539
135.000	0.83832	0.2079820
140.000	0.84519	0.1993020

(-continued)

Output File, Station 67+95, T=15.0, A*=10.0 (Continued)

145.000	0.85177	0.1912431
150.000	0.85810	0.1837432
155.000	0.86418	0.1767485
160.000	0.87003	0.1702114
165.000	0.87567	0.1640903
170.000	0.88111	0.1583481
175.000	0.88636	0.1529521
180.000	0.89143	0.1478731
185.000	0.89634	0.1430851
190.000	0.90109	0.1385646
195.000	0.90569	0.1342908
200.000	0.91015	0.1302449
205.000	0.91448	0.1264096
210.000	0.91868	0.1227698
215.000	0.92277	0.1193113
220.000	0.92673	0.1160216
225.000	0.93060	0.1128890
230.000	0.93435	0.1099030
235.000	0.93801	0.1070539
240.000	0.94158	0.1043329
245.000	0.94505	0.1017319
250.000	0.94844	0.0992435
255.000	0.95175	0.0968608
260.000	0.95498	0.0945774
265.000	0.95813	0.0923875
270.000	0.96121	0.0902858
275.000	0.96423	0.0882672
280.000	0.96717	0.0863271
285.000	0.97005	0.0844612
290.000	0.97287	0.0826655
295.000	0.97563	0.0809362
300.000	0.97833	0.0792698

Input File, Station 67+95, T=5.0, A*=1.0

1,1,1,0.0,
 0.27,0.73,1.0,10.0,106.0,3.8,0.25,
 10.6,0.0,300.0,5.0,1.0,1.0,
 1.0,5.0,1.0,29.86,0.0100,15.,1000.0,
 10600.0,0.050,

Output File, Station 67+95, T=5.0, A*=1.0

Calculation of Convergence Solution
 for the following parameters:

R/a = 1.000 T = 5.00 A* = 1.000

Time (days)	Convergence (mm)	Normalized Convergence Rate
0.000	0.00097	0.1421509
5.000	0.00256	0.5247728
10.000	0.08645	1286.8631592
15.000	0.33427	2.2914059
20.000	0.34552	1.5672050
25.000	0.35385	1.2203664
30.000	0.36049	0.9947336
35.000	0.36598	0.8347657
40.000	0.37065	0.7156088
45.000	0.37468	0.6236802
50.000	0.37821	0.5508143
55.000	0.38135	0.4917911
60.000	0.38417	0.4431176
65.000	0.38672	0.4023708
70.000	0.38904	0.3678189
75.000	0.39117	0.3381935
80.000	0.39313	0.3125448
85.000	0.39495	0.2901489
90.000	0.39664	0.2704447
95.000	0.39822	0.2529908
100.000	0.39970	0.2374358
105.000	0.40109	0.2234967
110.000	0.40240	0.2109430
115.000	0.40364	0.1995852
120.000	0.40481	0.1892664
125.000	0.40592	0.1798555
130.000	0.40698	0.1712419
135.000	0.40799	0.1633323
140.000	0.40895	0.1560468

(-continued)

Output File, Station 67+95, T=5.0, A*=1.0 (Continued)

145.000	0.40987	0.1493173
150.000	0.41076	0.1430847
155.000	0.41160	0.1372980
160.000	0.41242	0.1319129
165.000	0.41320	0.1268905
170.000	0.41395	0.1221967
175.000	0.41467	0.1178017
180.000	0.41537	0.1136787
185.000	0.41604	0.1098043
190.000	0.41670	0.1061576
195.000	0.41733	0.1027198
200.000	0.41794	0.0994741
205.000	0.41853	0.0964056
210.000	0.41910	0.0935006
215.000	0.41966	0.0907469
220.000	0.42020	0.0881335
225.000	0.42072	0.0856504
230.000	0.42123	0.0832884
235.000	0.42173	0.0810392
240.000	0.42221	0.0788953
245.000	0.42268	0.0768497
250.000	0.42314	0.0748961
255.000	0.42358	0.0730286
260.000	0.42402	0.0712420
265.000	0.42444	0.0695312
270.000	0.42486	0.0678918
275.000	0.42526	0.0663195
280.000	0.42566	0.0648105
285.000	0.42605	0.0633611
290.000	0.42642	0.0619681
295.000	0.42679	0.0606284
300.000	0.42716	0.0593391

Figure III-11. Curve Fit of the Normalized Deformation Rate Data, Station 67+95

Figure III-12. Curve Fit of the Deformation Data, Station 67+95

ATTACHMENT IV

**ILLUSTRATIVE CALCULATION OF CONVERGENCE USING NUMERICAL
INTEGRATION OF CONVERGENCE RATES**

This attachment provides an example for the calculation of the complete convergence using numerical integration of the convergence rates. This process is illustrated by the example of Station 31+02.

Numerical integration was conducted in the EXCEL spreadsheet. For the accuracy of the integration, normalized convergence rates at time interval of 0.05 day for the period between 10 days before excavation and 5 days after excavation were calculated using the program CONRATE. Convergence rate was then obtained from multiplying the normalized convergence rate to the monitored maximum convergence rate (5.71 mm/yr or 0.0157 mm/day). Convergence increment was calculated by multiplying the convergence rate to the time interval using the central difference scheme. Finally, the convergence was obtained by summing up the convergence increments.

Table IV-1 lists the calculation spreadsheet of Station 31+02 for the numerical integration. Column 1 is the time with reference to the day of excavation. Column 2 lists the normalized convergence rate calculated from program CONRATE. Column 3 includes the regular convergence rate (normalized convergence rate $\times$ 0.0157). Columns 4 and 5 are the convergence increment and the convergence.

Table IV-1. Spreadsheet for Calculation of the Complete Convergence Using Numerical Integration

Time (days)	Normalized Convergence Rate	Convergence Rate (mm/day)	Convergence Increment (mm)	Convergence (mm)
-9.95	0.04635	0.00073	0.00004	0.00004
-9.9	0.04663	0.00073	0.00004	0.00007
-9.85	0.04692	0.00073	0.00004	0.00011
-9.8	0.04722	0.00074	0.00004	0.00015
-9.75	0.04753	0.00074	0.00004	0.00018
-9.7	0.04784	0.00075	0.00004	0.00022
-9.65	0.04816	0.00075	0.00004	0.00026
-9.6	0.04849	0.00076	0.00004	0.00030
-9.55	0.04883	0.00076	0.00004	0.00033
-9.5	0.04917	0.00077	0.00004	0.00037
-9.45	0.04952	0.00078	0.00004	0.00041
-9.4	0.04988	0.00078	0.00004	0.00045
-9.35	0.05025	0.00079	0.00004	0.00049
-9.3	0.05063	0.00079	0.00004	0.00053
-9.25	0.05102	0.00080	0.00004	0.00057
-9.2	0.05141	0.00080	0.00004	0.00061
-9.15	0.05181	0.00081	0.00004	0.00065
-9.1	0.05223	0.00082	0.00004	0.00069
-9.05	0.05265	0.00082	0.00004	0.00073
-9	0.05308	0.00083	0.00004	0.00077
-8.95	0.05352	0.00084	0.00004	0.00082
-8.9	0.05398	0.00084	0.00004	0.00086
-8.85	0.05444	0.00085	0.00004	0.00090
-8.8	0.05491	0.00086	0.00004	0.00094
-8.75	0.05539	0.00087	0.00004	0.00099
-8.7	0.05589	0.00087	0.00004	0.00103
-8.65	0.05639	0.00088	0.00004	0.00108
-8.6	0.05691	0.00089	0.00004	0.00112
-8.55	0.05743	0.00090	0.00004	0.00116
-8.5	0.05797	0.00091	0.00005	0.00121
-8.45	0.05852	0.00092	0.00005	0.00126
-8.4	0.05909	0.00092	0.00005	0.00130
-8.35	0.05966	0.00093	0.00005	0.00135
-8.3	0.06025	0.00094	0.00005	0.00140
-8.25	0.06085	0.00095	0.00005	0.00144
-8.2	0.06147	0.00096	0.00005	0.00149
-8.15	0.06210	0.00097	0.00005	0.00154
-8.1	0.06274	0.00098	0.00005	0.00159
-8.05	0.06340	0.00099	0.00005	0.00164
-8	0.06407	0.00100	0.00005	0.00169
-7.95	0.06475	0.00101	0.00005	0.00174
-7.9	0.06546	0.00102	0.00005	0.00179
-7.85	0.06617	0.00104	0.00005	0.00184

Table IV-1. Spreadsheet for Calculation of the Complete Convergence Using Numerical Integration (Continued)

Time (days)	Normalized Convergence Rate	Convergence Rate (mm/day)	Convergence Increment (mm)	Convergence (mm)
-7.8	0.06691	0.00105	0.00005	0.00190
-7.75	0.06766	0.00106	0.00005	0.00195
-7.7	0.06843	0.00107	0.00005	0.00200
-7.65	0.06921	0.00108	0.00005	0.00206
-7.6	0.07001	0.00110	0.00005	0.00211
-7.55	0.07083	0.00111	0.00006	0.00217
-7.5	0.07167	0.00112	0.00006	0.00222
-7.45	0.07253	0.00114	0.00006	0.00228
-7.4	0.07341	0.00115	0.00006	0.00234
-7.35	0.07431	0.00116	0.00006	0.00239
-7.3	0.07523	0.00118	0.00006	0.00245
-7.25	0.07617	0.00119	0.00006	0.00251
-7.2	0.07713	0.00121	0.00006	0.00257
-7.15	0.07812	0.00122	0.00006	0.00263
-7.1	0.07913	0.00124	0.00006	0.00270
-7.05	0.08016	0.00125	0.00006	0.00276
-7	0.08122	0.00127	0.00006	0.00282
-6.95	0.08230	0.00129	0.00006	0.00289
-6.9	0.08341	0.00131	0.00007	0.00295
-6.85	0.08454	0.00132	0.00007	0.00302
-6.8	0.08571	0.00134	0.00007	0.00309
-6.75	0.08690	0.00136	0.00007	0.00315
-6.7	0.08812	0.00138	0.00007	0.00322
-6.65	0.08937	0.00140	0.00007	0.00329
-6.6	0.09065	0.00142	0.00007	0.00336
-6.55	0.09196	0.00144	0.00007	0.00344
-6.5	0.09331	0.00146	0.00007	0.00351
-6.45	0.09469	0.00148	0.00007	0.00358
-6.4	0.09610	0.00150	0.00008	0.00366
-6.35	0.09755	0.00153	0.00008	0.00373
-6.3	0.09904	0.00155	0.00008	0.00381
-6.25	0.10056	0.00157	0.00008	0.00389
-6.2	0.10213	0.00160	0.00008	0.00397
-6.15	0.10373	0.00162	0.00008	0.00405
-6.1	0.10538	0.00165	0.00008	0.00413
-6.05	0.10707	0.00168	0.00008	0.00422
-6	0.10881	0.00170	0.00009	0.00430
-5.95	0.11059	0.00173	0.00009	0.00439
-5.9	0.11242	0.00176	0.00009	0.00448
-5.85	0.11430	0.00179	0.00009	0.00457
-5.8	0.11623	0.00182	0.00009	0.00466
-5.75	0.11822	0.00185	0.00009	0.00475
-5.7	0.12026	0.00188	0.00009	0.00484

Table IV-1. Spreadsheet for Calculation of the Complete Convergence Using Numerical Integration (Continued)

Time (days)	Normalized Convergence Rate	Convergence Rate (mm/day)	Convergence Increment (mm)	Convergence (mm)
-5.65	0.12236	0.00192	0.00010	0.00494
-5.6	0.12451	0.00195	0.00010	0.00504
-5.55	0.12673	0.00198	0.00010	0.00514
-5.5	0.12901	0.00202	0.00010	0.00524
-5.45	0.13136	0.00206	0.00010	0.00534
-5.4	0.13377	0.00209	0.00010	0.00545
-5.35	0.13626	0.00213	0.00011	0.00555
-5.3	0.13881	0.00217	0.00011	0.00566
-5.25	0.14145	0.00221	0.00011	0.00577
-5.2	0.14416	0.00226	0.00011	0.00588
-5.15	0.14696	0.00230	0.00012	0.00600
-5.1	0.14984	0.00235	0.00012	0.00612
-5.05	0.15280	0.00239	0.00012	0.00624
-5	0.15587	0.00244	0.00012	0.00636
-4.95	0.15902	0.00249	0.00012	0.00648
-4.9	0.16228	0.00254	0.00013	0.00661
-4.85	0.16564	0.00259	0.00013	0.00674
-4.8	0.16911	0.00265	0.00013	0.00687
-4.75	0.17269	0.00270	0.00014	0.00701
-4.7	0.17639	0.00276	0.00014	0.00715
-4.65	0.18021	0.00282	0.00014	0.00729
-4.6	0.18416	0.00288	0.00014	0.00743
-4.55	0.18824	0.00295	0.00015	0.00758
-4.5	0.19246	0.00301	0.00015	0.00773
-4.45	0.19683	0.00308	0.00015	0.00788
-4.4	0.20134	0.00315	0.00016	0.00804
-4.35	0.20602	0.00322	0.00016	0.00820
-4.3	0.21086	0.00330	0.00017	0.00837
-4.25	0.21588	0.00338	0.00017	0.00854
-4.2	0.22108	0.00346	0.00017	0.00871
-4.15	0.22647	0.00354	0.00018	0.00889
-4.1	0.23206	0.00363	0.00018	0.00907
-4.05	0.23786	0.00372	0.00019	0.00925
-4	0.24387	0.00382	0.00019	0.00944
-3.95	0.25012	0.00392	0.00020	0.00964
-3.9	0.25661	0.00402	0.00020	0.00984
-3.85	0.26336	0.00412	0.00021	0.01005
-3.8	0.27038	0.00423	0.00021	0.01026
-3.75	0.27767	0.00435	0.00022	0.01048
-3.7	0.28527	0.00447	0.00022	0.01070
-3.65	0.29317	0.00459	0.00023	0.01093
-3.6	0.30141	0.00472	0.00024	0.01116
-3.55	0.30999	0.00485	0.00024	0.01141

Table IV-1. Spreadsheet for Calculation of the Complete Convergence Using Numerical Integration (Continued)

Time (days)	Normalized Convergence Rate	Convergence Rate (mm/day)	Convergence Increment (mm)	Convergence (mm)
-3.5	0.31894	0.00499	0.00025	0.01166
-3.45	0.32828	0.00514	0.00026	0.01191
-3.4	0.33803	0.00529	0.00026	0.01218
-3.35	0.34822	0.00545	0.00027	0.01245
-3.3	0.35886	0.00562	0.00028	0.01273
-3.25	0.37000	0.00579	0.00029	0.01302
-3.2	0.38165	0.00597	0.00030	0.01332
-3.15	0.39384	0.00616	0.00031	0.01363
-3.1	0.40662	0.00636	0.00032	0.01395
-3.05	0.42003	0.00657	0.00033	0.01427
-3	0.43409	0.00679	0.00034	0.01461
-2.95	0.44885	0.00703	0.00035	0.01497
-2.9	0.46437	0.00727	0.00036	0.01533
-2.85	0.48068	0.00752	0.00038	0.01571
-2.8	0.49785	0.00779	0.00039	0.01610
-2.75	0.51593	0.00808	0.00040	0.01650
-2.7	0.53499	0.00837	0.00042	0.01692
-2.65	0.55511	0.00869	0.00043	0.01735
-2.6	0.57635	0.00902	0.00045	0.01780
-2.55	0.59880	0.00937	0.00047	0.01827
-2.5	0.62255	0.00974	0.00049	0.01876
-2.45	0.64771	0.01014	0.00051	0.01927
-2.4	0.67438	0.01056	0.00053	0.01979
-2.35	0.70269	0.01100	0.00055	0.02034
-2.3	0.73276	0.01147	0.00057	0.02092
-2.25	0.76476	0.01197	0.00060	0.02152
-2.2	0.79883	0.01250	0.00063	0.02214
-2.15	0.83516	0.01307	0.00065	0.02279
-2.1	0.87396	0.01368	0.00068	0.02348
-2.05	0.91544	0.01433	0.00072	0.02420
-2	0.95985	0.01502	0.00075	0.02495
-1.95	1.00748	0.01577	0.00079	0.02573
-1.9	1.05863	0.01657	0.00083	0.02656
-1.85	1.11364	0.01743	0.00087	0.02744
-1.8	1.17293	0.01836	0.00092	0.02835
-1.75	1.23692	0.01936	0.00097	0.02932
-1.7	1.30612	0.02044	0.00102	0.03034
-1.65	1.38110	0.02162	0.00108	0.03142
-1.6	1.46251	0.02289	0.00114	0.03257
-1.55	1.55109	0.02428	0.00121	0.03378
-1.5	1.64769	0.02579	0.00129	0.03507
-1.45	1.75330	0.02744	0.00137	0.03644
-1.4	1.86905	0.02926	0.00146	0.03791

Table IV-1. Spreadsheet for Calculation of the Complete Convergence Using Numerical Integration (Continued)

Time (days)	Normalized Convergence Rate	Convergence Rate (mm/day)	Convergence Increment (mm)	Convergence (mm)
-1.35	1.99624	0.03125	0.00156	0.03947
-1.3	2.13642	0.03344	0.00167	0.04114
-1.25	2.29137	0.03587	0.00179	0.04294
-1.2	2.46321	0.03856	0.00193	0.04486
-1.15	2.65443	0.04155	0.00208	0.04694
-1.1	2.86800	0.04489	0.00224	0.04919
-1.05	3.10748	0.04864	0.00243	0.05162
-1	3.37715	0.05286	0.00264	0.05426
-0.95	3.68220	0.05764	0.00288	0.05714
-0.9	4.02898	0.06307	0.00315	0.06030
-0.85	4.42530	0.06927	0.00346	0.06376
-0.8	4.88088	0.07640	0.00382	0.06758
-0.75	5.40791	0.08465	0.00423	0.07181
-0.7	6.02182	0.09426	0.00471	0.07652
-0.65	6.74241	0.10554	0.00528	0.08180
-0.6	7.59539	0.11889	0.00594	0.08775
-0.55	8.61458	0.13484	0.00674	0.09449
-0.5	9.84519	0.15411	0.00771	0.10219
-0.45	11.34870	0.17764	0.00888	0.11108
-0.4	13.21034	0.20678	0.01034	0.12141
-0.35	15.55094	0.24342	0.01217	0.13359
-0.3	18.54612	0.29030	0.01452	0.14810
-0.25	22.45875	0.35155	0.01758	0.16568
-0.2	27.69605	0.43353	0.02168	0.18735
-0.15	34.91505	0.54653	0.02733	0.21468
-0.1	45.22934	0.70797	0.03540	0.25008
-0.05	60.64479	0.94927	0.04746	0.29754
0	379.22839	5.93606	0.29680	0.59435
0.05	241.05847	3.77329	0.18866	0.78301
0.1	163.26314	2.55556	0.12778	0.91079
0.15	116.14590	1.81803	0.09090	1.00169
0.2	85.95132	1.34540	0.06727	1.06896
0.25	65.71023	1.02856	0.05143	1.12039
0.3	51.63332	0.80822	0.04041	1.16080
0.35	41.53912	0.65021	0.03251	1.19331
0.4	34.11097	0.53394	0.02670	1.22001
0.45	28.52208	0.44646	0.02232	1.24233
0.5	24.23532	0.37936	0.01897	1.26130
0.55	20.89140	0.32701	0.01635	1.27765
0.6	18.24380	0.28557	0.01428	1.29193
0.65	16.11951	0.25232	0.01262	1.30454
0.7	14.39468	0.22532	0.01127	1.31581
0.75	12.97905	0.20316	0.01016	1.32597

Table IV-1. Spreadsheet for Calculation of the Complete Convergence Using Numerical Integration (Continued)

Time (days)	Normalized Convergence Rate	Convergence Rate (mm/day)	Convergence Increment (mm)	Convergence (mm)
0.8	11.80580	0.18480	0.00924	1.33521
0.85	10.82472	0.16944	0.00847	1.34368
0.9	9.99760	0.15649	0.00782	1.35150
0.95	9.29501	0.14549	0.00727	1.35878
1	8.69401	0.13609	0.00680	1.36558
1.05	8.17658	0.12799	0.00640	1.37198
1.1	7.72839	0.12097	0.00605	1.37803
1.15	7.33799	0.11486	0.00574	1.38377
1.2	6.99610	0.10951	0.00548	1.38925
1.25	6.69520	0.10480	0.00524	1.39449
1.3	6.42912	0.10063	0.00503	1.39952
1.35	6.19278	0.09694	0.00485	1.40437
1.4	5.98196	0.09364	0.00468	1.40905
1.45	5.79314	0.09068	0.00453	1.41358
1.5	5.62339	0.08802	0.00440	1.41798
1.55	5.47020	0.08563	0.00428	1.42226
1.6	5.33149	0.08345	0.00417	1.42644
1.65	5.20545	0.08148	0.00407	1.43051
1.7	5.09055	0.07968	0.00398	1.43450
1.75	4.98549	0.07804	0.00390	1.43840
1.8	4.88914	0.07653	0.00383	1.44222
1.85	4.80051	0.07514	0.00376	1.44598
1.9	4.71876	0.07386	0.00369	1.44967
1.95	4.64316	0.07268	0.00363	1.45331
2	4.57306	0.07158	0.00358	1.45689
2.05	4.50789	0.07056	0.00353	1.46041
2.1	4.44717	0.06961	0.00348	1.46390
2.15	4.39045	0.06872	0.00344	1.46733
2.2	4.33735	0.06789	0.00339	1.47073
2.25	4.28753	0.06711	0.00336	1.47408
2.3	4.24069	0.06638	0.00332	1.47740
2.35	4.19656	0.06569	0.00328	1.48069
2.4	4.15490	0.06504	0.00325	1.48394
2.45	4.11549	0.06442	0.00322	1.48716
2.5	4.07814	0.06384	0.00319	1.49035
2.55	4.04269	0.06328	0.00316	1.49351
2.6	4.00896	0.06275	0.00314	1.49665
2.65	3.97684	0.06225	0.00311	1.49976
2.7	3.94618	0.06177	0.00309	1.50285
2.75	3.91688	0.06131	0.00307	1.50592
2.8	3.88884	0.06087	0.00304	1.50896
2.85	3.86195	0.06045	0.00302	1.51198
2.9	3.83614	0.06005	0.00300	1.51499

Table IV-1. Spreadsheet for Calculation of the Complete Convergence Using Numerical Integration (Continued)

Time (days)	Normalized Convergence Rate	Convergence Rate (mm/day)	Convergence Increment (mm)	Convergence (mm)
2.95	3.81132	0.05966	0.00298	1.51797
3	3.78743	0.05928	0.00296	1.52093
3.05	3.76441	0.05892	0.00295	1.52388
3.1	3.74219	0.05858	0.00293	1.52681
3.15	3.72072	0.05824	0.00291	1.52972
3.2	3.69994	0.05792	0.00290	1.53262
3.25	3.67983	0.05760	0.00288	1.53550
3.3	3.66033	0.05730	0.00286	1.53836
3.35	3.64140	0.05700	0.00285	1.54121
3.4	3.62302	0.05671	0.00284	1.54405
3.45	3.60514	0.05643	0.00282	1.54687
3.5	3.58774	0.05616	0.00281	1.54968
3.55	3.57079	0.05589	0.00279	1.55247
3.6	3.55426	0.05563	0.00278	1.55525
3.65	3.53814	0.05538	0.00277	1.55802
3.7	3.52240	0.05514	0.00276	1.56078
3.75	3.50701	0.05490	0.00274	1.56352
3.8	3.49196	0.05466	0.00273	1.56626
3.85	3.47724	0.05443	0.00272	1.56898
3.9	3.46282	0.05420	0.00271	1.57169
3.95	3.44869	0.05398	0.00270	1.57439
4	3.43483	0.05377	0.00269	1.57708
4.05	3.42124	0.05355	0.00268	1.57975
4.1	3.40789	0.05334	0.00267	1.58242
4.15	3.39479	0.05314	0.00266	1.58508
4.2	3.38191	0.05294	0.00265	1.58772
4.25	3.36925	0.05274	0.00264	1.59036
4.3	3.35680	0.05254	0.00263	1.59299
4.35	3.34454	0.05235	0.00262	1.59561
4.4	3.33247	0.05216	0.00261	1.59821
4.45	3.32059	0.05198	0.00260	1.60081
4.5	3.30888	0.05179	0.00259	1.60340
4.55	3.29734	0.05161	0.00258	1.60598
4.6	3.28596	0.05144	0.00257	1.60855
4.65	3.27473	0.05126	0.00256	1.61112
4.7	3.26365	0.05109	0.00255	1.61367
4.75	3.25271	0.05091	0.00255	1.61622
4.8	3.24192	0.05075	0.00254	1.61876
4.85	3.23125	0.05058	0.00253	1.62128
4.9	3.22072	0.05041	0.00252	1.62380
4.95	3.21030	0.05025	0.00251	1.62632
5	2.01982	0.03162	0.00158	1.62790
10	1.69645	0.02655	0.13277	1.76067

Table IV-1. Spreadsheet for Calculation of the Complete Convergence Using Numerical Integration (Continued)

Time (days)	Normalized Convergence Rate	Convergence Rate (mm/day)	Convergence Increment (mm)	Convergence (mm)
15	1.45504	0.02278	0.11388	1.87455
20	1.26854	0.01986	0.09928	1.97383
25	1.12058	0.01754	0.08770	2.06153
30	1.00065	0.01566	0.07832	2.13985
35	0.90171	0.01411	0.07057	2.21042
40	0.81886	0.01282	0.06409	2.27451
45	0.74859	0.01172	0.05859	2.33310
50	0.68833	0.01077	0.05387	2.38697
55	0.63616	0.00996	0.04979	2.43676
60	0.59059	0.00924	0.04622	2.48298
65	0.55050	0.00862	0.04308	2.52607
70	0.51498	0.00806	0.04031	2.56637
75	0.48333	0.00757	0.03783	2.60420
80	0.45496	0.00712	0.03561	2.63981
85	0.42941	0.00672	0.03361	2.67342
90	0.40630	0.00636	0.03180	2.70522
95	0.38530	0.00603	0.03016	2.73537
100	0.36614	0.00573	0.02866	2.76403
105	0.34861	0.00546	0.02728	2.79131
110	0.33251	0.00520	0.02602	2.81733
115	0.31768	0.00497	0.02486	2.84220
120	0.30398	0.00476	0.02379	2.86599
125	0.29130	0.00456	0.02280	2.88879
130	0.27952	0.00438	0.02188	2.91066
135	0.26856	0.00420	0.02102	2.93168
140	0.25833	0.00404	0.02022	2.95190
145	0.24878	0.00389	0.01947	2.97137
150	0.23983	0.00375	0.01877	2.99014
155	0.23144	0.00362	0.01811	3.00826
160	0.22355	0.00350	0.01750	3.02575
165	0.21613	0.00338	0.01692	3.04267
170	0.20913	0.00327	0.01637	3.05904
175	0.20252	0.00317	0.01585	3.07489
180	0.19628	0.00307	0.01536	3.09025
185	0.19036	0.00298	0.01490	3.10515
190	0.18476	0.00289	0.01446	3.11961
195	0.17944	0.00281	0.01404	3.13365
200	0.17438	0.00273	0.01365	3.14730
205	0.16958	0.00265	0.01327	3.16057
210	0.16500	0.00258	0.01291	3.17348
215	0.16063	0.00251	0.01257	3.18606
220	0.15647	0.00245	0.01225	3.19830
225	0.15249	0.00239	0.01193	3.21024

Table IV-1. Spreadsheet for Calculation of the Complete Convergence Using Numerical Integration (Continued)

Time (days)	Normalized Convergence Rate	Convergence Rate (mm/day)	Convergence Increment (mm)	Convergence (mm)
230	0.14869	0.00233	0.01164	3.22187
235	0.14505	0.00227	0.01135	3.23323
240	0.14157	0.00222	0.01108	3.24431
245	0.13823	0.00216	0.01082	3.25513
250	0.13503	0.00211	0.01057	3.26569
255	0.13196	0.00207	0.01033	3.27602
260	0.12901	0.00202	0.01010	3.28612
265	0.12617	0.00198	0.00988	3.29599
270	0.12345	0.00193	0.00966	3.30566
275	0.12082	0.00189	0.00946	3.31511
280	0.11829	0.00185	0.00926	3.32437
285	0.11586	0.00181	0.00907	3.33344
290	0.11351	0.00178	0.00888	3.34232
295	0.11125	0.00174	0.00871	3.35103
300	0.10906	0.00171	0.00854	3.35956
305	0.10695	0.00167	0.00837	3.36793
310	0.10491	0.00164	0.00821	3.37614
315	0.10293	0.00161	0.00806	3.38420
320	0.10103	0.00158	0.00791	3.39211
325	0.09918	0.00155	0.00776	3.39987
330	0.09739	0.00152	0.00762	3.40749
335	0.09566	0.00150	0.00749	3.41498
340	0.09398	0.00147	0.00736	3.42234
345	0.09236	0.00145	0.00723	3.42956
350	0.09078	0.00142	0.00711	3.43667
355	0.08925	0.00140	0.00699	3.44365
360	0.08777	0.00137	0.00687	3.45052
365	0.08632	0.00135	0.00676	3.45728
370	0.08492	0.00133	0.00665	3.46393
375	0.08356	0.00131	0.00654	3.47047
380	0.08224	0.00129	0.00644	3.47690
385	0.08095	0.00127	0.00634	3.48324
390	0.07970	0.00125	0.00624	3.48948
395	0.07849	0.00123	0.00614	3.49562
400	0.07730	0.00121	0.00605	3.50167
405	0.07615	0.00119	0.00596	3.50763
410	0.07502	0.00117	0.00587	3.51350
415	0.07393	0.00116	0.00579	3.51929
420	0.07286	0.00114	0.00570	3.52499
425	0.07182	0.00112	0.00562	3.53061
430	0.07081	0.00111	0.00554	3.53615
435	0.06982	0.00109	0.00546	3.54162
440	0.06886	0.00108	0.00539	3.54701

Table IV-1. Spreadsheet for Calculation of the Complete Convergence Using Numerical Integration (Continued)

Time (days)	Normalized Convergence Rate	Convergence Rate (mm/day)	Convergence Increment (mm)	Convergence (mm)
445	0.06792	0.00106	0.00532	3.55232
450	0.06700	0.00105	0.00524	3.55757
455	0.06610	0.00103	0.00517	3.56274
460	0.06522	0.00102	0.00510	3.56784
465	0.06437	0.00101	0.00504	3.57288
470	0.06353	0.00099	0.00497	3.57785
475	0.06272	0.00098	0.00491	3.58276
480	0.06192	0.00097	0.00485	3.58761
485	0.06114	0.00096	0.00478	3.59239
490	0.06037	0.00095	0.00473	3.59712
495	0.05963	0.00093	0.00467	3.60178
500	0.05889	0.00092	0.00461	3.60639
505	0.05818	0.00091	0.00455	3.61095
510	0.05748	0.00090	0.00450	3.61545
515	0.05679	0.00089	0.00445	3.61989
520	0.05612	0.00088	0.00439	3.62428
525	0.05547	0.00087	0.00434	3.62862
530	0.05482	0.00086	0.00429	3.63292
535	0.05419	0.00085	0.00424	3.63716
540	0.05357	0.00084	0.00419	3.64135
545	0.05297	0.00083	0.00415	3.64550
550	0.05238	0.00082	0.00410	3.64959
555	0.05179	0.00081	0.00405	3.65365
560	0.05122	0.00080	0.00401	3.65766
565	0.05066	0.00079	0.00397	3.66162
570	0.05011	0.00078	0.00392	3.66554
575	0.04958	0.00078	0.00388	3.66942

ATTACHMENT V

FLAC ANALYSIS TO OBTAIN THE GF VALUE

This attachment provides the description of FLAC analysis to obtain the GF value. GF, the ratio between the roof deformation and the average convergence, was used to calculate the rock mass modulus of deformation described in Section 7.4.

A half-symmetry circular hole mesh was constructed for elastic analysis. The mesh was presented in Figure V-1. The left boundary was fixed in the horizontal direction for symmetry. The right and bottom boundaries were also fixed to simulate the far field. The top boundary is a pressure boundary which account for the depth of the excavation level. The ratio of horizontal stress to vertical stress (k) is set as 0.5. A lithostatic-equivalent pressure was applied at the perimeter of the circular opening for the in situ consolidation stage.

Figure V-2 shows the displacement field for the surrounding rock from FLAC analysis. A Fish routine was written to calculate the value of GF from the computed nodal point displacements at the perimeter of the opening. This routine is included in the input file GF-CAL.DAT. The calculated GF value from this analysis is 0.715. The input file and output printout are listed in the following.

Figure V-1. FLAC Mesh for Deformation Analysis

Figure V-2. Deformation Around the Circular Opening

FLAC Input File Listing (File Name: GF-CAL.DAT)

```

* -----
*
*  FLAC ANALYSIS FOR GF CALCULATION
*
* -----
*
gr 35 32
m e
*
; -----
; FISH Subroutine SQ_HOLE.FIS to create a Half-symmetry hole mesh
; each grid point is defined by its polar coordinates ALFA and RO
; The mesh is circular around the opening and its edges are square
; Modification of the Subroutine Listed in the FLAC User's Manual
; by Marek Mrugala (702) 295-4264
; -----
; RMAXIT = the maximum distance from the center for each ALFA
; RMIN    = radius of the excavation
; RMUL    = number of radii to the boundary
; RATIO   = grid's ratio
; Z_TH1   = thickness of elements in circular zone #1
; Z_TH2   = thickness of elements in circular zone #2
; N_ZE    = total number of layers in circular zones
; GAP     = thin ring generated for use in definition of the interface
; -----
def sq_hole.fis
; -----
loop j (1,jgp)
  alfa=-0.5*pi + (j-1)*pi/(jgp-1)
;
  if abs(alfa) <= .25*pi then
    rmaxit=rmin*rmul/cos(alfa)
  else
    rmaxit=rmin*rmul/sin(alfa)
  end_if
;
  rmaxit=abs(rmaxit)
;
  a_thick1 = 0.
  a_thick2 = 0.
  a_thick3 = 0.
  n_st     = n_ze+1
;
  loop i (1,igp)
    if i <= n_st then
      if i <= 3 then
        a_thick1=a_thick1+z_th1
        r_int1=rmin+a_thick1
        ro1=r_int1
        x(i,j)=ro1*cos(alfa)
        y(i,j)=ro1*sin(alfa)
      end_if
    end_if
  end_if
;

```

```

        if i = 4 then
            rmin1=ro1
            a_thick2=a_thick2+gap
            r_int=rmin1+a_thick2
            ro2=r_int
            x(i,j)=ro2*cos(alfa)
            y(i,j)=ro2*sin(alfa)
        end_if

;
        if i > 4 then
            rmin2=ro2
            a_thick3=a_thick3+z_th2
            r_int=rmin2+a_thick3
            ro3=r_int
            x(i,j)=ro3*cos(alfa)
            y(i,j)=ro3*sin(alfa)
        end_if
    else
;
        ro=ro3+(rmaxit-ro3)*(ratio^(i-n_st)-1)/(ratio^(igp-n_st)-1)
;
        x(i,j)=ro*cos(alfa)
        y(i,j)=ro*sin(alfa)
    end_if
end_loop
end_loop
end

;-----
; routine to calculate the applying equivalent pressure for excavation
;-----
def applypress

sigx = 2.55e6
sigy = 5.1e6

loop jc (1,jgp-1)

jc1=jc+1

theta = pi*(jc-1)/32.

if jc < 16 then
    apre =sigy*cos(theta)*cos(theta) + sigx*sin(theta)*sin(theta)
else
    apre =sigy*cos(pi-theta)*cos(pi-theta) + sigx*sin(pi-theta)*sin(pi-theta)
end_if

numb=string(apre)

dum=out(numb)

command

```

```

    apply press apre i=1 j=jc, jcl

end_command

end_loop
end

*
* -----
* Define the mesh geometry parameters
* -----
set rmin=3.8      ;Opening radius minus two inner layers & gap
set rmul=10       ;Outer model dimensions multiplier
set ratio=1.1
set z_th1=0.25    ;5in. thickness of one of the two inner layers
set gap=.25       ;Gap to be used in the Interface definition
set z_th2=.25     ;Thickness of circular layers surrounding the opening
set n_ze=20       ;Number of circular layers
* -----
*
sq_hole.fis

;+++++
*
* -----
* Add -245 m equal to the local depth and typical rock density of
* 2115 kg/m^3
* -----
*
ini y add -245.0
*
* -----
* Fix Boundary Conditions -----
*
fix x    i=1,36 j=1   ;Left Side Below Circle
fix x    i=1,36 j=33  ;Left Side - Above Circle
fix x    i=36 j=9,25 ;Right Side
fix x y  i=36 j=1,9   ;Model Bottom
* -----
* typical rock properties: bulk modulus: 3.72 GPa, shear modulus: 2.79 GPa
* -----
*
* Define the properties of the rock mass *****
prop bu=3.72e9 she=2.79e9 d=2115
*
* -----
* Apply Pressure on Model Top
* to Generate the Lithostatic Stress Field
* -----
*
apply press=4.326e6          i=36, j=25,33 ;pressure on model top
*
* -----
* Initial stress conditions, k=0.5

```

```
* -----
initial syy -5.841e6 var 0,1.515e6 j=1,33
initial sxx -2.920e6 var 0,0.757e6 j=1,33
initial szz -2.920e6 var 0,0.757e6 j=1,33
*
* -----
* Apply Pressure Inside the Opening to Simulate the Pre-Excavation Stage
* -----
applypress

*
set grav=9.81
*
set mech on
*
his unbal
his ydis i=1 j=33
*
his nstep=50

* -----
* In Situ Consolidation
* -----

step 1000

* -----

tit
Tunnel Deformation Analysis

* -----
* Displacements in Consolidation not Included in Calculation
* -----
ini xd 0
ini yd 0

* -----
* pressure set as 0 to simulate excavation
* -----
apply press=0 i=1

step 3000

save gfl.sav

* -----
* fish routine to calculate GF
* -----
def ratcon

tdc=0.

loop jc (1,jgp)
```

```
tdisp = sqrt(xdisp(1,jc)^2+ydisp(1,jc)^2)
```

```
section
```

```
    if jc = 1 then
        tdc= tdc+tdisp
        exit section
    end_if
```

```
    if jc = jgp then
        tdc= tdc+tdisp
        exit section
    end_if
```

```
    tdc=tdc+2*tdisp
```

```
end_section
```

```
end_loop
```

```
avgconv = tdc/(jgp-1)
```

```
tdisp1 = sqrt(xdisp(1,1)^2+ydisp(1,1)^2)
```

```
tdisp2 = sqrt(xdisp(1,jgp)^2+ydisp(1,jgp)^2)
```

```
cenconv = tdisp1+tdisp2
```

```
ratio = avgconv/cenconv
```

```
; output
```

```
str1 = ' * ----- *'
```

```
str2 = ' * Output from GF-CAL.DAT'
```

```
str3 = ' '
```

```
dum=out(str1)
```

```
dum=out(str2)
```

```
dum=out(str1)
```

```
dum=out(str3)
```

```
str4 = ' Convergence Measured from Roof and Floor: '
```

```
str4 = str4 + string(cenconv)
```

```
str5 = ' Average Convergence: '
```

```
str5 = str5 + string(avgconv)
```

```
dum=out(str4)
```

```
dum=out(str5)
```

```
str6 = ' GF = '
```

```
str6 = str6 + string(ratio)
```

```
dum=out(str3)
```

```
dum=out(str6)
```

```
end
```



```
Tunnel Deformation Analysis
From File : ratcon.fis
```

```
>ratcon
```

```
* ----- *
* Output from GF-CAL.DAT
* ----- *
```

```
Convergence Measured from Roof and Floor: 8.1047E-03
Average Convergence:                        5.7953E-03
```

```
GF = 7.1505E-01
```

```
>stop
```

Printout of the GF Calculation from Fish Routine RATCON