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This calculation is extensively revised in accordance with procedure *Calculations and Analyses* (EG-PRO-3DP-G04B-00037). All pages are affected.

This calculation supersedes the calculation previously issued under DI: 800-K0C-SSE0-00100-000-00B. In this calculation, in addition to editorial changes and some minor changes, the major changes are the analyses of emplacement drift stability using updated rock mass mechanical and thermal properties, examination of ground support response to seismic events with an annual probability of exceedance of 10^{-6}.

Branko Damjanac of Itasca Consulting Group, Inc. provided technical support presented in Section 6.11.

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DISCLAIMER

The calculations contained in this document were developed by Bechtel SAIC Company, LLC (BSC) and are intended solely for the use of BSC in its work for the Yucca Mountain Project.

CONTENTS

Page

1 PURPOSE 15

2 REFERENCES 16
2.1 PROCEDURES/DIRECTIVES 16
2.2 DESIGN INPUTS 16
2.3 DESIGN CONSTRAINTS 20
2.4 DESIGN OUTPUTS 20

3 ASSUMPTIONS 21
3.1 ASSUMPTIONS THAT REQUIRE VERIFICATION 21
3.1.1 Vendor Data 21
3.1.2 Concrete Block Properties for Numerical Rock Bolt Pull Test Simulation ... 21
3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION 21
3.2.1 Average Depth of Repository Host Horizon 21
3.2.2 Horizontal-to-Vertical In Situ Stress Ratios 22
3.2.3 Initial Ground Relaxation 22
3.2.4 Friction Angle of Lithophysal Rock 22
3.2.5 Tensile Strength of Lithophysal Rock 23
3.2.6 Rock Mass Coefficient of Thermal Expansion for Temperature Range of 20 – 25 ^{o}C 23

4 METHODOLOGY 24
4.1 QUALITY ASSURANCE 24
4.2 USE OF SOFTWARE 24
4.2.1 Level 1 Software Usage 24
4.2.2 Level 2 Software Usage 25
4.3 CALCULATION APPROACH 25
4.3.1 Empirical Methods 25
4.3.1.1 RMR System 25
4.3.1.2 Q System 27
4.3.1.3 Applicability of Empirical Methods 29
4.3.2 Analytical Methods 30
4.3.2.1 Modeling of Emplacement Drifts 30
4.3.2.2 Loading and Boundary Conditions 30
4.3.2.3 Evaluation of Factor of Safety 35
4.3.3 Uncertainties Associated with Design Inputs and Modeling 36

5 LIST OF ATTACHMENTS 37

6 BODY OF CALCULATION 38
6.1 GENERAL 38
6.1.1 Introduction 38
6.1.2 Input Parameters 38

CONTENTS (Continued)

Page

6.1.2.1 Time Histories of Rock Temperatures....38
6.1.2.2 Rock Thermal Properties....39
6.1.2.3 Rock Mass Mechanical Properties....40
6.1.2.4 Rock Mass Density....41
6.1.2.5 Properties of Swellex Rock Bolts....42
6.1.2.6 Seismic Velocity Histories....42
6.1.2.7 Emplacement Drift Configurations....42
6.2 REPOSITORY HOST HORIZON AND GEOTECHNICAL CHARACTERIZATION.... 44
6.3 GROUND SUPPORT FUNCTIONAL REQUIREMENTS.... 48
6.4 STABILITY OF UNSUPPORTED EMPLACEMENT DRIFTS.... 48
6.4.1 Temperature Increase in Rock....48
6.4.2 Rock Displacement and Stress....52
6.4.2.1 Drift Closures....52
6.4.2.2 Stresses in Rock Mass Adjacent to Drifts....60
6.4.3 Assessment of the Stability of Emplacement Drifts....67
6.4.3.1 Potential Yield Zone Around Emplacement Drifts....67
6.4.3.2 Factor of Safety of Emplacement Drifts....67
6.4.4 Ground Reaction Curves....78
6.5 EMPIRICAL ANALYSIS OF GROUND SUPPORT NEEDS.... 80
6.6 SELECTION OF GROUND SUPPORT METHODS.... 81
6.6.1 Candidate Ground Support Components and Materials....81
6.6.1.1 Friction-type Rock Bolts....82
6.6.1.2 Perforated Steel Sheets....84
6.6.1.3 Candidate Ground Support Materials....84
6.6.2 Candidate Ground Support Methods....85
6.6.2.1 Lithophysal Rock....85
6.6.2.2 Nonlithophysal Rock....85
6.6.3 Initial Ground Support Methods....86
6.7 EVALUATION OF GROUND SUPPORT PERFORMANCE.... 87
6.7.1 Numerical Calibration of Swellex Bolt Pull Test....87
6.7.2 Performance of Swellex Bolts in Emplacement Drifts....88
6.7.2.1 Swellex Bolts in Lithophysal Rock....89
6.7.2.2 Swellex Bolts in Nonlithophysal Rock....90
6.7.3 Performance of Bernold-type Steel Sheets....102
6.7.3.1 Estimate of Support Load....102
6.7.3.2 Estimate of Stress and Factor of Safety....105
6.7.4 Prevention of Rockfall by Ground Support....106
6.8 SENSITIVITY ANALYSIS.... 107
6.8.1 Sensitivity Study on Emplacement Drift Stability....107
6.8.2 Emplacement Drift Stability Under Seismic Event with an APE of 10^{-4}....116
6.8.2.1 Stability of Unsupported Emplacement Drifts....116
6.8.2.2 Performance of Rock Bolts in Emplacement Drifts....119

CONTENTS (Continued)

Page

6.9 UNCERTAINTY ASSOCIATED WITH CALCULATION METHODS 121
6.9.1 Continuum versus Discontinuum 121
6.9.2 Model Dimensions 121
6.10 EMPLACEMENT DRIFT STABILITY AT OFF-NORMAL TEMPERATURES. 122
6.10.1 Introduction 122
6.10.2 Time History of Rock Temperatures 123
6.10.3 Numerical Modeling Results 124
6.10.3.1 Drift Closures 124
6.10.3.2 Stresses in Rock Adjacent to Drifts 134
6.10.3.3 Potential Yield Zones and Factor of Safety Around Emplacement Drifts 143
6.10.3.4 Ground Support Performance 146
6.11 EXAMINATION OF GROUND SUPPORT RESPONSE TO SEISMIC EVENTS WITH AN APE OF 10^{-6} 153
6.11.1 Emplacement Drifts in the Lithophysal Rock 153
6.11.2 Emplacement Drifts in the Nonlithophysal Rock 154
6.11.3 Summary. 154
6.12 IMPACT OF MULTIPLE HEATING AND COOLING CYCLES 156

7 SUMMARY AND CONCLUSIONS 157

ATTACHMENT I LIST OF INPUT AND OUTPUT FILES 162

FIGURES

Page

Figure 4-1 Estimate Ground Support Needs Based on Q Index ... 29
Figure 4-2 Geometry and Boundary Conditions for FLAC Models ... 32
Figure 4-3 Time Histories of Rock Temperatures on Model Boundaries and Drift Wall ... 33
Figure 6-1 Time Histories of Velocity Components of Seismic Motion for Mean APE of 5×10^{-4} ... 43
Figure 6-2 Time Histories of Velocity Components of Seismic Motion for Mean APE of 1×10^{-4} ... 43
Figure 6-3 Current Underground Layout Configuration ... 45
Figure 6-4 Fractures in the Wall of the ECRB Cross Drift in the Tptpmn Unit ... 47
Figure 6-5 Lithophysae and Fracturing in the Tptpll Unit ... 47
Figure 6-6 Temperature Contours (°C) around Emplacement Drifts at Various Years Following Waste Emplacement at (a) initially, (b) 2 years, (c) 10 years, and (d) 50 years ... 50
Figure 6-7 Time Histories of Closures in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loads: (a) Ko=0.3; (b) Ko=1.0 ... 54
Figure 6-8 Time Histories of Closures in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loads: (a) Ko=0.3; (b) Ko=1.0 ... 55
Figure 6-9 Time Histories of Closures in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under Seismic Load at Year=0: (a) Category 1; (b) Category 5 ... 56
Figure 6-10 Time Histories of Closures in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under Seismic Load at Year=50: (a) Category 1; (b) Category 5 ... 57
Figure 6-11 Time Histories of Closures in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under Seismic Load at Year=0: (a) Category 1; (b) Category 5 ... 58
Figure 6-12 Time Histories of Closures in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under Seismic Load at Year=50: (a) Category 1; (b) Category 5 ... 59
Figure 6-13 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loads: (a) Ko=0.3; (b) Ko=1.0 ... 61
Figure 6-14 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loads: (a) Ko=0.3; (b) Ko=1.0 ... 62
Figure 6-15 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Loads (Year=0): (a) Ko=0.3; (b) Ko=1.0 ... 63
Figure 6-16 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ, Thermal, and Seismic Load (Year=50): (a) Ko=0.3; (b) Ko=1.0 ... 64

FIGURES (Continued)

Page

Figure 6-17 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Loads (Year=0): (a) Ko=0.3; (b) Ko=1.0 65
Figure 6-18 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ, Thermal, and Seismic Loads (Year=50): (a) Ko=0.3; (b) Ko=1.0 66
Figure 6-19 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Lithophysal Rock with Category 1 and Ko=0.3: (a) at 0 Year; (b) at 50 Years. 69
Figure 6-20 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Lithophysal Rock with Category 1 and Ko=1.0: (a) at 0 Year; (b) at 50 Years. 70
Figure 6-21 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Lithophysal Rock with Category 5 and Ko=0.3: (a) at 0 Year; (b) at 50 Years. 71
Figure 6-22 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Lithophysal Rock with Category 5 and Ko=1.0: (a) at 0 Year; (b) at 50 Years. 72
Figure 6-23 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Nonlithophysal Rock with Category 1 and Ko=0.3: (a) at 0 Year; (b) at 50 Years. 73
Figure 6-24 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Nonlithophysal Rock with Category 1 and Ko=1.0: (a) at 0 Year; (b) at 50 Years. 74
Figure 6-25 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Nonlithophysal Rock with Category 5 and Ko=0.3: (a) at 0 Year; (b) at 50 Years. 75
Figure 6-26 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Nonlithophysal Rock with Category 5 and Ko=1.0: (a) at 0 Year; (b) at 50 Years. 76
Figure 6-27 Average Factors of Safety for Unsupported Emplacement Drifts Under In Situ and Thermal Loads Based on STSR: (a) in Lithophysal Rock, (b) in Nonlithophysal Rock 77
Figure 6-28 Ground Reaction Curves for Unsupported Emplacement Drifts: (a) Lithophysal Rock; (b) Nonlithophysal Rock. 79
Figure 6-29 A Typical Split Set Rock Bolt 83
Figure 6-30 A Typical Swellex Rock Bolt 83
Figure 6-31 Bernold-type Perforated Steel Sheet 84
Figure 6-32 Ground Support Methods Recommended for Emplacement Drifts............ 87
Figure 6-33 Numerical Calibration of Super Swellex Bolt Pull Test............ 88
Figure 6-34 Axial Forces in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads: (a) K_o=0.3; (b) K_o=1.0 91

FIGURES (Continued)

Page

Figure 6-35 Distribution of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for Category 1 and K_o=0.3: (a) at 0 year (b) at 50 years ... 92
Figure 6-36 Distribution of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for Category 1 and K_o=1.0: (a) at 0 years (b) at 50 years ... 93
Figure 6-37 Distribution of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for Category 5 and K_o=0.3: (a) at 0 year (b) at 50 years ... 94
Figure 6-38 Distribution of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for Category 5 and K_o=1.0: (a) at 0 year (b) at 50 years ... 95
Figure 6-39 Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ, thermal and Seismic Loads for Category 1 and Ko=0.3: (a) Yr 0; (b) Yr 50. ... 96
Figure 6-40 Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ thermal and Seismic Loads for Category 1 and Ko=1.0: (a) Yr 0; (b) Yr 50. ... 97
Figure 6-41 Axial Forces in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads: (a) K_o=0.3; (b) K_o=1.0. ... 98
Figure 6-42 Distribution of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads for Category 1 and K_o=0.3: (a) at 0 years (b) at 50 years ... 99
Figure 6-43 Axial Forces (N) in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ thermal and Seismic Loads for Category 1 and Ko=0.3: (a) Yr 0; (b) Yr 50. ... 100
Figure 6-44 Axial Forces (N) in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ thermal and Seismic Loads for Category 1 and Ko=1.0: (a) Yr 0; (b) Yr 50. ... 101
Figure 6-45 Illustration of Potentially-loosened Rock on Periphery of an Emplacement Drift ... 103
Figure 6-46 Time Histories of Closures of Unsupported Emplacement Drifts under In Situ and Thermal Loads and Ko=0.5 in: (a) Lithophysal; (b) Nonlithophysal Rock ... 110
Figure 6-47 Time Histories of Closures of Unsupported Emplacement Drifts under Seismic Load and Ko=0.5 at Year 0 in: (a) Lithophysal; (b) Nonlithophysal Rock ... 111
Figure 6-48 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts under In Situ and Thermal Loads and Ko=0.5 in: (a) Lithophysal; (b) Nonlithophysal Rock ... 112
Figure 6-49 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts under Seismic Load and Ko=0.5 at Year 0 in: (a) Lithophysal; (b) Nonlithophysal Rock ... 113
Figure 6-50 Vertical Drift Closure vs Ko for (a) Lithophysal and (b) Nonlithophysal Rock .. 114

FIGURES (Continued)

Page

Figure 6-51 Maximum Principal Stress vs Ko for (a) Lithophysal and (b) Nonlithophysal Rock ... 115
Figure 6-52 Time Histories of Closures of Emplacement Drifts under Seismic Load at Year 0 and Ko=0.3 in (a) Lithophysal and (b) Nonlithophysal Category 1 Rock, ... 117
Figure 6-53 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts under In Situ, Thermal and Seismic Load at Year 0 and Ko=0.3 in (a) Lithophysal and (b) Nonlithophysal Category 1 Rock... 118
Figure 6-54 Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ, Thermal and Seismic Loads for Category 1 and Ko=0.3: (a) Yr 0; (b) Yr 50, ... 120
Figure 6-55 Time Histories of Drift Wall Temperature ... 123
Figure 6-56 Vertical and Horizontal Closures of Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loading for 50-Year Ventilation Scenario: (a) Ko = 0.3; (b) Ko = 1.0 ... 126
Figure 6-57 Vertical and Horizontal Closures of Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loading for 25-Year Ventilation Scenario: (a) Ko = 0.3; (b) Ko = 1.0 ... 127
Figure 6-58 Vertical and Horizontal Closures of Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loading for 50-Year Ventilation Scenario: (a) Ko = 0.3; (b) Ko = 1.0 ... 128
Figure 6-59 Vertical and Horizontal Closures of Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loading for 25-Year Ventilation Scenario: (a) Ko = 0.3; (b) Ko = 1.0 ... 129
Figure 6-60 Time Histories of Closures of Emplacement Drifts in Lithophysal Rock with Ko = 0.3 and Ko = 1.0 under Seismic Loading at Year 100 for 50-Year Ventilation Scenario: (a) Category 1; (b) Category 5 ... 130
Figure 6-61 Time Histories of Closures of Emplacement Drifts in Lithophysal Rock with Ko = 0.3 and Ko = 1.0 under Seismic Loading at Year 100 for 25-Year Ventilation Scenario: (a) Category 1; (b) Category 5 ... 131
Figure 6-62 Time Histories of Closures of Emplacement Drifts in Nonlithophysal Rock with Ko = 0.3 and Ko = 1.0 under Seismic Loading at Year 100 for 50-Year Ventilation Scenario: (a) Category 1; (b) Category 5 ... 132
Figure 6-63 Time Histories of Closures of Emplacement Drifts in Nonlithophysal Rock with Ko = 0.3 and Ko = 1.0 under Seismic Loading at Year 100 for 25-Year Ventilation Scenario: (a) Category 1; (b) Category 5 ... 133
Figure 6-64 Major Principal Stress near Springline and Crown of Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for 50-Year Ventilation Scenario for Categories 1 and 5: (a) Ko = 0.3; (b) Ko = 1.0 ... 135
Figure 6-65 Major Principal Stress near Springline and Crown of Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for 25-Year Ventilation Scenario for Categories 1 and 5: (a) Ko = 0.3; (b) Ko = 1.0 ... 136

FIGURES (Continued)

Page

Figure 6-66 Major Principal Stress near Springline and Crown of Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads for 50-Year Ventilation Scenario for Categories 1 and 5: (a) Ko = 0.3 (b) Ko = 1.0 137
Figure 6-67 Major Principal Stress near Springline and Crown of Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads for 25-Year Ventilation Scenario for Categories 1 and 5: (a) Ko = 0.3 (b) Ko = 1.0 138
Figure 6-68 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Load for 50-Year Ventilation Scenario: (a) Ko=0.3; (b) Ko=1.0 139
Figure 6-69 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Load for 25-Year Ventilation Scenario: (a) Ko=0.3; (b) Ko=1.0 140
Figure 6-70 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Load for 50-Year Ventilation Scenario: (a) Ko=0.3; (b) Ko=1.0 141
Figure 6-71 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Load for 25-Year Ventilation Scenario: (a) Ko=0.3; (b) Ko=1.0 142
Figure 6-72 Potential Yield Zones and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Lithophysal Rock with Category 1 and Ko = 0.3 at Year 100: (a) 50-year Ventilation Scenario; (b) 25-year Ventilation Scenario 144
Figure 6-73 Potential Yield Zones and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Nonlithophysal Rock with Category 1 and Ko = 0.3 at Year 100: (a) 50-year Ventilation Scenario; (b) 25-year Ventilation Scenario 145
Figure 6-74 Axial Forces in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for 50-Year Ventilation Scenario: (a) Ko = 0.3 ; (b) Ko = 1.0.............. 147
Figure 6-75 Axial Forces in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for 25-Year Ventilation Scenario: (a) Ko = 0.3 ; (b) Ko = 1.0.............. 148
Figure 6-76 Axial Forces in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads for 50-Year Ventilation Scenario: (a) Ko = 0.3 ; (b) Ko = 1.0.............. 149
Figure 6-77 Axial Forces in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads for 25-Year Ventilation Scenario: (a) Ko = 0.3 ; (b) Ko = 1.0.............. 150
Figure 6-78 Distributions of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loading for Category 1 and Ko

FIGURES (Continued)

Page

= 0.3 at 100 Years: (a) 50-Year Ventilation Scenario; (b) 25-Year Ventilation Scenario........ 151
Figure 6-79 Distributions of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loading for Cat. 5 and Ko = 0.3 at 100 Years: (a) 50-Year Ventilation Scenario; (b) 25-Year Ventilation Scenario........ 152
Figure 6-80 Stable Drift Profiles in Lithophysal Rock After Seismic Ground Motion at the 2.44 m/s PGV Level (or APE of 10-6 in Case of Unbounded Hazard Curve) 155

TABLES

Page

Table 4-1 Estimate of Ground Support Needs Based on RMR System 27
Table 5-1 List of Attachments 37
Table 6-1 Time Histories of Rock Temperatures 39
Table 6-2 Thermal Conductivity and Specific Heat of Lithophysal and Nonlithophysal Rocks 39
Table 6-3 Coefficients of Thermal Expansion for Lithophysal and Nonlithophysal Rocks 40
Table 6-4 Rock Mass Mechanical Properties for Lithophysal Rock at RHH 41
Table 6-5 Rock Mass Mechanical Properties for Nonlithophysal Rock at RHH 41
Table 6-6 Dimensions and Properties for Stainless Steel Super Swellex Rock Bolts 42
Table 6-7 Estimate of Ground Support Needs for Emplacement Drifts in Nonlithophysal Rock Based on RMR and Q Systems 81
Table 6-8 Estimated Stresses and Factors of Safety in Bernold-type Stainless Steel Sheets for Various Loading Conditions 105
Table 6-9 A Summary of Base Case Comparison 108
Table 6-10 Time Histories of Rock Temperatures for Off-normal Ventilation Scenarios 123

ACRONYMS AND ABBREVIATIONS

ANSYS ANSYS Computer Code
APE Annual Probability Exceedance
ASM American Society for Metals
ASTM American Society for Testing and Materials

BSC Bechtel SAIC Company, LLC.

CTE Coefficient of Thermal Expansion

DIRS Document Input Reference Sheet
DOE U.S. Department of Energy
DTN Data Tracking Number

ECRB Enhanced Characterization of the Repository Block
EDZ Excavation-disturbed Zone
ESF Exploratory Studies Facility
ESR Excavation Support Ratio

FLAC Fast Lagrangian Analysis of Continua

GRC Ground Reaction Curve

J_n Joint Set Number
J_r Joint Roughness Number
J_a Joint Alteration Number
J_w Joint Water Reduction Factor

IED Information Exchange Document

Ko Horizontal-to-vertical stress ratio

LA License Application

NGI Norwegian Geotechnical Institute

PGA Peak Ground Acceleration

Q Rock Mass Quality Index
QA Quality Assurance

RHH Repository Host Horizon
RMR Rock Mass Rating
RQD Rock Quality Designation

SC	Safety Category
SCM	Software Configuration Management
SRF	Stress Reduction Factor
STN	Software Tracking Number
STSR	Strength-to-stress Ratio
TBM	Tunnel Boring Machine
TDMS	Technical Data Management System
Tptpll	Topopah Spring Tuff crystal-poor lower lithophysal zone
Tptpln	Topopah Spring Tuff crystal-poor lower nonlithophysal zone
Tptpmn	Topopah Spring Tuff crystal-poor middle nonlithophysal zone
Tptpul	Topopah Spring Tuff crystal-poor upper lithophysal zone
TSPA	Total System Performance Assessment
TSw2	Topopah Spring welded, lithophysal-poor thermal-mechanical unit
YMP	Yucca Mountain Project

1 PURPOSE

The purpose of this calculation is to analyze the stability of repository emplacement drifts during the preclosure period, and to provide a final ground support method for emplacement drifts for the License Application (LA). This calculation will provide input for the development of LA documents.

The scope of the work includes determination of various input parameters, selection of appropriate process and methods for the calculation, application of selected methods, such as empirical or analytical, to the calculation, development and execution of numerical models, and evaluation of results. The calculation is limited to the emplacement drifts subjected to a combined loading of in-situ stress, seismic stress, and thermal stress. Other effects such as hydrological and chemical effects are not considered in this analysis.

Results from this calculation are limited to use for design of the emplacement drifts and the ground support system installed in these drifts. The design of non-emplacement openings and their ground support systems are not covered in this calculation.

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It should be noted that the use of Data Tracking Number (DTN): MO0306MWDALAFV.000 (Reference 2.2.43) has been approved by inclusion on the information exchange drawing, *IED Geotechnical and Thermal Parameters* (Reference 2.2.22). Similarly, DTNs: MO0306SDSAVDTH.000 (Reference 2.2.44) and MO0407TMHIS104.003 (Reference 2.2.45) are included in *IED Seismic Data* (Reference 2.2.24), and SNL02030193001.027 (Reference 2.2.48) is included in *IED Geotechnical and Thermal Parameters II* (Reference 2.2.23). DTN: MO0412MWDTCONS.000 and *Subsurface Geotechnical Parameters Report* (Reference 2.2.27) are owned by BSC Subsurface Organization and are not required to be included on the information exchange drawing. These data are qualified data and therefore are appropriate for use in this document. It should be noted that the data from MO0611ROCKFALL.000 (Reference 2.2.47) are unqualified, however, these are used indirectly for illustration purposes only.

2.3 DESIGN CONSTRAINTS

No design constraint.

2.4 DESIGN OUTPUTS

The design output of this calculation includes the initial and final ground support system for the emplacement drifts and will be used to revise drawing of *Typical Ground Support for Emplacement Drifts* (Reference 2.2.28).

3 ASSUMPTIONS

This section contains assumptions used in this calculation and the rationale for use.

3.1 ASSUMPTIONS THAT REQUIRE VERIFICATION

3.1.1 Vendor Data

Assumption: The following assumptions are made related to ground support components:

- The pull test data from Atlas Copco is assumed to be adequate for numerical pull test calibration in Section 6.7.1
- Dimension of stainless steel super Swellex-type rock bolt: 54 mm in diameter and 3 mm in thickness

Rational: The actual data for the stainless steel super Swellex-type rock bolt pull test information is not currently available. The above assumptions are based on the vendor data (References 2.2.30 and 2.2.6) and is considered appropriate for the purpose of this calculation.

The assumption in the first bullet is used in Section 6.7.1. The assumption in the second bullet is used in Table 6-6 and throughout in Section 6.

3.1.2 Concrete Block Properties for Numerical Rock Bolt Pull Test Simulation

Assumption: The concrete block properties for pull test in numerical simulation are 2.4 g/cm^3 for density, 60 MPa for compressive strength, and 0.15 for Poisson's ratio.

Rational: The actual data for the concrete block properties used in rock bolt pull test is not currently available. The above assumption is based on the data presented in Reference 2.2.40 (pp., 5 and 158). These values were selected in numerical simulation and is considered appropriate for the purpose of this calculation.

Used in Section 6.7.1.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Average Depth of Repository Host Horizon

Assumption: The average depth of repository host horizon (RHH) is assumed to be 400 m measured from the center of an emplacement drift.

Rationale: Depth of emplacement drifts varies from drift to drift, ranging approximately from 215 m to 450 m, and the majority is between 300 to 400 m (Reference 2.2.14, Section 4.2.1). Based on Table 6-67 of Reference 2.2.27, the maximum depth to Tptpll unit is 362.56 m based on the mapping data in Enhanced Characterization of the Repository Block (ECRB) Cross Drift. Note that the elevation of the Exploratory Studies Facility (ESF) main drift in the middle point between Stations 28+04.323 and 56+54.323 is at about 1,085 m (see Figure 3 of Reference 2.2.15) and the elevation of Station 16+02.05 m in ECRB Cross Drift is 1,106 m (Reference

2.2.15, p. 14). It shows that the emplacement drift level (i.e., about the same level of ESF main drift) is about 20 m below the ECRB Cross Drift in the area between Panels 1 and 2. Thus, the maximum depth to Tptpll unit is about 380 m in this emplacement area. In a scoping analysis on emplacement drift stability, it was indicated that the results for the maximum value of 450 m would be similar to those for the bounding case of 400 m (Reference 2.2.14, Section 4.2.1). Since the higher vertical stress will be induced with larger overburden depth, it is therefore, considered adequate to use this assumption, i.e., 400-m overburden depth for the purpose of this calculation. This assumption does not require verification..

Used in Section 6.

3.2.2 Horizontal-to-Vertical In Situ Stress Ratios

Assumption: The upper and lower bounds of horizontal-to-vertical in situ stress ratio (K_o) are assumed to be 1.0 and 0.3.

Rationale: According to the in situ stress measurement by hydraulic fracturing in a test hole located in the TSw2 unit, the minimum and maximum K_o values are 0.36 and 0.62 (Reference 2.2.31, pp. 1 and 15 of MOL.19970717.0008). The K_o values selected are considered bounding values and are adequate for the purpose of this calculation. This assumption does not require verification.

Used in Section 6.

3.2.3 Initial Ground Relaxation

Assumption: An initial ground relaxation value of 60 percent is assumed in the ground support analysis for rock bolts in emplacement drifts.

Rationale: The basis for use of this value is provided in the *Ground Control Methodology for Emplacement Drifts* (Reference 2.2.50, Table 6-1). This results in 40 percent of the pre-excavation in situ stress being imposed on the final ground support. This is conservative since the final ground support in the current configuration will not be installed until the tunnel boring machine (TBM) is switched to next drift. The initial ground relaxation is likely to be completed before the final support installed. This assumption does not require verification.

Used in Section 6.

3.2.4 Friction Angle of Lithophysal Rock

Assumption: A friction angle of 35 degrees is assumed for the lithophysal rock for the assessment of drift stability.

Rationale: The friction angles for typical rocks are generally much higher than 35 degrees based on Table 23 of Reference 2.2.41. Based on friction angles derived from numerical simulations on lithophysal rock mass (see Table 6.5-3 of Reference 2.2.17), the representative friction angle of lithophysal rock mass is about 35 degrees. Therefore, it is considered adequate to assume a friction angle of 35 degrees for the purpose of this calculation because the friction angle of 35 degrees is not only considered low for most rocks, it is also supported by the results of numerical simulations on the lithophysal rock mass. This assumption does not require verification.

Used in Section 6.

3.2.5 Tensile Strength of Lithophysal Rock

Assumption: Tensile strength is assumed to be one-tenths of the unconfined compressive strength of the lithophysal rock.

Rationale: The tensile strength value is typically considered by industry to be about one-tenths of the unconfined compressive strength. It is widely accepted by the industry and is considered adequate to make this assumption for the purpose of this calculation. This assumption does not require verification.

Used in Section 6.

3.2.6 Rock Mass Coefficient of Thermal Expansion for Temperature Range of 20 – 25 ^{o}C

Assumption: The rock mass coefficient of thermal expansion for nonlithophysal and lithophysal rocks for 20 – 25 ^{o}C is assumed to be equal to that for 25 – 50 ^{o}C as indicated in Table 6-3.

Rationale: There is no test data for the coefficient of thermal expansion (CTE) for 20 – 25 ^{o}C in Table 6-3. However, the CTE for 20 – 25 ^{o}C should be no greater than that for 25 – 50 ^{o}C. Therefore, it is conservative to make this assumption since a higher thermal stress will be induced with a higher coefficient of thermal expansion. This assumption does not require verification.

Used in Section 6.

4 METHODOLOGY

4.1 QUALITY ASSURANCE

The Q-List designates the ground control system for emplacement drifts as ‘not important to waste isolation’, and ‘not important to safety’, and the Safety Category (SC) is ‘Non-SC’ (Reference 2.2.18, p. A-11). However, this document is prepared with a QA:QA status since the Q-List designates the emplacement drifts as ‘important to waste isolation’, and ‘important to safety’, and the Safety Category is ‘SC’ (Reference 2.2.18, p. A-11).

The calculation is prepared per EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Reference 2.1.1). In addition, IT-PRO-0011, *Software Management* (Reference 2.1.2), is used for activities related to software usage.

4.2 USE OF SOFTWARE

All software documented in this section is appropriate for applications used in this calculation. The software is managed under IT-PRO-0011, *Software Management* (Reference 2.1.2), and was obtained from Software Configuration Management in accordance with IT-PRO-0011 (Reference 2.1.2).

4.2.1 Level 1 Software Usage

FLAC Version 4.0 (STN: 10167-4.0-00) is a two-dimensional explicit finite difference code which simulates the behavior of structures built of soil, rock, or other materials subjected to static, dynamic, and thermally-induced loads (Reference 2.2.38). Modeled materials respond to applied forces or boundary restraints according to prescribed linear or non-linear stress/strain laws and undergo plastic flow when a limiting yield condition is reached. FLAC is based upon a Lagrangian scheme that is well suited for large deflections and has been used primarily for analysis and design in mine engineering and underground construction. The explicit time-marching solution of the full equations of motion, including inertial terms, permits the analysis of progressive failure and collapse. A detailed discussion on the general features and fields of the FLAC computer software applications is presented in the user's manual (Reference 2.2.38).

FLAC was used in coupled thermomechanical and seismic analyses in this calculation. The validation test cases of Test 1, Test 3, Test 4, Test 5, and Test 7 documented in the Software Implementation Report for FLAC Version 4.0 (Reference 2.2.11, Table 2) support the application of mechanical, thermomechanical, and dynamic analyses conducted for this calculation. The input and output files generated by FLAC are listed in Attachment I and have been archived on two DVDs (Attachment II).

FLAC Version 4.0 (Reference 2.2.33) was obtained from the Software Configuration Management (SCM) in accordance with the IT-PRO-0011 procedure (Reference 2.1.2). FLAC is installed and run on stand-alone PCs with Windows 2000/NT 4.0 operating systems. FLAC Version 4.0 is qualified for use in design in accordance with the IT-PRO-0011 procedure (Reference 2.1.2). The software was appropriate for the applications used in this analysis, and used only within the range of validation, as specified in the software qualification documentation.

4.2.2 Level 2 Software Usage

Microsoft Excel 2000 (STN: 610236-2000-00) was used in displaying some of the FLAC results graphically and to perform simple conversions. In this application, results from the FLAC analyses were used as inputs, and outputs were charts. This is considered Level 2 Usage in accordance with IT-PRO-0011, *Software Management* (Reference 2.1.2).

Microsoft Excel 2000 was performed on personal computers with Windows 2000/NT 4.0 operating systems. All excel working files are included in Attachment I and have been archived on DVDs (Attachment II). The Excel computations were confirmed using hand calculations and by visual inspection.

4.3 CALCULATION APPROACH

Both empirical and analytical methods are employed in the design calculations. The empirical methods are primarily tools for assessing the needs for ground support of emplacement drifts as well as for its selection. Design issues such as personnel safety, constructability, and geologic mapping requirements are factored into the design of the ground support system. With the aid of computer modeling, the stability of the unsupported opening is analyzed further to assess the needs for ground support. Applicable thermal and seismic loads are considered in the design in addition to the in situ loading conditions. The ground support system recommended should either cover most ground conditions or else be adaptable to varying ground conditions. Its performance should be further analyzed using analytical methods to make sure that design requirements are met. Based on empirical estimates, design issues, and computer modeling results, the final ground support system is developed.

4.3.1 Empirical Methods

Two empirical methods used in the design calculation are Rock Mass Rating (RMR) classification system (Reference 2.2.9) and Rock Mass Quality (Q) system of Norwegian Geotechnical Institute (NGI) (Reference 2.2.7).

4.3.1.1 RMR System

The RMR system was developed by Bieniawski (Reference 2.2.9). This engineering classification of rock masses, especially evolved for rock engineering applications, provides a general RMR increasing with rock quality from 0 to 100. It is based upon the following six parameters:

- strength of the rock
- drill core quality or Rock Quality Designation (RQD)
- joint and fracture spacing
- joint conditions
- ground water conditions

- orientation of joints

These parameters not only are measurable in the field but can also be obtained from borings. Joints are the major factor in this classification system; four of the six parameters (RQD, joint spacing, joint conditions, and orientation of joints) are related to joint characteristics. Increments of rock mass rating corresponding to each parameter are summed to determine RMR.

The RMR values for various rock units at the RHH are generally available from the ECRB Cross Drift. In case these RMR values are not available, empirical correlation can be used to estimate RMR values based on known rock mass modulus. The empirical correlation used in this calculation is as follows (Reference 2.2.7, Eq. 8):

$$RMR = 40 \log E_m + 10 \quad \text{(Eq. 4-1)}$$

where E_m = rock mass modulus of deformation in GPa

Once the RMR values are determined, the rock mass quality for each rock unit considered can be judged based on the guidelines provided by Bieniawski (Reference 2.2.9, Tables 4.1 and 4.2). Recommendation for the excavation scheme and rock support needs can be made by following the guidelines presented in Table 4-1 (Reference 2.2.9, Table 4.4).

Details on how to apply the RMR classification system to the preliminary design of ground support for rock tunnels such as those in repository emplacement drifts can be found in the *Engineering Rock Mass Classifications* (Reference 2.2.9, Section 4).

Table 4-1 Estimate of Ground Support Needs Based on RMR System

Rock mass class	Excavation	Rock bolts (20 mm diameter, fully grouted)	Shotcrete	Steel sets
I - Very good rock *RMR*: 81-100	Full face, 3 m advance.	Generally no support required except spot bolting.		
II - Good rock *RMR*: 61-80	Full face , 1-1.5 m advance. Complete support 20 m from face.	Locally, bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh.	50 mm in crown where required.	None.
III - Fair rock *RMR*: 41-60	Top heading and bench 1.5-3 m advance in top heading. Commence support after each blast. Complete support 10 m from face.	Systematic bolts 4 m long, spaced 1.5 - 2 m in crown and walls with wire mesh in crown.	50-100 mm in crown and 30 mm in sides.	None.
IV - Poor rock *RMR*: 21-40	Top heading and bench 1.0-1.5 m advance in top heading. Install support concurrently with excavation, 10 m from face.	Systematic bolts 4-5 m long, spaced 1-1.5 m in crown and walls with wire mesh.	100-150 mm in crown and 100 mm in sides.	Light to medium ribs spaced 1.5 m where required.
V – Very poor rock *RMR*: < 20	Multiple drifts 0.5-1.5 m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting.	Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh. Bolt invert.	150-200 mm in crown, 150 mm in sides, and 50 mm on face.	Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close invert.

Source: Reference 2.2.9, Table 4.4.

4.3.1.2 Q System

The Q system, developed in Norway by Barton, Lien, and Lunde (Reference 2.2.8), provides for the design of rock support for tunnels and large underground chambers. The system utilizes the following six factors:

- RQD
- Number of joint sets
- Joint roughness
- Joint alteration
- Joint water condition
- Stress condition

The factors are combined in the following way to determine the rock mass quality (Q) as (Reference 2.2.8, Eq. 1),

$$Q = \left(\frac{RQD}{J_n}\right)\left(\frac{J_r}{J_a}\right)\left(\frac{J_w}{SRF}\right) \quad \text{(Eq. 4-2)}$$

where
- RQD = rock quality designation
- J_n = joint set number
- J_r = joint roughness number
- J_a = joint alteration number
- J_w = joint water reduction factor
- SRF = stress reduction factor (dependent on loading conditions)

The three ratios in the equation 4-2 - RQD/Jn, Jr/Ja, and Jw/SRF - represent block size, minimum inter-block shear strength, and active stress, respectively (Reference 2.2.8, p. 202).

Similar to the RMR values, Q indices for various rock units at the repository host horizon are generally available from the ECRB Cross Drift. In case these Q indices are not available, empirical correlation can be used to estimate Q indices based on given rock mass modulus. The empirical correlation used in this calculation is as follows (Reference 2.2.36, Eqs. 8.16 and 8.19):

$$Q = Q' \times \frac{J_w}{SRF} = e^{\frac{RMR-44}{9}} \times \frac{J_w}{SRF} \quad \text{(Eq. 4-3)}$$

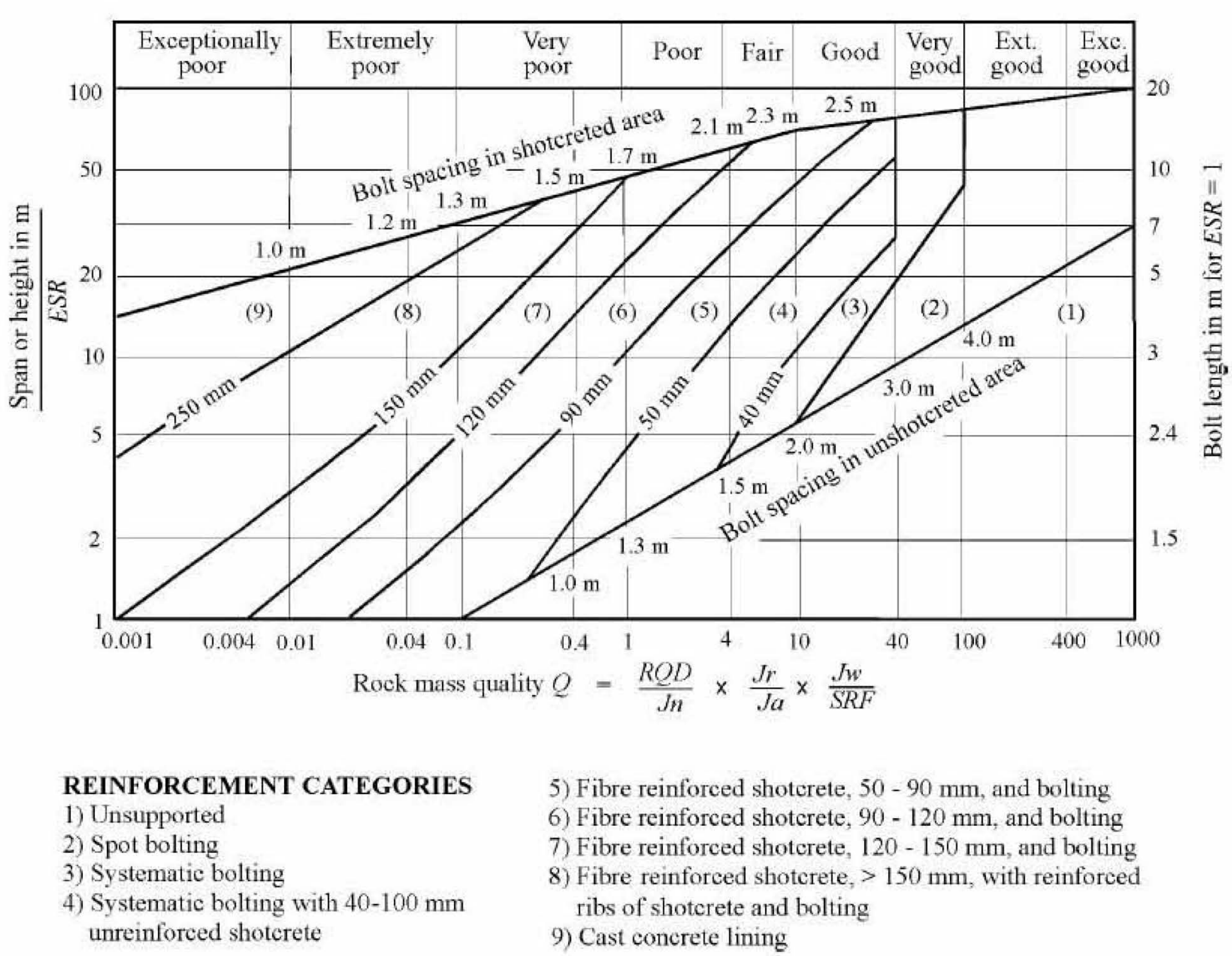
where

$$Q' = \left(\frac{RQD}{J_n}\right)\left(\frac{J_r}{J_a}\right)$$

The RMR value in Eq. 4-3 is estimated from the given rock mass modulus using Eq. 4-1.

The Q index is used with the Equivalent Dimension, defined as the largest of span, diameter, and height divided by the excavation support ratio (ESR). ESR is roughly analogous to the inverse of the factor of safety used in engineering design. The ESR reflects the degree of safety and ground support required for an excavation as determined by the purpose, presence of machinery, personnel, etc., to meet safety requirements. In essence, the safety factor of an opening can be increased by reducing the ESR value. The ESR values for various underground openings can be estimated based on Barton et al. (Reference 2.2.8, Table 7). As recommended by Hardy and Bauer (Reference 2.2.35, Section 12.7.1) an ESR value of 1.3 is appropriate for the Yucca Mountain repository drifts.

The Equivalent Dimension is plotted against Q on the design chart (Figure 4-1) to determine the required rock support category (Reference 2.2.36, Figure 4.3). Thermal or seismic loads can be included in an implicit way, by increasing the stress reduction factor, thereby requiring a higher degree of support.



Source: Reference 2.2.36, Figure 4.3.

Figure 4-1 Estimate Ground Support Needs Based on Q Index

4.3.1.3 Applicability of Empirical Methods

Empirical methods are usually applicable to mining or tunneling in jointed rock mass. The nonlithophysal rock is certainly a good example of this type of rock, and use of the RMR and Q approaches for emplacement drifts in the nonlithophysal rock is considered to be conventional.

For the emplacement drifts excavated in the lithophysal rock, however, use of the RMR or Q approach for the ground support design is non-conventional, and there are no sufficient data or field experiences available to support this application. This is primarily due to the fact that the lithophysal rock contains some air-filled large cavities and is hard to be characterized using the RMR or Q index since a RQD value is defined for a rock with fractures not with voids. Therefore, these empirical methods are not used in this calculation for evaluating the requirements of ground support for emplacement drifts in the lithophysal rock. Selection of ground support methods for this rock type is based on experiences and observations from the construction of the ESF and the ECRB Cross Drift, and assessment from numerical analyses.

4.3.2 Analytical Methods

Analytical methods, mainly numerical methods, are used in this calculation to evaluate the stability of emplacement drifts because the loading conditions such as thermal and seismic are complex and their effect on the stability of emplacement drifts is difficult to analyze with either empirical methods or closed-form solutions. Use of numerical methods to simulate the behavior of unsupported emplacement drifts is generally considered as one of the important steps during the analysis process for ground support design for this project. Modeling an unsupported drift is valuable for understanding the fundamental behavior of the drift subjected to various loading conditions without the effects of incorporating the ground support into the model.

4.3.2.1 Modeling of Emplacement Drifts

Emplacement drifts excavated in both lithophysal and nonlithophysal rock units are modeled using a two-dimensional continuum approach. Use of this approach for the ground support design calculation is consistent with the conventional practice in mining or tunneling industry. In a continuum approach, the effect of geologic features, such as fractures or lithophysae, in the rock mass is “lumped” into a thermomechanical constitutive model that represents the overall equivalent effect of these features.

From a ground support design perspective, stability of emplacement drifts is judged by overall rock mass displacements and stresses. Two-dimensional continuum approach that uses equivalent rock mass properties and constitutive model may provide good tools for bounding analyses and also allow ease of parametric examination and model interpretation. Therefore, it is appropriate for use in ground support design related analyses.

The FLAC computer code is employed in the two-dimensional analyses. In FLAC models, rock mass properties which reflect the effects of lithophysae and fractures on rock mass properties are used. These property values are presented in Table 6-4 and Table 6-5 for the lithophysal and nonlithophysal rocks, respectively. The behavior of rock mass is evaluated using the Mohr-Coulomb yield criterion. Figure 4-2 illustrates the configuration of a FLAC model. The vertical and horizontal dimensions of the model are 100 m and 81 m, respectively.

4.3.2.2 Loading and Boundary Conditions

In designing the repository openings, stresses resulting from various sources may need to be considered: in situ (including excavation effects), construction and operation activities, thermal (nuclear waste), and seismic. In the following sections, a description for each design load type is presented. However, it should be pointed out that the applicability and magnitude of some of the design loads will vary depending on the type of ground support system. Since the ground support design in this calculation is focused on the final ground support for emplacement drifts, the in situ stress, thermal load, seismic loads are considered in the evaluation of stability of emplacement drifts (Reference 2.2.20, Section 4.5.2.1).

4.3.2.2.1 In Situ Stress Loads

Average initial vertical stress (σ_v) at the center of an emplacement drift is estimated using the following expression (Reference 2.2.34, Eq. 4.1):

$$\sigma_v = -\sum_{i=1}^{n} \rho_i g h_i \qquad \text{(Eq. 4-4)}$$

where ρ_i = average bulk density of the *i*th layer of rock mass, kg/m^3
h_i = thickness of the *i*th layer of rock mass above an opening, m
g = gravitational acceleration, m/s^2
n = total number of overlaying layers of rock mass, dimensionless

The negative sign in Eq. 4-4 indicates a compressive stress. Average initial horizontal stress (σ_h) at the same location is estimated as:

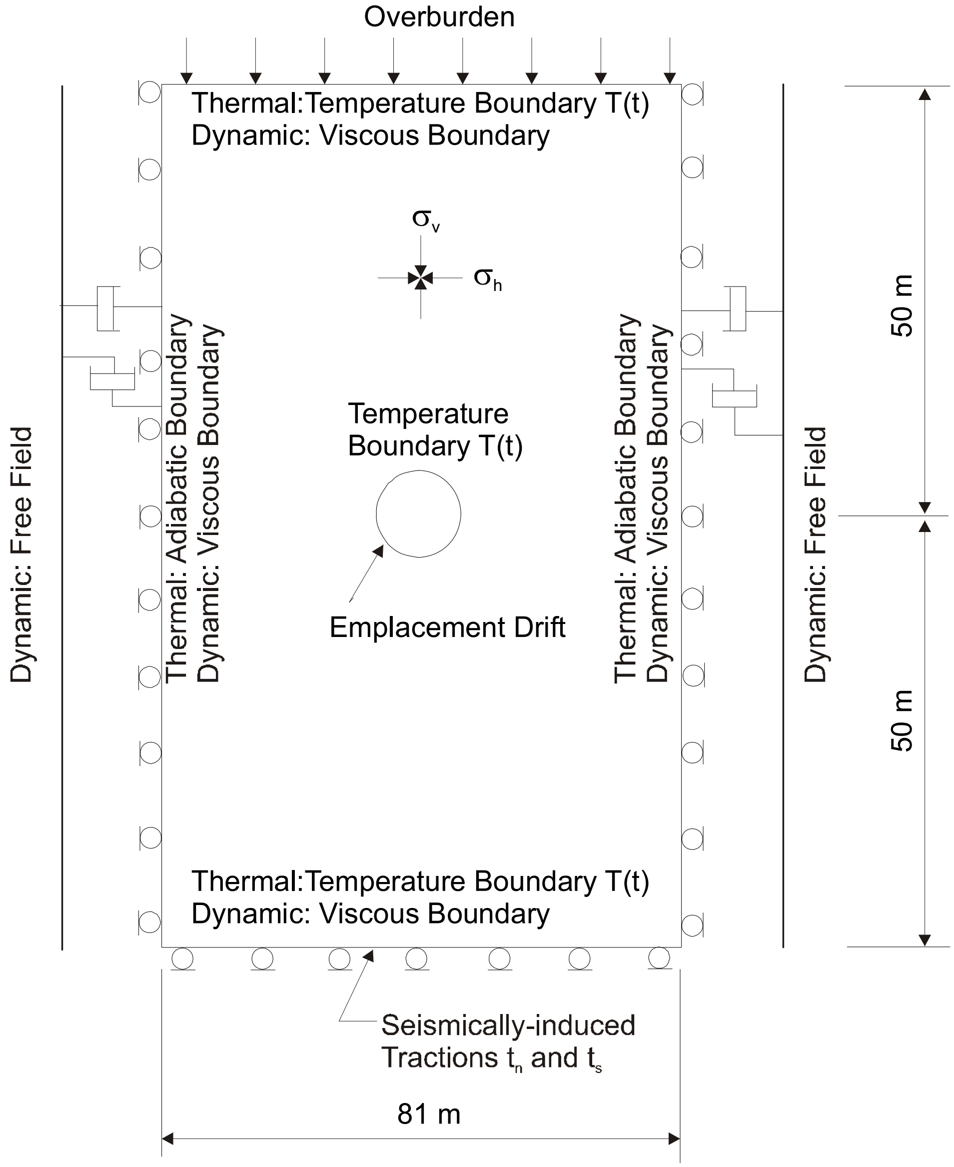
$$\sigma_h = K_0 \sigma_v \qquad \text{(Eq. 4-5)}$$

where K_o = horizontal-to-vertical stress ratio, dimensionless.

Given that a bulk density of 2,410 kg/m^3 (see Section 6.1.2.4), a gravitational acceleration of 9.81 m/s^2, a depth or thickness measured from the center of emplacement drifts to the ground surface of 400 m (Assumption 3.2.1), and a horizontal-to-vertical stress ratio of 0.3 (Assumption 3.2.2), the initial vertical and horizontal stresses at the center of emplacement drifts prior to excavation are estimated to be about -9.46 MPa and -2.84 MPa, respectively.

For bounding analyses, the lower and upper bound K_o values of 0.3 and 1.0, respectively, are used (Assumption 3.2.2).

As shown in Figure 4-2, for stress analysis, the lower boundary of the FLAC model is fixed in the vertical direction, and the two lateral boundaries are fixed in the horizontal direction. The overburden weight is applied as a stress boundary condition at the top of the model.



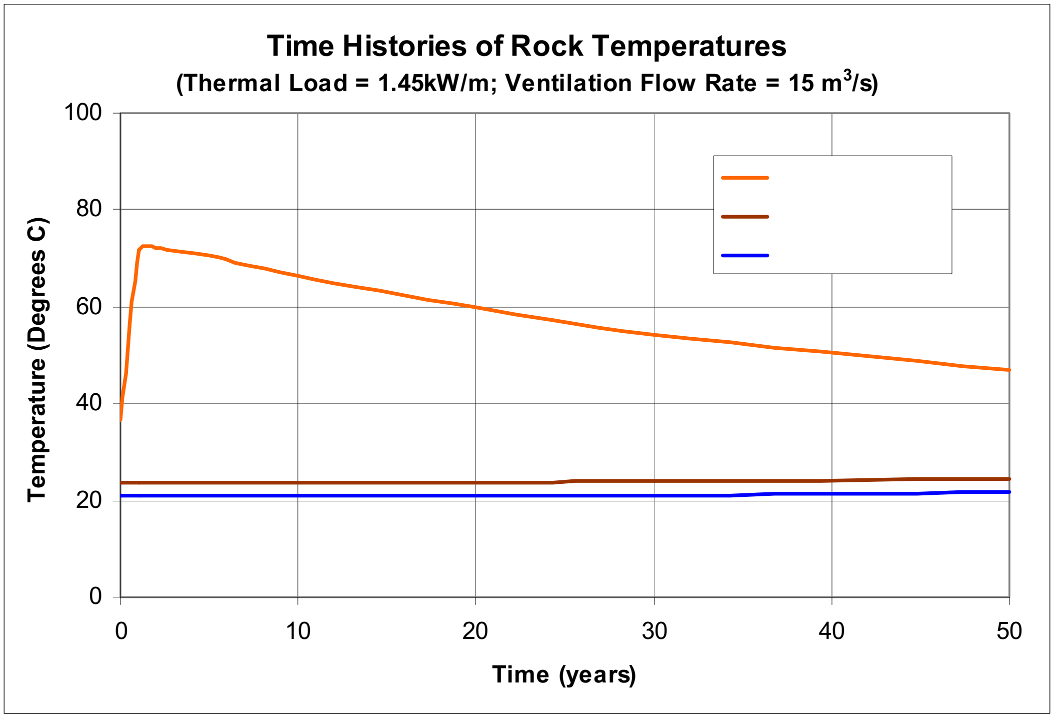
Note: t_n and t_s are seismically induced tractions in normal and shear directions.

Figure 4-2 Geometry and Boundary Conditions for FLAC Models

4.3.2.2.2 Thermal Loads

A design thermal load for LA design is 1.45 kW/m (Reference 2.2.19, Section 8.2.1.5). Instead of performing a thermal analysis to determine temperature distributions with time for this calculation, time-dependent temperatures from a ventilation model were employed. These time-dependent temperatures, as presented in Figure 4-3 (Reference 2.2.43), which was generated based on Table 6-1, were determined using this thermal load, and reflect the effect of forced ventilation of 15 m^3/s during the 50-year period (Reference 2.2.19, Section 22.2.1.8). This thermal loading scenario is used as base case for determination of the effect of thermal load on stability of emplacement drifts and performance of ground support.

In the FLAC models (see Figure 4-2), time histories of temperatures on the model boundaries (see Table 6-1, and Figure 4-3) are applied as time-dependent boundary conditions. Two lateral boundaries are adiabatic due to a thermal symmetry, meaning that there is no heat flow across these boundaries. The temperature distributions within rock are calculated based on these thermal boundary conditions and the thermal conductivity and specific heat values using thermal analysis logic built in FLAC code. Thermally-induced stresses within rock at a given time are then estimated from the changes in temperature and rock mass coefficient of thermal expansion through a thermomechanical analysis.



Source: Reference 2.2.43.

Figure 4-3 Time Histories of Rock Temperatures on Model Boundaries and Drift Wall

4.3.2.2.3 Seismic Loads

Seismic load corresponding to a mean annual probability of exceedance (APE) of 5×10^{-4} (2,000 year return period), as mentioned in Section 6.1.2.6, are used as a basis for determination of the effect of seismic motions on stability of emplacement drifts and performance of ground support. Note that seismic velocity history with an APE of 1×10^{-4} (10,000-year return period) is also used in some analyses (see Section 6.1.2.6). This load is time-dependent, resulting in transient variations in displacements and stresses in rock mass and installed ground support components. The seismic load is considered in the FLAC models by applying seismically-induced stresses (both normal and shear tractions) to the lower boundary of a model (see Figure 4-2). These boundary stresses are calculated based on time-dependent ground velocities (P- and S-plane waves or vertical and horizontal velocities), as shown in Figure 6-1, using the following equations (Reference 2.2.38, FLAC Version 4.0, *Optional Features*, Equations 3.12 and 3.13):

$$t_n = 2\rho C_p v_n$$
$$t_s = 2\rho C_s v_s \qquad \text{(Eq. 4-6)}$$

where t_n = normal traction, Pa
t_s = shear traction, Pa
ρ = rock mass density, kg/m^3
C_p = speed of P-wave propagation through the rock, m/s
C_s = speed of S-wave propagation through the rock, m/s
v_n = particle velocity in normal direction, m/s
v_s = particle velocity in shear direction, m/s

C_p and C_s are given by (Reference 2.2.38, FLAC Version 4.0, *Optional Features*, Equations 3.14 and 3.15):

$$C_p = \sqrt{\frac{K + 4G/3}{\rho}} \qquad \text{(Eq. 4-7)}$$

$$C_s = \sqrt{\frac{G}{\rho}} \qquad \text{(Eq. 4-8)}$$

where K = bulk modulus of the rock mass, N/m^2
G = shear modulus of the rock mass, N/m^2

The factor 2 in Equation 4-6 is due to quiet or viscous boundary. Both P- and S-waves are applied simultaneously. The boundary conditions used in the dynamic analysis of the FLAC models are illustrated in Figure 4-2. Quiet boundaries, as indicated in Figure 4-2 as viscous boundaries, are used on all outside boundaries. These boundaries prevent outgoing seismic waves from reflecting back into the model. Quiet boundaries are combined with free-field boundaries on two lateral boundaries, as also shown in Figure 4-2. The free-field boundaries perform one-dimensional simulation of vertically propagating plane waves that represent motions of truncated, semi-infinite medium. They prevent distortion of vertically propagating plane waves along the quiet boundaries.

In order to reduce computational time, only a dominant portion of the velocity time histories that covers 5 to 95 percent of energy bracket is used. For example, the dynamic time corresponding to this portion of velocity time histories for the seismic ground motion with 10,000-year return period is from 9.78 to 58.79 seconds (Reference 2.2.44, MatH1.dur, MatH2.dur, and MatV.dur).

4.3.2.2.4 Operational Loads

Operational loads, such as waste package weight and invert material weight, are not considered in this calculation due to the preliminary nature of the design. Exclusion of these loads was believed to result in an overestimate of the inward rock displacements (particularly below the springline) since these loads are expected to offset some of the displacements caused by excavation and heating.

4.3.2.3 Evaluation of Factor of Safety

4.3.2.3.1 Factor of Safety on Drift Stability

Stability of unsupported emplacement drifts can be evaluated using the concept of factor of safety. Factor of safety is defined as the average ratio of rock mass shear strength to shear stresses in rock adjacent to the drift. Shear strength of rock mass is determined by cohesion and frictional angle if the Mohr-Coulomb yield criterion is used. This yield criterion is expressed as (Reference 2.2.34, Eq. 3.7):

$$\tau_p = c + \sigma \tan \phi \qquad \text{(Eq. 4-9)}$$

where τ_p = shear strength, Pa
c = cohesion, Pa
σ = normal stress, Pa
ϕ = angle of internal friction, degree

In a numerical model of the specific category rock mass, shear stress (τ) at each nodal point or centroid of an element is calculated as:

$$\tau = \frac{\sigma_1 - \sigma_3}{2} \qquad \text{(Eq. 4-10)}$$

where σ_1 and σ_3 = major and minor principal stresses, respectively, Pa

Hence, a strength-to-stress ratio (STSR) at a given point can be estimated as:

$$STSR = \frac{\tau_p}{\tau} \qquad \text{(Eq. 4-11)}$$

Strength-to-stress ratios vary from point to point, and usually are lower near a drift wall and higher away from the wall. Using the lowest STSR value for a specific point as a yardstick of factor of safety to judge the entire drift performance is too conservative, and may lead to over-design. A more reasonable approach is to use an average value of STSR over a representative or critical region of emplacement drift. This average value of STSR can then be judged as a factor of safety for a drift under a specific loading condition.

There are many ways to determine a representative region over which a factor of safety is estimated. In this calculation, an annulus around an emplacement drift is considered since this is the area in which the stability is most concerned. The thickness of the annulus may be determined based on the anticipated area of reinforcement by installed ground support.

4.3.2.3.2 Factor of Safety on Ground Support Performance

Similar to a structural design, factor of safety of a ground support component can be evaluated using the following expression:

$$FS = \frac{Strength}{Stress} \quad or \quad \frac{Anchorage\ Capacity}{Bolt\ Force} \qquad \text{(Eq. 4-12)}$$

In this calculation, friction-type rock bolts are used in the analysis of ground support performance.

4.3.3 Uncertainties Associated with Design Inputs and Modeling

To minimize uncertainties associated with input data and design approaches, bounding input values and conservative design approaches are used in this calculation. The uncertainty analysis on the design inputs and design approaches for this calculation is presented in Section 6.9. Comprehensive sensitivity studies that address uncertainties associated with variations in data, loading conditions, and modeling approaches are covered in *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (Reference 2.2.14, Sections 6.3 through 6.6).

5 LIST OF ATTACHMENTS

Table 5-1 List of Attachments

Attachment	Description	Number of Pages
I	List of Input and Output Files	45
II	Two (2) DVDs	N/A

6 BODY OF CALCULATION

6.1 GENERAL

6.1.1 Introduction

This calculation provides the technical basis for the design of the ground control systems for emplacement drifts for LA. The design and construction of an underground high-level nuclear waste repository facility introduce unique challenges that are not commonly experienced for other subsurface facilities. For example, the presence of high level nuclear waste and the resultant thermal loading conditions introduce a series of additional requirements to the overall design and construction of the facility in addition to the waste isolation requirements. In situ (excavation) loads, thermal loads due to the presence of nuclear waste, and loads due to seismic loading conditions during an earthquake must also be addressed in the design.

The emplacement drift ground support design effort includes both empirical and analytical methods, coupled by observational approach (i.e., engineering experience). The empirical methods are primarily used for assessing the needs for ground support of emplacement drifts as well as for its selection. Design issues such as personnel safety, constructability, and geologic mapping requirements are factored into the design of the ground support system at this approach. However, due to the complexity of the problem involved with ground support design for nuclear waste repository, the repository ground control design effort will focus mainly on analytical methods by using computer programs to evaluate the stability of unsupported and supported openings. Applicable thermal and seismic loads will be considered in the design in addition to the in situ loading conditions. The best available experience of drift stability for the repository host rock can be obtained from observation of stability condition of openings in the ESF and the ECRB Cross Drift, which will also be discussed.

Unless otherwise indicated, the term “ground support” or “ground control” used in this section is referred to as the final ground support. When the initial ground support is discussed, it will be explicitly indicated.

6.1.2 Input Parameters

Input parameters for this calculation include time histories of rock temperatures, thermal and mechanical properties of the rock mass surrounding the emplacement drifts, rock bolt properties, seismic velocity histories, and emplacement drift configurations.

6.1.2.1 Time Histories of Rock Temperatures

Time histories of rock temperatures are listed in Table 6-1. These values reflect the effect of forced continuous ventilation at 15 m^3/s during the 50-year period and are obtained from the ANSYS output files associated with the ventilation model (Reference 2.2.43). The rock temperatures at 50 m above and below from the drift center are estimated from two neighboring points by using linear interpolation as shown in Equation 6-1 from the source reference. Note that this simple linear interpolation is used in Table 6-1, Table 6-10(a) and Table 6-10(b). These ANSYS output files were obtained from TDMS under Reference 2.2.43.

Table 6-1 Time Histories of Rock Temperatures

Time (years)	Temperatures (°C)		
	Drift Wall	50-m Above Drift Center[a]	50-m Below Drift Center[a]
0	22.28	21.68	23.08
0.01	36.64	21.68	23.08
1	71.80	21.68	23.08
2	72.22	21.68	23.08
5	70.42	21.71	23.10
7	68.63	21.81	23.19
10	66.32	22.09	23.45
20	59.88	23.42	24.72
30	54.32	24.68	25.96
50	46.78	26.53	27.81

Source: Reference 2.2.43, ANSYS-LA-Fine.xls, and la600c24.rth. Note: [a] Temperature data at these locations were estimated by using linear interpolation shown in Eq. 6-1 between two neighboring points from the source reference.

$$T(y) = T_u + ((y - y_u)/(y_l - y_u))(T_l - T_u) \qquad \text{(Eq. 6-1)}$$

where T is for temperature, y for elevation, u and l for upper and lower elevations, respectively.

6.1.2.2 Rock Thermal Properties

Thermal conductivity and specific heat of lithophysal and nonlithophysal rocks used in the numerical analysis are listed in Table 6-2.

Table 6-2 Thermal Conductivity and Specific Heat of Lithophysal and Nonlithophysal Rocks

Litho-Stratigraphic Unit	Thermal Conductivity (W/m·K)		Specific Heat (J/kg·K)		
	Wet	Dry	25 - 94°C	95 - 114°C	115 - 325°C
Tptpmn	2.07	1.42	910	3000	990
Tptpll	1.89	1.28	930	3300	990

Source: Thermal conductivity from Table 6-90 and specific heat from Table 6-94 of Reference 2.2.27.

The mean rock mass coefficients of thermal expansion for lithophysal and nonlithophysal rocks used in the numerical analysis are tabulated in Table 6-3 (Reference 2.2.27, Table 6-86).

Table 6-3 Coefficients of Thermal Expansion for Lithophysal and Nonlithophysal Rocks

Temperature Range (°C)	CTE (10^{-6}/°C)[a]
20 - 25	7.34[b]
25 - 50	7.34
50 - 75	8.99
75 - 100	9.73
100 - 125	10.22
125 - 150	10.91
150 - 175	12.20
175 - 200	14.74
200 - 225	22.31

Source: Reference 2.2.27, Table 6-86. [a] Values from heating cycle. [b] Assumption 3.2.6.

6.1.2.3 Rock Mass Mechanical Properties

Rock mass mechanical properties for lithophysal rock are listed in Table 6-4, which are primarily obtained from Tables 6-76, 6-77, and 6-70 of *Subsurface Geotechnical Parameters Report* (Reference 2.2.27). The values of bulk modulus and shear modulus are calculated based on values of modulus of elasticity (E) and Poisson's ratio (ν) in Table 6-4 and from Equations 6-2 and 6-3 (see equations 14 and 13, p. 111 of Reference 2.2.39). Values of cohesion (*c*) corresponding to friction angle of 35 degrees (see Assumption 3.2.4) are estimated based on the unconfined compressive strength (q_u) values for each category identified in Table 6-4 and using Equation 6-4 (Reference 2.2.36, Eq. 8.15):

$$K = \frac{E}{3(1-2\nu)} \quad \text{(Eq. 6-2)}$$

$$G = \frac{E}{2(1+\nu)} \quad \text{(Eq. 6-3)}$$

$$c = \frac{q_u(1-\sin\phi)}{2\cos\phi} \quad \text{(Eq. 6-4)}$$

Table 6-4 Rock Mass Mechanical Properties for Lithophysal Rock at RHH

Parameter	Lithophysal Rock				
Rock Mass Category	1	2	3	4	5
Lithophysal Porosity (%)[a]	>30	25-30	15-25	10-15	<10
Poisson's Ratio[b]	0.22	0.22	0.22	0.22	0.22
Modulus of Elasticity (GPa)[c]	1.90	6.40	10.80	15.30	19.70
Bulk Modulus (GPa)	1.13	3.81	6.43	9.11	11.73
Shear Modulus (GPa)	0.78	2.62	4.43	6.27	8.07
Unconfined Compressive Strength (MPa)[c]	10	15	20	25	30
Cohesion (MPa)	2.60	3.90	5.21	6.51	7.81
Friction Angle (degrees)	35	35	35	35	35
Tensile Strength (MPa)[d]	1.0	1.5	2.0	2.5	3.0

Source: Reference 2.2.27, [a] Table 6-70, [b] Table 6-76, [c] Table 6-77, [d] Assumption 3.2.5.

Rock mass properties for nonlithophysal rock (Tptpmn) are listed in Table 6-5. Note that all data are obtained from Table 6-76 of *Subsurface Geotechnical Parameters Report* (Reference 2.2.27) except that values of bulk modulus and shear modulus are calculated based on values of modulus of elasticity and Poisson's ratio in Table 6-5 and from Equations 6-2 and 6-3 (Equations 14 and 13, p. 111 of Reference 2.2.39).

Table 6-5 Rock Mass Mechanical Properties for Nonlithophysal Rock at RHH

Parameter	Nonlithophysal Rock (Tptpmn)				
Rock Mass Category	1	2	3	4	5
Geologic Strength Index (GSI)	51	59	62	68	72
Poisson's Ratio	0.19	0.19	0.19	0.19	0.19
Modulus of Elasticity (GPa)	10.59	16.79	19.95	28.18	35.48
Bulk Modulus (GPa)	5.69	9.03	10.73	15.15	19.08
Shear Modulus (GPa)	4.45	7.05	8.38	11.84	14.91
Unconfined Compressive Strength (MPa)	26.90	32.02	34.28	39.57	43.90
Cohesion (MPa)	7.36	8.33	8.75	9.73	10.52
Friction Angle (degrees)	32.64	35.02	35.91	37.65	38.79
Tensile Strength (MPa)	0.27	0.50	0.63	0.99	1.33

Source: Reference 2.2.27, Table 6-76.

6.1.2.4 Rock Mass Density

A rock mass saturated bulk density of 2,410 kg/m^3 is used to estimate overburden and in situ stress state. This value is the mean saturated density for the rock unit of Tptpln (Reference 2.2.48) at RHH, and is the highest value of lithostratigraphic units, which is conservative for the purpose of this calculation.

6.1.2.5 Properties of Swellex Rock Bolts

Swellex-type stainless steel rock bolts are proposed for use in emplacement drifts (see Section 6.6). Their thermal and mechanical properties are listed in Table 6-6.

Table 6-6 Dimensions and Properties for Stainless Steel Super Swellex Rock Bolts

Parameter	Value	Source
Diameter of Rock Bolt (m)	0.054	Assumption 3.1.1 and Reference 2.2.6, p. 10.
Thickness of Bolt Tube (m)	0.003	Assumption 3.1.1 and Reference 2.2.6, p. 10.
Density (kg/m^3)	8,000	Reference 2.2.1, Table 21, p. 871, for 316 type stainless steel.
Young's Modulus of Stainless Steel (GPa)	193	Reference 2.2.1, Table 21, p. 871, for 316 type stainless steel.
Tensile Strength (MPa)	620	Reference 2.2.4, Table 2, p. 4, for 316 type steel.
Limit Axial Force (kN)	298	Calculated from $620\times10^6\times\pi/4\times(0.054^2-0.048^2)/1000=298$ kN.
Bolt Anchorage Capacity (Tonnes)	20	Reference 2.2.49, p. 14
Coefficient of Thermal Expansion (m/m·°C)	15.9×10^{-6}	Reference 2.2.1, Table 21, p. 871, for 316 type stainless steel at a temperature range of 0 to 100°C.
Bond Stiffness (N/m/m)	3×10^8	Calibrated from pull test data. See Section 6.7.1.
Bond Shear Strength (N/m)	2.75×10^5	Calibrated from pull test data. See Section 6.7.1.

It is noted that the bolt data is from the catalog information (Reference 2.2.6) of Atlas Copco, the manufacturer of Swellex bolts, which are standard industry products, therefore, use of the data is judged as justified for the purpose of this calculation.

6.1.2.6 Seismic Velocity Histories

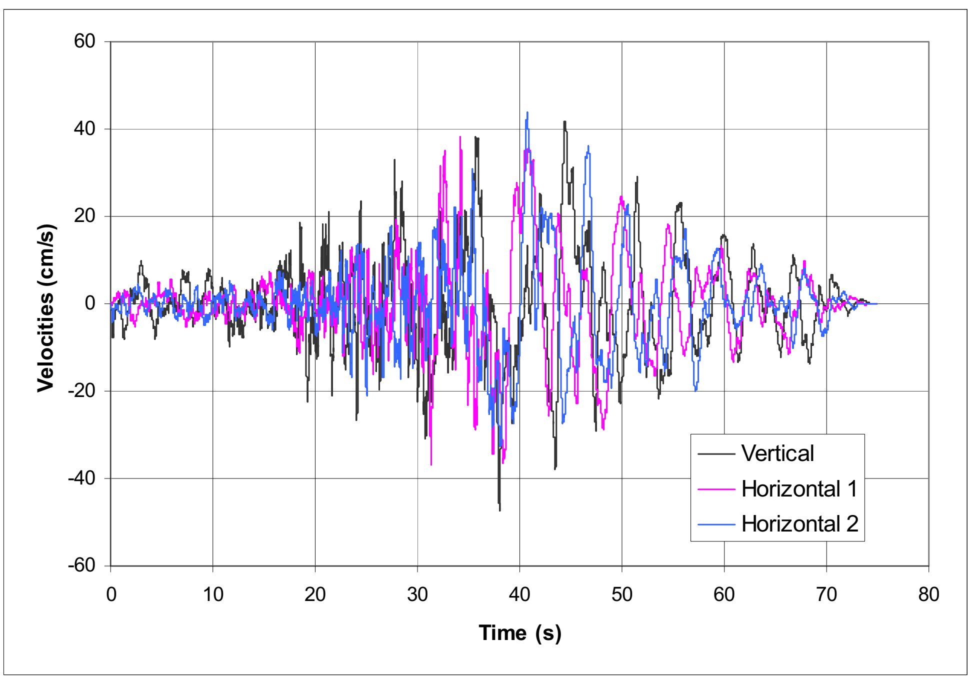
Seismic velocity histories for the mean APE of 5×10^{-4} (2,000-year return period) are shown in Figure 6-1 (Reference 2.2.45, V.vth, H1.vth, and H2.vth). This seismic velocity history is used in all the numerical analyses in Section 6 except in Sections 6.8.2, 6.7.3, and 6.7.4, in which seismic velocity history with an APE of 1×10^{-4} (10,000-year return period) as shown in Figure 6-2 (Reference 2.2.44) is used. Details on how these seismic velocity histories are applied in numerical calculations are described in Section 4.3.2.2.3.

6.1.2.7 Emplacement Drift Configurations

The nominal excavated diameter of emplacement drifts shall be 5.5 meters (Reference 2.2.29, Table 3). The repository emplacement drift spacing shall be 81 meters (Reference 2.2.19, Section 8.2.1.8).

Source: Reference 2.2.45, V.vth, H1.vth, and H2.vth.

Figure 6-1 Time Histories of Velocity Components of Seismic Motion for Mean APE of 5×10^{-4}



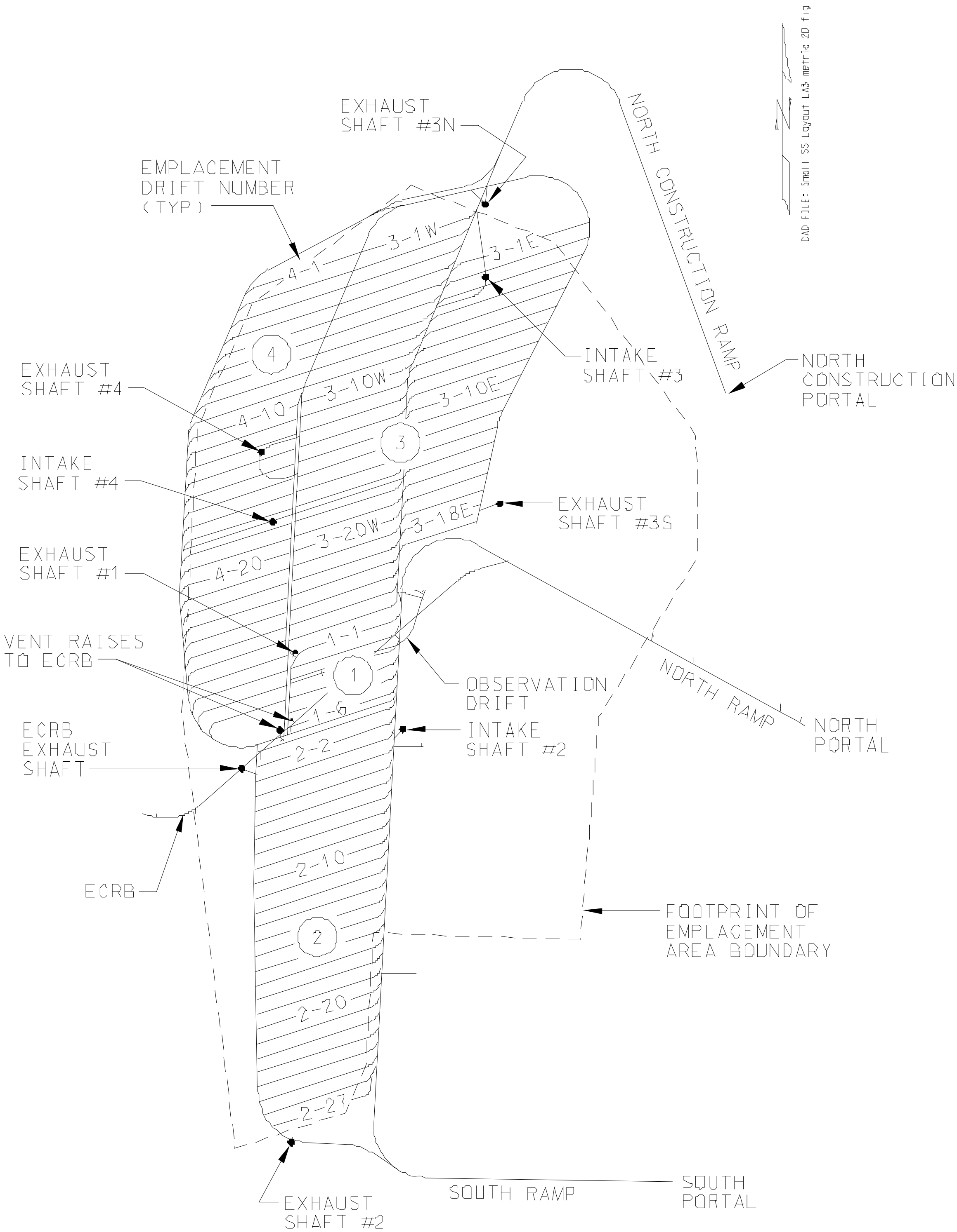
Source: Reference 2.2.44, MatH1.vth, MatH2.vth, and MatV.vth.

Figure 6-2 Time Histories of Velocity Components of Seismic Motion for Mean APE of 1×10^{-4}

6.2 REPOSITORY HOST HORIZON AND GEOTECHNICAL CHARACTERIZATION

In order to design the ground support system in emplacement drifts, it is important to understand the environment conditions in which these drifts will be located.

According to the *Underground Layout Configuration* calculation (Reference 2.2.15, Section 7.1.7), the RHH will be located in the lower part of the lithophysal zone of the densely welded devitrified lithophysal-rich tuff unit and the entire densely welded devitrified lithophysal-poor tuff unit of the Topopah Spring Tuff. The RHH contains four lithostratigraphic units, namely the upper lithophysal unit (Tptpul), the middle nonlithophysal unit (Tptpmn), the lower lithophysal unit (Tptpll), and the lower nonlithophysal unit (Tptpln). The current underground layout configuration is shown in Figure 6-3 (Reference 2.2.29, Figure 11). Of the total emplacement areas, approximately 85% will lie within the Tptpll and Tptpul units combined and the rest 15% will be located in the Tptpmn and Tptpln units (Reference 2.2.15, Table II-2).



Source: Reference 2.2.29, Figure 11.

Figure 6-3 Current Underground Layout Configuration

Geological mapping was conducted in the ESF tunnel and the ECRB cross drift to characterize the rock units within the RHH. The data collected were analyzed using two empirical rock mass classification systems, the Geomechanics RMR system (Reference 2.2.9) and the Rock Mass Quality (Q) system of NGI (Reference 2.2.8). The geotechnical characteristics of the four lithostratigraphic units can be summarized as follows (Reference 2.2.10, Section 3.4):

Tptpul Unit. The Tptpul unit on average has a RQD rating of 36 (poor), a RMR value of 57 (fair) and a Q value of 14 (good). Its lithophysae content ranges from 10 to 40 percent by volume. These cavities have an average diameter of 10 cm. Fractures are hard to distinguish, with an average of only one joint set. Keyblock-type failures are not likely to occur in this unit, though some horizontal cooling joints are observed.

Tptpmn Unit. The Tptpmn unit has a mean horizontal RQD rating ranging from 60 to 62 (fair), and a RMR value of 60 (fair). It is characterized by less than 3 percent lithophysae by volume. This unit has an average of three to three plus random joint sets, with predominately two vertical joint sets and one horizontal joint set. The horizontal joint set, or vapor-phase partings, is the primary cause of potential formation of keyblocks. A typical fracture pattern in the Tptpmn unit is shown in Figure 6-4.

Tptpll Unit. The Tptpll unit has a horizontal RQD rating of 42 (poor), a Q rating of 7.9 (fair), and a RMR value of 57 (fair). Its content of lithophysae varies from 5 to 30 percent by volume, with a size ranging from 5 to 130 cm. The larger lithophysal cavities tend to be irregular or ellipsoidal features that exhibit prismatic fracturing. The unit has an average of two plus random joint sets; however no keyblock problems are expected. Typical lithophysae and fracturing in the Tptpll are shown in Figure 6-5.

Tptpln Unit. The Tptpln has a RQD rating ranging from 62 to 67 (fair), a RMR value of 60 (fair), and a Q value of 12.3 (good). This unit contains less than 3 percent lithophysal cavities by volume. It has an average of three joint sets, with no keyblock problems anticipated.

Source: Reference 2.2.10, Figure 8.

Figure 6-4 Fractures in the Wall of the ECRB Cross Drift in the Tptpmn Unit

Source: Reference 2.2.10, Figure 10b.

Figure 6-5 Lithophysae and Fracturing in the Tptpll Unit

6.3 GROUND SUPPORT FUNCTIONAL REQUIREMENTS

Ground support design for emplacement drifts has the following functional and performance requirements:

- Prevent rock loosening and potential rockfall onto waste packages during the preclosure period (Reference 2.2.20, Section 4.5.2.2)
- Account for the appropriate worst possible case in terms of combinations of in situ, thermal, seismic, construction, and operation loads (Reference 2.2.20, Section 4.5.2.1)
- Prevent rock falls that could potentially result in personnel injury (Reference 2.2.20, Section 4.5.2.2)
- Interface with TSPA to ensure general acceptance of committed ground support materials (Reference 2.2.20, Section 4.5.2.12)
- Function without planned maintenance during the operational life, while providing for the ability to perform unplanned maintenance in emplacement drifts on as-needed basis (Reference 2.2.20, Section 4.5.2.13)
- Use the site-specific geotechnical data that are obtained from rock at Yucca Mountain (Reference 2.2.20, Section 4.5.2.7)
- Interface with the subsurface development and emplacement drift subsystems to accommodate opening orientation, configuration, and excavated opening sizes (Reference 2.2.20, Section 4.5.2.11).

These functional and performance requirements should be addressed in the design and selection of ground support system for emplacement drifts.

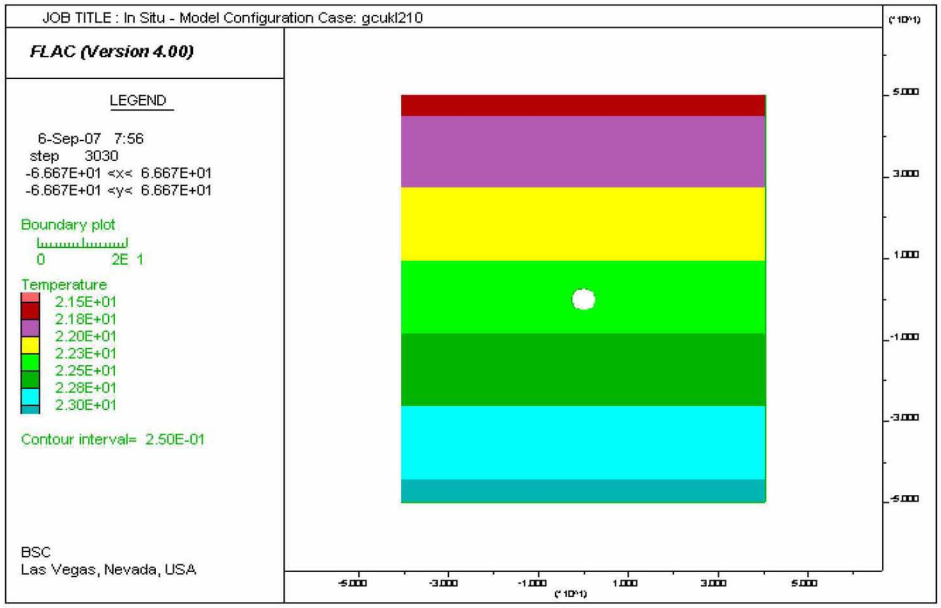
6.4 STABILITY OF UNSUPPORTED EMPLACEMENT DRIFTS

This section presents the results of assessment of stability of unsupported emplacement drifts. The assessment is based on numerical analysis using the FLAC computer code. The analysis evaluates temperature increases in rock following waste emplacement, displacement and stress in the vicinity of an unsupported emplacement drift, factor of safety, and ground reaction curves (GRC).

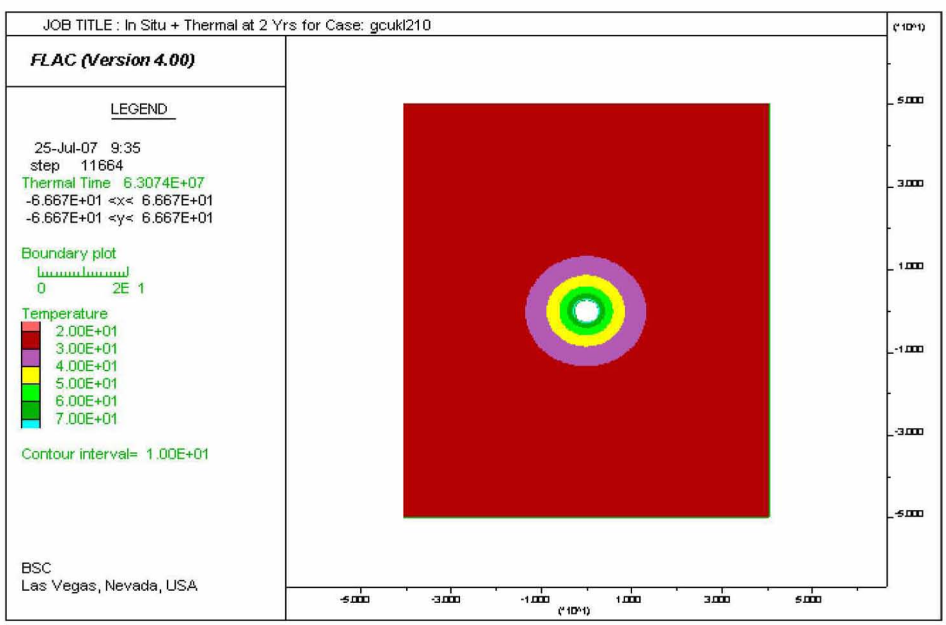
6.4.1 Temperature Increase in Rock

Temperatures in rock around an emplacement drift increase due to heating by waste packages. The distributions of rock temperatures at different years following waste emplacement are presented in Figure 6-6. These temperature contours are generated by FLAC based on the time-dependent boundary temperatures shown in Table 6-1. With these temperatures, thermally-induced displacements and stresses in rock are calculated through thermomechanical analyses.

It can be seen that the peak temperature on drift wall is recorded at 2 years after waste emplacement, but the heat front continues to propagate. As a result, the heated rock volume increases with time over a period of 50 years, which dictates the continuous changes in rock displacements and stresses. In general, the increase in temperatures (less than 50°C) is not significant owing to the effect of forced ventilation during the preclosure period.

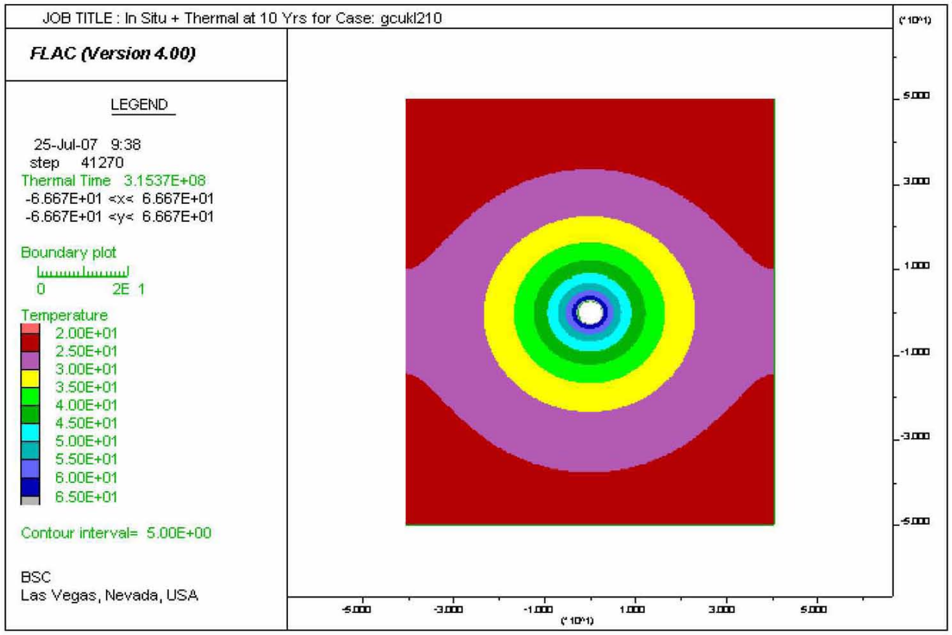


(a) initial

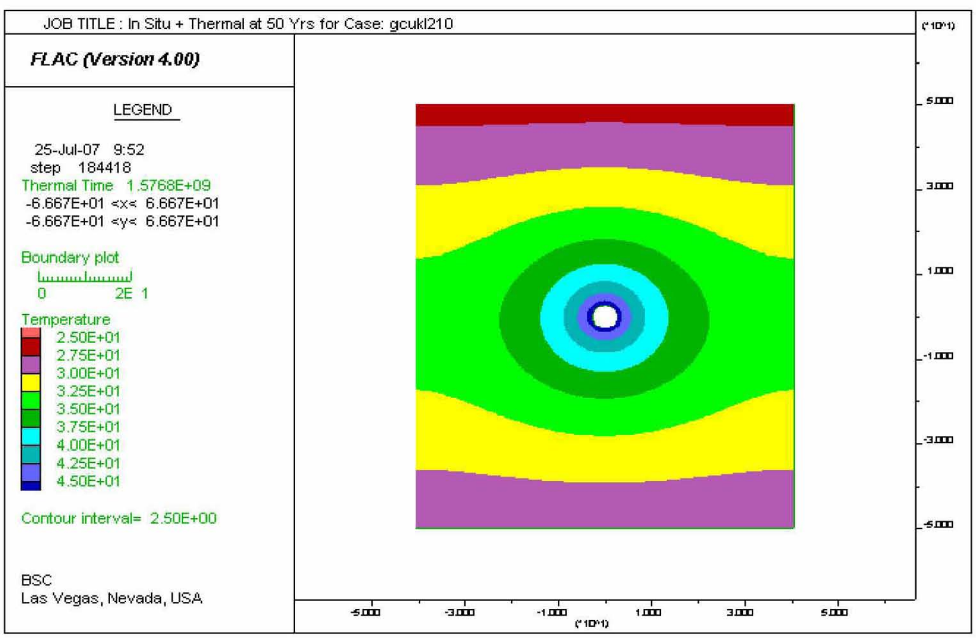


(b) at 2 years

Figure 6-6 Temperature Contours (°C) around Emplacement Drifts at Various Years Following Waste Emplacement at (a) initially, (b) 2 years, (c) 10 years, and (d) 50 years



(c) at 10 years



(d) at 50 years

Figure 6-6 Temperature Contours (°C) around Emplacement Drifts at Various Years Following Waste Emplacement at (a) initially, (b) 2 years, (c) 10 years, and (d) 50 years (continued)

6.4.2 Rock Displacement and Stress

Drift closures, defined as the relative displacements between two points of interest on the surface of a drift, are commonly used to evaluate the status of drift stability. The magnitude of stress near the vicinity of drift may also provide some information on the drift stability since excess overstress in rock mass may result in yielding or failure in rock mass. Therefore, predicted displacement and stress around an unsupported emplacement drift are examined closely to evaluate its stability under anticipated loading conditions.

6.4.2.1 Drift Closures

Both vertical and horizontal drift closures in emplacement drifts are predicted under in situ, thermal, and seismic loading conditions. The vertical closure is defined as the relative displacements between the invert and the crown, while the horizontal closure is defined as those between the springlines. The positive closure indicates that two reference points move toward each other, i.e., a reduction in dimension.

In the lithophysal rock, analyses were performed by considering the upper and lower bounds of rock mass properties. For examples, only the rock mass properties associated with the categories 1 and 5 were used. Responses associated with other categories of rock mass properties are anticipated to be bounded by those cases considered.

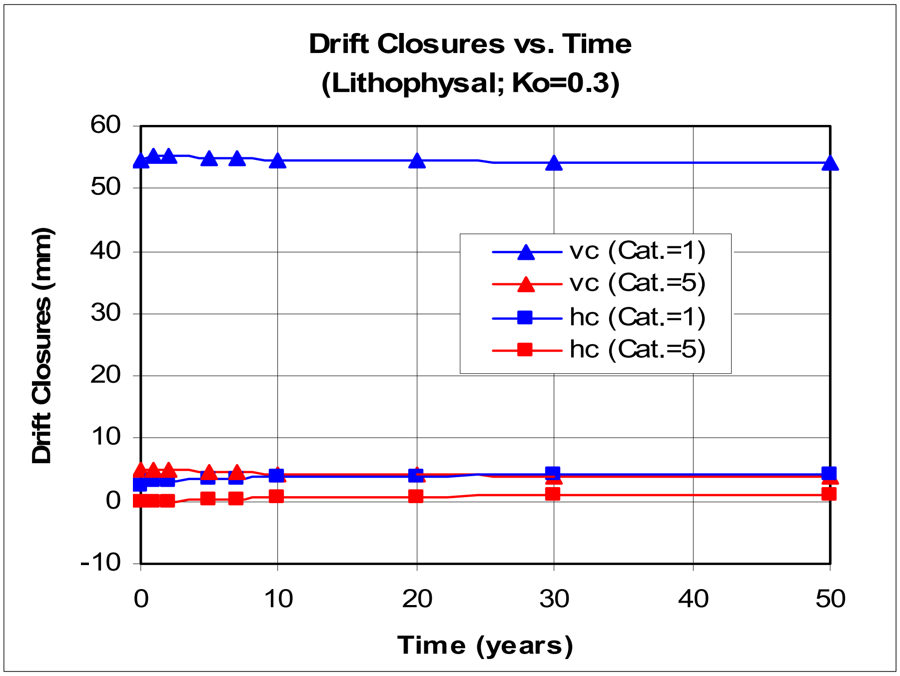
Time histories of the vertical and horizontal closures in emplacement drifts are illustrated in Figure 6-7(a) and Figure 6-7(b) for unsupported emplacement drifts in the lithophysal rock subjected to in situ and thermal loads corresponding to the initial horizontal-to-vertical stress ratios (K_o) of 0.3 and 1.0, respectively.

The maximum vertical closures are predicted to range from about 40 mm at K_o=1.0 to about 55 mm at K_o=0.3 for category 1 rock mass, and from about 3 mm at K_o=1.0 to about 5 mm at K_o=0.3 for category 5 rock mass. The maximum horizontal closures are expected to vary from about 4 mm at K_o=0.3 to about 40 mm at K_o=1.0 for category 1 rock mass, and from about 1 mm at K_o=0.3 to about 5 mm at K_o=1.0 for category 5 rock mass. It appears that the rock deformation is induced primarily by in situ stress during excavation. Thermally-induced deformation is minimal (a maximum of about 2 mm for all cases analyzed) because the increase in temperature during the 50-year period is insignificant.

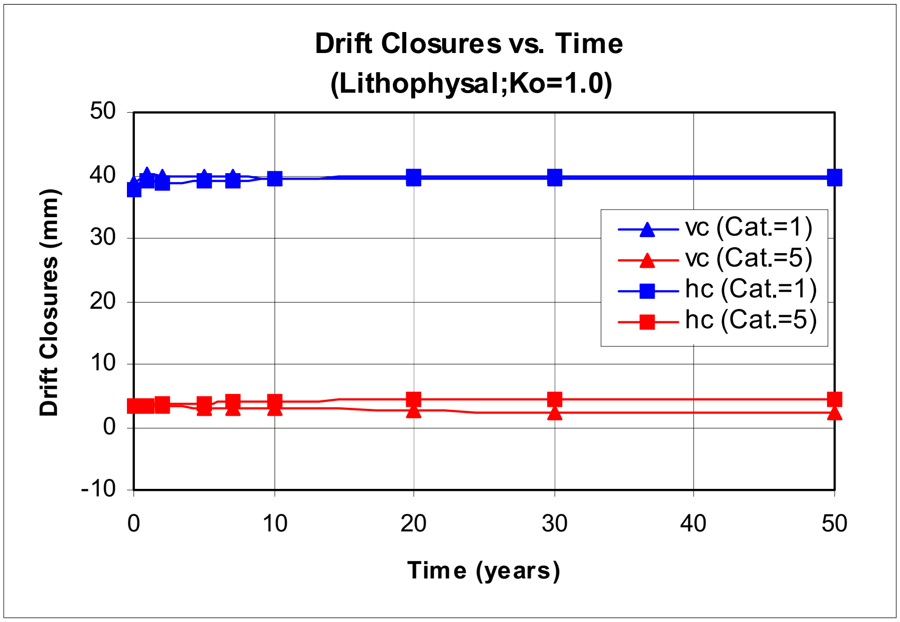
Similarly, the drift closures in the nonlithophysal rock were also predicted with the bounding rock mass properties, as shown in Figure 6-8(a) and Figure 6-8(b) for K_o=0.3 and K_o=1.0, respectively. The maximum vertical closures are predicted to range from about 6 mm at K_o=1.0 to about 9 mm at K_o=0.3 for category 1 rock mass, and from about 2 mm with K_o=1.0 to about 3 mm at K_o=0.3 for category 5 rock mass. The maximum horizontal closures are shown to vary from about 1 mm at K_o=0.3 to about 7 mm at K_o=1.0 for category 1 rock mass, and from about 1 mm with K_o=0.3 to about 3 mm at K_o=1.0 for category 5 rock mass. Again, it can be seen from Figure 6-8 that the rock deformation in the nonlithophysal rock is induced primarily by excavation under the in situ stress. Thermally induced deformation in the nonlithophysal rock is insignificant.

Drift closures induced by seismic motions were calculated for emplacement drifts in both the lithophysal and nonlithophysal rocks, and are presented in Figure 6-9 through Figure 6-12. It is indicated that seismically-induced rock deformation using FLAC, i.e., a continuum model, is not significant. The maximum closures due to seismic loadings are predicted to vary from less than 3 mm for the category 1 lithophysal rock to less than 2 mm for the category 1 nonlithophysal rock. The results also indicate that the rock is not expected to behave much differently if the seismic motions occur at the beginning of waste emplacement (year=0) or at 50 years following waste emplacement. This is due to the fact that the same seismic ground motion is applied at different times, e.g., year 0 and year 50. In addition, the effect of heating by waste on rock mass behavior is minimized by the use of continuous ventilation during the preclosure period.

Combining the rock displacements induced by in situ and thermal loads with those caused by seismic load results in the maximum anticipated drift closures of about 60 mm for the weakest lithophysal rock (category=1) and about 10 mm for the weakest nonlithophysal rock (category=1).

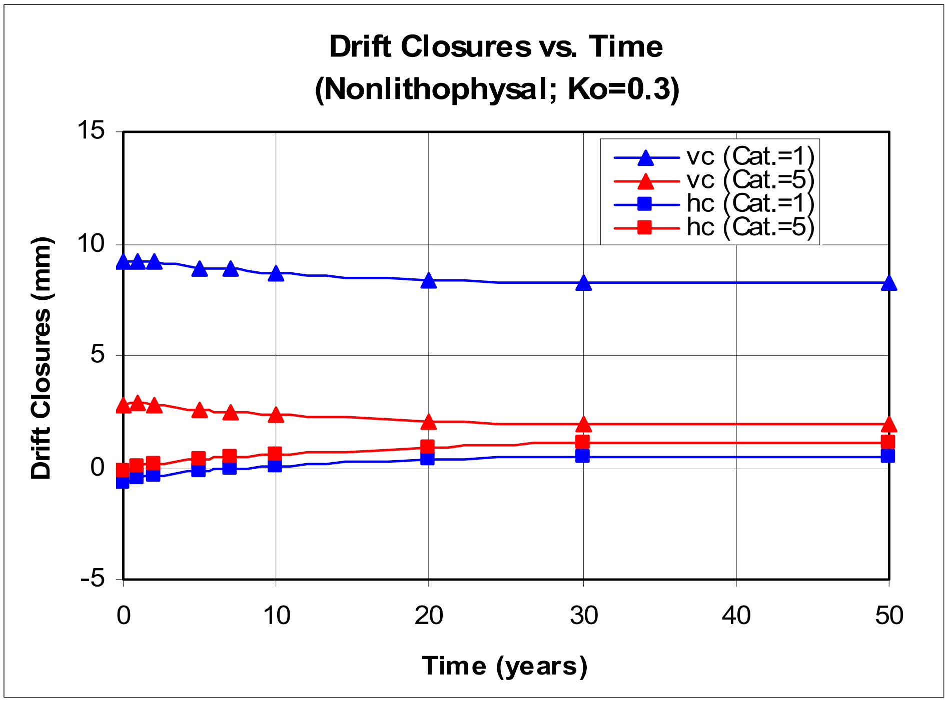


(a)

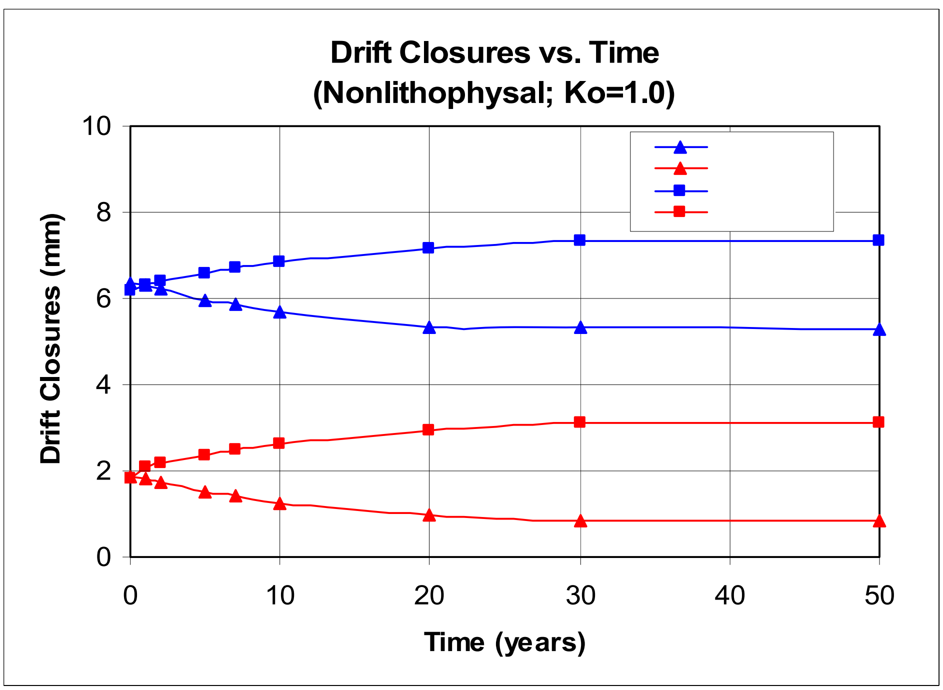


(b)

Figure 6-7 Time Histories of Closures in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loads: (a) Ko=0.3; (b) Ko=1.0

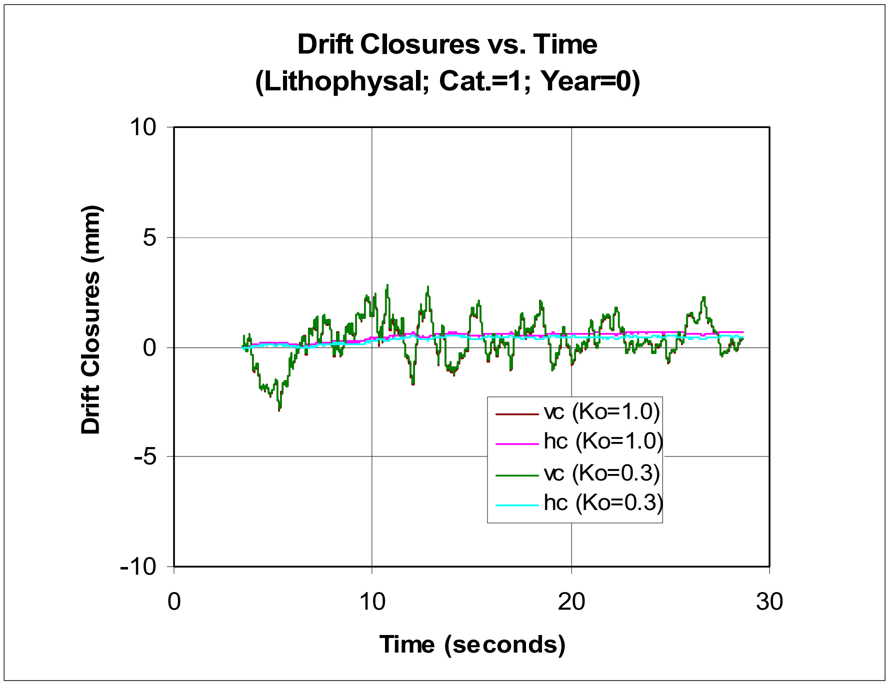


(a)

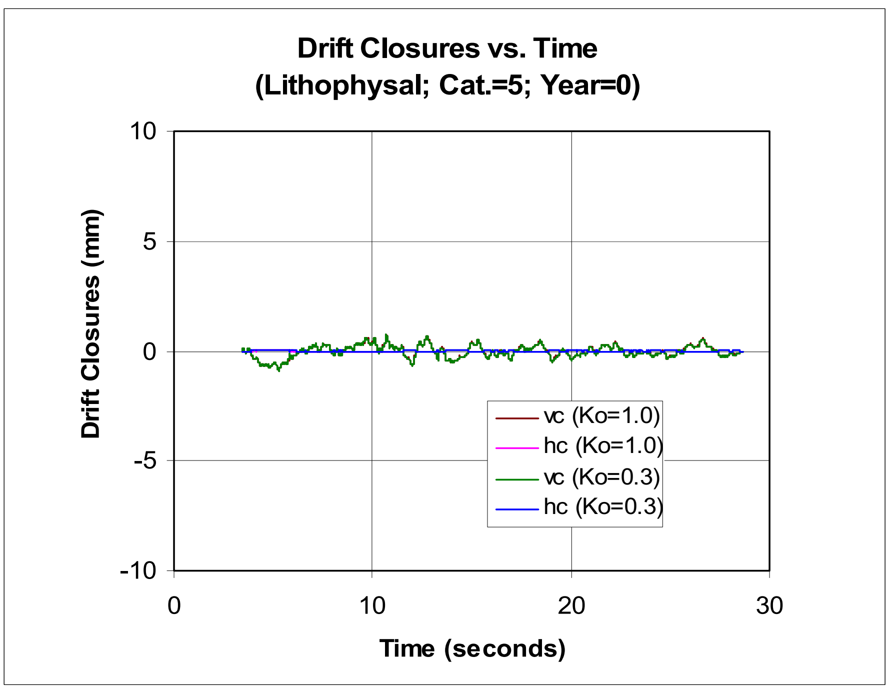


(b)

Figure 6-8 Time Histories of Closures in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loads: (a) Ko=0.3; (b) Ko=1.0

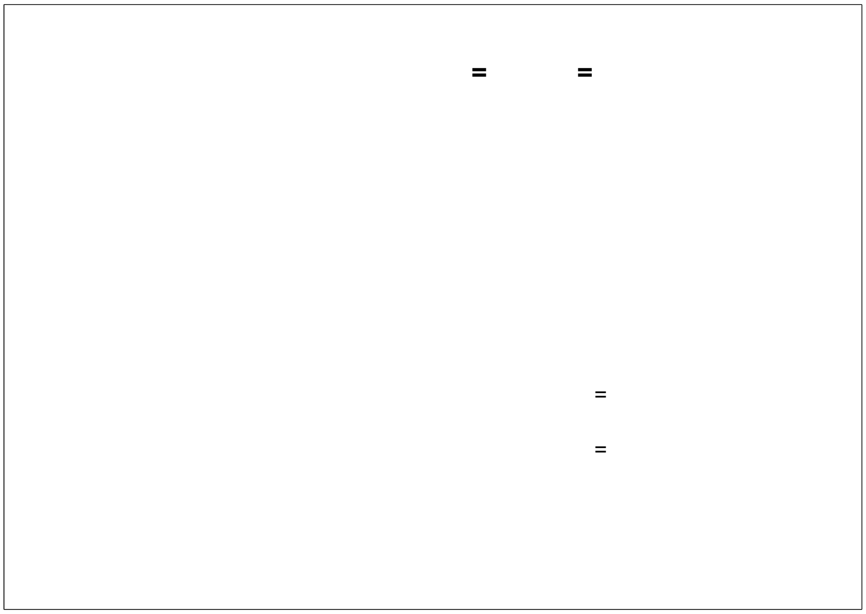


(a)

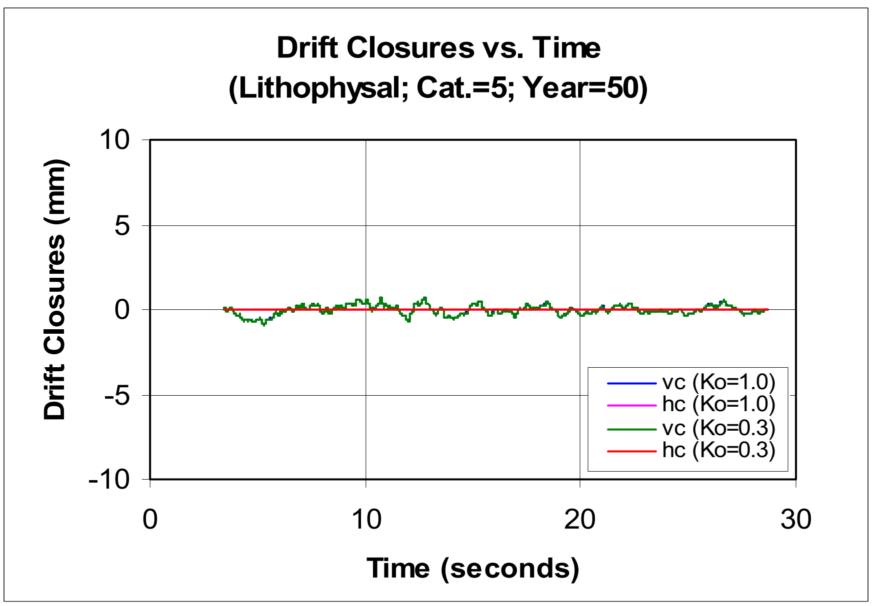


(b)

Figure 6-9 Time Histories of Closures in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under Seismic Load at Year=0: (a) Category 1; (b) Category 5

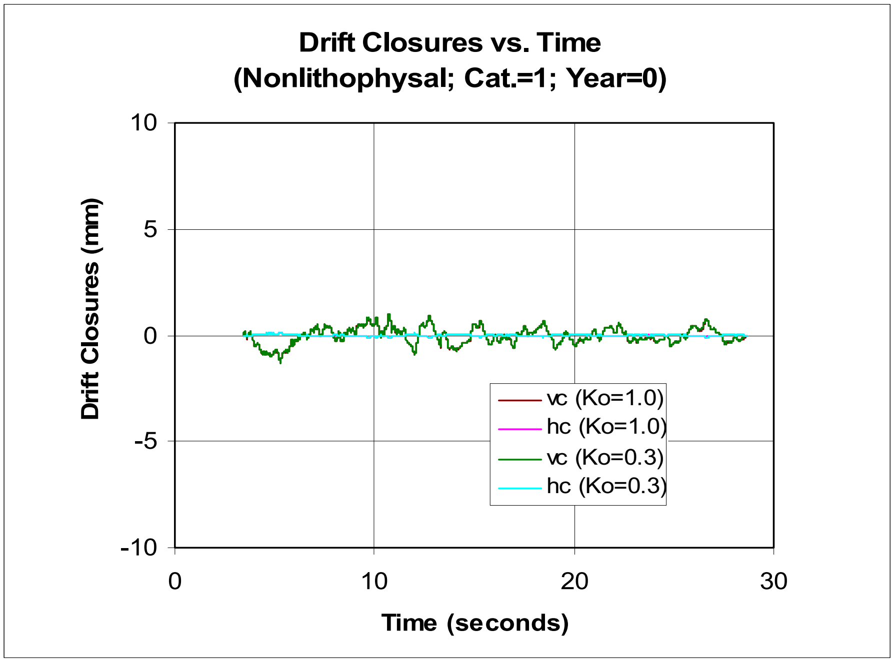


(a)

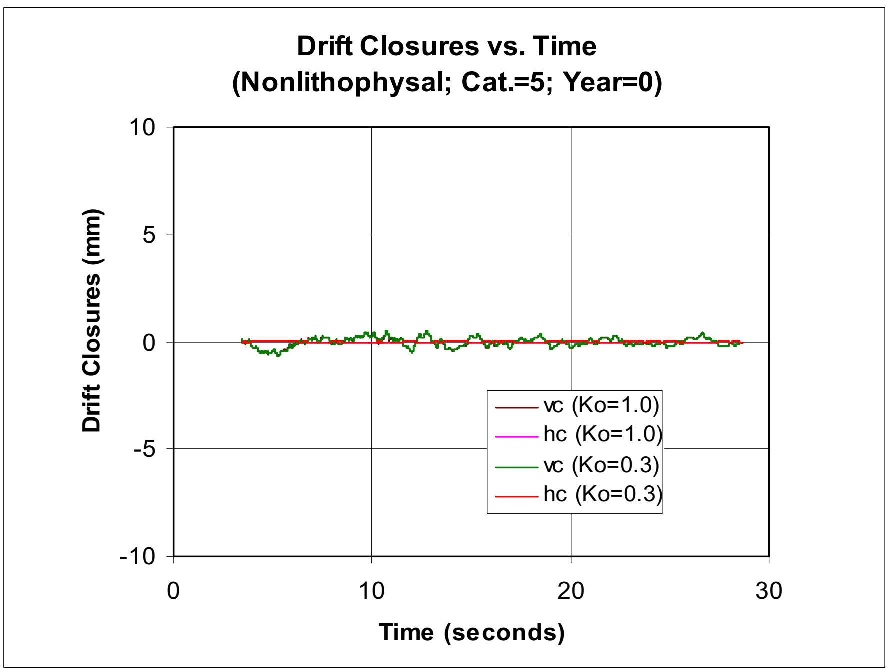


(b)

Figure 6-10 Time Histories of Closures in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under Seismic Load at Year=50: (a) Category 1; (b) Category 5

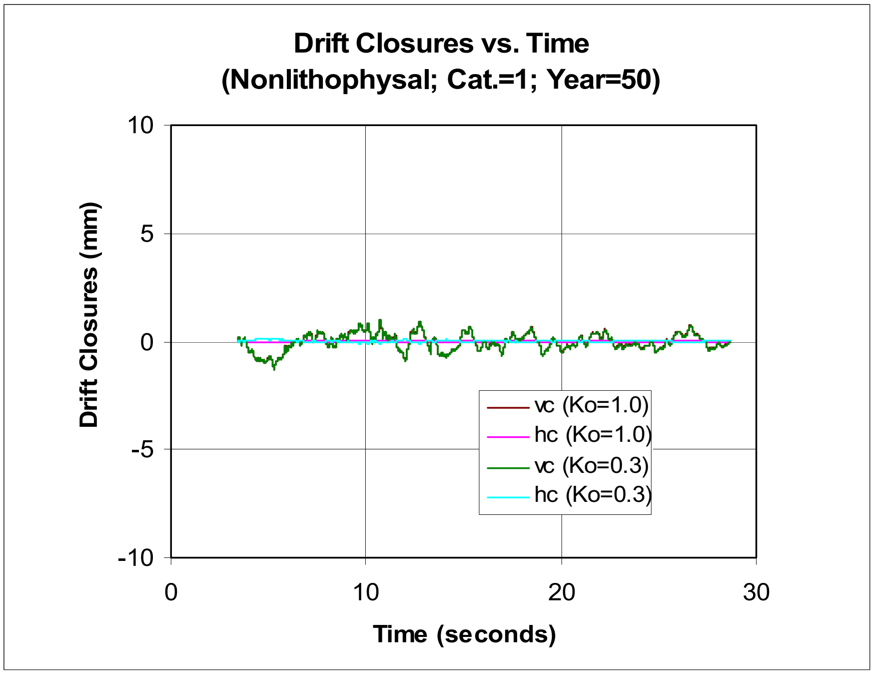


(a)

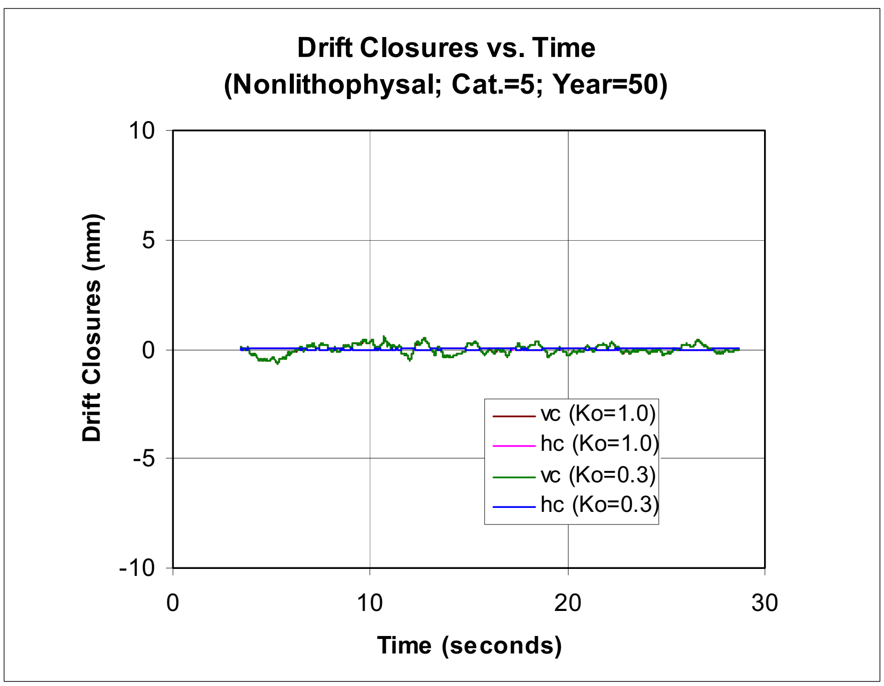


(b)

Figure 6-11 Time Histories of Closures in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under Seismic Load at Year=0: (a) Category 1; (b) Category 5



(a)



(b)

Figure 6-12 Time Histories of Closures in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under Seismic Load at Year=50: (a) Category 1; (b) Category 5

6.4.2.2 Stresses in Rock Mass Adjacent to Drifts

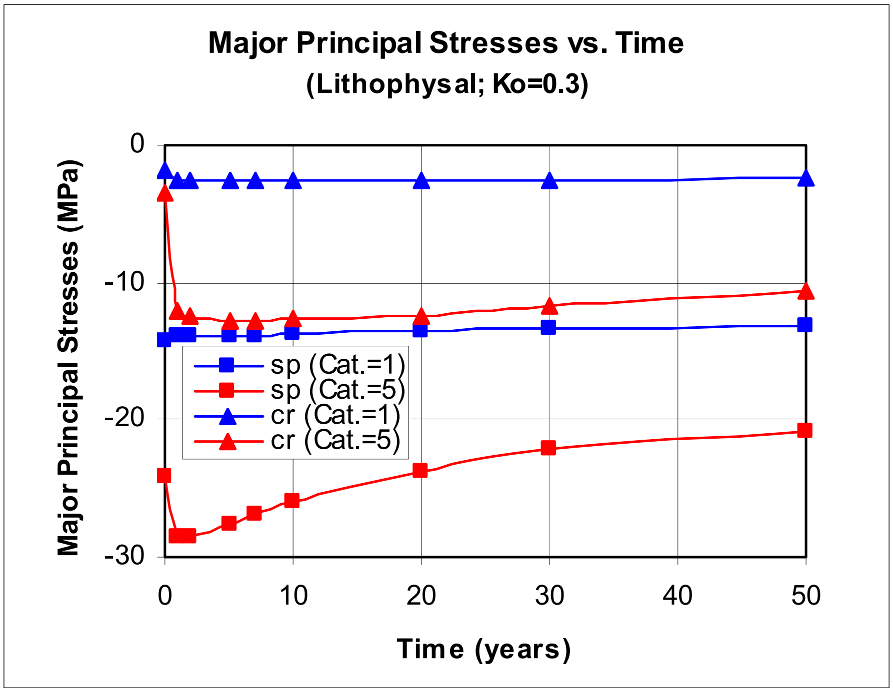
Stresses in rock mass adjacent to emplacement drifts were predicted to evaluate the stability of these drifts subjected to in situ, thermal, and seismic loads. Areas where the magnitude of stresses is critical to the stability of emplacement drifts are those near the crown and the springlines. The major principal stresses in these areas are examined to ensure that any potential unstable conditions due to excessive stresses are prevented by appropriate ground support measures.

Time histories of the major principal stresses at the crown and the springline are shown in Figure 6-13(a) and Figure 6-13(b) for unsupported emplacement drifts in the lithophysal rock subjected to in situ and thermal loads corresponding to the initial horizontal-to-vertical stress ratio (K_o) of 0.3 and 1.0, respectively. It is indicated that stresses change with temperature, especially in category 5 rock mass, though the magnitude of change is not substantial for category 1 rock mass. The maximum major principal stresses are expected to vary from about 15 MPa for category 1 rock to about 29 MPa for category 5 rock mass.

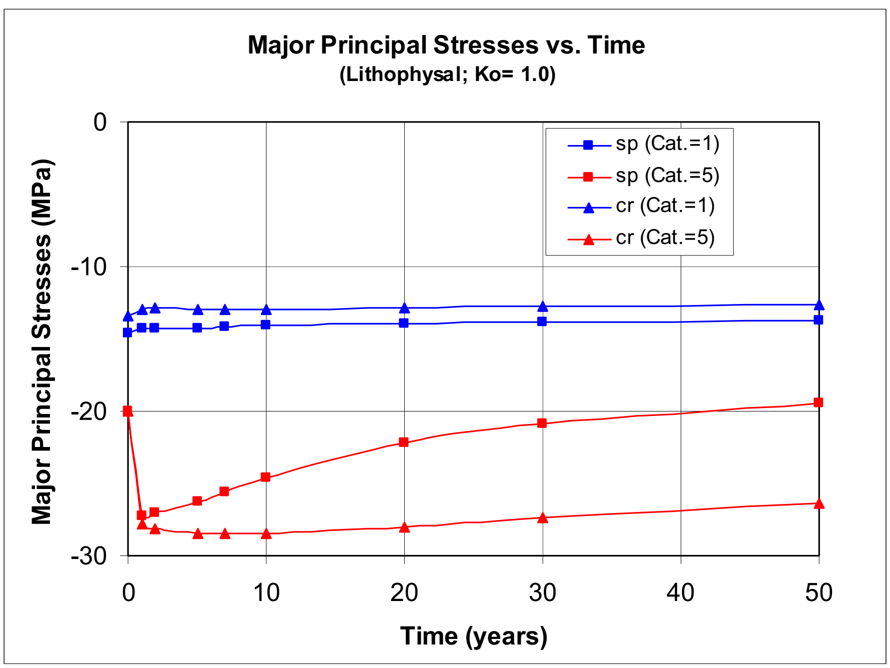
Time histories of the major principal stresses at the crown and the springline are shown in Figure 6-14(a) and Figure 6-14(b) for unsupported emplacement drifts in the nonlithophysal rock subjected to in situ and thermal loads corresponding to the initial horizontal-to-vertical stress ratio (K_o) of 0.3 and 1.0, respectively. Similar to what is observed for the lithophysal rock, stresses change with temperature. The maximum major principal stresses are expected to vary from about 24 to 27 MPa for category 1 rock and about 38 MPa for category 5 rock mass.

During seismic event, stresses fluctuate with seismic velocities, as illustrated in Figure 6-15 and Figure 6-16 for the lithophysal rock and in Figure 6-17 and Figure 6-18 for the nonlithophysal rock, respectively. The magnitude of fluctuation in stresses varies with locations. Near the crown of emplacement drifts, the variations are small, while near the springlines, the fluctuations are larger. The maximum fluctuation in the major principal stresses near the springline is predicted to vary from about 2 MPa for category 1 lithophysal rock to about 5 MPa for category 5 lithophysal rock (see Figure 6-15(a) and Figure 6-15(b)). For emplacement drifts in the nonlithophysal rock, the maximum fluctuation is predicted to vary from about 2 MPa for category 1 rock to about 6 MPa for category 5 rock (see Figure 6-17(a) and Figure 6-17(b)). These results suggest that the stronger the rock is, the greater the variations in stress will be.

Combining the stresses induced by in situ, thermal, and seismic loads, the maximum major principal stresses in the lithophysal rock are expected to vary from about 16 to 17 MPa for category 1 rock to about 34 MPa for category 5 rock. In the nonlithophysal rock, the maximum major principal stresses are expected to vary from about 26 to 29 MPa for category 1 rock mass to about 44 MPa for category 5 rock mass.

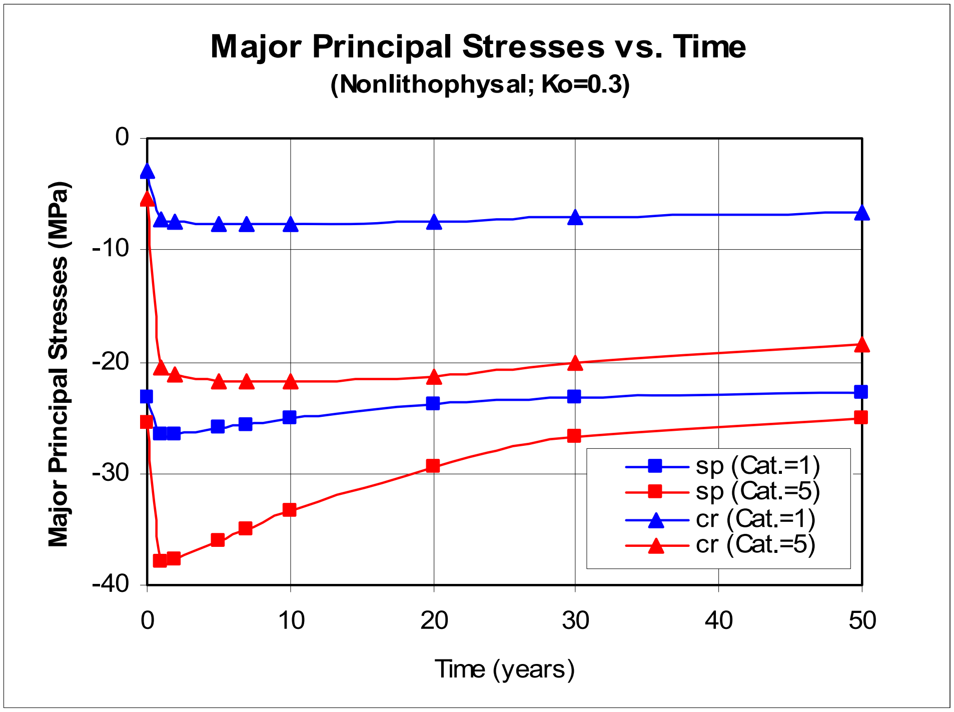


(a)

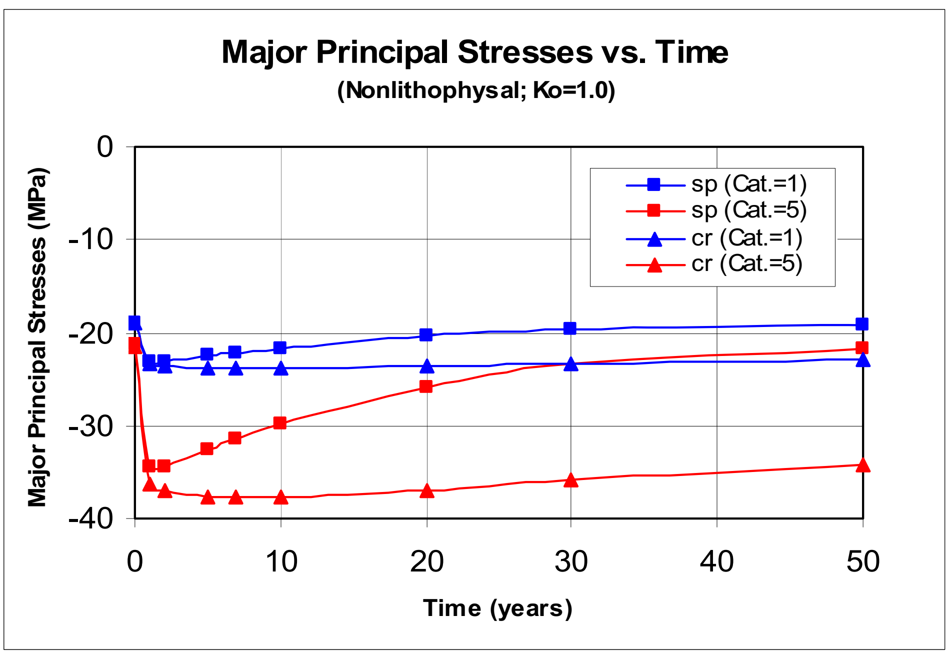


(b)

Figure 6-13 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loads: (a) Ko=0.3; (b) Ko=1.0

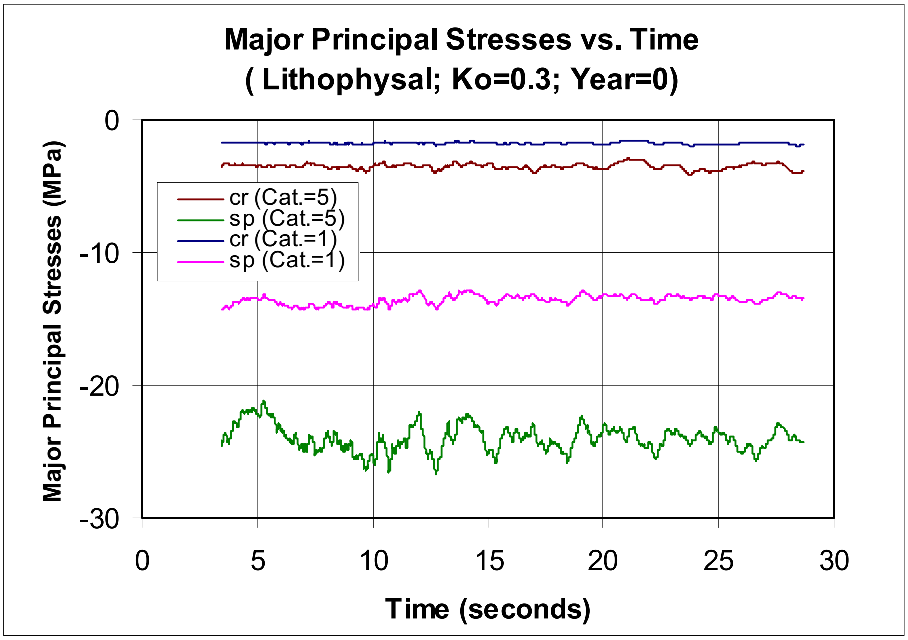


(a)

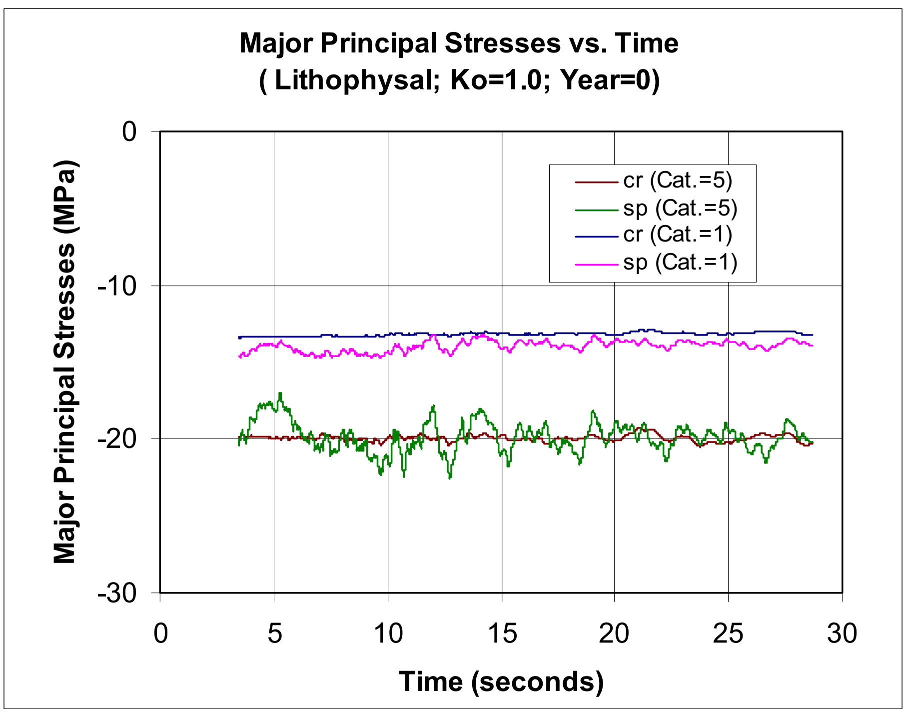


b)

Figure 6-14 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loads: (a) Ko=0.3; (b) Ko=1.0

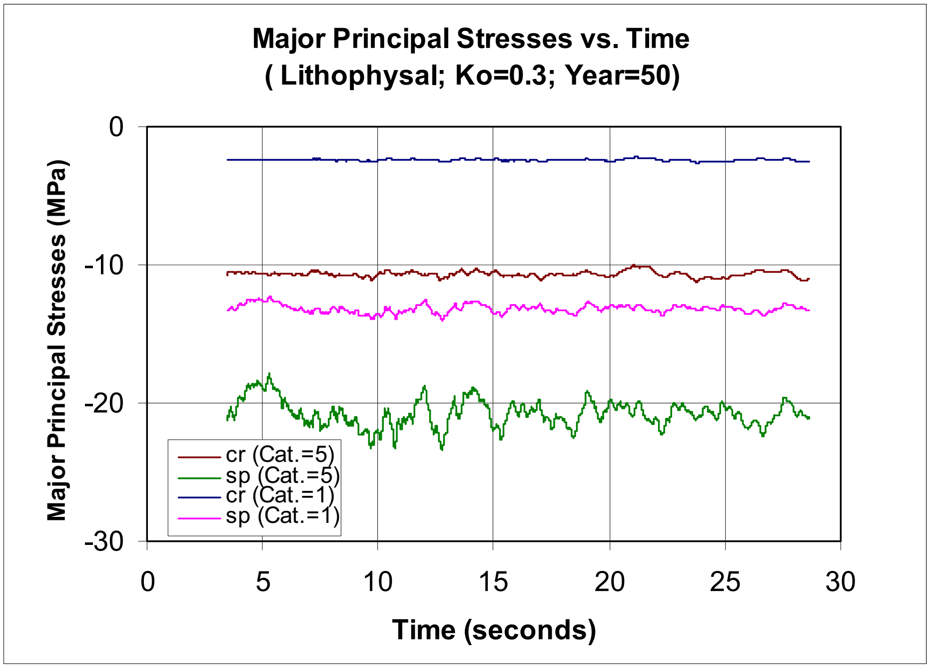


(a)

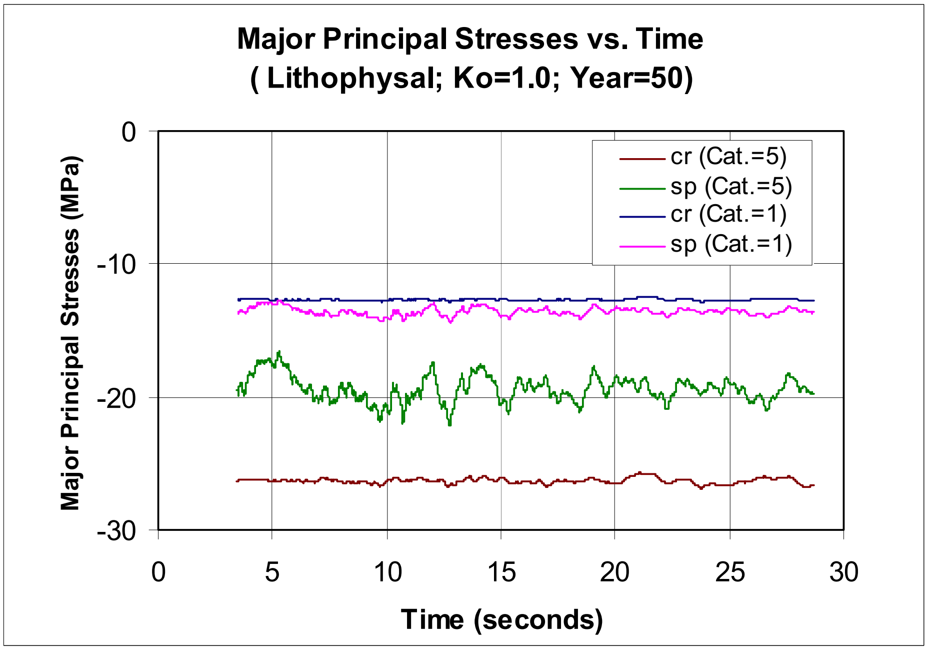


(b)

Figure 6-15 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Loads (Year=0): (a) Ko=0.3; (b) Ko=1.0

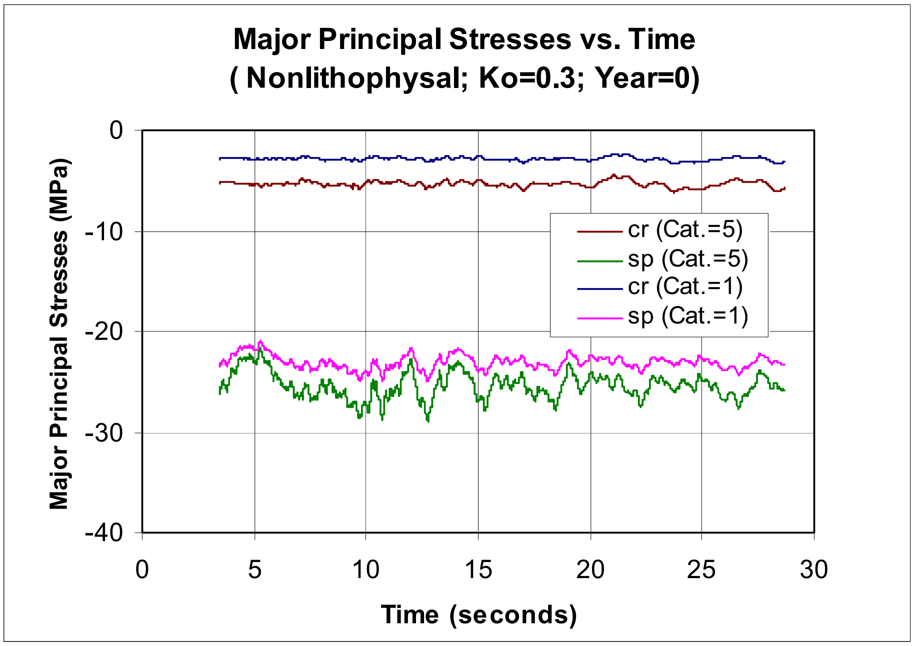


(a)

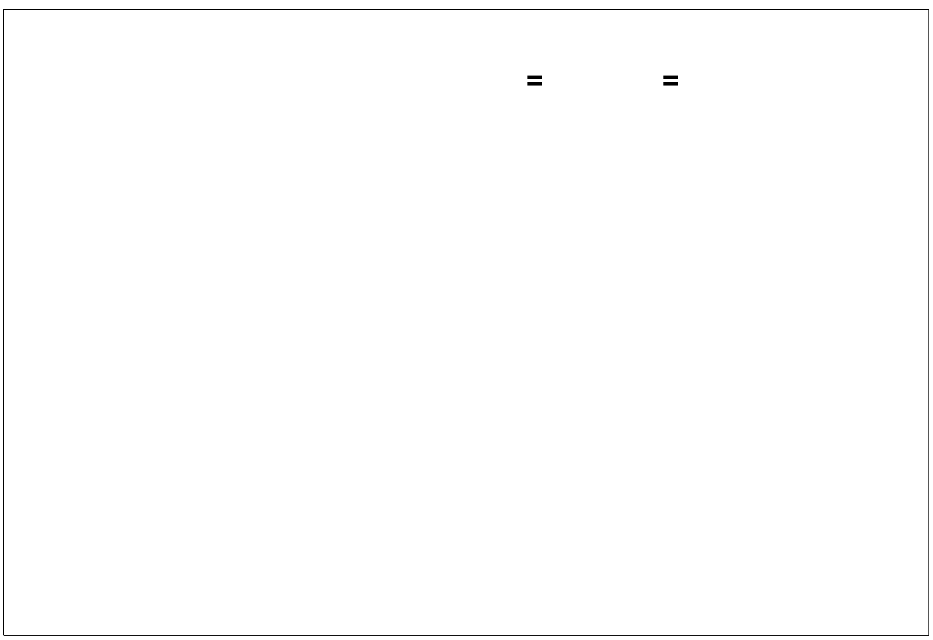


(b)

Figure 6-16 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ, Thermal, and Seismic Load (Year=50): (a) Ko=0.3; (b) Ko=1.0

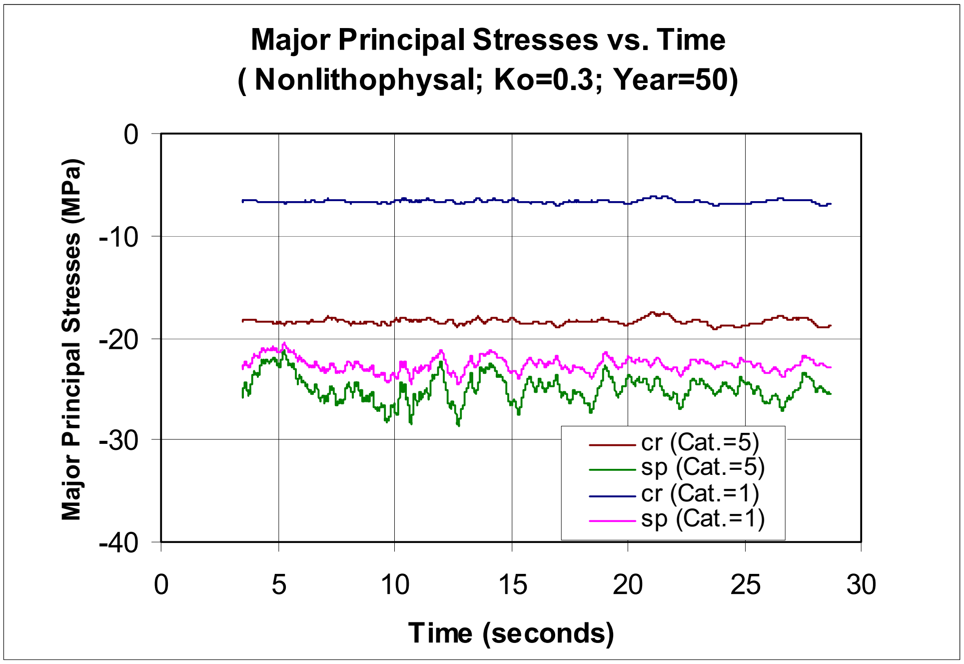


(a)

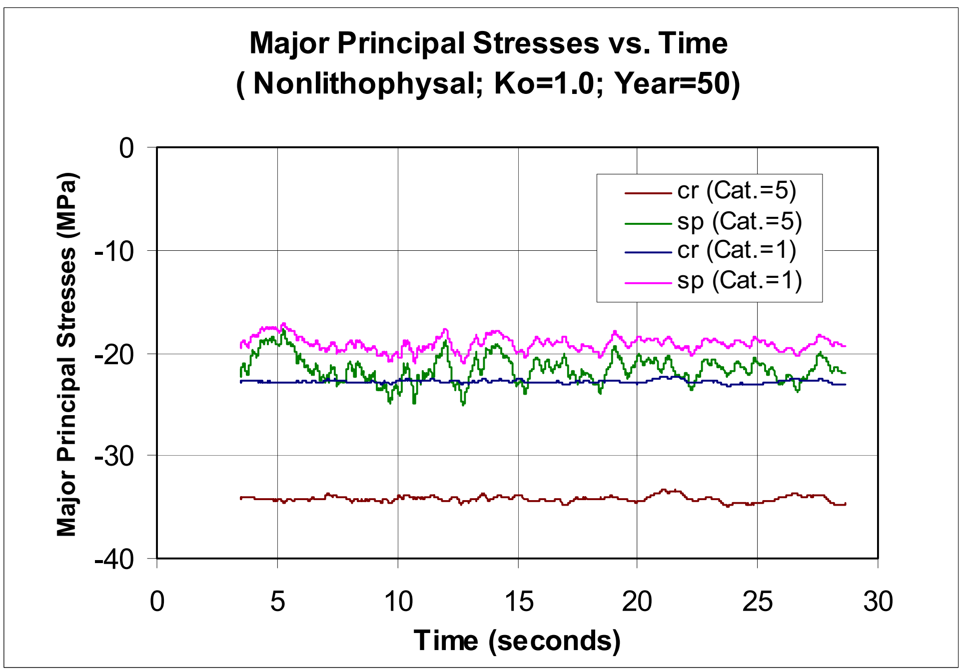


(b)

Figure 6-17 Time Histories of Majo r Principal Stresses near Crown and Springline in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Loads (Year=0): (a) Ko=0.3; (b) Ko=1.0



a)



(b)

Figure 6-18 Time Histories of Major Principal Stresses near Crown and Springline in Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ, Thermal, and Seismic Loads (Year=50): (a) Ko=0.3; (b) Ko=1.0

6.4.3 Assessment of the Stability of Emplacement Drifts

There are several ways to assess the stability of unsupported emplacement drifts. One commonly used method is to examine the potential yield zone around an opening. Another is to evaluate the factor of safety of the excavation under various loading conditions. Results of these stability analyses for emplacement drifts are presented in the following subsections.

6.4.3.1 Potential Yield Zone Around Emplacement Drifts

Potential yield zones around unsupported emplacement drifts in the lithophysal rock are predicted from the FLAC analyses, and plotted in Figure 6-19 through Figure 6-22. The depth of potential yield zone for the lithophysal rock is observed about 1 m for category 1 rock and K_o=0.3 (see Figure 6-19). For category 5 rock mass, the depth of potential yield zone is typically less than 1 m (see Figures 6-21 and 6-22).

Comparing the distribution of potential yield zone induced by excavation (Figure 6-19(a)) to that following 50 years of heating (Figure 6-19(b)) for category 1 rock mass, it is seen that heating slightly expands the overstress zone near the drift wall, but generally the overall stress distribution is not significantly altered. This trend is also observed for category 5 rock mass.

In the nonlithophysal rock, the depth of potential yield zones for both rock categories 1 and 5 and initial stress ratios of 0.3 and 1.0 is observed about 1 m or less (see Figure 6-23 through Figure 6-26). Heating following waste emplacement does not change the stress conditions around the drift much, as observed in the lithophysal rock.

Overall, the unsupported emplacement drift openings in both the lithophysal and nonlithophysal rocks are considered stable under in situ and thermal loads judged by the stress conditions and the depth of potential zones.

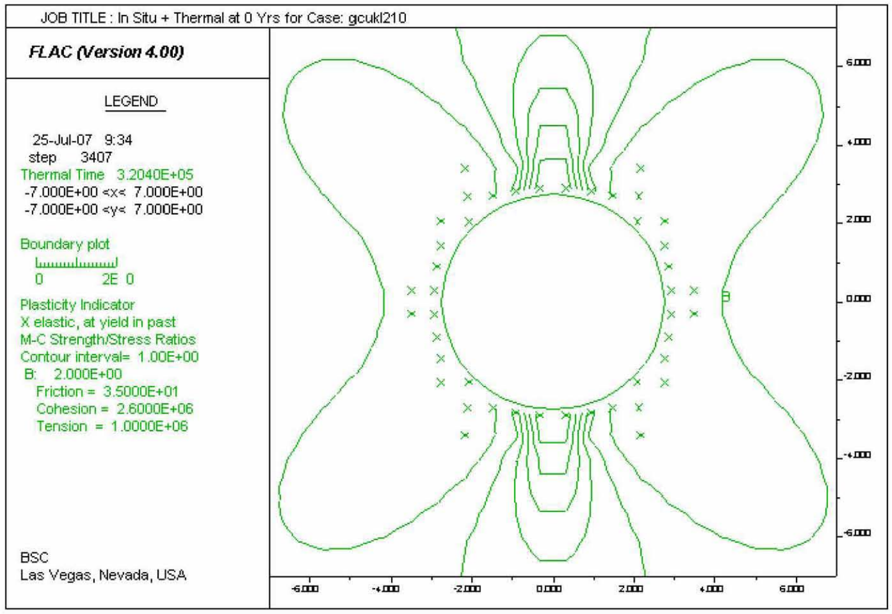
6.4.3.2 Factor of Safety of Emplacement Drifts

The average factors of safety for unsupported emplacement drifts were evaluated based on strength-to stress ratio. Mohr-Coulomb STSRs for unsupported emplacement drifts in both the lithophysal and nonlithophysal rocks are shown in Figure 6-19 through Figure 6-26. Since stresses are higher near the springline compare to the crown for K_o=0.3, a higher STSR is predicted near the crown than that near the springline as shown on Figure 6-19, Figure 6-21, Figure 6-23, and Figure 6-25. For K_o=1.0, the stress condition is close to a hydrostatic state, and the predicted STSRs are nearly uniform around an emplacement drift opening as observed on Figure 6-20, Figure 6-22, Figure 6-24, and Figure 6-26.

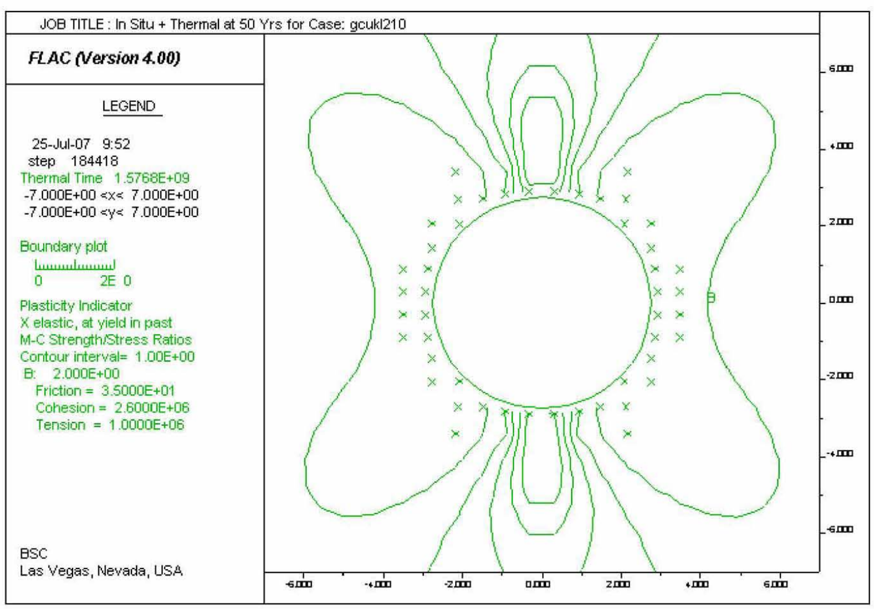
Using these STSR distributions, an overall factor of safety is estimated for the unsupported emplacement drift under a specific loading condition. The estimated factor of safety is an average value of STSRs over an annulus around the drift. The thickness of the annulus used is 3 m, which is equal to the proposed rock bolt length (see Section 6.6.2). Due to nonuniform stresses during heating (see Figure 6-13 and Figure 6-14), the estimated factors of safety are time-dependent. Time histories of the average factors of safety under in situ and thermal loads are shown in Figure 6-27(a) and Figure 6-27(b) for unsupported emplacement drifts in the lithophysal and nonlithophysal rocks, respectively.

It indicates that an overall factor of safety for unsupported emplacement drifts varies from 2.2 to 6.0 in the lithophysal rock, and from 4.2 to 7.2 in the nonlithophysal rock. It is noted that there is a slight increase in the factor of safety for category 5 rock at lower bound K_o (0.3) over the 50-year heating in rock.

As discussed Section 6.4.2.2, stresses fluctuate slightly during seismic shaking. Both the major and the minor principal stresses are expected to change in the same trend, either both increase or both decrease. This will result in a minimal variation in shear stresses. The average factors of safety due to seismic loading condition is not expected to alter significantly the ones under combined in situ and thermal loading conditions. Therefore, the factors of safety discussed above may also serve as reasonable estimates for emplacement drifts subjected to the combined loading of in situ, thermal and seismic loads.

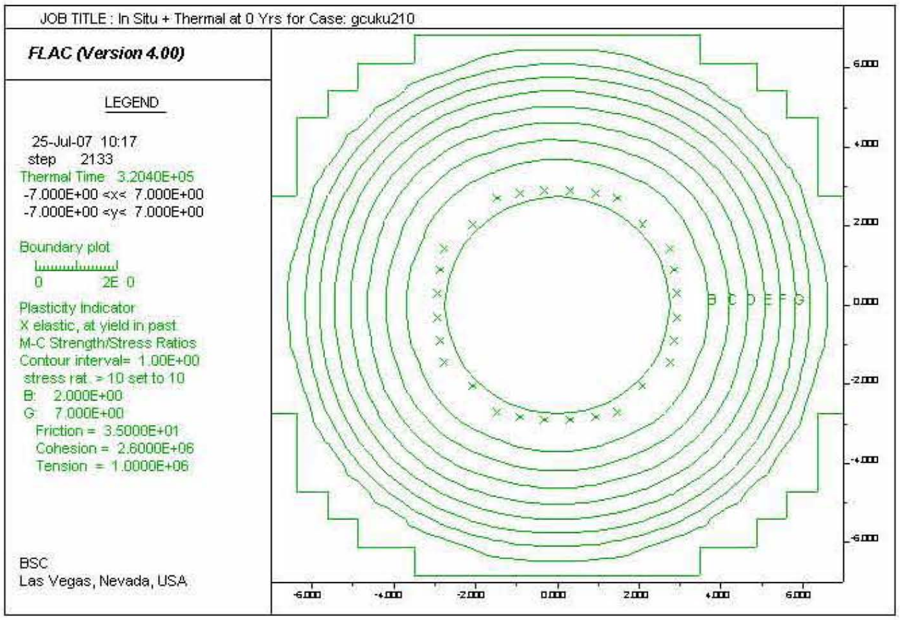


(a)

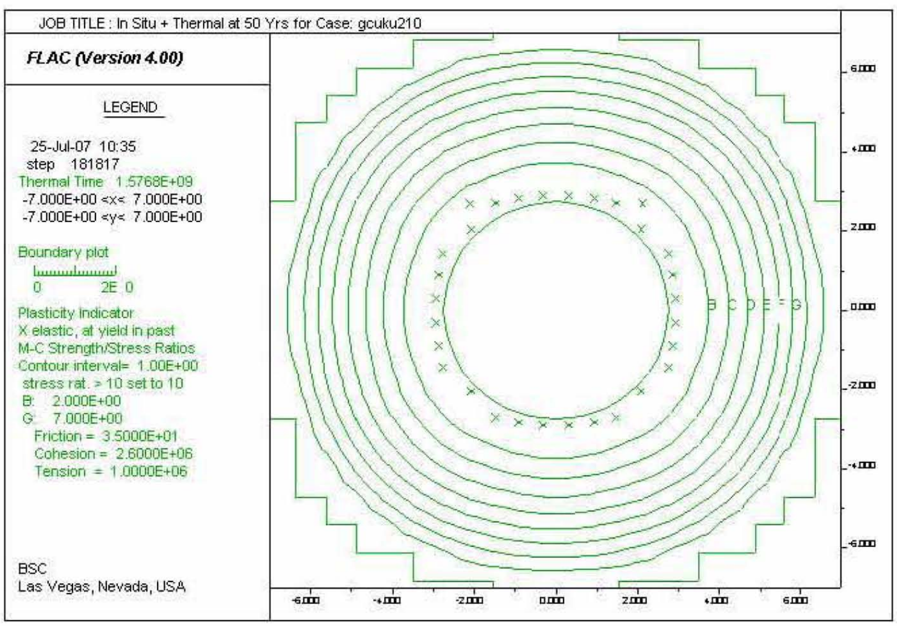


(b)

Figure 6-19 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Lithophysal Rock with Category 1 and Ko=0.3: (a) at 0 Year; (b) at 50 Years.

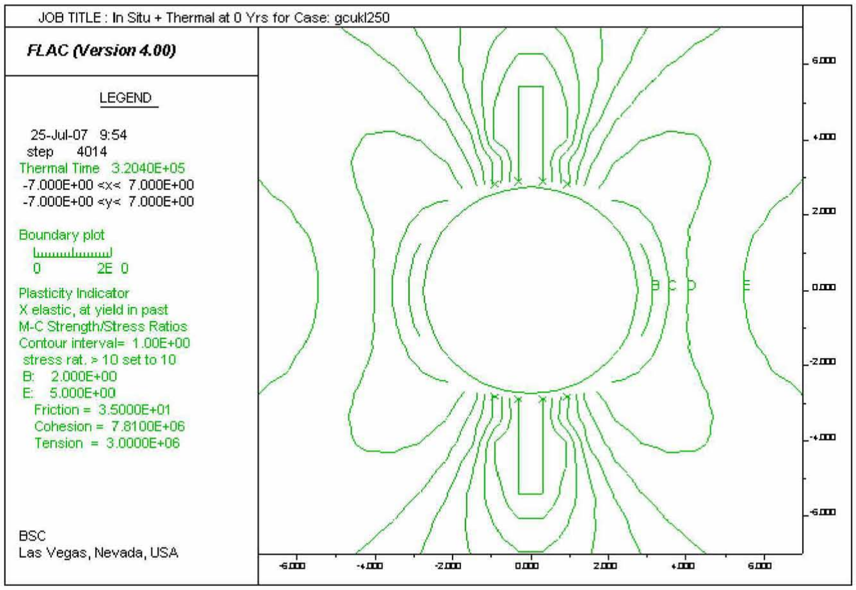


(a)

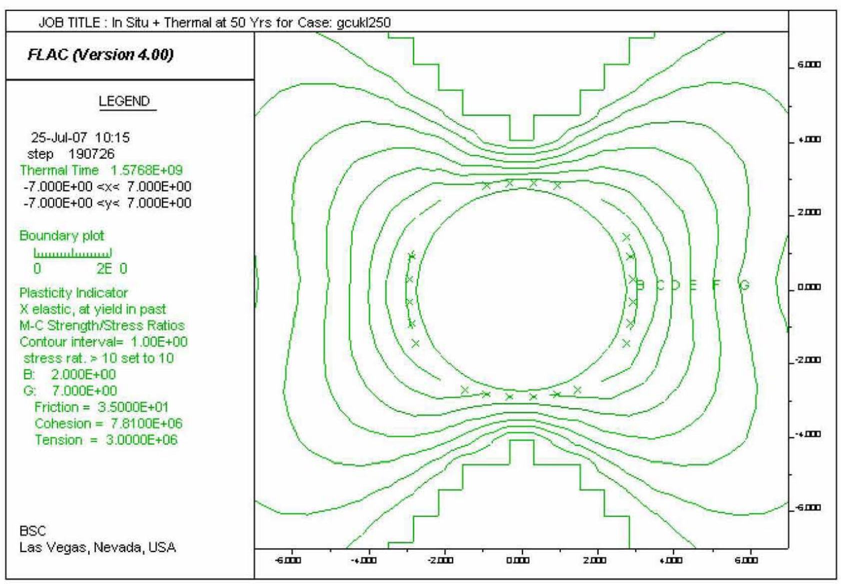


(b)

Figure 6-20 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Lithophysal Rock with Category 1 and Ko=1.0: (a) at 0 Year; (b) at 50 Years.

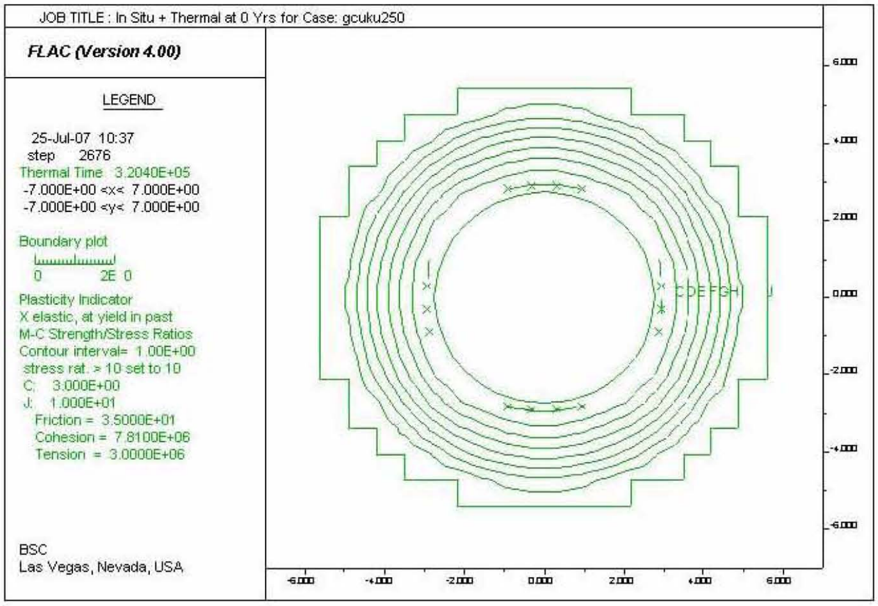


(a)

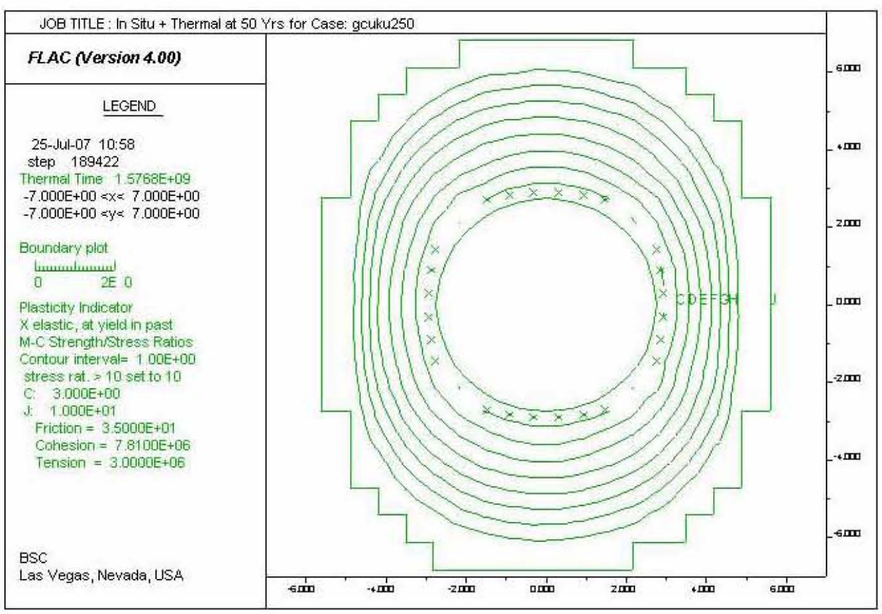


(b)

Figure 6-21 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Lithophysal Rock with Category 5 and Ko=0.3: (a) at 0 Year; (b) at 50 Years.

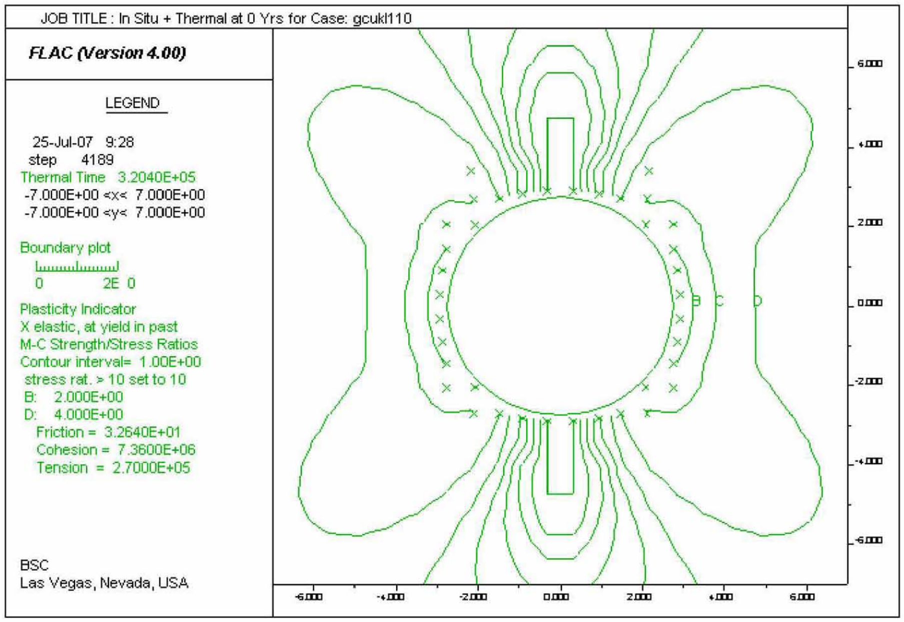


(a)

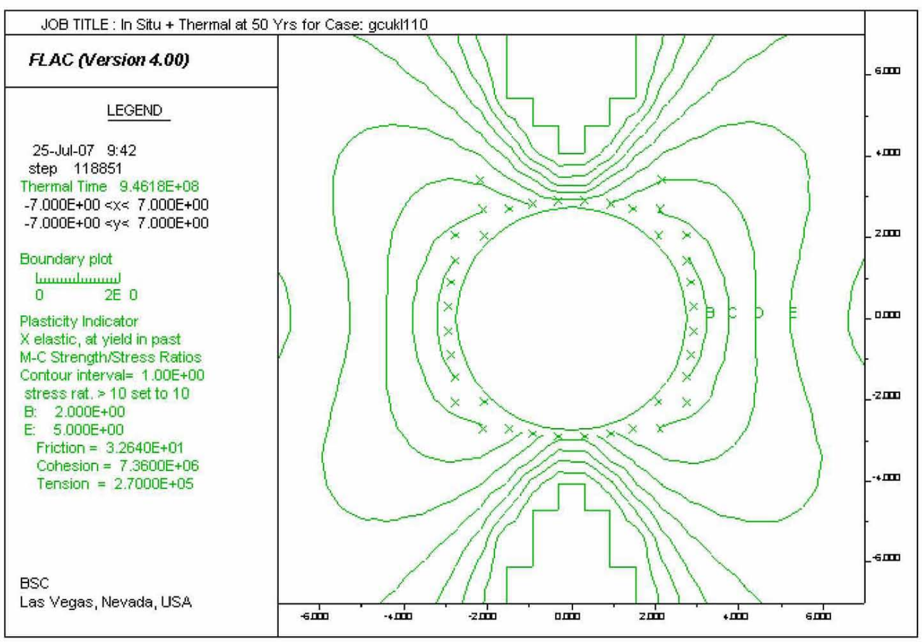


(b)

Figure 6-22 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Lithophysal Rock with Category 5 and Ko=1.0: (a) at 0 Year; (b) at 50 Years.

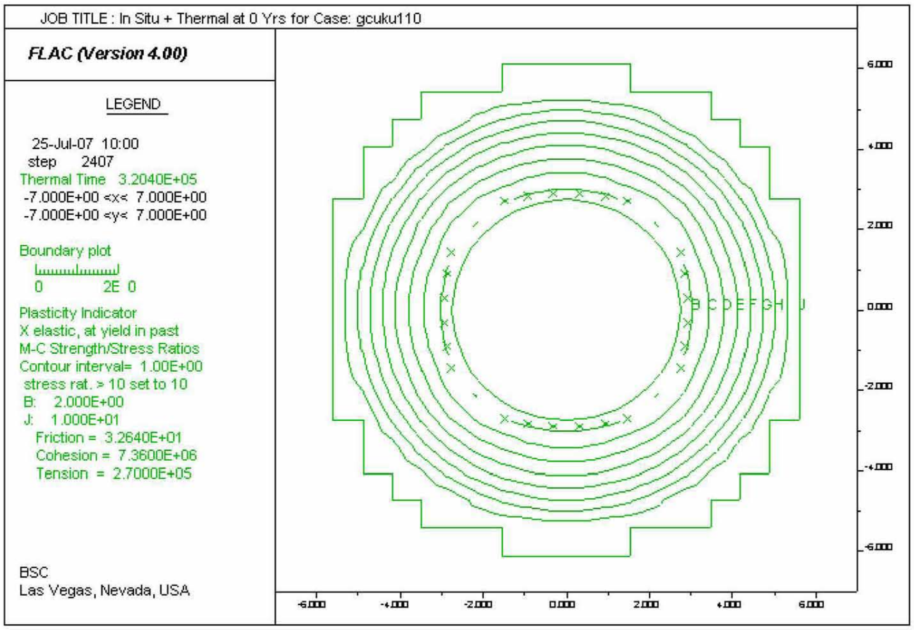


(a)

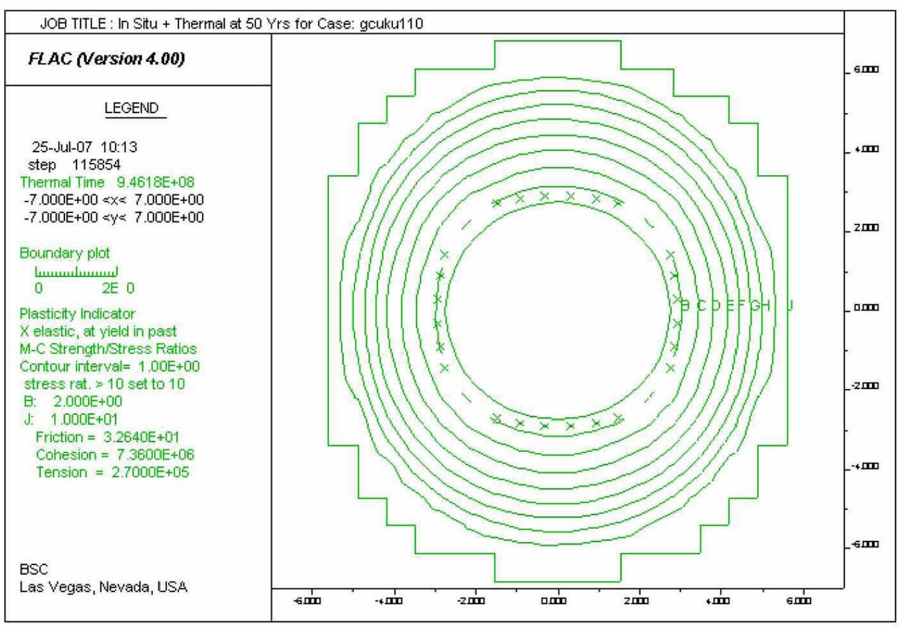


(b)

Figure 6-23 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Nonlithophysal Rock with Category 1 and Ko=0.3: (a) at 0 Year; (b) at 50 Years.

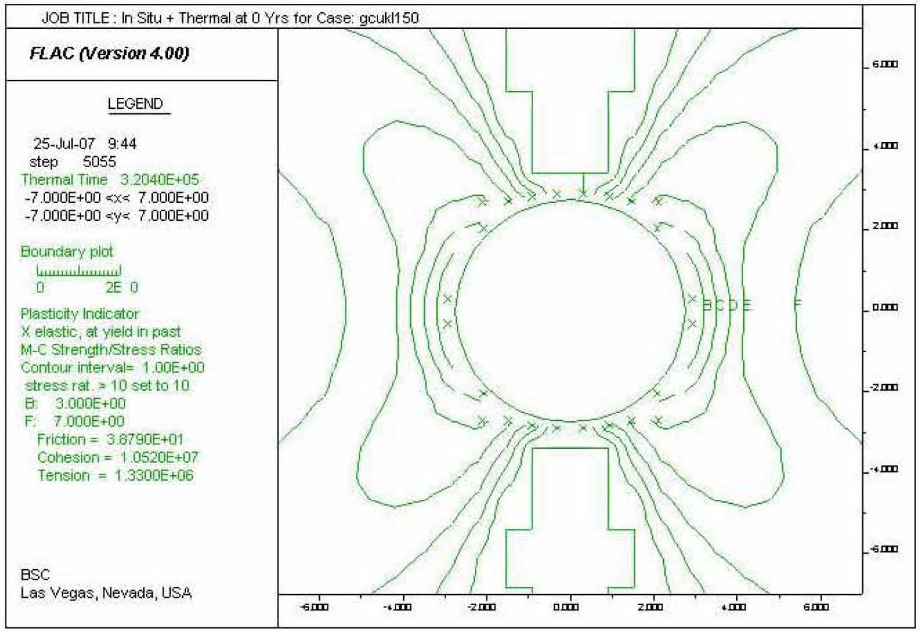


(a)

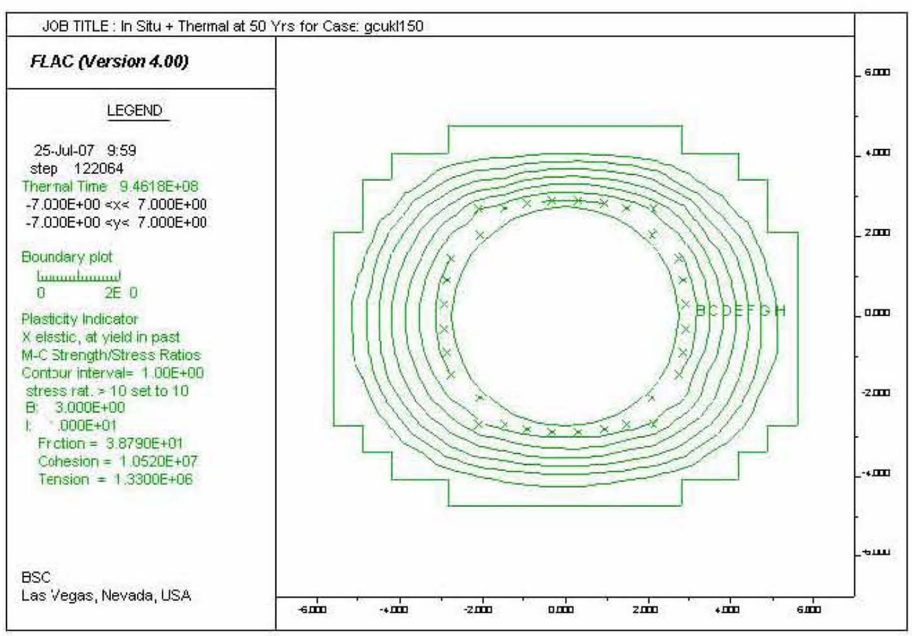


(b)

Figure 6-24 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Nonlithophysal Rock with Category 1 and Ko=1.0: (a) at 0 Year; (b) at 50 Years.

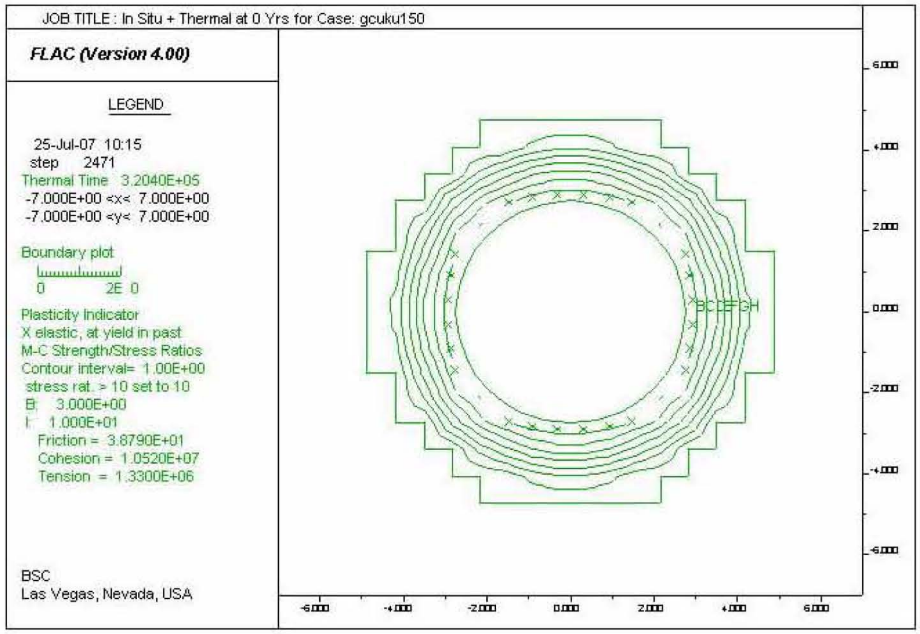


(a)

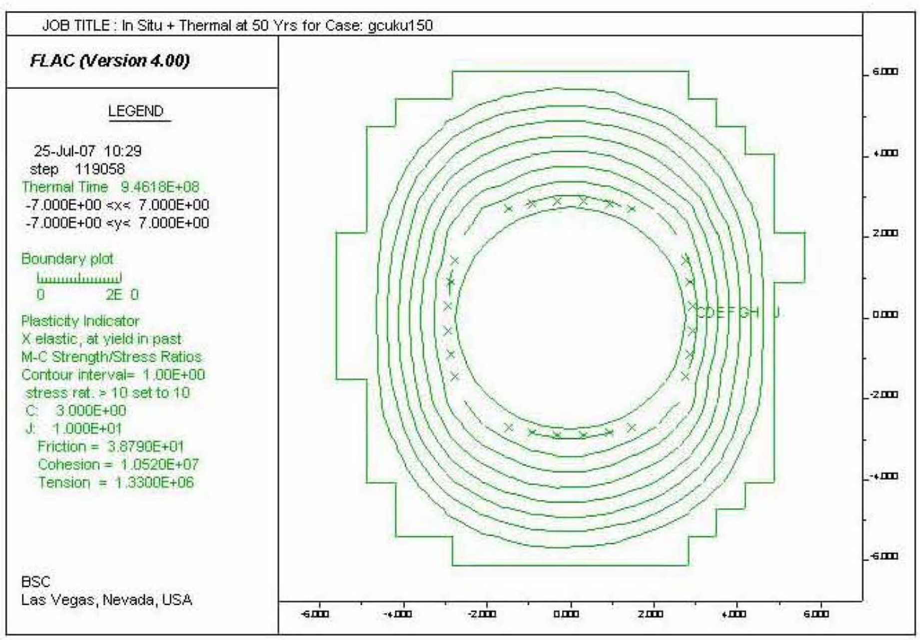


(b)

Figure 6-25 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Nonlithophysal Rock with Category 5 and Ko=0.3: (a) at 0 Year; (b) at 50 Years.

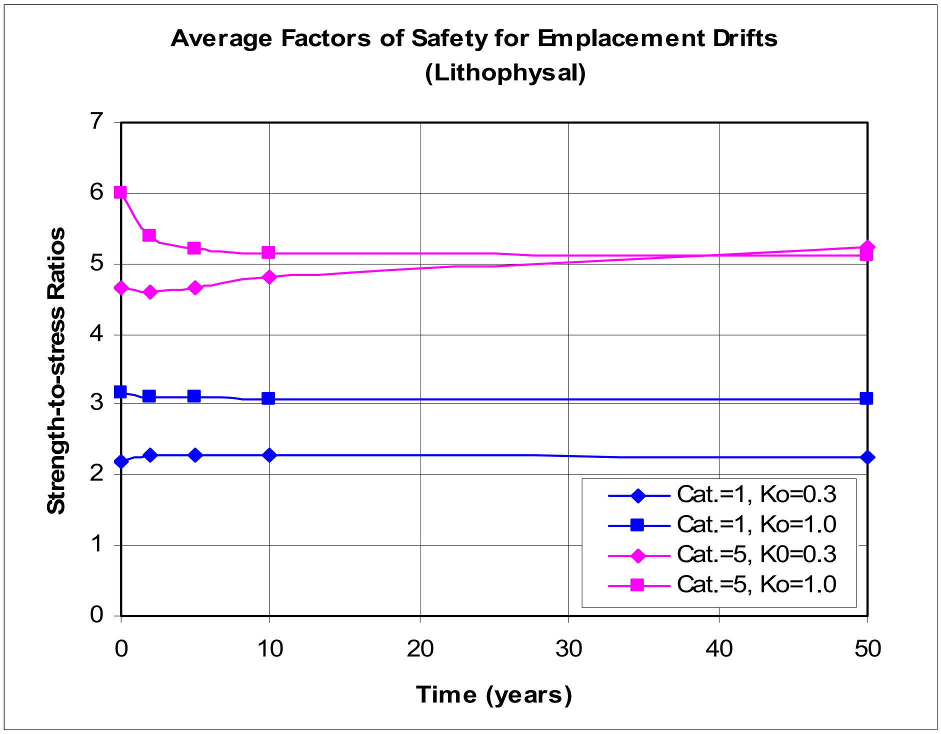


(a)

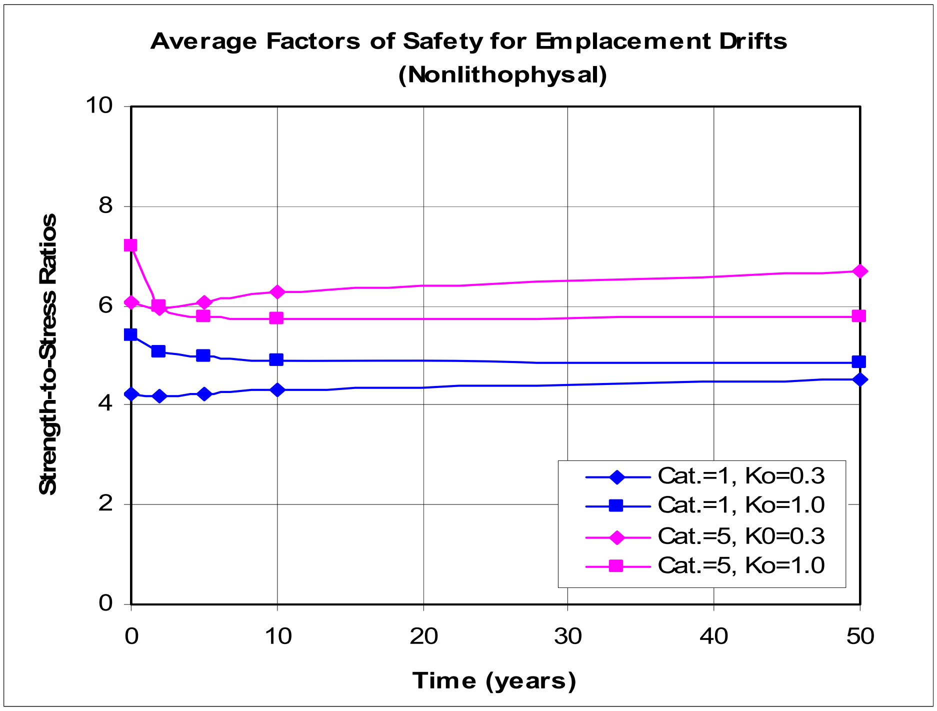


(b)

Figure 6-26 Potential Yield Zone and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Nonlithophysal Rock with Category 5 and Ko=1.0: (a) at 0 Year; (b) at 50 Years.



(a)



(b)

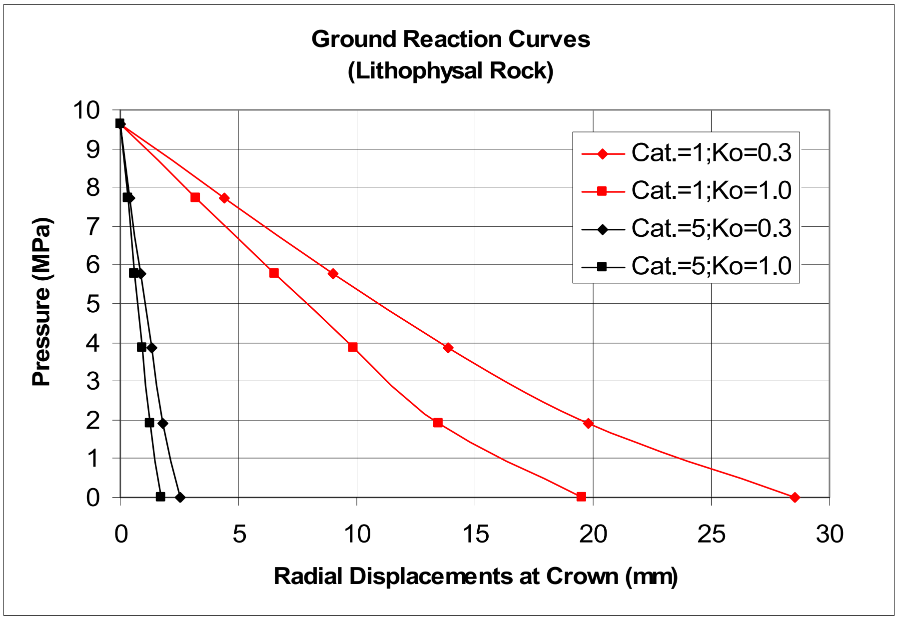
Figure 6-27 Average Factors of Safety for Unsupported Emplacement Drifts Under In Situ and Thermal Loads Based on STSR: (a) in Lithophysal Rock, (b) in Nonlithophysal Rock

6.4.4 Ground Reaction Curves

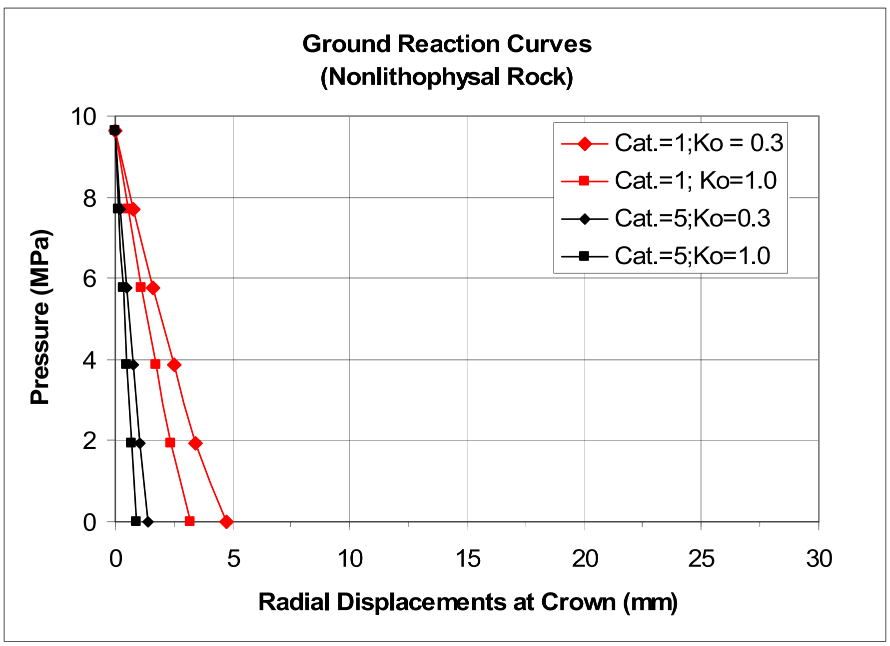
For ground support design purposes, the concept of GRC is used to examine the interaction between rock bolts and rock mass. The visualization of GRC can also serve as an additional check of the stability of unsupported emplacement drifts, and to quantify the potential load that may be induced in rock bolts due to further ground convergence after bolt installation.

Ground reaction curves for emplacement drifts with various rock categories and K_o values were generated using the FLAC models. These curves are shown in Figure 6-28(a) and Figure 6-28(b) for the lithophysal and nonlithophysal rocks, respectively. For each point on a curve, a FLAC run was conducted by applying a pressure (or stress) on the drift wall to determine the relation between the applied pressure and the drift wall radial displacements. The applied pressure selected varies from zero to the in situ stress at the drift center, with five equal intervals. This resulted in a total of six points, or six FLAC runs, for each curve. Each point demonstrates the drift state of equilibrium at a specific level of pressure imposed by ground support.

As shown in Figure 6-28(a) and Figure 6-28(b), the ground reaction curves are generally straight lines and all intersect with the displacement axis, indicating that the drifts are anticipated to be stable and self-supporting. The ground support function in these cases is merely retention of occasional loose pieces of rock. The ground reaction curves for the emplacement drifts in category 1 lithophysal rock show stable conditions but the rock displacements are relatively large, i.e., about 19 and 28 mm for K_o values of 1.0 and 0.3, respectively. To prevent any potential unstable conditions caused by excessive rock displacements, rock reinforcement by installing rock bolts quickly or using lining type support is necessary.



(a)



(b)

Figure 6-28 Ground Reaction Curves for Unsupported Emplacement Drifts: (a) Lithophysal Rock; (b) Nonlithophysal Rock.

6.5 EMPIRICAL ANALYSIS OF GROUND SUPPORT NEEDS

For emplacement drifts in the nonlithophysal rock, use of the RMR and Q approaches for ground support design is considered to be conventional (see Section 4.3.1.3).

For NGI Rock Mass Classification approach, Q values for various rock mass categories need to be calculated. The following steps are needed for estimating the Q values:

- Calculate the RMR values (shown in Table 6-7) from E_m (elastic modulus) values (shown in Table 6-5) based on Eq. 4-1.
- Determine the unconfined compressive strength (σ_c) of intact representative nonlithophysal rock (Tptpmn), which is about 165 MPa (Reference 2.2.27, Table 6-9).
- Estimate the major principal stress (σ_1) of rock adjacent to emplacement drifts, which is estimated to be about 25 to 40 MPa (Section 6.4.2.2).
- Calculate the ratio σ_c/σ_1 to be in the ranges of 4 to 7.
- The joint water reduction factor J_w in Eq. 4-3 is set to 1 for dry rock condition.
- Assign SRF value according to Table 4.6 of the *Support of Underground Excavations in Hard Rock* (Reference 2.2.36, p. 43). A SRF value ranging from 0.5 to 2 is considered appropriate.
- The Q values for various categories are then calculated based on Eq. 4-3, and listed in Table 6-7.

Based on the Q values obtained (shown in Table 6-7) by following steps above and Figure 4-1, the needs for ground support in emplacement drifts in the nonlithophysal rock can be estimated. To estimate the requirements of ground support using the Q system, an excavation support ratio (ESR) needs to be selected. The value of ESR is related to the intended use of the excavation and to the degree of security which is demanded of the support system installed to maintain the stability of the excavation. A suggested value for the emplacement drifts is 1.3 (Reference 2.2.36, p. 40). Hence, the equivalent dimension (D_e), defined as the ratio of span or height to ESR (Reference 2.2.36, p. 39), for the emplacement drifts is determined as 4.2 m (5.5/1.3=4.2 m). With the Q and D_e values determined, the needs for ground support for emplacement drifts in the nonlithophysal rock can be estimated. A recommended ground support system based on this approach is presented in Table 6-7 for each category of nonlithophysal rocks considered.

Based on discussion in Section 6.2, typical rock conditions are close to rock mass categories 3 and 4. Use of pattern bolting with 3 m long, spaced at 1.25 m, in conjunction with 30 to 50 mm thick shotcrete is adequate, and should also be able to accommodate the category 1 rock conditions. Note that since shotcrete cannot be installed in emplacement drifts in order to meet the material requirement for long-term waste isolation, the recommended use of shotcrete is replaced by the Bernold-type stainless steel sheet.

Table 6-7 Estimate of Ground Support Needs for Emplacement Drifts in Nonlithophysal Rock Based on RMR and Q Systems

Rock Mass Category	E_m (GPa)	RMR	SRF	Q	Ground Support Needs
1	10.59	51	0.5 – 2.0	1.09 – 4.35	Bolts: 3 m long, spaced 1.7-2.1 m in crown and walls, with Bernold-type sheet, or wire mesh and 40-60 mm shotcrete
2	16.79	59	0.5 – 2.0	2.65 – 10.59	Bolts: 3 m long, spaced 1.8-2.3 m in crown and walls, with Bernold-type sheet, or wire mesh and 30-50 mm shotcrete
3	19.95	62	0.5 – 2.0	3.69 – 14.78	Bolts: 3 m long, spaced 2.0-2.3 m in crown and walls, with Bernold-type sheet, or wire mesh and 30-50 mm shotcrete
4	28.18	68	0.5 – 2.0	7.20 – 28.78	Bolts: 3 m long, spaced 2.2-2.4 m in crown and walls, with Bernold-type sheet, or wire mesh and 30-50 mm shotcrete
5	35.48	72	0.5 – 2.0	11.22 – 44.89	Bolts: 3 m long, spaced 2.2-2.6 m in crown and walls, with Bernold-type sheet, or wire mesh and 30-40 mm shotcrete

For the emplacement drifts excavated in the lithophysal rock, however, use of the RMR or Q approach for the ground support design is non-conventional, and there are no sufficient data or field experiences available to support this application. This is primarily due to the fact that the lithophysal rock contains air-filled large cavities and is hard to be characterized using the RMR or Q index since a RQD value is defined for a rock with fractures not with voids. Therefore, these empirical methods are not used in this calculation for evaluating the requirements of ground support for emplacement drifts in the lithophysal rock. Selection of ground support methods for this rock type is based on experiences and observations from the construction of the ESF and the ECRB Cross Drift, and assessment from numerical analyses.

6.6 SELECTION OF GROUND SUPPORT METHODS

The ground support methods for emplacement drifts are selected based on the requirements of functions, performance, and service life of ground support system. As stated in Section 6.3, ground support installed in emplacement drifts must ensure stable conditions required for operational worker safety, limit the potential rockfall which might damage waste packages, and be functional with little or no planned maintenance throughout the preclosure period of 100 years (Reference 2.2.19, Section 8.2.2.1). In addition, the ground support materials selected should have acceptable long-term effect on waste isolation (Reference 2.2.20, Section 4.5.2.12).

6.6.1 Candidate Ground Support Components and Materials

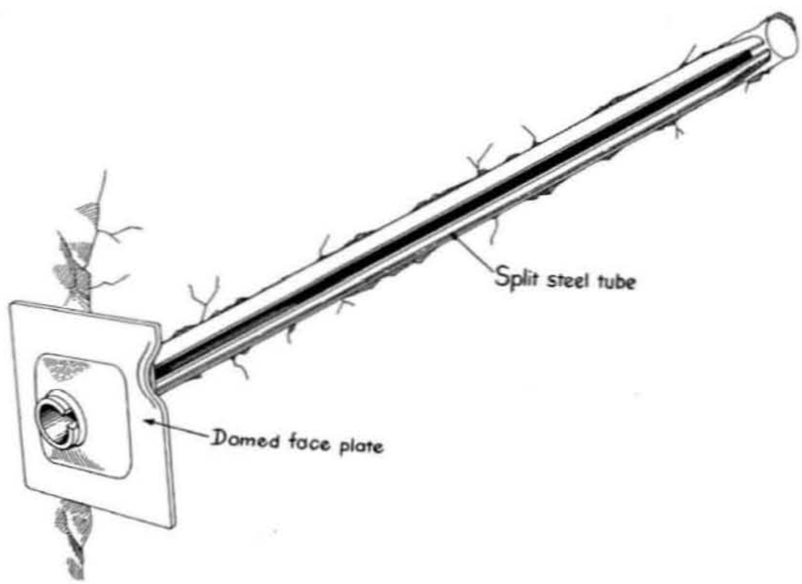
Cementious materials are ruled out for use in emplacement drifts due to their potential adverse impact on the long-term waste isolation. As a result, proposed ground support components to be installed in emplacement drifts will made of steel based, either carbon steel or stainless steel. Candidate ground support components that meet this criterion and functional and performance requirements listed in Section 6.3 are friction-type rock bolts and perforated steel sheets (Reference 2.2.12, Section 6.3).

6.6.1.1 Friction-type Rock Bolts

There are two kinds of widely used friction-type, or friction-anchored, rock bolts: the Split Sets and the Swellex. Both types of rock bolting system rely on frictional resistance along the whole length of a bolt to prevent potential loosening rock blocks from becoming detached from the rock mass. The frictional resistance is generated by a radial force against the borehole wall during installation of the bolts.

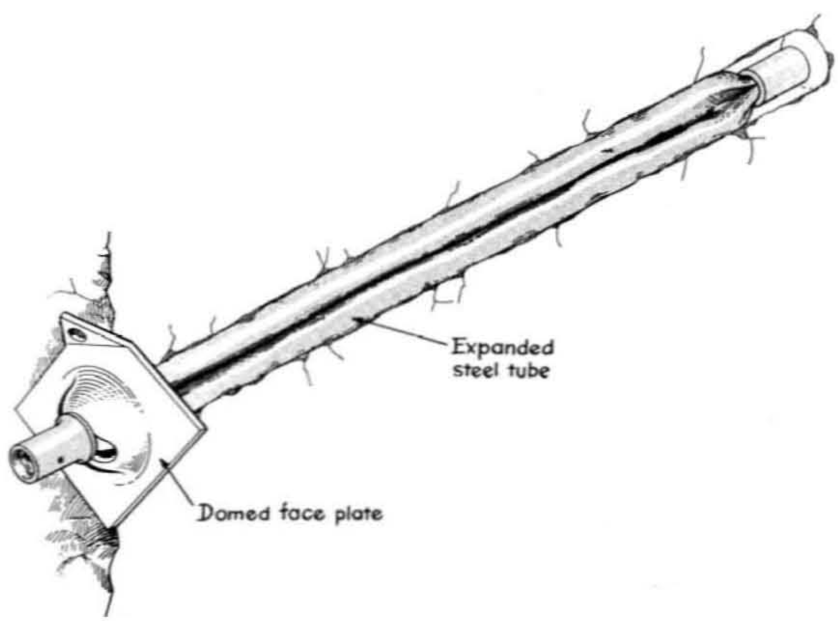
Split Sets The Split Set system, as shown in Figure 6-29, has two parts, a tube and a bearing plate. The steel tube has a slot along its length; one end is tapered for easy insertion, and the other has a welded ring flange to hold the plate. With the bearing plate in place, the tube is driven into a slightly smaller hole. As the tube slides into place, its full-length slot narrows; the tube exerts radial pressure against the rock over its full contact length. Plate loading is generated immediately. The result is a tight grip which actually grows stronger with time and ground movement. The anchorage capacity of a Split Set rock bolt depends on the borehole diameter and the tube length. It typically ranges from 6 to 10 tons for upper range (i.e., for SS-46 Split Set) (Reference 2.2.37, p. 9).

Swellex The Swellex system, as illustrated in Figure 6-30, consists of rock bolts made from circular steel tube, which has been folded to reduce its diameter, and a high pressure water pump. The Swellex rock bolts are placed in a drilled hole and expanded by high pressure water. During the expansion process, the Swellex bolt compacts the material surrounding the hole and adapts its shape to fit the irregularities of the borehole. A combination of frictional and mechanical interlock is generated throughout the entire bolt length, reinforcing and increasing the load-bearing strength of the rock surrounding the drilled hole. The anchorage capacity of a Swellex bolt relies on the original tube diameter and material thickness and the tube length. It varies from 10 metric tons for standard Swellex bolts to 20 metric tons for Super Swellex bolts (Reference 2.2.6, p. 10). The advantages of a Swellex bolt over a Split Set bolt are: a) it can adapt to irregularities of the borehole, which may increase its anchorage capacity, especially for the lithophysal rock with various cavities; and b) it has a higher anchorage capacity than Split Set.



Source: Reference 2.2.49, p. 13.

Figure 6-29 A Typical Split Set Rock Bolt

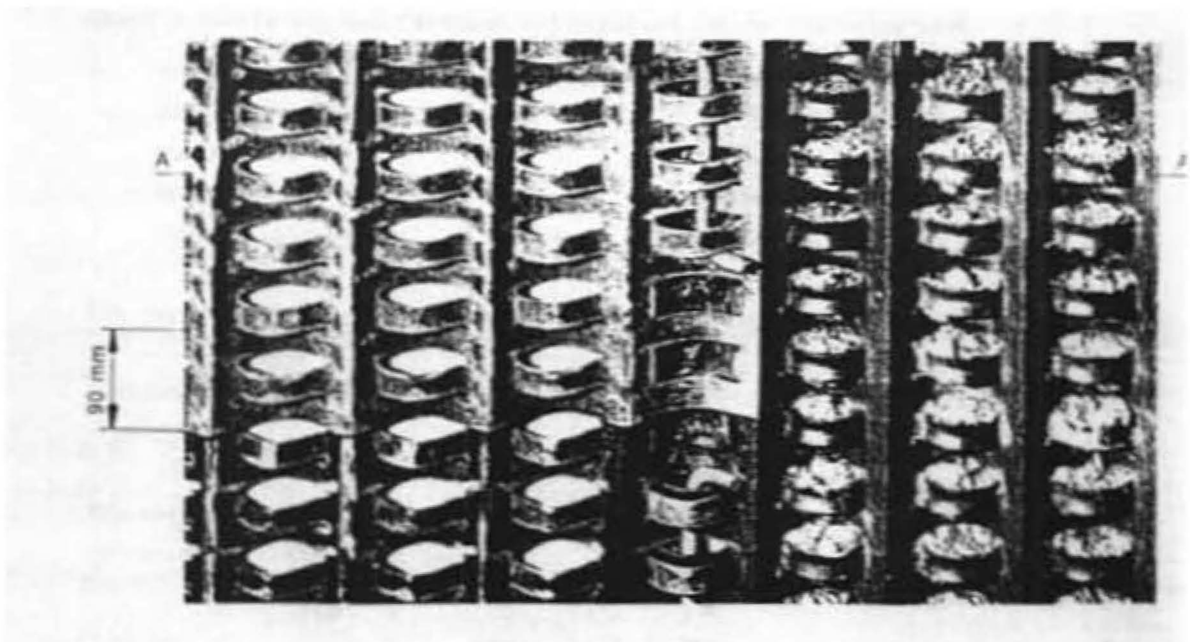


Source: Reference 2.2.49, p. 14.

Figure 6-30 A Typical Swellex Rock Bolt

6.6.1.2 Perforated Steel Sheets

The perforated steel sheets, often called Bernold sheets (Reference 2.2.42, p. 10), as shown in Figure 6-31, consists of thin (2 to 3 mm thick), slotted and slightly corrugated steel sheets and can be bolted tight to the drift surface using friction-type rock bolts. The close contact of the sheets to the drift wall, combined with the holding action of the rock bolts and the extensional strain resistance of the sheets, provides a confinement to potential surface loosening and raveling. The holes stamped in sheets also allow air circulation for rock dry-out and reduce the relative humidity between the sheets and the rock (Reference 2.2.12, Section 6.3.2).



Source: Reference 2.2.42, p. 10.

Figure 6-31 Bernold-type Perforated Steel Sheet

6.6.1.3 Candidate Ground Support Materials

According to the *Longevity of Emplacement Drift Ground Support Materials for LA* (Reference 2.2.12, Section 7.4), candidate material for both friction-type rock bolts and Bernold-type perforated sheets is stainless steel, such as 316 (Reference 2.2.4) equivalent or better, in order to prevent ground support failure prematurely due to corrosion and achieve its longevity during the preclosure period (Reference 2.2.12, Section 7.4).

Steel components that are manufactured based on the following standard specifications included in the American Society for Testing and Materials (ASTM) are expected to perform satisfactorily in the emplacement drift environment:

- ASTM A 36 *Standard Specification for Carbon Structural Steel* (Reference 2.2.2)
- ASTM A 276 *Standard Specification for Stainless Steel Bars and Shapes* (Reference 2.2.4)
- ASTM F 432 *Standard Specification for Roof and Rock Bolts and Accessories* (Reference 2.2.5)

- ASTM A 82 *Standard Specification for Steel Wire, Plain, for Concrete Reinforcement* (Reference 2.2.3)

This ground support system is designed to last at least 100 years without planned maintenance even in severe environmental conditions assumed in emplacement drifts. Any necessary maintenance needs triggered by unfavorable inspection results or by off-normal operational conditions will be evaluated considering full account of the information gathered by the inspection and monitoring activities (Reference 2.2.21, Section 7).

6.6.2 Candidate Ground Support Methods

6.6.2.1 Lithophysal Rock

Observations made in the ESF and the ECRB Cross Drift (Reference 2.2.10, Section 7.3.1.3) indicate that the lithophysal rock contains intense small-scale fractures together with voids of various sizes. Ground support in this type rock should primarily play a role of retention to hold small pieces of loosening rock in place. Swellex bolts and wire mesh installed in the crown and springline of these tunnels appear to provide adequate support and stability. It is noted that ground support required in the ECRB Cross Drift is considered to be very minimal.

Numerical analyses of the unsupported emplacement drifts in the lithophysal rock, as discussed in Sections 6.4.2 and 6.4.3, indicate that the unsupported emplacement drifts are generally stable under combined in situ, thermal, and seismic loading conditions, with small anticipated rock deformation and potential yield zone less than 1 m. The estimated minimum factor of safety for unsupported emplacement drifts in the lithophysal rock under in situ and thermal loading rock is 2.2.

By considering observations from the ESF and the ECRB Cross Drift and results from numerical analyses, the final ground support consisting of Super Swellex-type bolts of 3 m long, spaced at 1.25 m, and 3 mm thick perforated Bernold-type sheets, all installed in a 240° arc around the drift periphery, is recommended for use in emplacement drifts in various rock conditions. As recommended by the *Longevity of Emplacement Drift Ground Support Materials for LA* (Reference 2.2.12, Section 7.4), the materials of these bolts and Bernold-type perforated sheets need to be made of stainless steel in order to prevent ground support failure prematurely due to corrosion and achieve its longevity during the preclosure period.

Swellex rock bolts are preferred over Split Sets because the former generally has higher holding capacity, and will deform, to a certain degree, to accommodate lithophysal cavities along the borehole, which will further increase the holding capacity.

6.6.2.2 Nonlithophysal Rock

Observations made in the ESF and the ECRB Cross Drift (Reference 2.2.10, Section 7.3.1.2) indicate that the nonlithophysal rock (Tptpmn) contains multiple joint sets, dominated by three major subsets, two horizontal and one vertical. This ground condition will most likely result in gravity-induced wedge-type failures, which have occurred in both the ESF and the ECRB Cross Drift. The primary function of the ground support for the nonlithophysal rock is to prevent wedge-type rockfall. Rock bolts with appropriate length and spacing supplemented by wire mesh perform adequately under these ground conditions.

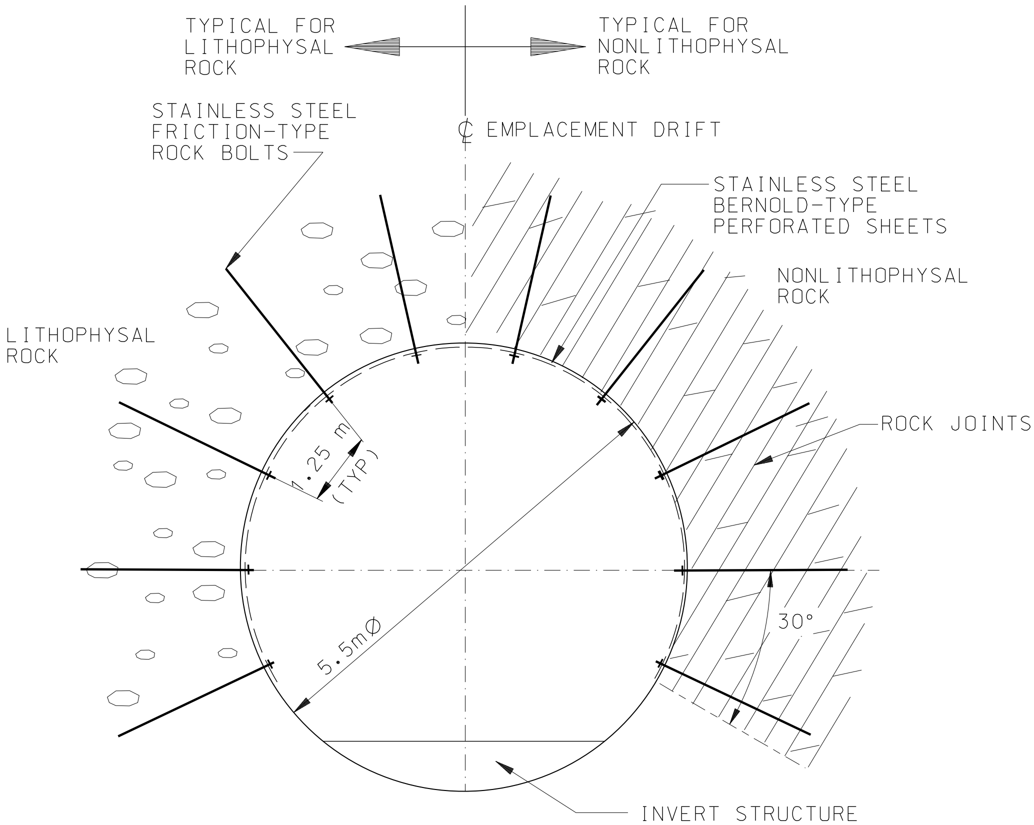
Numerical analyses of the unsupported emplacement drifts using the nonlithophysal rock properties, as presented in Sections 6.4.2 and 6.4.3, show that the drifts are expected to be stable under combined in situ, thermal, and seismic loading conditions, with very small rock deformation and little yield zone for various rock categories. An estimated minimum factor of safety is 4.2 for the nonlithophysal rock under in situ and thermal loading.

Empirical analyses discussed in Section 6.5 suggest that the ground support for emplacement drifts in the nonlithophysal rock consist of friction-type bolts of 3 m long, spaced at 1.25 m, with wire mesh and 30 to 50 mm thick shotcrete in crown and springline for the ground conditions anticipated. Bernold-type perforated steel sheets (3 mm thick), installed in a 240° arc should be in place of shotcrete in consideration of the material restriction as stated in Section 6.6.1.

Figure 6-32 illustrates the recommended ground support methods for emplacement drifts in both lithophysal and nonlithophysal rocks.

6.6.3 Initial Ground Support Methods

The initial ground support will be installed as necessary for worker safety during excavation of the emplacement drifts if a two-pass construction scheme is used. The initial ground support consists of friction-type rock bolts, such as Split Sets, and wire mesh based on industry standard materials (carbon steel). Rock bolts with a length of 1.5 m and a spacing of 1.5 m (four bolts in each row), and wire mesh with W2 x W2 and 100 mm center-to-center spacing, installed in the crown, are considered adequate for the rock conditions anticipated. Wire mesh will be removed prior to the installation of the final ground support, while rock bolts will remain in place depending on the construction practice. During the preclosure period, these carbon steel rock bolts may corrode, however, they are very unlikely to fall out because they are friction-type bolts (anchored over their entire length). In addition, all of these bolts will be covered by the Bernold-type sheets (see Section 6.6.2).



Source: Modified from Reference 2.2.28, Sections A and B. Note: Figure is not to scale.

Figure 6-32 Ground Support Methods Recommended for Emplacement Drifts.

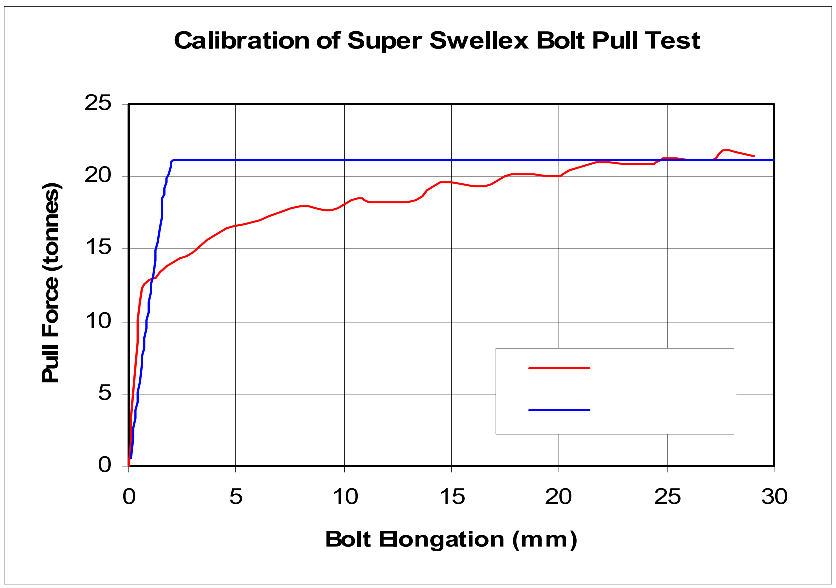
6.7 EVALUATION OF GROUND SUPPORT PERFORMANCE

To evaluate the performance of proposed final ground support system under in situ, thermal, and seismic loading conditions, numerical analyses were conducted. These analyses were based on two-dimensional FLAC models.

6.7.1 Numerical Calibration of Swellex Bolt Pull Test

As discussed in Section 6.6.1.1, reinforcing mechanism of Swellex bolts is frictional and mechanical interlock over the entire bolt length. This kind of mechanism can be simulated using the approach similar to what is used for fully-grouted bolts. Two key input parameters in this approach are the bond stiffness (K_{bond}) and the bond shear strength (S_{bond}), which reflect the interaction between the bolt and the rock mass and control the bolt behavior. These parameter values depend on the frictional resistance at the interface, stiffness of the rock mass, and any near-field stress changes. Values of these two parameters can be estimated either based on empirical correlations developed from pull test data or using numerical calibrations of pull test results. Since there is no empirical correlation currently available, the latter is adopted for this calculation. The numerical calibration was performed using the FLAC code. The pull test data used was for a Super Swellex bolt, and obtained from the Atlas Copco (Reference 2.2.30, Bolt

12, p. 16). Since the pull test data are obtained from Atlas Copco, the manufacturer of Swellex bolts, which are standard industry products, therefore, use of the pull test data is judged as justified for the purpose of this calculation. In numerical calibration, a pull test of rock bolts was simulated using the following properties of concrete block: 2.4 g/cm^3 for density, 60 MPa for compressive strength, and 0.15 for Poisson's ratio (Assumption 3.1.2). During the simulation, an initial value of K_{bond} was chosen to be the same order of magnitude as the stiffness of rock. The stiffness is then decreased until the slope on the load-versus-displacement curve matches the measured from the pull test (Assumption 3.1.1 and Reference 2.2.30, Bolt 12, p. 16). The value of S_{bond} was then adjusted until the model approximated the pull-out load determined from the test. Figure 6-33 shows the results of numerical calibration of the Super Swellex bolt pull test. The values of K_{bond} and S_{bond} estimated from this calibration are 3×10^8 N/m/m and 2.75×10^5 N/m, respectively.



Source: Reference 2.2.30, Bolt 12, p. 16.

Figure 6-33 Numerical Calibration of Super Swellex Bolt Pull Test

6.7.2 Performance of Swellex Bolts in Emplacement Drifts

Performance of Swellex bolts is evaluated using the two-dimensional FLAC models. In these models, the bolts are simulated by one-dimensional cable elements. Each cable element is divided by two nodes, together with the cross-sectional area and the material properties. The cable element is an axial member, meaning that only the uniaxial resistance, compression or tension, is taken into account. Since two-dimensional modeling the bolts with regular spacing in the drift axial direction involves averaging the three-dimensional effect over the distance between the adjacent rows of bolts, linear scaling of material properties of bolt is required in the FLAC models. This scaling is achieved by dividing the actual property by the bolt spacing along the drift. The material properties that need to be scaled include the modulus of elasticity, the strength, K_{bond}, and S_{bond}. Axial force outputs from the models are then multiplied by the bolt spacing to obtain the actual loads. The sign convention in the FLAC models is that axial forces in bolts are positive in compression and negative in tension.

In calculating the effect of excavation-induced rock displacements on rock bolts, a ground relaxation of 60 percent (Assumption 3.2.3) is used in this calculation, which is considered very conservative as far as the in situ load is concerned.

It should be noted that the ground relaxation will depend on the construction sequence, or the time when ground support is installed. If the final ground support is installed after the excavation of an entire emplacement drift is completed, the ground relaxation will likely be about 100 percent. Any loads induced in ground support will be subsequently cased by nearby mining activities or thermal and seismic loading conditions.

It should be also noted that in analyzing the behavior of Swellex rock bolts the effect of Bernold-type steel sheet is not accounted for. This will result in a slightly higher stress or load in rock bolts than anticipated, and is therefore conservative for the purpose of this calculation.

6.7.2.1 Swellex Bolts in Lithophysal Rock

Time histories of axial forces in Swellex bolts installed in emplacement drifts in the lithophysal rock are shown in Figure 6-34 under in situ and thermal loading conditions. The results indicate that axial forces in the bolts are sensitive to the rock mass deformation modulus. In weak rock conditions (category 1), the bolts will be in tension throughout the operational time of 50 years considered. In strong rock conditions (category 5), the bolts will be in tension when subjected to in situ load, and become in compression when the rock mass is heated up. In general, heating in rock is expected to reduce the tensile forces in bolts.

The maximum axial forces in the Swellex bolts are predicted about 100 kN in tension for category 1 lithophysal rock and from about 8 kN in tension to about 25 kN in compression for category 5 rock. These give a minimum factor of safety of approximately 3 (298/100=3) (see Table 6-6).

Distributions of axial forces in Swellex bolts are presented in Figure 6-35 to Figure 6-38 for the lithophysal rock under in situ and thermal loading and various initial stress conditions. These forces are not uniformly distributed, and generally higher near the crown than near the springline. Under heating, some bolts, especially near the springline, experience tension close to the drift surface and compression away from the drift surface. Comparing the axial forces under in situ loading condition (year=0) to those under combined in situ and thermal conditions (year=50), the maximum values in bolts are reduced for the category 1 rock, and change from negative (in tension) to positive (in compression) for the category 5 rock. It should be noted that the actual loads in bolts illustrated in Figure 6-35 to Figure 6-38 are equal to those shown in the figures times the bolt spacing of 1.25 m.

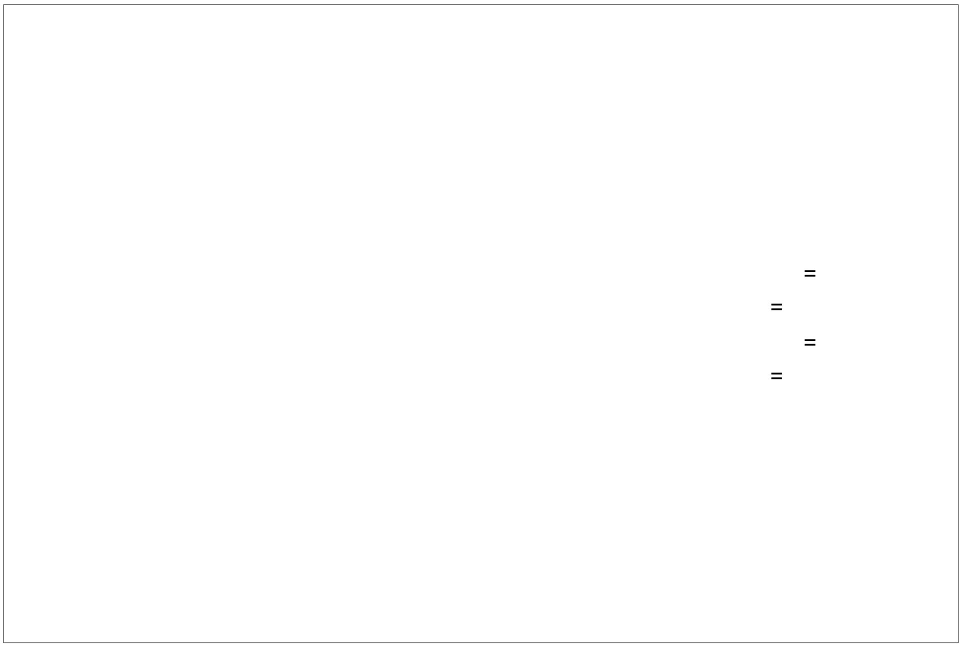
Distributions of axial forces in Swellex bolts for lithophysal rock under in situ, thermal and seismic loads at 0 year and 50 years after waste emplacement are presented in Figure 6-39 and Figure 6-40, respectively. It is seen that the seismic motions are expected to induce additional forces in the bolts installed in the weakest rock, and these additional forces vary with location, rock quality, and loading condition prior to earthquake motions. For a bolt installed near the crown, a total axial force of about 102 kN is predicted for combined in situ and seismic loading conditions at year 0 for Ko=0.3 (see Figure 6-39(a)). As mentioned above, heating will result in a reduction in tensile forces (compared the axial forces shown in Figure 6-39(b) with those in Figure 6-39(a)). So the total tensile force predicted in the same bolt near the crown is about 90 kN (9 tonnes), when subjected to combined in situ, thermal, and seismic loading conditions at year 50 (see Figure 6-40a). The factor of safety under the worst condition is estimated about 2.9 (298/102=2.9).

In summary, the recommended Swellex-type bolts for emplacement drifts in the lithophysal rock are expected to behave satisfactorily under in situ, thermal and seismic loading conditions, with a factor of safety greater than 2.

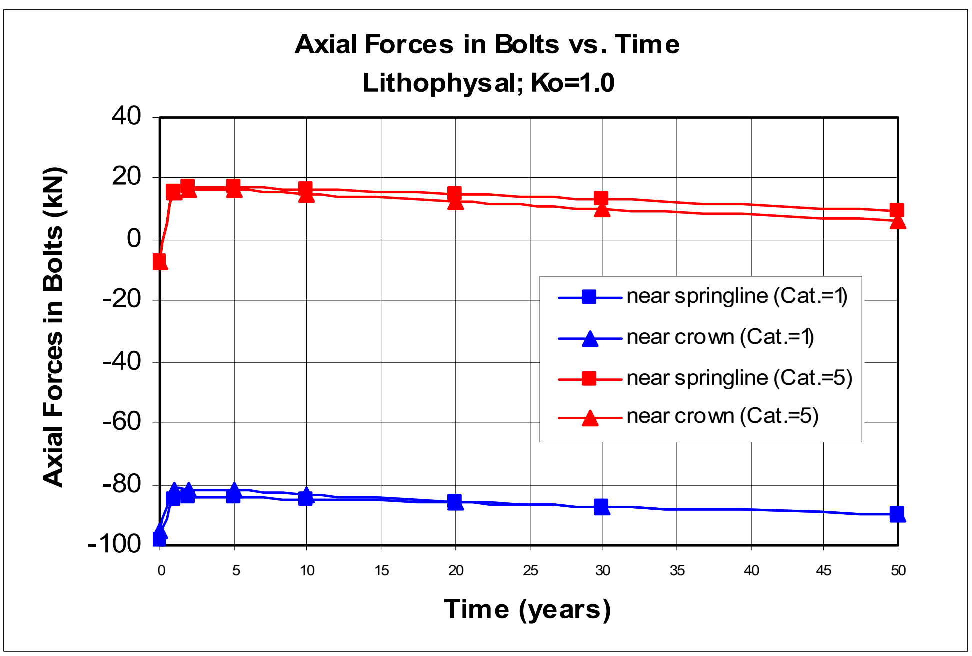
6.7.2.2 Swellex Bolts in Nonlithophysal Rock

Time histories of predicted axial forces in the Swellex bolts installed in emplacement drifts in the nonlithophysal rock are shown in Figure 6-41 for in situ and thermal loading conditions. The behavior of the bolts is also dependent on the rock mass deformation modulus. The bolts are in tension under in situ loading condition, and turn to compression when the rock is heated up following waste emplacement. The axial forces induced are generally very low. The maximum axial forces predicted vary from 17 kN in tension to 26 kN in compression in the category 1 nonlithophysal rock and from 3 kN in tension to 26 kN in compression in the category 5 rock. The expected factor of safety based on these values exceeds 10.

Axial forces in bolts installed in emplacement drifts in nonlithophysal rock under in situ and thermal loads for category 1 and Ko=0.3 for year 0 and year 50 are shown in Figure 6-42(a) and Figure 6-42(b), respectively. Distributions of axial forces in Swellex bolts for nonlithophysal rock under in situ, thermal and seismic loads at 0 year and 50 years after waste emplacement are presented in Figure 6-43 and Figure 6-44 for Ko=0.3 and Ko=1.0, respectively. Comparing Figure 6-42(a) with Figure 6-43(a), it indicates an insignificant axial force induced by the seismic motions. Therefore, the proposed Swellex-type bolts for emplacement drifts in the nonlithophysal rock are anticipated to perform satisfactorily under combined in situ, thermal, and seismic loading conditions, with a factor of safety greater than 10.



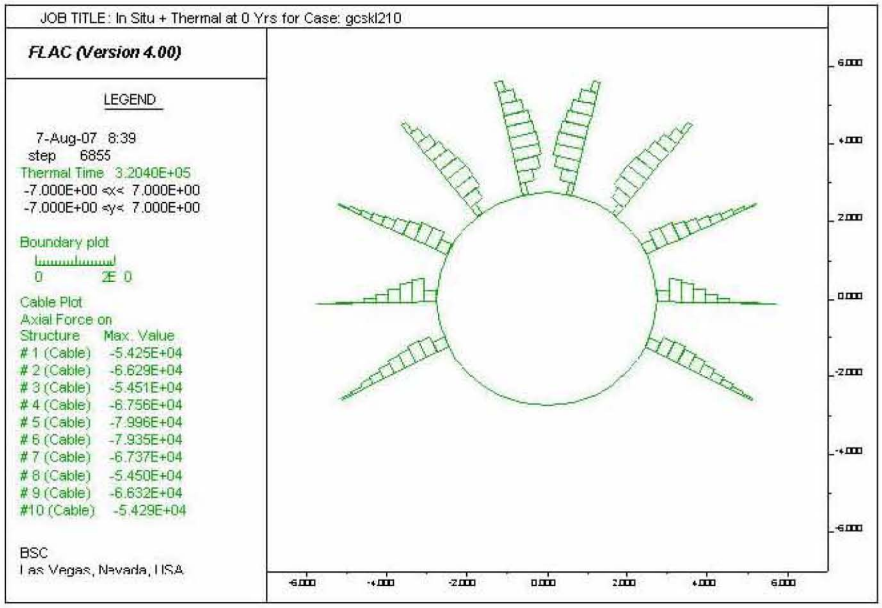
(a)



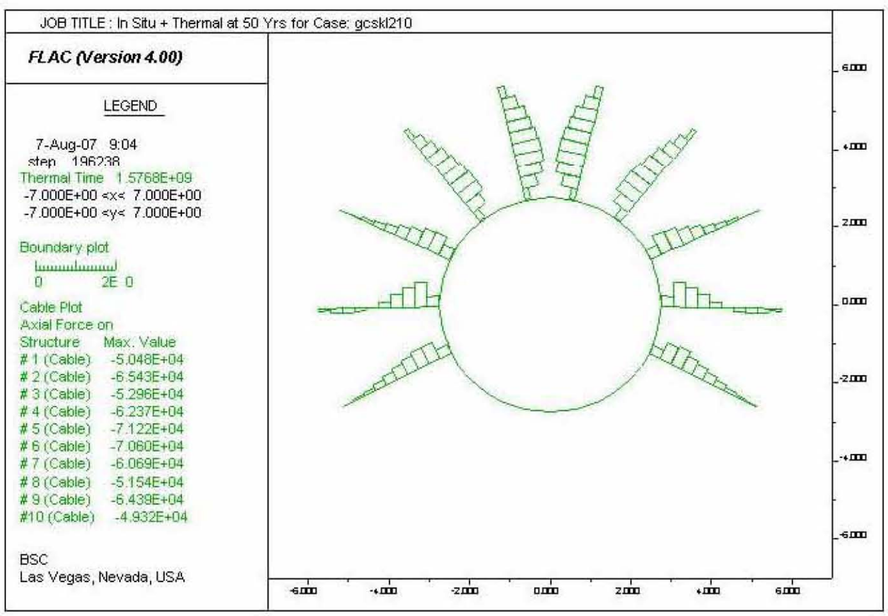
(b)

Note: Axial bolt forces are positive in compression and negative in tension.

Figure 6-34 Axial Forces in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads: (a) K_o=0.3; (b) K_o=1.0



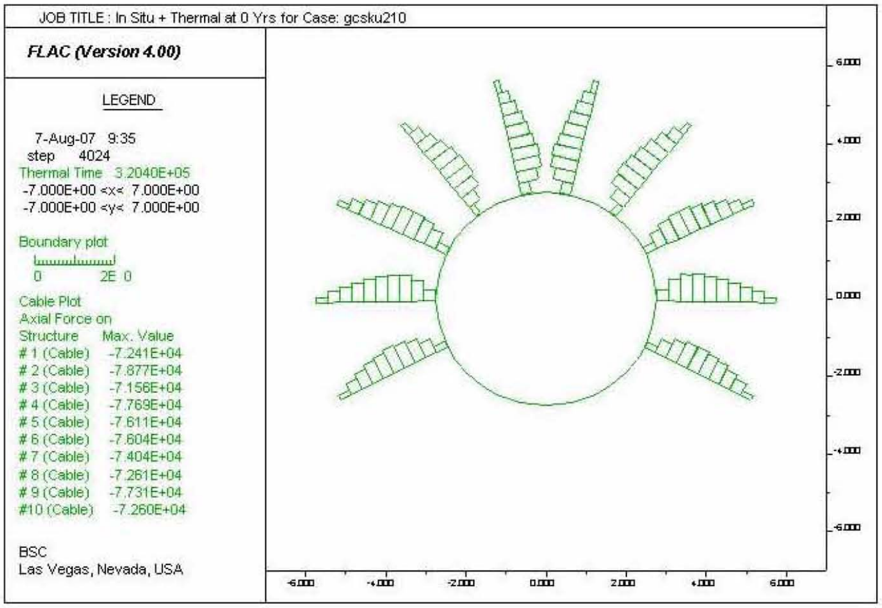
(a)



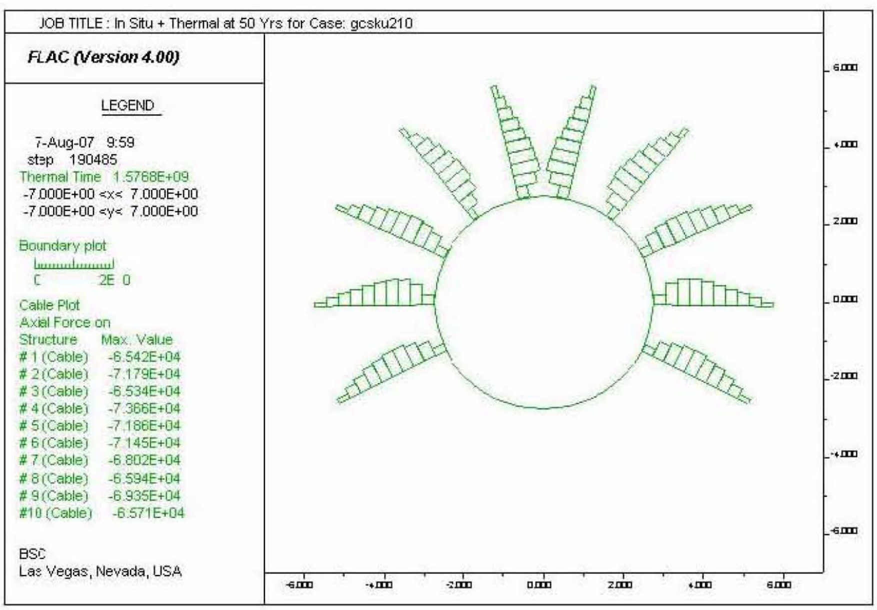
(b)

Notes: Actual forces in bolts are equal to those shown times the bolt spacing of 1.25 m. Axial bolt forces are positive in compression and negative in tension.

Figure 6-35 Distribution of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for Category 1 and K_o=0.3: (a) at 0 year (b) at 50 years



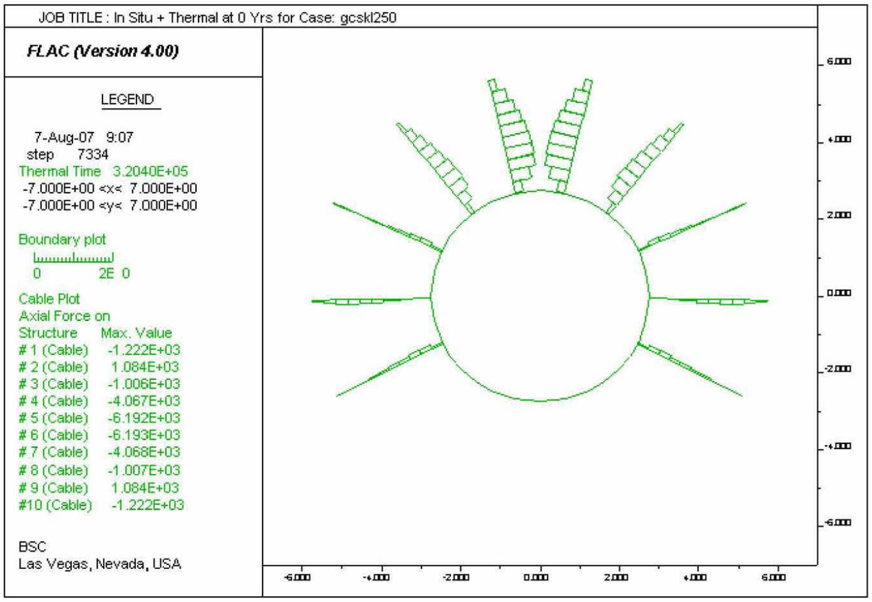
(a)



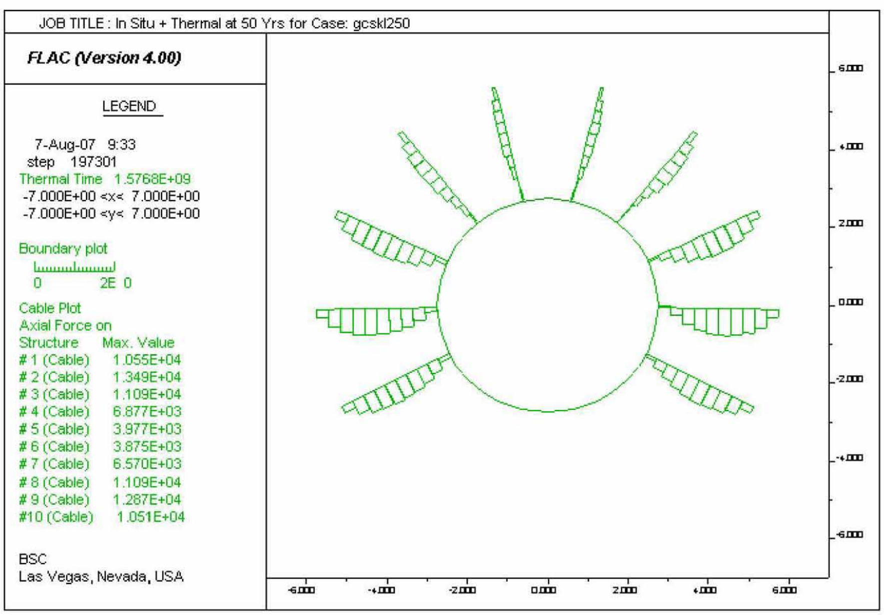
(b)

Notes: Actual forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-36 Distribution of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for Category 1 and K_o=1.0: (a) at 0 years (b) at 50 years



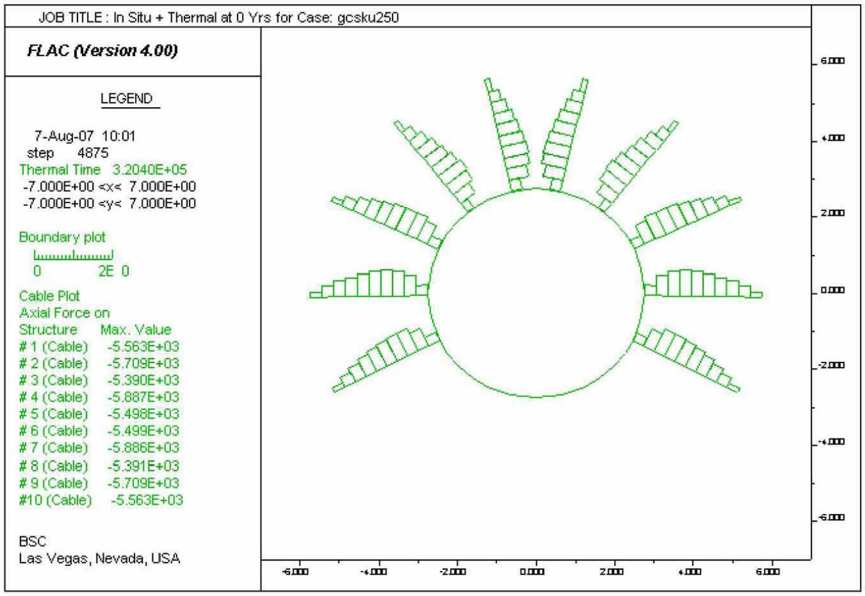
(a)



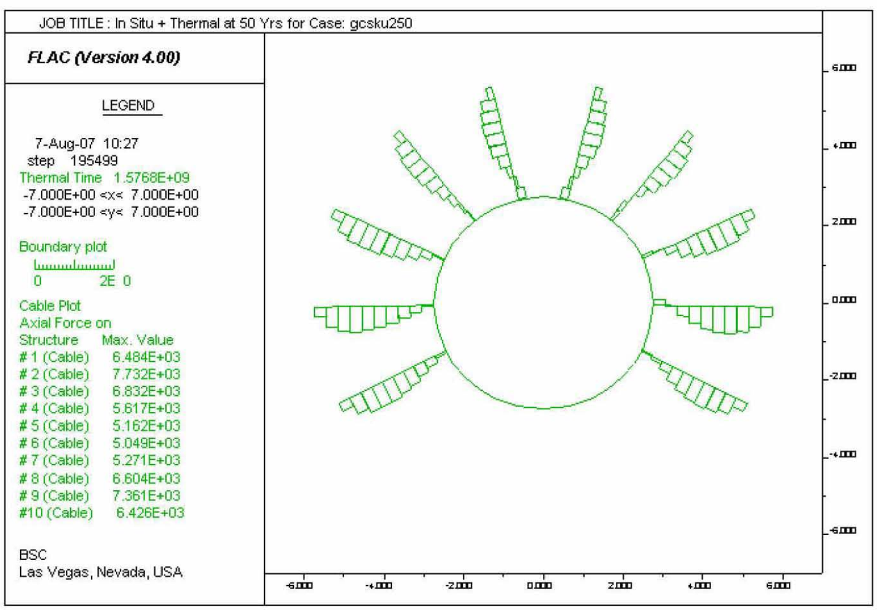
(b)

Notes: Actual forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-37 Distribution of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for Category 5 and K_o=0.3: (a) at 0 year (b) at 50 years



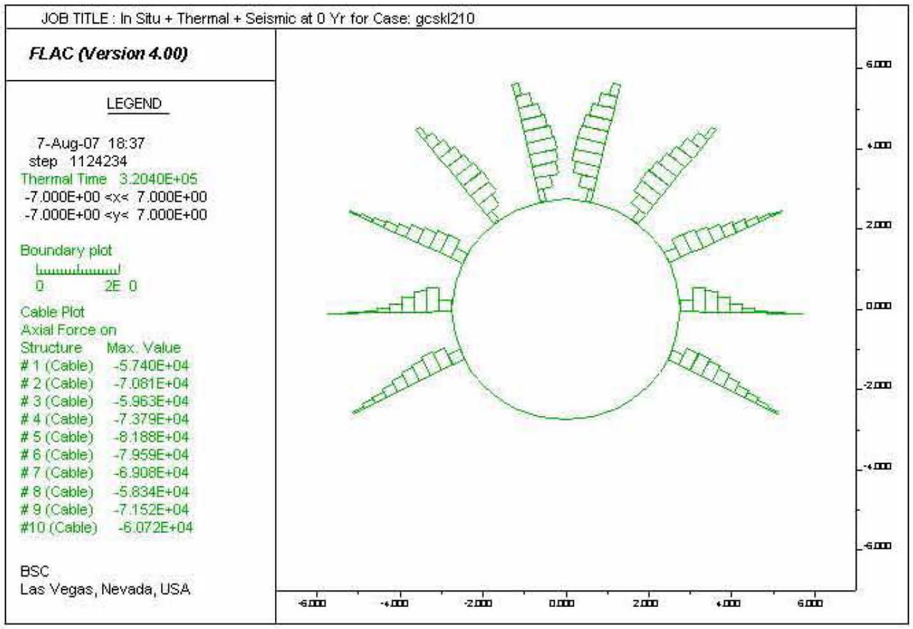
(a)



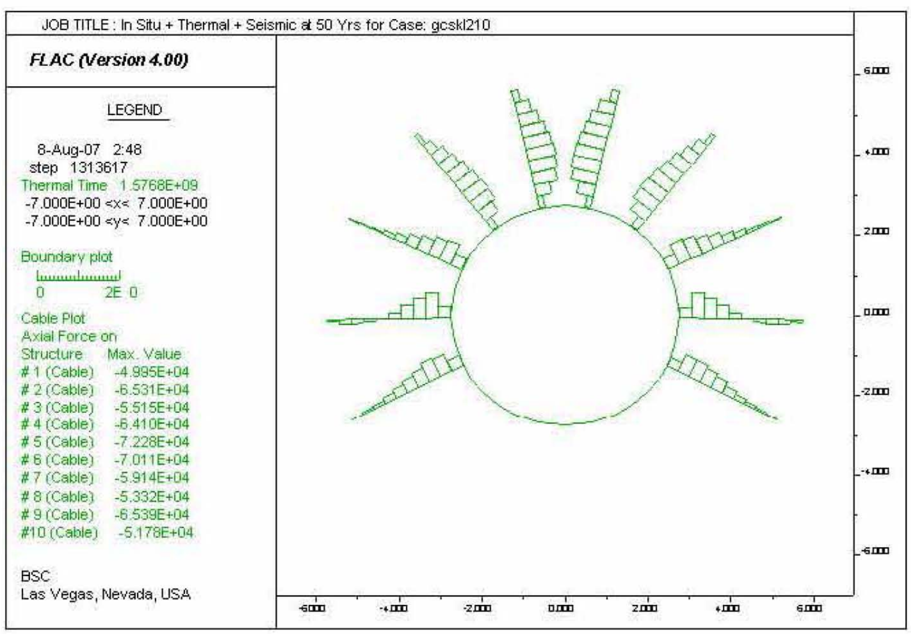
(b)

Notes: Actual forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-38 Distribution of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for Category 5 and K_o=1.0: (a) at 0 year (b) at 50 years



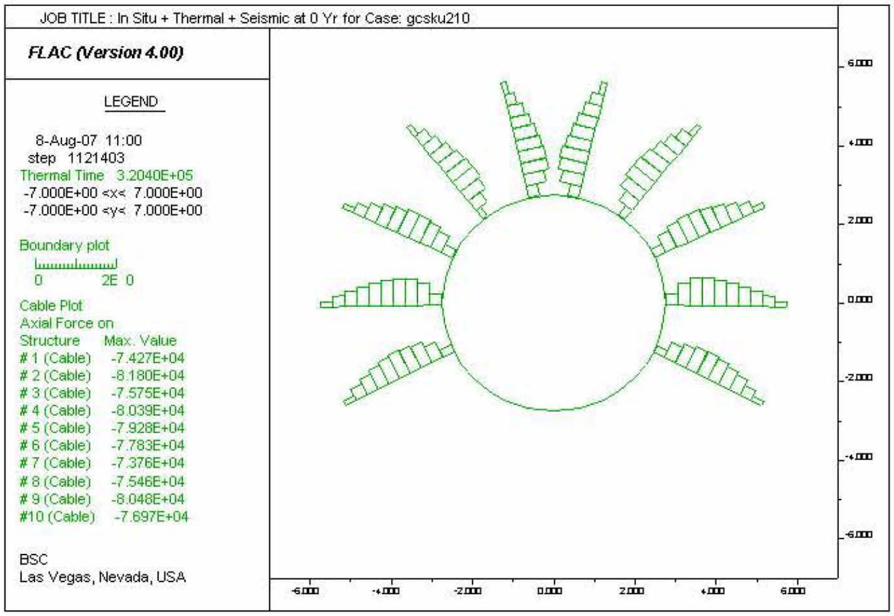
(a)



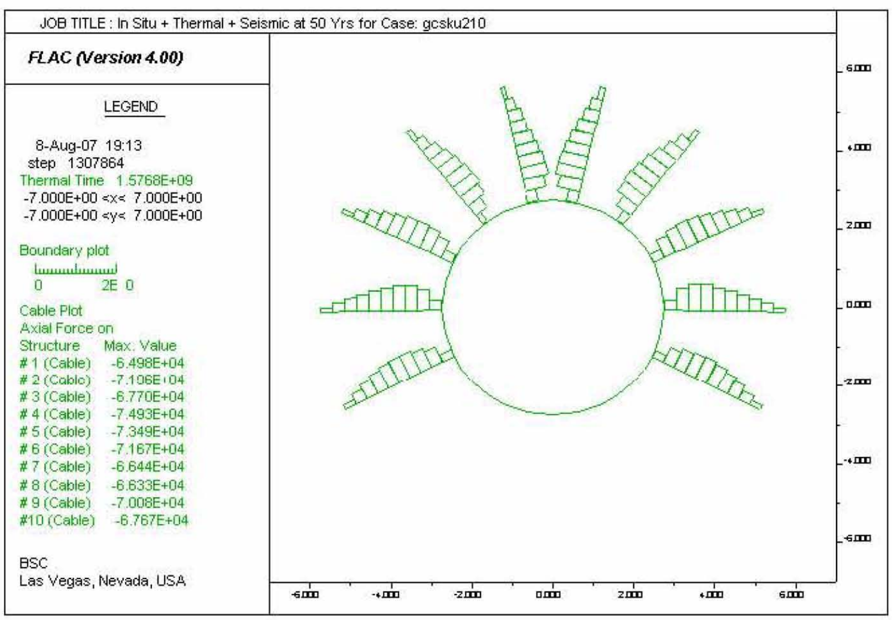
(b)

Note: Axial bolt forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-39 Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ, thermal and Seismic Loads for Category 1 and Ko=0.3: (a) Yr 0; (b) Yr 50.



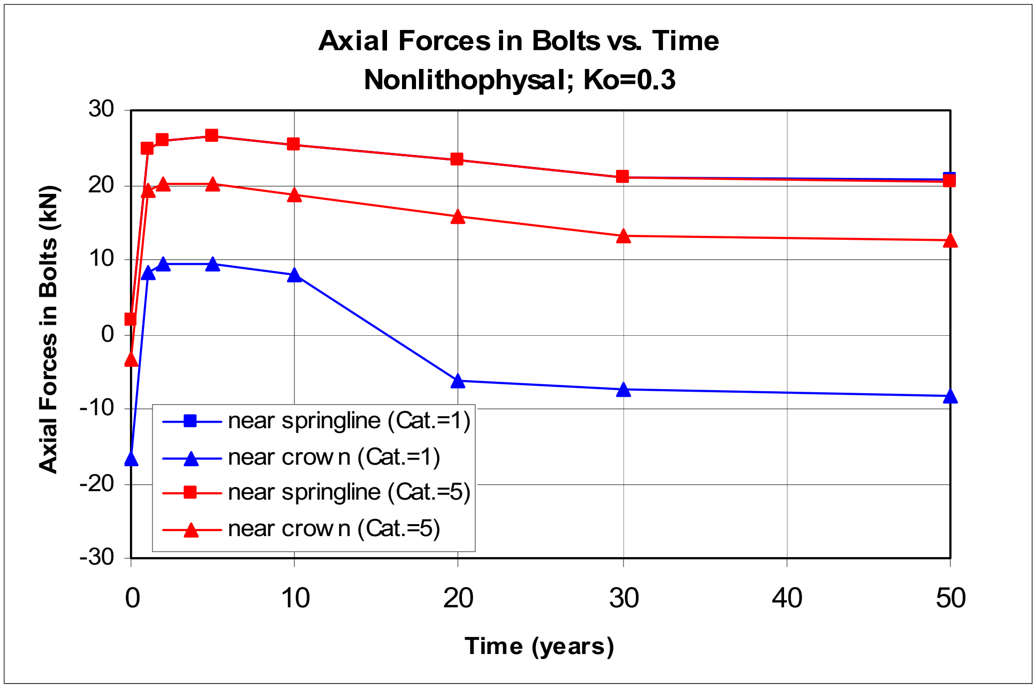
(a)



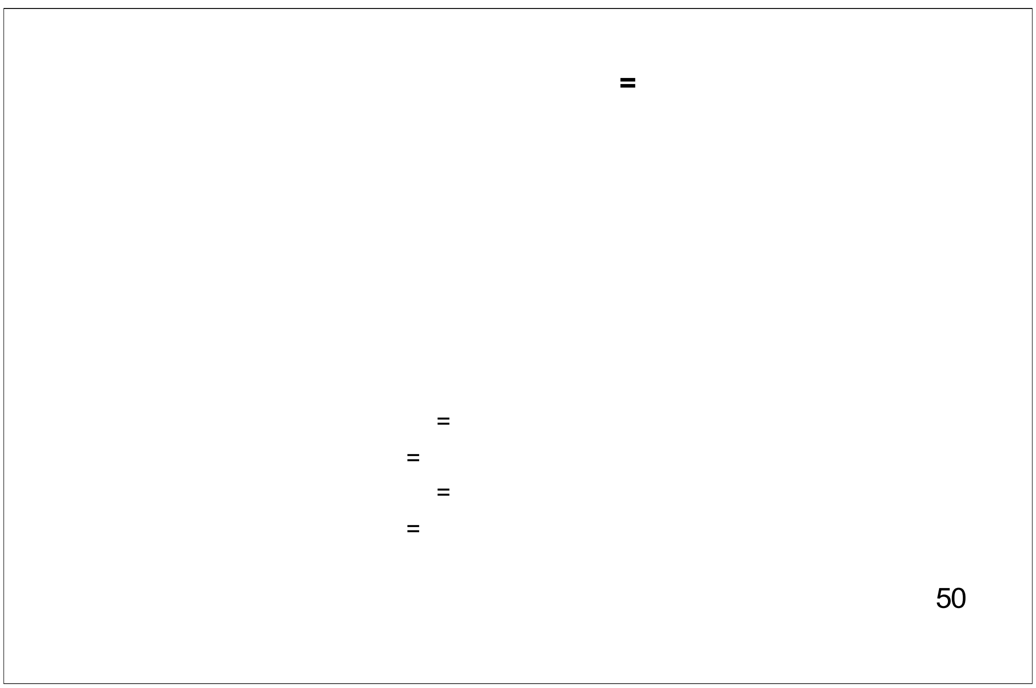
(b)

Note: Axial bolt forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-40 Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ thermal and Seismic Loads for Category 1 and Ko=1.0: (a) Yr 0; (b) Yr 50.



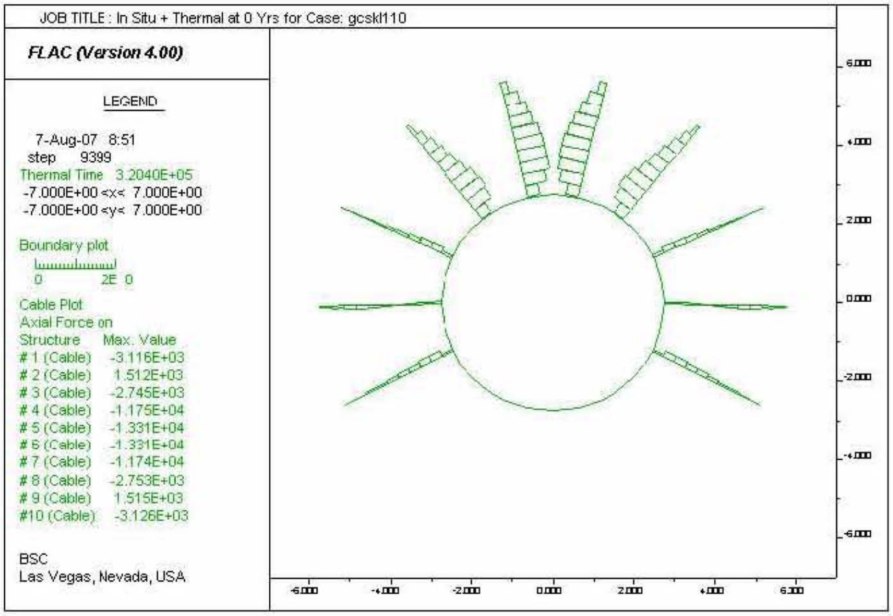
(a)



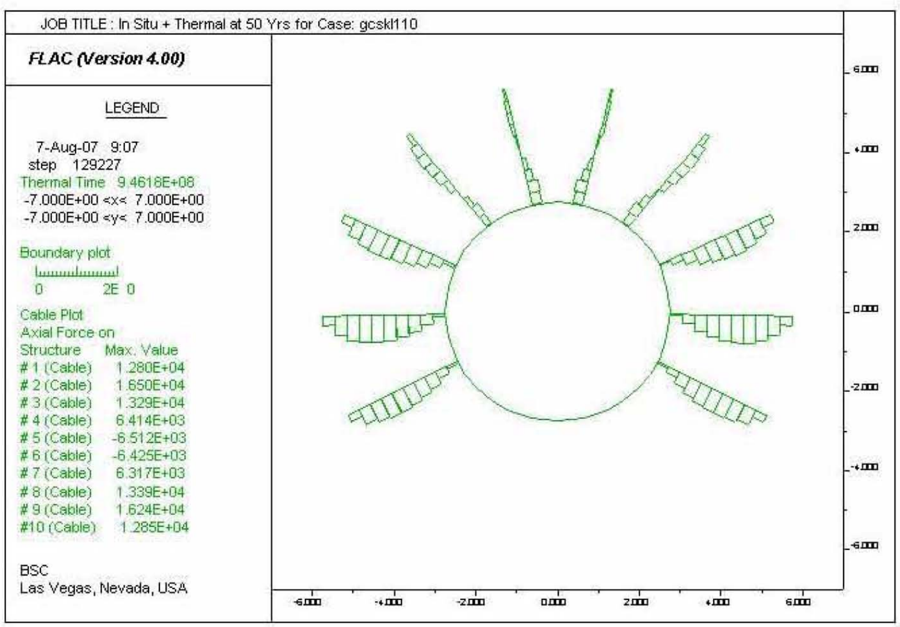
(b)

Note: Axial bolt forces are positive in compression and negative in tension.

Figure 6-41 Axial Forces in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads: (a) K_o=0.3; (b) K_o=1.0.



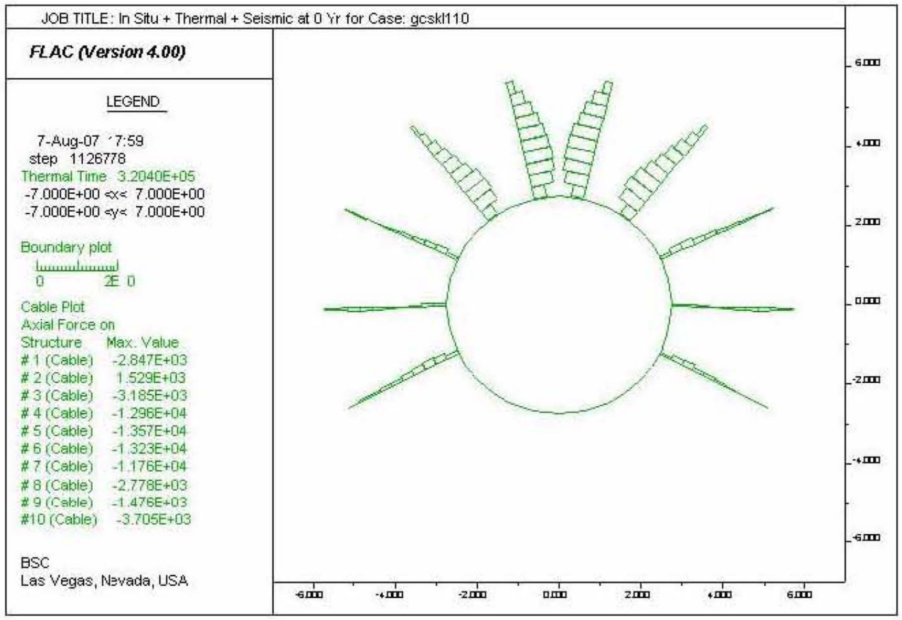
(a)



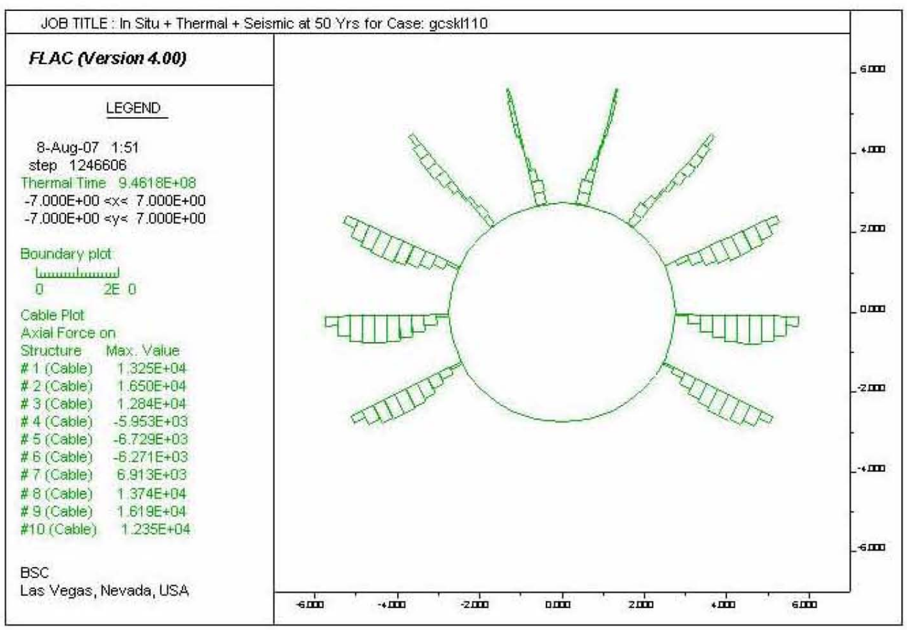
(b)

Note: Axial bolt forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-42 Distribution of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads for Category 1 and K_o=0.3: (a) at 0 years (b) at 50 years



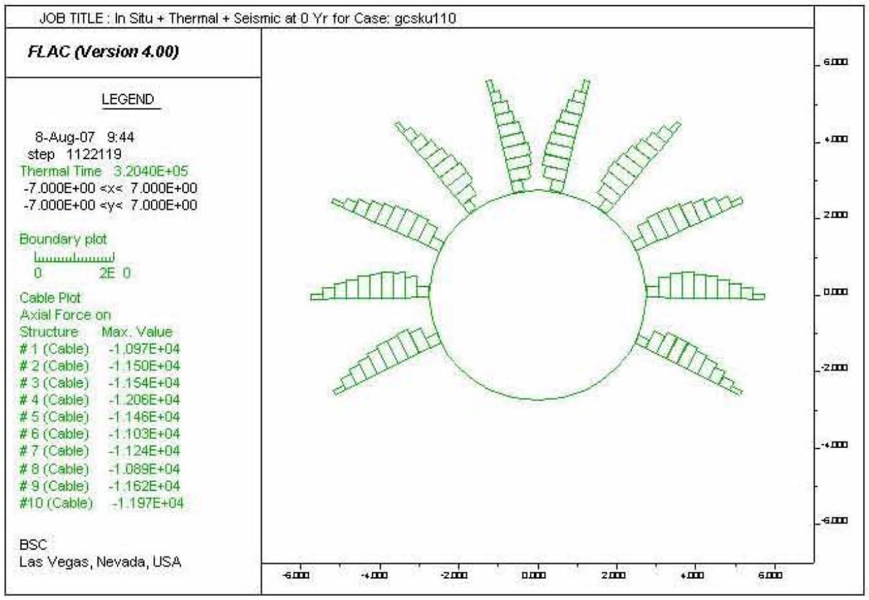
(a)



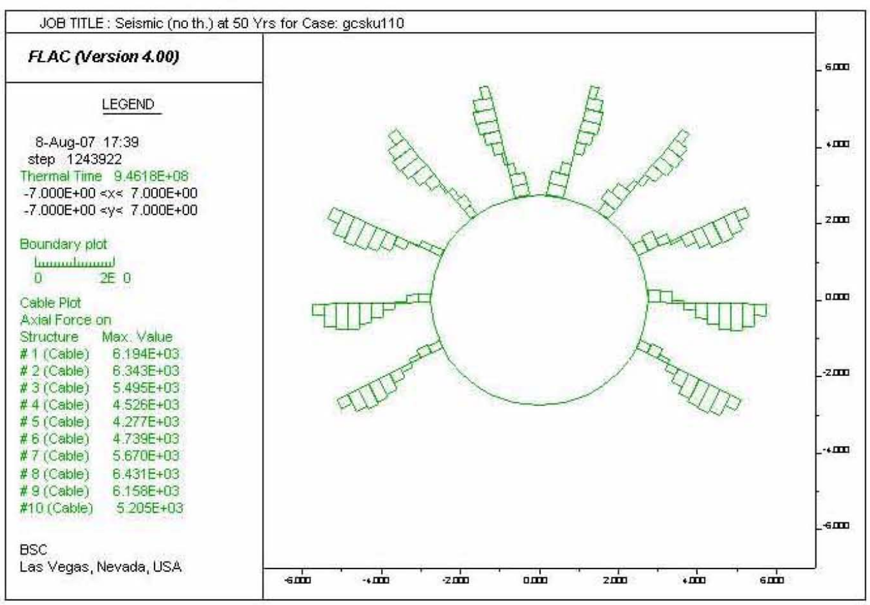
(b)

Note: Axial bolt forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-43 Axial Forces (N) in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ thermal and Seismic Loads for Category 1 and Ko=0.3: (a) Yr 0; (b) Yr 50.



(a)



(b)

Note: Axial bolt forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-44 Axial Forces (N) in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ thermal and Seismic Loads for Category 1 and Ko=1.0: (a) Yr 0; (b) Yr 50.

6.7.3 Performance of Bernold-type Steel Sheets

Performance of the Bernold-type stainless steel sheets is evaluated using a simple hand calculation based on the plate theory. The approach and results are presented below.

6.7.3.1 Estimate of Support Load

The design loads considered in this section include in situ stress, seismic, and thermal loads.

Estimate of In Situ Stress Induced Load

Three (3) mm thick Bernold-type sheets will be installed to the rock surface pinned by 3-m long Super Swellex-type rock bolts, spaced at 1.25 m. The sheets act more like an assembly of arched plates with each of them supported at its four corners, subjected to a dead load shaped like a pyramid between bolts, as illustrated in Figure 6-45. For simplicity, the sheets are treated to be flat with a span (*l*) of 1.25 m in both sides (see Figure 6-45). So, the load pyramid has a height of 0.625 m, and a volume of

$$V = \frac{1}{3} \times 1.25^2 \times 0.625 = 0.33 \quad m^3$$

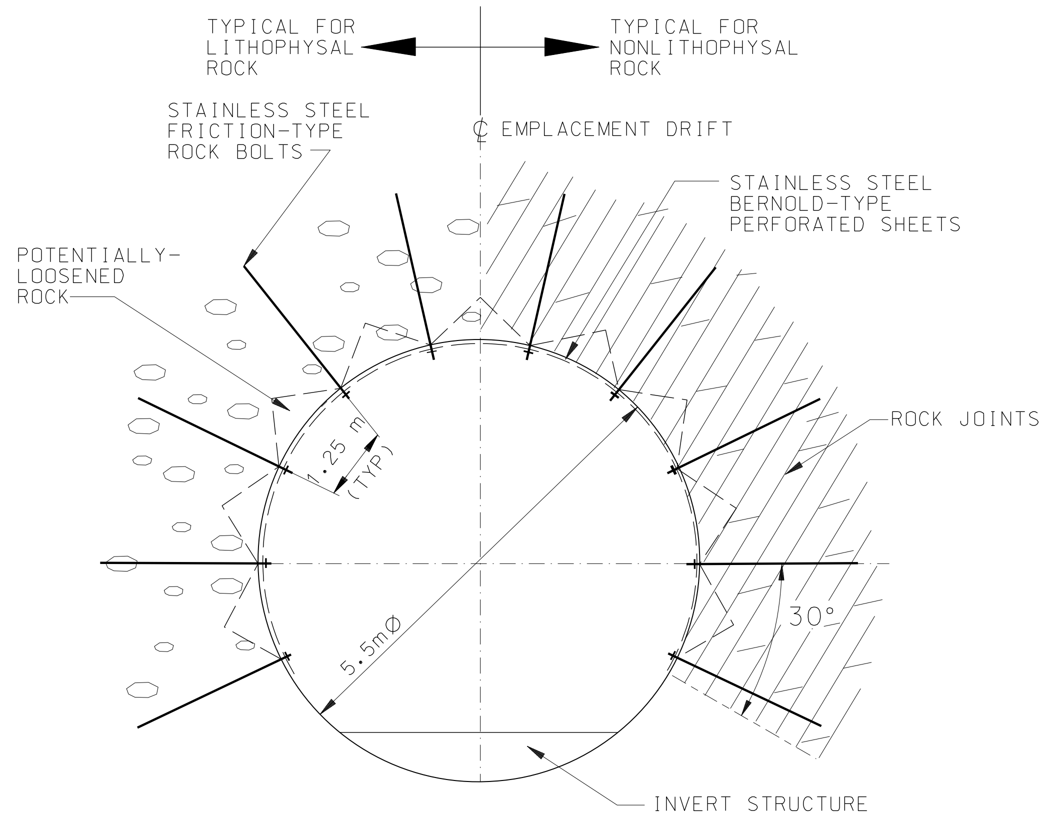
The total dead load over the plate can be estimated as

$$W = V\gamma = 0.33 \times 2410 \times 9.81 = 7.8 \quad KN$$

where γ = rock mass density, kg/m^3

If this dead load is distributed uniformly over the entire area of plate (sheet), the unit load is

$$w_s = \frac{W}{A} = \frac{0.0078}{1.25^2} = 5 \quad KN / m^2$$



Note: Figure is not to scale.

Figure 6-45 Illustration of Potentially-loosened Rock on Periphery of an Emplacement Drift

Estimate of Seismically-induced Load

Seismically-induced load on the Bernold-type sheets is treated similarly to that of in situ stress, as discussed above. This is considered adequate since the wavelength of the ground motion is much larger than the dimension of the rock wedge. The increased dynamic load component can then be treated as a quasi-static problem in which the peak ground acceleration (PGA) is added to the gravitational acceleration. The dynamic effect is reflected in an increased value of gravitational acceleration as

$$g_d = g + PGA \quad \text{(Eq. 6-5)}$$

where g_d = effective gravitational acceleration during seismic motions, m/s^2
g = gravitational acceleration, equal to 9.81 m/s^2
PGA = peak ground acceleration during seismic motions, m/s^2

According to Reference 2.2.44 (MatH1.ath, MatH2.ath, and MatV.ath), the maximum value of PGA associated with a seismic event of the mean APE of 1×10^{-4} is about 0.47*g*. With this PGA value, the equivalent uniform load on the sheets induced during seismic shaking can be estimated as

$$w_{s+d} = w_s + w_d = (g + 0.47g)\frac{w_s}{g} = 1.47 w_s = 1.47 \times 0.005 = 7.4 \quad KN / m^2$$

This is the total load under combined in situ and seismic effects.

Estimate of Thermally-induced Load

Thermally-induced load on Bernold-type sheets is mainly due to thermal expansion of rock mass and sheets themselves. This load depends on the nature of contact between the sheets and the rock surface. In general, the corrugated Bernold-type sheets are not in perfect contact with the rock. Any gap present between the sheets and the rock surface will allow a relief in thermally-induced load. In this calculation, it is considered adequate that the sheets are in perfect contact with the rock, and thermally-induced rock displacements will result in additional load on the sheets. This load can be estimated by using the plate theory.

For a square flat plate with all four edges rigidly fixed, the equivalent uniform load (w_T) over the entire plate, which causes a maximum deflection (δ_T), can be calculated as (Reference 2.2.51, p. 464, Case No. 8, Loading Case No. 8a):

$$w_T = \frac{Et^3}{\alpha l^4}\delta_T \qquad \text{(Eq. 6-6)}$$

where E = Young's modulus of sheet material, Pa
t = thickness of sheet, m
α = a constant, equal to 0.0138 for a square plate with uniform load.

According to Section 6.4.2.1, the maximum thermally-induced drift closure is about 2 mm for all rock categories considered. So the actual maximum deflection of a sheet between bolts is approximately 1 mm, or half of the maximum drift closure. For conservatism, a deflection of 2 mm is used. With this deflection, the equivalent uniform load induced by increase in rock temperature can be estimated based on Eq. 6-6 as

$$w_T = \frac{193 \times 10^9 \times 0.003^3}{0.0138 \times 1.25^4 \times 10^6} \times 0.002 = 0.31 \quad KN / m^2$$

It should be noted that the calculation presented here is very conservative. In reality, the opening closes more or less uniformly under thermal load. The heads of the rock bolts will move inward with the tunnel surface, which will put some differential strain on the bolt, over its length, and load it. However, the Bernold-type sheets and the heads of rock bolts will likely move together, as the circular opening is closing more or less uniformly and becoming smaller. At the same time, the Bernold-type sheets themselves will thermally expand more than the drift closure. The end result is that the sheets will probably be compressed rather than tensioned since the sheet thermal expansion is greater than the rock thermal expansion. The thermally-induced stress will likely offset the tensile stress caused by the load from dead weight of potentially loosened rock. In other words, all of these things would indicate that the sheets will be under little additional strain from thermal loading.

Combined In Situ, Thermal, and Seismic Loads

The total combined in situ, thermal, and seismic load over the square flat sheet is determined as

$$w = w_s + w_d + w_T = 7.4 + 0.31 = 7.7 \quad KN/m^2$$

It is seen that major contributor of the load is the dead weight of a potentially-loosened rock wedge.

6.7.3.2 Estimate of Stress and Factor of Safety

As mentioned above, thin-walled, corrugated Bernold-type stainless steel sheets installed in emplacement drifts may be very conservatively treated to behave like a flat plate, rigidly fixed on all edges, subjected to a uniform load over its entire area. The maximum stress at the center of the plate under a uniform load can be estimated using the following expression (Reference 2.2.51, p. 464, Case No. 8, Loading Case No. 8a):

$$\sigma = \frac{\beta w l^2}{t^2} \qquad \text{(Eq. 6-7)}$$

where β = a constant, equal to 0.1386 for the case considered.

Using this expression and the loads estimated for different loading conditions, stresses in Bernold-type sheets can be estimated. Their values and corresponding safety factors are presented in Table 6-8. The factor of safety is calculated based on a tensile strength of 620 MPa for stainless steel (see Table 6-6). Note that the factor of safety calculated is against the stress associated with peak elastic strain in the steel, i.e., the stress state at onset of inelastic hardening. However, it is not the rupture condition since this sheet will have considerable inelastic strain prior to rupture.

Table 6-8 Estimated Stresses and Factors of Safety in Bernold-type Stainless Steel Sheets for Various Loading Conditions

Loading Conditions	Load (KN/m^2)	Stress (MPa)	Factor of Safety
In Situ	5	120	5.2
In Situ + Seismic	7.4	178	3.5
In Situ + Thermal	5.3	128	4.8
In Situ + Thermal + Seismic	7.7	185	3.4

In summary, Bernold-type stainless steel sheets are expected to perform satisfactorily under combined in situ, thermal, and seismic loading conditions. The key factor that controls the stresses in the sheets is the in situ load, or dead load of potentially loosened rock formed between rock bolts. The thermal load has minimal effect. The results are based on a simple hand calculation. Further analyses based on more comprehensive numerical methods may be desirable in the detailed design stage since numerical analyses can simulate the interaction between the Bernold-type sheets and the rock as well as the loading history during heating and seismic motions.

6.7.4 Prevention of Rockfall by Ground Support

The key function of Swellex-type bolts installed in emplacement drifts is to reinforce rock mass and to prevent any potential rockfall. A comprehensive analysis of potential rockfall in emplacement drifts in both lithophysal and nonlithophysal rocks was performed in the *Drift Degradation Analysis* (Reference 2.2.16, Sections 6.3 and 6.4).

According to the *Drift Degradation Analysis*, the probability of wedge-type failure in the lithophysal rock during the preclosure period is very low, with a volume of rockfall per linear kilometer drift of 0.19 m^3 (Reference 2.2.16, Table 6-49). Any potential rockfall will be associated with small loosening and unraveling rock pieces, which can be prevented by installed Bernold-type steel sheets.

In the nonlithophysal rock, the predicted heaviest key block is 2.72 tonnes (Reference 2.2.16, Table 6-20). Using the rock has a density of 2,410 kg/m^3 (see Section 6.1.2.4) and the shape of the key block is a cube. So the dimension of the cube is 1.04 m. Also consider that the key block is fully mobilized and its total weight is carried by a single Swellex bolt, meaning that frictional resistance or confinement along discontinuities is neglected. The holding capacity of the bolt may be estimated based on the smaller of the anchorage force and the shear resistance force along the interface between the bolt and the key block. The effective anchorage force of the bolt is about 13 tonnes ($20/3\times(3-1.04)=13$) (note: 20 tonnes of anchorage capacity is from Reference 2.2.49, p. 14, also see Table 6-6), while the shear resistance force is about 4.9 tonnes ($2.75\times10^5\times\pi\times0.054\times1.04/1000/9.81=4.9$), both exceeding the weight of 2.72 tonnes with factors of safety of about 4.8 and 1.8, respectively.

It should be noted that the calculation presented here is simplified and is for illustrative purpose. More detailed analysis is needed to further evaluate the bolt function for preventing rockfall. It is also noted that the predicted sizes of rockfall provided by the *Drift Degradation Analysis* (Reference 2.2.16) are based on a seismic event with the mean APE of 1×10^{-4} (10,000 years).

Therefore, with proposed ground support system installed, any potential rockfall in emplacement drifts is expected to be prevented as long as the ground support is functional during the anticipated service life.

6.8 SENSITIVITY ANALYSIS

6.8.1 Sensitivity Study on Emplacement Drift Stability

The sensitivity of the emplacement drift stability with respect to rock mass mechanical properties and various loadings including in situ, thermal, and seismic loads during the preclosure period has been assessed in the *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (Reference 2.2.14) completed in 2003. This section examines whether the subsequent updates on rock mass properties have any significant impact on the results and conclusions presented in the *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (Reference 2.2.14).

Base case stability analysis on unsupported emplacement drifts was performed using the same input parameters used in Section 6.4 with K_o of 0.5. Base case was defined as case with the mostly likely scenario for material property variation, modeling parameter setting, and load considerations. The results of this analysis are presented in Figure 6-46 through Figure 6-49.

Figure 6-46(a) and Figure 6-46(b) show the time histories of closures of unsupported emplacement drifts under in situ and thermal loads and K_o=0.5 for categories 1, 3, and 5 rock in lithophysal and nonlithophysal units, respectively. The maximum vertical closures are predicted to be about 50, 8, and 4 mm for the lithophysal rock categories 1, 3 and 5, respectively, and about 13, 3, and 2 mm for the nonlithophysal rock categories 1, 3 and 5, respectively. The horizontal closures are generally small compared to the vertical closures as seen in these figures.

Figure 6-47 presents the drift closures of unsupported emplacement drifts induced by seismic motions at year 0 in both the lithophysal and nonlithophysal rocks for K_o=0.5 and indicates that seismically-induced rock deformation is not significant. The maximum closures due to seismic loadings are predicted to vary from less than 3 mm for the category 1 lithophysal rock to less than 1 mm for the category 1 nonlithophysal rock.

Time histories of the major principal stresses at the crown and the springline for unsupported emplacement drifts subjected to in situ and thermal loads for K_o=0.5 are presented in Figure 6-48(a) and Figure 6-48(b) for lithophysal and nonlithophysal rock, respectively. The maximum major principal stresses are expected to vary from about 15 to 25 MPa for category 1 rock to about 28 to 38 MPa for category 5 rock and indicates that the stress changes due to the thermal loads is not substantial. The maximum major principal stresses changes due to thermal load is predicted about 15 MPa for category 5 nonlithophysal rock at the crown location.

Figure 6-49 presents the major principal stresses at the crown and the springline for unsupported emplacement drifts subjected to seismic loads for K_o=0.5 for lithophysal and nonlithophysal rock, respectively. Based on this figure, the stress variations due to seismic event are small near crown and larger near springline. The maximum stress fluctuation due to seismic event is predicted about 5 MPa for category 5 nonlithophysal rock at the springline location.

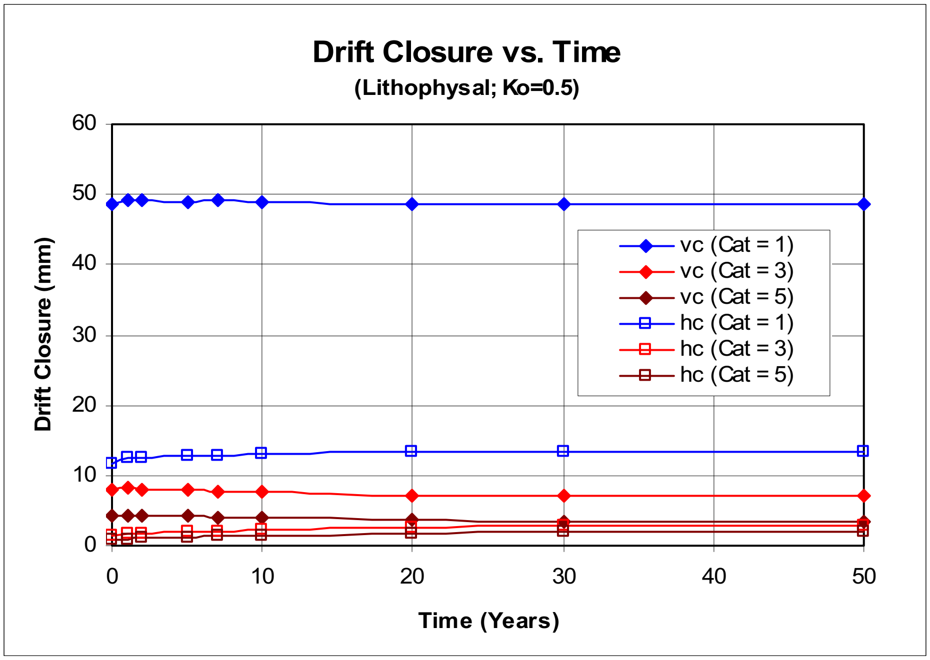
The numerical results obtained from simulating the base case using the updated rock properties are compared with the base case results presented in Reference 2.2.14 (Section 6.1) and are summarized in Table 6-9. The comparisons do not indicate any significant difference. Based on this limited base case study, it can be concluded that the sensitivity study presented in Rev. 00 of the *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (Reference 2.2.14) is still considered valid and adequate for supporting the ground support design analyses.

Table 6-9 A Summary of Base Case Comparison

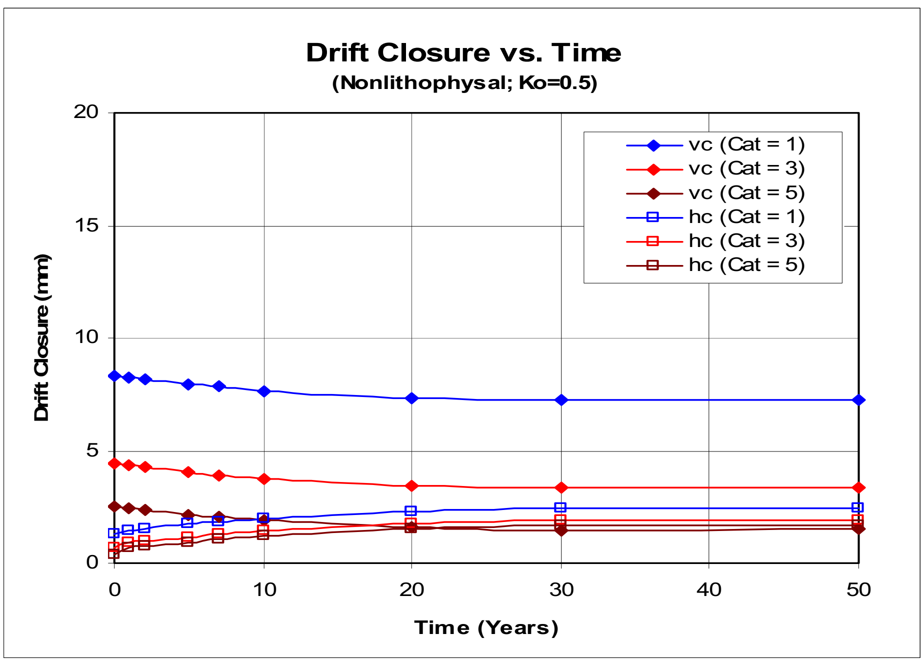
Description	**Rock type**	**Rock Mass Category**	**Current Calculation**	**Scoping Analysis (Reference 2.2.14)**
Results of excavation for in situ condition	Lithophysal	1	Minor yielding	Minor yielding
		3	Minor yielding	No Yielding
		5	No Yielding	No Yielding
	Nonlithophysal	1	No Yielding	No Yielding
		3	No Yielding	No Yielding
		5	No Yielding	No Yielding
Maximum Stress changes due to thermal loading	Lithophysal	1, 3, and 5	Springline: at 2 years Crown: at 10 years	Springline: at 2 years Crown: max at 10 years
	Nonlithophysal	1, 3, and 5	Springline: at 2 years Crown: at 10 years	NA
Opening closure due to thermal loading	Lithophysal	1	Minimal, <2 mm	Minimal, <2 mm
		3	Minimal, <2 mm	Minimal, <2mm
		5	Minimal, <2 mm	Minimal, <2mm
	Nonlithophysal	1	Minimal, <2 mm	Minimal, <2 mm
		3	Minimal, <2mm	Minimal, <2mm
		5	Minimal, <2mm	Minimal, <2mm
Yielding due to seismic loading	Lithophysal	1	No Yielding	No Yielding
		3	No Yielding	No Yielding
		5	No Yielding	No Yielding
	Nonlithophysal	1	No Yielding	No Yielding
		3	No Yielding	No Yielding
		5	No Yielding	No Yielding
Stress changes due to seismic loading	Lithophysal	1, 3, and 5	Minimal fluctuation at crown and moderate fluctuation at springline (All 3 cases).	Minimal fluctuation at crown. No analysis for springline. Seismic at 0 and 50 years
	Nonlithophysal	1, 3, and 5	Minimal fluctuation at crown and moderate fluctuation at springline (All 3 cases).	Minimal fluctuation at crown. No analysis for springline. Seismic at 0 and 50 years
Opening closure due to Seismic loading	Lithophysal	1	About 3 mm (vertical)	Up to 2 mm (vertical)
		3	About 1 mm (vertical)	Up to 1 mm (vertical)
		5	Up to 1 mm (vertical)	Up to 1 mm (vertical)
	Nonlithophysal	1	About 1 mm (vertical)	Up to 1 mm (vertical)
		3	Less than 1 mm (vertical)	Less than 1 mm (vertical)
		5	Less than 1 mm (vertical)	Less than 1 mm (vertical)
Overall Stability of Drift due to combined in-situ, thermal , and seismic loadings	Lithophysal	1, 3, and 5	Stable	Stable
	Nonlithophysal	1, 3, and 5	Stable	Stable

Figure 6-50 presents the plot of maximum closure versus various K_o values and indicates a linear relationship between the drift closure and the K_o value. Based on this figure, the drift closure is generally insensitive to the K_o value in most rock categories with the exception in the category 1 lithophysal rock. The changes of maximum drift closure within K_o bounding values are 5 mm or less in most rock mass categories and 15 mm in category 1 lithophysal rock.

Similarly, Figure 6-51 shows major principal stress versus various K_o values and indicates an approximately linear relationship between the major principal stress and the K_o value. Based on this figure, the major principal stress is generally insensitive to the K_o value in all three rock categories. The changes of maximum major principal stress within K_o bounding values are 4 MPa or less in all three rock mass categories.

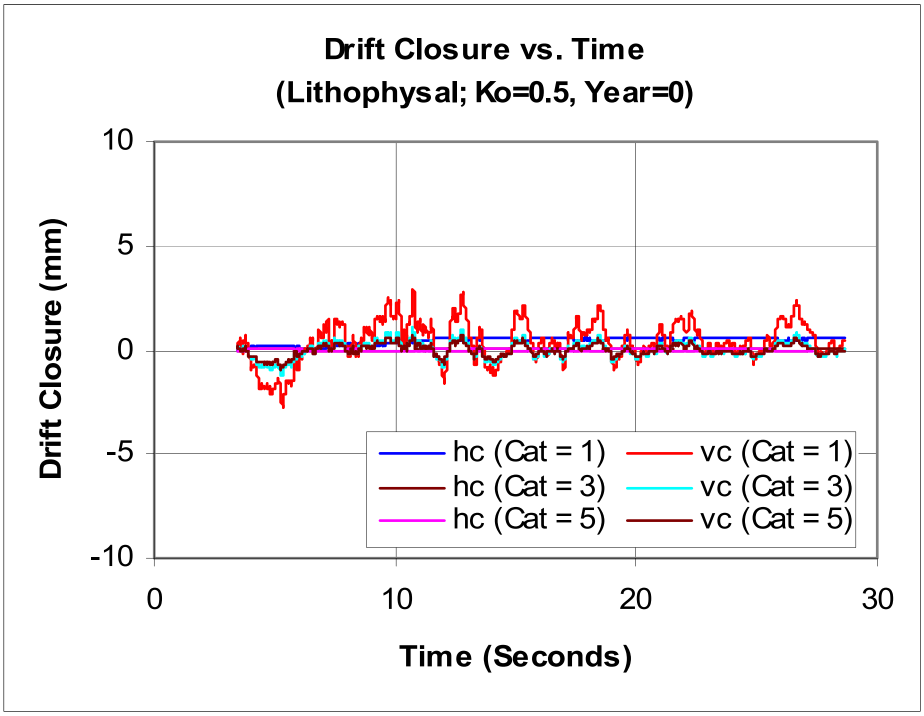


(a)

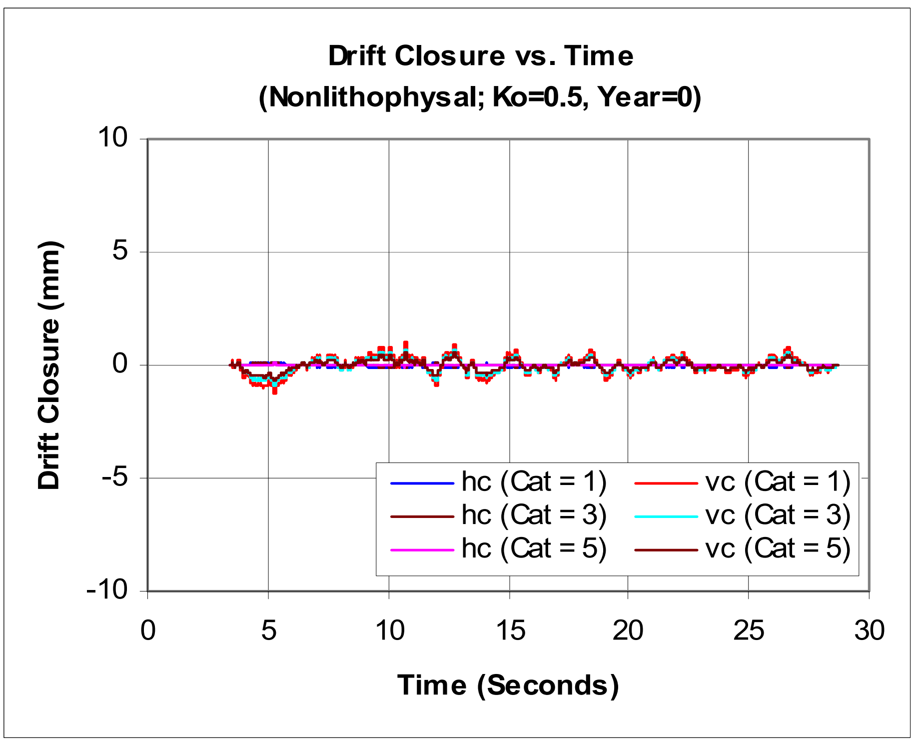


(b)

Figure 6-46 Time Histories of Closures of Unsupported Emplacement Drifts under In Situ and Thermal Loads and Ko=0.5 in: (a) Lithophysal; (b) Nonlithophysal Rock

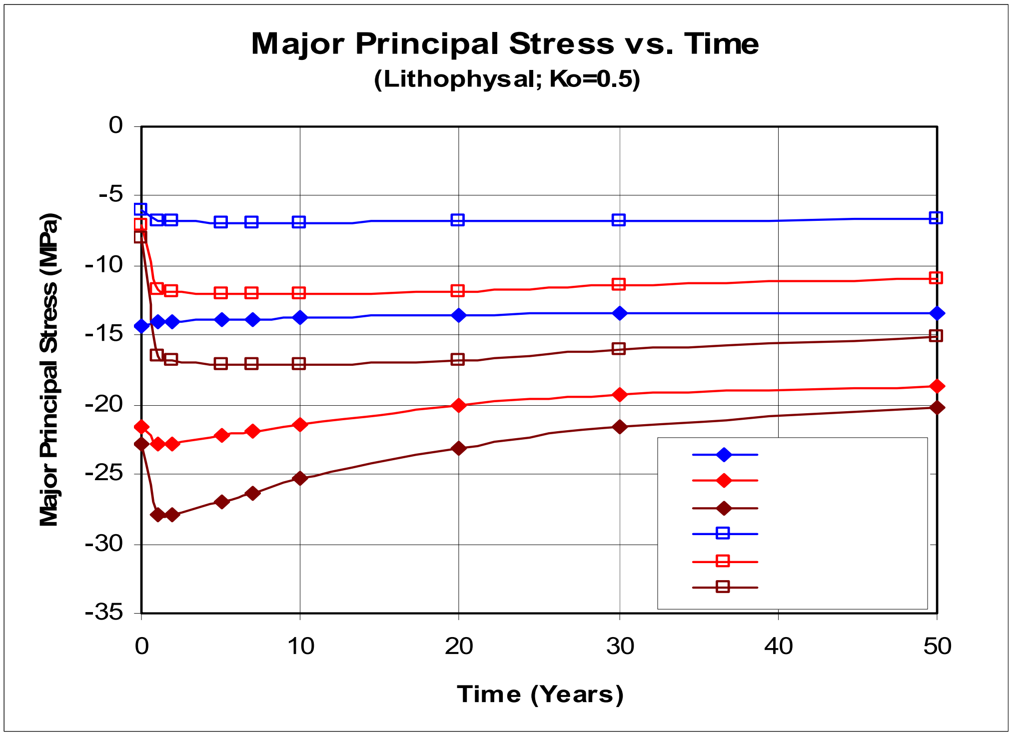


(a)



(b)

Figure 6-47 Time Histories of Closures of Unsupported Emplacement Drifts under Seismic Load and Ko=0.5 at Year 0 in: (a) Lithophysal; (b) Nonlithophysal Rock



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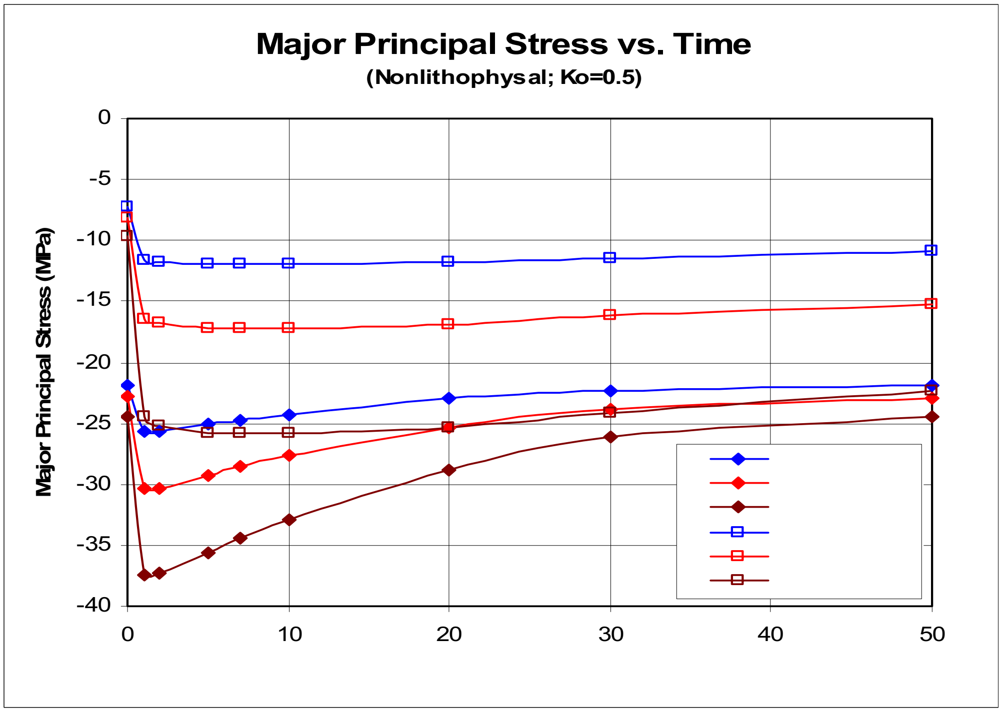
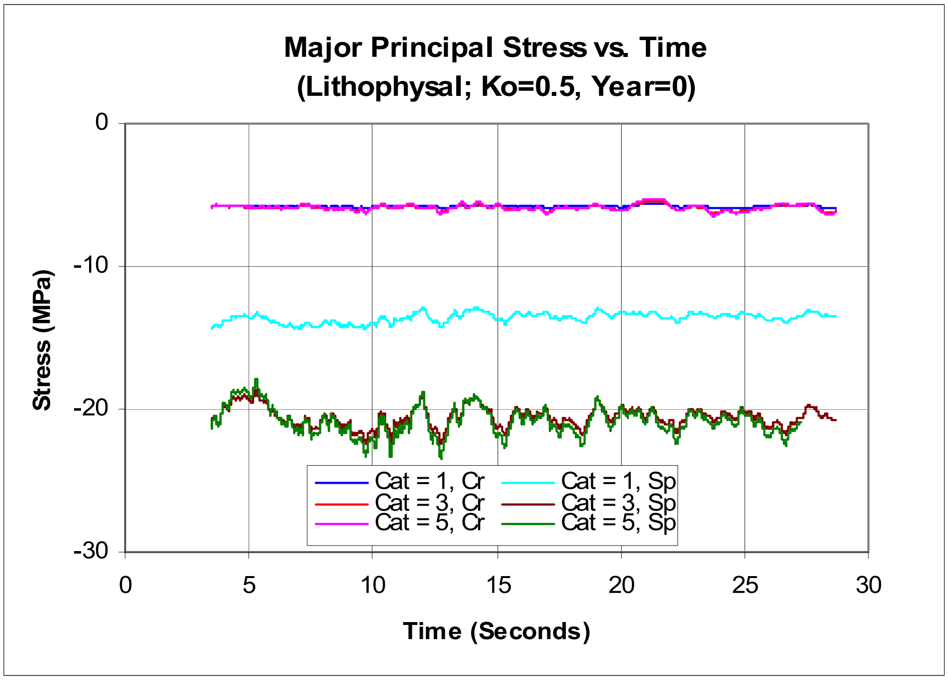
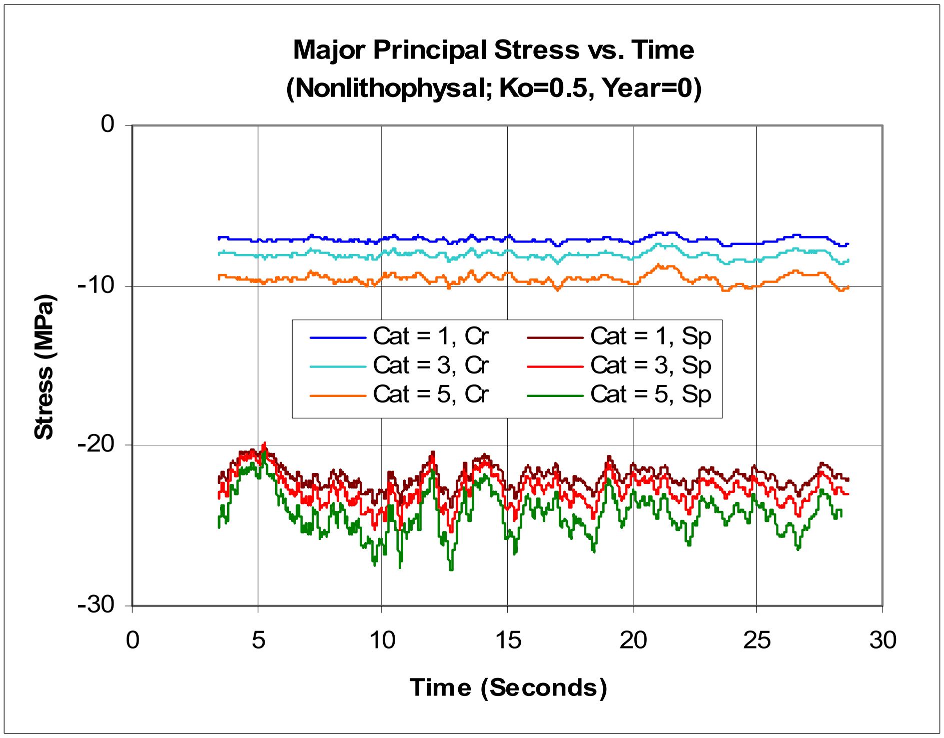


(b)

Figure 6-48 Time Histories of Major Principal Stresses near Crown and Springline of Em placement Drifts under In Situ and Thermal Loads and Ko=0.5 in: (a) Lithophysal; (b) Nonlithophysal Rock

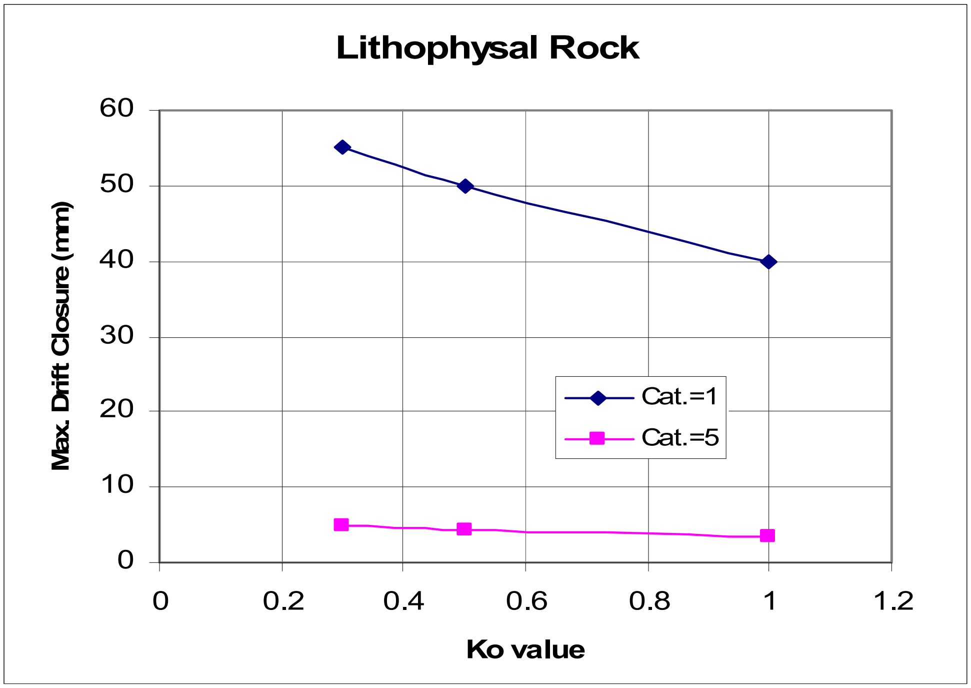


(a)

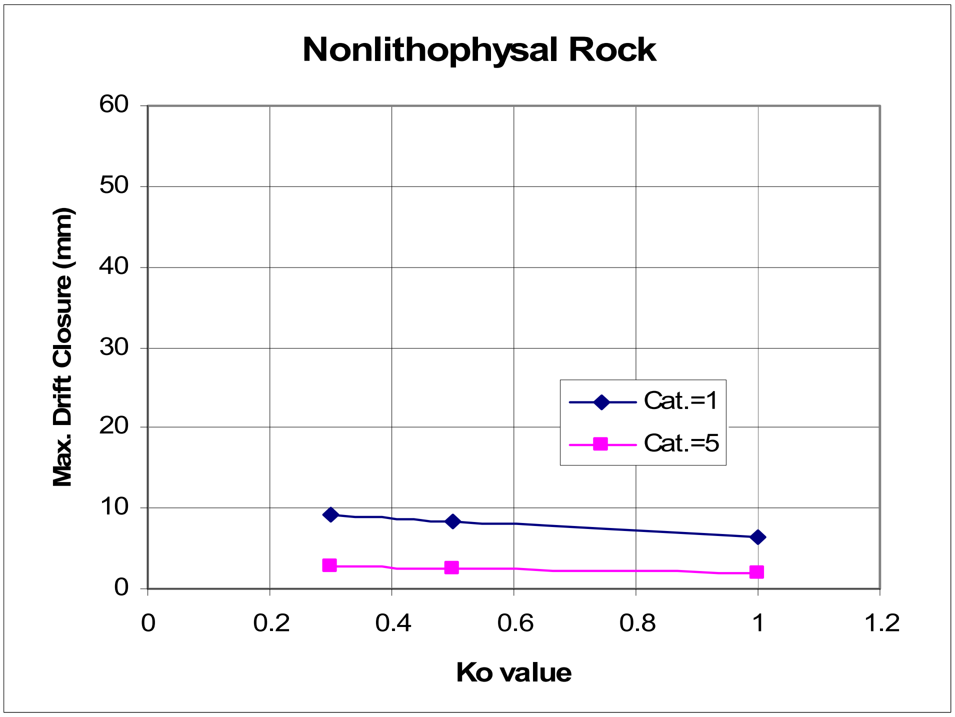


(b)

Figure 6-49 Time Histor ies of Major Principal Stresses near Crown and Springline of Emplacement Drifts under Seismic Load and Ko=0.5 at Year 0 in: (a) Lithophysal; (b) Nonlithophysal Rock

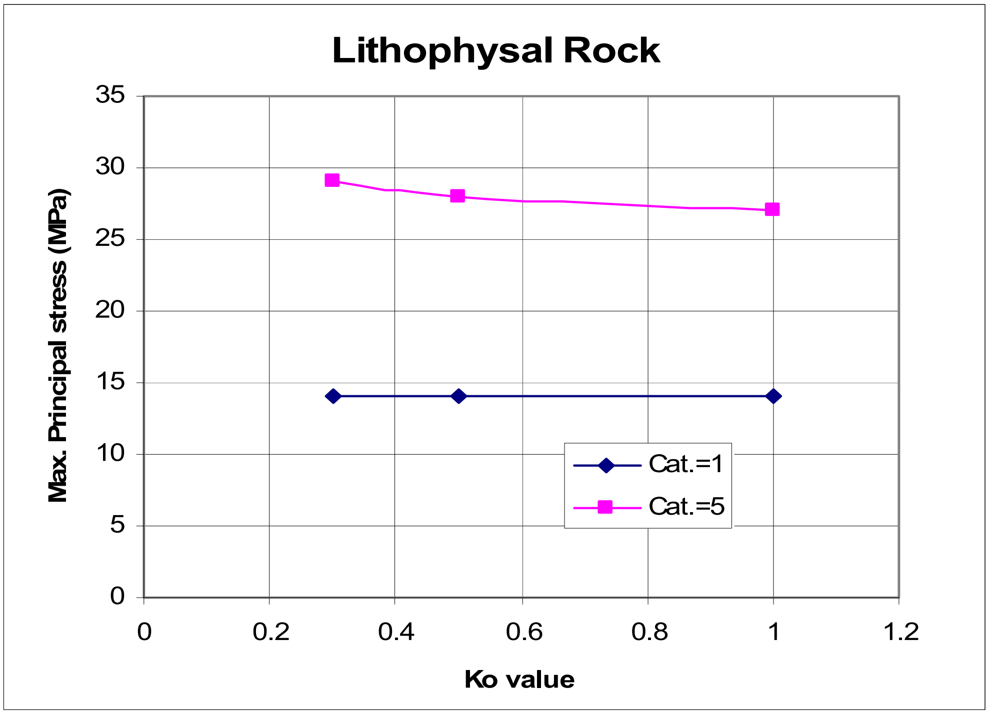


(a)

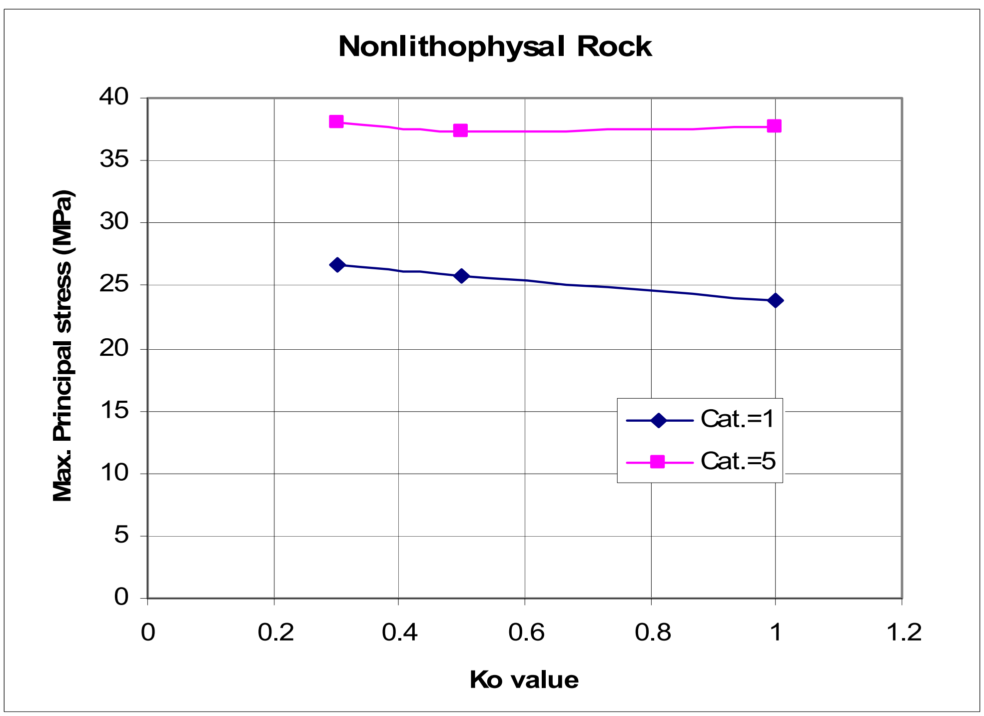


(b)

Figure 6-50 Vertical Drift Closure vs Ko for (a) Lithophysal and (b) Nonlithophysal Rock



(a)



(b)

Figure 6-51 Maximum Principal Stress vs Ko for (a) Lithophysal and (b) Nonlithophysal Rock

6.8.2 Emplacement Drift Stability Under Seismic Event with an APE of 10^{-4}

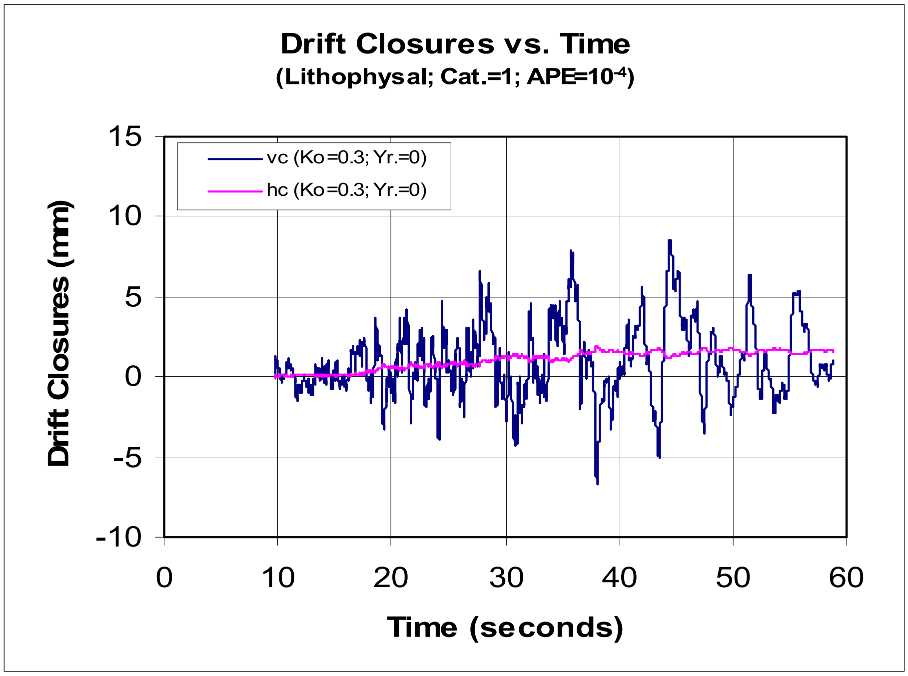
6.8.2.1 Stability of Unsupported Emplacement Drifts

This section addresses the assessment of stability of unsupported emplacement drifts subjected to the seismic events with an APE of 10^{-4}.

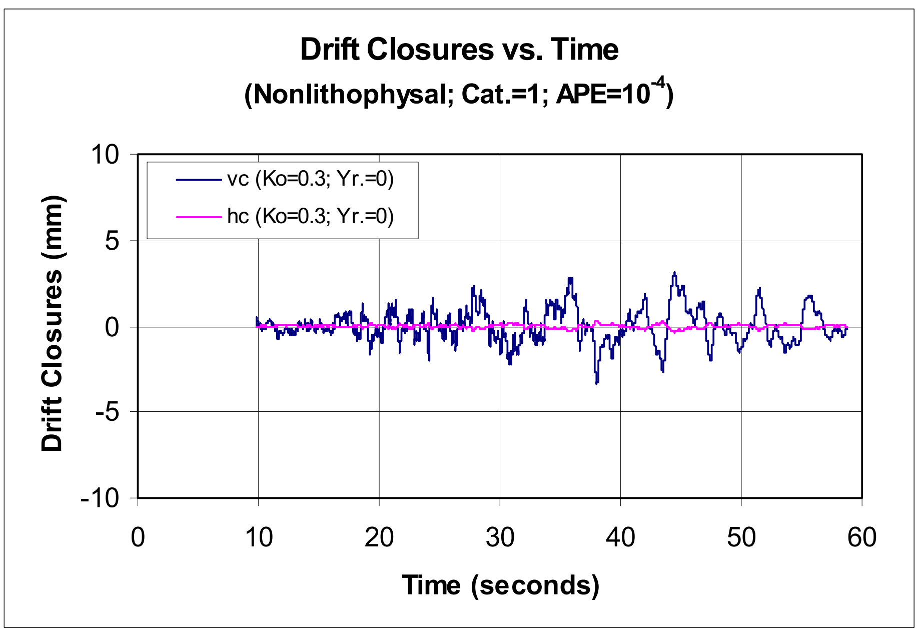
Drift closures induced by seismic motions were calculated for unsupported emplacement drifts in both the lithophysal and nonlithophysal category 1 rocks, and are presented in Figure 6-52(a) and Figure 6-52(b), respectively. The maximum closures due to seismic loadings are predicted to vary from less than 9 mm for the category 1 lithophysal rock to less than 4 mm for the category 1 nonlithophysal rock. Compared with the results subjected to the seismic events with an APE of 5×10^{-4} (see Figure 6-9(a) and Figure 6-11(a)), the closures are slightly higher for the emplacement drifts subjected to the seismic events with an APE of 10^{-4} but still insignificant.

Time histories of the major principal stresses near crown and springline are shown in Figure 6-53(a) and Figure 6-53(b) for unsupported emplacement drifts subjected to seismic loads and K_o of 0.3, in the lithophysal and nonlithophysal rocks, respectively. During a seismic event, dynamically induced stresses fluctuate with seismic velocities for the lithophysal rock and the nonlithophysal rock. The magnitude of fluctuation in stress varies with locations. The maximum fluctuation in the major principal stresses near the springline is predicted to vary from about 3 MPa for category 1 lithophysal rock to about 5 MPa for nonlithophysal category 1 rock. Compared with the results subjected to the seismic events with an APE of 5×10^{-4} (see Figure 6-15(a) and Figure 6-17(a)), the stresses are a little higher for the emplacement drifts subjected to the seismic events with an APE of 10^{-4} but still insignificant.

Based on the results of this sensitivity analysis, it can be predicted that emplacement drifts will be stable under seismic event with an APE of 10^{-4} using FLAC, i.e., a continuum model.

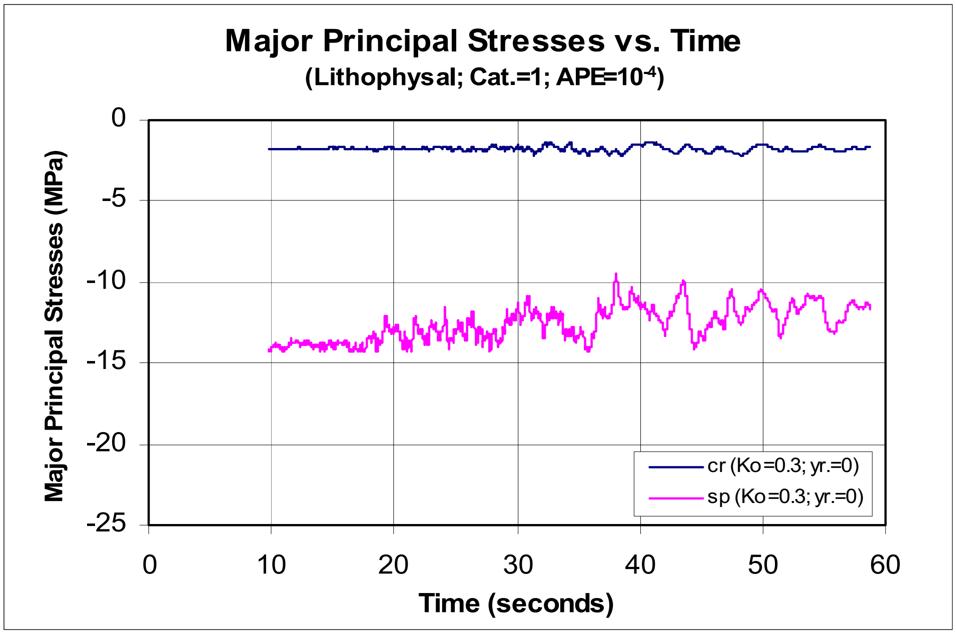


(a)

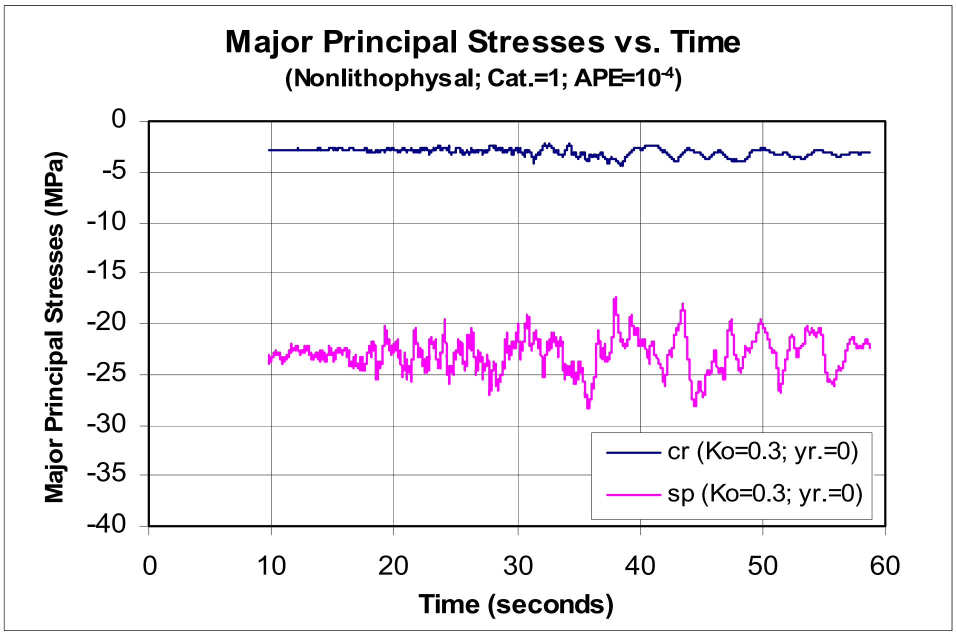


(b)

Figure 6-52 Time Histories of Closures of Emplacement Drifts under Seismic Load at Year 0 and Ko=0.3 in (a) Lithophysal and (b) Nonlithophysal Category 1 Rock,



(a)

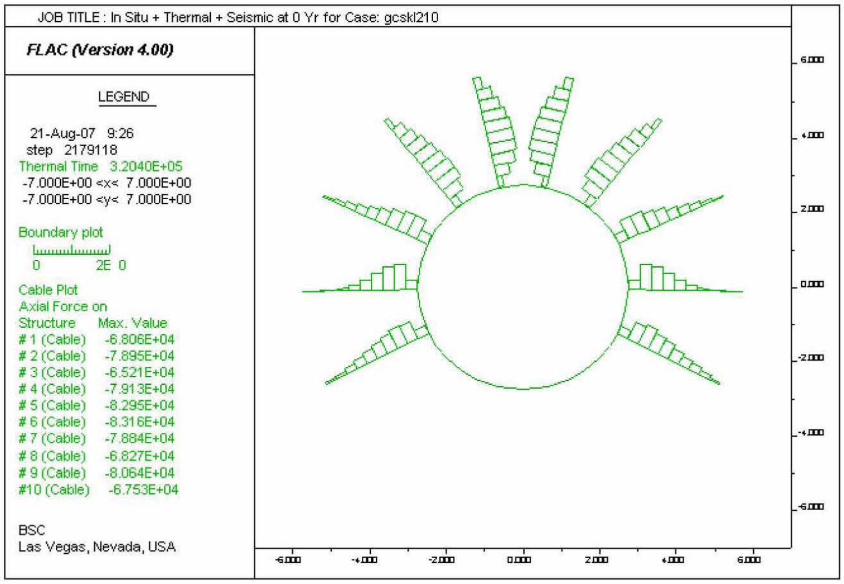


(b)

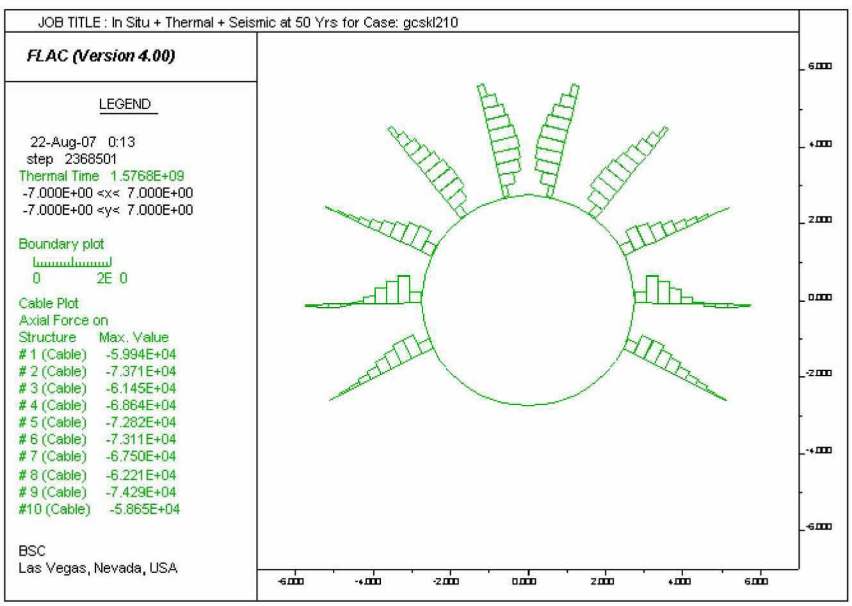
Figure 6-53 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts under In Situ, Thermal and Seismic Load at Year 0 and Ko=0.3 in (a) Lithophysal and (b) Nonlithophysal Category 1 Rock

6.8.2.2 Performance of Rock Bolts in Emplacement Drifts

Distributions of axial forces in Swellex bolts for lithophysal rock under in situ, thermal and seismic loads at 0 year and 50 years after waste emplacement are presented in Figure 6-54(a) and Figure 6-54(b), respectively. Comparing Figure 6-54 with Figure 6-39, which shows axial forces in bolts under a seismic event with an APE of 5×10^{-4}, it is seen that the bolt forces are slightly increased. For bolts installed near the crown, the maximum axial forces increase from about 102 kN to 104 kN at year 0 and from 90 kN to 91 kN. The increase of bolt forces is very small for bolts installed in emplacement drifts under a seismic event with an APE of 10^{-4}. The factor of safety under the combined loading combinations is about 2.9 (298/104=2.9).



(a)



(b)

Note: Axial bolt forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-54 Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ, Thermal and Seismic Loads for Category 1 and Ko=0.3: (a) Yr 0; (b) Yr 50,

6.9 UNCERTAINTY ASSOCIATED WITH CALCULATION METHODS

Design calculations usually involve simplification of the actual system to reduce computational efforts. Without the idealization or simplification, the calculations are sometimes impractical or even impossible based on the tools currently available. The greater the difference between the actual system and the simulated one, the greater the uncertainties can be expected.

6.9.1 Continuum versus Discontinuum

The rock mass considered in this calculation contains many joints and voids. These discontinuities affect the behavior of emplacement drifts excavated in the discontinuous rock mass. Ideally, a discontinuum approach that explicitly simulates these discontinuities is preferred. In conventional mining or tunnel design, however, an equivalent continuum approach is most popular due to its simplicity and easy understanding of the results. In the continuum approach, the values of rock mass properties used are equivalent, meaning that the effect of discontinuities can be accounted for by choosing these property values. The continuum approach has been proved useful and reasonable through many years of industry practice.

The ground support designs for the ESF tunnels and the ECRB Cross Drift were based primarily on the conventional continuum approach. The experiences from these tunnel designs and excavations indicate that the continuum approach is still applicable to the ground support design for emplacement drifts. Results from the continuum approach, such as rock deformation and stress, are considered equivalent to those that would be generated otherwise by using a discontinuum approach.

Some information, such as size of potential rockfall, may not be obtained from a continuum approach. A discontinuum approach should be supplemented to address some specific design issues. Since the *Drift Degradation Analysis* (Reference 2.2.16) uses the discontinuum approach to quantify the effect of joints on potential wedge failure and the results are available, it is not necessary for this calculation to conduct similar analyses in order to obtain the information about rockfall.

6.9.2 Model Dimensions

Most of the calculations on ground support design are performed using numerical modeling. In developing a numerical model, a model dimension needs to be decided first. The model dimension covers two aspects, one is related to the choice of either two dimensions or three dimensions, and the other is the selection of a model size.

Factors that are considered in the choice of model dimensions include the location where an opening of interest is excavated, the loading conditions that the excavation is subjected to, and the size of the opening. For emplacement drifts, the average length is about 600 m (Reference 2.2.15, Section 8), and the loads are generally perpendicular to the drift axis. Use of two-dimensional models is appropriate to assess the behavior of emplacement drifts if a continuum approach is employed. Uncertainties are primarily associated with evaluating the performance of the drifts located near intersections, where the loading and stress conditions are predominately three-dimensional. Generally, two-dimensional models give more conservative results than three-dimensional ones, which will in part offset some related uncertainties.

The configuration including dimension of simulation used in this calculation is presented in Figure 4-2. The size of a model usually affects the accuracy of results and the computational time. However, the accuracy will not necessarily be improved by increasing the model size. For the ground support design, a model size equal to about 5 to 10 times the drift diameter is adequate. Any uncertainties associated with the variations of model size are considered to have insignificant effect on the results. Details on the evaluation of this effect are presented in the *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (Reference 2.2.14, Section 6.2.1).

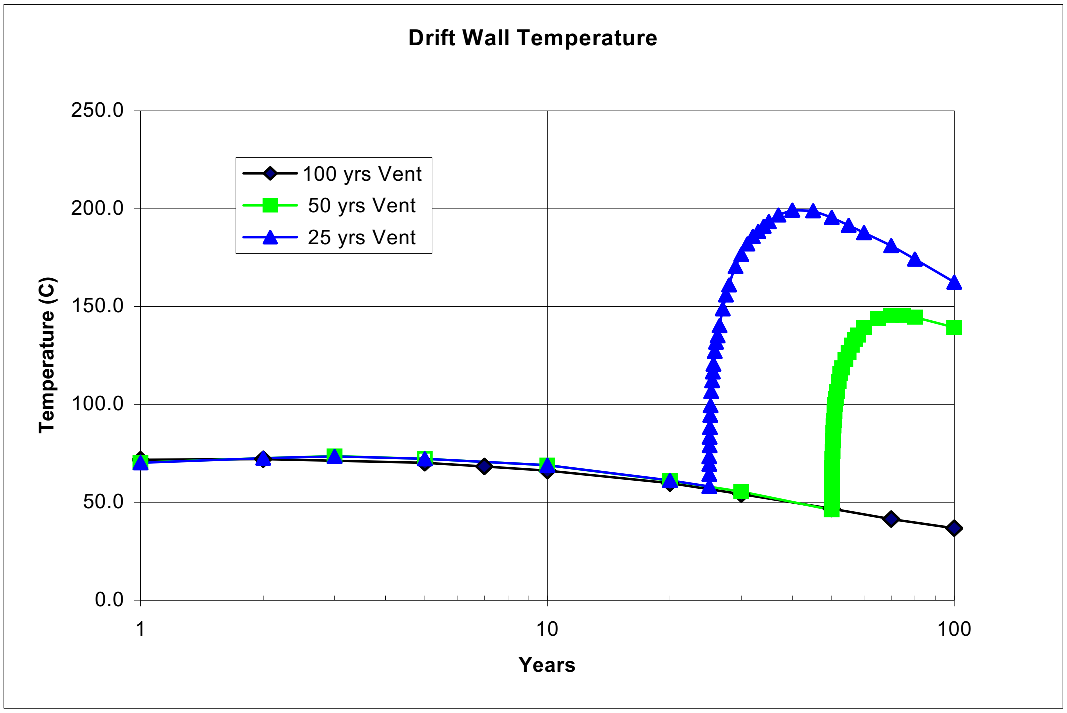
6.10 EMPLACEMENT DRIFT STABILITY AT OFF-NORMAL TEMPERATURES

During the repository normal operation, the ventilation system will function as designed, thus controlling the emplacement drift wall temperature below the boiling point (Reference 2.2.19, Section 22.2.1.3). However, an off-normal thermal condition would occur should the ventilation system get interrupted or shut down due to system failure or the airway get completely blocked due to unexpected rockfalls in the emplacement drifts. As a result, temperatures at these affected emplacement drifts may rise far beyond normal operation levels, depending upon how rapidly the ventilation system can be restored to normal. Because of high radiation and hot temperature, any attempt to perform unexpected repair or maintenance on ground support in these drifts is quite difficult. Therefore, an engineering evaluation of off-normal thermal conditions and resulting thermomechanical responses of both surrounding rock and ground support is needed for helping address the adequacy and longevity of ground support. Furthermore, this study will form the basis for consideration of design risk and risk management pertaining to this subject.

6.10.1 Introduction

In this section, emplacement drift stability for two off-normal ventilation scenarios are evaluated. They are: (1) ventilation for first 50 years and without ventilation for another 50 years, and (2) ventilation for first 25 years and without ventilation for another 75 years. The temperature histories of the drift wall for the two temperature scenarios are depicted in Figure 6-55. It is noted that a 100-year ventilation case is also shown in this figure, which is only shown for comparison. The focus of discussion in this section is on 50- and 25-year ventilation scenarios. It can be seen clearly from this figure that the drift wall temperature rapidly reaches to about 150 ^{o}C and 200 ^{o}C, respectively for the 50- and 25-year ventilation scenarios, after the ventilation system is shut down. These temperature levels are far above the maximum temperature limit of the normal operation, i.e., 96 ^{o}C, during the preclosure period (Reference 2.2.19, Section 22.2.1.3).

The mechanical and thermal properties of lithophysal and nonlithophysal rocks and rock bolt properties used in this evaluation are the same as those used in Section 6.1.2. For this evaluation, dynamic loading was imposed immediately after waste emplacement (i.e., year 0) and 100 years after waste emplacement. Dynamic excitation with a mean annual probability of occurrence of 5×10^{-4} (Reference 2.2.45) was used in the simulations (see Figure 6-1).



Source of curves: 25-yr: Reference 2.2.46, 25yr_vent folder, P2WR5C10-LDTH55-1Dds_mc-mi-01.m.EBS.ext
50-yr: Reference 2.2.46, basecase folder, P2WR5C10-LDTH55-1Dds_mc-mi-01.m.EBS.ext.
100-yr: Reference 2.2.13, LA1450_ANSYS_Temp_crss-sctn.xls

Figure 6-55 Time Histories of Drift Wall Temperature

6.10.2 Time History of Rock Temperatures

The time histories of rock temperatures for the 50- and 25-year ventilation scenarios are shown in Table 6-10 (a) and Table 6-10 (b).

Table 6-10 Time Histories of Rock Temperatures for Off-normal Ventilation Scenarios

(a) 50 years of ventilation and 50 years without ventilation

Time (years)	Temperatures (°C)		
	Drift Wall	50-m Above Drift Center[a]	50-m Below Drift Center[a]
1	70.3	21.71	23.11
50	46.1	26.61	28.01
60	139.1	27.92	29.33
70	145.5	31.10	32.50
100	139.2	40.99	42.35

Source: Reference 2.2.46, basecase folder, P2WR5C10-LDTH55-1Dds_mc-mi-01.m.EBS.ext.

Note: [a] Temperature data at the exact locations were obtained by linear interpolation between two neighboring points from the source reference.

(b) 25 years of ventilation and 75 years without ventilation

Time (years)	Temperatures (°C)		
	Drift Wall	50-m Above Drift Center[a]	50-m Below Drift Center[a]
0	22.28[b]	21.68[b]	23.08[b]
0.01	36.64[b]	21.68[b]	23.08[b]
1	70.2	21.71	23.11
25	58.1	24.27	25.64
40	199.2	28.74	30.28
100	162.5	53.39	54.72

Source: Reference 2.2.46, 25yr_vent folder, P2WR5C10-LDTH55-1Dds_mc-mi-01.m.EBS.ext.

Notes: [a] Temperature data at the exact locations were obtained by linear interpolation between two neighboring points from the source reference.
[b] Data were taken from Table 6-1.

6.10.3 Numerical Modeling Results

6.10.3.1 Drift Closures

Figure 6-56 through Figure 6-59 depict the horizontal and vertical closures of emplacement drifts due to in situ and thermal loading for 50- and 25-year ventilation scenarios. Positive closure indicates reduction in the emplacement drift dimension.

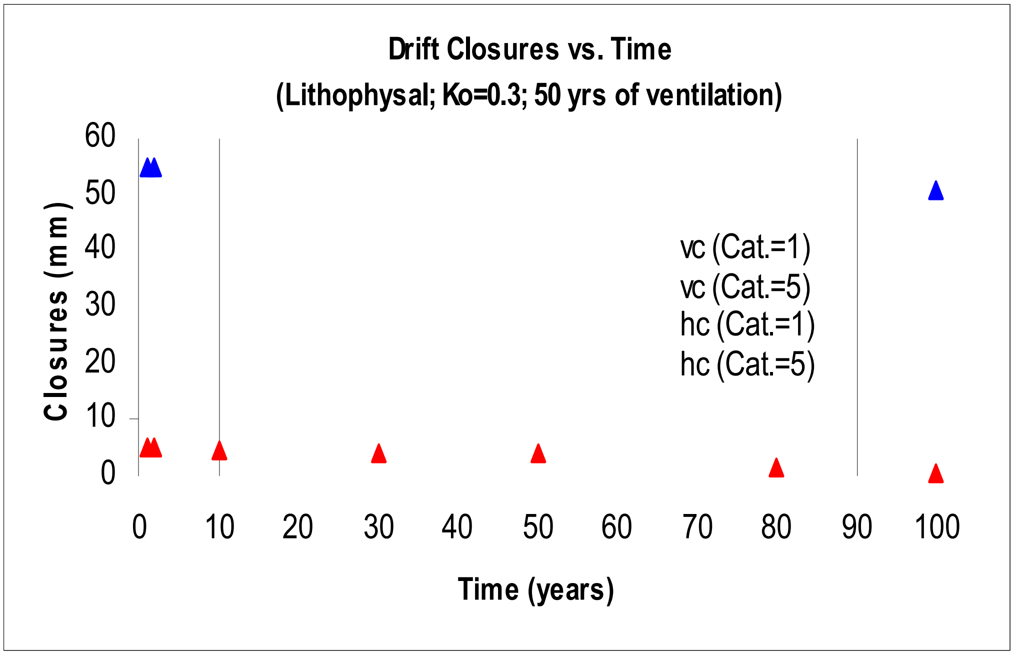
For the lithophysal rock (Figure 6-56 and Figure 6-57), category 1 rock with K_o = 0.3, the vertical closure due to in situ and thermal loads reaches to the maximum of about 55 mm at 1 year after waste emplacement for both ventilation scenarios then decreases to about 51 and 52 mm at 100-year after waste emplacement for 50- and 25-year scenarios, respectively. The maximum vertical closure for the same rock with K_o = 1.0 is about 40 mm at 1 year after waste emplacement for both ventilation scenarios. Based on Figure 6-56 and Figure 6-57, the temperature increase due to ventilation shut down has insignificant impact on vertical closures of emplacement drifts. The temperature effect due to ventilation shut down has more impact on the horizontal closure. For rock with K_o = 0.3, horizontal closure increases from about 5 mm at year 50 to 9 mm at year 100 for 50-year ventilation scenario. For 25-year ventilation scenario, it increases from 4 mm at year 25 to 14 mm at year 100. Under K_o = 1.0, the similar trend is observed except the magnitudes. The horizontal closure increases from 40 mm at year 50 to 45 mm at year 100 and from 40 mm at year 25 to 53 mm at year 100 for 50- and 25-year ventilation scenario, respectively.

Category 5 lithophysal rock shows smaller deformations. Vertical closure has peak values of 5 mm with K_o = 0.3 for both ventilation scenarios and 3 mm and 5 mm with K_o = 1 for 50-year and 25-year ventilation scenarios, respectively. Horizontal closure has peak values of 5 mm and 13 mm with K_o = 0.3 and 9 mm and 18 mm with K_o = 1 for 50- and 25-year ventilation scenario, respectively.

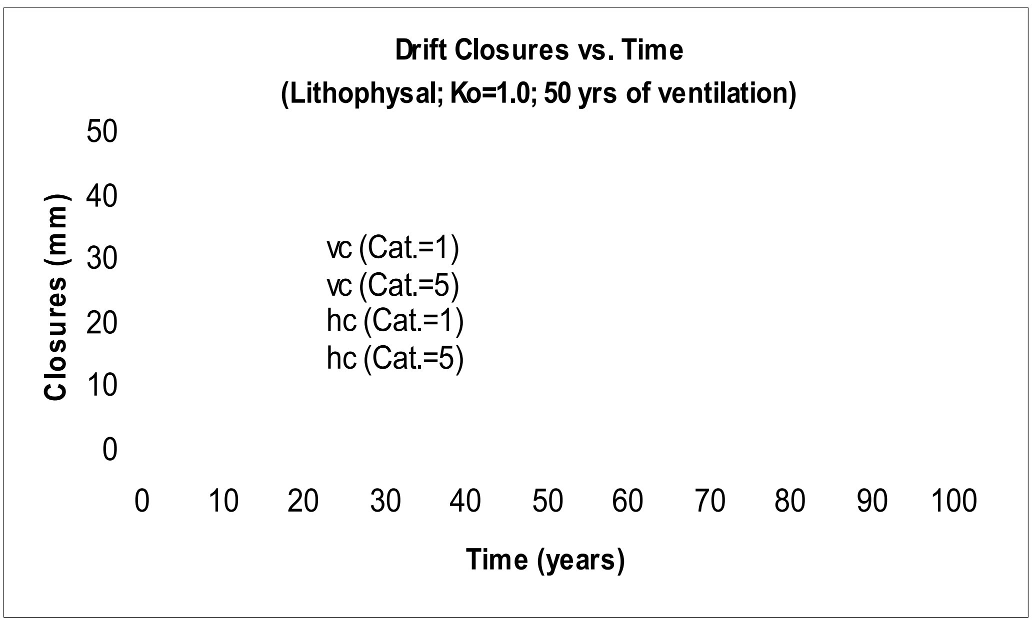
For category 1 nonlithophysal rock (Figure 6-58 and Figure 6-59), the maximum vertical closure is 9 mm (K_o = 0.3) and 6 mm (K_o = 1) for both ventilation scenarios. The maximum horizontal closure are 4 mm and 9 mm (K_o = 0.3) and 11 mm and 16 mm (K_o = 1.0) for 50- and 25-year ventilation scenario, respectively.

Category 5 nonlithophysal rock shows smaller deformations. Vertical closure has peak values of about 3 mm and 4 mm with K_o = 0.3 and 2 mm with K_o = 1.0 for 50- and 25-year ventilation scenario, respectively. Horizontal closure has peak values of 5 mm with K_o = 0.3 and 7 mm with K_o = 1.0 for 50-year ventilation scenario. Horizontal closure has peak values of 14 mm with K_o = 0.3 and 15 mm with K_o = 1.0 for 25-year ventilation scenario.

Transient drift closures due to seismic loading are depicted in Figure 6-60 through Figure 6-63. The maximum transient closures during seismic loading vary from about 3 mm for category 1 lithophysal rock to about 1 mm for category 5 lithophysal rock. For nonlithophysal rock, they are smaller, varying from less than 1.5 mm for category 1 rock to less than 1 mm for category 5 rock.

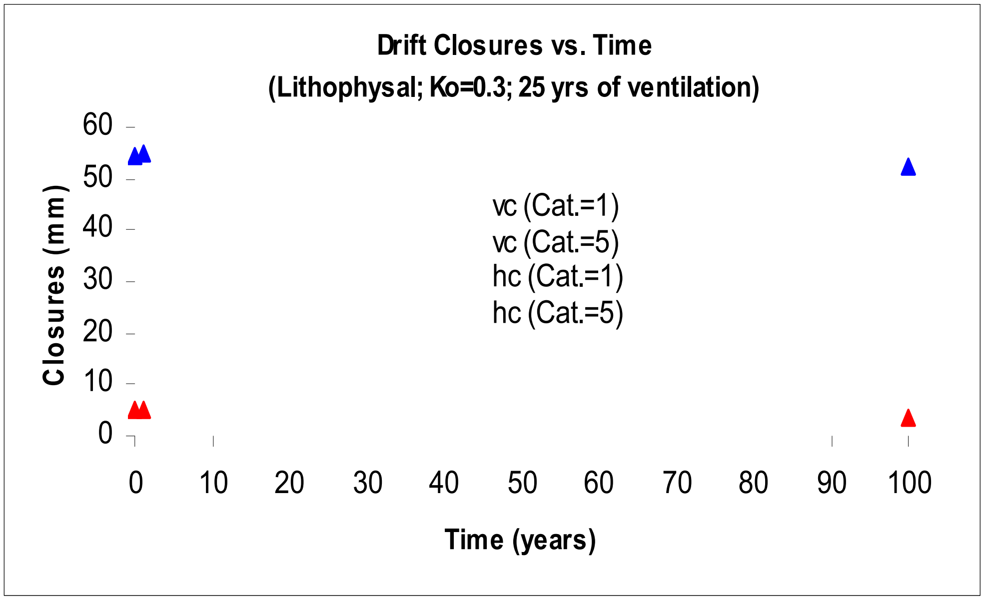


(a)

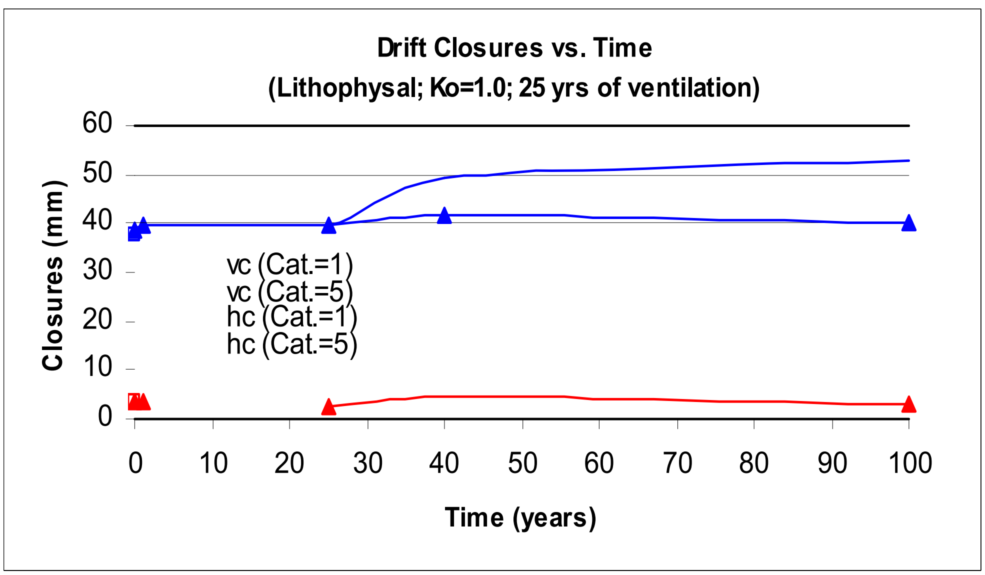


(b)

Figure 6-56 Vertical and Horizontal Closures of Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loading for 50-Year Ventilation Scenario: (a) Ko = 0.3; (b) Ko = 1.0

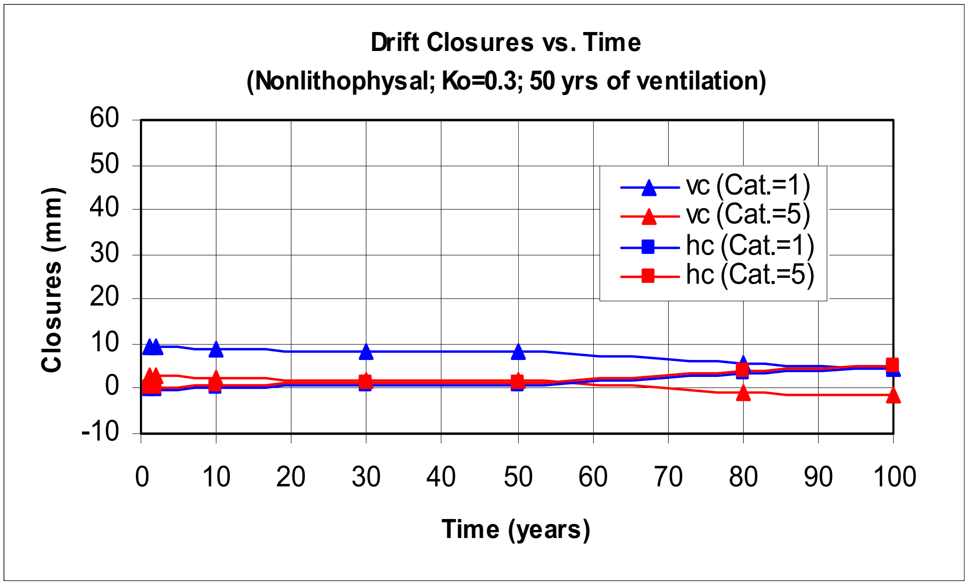


(a)

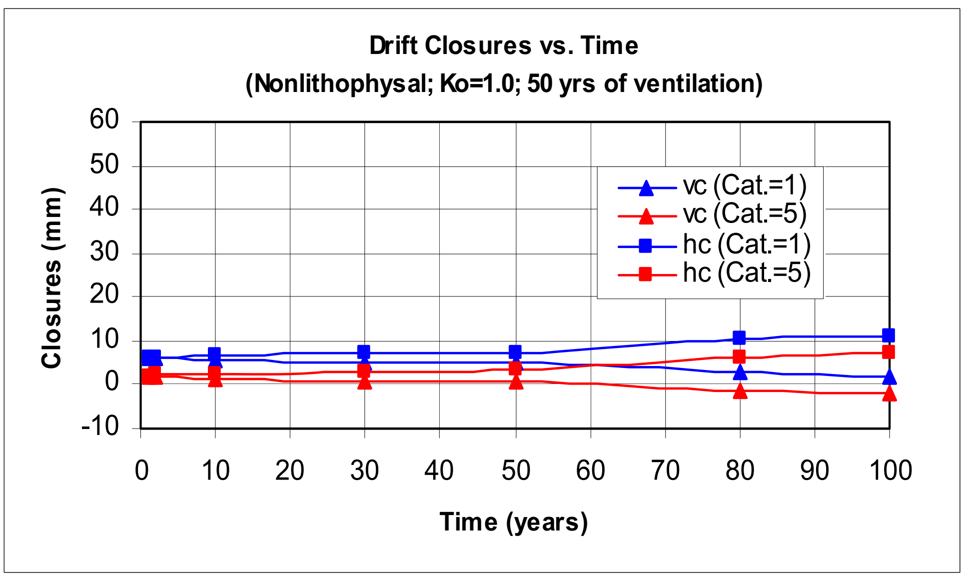


(b)

Figure 6-57 Vertical and Horizontal Closures of Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loading for 25-Year Ventilation Scenario: (a) Ko = 0.3; (b) Ko = 1.0

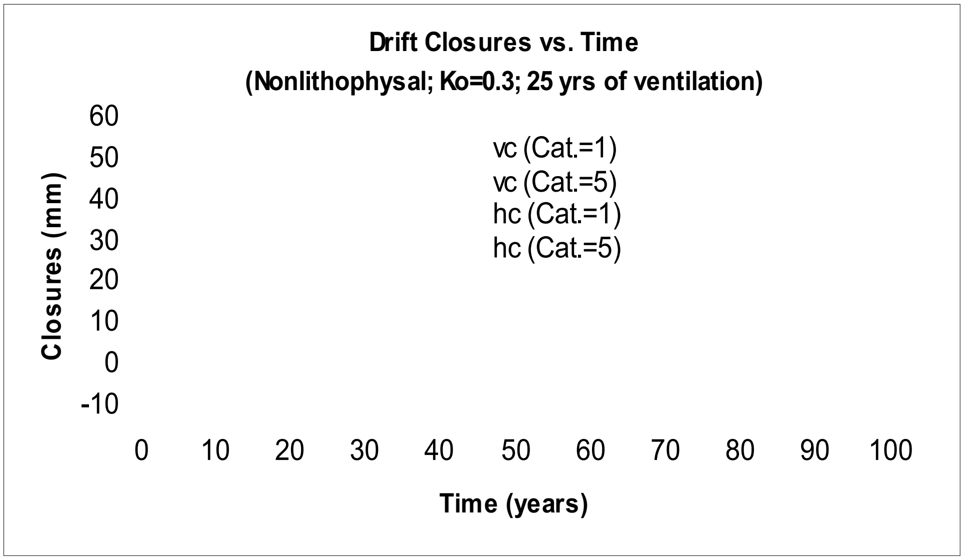


(a)

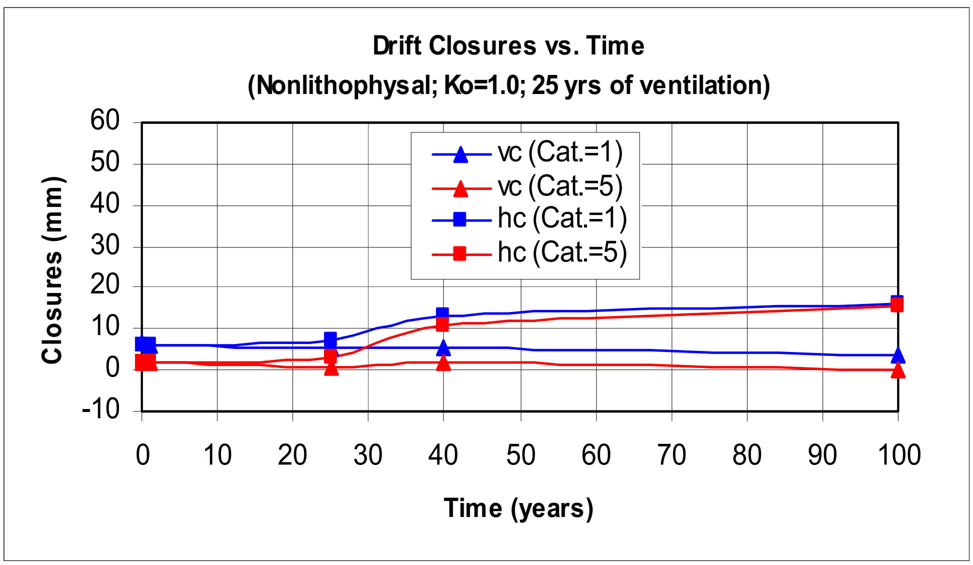


(b)

Figure 6-58 Vertical and Hori zontal Closures of Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loading for 50-Year Ventilation Scenario: (a) Ko = 0.3; (b) Ko = 1.0

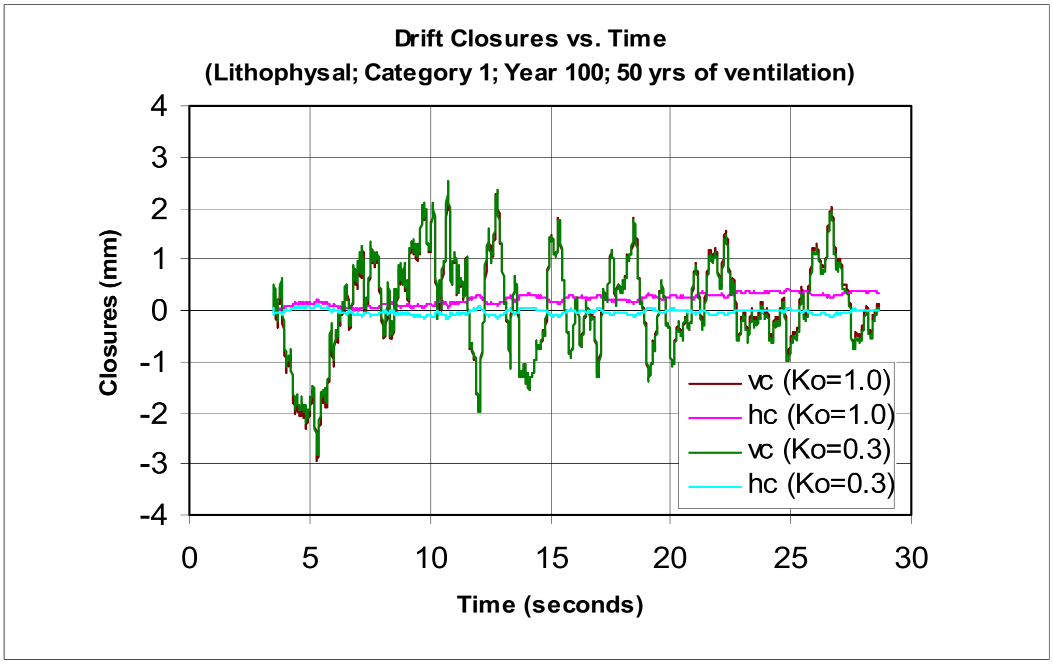


(a)

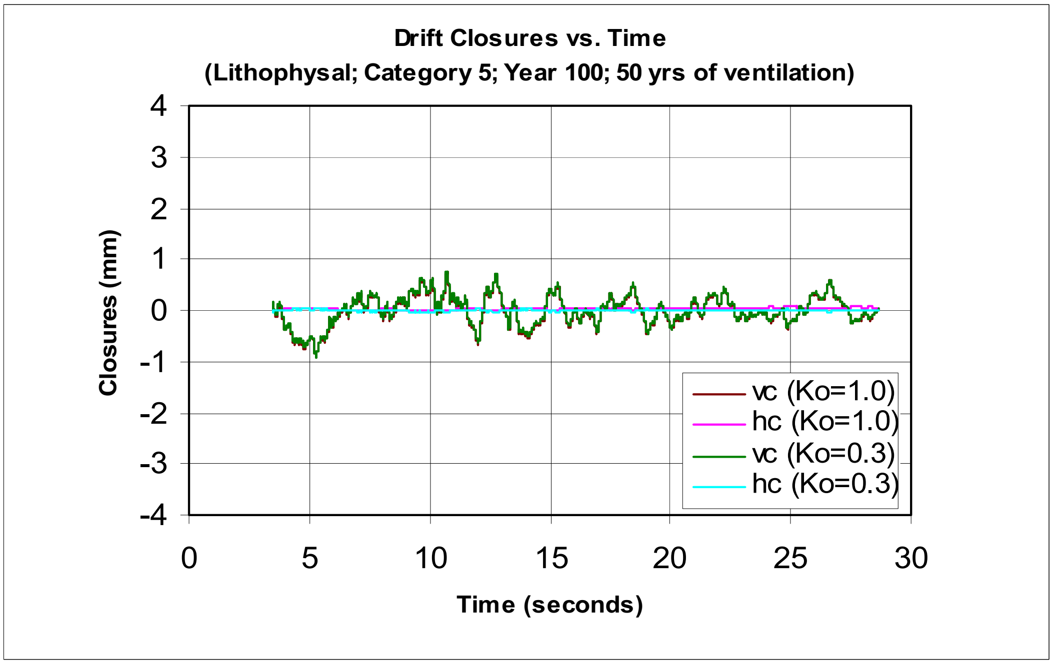


(b)

Figure 6-59 Vertical and Horizontal Closures of Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ and Thermal Loading for 25-Year Ventilation Scenario: (a) Ko = 0.3; (b) Ko = 1.0

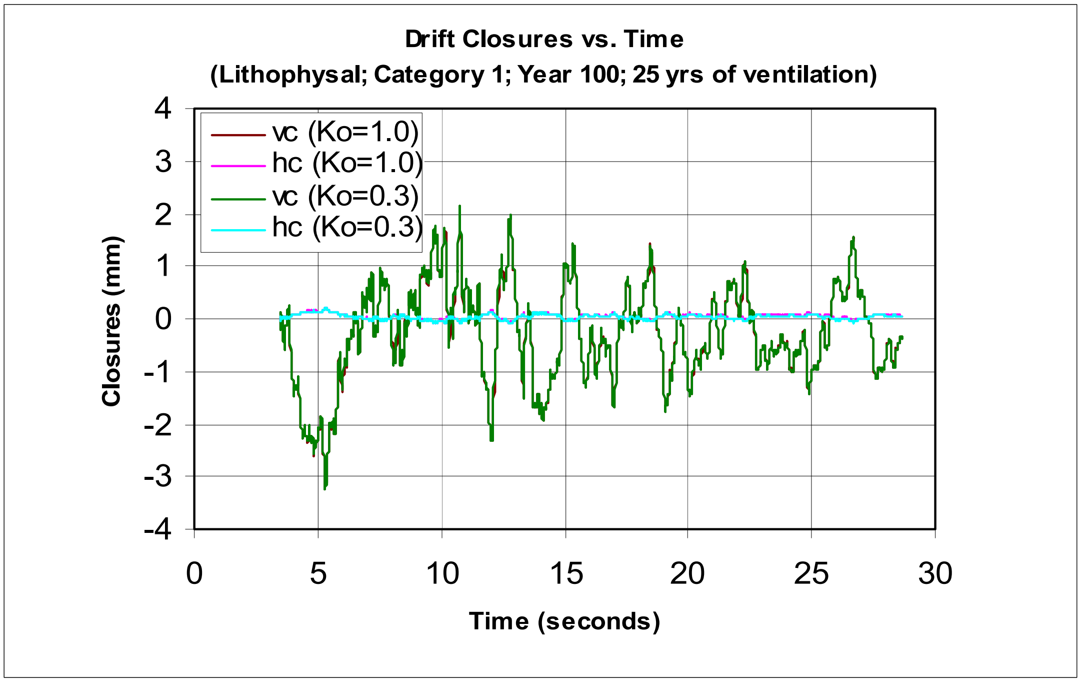


(a)

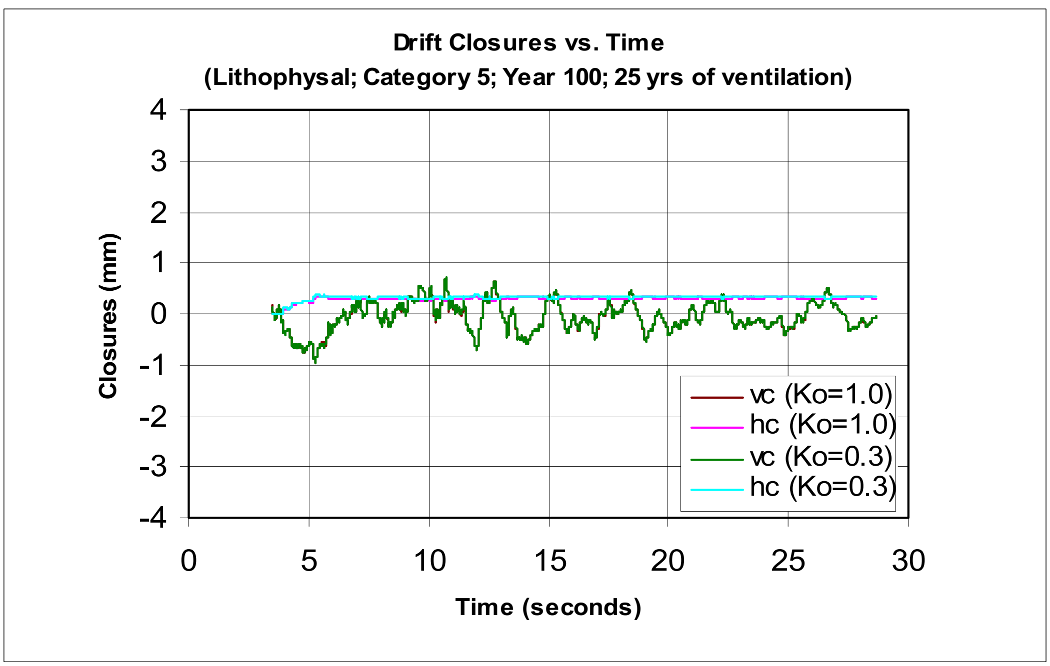


(b)

Figure 6-60 Time Histories of Closures of Emplacement Drifts in Lithophysal Rock with Ko = 0.3 and Ko = 1.0 under Seismic Loading at Year 100 for 50-Year Ventilation Scenario: (a) Category 1; (b) Category 5

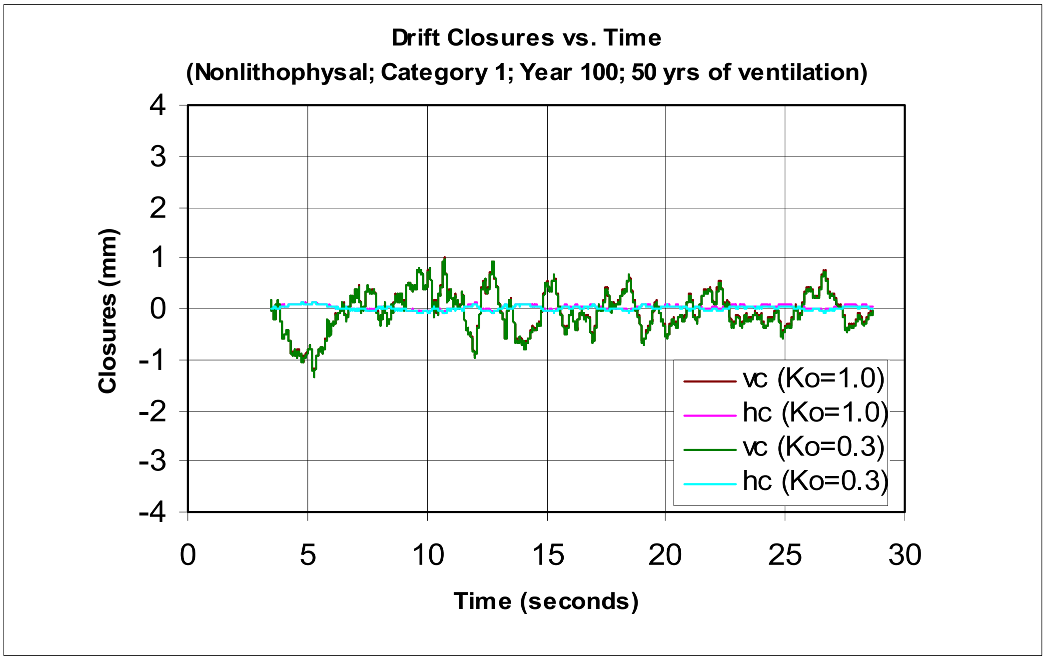


(a)

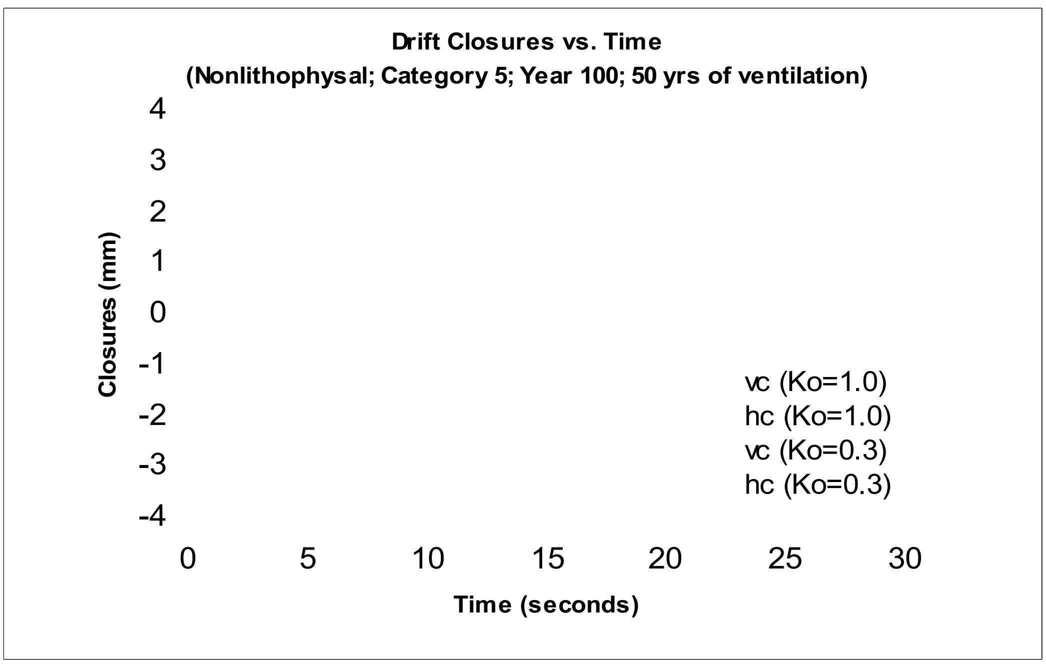


(b)

Figure 6-61 Time Histories of Closures of Emplacement Drifts in Lithophysal Ro ck with Ko = 0.3 and Ko = 1.0 under Seismic Loading at Year 100 for 25-Year Ventilation Scenario: (a) Category 1; (b) Category 5

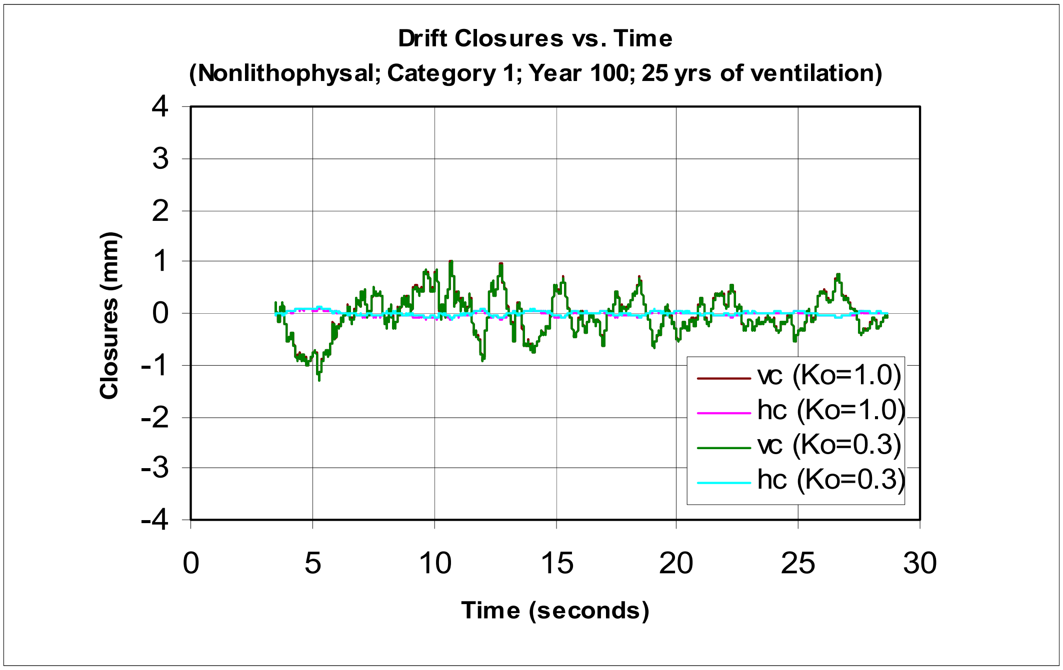


(a)

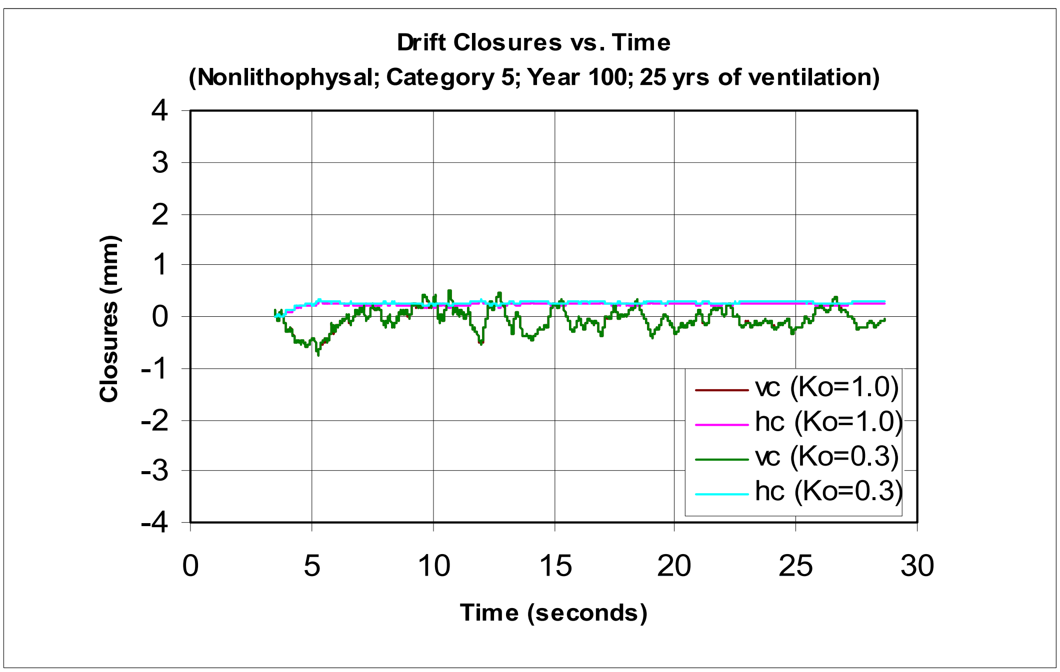


(b)

Figure 6-62 Time Histori es of Closures of Emplacement Drifts in Nonlithophysal Rock with Ko = 0.3 and Ko = 1.0 under Seismic Loading at Year 100 for 50-Year Ventilation Scenario: (a) Category 1; (b) Category 5



(a)



(b)

Figure 6-63 Time Histories of Cl osures of Emplacement Drifts in Nonlithophysal Rock with Ko = 0.3 and Ko = 1.0 under Seismic Loading at Year 100 for 25-Year Ventilation Scenario: (a) Category 1; (b) Category 5

6.10.3.2 Stresses in Rock Adjacent to Drifts

Time histories of the major principal stresses at two critical locations, the crown and the springline, due to in situ and thermal loads for 50- and 25-year ventilation scenarios are shown in Figure 6-64 and Figure 6-65 for lithophysal rock and Figure 6-66 and Figure 6-67 for nonlithophysal rock, respectively.

The major principal stress for category 1 lithophysal rock reaches a maximum value of about 14 MPa for both 50- and 25-year ventilation scenarios and indicates no significant changes due to ventilation shut down. For the category 5 rock, the major principal stress reaches a maximum value of about 40 and 30 MPa for 50- and 25-year ventilation scenarios, respectively.

The stress behaviors in the nonlithophysal rock for both ventilation scenarios are similar to those for lithophysal rock. The major principal stress for category 1 nonlithophysal rock reaches a maximum value of about 35 and 29 MPa for 50- and 25-year ventilation scenarios, respectively. For the category 5 rock, the major principal stress reaches a maximum value of about 63 and 48 MPa for 50- and 25-year ventilation scenarios, respectively. The stress change due to elevated temperature caused by ventilation shut down is higher in the nonlithophysal rock than that in the lithophysal rock, especially in category 5 rock mass. However, this stress change is not expected to impact the overall stability of the emplacement drifts.

Principal stress fluctuations due to seismic loading for the lithophysal rock are shown in Figure 6-68 and Figure 6-69 for 50- and 25-year ventilation scenarios, respectively. For category 1 lithophysal rock, stress variation due to seismic loading in the lithophysal rock is less than 2 MPa and about 4 MPa for category 5 rock. The magnitudes of stress fluctuations due to seismic loading for the nonlithophysal rock are shown in Figure 6-70 and Figure 6-71 for 50- and 25-year ventilation scenarios, respectively. For category 1 nonlithophysal rock, stress variation due to seismic loading is about 2 MPa and about 4 MPa for category 5 rock. It indicates that stress variations due to seismic loading are much less affected compared to thermal loading changes due to different ventilation scenarios.

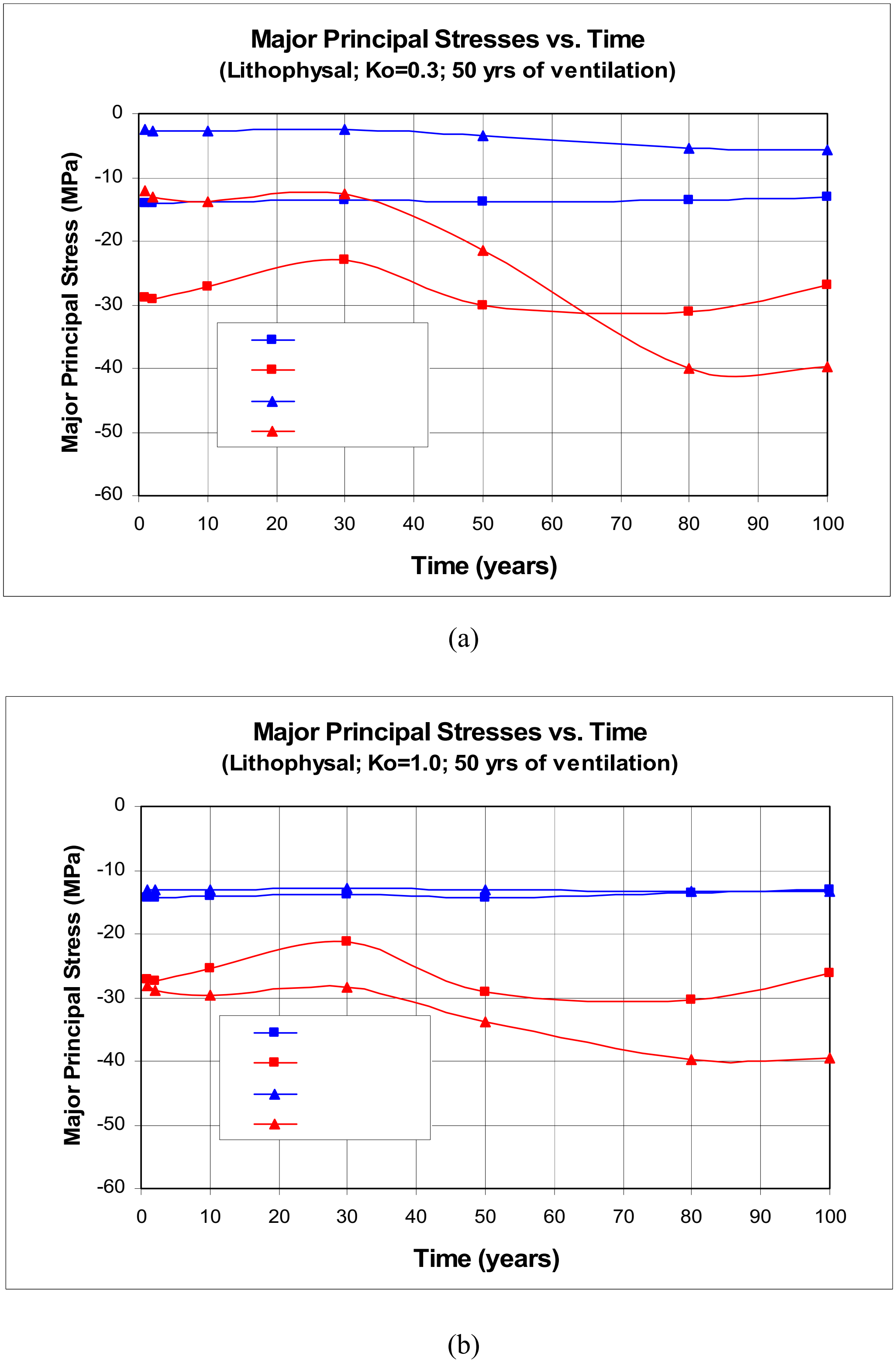
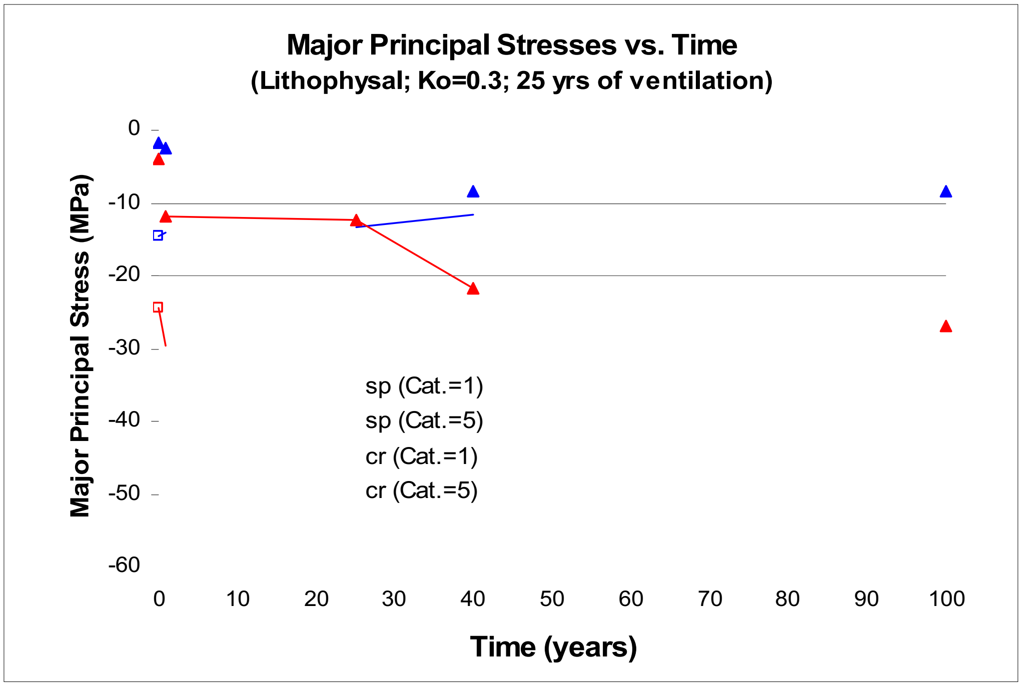
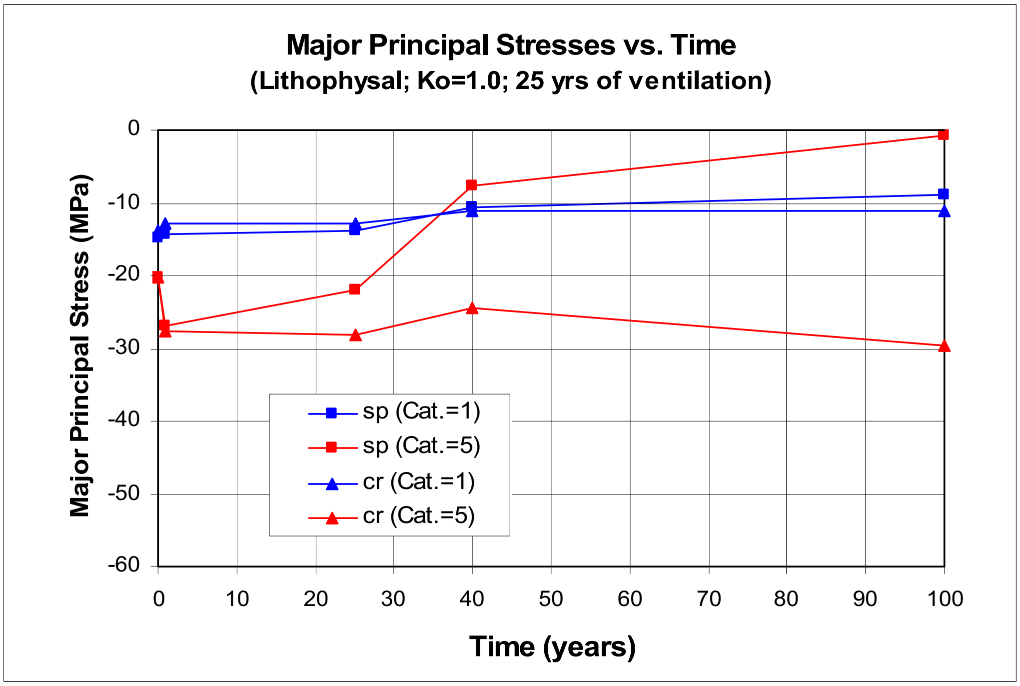


Figure 6-64 Major Principal Stress near Springline and Crown of Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for 50-Year Ventilation Scenario for Categories 1 and 5: (a) Ko = 0.3; (b) Ko = 1.0

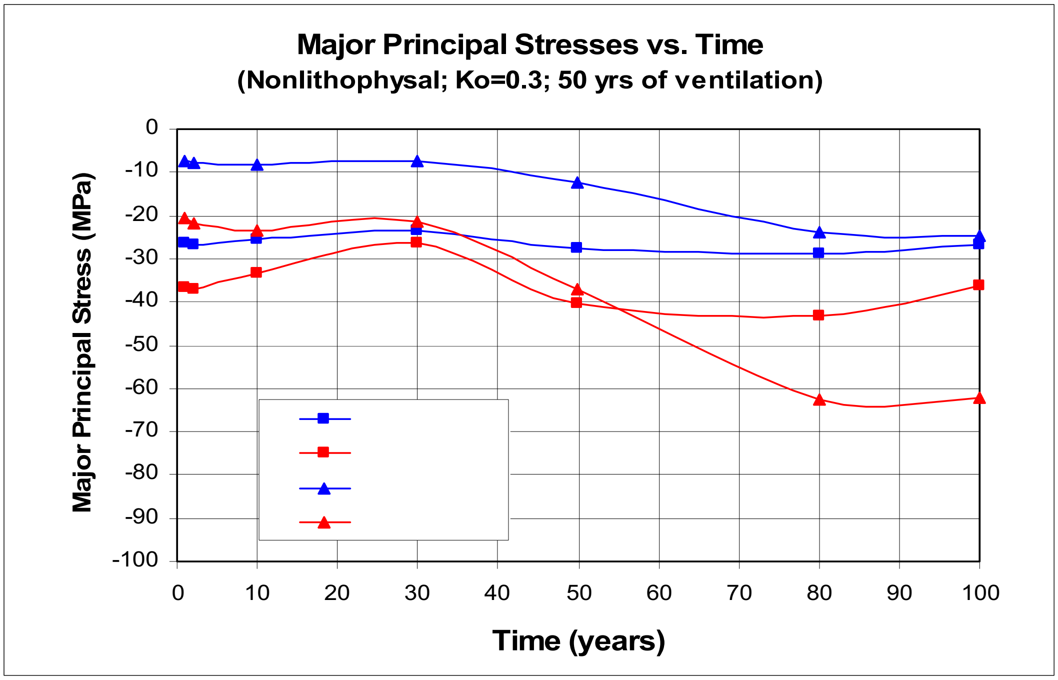


(a)

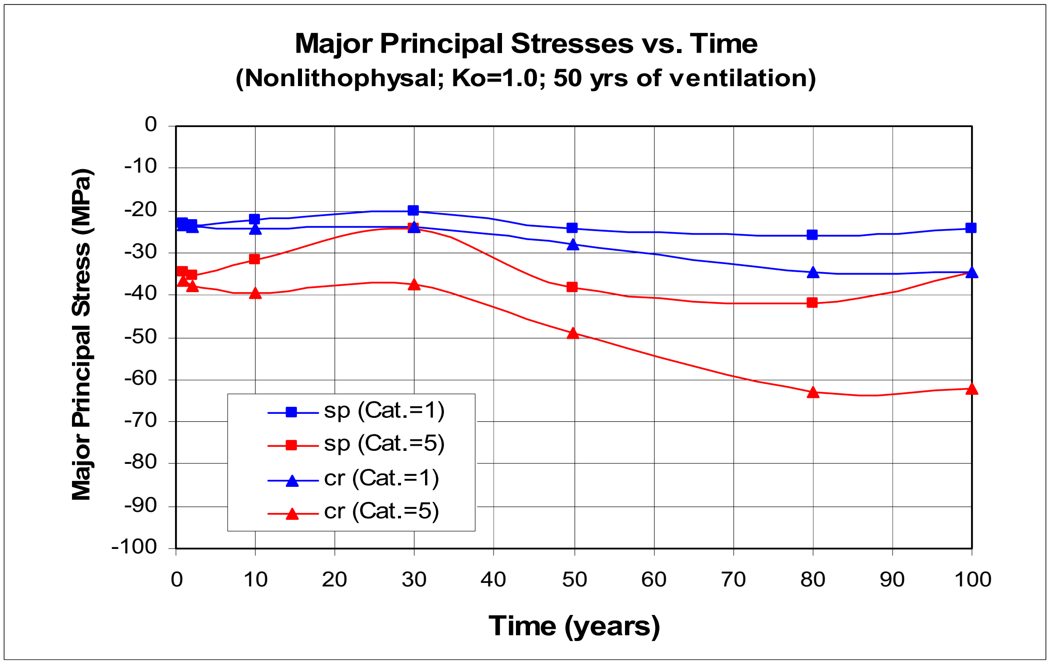


(b)

Figure 6-65 Major Princip al Stress near Springline and Crown of Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for 25-Year Ventilation Scenario for Categories 1 and 5: (a) Ko = 0.3; (b) Ko = 1.0

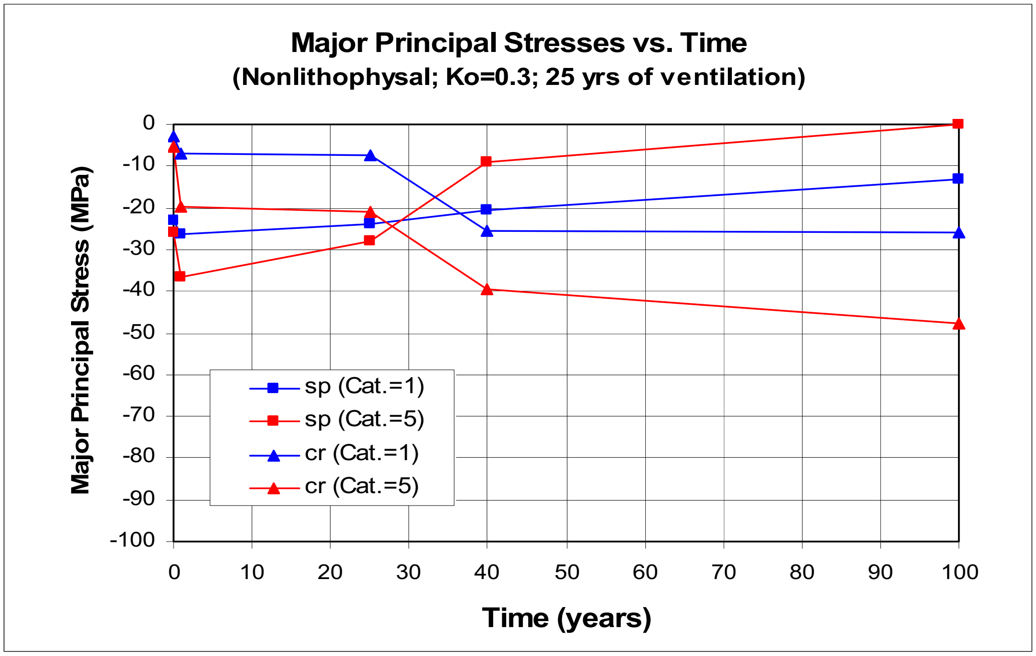


(a)

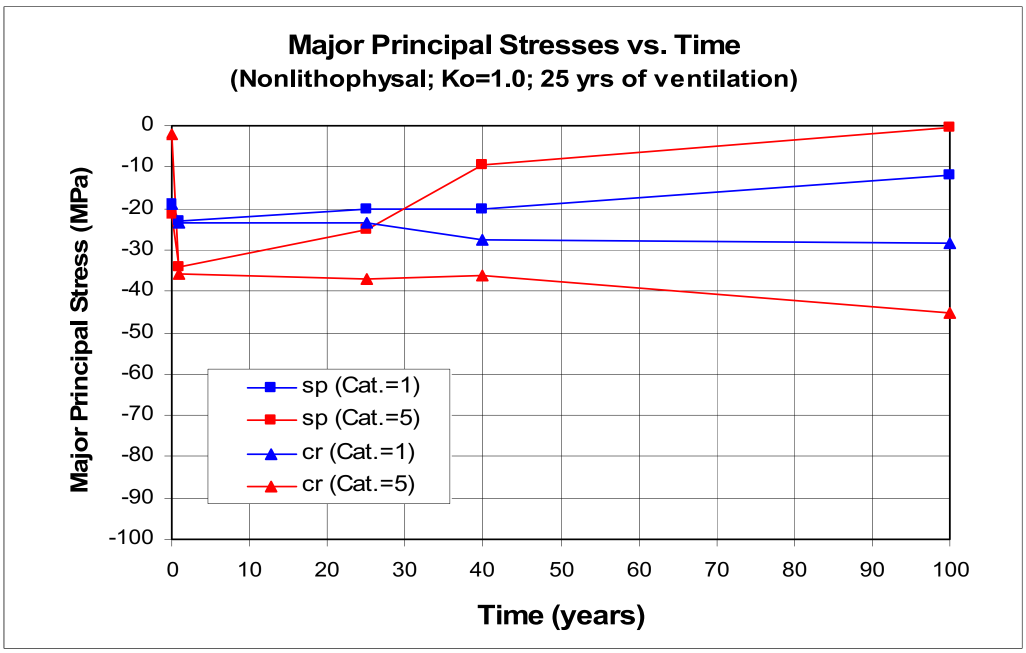


(b)

Figure 6-66 Major Principal Stress near Springline and Crown of Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads for 50-Year Ventilation Scenario for Categories 1 and 5: (a) Ko = 0.3 (b) Ko = 1.0

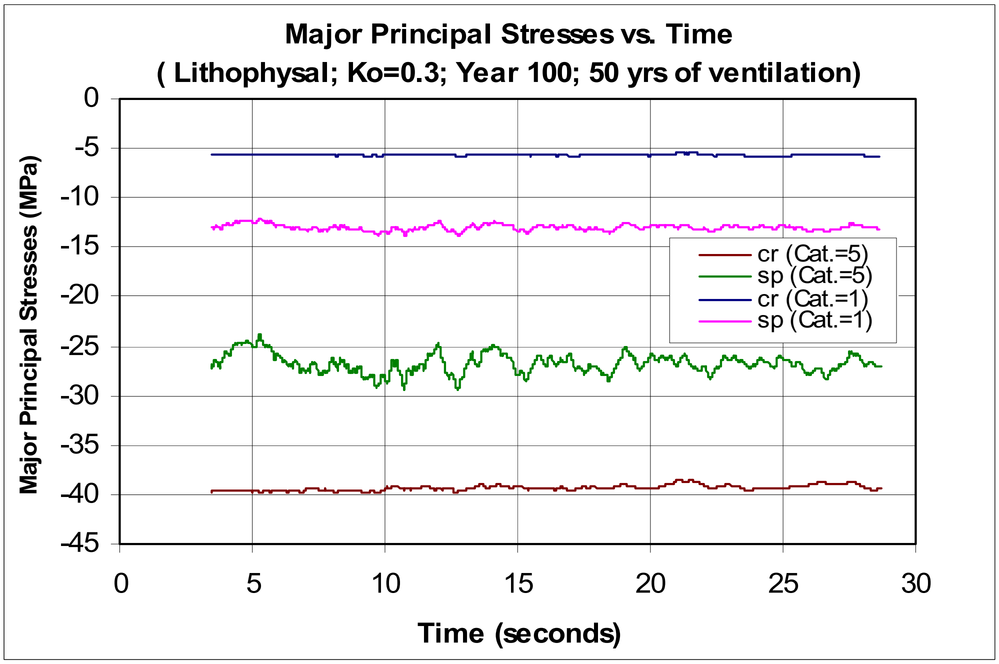


(a)

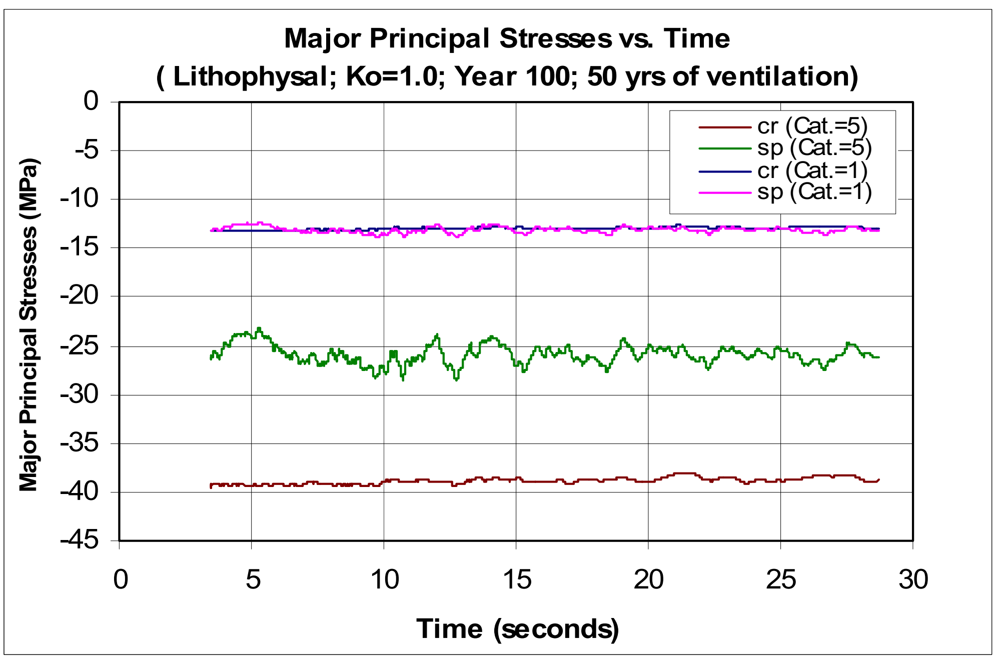


(b)

Figure 6-67 Major Principal Stress near Springline and Crown of Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads for 25-Year Ventilation Scenario for Categories 1 and 5: (a) Ko = 0.3 (b) Ko = 1.0

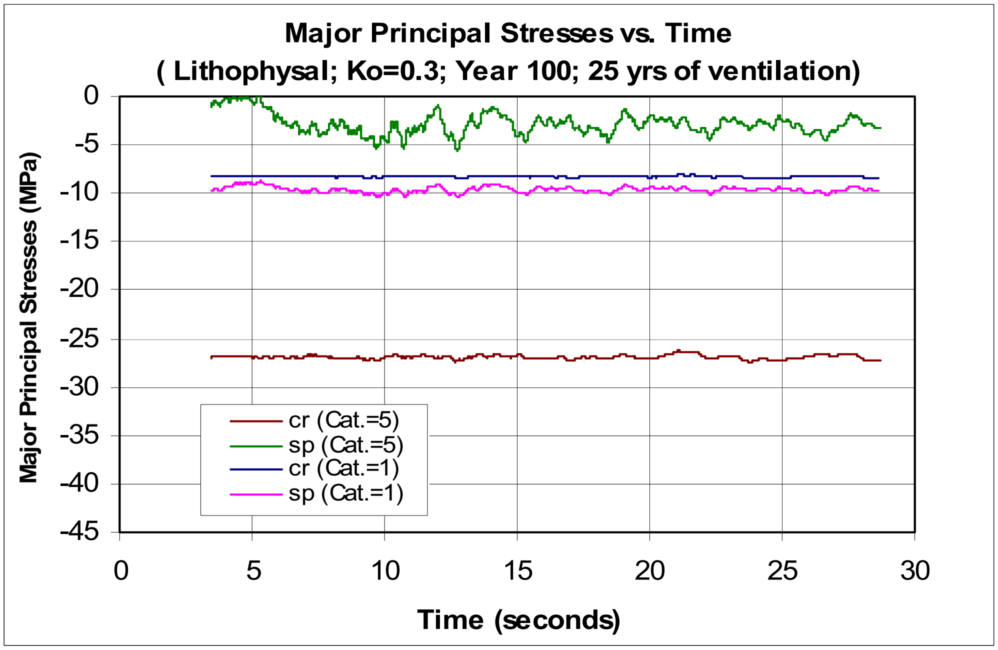


(a)

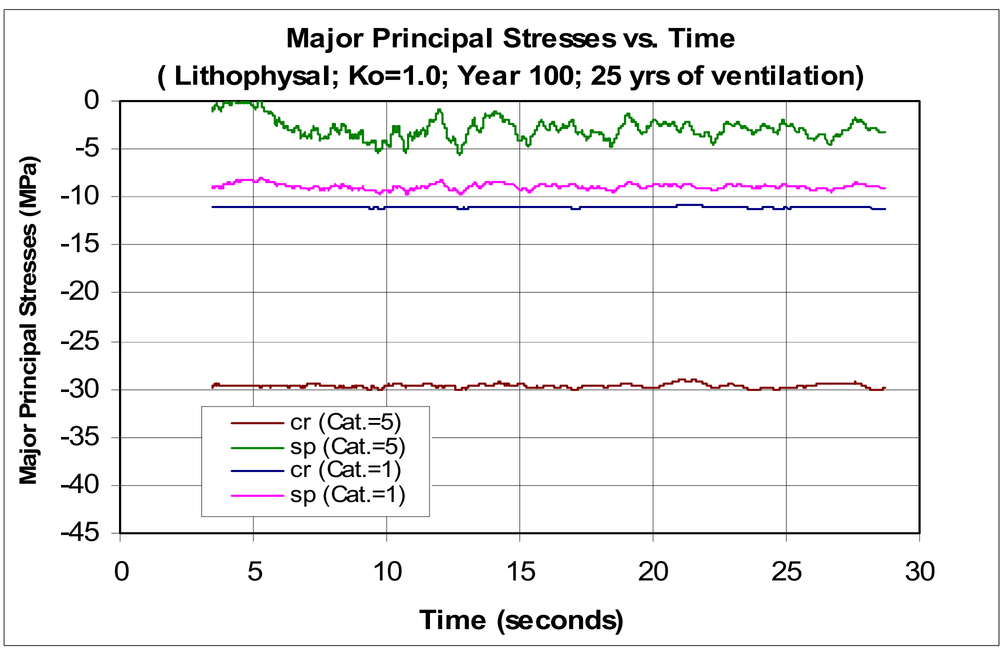


(b)

Figure 6-68 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Load for 50-Year Ventilation Scenario: (a) Ko=0.3; (b) Ko=1.0

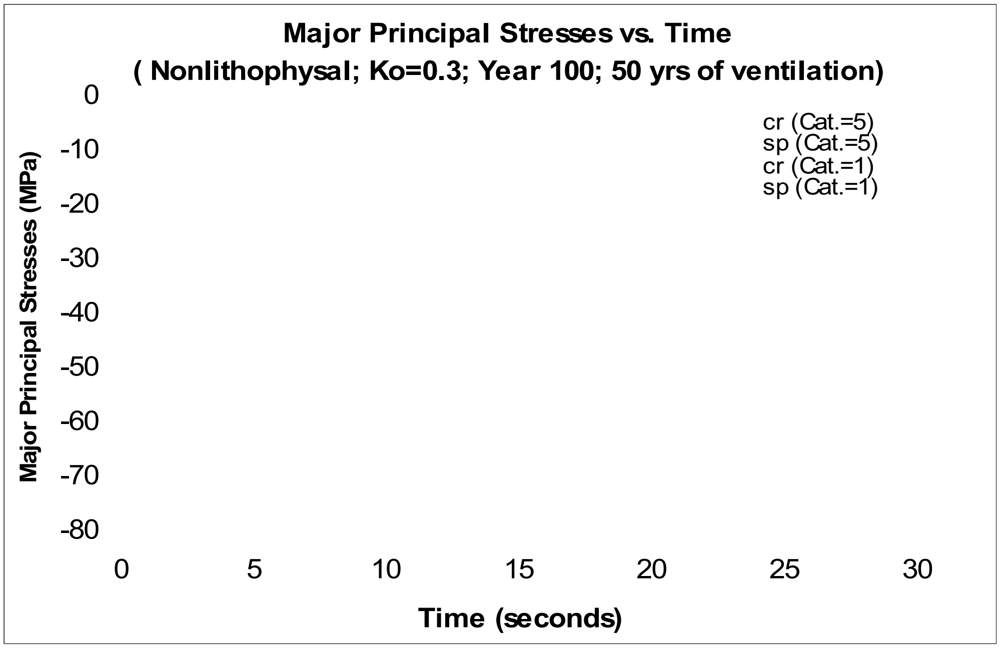


(a)

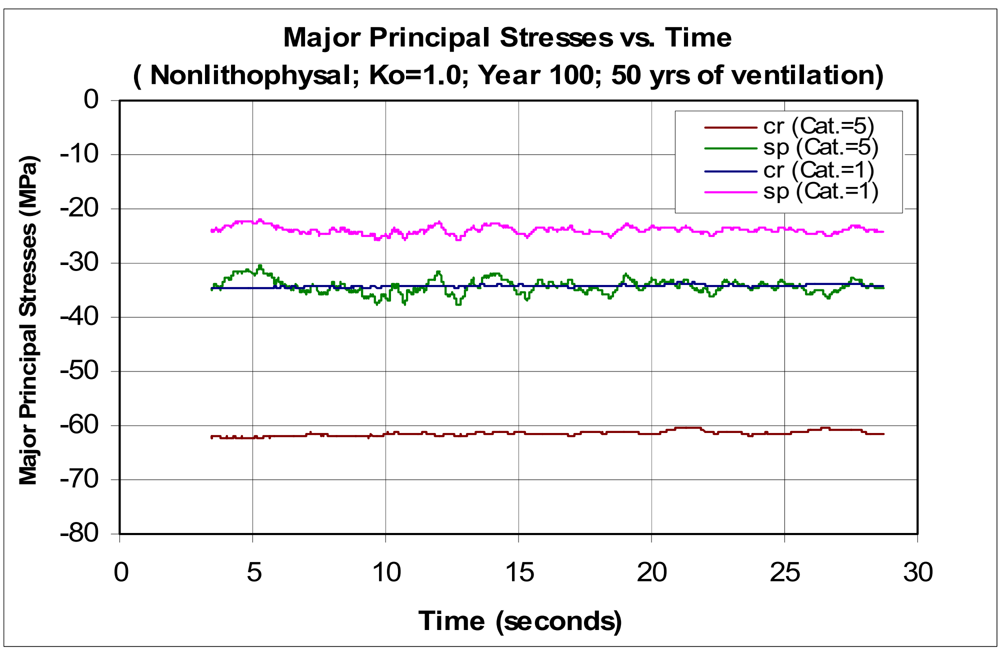


(b)

Figure 6-69 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts in Lithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Load for 25-Year Ventilation Scenario: (a) Ko=0.3; (b) Ko=1.0

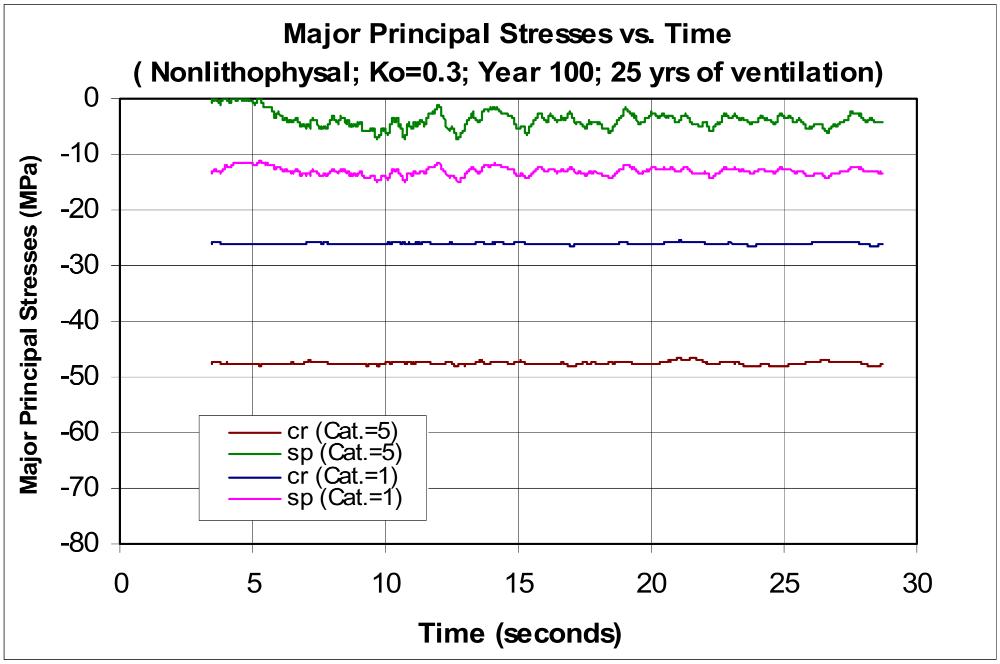


(a)

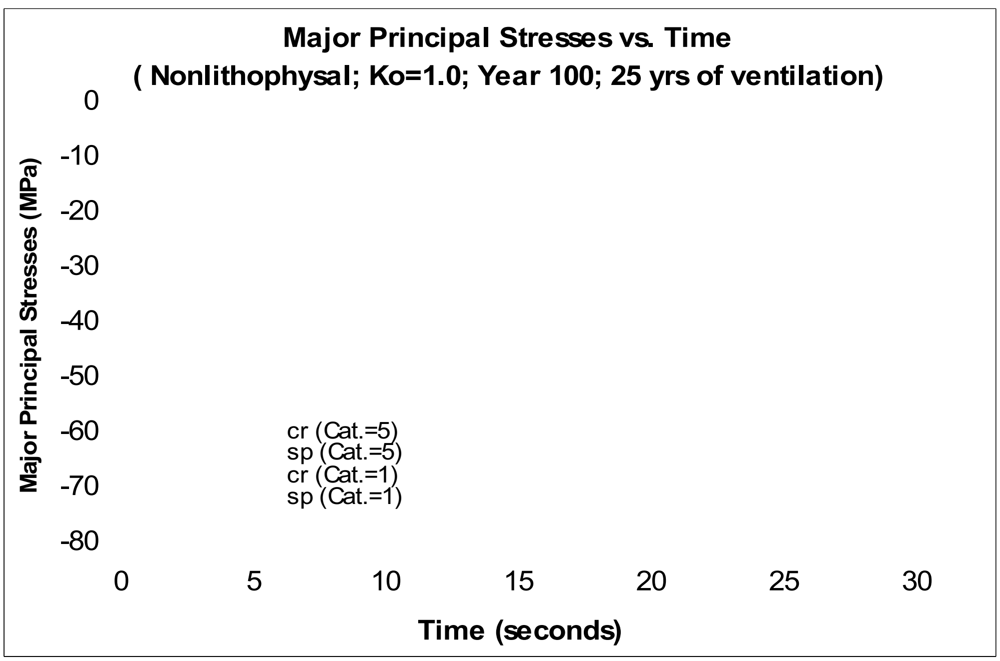


(b)

Figure 6-70 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Load for 50-Year Ventilation Scenario: (a) Ko=0.3; (b) Ko=1.0



(a)



(b)

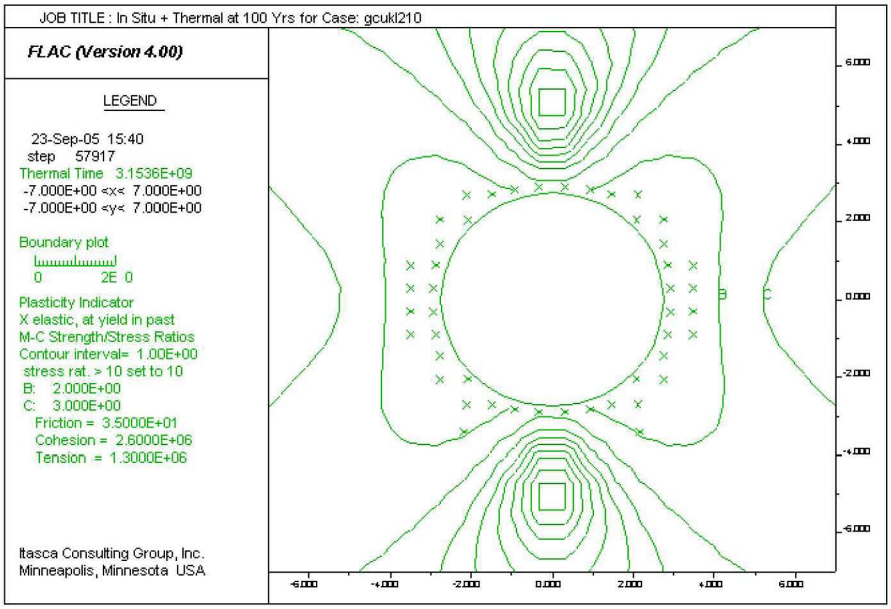
Figure 6-71 Time Histories of Major Principal Stresses near Crown and Springline of Emplacement Drifts in Nonlithophysal Rock with Categories 1 and 5 under In Situ, Thermal and Seismic Load for 25-Year Ventilation Scenario: (a) Ko=0.3; (b) Ko=1.0

6.10.3.3 Potential Yield Zones and Factor of Safety Around Emplacement Drifts

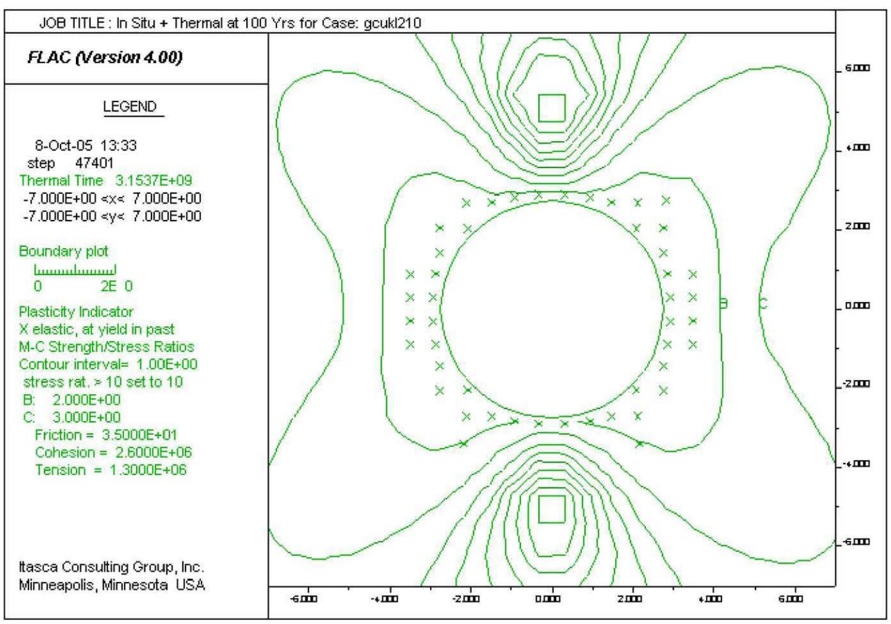
Potential yield zones and contours of strength-to-stress ratios due to in situ and thermal loads for both ventilation scenarios are shown in Figure 6-72 and Figure 6-73 for lithophysal and nonlithophysal rock, respectively. These figures show the results at year 100 for 50- and 25-year ventilation scenarios, respectively.

The potential yield zone for lithophysal rock extends to a depth of about 1 m for 50-year ventilation scenario and about 1.5 m for 25-year ventilation scenario. The similar behavior is also found for to the nonlithophysal rock.

The strength-to-stress contours displayed in Figure 6-72 and Figure 6-73 shows that drifts are stable at the end of the preclosure period. The potential yield zones adjacent to the drifts indicate the potential overstressing or loosening zones, which can be controlled by the ground support system.

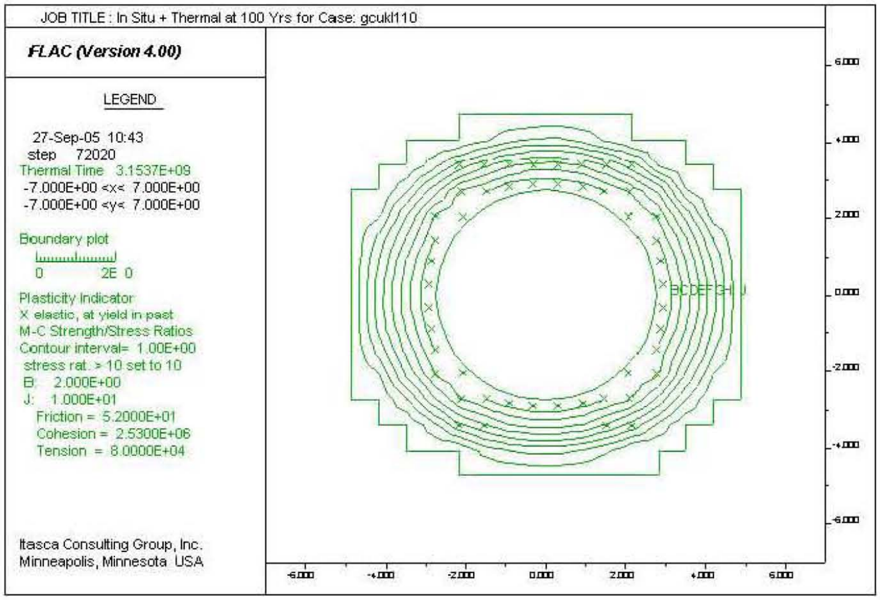


(a)

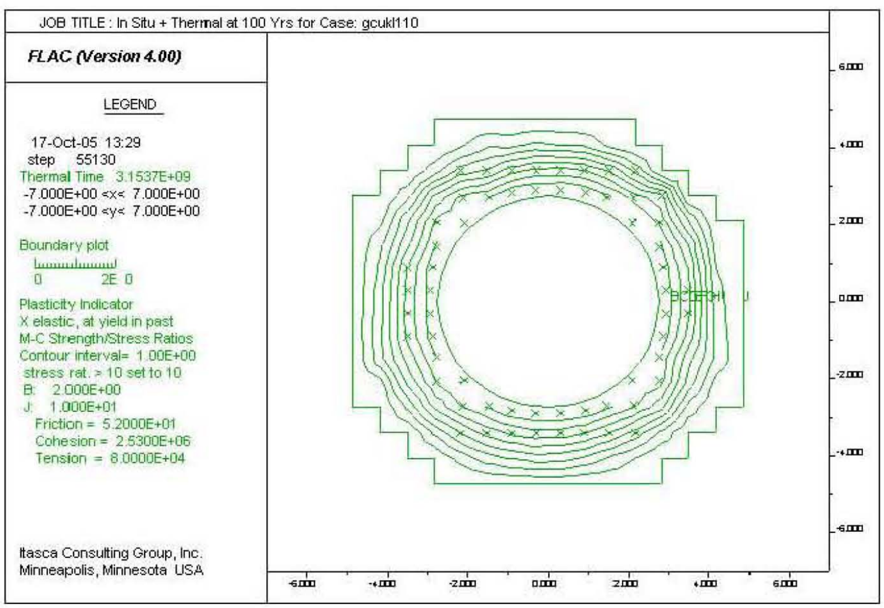


(b)

Figure 6-72 Potential Yield Zones and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Lithophysal Rock with Category 1 and Ko = 0.3 at Year 100: (a) 50-year Ventilation Scenario; (b) 25-year Ventilation Scenario



(a)



(b)

Figure 6-73 Potential Yield Zones and Contours of Strength-to-Stress Ratios around Emplacement Drifts in Nonlithophysal Rock with Category 1 and Ko = 0.3 at Year 100: (a) 50-year Ventilation Scenario; (b) 25-year Ventilation Scenario

6.10.3.4 Ground Support Performance

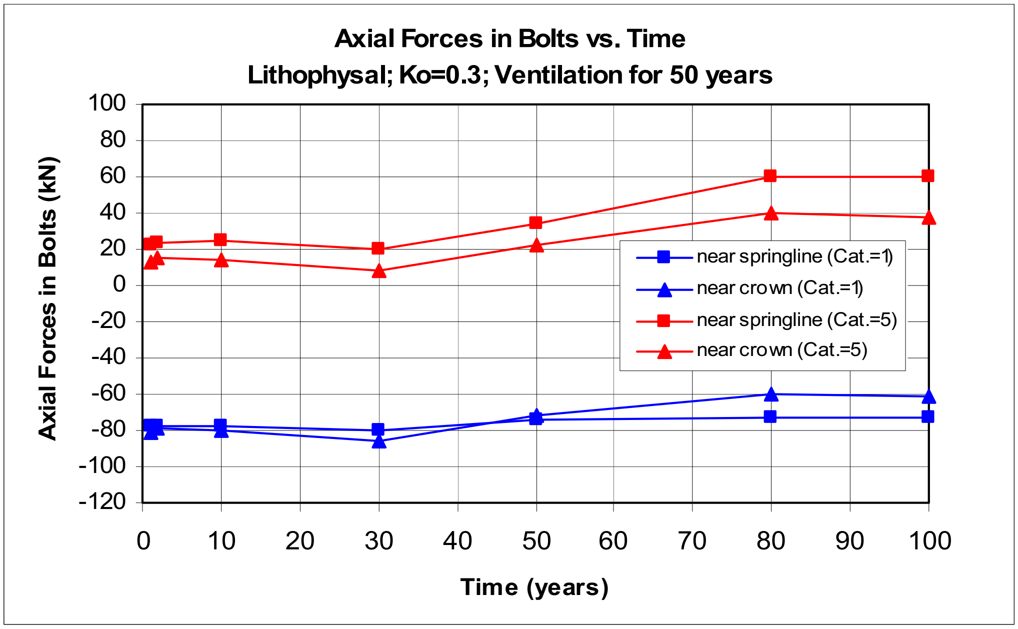
Time histories of axial forces in Swellex bolts due to in situ and thermal loads for 50- and 25-year ventilation scenarios are shown in Figure 6-74 and Figure 6-75 for lithophysal rock and in Figure 6-76 and Figure 6-77 for nonlithophysal rock, respectively.

The maximum tensile force in bolts for category 1 lithophysal rock is about 100 kN and decreases due to heating (see Figure 6-74 and Figure 6-75), but it stays in the tensile region for 50-year ventilation scenario, however, the maximum force in a bolt near the springline becomes compression of about 80 kN for 25-year ventilation scenario. These give a minimum factor of safety of approximately 3.5 (298/86=3.5) (see 298 kN in Table 6-6).

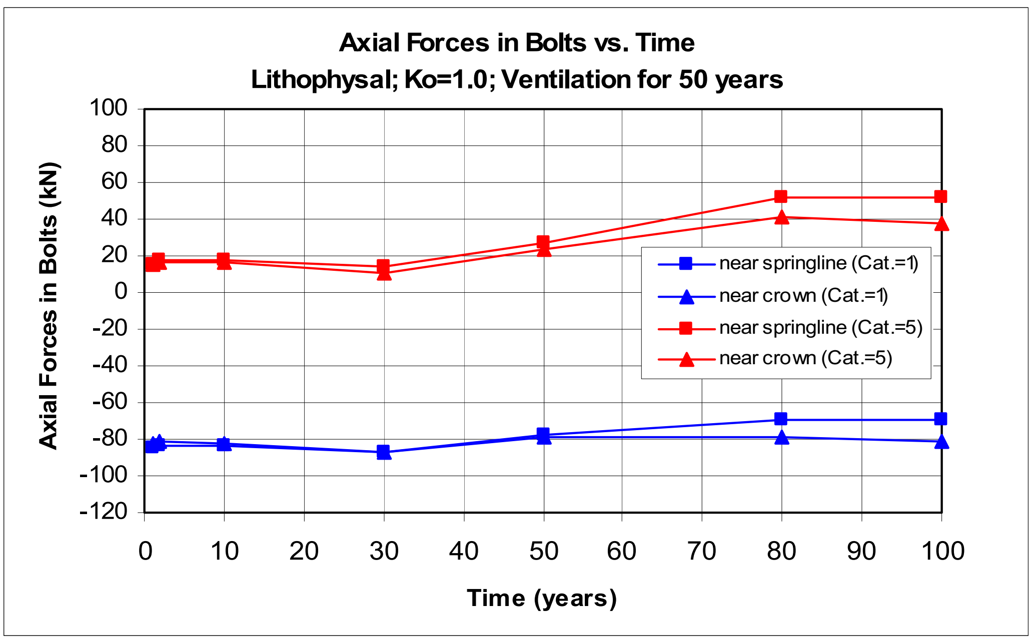
The maximum force in bolts for category 5 lithophysal rock stays in compression for both ventilation scenarios. For 50-year ventilation scenario, the compressive forces in bolts generally increase due to heating, with higher forces near the springline than those near the crown. The maximum compressive axial force is about 60 kN at year 100 for the 50-year ventilation scenario. For 25-year ventilation scenario, the compressive forces in bolts reach to peak at 40 years after heating then slightly decreases to year 100. The highest compressive axial force is about 80 kN for the 25-year ventilation scenario.

The axial force in bolts in category 1 nonlithophysal rock is in compression for both ventilation scenarios except for bolts near crown which changes slightly into tension around year 30 for 50-year ventilation scenario and year 25 for 25-year ventilation scenario. A maximum compressive force of 92 kN is observed for the 25-year ventilation scenario and 64 kN for the 50-year ventilation scenario. Bolt forces in category 5 nonlithophysal rock stays in compression for both ventilation scenarios. The maximum tensile forces in bolts in category 5 are 63 kN for 50-year ventilation scenario and 85 kN for 25-year ventilation scenario.

It should be noted that the axial forces along a bolt could change from tension to compression. For example, Figure 6-78 and Figure 6-79 depict the distribution of axial forces along bolts for lithophysal rock under K_o = 0.3 at year 100 for categories 1 and 5, respectively, for both ventilation scenarios. Due to heating, the initial tensile force in the bolts is decreased, and, in most cases, the force becomes compressive, especially near the springline for category 5 rock.



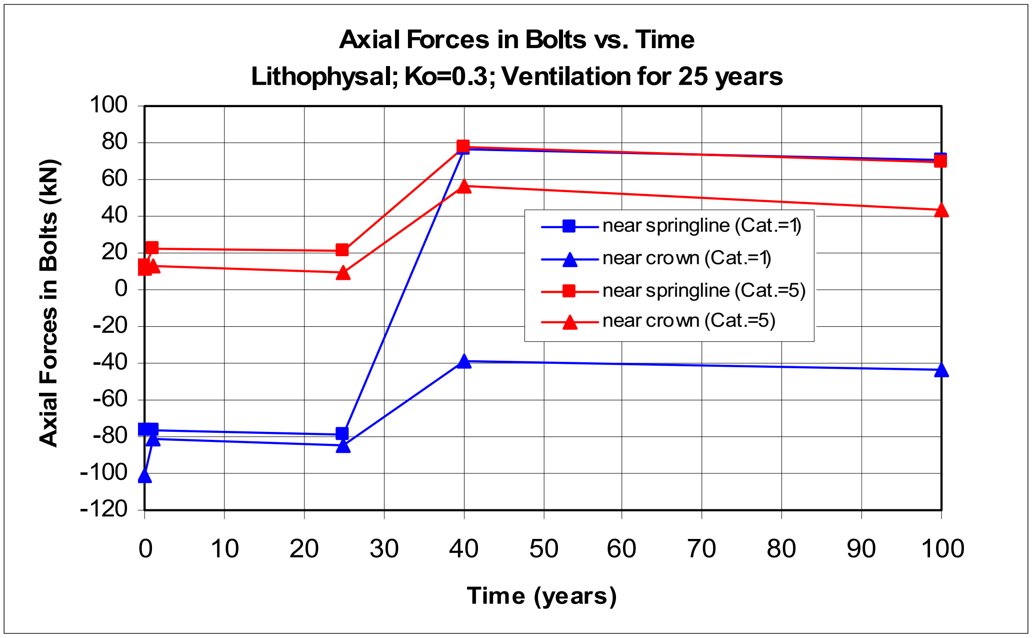
(a)



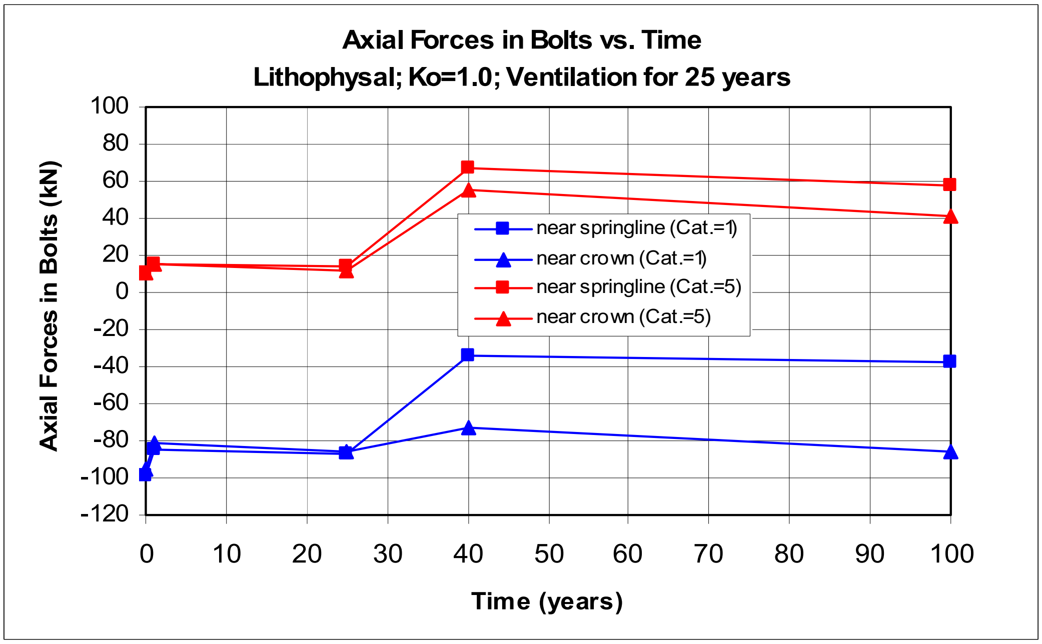
(b)

Note: Axial bolt forces are positive in compression and negative in tension.

Figure 6-74 Axial Forces in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for 50-Year Ventilation Scenario: (a) Ko = 0.3 ; (b) Ko = 1.0



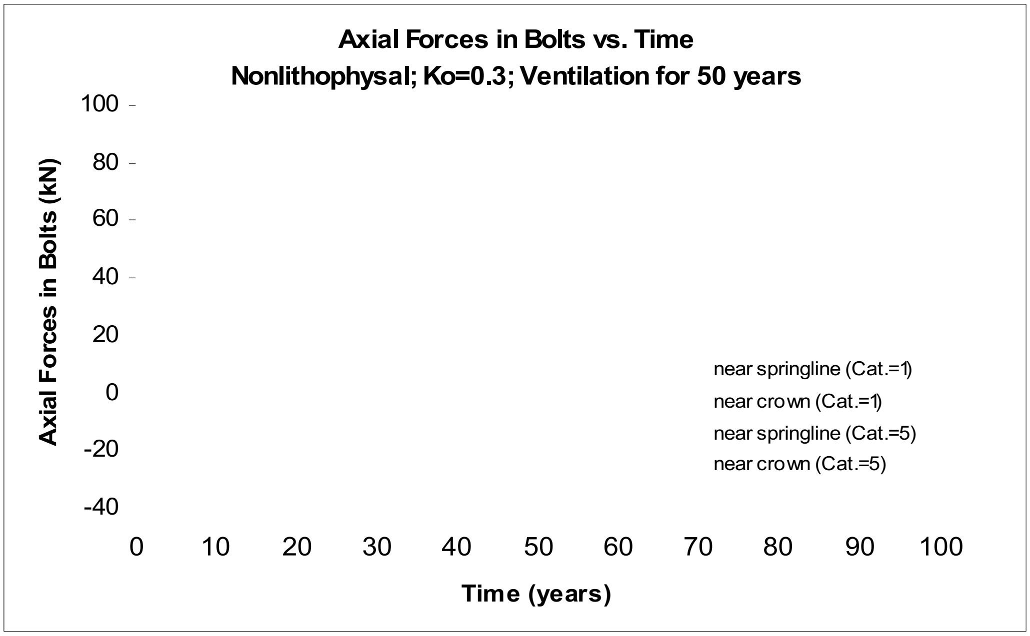
(a)



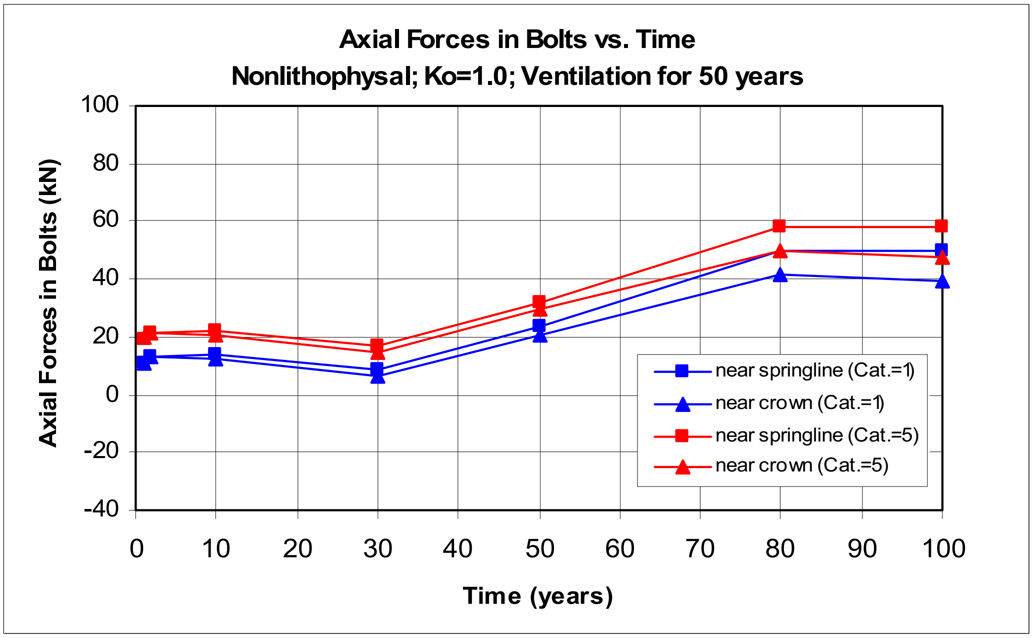
(b)

Note: Axial bolt forces are positive in compression and negative in tension.

Figure 6-75 Axial Forces in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loads for 25-Year Ventilation Scenario: (a) Ko = 0.3 ; (b) Ko = 1.0



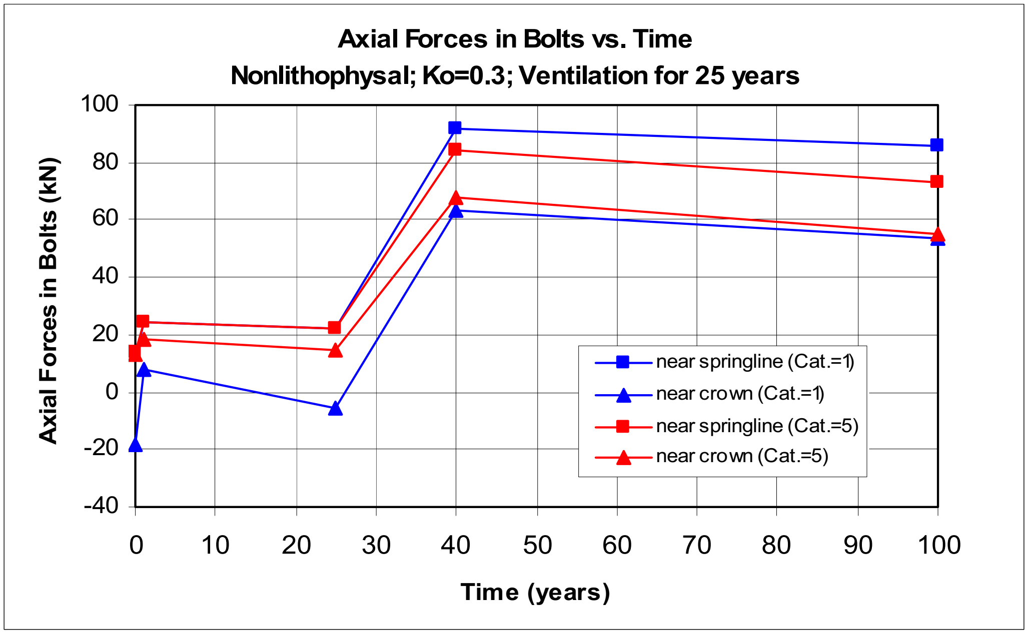
(a)



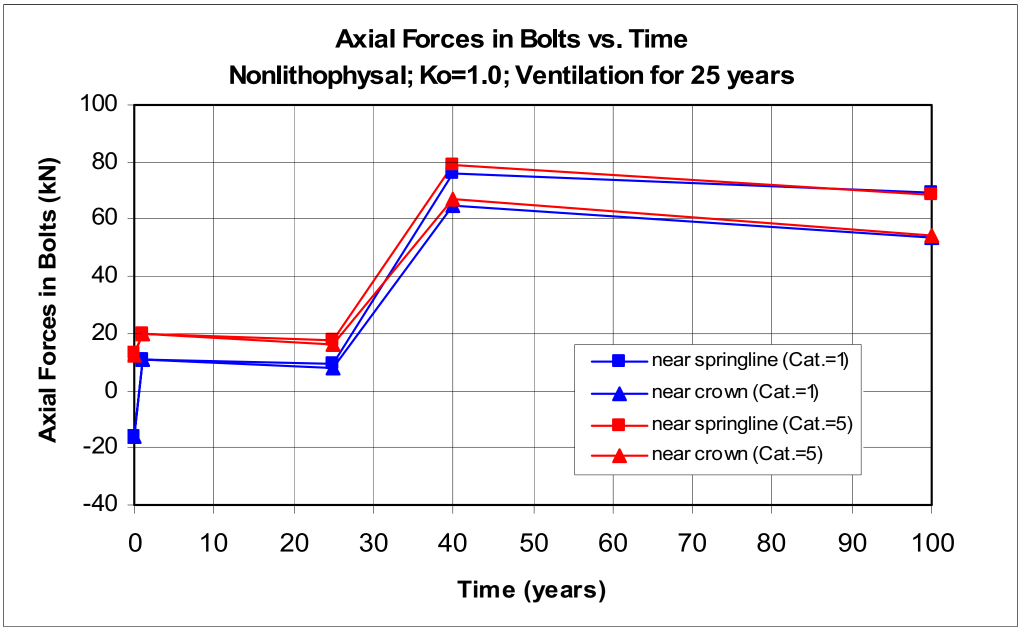
(b)

Note: Axial bolt forces are positive in compression and negative in tension.

Figure 6-76 Axial Forces in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads for 50-Year Ventilation Scenario: (a) Ko = 0.3 ; (b) Ko = 1.0



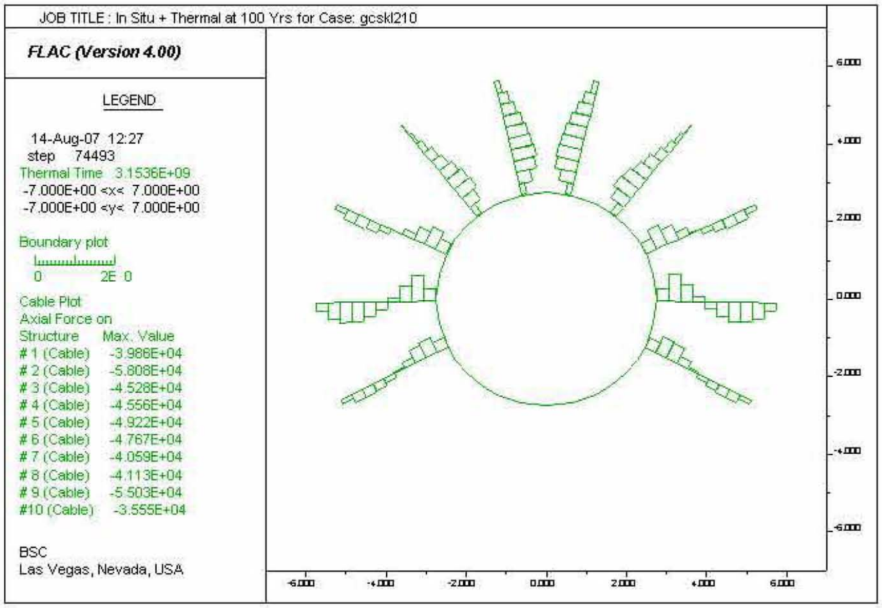
(a)



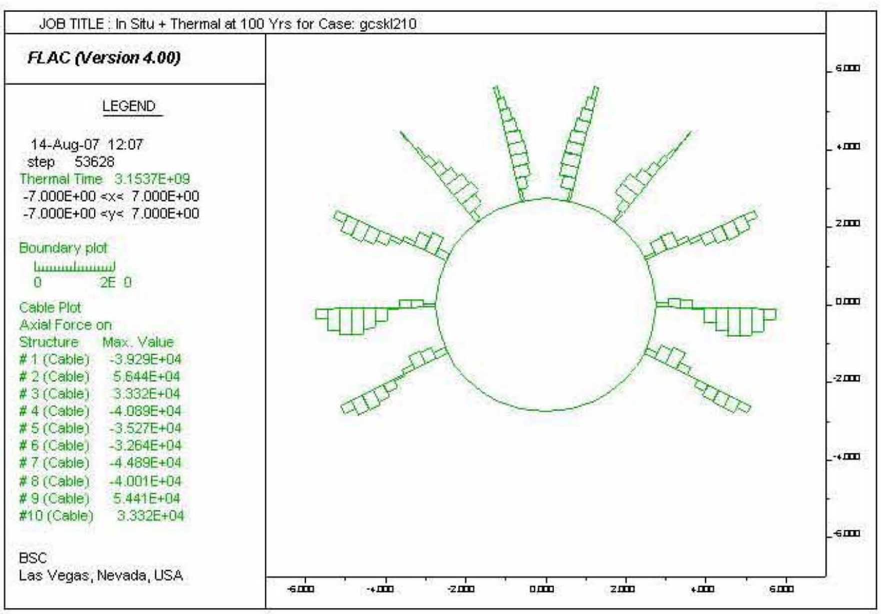
(b)

Note: Axial bolt forces are positive in compression and negative in tension.

Figure 6-77 Axial Forces in Bolts Installed in Emplacement Drifts in Nonlithophysal Rock under In Situ and Thermal Loads for 25-Year Ventilation Scenario: (a) Ko = 0.3 ; (b) Ko = 1.0



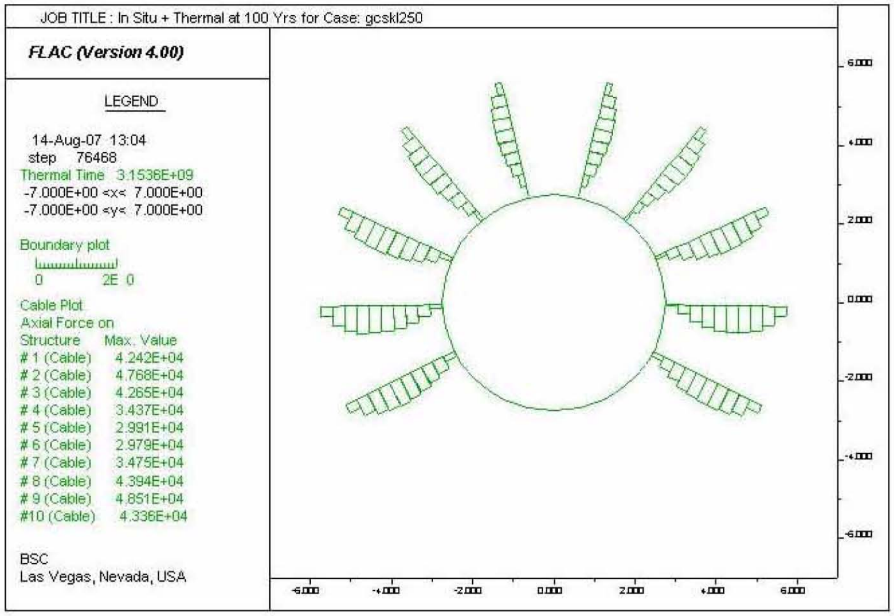
(a)



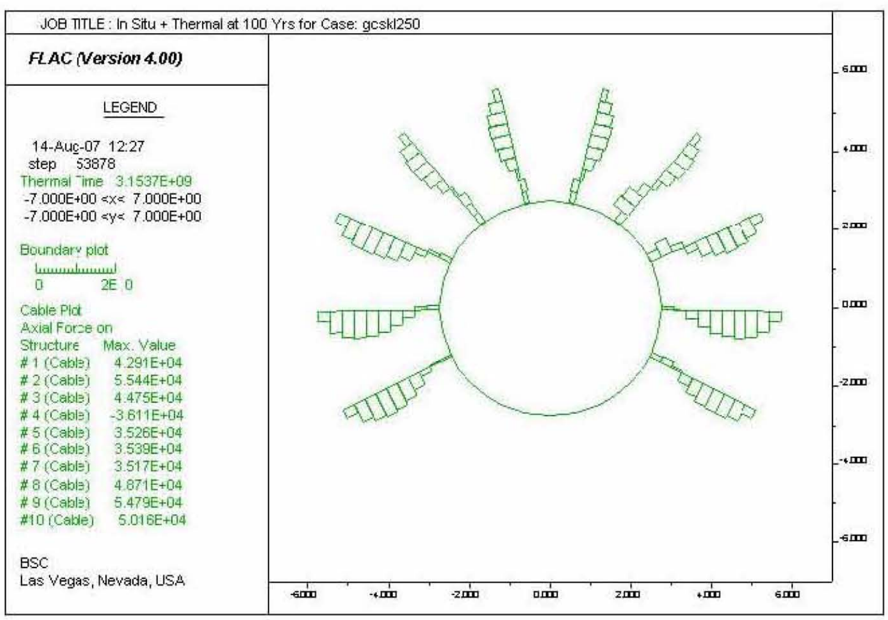
(b)

Notes: Actual forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-78 Distributions of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loading for Category 1 and Ko = 0.3 at 100 Years: (a) 50-Year Ventilation Scenario; (b) 25-Year Ventilation Scenario



(a)



(b)

Notes: Actual forces in bolts are equal to those shown times the bolt spacing of 1.25 m.

Figure 6-79 Distributions of Axial Forces (N) in Bolts Installed in Emplacement Drifts in Lithophysal Rock under In Situ and Thermal Loading for Cat. 5 and Ko = 0.3 at 100 Years: (a) 50-Year Ventilation Scenario; (b) 25-Year Ventilation Scenario

6.11 EXAMINATION OF GROUND SUPPORT RESPONSE TO SEISMIC EVENTS WITH AN APE OF 10^{-6}

This section addresses what would happen to ground support systems when the repository is subject to a seismic event corresponding to an APE of 10^{-6}. Recognizing that a 10^{-6} seismic event is far beyond the current design basis ground motions taken into account in design, the purported examination is not to assess the adequacy of ground support design, but to demonstrate the behavior and response of ground support systems. The results will support the evaluation of rockfalls on waste packages and drip shields.

A recently completed preclosure safety report, *Probabilistic Characterization of Preclosure Rockfalls in Emplacement Drifts* (Reference 2.2.26), presents credible rockfalls that have at least one chance in 10,000 of occurring in emplacement drifts during the preclosure period. Such an event could result in a Category 2 event sequence. Accordingly, a seismic event with an APE of 10^{-6} during the 100-year preclosure period could potentially manifest itself as a Category 2 event. Under such a seismic event, there are two specific concerns to be addressed in this examination: one is whether the current ground support system proposed for emplacement drifts would be capable of still keeping the drift stable, the other is whether the presence of the ground support system could have adverse effects with regard to the severity of rockfall impacts on waste packages emplaced in emplacement drifts, as evaluated in a recent calculation (Reference 2.2.25).

While responses of emplacement drifts and their ground support systems to potential preclosure seismic events with APEs of 5 x 10^{-4} and 1x 10^{-4} have been analyzed using the two-dimensional FLAC code and the results are discussed and presented in earlier sections of this calculation, the *Drift Degradation Analysis* report (Reference 2.2.16) provides another extensive analysis of responses of the emplacement drifts to potential seismic events with APEs of 5 x 10^{-4}, 10^{-4}, 10^{-5}, 10^{-6} and 10^{-7} by using the three-dimensional 3DEC code. The drift degradation analyses were conducted for both lithophysal and nonlithophysal rock masses, and the ground support systems were not included in 3DEC models. The results obtained under seismic loads corresponding to 10^{-5}, 10^{-6} and 10^{-7} APEs feed to the total system performance assessment of the repository during postclosure. For this calculation, the drift responses obtained under the 10^{-6} ground motions and documented in the *Drift Degradation Analysis* are used to address the two concerns mentioned earlier.

6.11.1 Emplacement Drifts in the Lithophysal Rock

The effects of varying lithophysal porosity and quality of lithophysal rock mass on drift stability during strong seismic ground motions were addressed by considering different lithophysal rock mass categories in the analysis. Because the main objective of the drift degradation analyses was to demonstrate the performance of the emplacement drifts during the postclosure period, the effect of ground support was not taken into account—the drift is always considered to be unsupported. The results of the *Drift Degradation Analysis* indicate that the entire drift will collapse when subjected to seismic ground motions corresponding to the APE of 10^{-6} in the lithophysal rock mass units regardless of rock mass category (Section 6.4.2.2.2.2, Reference 2.2.16). Given the results obtained without accounting for the presence of ground support, the reinforcing effect of the ground support system on response of the emplacement drift to strong seismic ground shaking at APE of 10^{-6} can be assessed indirectly. The drift profiles after simulations of 15 combinations of ground motion numbers and lithophysal rock mass categories (Table 6-44, Reference 2.2.16) are shown in Figure 6-80. These cross-sectional views of a typical emplacement drift show that stable drift configurations were achieved after collapse because the collapsed rock mass filled the emplacement drift as a result of its bulking or volume increase after disintegration (Bulking is a consequence of increased porosity in the rubble compared to porosity of the rock mass in situ.). Once the drift is filled, the rubble provides backpressure and kinetic constraint to further rockfall. The intensity of seismic shaking is so high that the rock surrounding an emplacement drift is damaged and becomes destabilized instantly. The drift just provides open space into which loosened rock blocks fall under gravity. Figure 6-80 also shows 3-m long rock bolts relative to the drift outline in the original configuration. With exception of one or two lowest bolts in the drift wall, all of the other bolts (particularly in the drift crown) are shown to be too short to go beyond the loosened zones, rendering them useless in terms of reinforcing the rock mass. It is clear that rock bolts will not have any significant effect on drift stability during seismic ground shaking at APE of 10^{-6}. The bolts will fall together with the loosened surrounding rock mass. The rock bolts may have some minor effect on improving drift stability in the drift walls at the springline level or below.

6.11.2 Emplacement Drifts in the Nonlithophysal Rock

Rockfall in nonlithophysal units (which comprise approximately 15% of the repository horizon) is very much controlled by jointing in the rock mass. Although the damage and rockfall are not as extensive as in lithophysal rock units, significant breakouts are predicted for APE of 10^{-6} (e.g., Figure 6-110, Reference 2.2.16).

The effect of ground support presence on rockfalls in emplacement drifts excavated in the nonlithophysal rock during seismic ground shaking at APE of 10^{-6} will be more significant than in the lithophysal units. Because analysis for the nonlithophysal rock mass does not predict complete drift collapse, the rock bolts could prevent some breakouts and dislodging of smaller blocks.

6.11.3 Summary

Based on the numerical modeling results obtained under the 10^{-6} seismic ground motions and documented in the *Drift DegradationAanalysis* (Reference 2.2.16), the conclusion is that the current ground support system proposed for emplacement drifts is unlikely to prevent total drift collapse in the lithophysal rock, and may be capable of controlling or limiting some rockfalls in certain areas in the nonlithophysal rock. For the 85% of emplacement drifts in the lithophysal rock, loosened rock blocks or fragments nearest the drift will fall first, leaving the rockbolts dangling in the air. As the drift collapses further, the rockbolts will fall, together with the detached rock blocks within the collapsed zones. The falling rockbolts may not aggravate the impacts to waste packages because they may not hit the waste packages directly. For the 15 % of emplacement drifts in the nonlithophysal rock where large discrete rockfall blocks are likely to form and to fall, there is a possibility that a large rock block with rockbolts embedded in it falls and hits a waste package. The protruding rockbolt can hit the waste package first. Since rockbolts are spaced on a 1.25 m x 1.25 m center to center spacing, reach 3 m into the rock, and have a holding capacity of about 20 tons each, the chance to have a rock block formed with a rockbolt or rockbolts embedded in it is rather low. Therefore, the presence of rock support is not considered to be detrimental to the severity of rockfall impacts to waste packages during a 10^{-6} seismic event during preclosure.

Source: Reference 2.2.47, file \resultsrockfall\summary\244ms.pcx
Note: This figure is modified from the figure in the source and is used for illustration purpose.

Figure 6-80 Stable Drift Profiles in Lithophysal Rock After Seismic Ground Motion at the 2.44 m/s PGV Level (or APE of 10-6 in Case of Unbounded Hazard Curve)

6.12 IMPACT OF MULTIPLE HEATING AND COOLING CYCLES

In this section, the impact of multiple cycles of heating and rapid cooling on the emplacement drift stability is discussed. Focus is on the resulting stress and displacement due to the significant change in temperature. However, it should be noted that the condition with multiple cycles of heating and rapid cooling is not expected to occur during the normal repository operation.

Detailed analysis on impact of multiple heating and cooling on the emplacement drift stability was discussed in *Evaluation of Ground Support Heating and Cooling Cycles* (Reference 2.2.32). Although the thermal loading level, drift spacing, rock mass mechanical and thermal properties from this analysis (Reference 2.2.32) are different from those used in Section 6.1.2, the conclusions derived from this analysis on impact from multiple heating and cooling cycles on drift stability are still valid and could provide valuable insight and guidance.

In this analysis (Reference 2.2.32), two cooling scenarios were considered, one with an airflow rate of 50 m^3/s and the other with an airflow rate of 2.5 m^3/s, with the ventilation cooling duration of two months and two weeks, respectively. The cooling was applied for every 10 years beginning at 10 years after waste emplacement. Ten cycles of heating and cooling were used in the evaluation. The following conclusions are drawn from this analysis (Reference 2.2.32, Section 8):

- Rapid ventilation is expected to result in a reduction in rock deformation near a drift opening during the heating and cooling cycles. The reduction in deformation is not very sensitive to the rock mass mechanical properties, i.e., the modulus of elasticity. Impact on the long-term rock deformation due to cooling cycles is minimal.

- Decrease in rock mass stresses is predicted due to the cooling during the heating and cooling cycles. However, tensile stresses are indicated at the springline of a drift opening. This suggests a need of ground support to prevent rock mass from tensile failure when the rapid cooling is considered.

- Rock block loosening is predicted near the drift wall due to the temperature decrease during the cooling cycles. Ground supports in the emplacement drifts will help prevent any potential rock falls.

- Number of cooling and heating cycles used in the analysis is hypothetical. No significant change is expected in the results or conclusion of this analysis as a result of the increase or decrease in number of cooling and heating cycles.

In general, multiple cycles of heating and cooling in the emplacement drifts can produce larger deformation adjacent to emplacement drifts but it is not expected to produce more extensive deformation or emplacement drift failure. Overall stability can be maintained with appropriate ground support systems.

7 SUMMARY AND CONCLUSIONS

This calculation analyzes the stability of emplacement drifts excavated in both the lithophysal and the nonlithophysal rocks and the performance of ground support system installed in these drifts during the repository preclosure period. The loading conditions considered include in situ, thermal, and seismic. Both empirical and numerical methods are employed. The empirical methods used are the RMR and the Q systems. The numerical methods are based on the continuum approach using the FLAC computer code.

Results from this calculation can be summarized and concluded as follows:

Thermomechanical Response and Stability of Unsupported Emplacement Drifts

- Unsupported emplacement drifts are predicted to remain largely in the elastic domain of deformation with shallow yield zones induced by excavation. Rock displacements and stresses are sensitive to the rock mass modulus of deformation and the initial horizontal-to-vertical in situ stress ratio.

- The maximum drift closures anticipated for in situ and thermal loading conditions vary from 3 to 55 mm in the vertical direction and from about 1 to about 40 mm in the horizontal direction depending on rock mass categories. With the magnitudes of these displacements, the impact on drift operating envelopes is insignificant.

- Combining the stresses induced by in situ, thermal, and seismic loads, the maximum major principal stresses in the lithophysal rock are expected to vary from about 16 to 17 MPa for category 1 rock mass to about 34 MPa for category 5 rock mass. In the nonlithophysal rock, the maximum major principal stresses are predicted to vary from about 26 to 29 MPa for category 1 rock to about 44 MPa for category 5 rock mass. Potential yield zones developed around the openings are predicted about 1 m deep or less depending on the rock mass categories.

- Heating after waste emplacement does not show a profound effect on rock displacements and stresses. This is because that increase in temperature is not significant (less than 50°C) owing to the thermal management measures of continuous ventilation during the preclosure period.

- Seismic ground motions associated with a mean annual probability of exceedance of 5×10^{-4} are not shown to significantly change the stable conditions of emplacement drifts.

- An overall factor of safety for unsupported emplacement drifts under in situ and thermal loads is predicted to vary from 2.2 to 6.0 in the lithophysal rock, and from 4.2 to 7.2 in the nonlithophysal rock.

Performance of Ground Support

The initial ground support system is installed as necessary to provide worker safety until the final ground support system is installed. An initial ground support system consisting of 1.5 m long friction-type rock bolts, such as Split Sets, spaced at 1.5 m, and wire mesh with W2 x W2 and 100 mm center-to-center spacing, installed in the crown, is considered adequate for the rock conditions anticipated. These rock bolts will be installed in the drift crown (four bolts in each row), using industry standard materials (carbon steel). Wire mesh will be removed prior to the installation of the final ground support, while rock bolts will remain in place depending on the construction practice. The recommended final ground support system consists of 3 m long Super Swellex-type rock bolts, spaced at 1.25 m, and 3 mm thick Bernold-type perforated sheets, all installed in a 240° arc around the drift periphery. The materials for the final ground support should be made of stainless steel of 316 or better in order to ensure their longevity. This ground support system is considered suitable for various ground conditions anticipated during the preclosure period.

- Swellex-type rock bolts are expected to perform satisfactorily under in situ, thermal, and seismic loads, with a minimum factor of safety of about 2.9.
- Swellex-type rock bolts are capable of preventing rockfall with rock block weight up to about 2.7 tonnes during the preclosure period.
- Bernold-type stainless steel sheets are expected to perform satisfactorily under in situ, thermal, and seismic loads, with a minimum factor of safety of 3.4.

This ground support system is designed to last at least 100 years without planned maintenance even in severe environmental conditions assumed in emplacement drifts. Any necessary maintenance needs triggered by unfavorable inspection results or by off-normal operational conditions will be evaluated considering full account of the information gathered by the inspection and monitoring activities.

Sensitivity Analysis on Emplacement Drift Stability

The sensitivity of the emplacement drift stability with respect to rock mass mechanical properties and various loadings including in situ, thermal, and seismic loads during the preclosure period has been assessed in the *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (Reference 2.2.14). This calculation examines whether the subsequent updates on rock mass properties have any significant impact on the results and conclusions presented in the above mentioned scoping analysis (Reference 2.2.14). The results of the analysis are presented as follows:

- The maximum vertical closures are predicted to be about 50, 8, and 4 mm for the lithophysal rock categories 1, 3 and 5, respectively, and about 13, 3, and 2 mm for the nonlithophysal rock categories 1, 3 and 5, respectively. The horizontal closures are generally small compared to the vertical closures. The maximum closures due to seismic loadings are predicted to vary from less than 3 mm for the category 1 lithophysal rock to less than 1 mm for the category 1 nonlithophysal rock.

- The maximum major principal stresses are expected to vary from about 15 to 25 MPa for category 1 rock to about 28 to 38 MPa for category 5 rock and the stress changes due to the thermal loads is not substantial. The maximum major principal stresses changes due to thermal load is predicted about 15 MPa for category 5 nonlithophysal rock at the crown location. The maximum stress fluctuation due to seismic event is predicted about 5 MPa for category 5 nonlithophysal rock at the springline location.

- The numerical results obtained from simulating the base case using the updated rock properties are compared with the base case results presented in the *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (Reference 2.2.14). The comparisons do not indicate any significant difference. Based on this limited base case study, it can be concluded that the sensitivity study presented in the *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* is still considered valid and adequate for supporting the ground support design analyses.

Sensitivity Analysis on Emplacement Drift Stability Under Seismic Event with an APE of 10^{-4}

The stability of emplacement drifts subjected to the seismic events with an APE of 10^{-4} was assessed and the results are as follows:

- Compared with the results subjected to the seismic events with an APE of 5 x 10^{-4}, the closures are slightly higher for the emplacement drifts subjected to a seismic event with an APE of 10^{-4}. The major principal stresses near crown and springline for unsupported emplacement drifts are a little higher for the emplacement drifts subjected to the seismic events with an APE of 10^{-4} but still insignificant.

- The increase of bolt forces is very small for bolts installed in emplacement drifts under a seismic event with an APE of 10^{-4}. The factor of safety under the combined loading conditions is about 2.9.

- It is predicted that emplacement drifts will remain stable under a seismic event corresponding to an APE of 10^{-4}.

Uncertainty Analysis

Uncertainties associated with calculation methods in terms of continuum versus discontinuum and model dimensions are discussed. Results from the continuum approach, such as rock deformation and stress, are considered equivalent to those that would be generated otherwise by using a discontinuum approach. Some information, such as size of potential rockfall, may not be obtained from a continuum approach. A discontinum approach to quantify the effect of joints on potential wedge failure and the results are available in *Drift Degradation Analysis* (Reference 2.2.16).

Emplacement Drift Stability at Off-normal Temperatures

The emplacement drift stability at off-normal temperature conditions is evaluated. The emplacement drift stability for two off-normal ventilation scenarios are evaluated: 1) ventilation for first 50 years and without ventilation for another 50 years, and 2) ventilation for first 25 years and without ventilation for another 75 years.

- The drift wall temperature reaches to about 150 ^{o}C and 200 ^{o}C, respectively for the 50- and 25-year ventilation scenarios, i.e., these temperature levels are far above temperature limit of the normal operation, i.e., 96 ^{o}C, during the preclosure.

- For the lithophysal rock, the maximum vertical closure due to in situ and thermal loads is about 55 mm for both ventilation scenarios. The maximum horizontal closure is 45 mm for the 50-year ventilation scenario and 53 mm for the 25-year ventilation scenario. The nonlithophysal rock shows much smaller deformation. The change in closure due to the high drift temperature caused by ventilation shut down is not significant.

- The major principal stress for category 1 lithophysal rock does not vary much with temperature and reaches a maximum value of about 14 MPa for both values of initial horizontal-to-vertical stress ratio Ko and both ventilation scenarios. For category 5 lithophysal rock, the major principal stress reaches a maximum value of about 40 and 30 MPa for 50- and 25-year ventilation scenarios, respectively. The stress behaviors in the nonlithophysal rock for both ventilation scenarios are similar to those for the lithophysal rock except that the magnitudes of stresses are higher. The nonlithophysal rock reaches a peak stress value of 63 and 48 MPa, for 50- and 25-year ventilation scenarios, respectively. The stress change due to elevated temperature caused by ventilation shut down is higher in the nonlithophysal rock than that in the lithophysal rock, especially in category 5 rock mass. However, this stress change is not expected to impact the overall stability of the emplacement drifts.

- The magnitudes of stress fluctuations due to the seismic loading vary from less than 2 MPa to about 4 MPa for the lithophysal rock and from about 2 MPa to about 4 MPa for the nonlithophysal rock. It indicates that stress fluctuations due to the seismic loading are much less affected compared by those due to the thermal loading.

- The potential yield zone for the lithophysal rock extends to a depth of about 1 m for the 50-year ventilation scenario and about 1.5 m for the 25-year ventilation scenario. The same behavior is also found for the nonlithophysal rock.

- The off-normal thermal conditions after shut-down of ventilation show some effects on rock displacements and stresses for both ventilation scenarios. This is because that increase in temperature is significant (about 100 °C and 150 °C above the normal continuous ventilation scenario, see Figure 6-55). However, the strength-to-stress contours around emplacement drifts show that drifts are stable within selected time periods. The potential yield zones adjacent to the drifts indicate the potential overstressing or loosening zones, which can be controlled by the ground support system.

Examination of Ground Support Response to Seismic Events with an APE of 10^{-6}

Based on the numerical modeling results obtained under the 10^{-6} seismic ground motions and documented in the drift degradation analysis, the conclusion is that the current ground support system proposed for emplacement drifts is unlikely to prevent total drift collapse in the lithophysal rock, and may be capable of controlling or limiting some rockfalls in certain areas in the nonlithophysal rock. For the 85% of emplacement drifts in the lithophysal rock, loosened rock blocks or fragments nearest the drift will fall first, leaving the rockbolts dangling in the air. As the drift collapses further, the rockbolts will fall, together with the detached rock blocks within the collapsed zones. The falling rockbolts may not aggravate the impacts to waste packages because they may not hit the waste packages directly. For the 15 % of emplacement drifts in the nonlithophysal rock where large discrete rockfall blocks are likely to form and to fall, there is a possibility that a large rock block with rockbolts embedded in it falls and hits a waste package. The protruding rockbolt can hit the waste package first. Since rockbolts are spaced on a 1.25 m x 1.25 m center to center spacing, reach 3 m into the rock, and have a holding capacity of about 20 tons each, the chance to have a rock block formed with a rockbolt or rockbolts embedded in it is rather low. Therefore, the presence of rock support is not considered to be detrimental to the severity of rockfasll impacts to waste packages during a 10^{-6} seismic event during preclosure.

Impact of Multiple Heating and Cooling Cycles

The impact of multiple cycles of heating and cooling on emplacement drift stability is discussed.

- Rapid ventilation is expected to result in a reduction in rock deformation near a drift opening during the heating and cooling cycles. The reduction in deformation is not very sensitive to the rock mass mechanical properties, i.e., the modulus of elasticity. Impact on the long-term rock deformation due to cooling cycles is minimal.

- Rock block loosening is predicted near the opening due to the temperature decrease during the cooling cycles. Ground supports in the emplacement drifts will help prevent any potential rock falls.

- No change is expected in the results or conclusion as a result of the increase or decrease of the number of cooling and heating cycles.

- In general, multiple cycles of heating and cooling in the emplacement drifts can produce larger deformation adjacent to emplacement drifts but it is not expected to produce more extensive deformation or emplacement drift failure. Overall stability can be maintained with appropriate ground support systems.

The outputs of this calculation are reasonable compared to the inputs, and the results are suitable for the intended use.

ATTACHMENT I LIST OF INPUT AND OUTPUT FILES

List of Files in Attachment II (DVD 1)

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09/05/2007  06:14p             1,634 thermal_50_a.dat
09/05/2007  06:15p             2,436 driver_a.dat
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 Volume Serial Number is 683C-0946

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08/11/2007  12:14p            86,126 L210dy_spsig1_0.his
07/16/2007  08:06a             1,625 MCFOS.FIS
08/11/2007  12:14p           277,086 L250dy_crsig1_0.his
08/11/2007  12:14p           277,086 L250dy_spsig1_0.his
08/11/2007  12:14p            86,126 L210dy_crsig1_50.his
08/11/2007  12:14p            86,126 L210dy_spsig1_50.his
08/11/2007  12:14p           277,086 L250dy_crsig1_50.his
08/11/2007  12:14p           277,086 L250dy_spsig1_50.his
08/11/2007  01:14p            32,696 kl21_SS_0.pcx
08/11/2007  01:19p            32,439 kl21_SS_50.pcx
08/11/2007  01:33p            42,828 ku21_SS_0.pcx
08/11/2007  01:41p            43,409 ku21_SS_50.pcx
08/11/2007  02:23p            37,094 kl25_SS_0.pcx
08/11/2007  02:29p            36,413 kl25_SS_50.pcx
08/11/2007  02:41p            38,418 ku25_SS_0.pcx
08/11/2007  02:46p            41,024 ku25_SS_50.pcx
08/13/2007  08:19a             1,336 FSindex_for_excel.dat
08/13/2007  08:14a            11,323 fs_kl21_3m.log
08/13/2007  08:16a            10,270 fs_ku21_3m.log
08/13/2007  08:18a            10,270 fs_ku25_3m.log
08/13/2007  08:19a            10,270 fs_kl25_3m.log
             123 File(s)    329,050,216 bytes
               2 Dir(s)  184,584,036,352 bytes free
```

```
Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_25+75L\Input

09/19/2007  03:11p    <DIR>          .
09/19/2007  02:27p    <DIR>          ..
08/14/2007  09:43a               854 seismic_ll.dat
03/21/2007  12:48a               659 hiszones_50.fis
03/21/2007  12:48a               392 initemp.fis
03/21/2007  01:44a             3,408 makemovie.fis
07/14/2007  02:52p             3,823 properties.fis
08/14/2007  09:56a             2,430 driver_ll.dat
03/21/2007  12:48a             2,154 relaxation.fis
03/21/2007  12:48a             2,070 setup.fis
03/21/2007  12:48a             2,874 shake.fis
08/15/2007  12:36p               658 temphis_50.tab
03/20/2007  11:16p             1,518 thermal_50.dat
08/14/2007  09:53a             3,679 thermoprop.fis
03/21/2007  12:48a             3,018 tunnel.dat
03/21/2007  01:44a           203,437 vel_hori_5e-4.tab
03/21/2007  01:44a           195,677 vel_vert_5e-4.tab
08/15/2007  12:39p               658 temphis_25.tab
09/19/2007  03:11p               147 listfiles.dat
              17 File(s)        427,456 bytes
               2 Dir(s)  184,584,093,696 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_25+75L\Output

09/19/2007  03:12p    <DIR>          .
09/19/2007  02:27p    <DIR>          ..
08/14/2007  10:24a         6,082,583 gcuku210th.100
08/14/2007  10:10a         3,790,855 gcukl210is.ini
08/14/2007  10:11a         3,943,871 gcukl210is.exv
08/14/2007  10:12a         3,959,395 gcukl210th.0
08/14/2007  10:12a         4,029,459 gcukl210th.1
08/14/2007  10:14a         4,691,255 gcukl210th.25
08/14/2007  10:15a         5,145,403 gcukl210th.40
08/14/2007  10:17a         6,175,631 gcukl210th.100
08/14/2007  10:17a         3,790,855 gcuku210is.ini
08/14/2007  10:18a         3,880,511 gcuku210is.exv
08/14/2007  10:18a         3,896,587 gcuku210th.0
08/14/2007  10:19a         3,957,579 gcuku210th.1
08/14/2007  10:20a         4,603,751 gcuku210th.25
08/14/2007  10:21a         5,053,363 gcuku210th.40
08/15/2007  01:00p               400 Shortcut to flacw_sp.exe.lnk
08/14/2007  10:24a         3,790,855 gcukl250is.ini
08/14/2007  10:25a         3,954,431 gcukl250is.exv
08/14/2007  10:26a         3,969,955 gcukl250th.0
08/14/2007  10:26a         4,093,947 gcukl250th.1
08/14/2007  10:28a         4,773,383 gcukl250th.25
08/14/2007  10:30a         5,263,819 gcukl250th.40
```

```
08/14/2007  10:32a        6,360,575 gcukl250th.100
08/14/2007  10:32a        3,790,855 gcuku250is.ini
08/14/2007  10:33a        3,899,711 gcuku250is.exv
08/14/2007  10:34a        3,915,787 gcuku250th.0
08/14/2007  10:34a        4,033,731 gcuku250th.1
08/14/2007  10:36a        4,712,159 gcuku250th.25
08/14/2007  10:38a        5,202,091 gcuku250th.40
08/14/2007  10:41a        6,301,871 gcuku250th.100
08/14/2007  11:42a        5,319,095 gcukl210dy.100
08/14/2007  03:01p        8,059,931 gcukl250dy.100
08/14/2007  04:03p        5,319,095 gcuku210dy.100
08/14/2007  07:22p        8,059,931 gcuku250dy.100
08/15/2007  01:11p              741 closure_for_excel.dat
08/16/2007  07:23a            1,840 flac.log
09/19/2007  03:12p              148 listfiles.dat
08/15/2007  01:01p            4,769 closure_kl21.log
08/15/2007  01:08p            4,769 closure_kl25.log
08/15/2007  01:09p            4,769 closure_ku25.log
08/15/2007  01:11p            4,769 closure_ku21.log
08/15/2007  01:47p              532 eq_closure_for_excel.dat
08/15/2007  01:53p          277,086 U250dy_vc_100.his
08/15/2007  01:53p          277,086 U250dy_hc_100.his
08/15/2007  01:53p          277,086 L250dy_vc_100.his
08/15/2007  01:53p          277,086 L250dy_hc_100.his
08/15/2007  01:53p           86,182 U210dy_vc_100.his
08/15/2007  01:53p           86,182 U210dy_hc_100.his
08/15/2007  01:53p           86,182 L210dy_vc_100.his
08/15/2007  02:07p           86,182 L210dy_hc_100.his
08/16/2007  07:51a            1,477 stress_for_excel.dat
08/16/2007  07:47a            9,224 stress_ku21.log
08/16/2007  07:48a            9,224 stress_ku25.log
08/16/2007  07:50a            9,224 stress_kl25.log
08/16/2007  07:51a            9,224 stress_kl21.log
08/16/2007  09:09a              554 eq_stress_for_excel.dat
08/16/2007  09:13a           86,182 L210dy_crsig1_100.his
08/16/2007  09:13a           86,182 L210dy_spsig1_100.his
08/16/2007  09:13a          277,086 L250dy_crsig1_100.his
08/16/2007  09:13a          277,086 L250dy_spsig1_100.his
08/16/2007  09:13a           86,182 U210dy_crsig1_100.his
08/16/2007  09:13a           86,182 U210dy_spsig1_100.his
08/16/2007  09:13a          277,086 U250dy_crsig1_100.his
08/16/2007  09:13a          277,086 U250dy_spsig1_100.his
              63 File(s)    156,790,128 bytes
               2 Dir(s)  184,584,089,600 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_50+50L\Input

09/19/2007  03:13p    <DIR>          .
09/19/2007  02:28p    <DIR>          ..
03/21/2007  12:48a            2,154 relaxation.fis
03/21/2007  12:48a              659 hiszones_50.fis
03/21/2007  12:48a              392 initemp.fis
03/21/2007  01:44a            3,408 makemovie.fis
```

```
07/14/2007  02:52p             3,823 properties.fis
08/14/2007  09:56a             2,430 driver_ll.dat
08/14/2007  09:43a               854 seismic_ll.dat
03/21/2007  12:48a             2,070 setup.fis
03/21/2007  12:48a             2,874 shake.fis
03/21/2007  12:48a             1,926 temphis_50.tab
03/21/2007  12:48a             1,515 thermal_50.dat
08/14/2007  09:53a             3,679 thermoprop.fis
03/21/2007  12:48a             3,018 tunnel.dat
03/21/2007  01:44a           203,437 vel_hori_5e-4.tab
03/21/2007  01:44a           195,677 vel_vert_5e-4.tab
09/19/2007  03:13p               147 listfiles.dat
              16 File(s)        428,063 bytes
               2 Dir(s)  184,584,089,600 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_50+50L\Output

09/19/2007  03:13p    <DIR>          .
09/19/2007  02:28p    <DIR>          ..
08/14/2007  10:00a         4,618,339 gcukl210th.20
08/14/2007  09:56a         3,790,855 gcukl210is.ini
08/14/2007  09:57a         3,943,871 gcukl210is.exv
08/14/2007  09:58a         4,025,515 gcukl210th.1
08/14/2007  09:58a         4,062,819 gcukl210th.2
08/14/2007  09:59a         4,173,219 gcukl210th.5
08/14/2007  09:59a         4,323,967 gcukl210th.10
08/16/2007  09:09a               410 Shortcut to flacw_sp.exe.lnk
08/14/2007  10:01a         4,879,447 gcukl210th.30
08/14/2007  10:03a         5,536,439 gcukl210th.50
08/14/2007  10:03a         5,610,103 gcukl210th.52
08/14/2007  10:04a         5,764,903 gcukl210th.58
08/14/2007  10:04a         5,816,895 gcukl210th.60
08/14/2007  10:05a         5,931,375 gcukl210th.65
08/14/2007  10:05a         6,059,471 gcukl210th.70
08/14/2007  10:06a         6,178,487 gcukl210th.75
08/14/2007  10:06a         6,298,519 gcukl210th.80
08/14/2007  10:07a         6,673,079 gcukl210th.100
08/14/2007  10:07a         3,790,855 gcuku210is.ini
08/14/2007  10:08a         3,880,511 gcuku210is.exv
08/14/2007  10:09a         3,958,123 gcuku210th.1
08/14/2007  10:09a         3,993,915 gcuku210th.2
08/14/2007  10:09a         4,082,643 gcuku210th.5
08/14/2007  10:10a         4,226,839 gcuku210th.10
08/14/2007  10:10a         4,509,619 gcuku210th.20
08/14/2007  10:11a         4,784,839 gcuku210th.30
08/14/2007  10:13a         5,385,839 gcuku210th.50
08/14/2007  10:13a         5,454,463 gcuku210th.52
08/14/2007  10:14a         5,598,175 gcuku210th.58
08/14/2007  10:14a         5,652,183 gcuku210th.60
08/14/2007  10:15a         5,760,615 gcuku210th.65
08/14/2007  10:15a         5,874,599 gcuku210th.70
08/14/2007  10:15a         5,992,607 gcuku210th.75
08/14/2007  10:16a         6,107,599 gcuku210th.80
```

08/14/2007	10:17a	6,478,127	gcuku210th.100
08/14/2007	10:17a	3,790,855	gcukl250is.ini
08/14/2007	10:18a	3,954,431	gcukl250is.exv
08/14/2007	10:20a	4,091,011	gcukl250th.1
08/14/2007	10:20a	4,174,683	gcukl250th.2
08/14/2007	10:21a	4,312,803	gcukl250th.5
08/14/2007	10:22a	4,507,903	gcukl250th.10
08/14/2007	10:23a	4,830,499	gcukl250th.20
08/14/2007	10:24a	5,147,551	gcukl250th.30
08/14/2007	10:27a	5,928,023	gcukl250th.50
08/14/2007	10:28a	6,041,503	gcukl250th.52
08/14/2007	10:29a	6,227,551	gcukl250th.58
08/14/2007	10:29a	6,314,823	gcukl250th.60
08/14/2007	10:30a	6,461,559	gcukl250th.65
08/14/2007	10:31a	6,609,815	gcukl250th.70
08/14/2007	10:31a	6,759,575	gcukl250th.75
08/14/2007	10:32a	6,906,319	gcukl250th.80
08/14/2007	10:34a	7,310,111	gcukl250th.100
08/14/2007	10:34a	3,790,855	gcuku250is.ini
08/14/2007	10:34a	3,899,711	gcuku250is.exv
08/14/2007	10:36a	4,038,811	gcuku250th.1
08/14/2007	10:36a	4,123,491	gcuku250th.2
08/14/2007	10:37a	4,264,131	gcuku250th.5
08/14/2007	10:38a	4,456,711	gcuku250th.10
08/14/2007	10:39a	4,769,731	gcuku250th.20
08/14/2007	10:40a	5,088,295	gcuku250th.30
08/14/2007	10:43a	5,844,023	gcuku250th.50
08/14/2007	10:44a	5,959,519	gcuku250th.52
08/14/2007	10:45a	6,144,055	gcuku250th.58
08/14/2007	10:45a	6,226,287	gcuku250th.60
08/14/2007	10:46a	6,370,503	gcuku250th.65
08/14/2007	10:47a	6,516,743	gcuku250th.70
08/14/2007	10:47a	6,658,943	gcuku250th.75
08/14/2007	10:48a	6,803,167	gcuku250th.80
08/14/2007	10:49a	7,211,999	gcuku250th.100
08/14/2007	11:58a	5,326,523	gcukl210dy.100
08/14/2007	03:39p	8,067,359	gcukl250dy.100
08/14/2007	04:48p	5,326,523	gcuku210dy.100
08/14/2007	08:29p	8,067,359	gcuku250dy.100
08/16/2007	07:06a	2,001	stress_for_excel.dat
08/15/2007	01:47p	532	eq_closure_for_excel.dat
08/16/2007	09:09a	554	eq_stress_for_excel.dat
08/15/2007	01:06p	1,043	closure_for_excel.dat
09/19/2007	03:13p	148	listfiles.dat
08/15/2007	12:49p	6,679	closure_ku21.log
08/15/2007	12:52p	6,679	closure_kl21.log
08/15/2007	01:05p	6,679	closure_kl25.log
08/15/2007	01:06p	6,679	closure_ku25.log
08/15/2007	01:49p	277,086	U250dy_vc_100.his
08/15/2007	01:49p	277,086	U250dy_hc_100.his
08/15/2007	01:49p	277,086	L250dy_vc_100.his
08/15/2007	01:49p	277,086	L250dy_hc_100.his
08/15/2007	01:49p	86,182	U210dy_vc_100.his
08/15/2007	01:49p	86,182	U210dy_hc_100.his
08/16/2007	07:06a	13,159	stress_kl21.log
08/15/2007	01:49p	86,182	L210dy_vc_100.his

```
08/15/2007  01:49p            86,182 L210dy_hc_100.his
08/16/2007  06:57a            13,159 stress_ku21.log
08/16/2007  07:03a            13,159 stress_ku25.log
08/16/2007  07:05a            13,159 stress_kl25.log
08/16/2007  09:10a            86,182 L210dy_crsig1_100.his
08/16/2007  09:10a            86,182 L210dy_spsig1_100.his
08/16/2007  09:10a           277,086 L250dy_crsig1_100.his
08/16/2007  09:10a           277,086 L250dy_spsig1_100.his
08/16/2007  09:10a            86,182 U210dy_crsig1_100.his
08/16/2007  09:10a            86,182 U210dy_spsig1_100.his
08/16/2007  09:10a           277,086 U250dy_crsig1_100.his
08/16/2007  09:13a           277,086 U250dy_spsig1_100.his
             102 File(s)    388,532,792 bytes
               2 Dir(s)  184,584,019,968 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_grc\Input

09/19/2007  03:15p    <DIR>          .
09/19/2007  02:31p    <DIR>          ..
07/14/2007  02:52p             3,823 properties.fis
08/10/2007  09:21a            12,294 driver_grcll.dat
03/20/2007  10:08p               659 hiszones_50.fis
05/15/2007  07:39p             2,152 relaxation.fis
05/15/2007  07:39p             2,087 setup.fis
07/19/2007  04:05p             3,025 tunnel.dat
09/19/2007  03:15p               144 listfiles.dat
               7 File(s)         24,184 bytes
               2 Dir(s)  184,583,983,104 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_grc\Output

09/19/2007  03:15p    <DIR>          .
09/19/2007  02:31p    <DIR>          ..
08/10/2007  09:35a         3,791,091 gcuklgrc6250is.ini
08/10/2007  09:28a         3,791,091 gcuklgrc2210is.ini
08/10/2007  09:29a         3,969,003 gcuklgrc2210is.exv
08/10/2007  09:29a         3,791,091 gcuklgrc4210is.ini
08/10/2007  09:30a         3,903,723 gcuklgrc4210is.exv
08/10/2007  09:30a         3,791,091 gcuklgrc6210is.ini
08/10/2007  09:31a         3,882,603 gcuklgrc6210is.exv
08/10/2007  09:31a         3,791,091 gcuklgrc8210is.ini
08/10/2007  09:31a         3,798,603 gcuklgrc10210is.exv
08/10/2007  09:31a         3,791,163 gcuklgrc10210is.ini
08/10/2007  09:31a         3,853,323 gcuklgrc8210is.exv
08/10/2007  09:31a         3,791,091 gcukugrc2210is.ini
08/10/2007  09:32a         3,878,763 gcukugrc2210is.exv
08/10/2007  09:32a         3,791,091 gcukugrc4210is.ini
08/10/2007  09:32a         3,861,003 gcukugrc4210is.exv
08/10/2007  09:32a         3,791,091 gcukugrc6210is.ini
08/10/2007  09:33a         3,850,923 gcukugrc6210is.exv
```

08/10/2007 09:33a 3,791,091 gcukugrc8210is.ini
08/10/2007 09:33a 3,791,091 gcuklgrc2250is.ini
08/10/2007 09:33a 3,798,603 gcukugrc10210is.exv
08/10/2007 09:33a 3,791,163 gcukugrc10210is.ini
08/10/2007 09:33a 3,837,483 gcukugrc8210is.exv
08/10/2007 09:34a 3,914,763 gcuklgrc2250is.exv
08/10/2007 09:34a 3,791,091 gcuklgrc4250is.ini
08/10/2007 09:35a 3,899,403 gcuklgrc4250is.exv
08/10/2007 10:29a 402 Shortcut to flacw_sp.exe.lnk
08/10/2007 09:35a 3,878,283 gcuklgrc6250is.exv
08/10/2007 09:36a 3,791,091 gcuklgrc8250is.ini
08/10/2007 09:36a 3,798,603 gcuklgrc10250is.exv
08/10/2007 09:36a 3,791,163 gcuklgrc10250is.ini
08/10/2007 09:36a 3,855,723 gcuklgrc8250is.exv
08/10/2007 09:36a 3,791,091 gcukugrc2250is.ini
08/10/2007 09:37a 3,871,563 gcukugrc2250is.exv
08/10/2007 09:37a 3,791,091 gcukugrc4250is.ini
08/10/2007 09:37a 3,863,403 gcukugrc4250is.exv
08/10/2007 09:37a 3,791,091 gcukugrc6250is.ini
08/10/2007 09:38a 3,847,563 gcukugrc6250is.exv
08/10/2007 09:38a 3,791,091 gcukugrc8250is.ini
08/10/2007 09:38a 3,838,443 gcukugrc8250is.exv
08/10/2007 09:38a 3,798,603 gcukugrc10250is.exv
08/10/2007 09:38a 3,791,163 gcukugrc10250is.ini
09/19/2007 03:15p 145 listfiles.dat
08/10/2007 10:29a 0 FC112904.tmp
08/10/2007 11:57a 1,225 ydisp_gcu1kl10
08/10/2007 11:59a 1,225 ydisp_gcu1kl8
08/10/2007 12:56p 16,384 FH135617.tmp
08/10/2007 12:03p 1,225 ydisp_gcu1kl6
08/10/2007 12:05p 1,225 ydisp_gcu1kl4
08/10/2007 12:08p 1,225 ydisp_gcu1kl2
08/10/2007 12:12p 1,225 ydisp_gcu5kl8
08/10/2007 12:10p 1,225 ydisp_gcu5kl10
08/10/2007 12:13p 1,225 ydisp_gcu5kl6
08/10/2007 12:14p 1,225 ydisp_gcu5kl4
08/10/2007 12:19p 1,225 ydisp_gcu5kl2
08/10/2007 12:21p 1,387 ydisp_gcu1ku10
08/10/2007 12:25p 1,225 ydisp_gcu1ku8
08/10/2007 12:26p 1,225 ydisp_gcu1ku6
08/10/2007 12:27p 1,225 ydisp_gcu1ku4
08/10/2007 12:29p 1,225 ydisp_gcu1ku2
08/10/2007 12:30p 1,225 ydisp_gcu5ku10
08/10/2007 12:31p 1,225 ydisp_gcu5ku8
08/10/2007 12:40p 1,225 ydisp_gcu5ku4
08/10/2007 12:56p 1,225 ydisp_gcu5ku6
08/10/2007 12:59p 787 ydisp_gcu5ku2
64 File(s) 153,063,643 bytes
2 Dir(s) 184,584,077,312 bytes free

Volume in drive D is New Volume
Volume Serial Number is 683C-0946

Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_K=0.5_new\Input

09/19/2007 03:16p <DIR> .

```
09/19/2007  02:31p    <DIR>          ..
07/18/2007  09:28a             3,820 properties.fis
03/20/2007  10:08p               659 hiszones_50.fis
05/15/2007  07:41p               392 initemp.fis
09/19/2007  03:19p               150 listfiles.dat
08/30/2007  07:18a             1,227 driver.dat
05/15/2007  07:39p             3,408 makemovie.fis
05/15/2007  07:39p             2,152 relaxation.fis
08/30/2007  07:21a               727 seismic.dat
05/25/2007  03:20p             2,077 setup.fis
07/18/2007  07:15a             2,872 shake.fis
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:41p             1,628 thermal_50.dat
05/15/2007  03:11p             3,679 thermoprop.fis
07/17/2007  12:59p             3,016 tunnel.dat
05/15/2007  07:39p           203,437 vel_hori_5e-4.tab
05/15/2007  07:39p           195,677 vel_vert_5e-4.tab
              16 File(s)        425,866 bytes
               2 Dir(s)  184,559,005,696 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_K=0.5_new\Output

09/19/2007  03:17p    <DIR>          .
09/19/2007  02:31p    <DIR>          ..
08/30/2007  07:24a         3,959,275 gcukm210is.exv
08/30/2007  07:23a         3,790,915 gcukm210is.ini
08/30/2007  07:22a               452 Shortcut to flacw_sp.exe.lnk
08/30/2007  07:25a         3,985,195 gcukm210th.0
08/30/2007  07:26a         4,197,439 gcukm210th.1
08/30/2007  07:26a         4,388,507 gcukm210th.2
08/30/2007  07:28a         4,951,527 gcukm210th.5
08/30/2007  07:29a         5,316,483 gcukm210th.7
08/30/2007  07:30a         5,875,443 gcukm210th.10
08/30/2007  07:34a         7,698,387 gcukm210th.20
08/30/2007  07:39a         9,501,211 gcukm210th.30
08/30/2007  07:47a        13,074,595 gcukm210th.50
08/30/2007  07:47a         3,790,915 gcukm250is.ini
08/30/2007  07:48a         3,921,355 gcukm250is.exv
08/30/2007  07:49a         3,972,523 gcukm250th.0
08/30/2007  07:50a         4,244,743 gcukm250th.1
08/30/2007  07:51a         4,479,659 gcukm250th.2
08/30/2007  07:53a         5,074,431 gcukm250th.5
08/30/2007  07:54a         5,476,683 gcukm250th.7
08/30/2007  07:56a         6,061,347 gcukm250th.10
08/30/2007  08:00a         7,914,531 gcukm250th.20
08/30/2007  08:05a         9,765,739 gcukm250th.30
08/30/2007  08:14a        13,376,923 gcukm250th.50
08/30/2007  10:41a         5,301,819 gcukm210dy.0
08/30/2007  06:33p         8,042,655 gcukm250dy.0
09/19/2007  03:20p               151 listfiles.dat
              26 File(s)    148,162,903 bytes
               2 Dir(s)  184,559,005,696 bytes free
```

```
Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_sup\Input

09/19/2007  03:17p    <DIR>          .
09/19/2007  02:32p    <DIR>          ..
03/20/2007  10:08p               659 hiszones_50.fis
03/20/2007  10:08p             1,592 boltprop.fis
08/07/2007  07:23a             2,503 driver.dat
06/22/2007  04:32p               630 bolt.dat
05/15/2007  07:41p               392 initemp.fis
05/15/2007  07:39p             3,408 makemovie.fis
07/18/2007  09:28a             3,820 properties.fis
05/15/2007  07:39p             2,152 relaxation.fis
08/07/2007  07:32a             1,453 seismic.dat
05/25/2007  03:20p             2,077 setup.fis
07/25/2007  08:31a             2,871 shake.fis
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:41p             1,628 thermal_50.dat
07/25/2007  08:31a             3,679 thermoprop.fis
05/15/2007  07:39p             3,041 tunnel_b.dat
05/15/2007  07:39p           203,437 vel_hori_5e-4.tab
05/15/2007  07:39p           195,677 vel_vert_5e-4.tab
09/19/2007  03:20p               144 Listfiles.dat
              18 File(s)        430,108 bytes
               2 Dir(s)  184,558,948,352 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_sup\Output

09/19/2007  03:18p    <DIR>          .
09/19/2007  02:32p    <DIR>          ..
08/07/2007  07:40a         4,897,795 gcskl210th.1
08/07/2007  07:35a         3,790,915 gcskl210is.ini
08/07/2007  07:36a         3,903,595 gcskl210is.exv
08/07/2007  07:38a         4,268,191 gcskl210is.sup
08/07/2007  07:39a         4,365,015 gcskl210th.0
08/16/2007  09:58a               400 Shortcut to flacw_sp.exe.lnk
08/07/2007  07:41a         5,235,319 gcskl210th.2
08/07/2007  07:43a         6,387,587 gcskl210th.5
08/07/2007  07:45a         7,163,159 gcskl210th.7
08/07/2007  07:46a         8,213,447 gcskl210th.10
08/07/2007  07:51a        11,433,183 gcskl210th.20
08/07/2007  07:55a        14,519,919 gcskl210th.30
08/07/2007  08:04a        20,731,735 gcskl210th.50
08/07/2007  08:04a         3,790,915 gcskl250is.ini
08/07/2007  08:05a         3,899,275 gcskl250is.exv
08/07/2007  08:06a         4,227,751 gcskl250is.sup
08/07/2007  08:07a         4,410,927 gcskl250th.0
08/07/2007  08:09a         4,908,283 gcskl250th.1
08/07/2007  08:10a         5,343,439 gcskl250th.2
08/07/2007  08:11a         6,394,619 gcskl250th.5
08/07/2007  08:13a         7,146,863 gcskl250th.7
```

08/07/2007	08:15a	8,188,511	gcskl250th.10
08/07/2007	08:19a	11,405,655	gcskl250th.20
08/07/2007	08:24a	14,608,167	gcskl250th.30
08/07/2007	08:33a	20,828,623	gcskl250th.50
08/07/2007	08:33a	3,790,915	gcsku210is.ini
08/07/2007	08:33a	3,860,875	gcsku210is.exv
08/07/2007	08:34a	4,112,911	gcsku210is.sup
08/07/2007	08:35a	4,157,847	gcsku210th.0
08/07/2007	08:36a	4,656,067	gcsku210th.1
08/07/2007	08:37a	4,984,951	gcsku210th.2
08/07/2007	08:39a	6,043,907	gcsku210th.5
08/07/2007	08:40a	6,752,087	gcsku210th.7
08/07/2007	08:42a	7,795,463	gcsku210th.10
08/07/2007	08:46a	10,977,183	gcsku210th.20
08/07/2007	08:50a	14,061,327	gcsku210th.30
08/07/2007	08:59a	20,272,279	gcsku210th.50
08/07/2007	08:59a	3,790,915	gcsku250is.ini
08/07/2007	08:59a	3,863,275	gcsku250is.exv
08/07/2007	09:00a	4,113,631	gcsku250is.sup
08/07/2007	09:01a	4,229,415	gcsku250th.0
08/07/2007	09:03a	4,730,227	gcsku250th.1
08/07/2007	09:04a	5,166,247	gcsku250th.2
08/07/2007	09:06a	6,218,291	gcsku250th.5
08/07/2007	09:07a	6,970,535	gcsku250th.7
08/07/2007	09:09a	8,014,775	gcsku250th.10
08/07/2007	09:14a	11,237,103	gcsku250th.20
08/07/2007	09:18a	14,441,343	gcsku250th.30
08/07/2007	09:27a	20,703,271	gcsku250th.50
08/07/2007	05:37p	13,113,703	gcskl210dy.0
08/08/2007	01:48a	13,118,179	gcskl210dy.50
08/08/2007	10:00a	13,113,703	gcsku210dy.0
08/08/2007	06:13p	13,118,179	gcsku210dy.50
08/09/2007	02:23a	13,113,703	gcskl250dy.0
08/09/2007	10:34a	13,117,375	gcskl250dy.50
08/09/2007	06:46p	13,113,703	gcsku250dy.0
08/10/2007	03:00a	13,118,179	gcsku250dy.50
08/16/2007	10:01a	658	find_for.fis
08/16/2007	10:11a	790	bolt_forces_for_excel.dat
06/29/2007	06:15a	13,731	Str.fin
08/18/2007	09:26a	30,539	bolt_force_kl21_0yr.pcx
08/18/2007	09:30a	30,579	bolt_force_kl21_50yr.pcx
08/16/2007	10:05a	3,746	bolt_force_kl21.log
08/18/2007	09:35a	31,943	bolt_force_ku21_0yr.pcx
08/18/2007	09:38a	31,846	bolt_force_ku21_50yr.pcx
08/18/2007	09:44a	29,180	bolt_force_kl25_0yr.pcx
08/16/2007	10:08a	3,746	bolt_force_kl25.log
08/18/2007	09:47a	30,959	bolt_force_kl25_50yr.pcx
08/18/2007	09:54a	32,055	bolt_force_ku25_0yr.pcx
08/18/2007	09:57a	31,228	bolt_force_ku25.50yr.pcx
08/16/2007	10:10a	3,746	bolt_force_ku25.log
08/20/2007	09:27a	30,824	bolt_force_kl21_50yrdy.pcx
08/20/2007	08:48a	30,963	bolt_force_kl25_50yrdy.pcx
08/20/2007	10:05a	32,082	bolt_force_ku21_50yrdy.pcx
08/16/2007	10:12a	3,746	bolt_force_ku21.log
08/20/2007	09:17a	30,924	bolt_force_kl21_0yrdy.pcx
08/20/2007	10:04a	32,082	bolt_force_ku21_0yrdy.pcx

09/19/2007 03:21p 145 listfiles.dat
78 File(s) 480,370,364 bytes
2 Dir(s) 184,558,952,448 bytes free

Volume in drive D is New Volume
Volume Serial Number is 683C-0946

Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_sup_25+75L\Input

09/19/2007 03:22p <DIR> .
09/19/2007 02:31p <DIR> ..
03/21/2007 02:17a 392 initemp.fis
03/21/2007 02:17a 1,592 boltprop.fis
08/14/2007 10:31a 2,503 driver_bll.dat
03/21/2007 02:17a 659 hiszones_50.fis
06/22/2007 04:32p 630 bolt.dat
03/21/2007 03:30a 3,408 makemovie.fis
07/14/2007 02:52p 3,823 properties.fis
03/21/2007 02:17a 2,154 relaxation.fis
08/14/2007 10:34a 854 seismic_bll.dat
03/21/2007 02:17a 2,070 setup.fis
03/21/2007 03:30a 2,874 shake.fis
03/20/2007 11:16p 658 temphis_50.tab
03/20/2007 11:16p 1,518 thermal_50.dat
08/14/2007 09:53a 3,679 thermoprop.fis
03/21/2007 02:17a 3,041 tunnel_b.dat
03/21/2007 03:30a 203,437 vel_hori_5e-4.tab
03/21/2007 03:30a 195,677 vel_vert_5e-4.tab
09/19/2007 03:22p 151 listfiles.dat
18 File(s) 429,120 bytes
2 Dir(s) 184,559,022,080 bytes free

Volume in drive D is New Volume
Volume Serial Number is 683C-0946

Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_sup_25+75L\Output

09/19/2007 03:22p <DIR> .
09/19/2007 02:31p <DIR> ..
08/14/2007 11:07a 8,407,243 gcskl210th.100
08/14/2007 10:57a 3,903,551 gcskl210is.exv
08/14/2007 10:56a 3,790,855 gcskl210is.ini
08/14/2007 10:59a 4,268,147 gcskl210is.sup
08/14/2007 10:59a 4,284,663 gcskl210th.0
08/14/2007 11:00a 4,531,407 gcskl210th.1
08/14/2007 07:23p 13,114,823 gcskl210dy.100
08/14/2007 11:02a 5,727,739 gcskl210th.25
08/14/2007 11:04a 6,509,335 gcskl210th.40
08/15/2007 03:12a 13,114,823 gcskl250dy.100
08/14/2007 11:18a 3,899,231 gcskl250is.exv
08/14/2007 11:17a 3,790,855 gcskl250is.ini
08/14/2007 11:19a 4,227,707 gcskl250is.sup
08/14/2007 11:20a 4,243,311 gcskl250th.0
08/14/2007 11:21a 4,478,823 gcskl250th.1
08/14/2007 11:27a 8,433,283 gcskl250th.100
08/14/2007 11:23a 5,667,379 gcskl250th.25

```
08/14/2007  11:24a         6,559,567 gcskl250th.40
08/15/2007  10:59a        13,114,823 gcsku210dy.100
08/14/2007  11:07a         3,860,831 gcsku210is.exv
08/14/2007  11:07a         3,790,855 gcsku210is.ini
08/14/2007  11:08a         4,112,867 gcsku210is.sup
08/14/2007  11:09a         4,128,471 gcsku210th.0
08/14/2007  11:10a         4,367,439 gcsku210th.1
08/14/2007  11:17a         8,479,147 gcsku210th.100
08/14/2007  11:11a         5,531,803 gcsku210th.25
08/14/2007  11:14a         6,556,183 gcsku210th.40
08/15/2007  06:44p        13,114,823 gcsku250dy.100
08/14/2007  11:28a         3,863,231 gcsku250is.exv
08/14/2007  11:27a         3,790,855 gcsku250is.ini
08/14/2007  11:29a         4,113,587 gcsku250is.sup
08/14/2007  11:29a         4,129,191 gcsku250th.0
08/14/2007  11:30a         4,369,023 gcsku250th.1
08/14/2007  11:38a         8,508,379 gcsku250th.100
08/14/2007  11:33a         5,687,179 gcsku250th.25
08/14/2007  11:35a         6,573,319 gcsku250th.40
08/16/2007  12:44p               402 Shortcut to flacw_sp.exe.lnk
06/29/2007  06:15a            13,731 Str.fin
08/16/2007  10:01a               658 find_for.fis
08/16/2007  12:48p               505 bolt_forces_for_excel.dat
09/19/2007  03:22p               152 listfiles.dat
08/17/2007  04:56p            31,211 bolt_force_kl25_100yr.pcx
08/17/2007  04:42p            30,761 bolt_force_kl21_100yr.pcx
08/16/2007  12:44p             2,339 bolt_force_kl21.log
08/16/2007  12:46p             2,339 bolt_force_kl25.log
08/16/2007  12:47p             2,339 bolt_force_ku25.log
08/16/2007  12:49p             2,339 bolt_force_ku21.log
              47 File(s)    217,131,524 bytes
               2 Dir(s)  184,559,013,888 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_sup_50+50L\Input

09/19/2007  03:23p    <DIR>          .
09/19/2007  02:25p    <DIR>          ..
03/21/2007  02:17a             2,154 relaxation.fis
03/21/2007  02:17a             1,592 boltprop.fis
08/14/2007  10:31a             2,503 driver_bll.dat
03/21/2007  02:17a               659 hiszones_50.fis
03/21/2007  02:17a               392 initemp.fis
06/22/2007  04:32p               630 bolt.dat
07/14/2007  02:52p             3,823 properties.fis
03/21/2007  03:30a             3,408 makemovie.fis
03/21/2007  02:17a             2,070 setup.fis
03/21/2007  03:30a             2,874 shake.fis
03/21/2007  12:48a             1,926 temphis_50.tab
03/21/2007  12:48a             1,515 thermal_50.dat
08/14/2007  09:53a             3,679 thermoprop.fis
03/21/2007  02:17a             3,041 tunnel_b.dat
03/21/2007  03:30a           203,437 vel_hori_5e-4.tab
03/21/2007  03:30a           195,677 vel_vert_5e-4.tab
```

```
08/14/2007  10:34a               854 seismic_bll.dat
09/19/2007  03:23p               151 listfiles.dat
              18 File(s)        430,385 bytes
               2 Dir(s)  184,559,009,792 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1,5_sup_50+50L\Output

09/19/2007  03:23p    <DIR>          .
09/19/2007  02:25p    <DIR>          ..
08/14/2007  12:12p         6,330,843 gcsku250th.30
08/14/2007  11:08a         3,790,855 gcskl210is.ini
08/14/2007  11:09a         3,903,551 gcskl210is.exv
08/14/2007  11:11a         4,268,147 gcskl210is.sup
08/14/2007  11:12a         4,550,823 gcskl210th.1
08/14/2007  11:13a         4,616,127 gcskl210th.2
08/14/2007  11:13a         4,887,959 gcskl210th.5
08/14/2007  11:14a         5,244,475 gcskl210th.10
08/14/2007  11:16a         5,811,807 gcskl210th.20
08/14/2007  11:16a         6,263,355 gcskl210th.30
08/14/2007  11:20a         7,744,783 gcskl210th.50
08/14/2007  11:21a         7,970,871 gcskl210th.52
08/14/2007  11:22a         8,324,823 gcskl210th.58
08/14/2007  11:23a         8,508,567 gcskl210th.60
08/14/2007  11:24a         8,761,439 gcskl210th.65
08/14/2007  11:24a         9,015,167 gcskl210th.70
08/14/2007  11:25a         9,268,039 gcskl210th.75
08/14/2007  11:26a         9,521,767 gcskl210th.80
08/14/2007  11:27a        10,217,887 gcskl210th.100
08/14/2007  11:27a         3,790,855 gcsku210is.ini
08/14/2007  11:28a         3,860,831 gcsku210is.exv
08/14/2007  11:29a         4,112,867 gcsku210is.sup
08/14/2007  11:30a         4,363,575 gcsku210th.1
08/14/2007  11:31a         4,425,423 gcsku210th.2
08/14/2007  11:31a         4,691,207 gcsku210th.5
08/14/2007  11:32a         5,044,267 gcsku210th.10
08/14/2007  11:33a         5,588,271 gcsku210th.20
08/14/2007  11:34a         6,042,411 gcsku210th.30
08/14/2007  11:37a         7,344,991 gcsku210th.50
08/14/2007  11:38a         7,568,487 gcsku210th.52
08/14/2007  11:39a         7,872,327 gcsku210th.58
08/14/2007  11:39a         7,945,479 gcsku210th.60
08/14/2007  11:40a         8,206,127 gcsku210th.65
08/14/2007  11:41a         8,471,951 gcsku210th.70
08/14/2007  11:42a         8,742,967 gcsku210th.75
08/14/2007  11:43a         9,014,839 gcsku210th.80
08/14/2007  11:44a         9,721,327 gcsku210th.100
08/14/2007  11:44a         3,790,855 gcskl250is.ini
08/14/2007  11:45a         3,899,231 gcskl250is.exv
08/14/2007  11:46a         4,227,707 gcskl250is.sup
08/14/2007  11:48a         4,476,687 gcskl250th.1
08/14/2007  11:48a         4,652,583 gcskl250th.2
08/14/2007  11:49a         4,913,183 gcskl250th.5
08/14/2007  11:50a         5,266,243 gcskl250th.10
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08/14/2007  11:51a         5,856,903 gcskl250th.20
08/14/2007  11:53a         6,425,091 gcskl250th.30
08/14/2007  11:57a         7,910,023 gcskl250th.50
08/14/2007  11:58a         8,133,519 gcskl250th.52
08/14/2007  11:59a         8,460,687 gcskl250th.58
08/14/2007  11:59a         8,646,159 gcskl250th.60
08/14/2007  12:00p         8,919,767 gcskl250th.65
08/14/2007  12:01p         9,176,087 gcskl250th.70
08/14/2007  12:02p         9,435,871 gcskl250th.75
08/14/2007  12:02p         9,699,103 gcskl250th.80
08/14/2007  12:04p        10,392,631 gcskl250th.100
08/14/2007  12:04p         3,790,855 gcsku250is.ini
08/14/2007  12:04p         3,863,231 gcsku250is.exv
08/14/2007  12:05p         4,113,587 gcsku250is.sup
08/14/2007  12:07p         4,366,887 gcsku250th.1
08/14/2007  12:08p         4,547,967 gcsku250th.2
08/14/2007  12:09p         4,812,023 gcsku250th.5
08/14/2007  12:09p         5,164,219 gcsku250th.10
08/14/2007  12:11p         5,759,199 gcsku250th.20
08/16/2007  12:27p               400 Shortcut to flacw_sp.exe.lnk
08/14/2007  12:16p         7,836,511 gcsku250th.50
08/14/2007  12:17p         8,064,327 gcsku250th.52
08/14/2007  12:18p         8,390,631 gcsku250th.58
08/14/2007  12:19p         8,576,103 gcsku250th.60
08/14/2007  12:20p         8,841,071 gcsku250th.65
08/14/2007  12:20p         9,094,799 gcsku250th.70
08/14/2007  12:21p         9,361,495 gcsku250th.75
08/14/2007  12:22p         9,627,319 gcsku250th.80
08/14/2007  12:23p        10,333,807 gcsku250th.100
08/14/2007  08:30p        13,122,259 gcskl210dy.100
08/15/2007  04:36a        13,122,259 gcskl250dy.100
08/15/2007  12:44p        13,121,455 gcsku210dy.100
08/15/2007  08:51p        13,122,259 gcsku250dy.100
06/29/2007  06:15a            13,731 Str.fin
08/16/2007  10:01a               658 find_for.fis
08/16/2007  12:39p               693 bolt_forces_for_excel.dat
08/17/2007  04:34p            30,763 bolt_force_kl21_100yr.pcx
09/19/2007  03:23p               152 listfiles.dat
08/17/2007  04:50p            31,541 bolt_force_kl25_100yr.pcx
08/16/2007  12:27p             3,277 bolt_force_ku21.log
08/16/2007  12:36p             3,277 bolt_force_ku25.log
08/16/2007  12:38p             3,277 bolt_force_kl25.log
08/16/2007  12:39p             3,277 bolt_force_kl21.log
              87 File(s)    539,215,126 bytes
               2 Dir(s)  184,558,940,160 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1_g10k\Input

09/19/2007  03:24p    <DIR>          .
09/19/2007  02:35p    <DIR>          ..
05/15/2007  07:39p             3,408 makemovie.fis
03/20/2007  10:08p               659 hiszones_50.fis
05/15/2007  07:41p               392 initemp.fis
```

```
05/15/2007  07:39p             2,152 relaxation.fis
07/18/2007  09:28a             3,820 properties.fis
08/20/2007  03:53p               625 driver.dat
06/20/2007  01:31p               389 seismic.dat
05/25/2007  03:20p             2,077 setup.fis
06/20/2007  01:34p             2,871 shake.fis
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:41p             1,628 thermal_50.dat
08/20/2007  03:55p             3,679 thermoprop.fis
07/17/2007  12:59p             3,016 tunnel.dat
06/30/2003  10:41a           373,597 vel_hori_1e-4.tab
06/30/2003  10:40a           373,120 vel_vert_1e-4.tab
09/19/2007  03:24p               143 listfiles.dat
              16 File(s)        772,521 bytes
               2 Dir(s)  184,558,997,504 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1_g10k\Output

09/19/2007  03:24p    <DIR>          .
09/19/2007  02:35p    <DIR>          ..
08/20/2007  04:03p         4,968,927 gcukl210th.5
08/20/2007  03:59p         3,943,915 gcukl210is.exv
08/20/2007  04:00p         3,978,907 gcukl210th.0
08/20/2007  04:01p         4,202,743 gcukl210th.1
08/20/2007  04:01p         4,396,331 gcukl210th.2
08/20/2007  03:58p         3,790,915 gcukl210is.ini
08/21/2007  07:51a               402 Shortcut to flacw_sp.exe.lnk
08/20/2007  04:03p         5,333,379 gcukl210th.7
08/20/2007  04:05p         5,890,323 gcukl210th.10
08/20/2007  04:09p         7,717,803 gcukl210th.20
08/20/2007  04:12p         9,537,763 gcukl210th.30
08/20/2007  04:19p        13,106,107 gcukl210th.50
08/20/2007  06:33p         6,690,931 gcukl210dy.0
08/20/2007  08:46p         6,695,431 gcukl210dy.50
09/19/2007  03:24p               144 listfiles.dat
08/21/2007  08:08a             2,296 stress_for_excel.dat
08/21/2007  08:12a               255 eq_closure_for_excel.dat
08/21/2007  08:17a               275 eq_stress_for_excel.dat
08/21/2007  08:06a             1,353 closure_for_excel.dat
08/21/2007  08:16a           167,326 L210dy_vc_50.his
08/21/2007  08:07a             8,589 closure_kl21.log
08/21/2007  08:09a            16,932 stress_kl21.log
08/21/2007  08:16a           167,326 L210dy_hc_50.his
08/21/2007  08:16a           167,326 L210dy_vc_0.his
08/21/2007  08:16a           167,326 L210dy_hc_0.his
08/21/2007  08:18a           167,326 L210dy_crsig1_0.his
08/21/2007  08:18a           167,326 L210dy_spsig1_0.his
08/21/2007  08:18a           167,326 L210dy_crsig1_50.his
08/21/2007  08:20a           167,326 L210dy_spsig1_50.his
              29 File(s)     81,622,329 bytes
               2 Dir(s)  184,558,927,872 bytes free

 Volume in drive D is New Volume
```

```
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1_sup_g10k\Input

09/19/2007  03:25p    <DIR>          .
09/19/2007  02:35p    <DIR>          ..
07/18/2007  09:28a             3,820 properties.fis
03/20/2007  10:08p             1,592 boltprop.fis
08/20/2007  05:13p               644 driver.dat
03/20/2007  10:08p               659 hiszones_50.fis
05/15/2007  07:41p               392 initemp.fis
05/15/2007  07:39p             3,408 makemovie.fis
06/22/2007  04:32p               630 bolt.dat
05/15/2007  07:39p             2,152 relaxation.fis
08/20/2007  04:24p               389 seismic.dat
05/25/2007  03:20p             2,077 setup.fis
06/20/2007  01:34p             2,871 shake.fis
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:41p             1,628 thermal_50.dat
08/20/2007  03:55p             3,679 thermoprop.fis
05/15/2007  07:39p             3,041 tunnel_b.dat
06/30/2003  10:41a           373,597 vel_hori_1e-4.tab
06/30/2003  10:40a           373,120 vel_vert_1e-4.tab
09/19/2007  03:25p               147 listfiles.dat
              18 File(s)        774,791 bytes
               2 Dir(s)  184,558,989,312 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1_sup_g10k\Output

09/19/2007  03:26p    <DIR>          .
09/19/2007  02:35p    <DIR>          ..
08/20/2007  05:19p         5,235,319 gcskl210th.2
08/20/2007  05:14p         3,790,915 gcskl210is.ini
08/20/2007  05:15p         3,903,595 gcskl210is.exv
08/20/2007  05:17p         4,268,191 gcskl210is.sup
08/20/2007  05:17p         4,365,015 gcskl210th.0
08/20/2007  05:19p         4,897,795 gcskl210th.1
08/22/2007  09:42a               400 Shortcut to flacw_sp.exe.lnk
08/20/2007  05:21p         6,387,587 gcskl210th.5
08/20/2007  05:23p         7,163,159 gcskl210th.7
08/20/2007  05:24p         8,213,447 gcskl210th.10
08/20/2007  05:28p        11,433,183 gcskl210th.20
08/20/2007  05:32p        14,519,919 gcskl210th.30
08/20/2007  05:39p        20,731,735 gcskl210th.50
08/21/2007  08:26a        21,803,091 gcskl210dy.0
08/21/2007  11:13p        21,807,559 gcskl210dy.50
06/29/2007  06:15a            13,731 Str.fin
08/16/2007  10:01a               658 find_for.fis
08/22/2007  09:42a               790 bolt_forces_for_excel.dat
09/19/2007  03:26p               148 listfiles.dat
08/22/2007  09:43a             3,746 bolt_force.log
08/22/2007  11:52a            31,258 bolt_force_kl21_0yrdy.pcx
08/22/2007  10:05a            31,026 bolt_force_kl21_50yrdy.pcx
```

```
              22 File(s)    138,602,267 bytes
               2 Dir(s)  184,558,985,216 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1_sup_K=0.5_new\Input

09/19/2007  03:26p    <DIR>          .
09/19/2007  02:37p    <DIR>          ..
05/15/2007  07:39p             3,408 makemovie.fis
03/20/2007  10:08p             1,592 boltprop.fis
08/30/2007  07:51a               644 driver.dat
03/20/2007  10:08p               659 hiszones_50.fis
05/15/2007  07:41p               392 initemp.fis
06/22/2007  04:32p               630 bolt.dat
07/18/2007  09:28a             3,820 properties.fis
05/15/2007  07:39p             2,152 relaxation.fis
08/30/2007  07:53a               365 seismic.dat
05/25/2007  03:20p             2,077 setup.fis
07/25/2007  08:31a             2,871 shake.fis
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:41p             1,628 thermal_50.dat
07/25/2007  08:31a             3,679 thermoprop.fis
05/15/2007  07:39p             3,041 tunnel_b.dat
05/15/2007  07:39p           203,437 vel_hori_5e-4.tab
05/15/2007  07:39p           195,677 vel_vert_5e-4.tab
09/19/2007  03:26p               152 listfiles.dat
              18 File(s)        427,169 bytes
               2 Dir(s)  184,558,981,120 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Litho\cat_1_sup_K=0.5_new\Output

09/19/2007  03:27p    <DIR>          .
09/19/2007  02:37p    <DIR>          ..
08/30/2007  08:11a        14,244,759 gcskm210th.30
08/30/2007  07:54a         3,790,915 gcskm210is.ini
08/30/2007  07:56a         4,215,991 gcskm210is.sup
08/30/2007  07:57a         4,321,407 gcskm210th.0
08/30/2007  07:58a         4,817,899 gcskm210th.1
08/30/2007  08:04a         7,981,487 gcskm210th.10
08/30/2007  07:59a         5,146,783 gcskm210th.2
08/30/2007  08:00a         6,205,739 gcskm210th.5
08/30/2007  08:02a         6,932,063 gcskm210th.7
08/30/2007  07:54a               452 Shortcut to flacw_sp.exe.lnk
08/30/2007  08:08a        11,162,343 gcskm210th.20
08/30/2007  07:55a         3,899,275 gcskm210is.exv
08/30/2007  08:19a        20,458,303 gcskm210th.50
08/30/2007  04:10p        13,113,703 gcskm210dy.0
08/31/2007  12:01a        13,117,375 gcskm210dy.50
09/19/2007  03:27p               153 listfiles.dat
              16 File(s)    119,408,647 bytes
               2 Dir(s)  184,558,972,928 bytes free
```

```
Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Sensitivity on Ko=0.5\Litho\Ko=0.5\cat_1,3,5_Input

09/19/2007  02:40p    <DIR>          .
09/19/2007  02:41p    <DIR>          ..
07/18/2007  09:20a             3,820 properties.fis
07/18/2007  08:59a               659 hiszones_50.fis
05/15/2007  07:41p               392 initemp.fis
05/15/2007  07:39p             3,408 makemovie.fis
07/18/2007  02:18p             1,825 driver.dat
05/15/2007  07:39p             2,152 relaxation.fis
07/17/2007  04:32p               987 seismic.dat
05/25/2007  03:20p             2,077 setup.fis
07/25/2007  08:19a             2,871 shake.fis
07/17/2007  05:02p               452 Shortcut to flacw_sp.exe.lnk
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:41p             1,628 thermal_50.dat
05/15/2007  03:11p             3,679 thermoprop.fis
07/17/2007  12:59p             3,016 tunnel.dat
05/15/2007  07:39p           203,437 vel_hori_5e-4.tab
05/15/2007  07:39p           195,677 vel_vert_5e-4.tab
09/19/2007  03:29p               171 listfiles.dat
              17 File(s)        427,196 bytes
               2 Dir(s)  184,558,964,736 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Sensitivity on Ko=0.5\Litho\Ko=0.5\cat_1,3,5_Output

09/19/2007  03:30p    <DIR>          .
09/19/2007  02:41p    <DIR>          ..
07/19/2007  06:41a         8,042,655 gcukm250dy.0
07/18/2007  02:21p         3,959,275 gcukm210is.exv
07/18/2007  02:19p         3,790,915 gcukm210is.ini
07/18/2007  02:21p         3,985,195 gcukm210th.0
07/18/2007  02:22p         4,197,439 gcukm210th.1
07/18/2007  02:26p         5,875,443 gcukm210th.10
07/18/2007  02:23p         4,388,507 gcukm210th.2
07/18/2007  02:30p         7,698,387 gcukm210th.20
07/18/2007  02:33p         9,501,211 gcukm210th.30
07/18/2007  02:24p         4,951,527 gcukm210th.5
07/18/2007  02:41p        13,074,595 gcukm210th.50
07/18/2007  02:25p         5,316,483 gcukm210th.7
07/18/2007  11:16p         7,010,319 gcukm230dy.0
07/18/2007  02:42p         3,933,835 gcukm230is.exv
07/18/2007  02:41p         3,790,915 gcukm230is.ini
07/18/2007  02:43p         3,976,435 gcukm230th.0
07/18/2007  02:44p         4,243,111 gcukm230th.1
07/18/2007  02:49p         6,026,955 gcukm230th.10
07/18/2007  02:45p         4,464,419 gcukm230th.2
07/18/2007  02:53p         7,871,067 gcukm230th.20
07/18/2007  02:57p         9,709,675 gcukm230th.30
```

07/18/2007 02:46p 5,055,159 gcukm230th.5
07/18/2007 03:04p 13,312,795 gcukm230th.50
07/18/2007 02:47p 5,451,867 gcukm230th.7
07/18/2007 05:46p 5,301,819 gcukm210dy.0
07/18/2007 03:05p 3,921,355 gcukm250is.exv
07/18/2007 03:04p 3,790,915 gcukm250is.ini
07/18/2007 03:06p 3,972,523 gcukm250th.0
07/18/2007 03:07p 4,244,743 gcukm250th.1
07/18/2007 03:12p 6,061,347 gcukm250th.10
07/18/2007 03:08p 4,479,659 gcukm250th.2
07/18/2007 03:16p 7,914,531 gcukm250th.20
07/18/2007 03:20p 9,765,739 gcukm250th.30
07/18/2007 03:10p 5,074,431 gcukm250th.5
07/18/2007 03:28p 13,376,923 gcukm250th.50
07/18/2007 03:11p 5,476,683 gcukm250th.7
08/01/2007 07:30a 402 Shortcut to flacw_sp.exe.lnk
09/17/2007 12:39p 25,600 Closure_Th_Lith.xls
09/17/2007 01:15p 827,392 Closures_Dy0_Lith.xls
09/17/2007 01:16p 824,320 Closures_Dy2_Lith.xls
09/17/2007 01:16p 824,832 Closures_Dy50_Lith.xls
09/17/2007 01:22p 24,064 stresses_Th_Lith.xls
09/17/2007 01:04p 1,067,008 Stress_Dy0_Lith.xls
09/17/2007 12:57p 1,066,496 Stress_Dy2_Lith.xls
08/01/2007 08:47a 374 checkplot2.txt
08/01/2007 03:04p 1,284 case1.txt
08/01/2007 01:25p 0 FC132545.tmp
08/01/2007 01:25p 49,152 FH132553.tmp
08/01/2007 02:59p 0 FC145939.tmp
08/01/2007 03:00p 3,162,112 FH150009.tmp
08/01/2007 03:00p 42 Fil_50.txt
08/01/2007 03:01p 0 FC150120.tmp
08/01/2007 03:01p 334 Fil_10.txt
08/01/2007 03:02p 3,162,112 FH150154.tmp
08/06/2007 09:25a 0 FC092502.tmp
08/06/2007 03:41p 4,051 stress_for_excel.dat
08/06/2007 04:22p 3,484 closure_for_excel.dat
08/09/2007 08:38a 387 eq_closure_for_excel.dat
08/06/2007 02:24p 3,162,112 FH142343.tmp
08/06/2007 03:34p 0 FC153431.tmp
08/06/2007 04:23p 25,791 stress.log
08/06/2007 04:23p 3,178,496 FH162339.tmp
08/07/2007 07:28a 0 FC072855.tmp
08/07/2007 08:15a 1,325,276 FH081507.tmp
08/07/2007 08:19a 0 FC081930.tmp
08/09/2007 08:12a 501 eq_stress_for_excel.dat
08/07/2007 09:33a 1,325,276 FH093335.tmp
09/17/2007 01:18p 896,000 Stress_Cr_Dy0_Lith.xls
09/17/2007 01:12p 1,092,096 Stress_Sp_Dy0_Lith.xls
08/07/2007 04:18p 7,027,547 gcukm230dy.2
08/07/2007 07:25p 8,060,687 gcukm250dy.2
08/07/2007 01:59p 5,318,243 gcukm210dy.2
08/07/2007 05:36p 7,030,943 gcukm230dy.50
08/08/2007 12:25a 8,063,279 gcukm250dy.50
08/07/2007 12:33p 5,321,639 gcukm210dy.50
08/08/2007 01:50p 0 FC135041.tmp
08/08/2007 01:51p 409,600 FH135128.tmp

```
08/08/2007  03:18p                 0 FC151802.tmp
08/08/2007  03:18p         1,325,276 FH151831.tmp
08/08/2007  03:19p                 0 FC151950.tmp
08/08/2007  03:20p            86,182 M210dy_crsig1_0.his
08/08/2007  03:20p            86,182 M210dy_spsig1_0.his
08/08/2007  03:20p           205,182 M230dy_crsig1_0.his
08/08/2007  03:20p           205,182 M230dy_spsig1_0.his
08/08/2007  03:20p         1,325,276 FH152021.tmp
08/08/2007  03:20p           277,086 M250dy_crsig1_0.his
08/08/2007  03:20p           262,162 M250dy_spsig1_0.his
08/09/2007  07:30a                 0 FC073035.tmp
08/09/2007  07:33a            86,126 M210dy_crsig1_50.his
08/09/2007  07:33a            86,126 M210dy_spsig1_50.his
08/09/2007  07:33a           205,182 M230dy_crsig1_50.his
08/09/2007  07:33a           205,182 M230dy_spsig1_50.his
08/09/2007  07:33a           277,086 M250dy_crsig1_50.his
08/09/2007  07:54a           277,086 M250dy_spsig1_50.his
08/09/2007  07:54a            86,126 M210dy_crsig1_2.his
08/09/2007  07:54a            86,126 M210dy_spsig1_2.his
08/09/2007  07:54a           205,182 M230dy_crsig1_2.his
08/09/2007  07:54a           205,182 M230dy_spsig1_2.his
08/09/2007  07:54a           277,142 M250dy_crsig1_2.his
08/09/2007  08:12a           277,142 M250dy_spsig1_2.his
08/09/2007  08:12a            86,126 m210dy_vc_2.his
08/09/2007  08:12a            86,126 m210dy_hc_2.his
08/09/2007  08:12a           205,182 m230dy_vc_2.his
08/09/2007  08:12a           205,182 m230dy_hc_2.his
08/09/2007  08:12a           277,142 m250dy_vc_2.his
08/09/2007  08:38a           277,142 m250dy_hc_2.his
08/09/2007  08:38a         1,325,276 FH083842.tmp
08/09/2007  08:38a            86,126 m210dy_vc_50.his
08/09/2007  08:38a            86,126 m210dy_hc_50.his
08/09/2007  08:38a           205,182 m230dy_vc_50.his
08/09/2007  08:38a           205,182 m230dy_hc_50.his
08/09/2007  08:38a           277,086 m250dy_vc_50.his
08/09/2007  08:39a           262,162 m250dy_hc_50.his
09/17/2007  01:10p         1,470,976 Stress_Dy50_Lith.xls
09/19/2007  03:30p               172 listfiles.dat
             115 File(s)    297,391,188 bytes
               2 Dir(s)  184,558,895,104 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Sensitivity on Ko=0.5\Litho\Ko=0.5\cat_1,3,5_sup_Input

09/19/2007  02:41p    <DIR>          .
09/19/2007  02:41p    <DIR>          ..
05/25/2007  03:20p             2,077 setup.fis
07/18/2007  08:59a               659 hiszones_50.fis
05/15/2007  07:41p               392 initemp.fis
05/15/2007  07:39p             3,408 makemovie.fis
08/07/2007  12:33p             1,865 driver.dat
05/15/2007  07:39p             2,152 relaxation.fis
08/07/2007  12:34p               987 seismic.dat
07/18/2007  09:20a             3,820 properties.fis
```

```
07/25/2007  08:19a             2,871 shake.fis
07/17/2007  05:02p               452 Shortcut to flacw_sp.exe.lnk
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:41p             1,628 thermal_50.dat
08/07/2007  12:35p             3,679 thermoprop.fis
05/15/2007  07:39p           203,437 vel_hori_5e-4.tab
05/15/2007  07:39p           195,677 vel_vert_5e-4.tab
06/22/2007  04:32p               630 bolt.dat
03/20/2007  10:08p             1,592 boltprop.fis
05/15/2007  07:39p             3,041 tunnel_b.dat
09/19/2007  03:30p               175 listfiles.dat
              19 File(s)        429,487 bytes
               2 Dir(s)  184,558,960,640 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Sensitivity on Ko=0.5\Litho\Ko=0.5\cat_1,3,5_sup_Output

09/19/2007  02:43p    <DIR>          .
09/19/2007  02:41p    <DIR>          ..
08/07/2007  01:30p         4,386,183 gcskm250th.0
08/08/2007  05:34a        13,117,375 gcskm210dy.50
08/07/2007  12:39p         3,899,275 gcskm210is.exv
08/07/2007  12:39p         3,790,915 gcskm210is.ini
08/07/2007  12:41p         4,215,991 gcskm210is.sup
08/07/2007  12:42p         4,321,407 gcskm210th.0
08/07/2007  12:43p         4,817,899 gcskm210th.1
08/07/2007  12:48p         7,981,487 gcskm210th.10
08/07/2007  12:43p         5,146,783 gcskm210th.2
08/07/2007  12:52p        11,162,343 gcskm210th.20
08/07/2007  12:56p        14,244,759 gcskm210th.30
08/07/2007  12:45p         6,205,739 gcskm210th.5
08/07/2007  01:04p        20,458,303 gcskm210th.50
08/07/2007  12:46p         6,932,063 gcskm210th.7
08/08/2007  08:07a         7,026,443 gcskm230dy.0
08/08/2007  10:40a         7,031,747 gcskm230dy.50
08/07/2007  01:04p         3,904,555 gcskm230is.exv
08/07/2007  01:04p         3,790,915 gcskm230is.ini
08/07/2007  01:05p         3,951,643 gcskm230th.0
08/07/2007  01:06p         4,214,287 gcskm230th.1
08/07/2007  01:11p         6,005,187 gcskm230th.10
08/07/2007  01:07p         4,444,163 gcskm230th.2
08/07/2007  01:15p         7,850,307 gcskm230th.20
08/07/2007  01:19p         9,688,411 gcskm230th.30
08/07/2007  01:09p         5,035,407 gcskm230th.5
08/07/2007  01:26p        13,293,043 gcskm230th.50
08/07/2007  01:09p         5,422,539 gcskm230th.7
08/08/2007  06:31p        13,113,703 gcskm250dy.0
08/09/2007  02:21a        13,118,179 gcskm250dy.50
08/07/2007  01:27p         3,912,235 gcskm250is.exv
08/07/2007  01:26p         3,790,915 gcskm250is.ini
08/07/2007  01:29p         4,229,791 gcskm250is.sup
08/07/2007  09:43p        13,113,703 gcskm210dy.0
08/07/2007  01:31p         4,881,811 gcskm250th.1
08/07/2007  01:37p         8,169,815 gcskm250th.10
```

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08/07/2007  01:32p         5,316,967 gcskm250th.2
08/07/2007  01:41p        11,365,359 gcskm250th.20
08/07/2007  01:45p        14,573,055 gcskm250th.30
08/07/2007  01:34p         6,374,195 gcskm250th.5
08/07/2007  01:53p        20,796,967 gcskm250th.50
08/07/2007  01:35p         7,127,303 gcskm250th.7
08/16/2007  12:27p               400 Shortcut to flacw_sp.exe.lnk
08/09/2007  01:44p                 0 FC134427.tmp
08/09/2007  01:45p           147,456 FH134506.tmp
08/09/2007  02:31p                 0 FC143151.tmp
08/09/2007  02:41p                 0 FH144118.tmp
08/09/2007  02:42p                 0 FC144234.tmp
08/10/2007  03:12p            25,779 flac.log
08/28/2007  07:19a               658 find_for.fis
08/27/2007  03:54p           827,392 Closures_Dy0_Lith.xls
08/09/2007  02:51p           311,296 FH145053.tmp
08/28/2007  09:53a           825,856 Closures_Dy2_Lith.xls
08/28/2007  07:37a               810 bolt_forces_for_excel.dat
08/27/2007  03:44p            24,064 stresses_Th_Lith.xls
08/10/2007  03:06p             3,484 closure_for_excel.dat
08/28/2007  09:55a         1,067,008 Stress_Dy0_Lith.xls
08/09/2007  08:38a               387 eq_closure_for_excel.dat
08/09/2007  08:12a               501 eq_stress_for_excel.dat
08/28/2007  09:54a           896,000 Stress_Cr_Dy0_Lith.xls
08/28/2007  10:25a         1,068,032 Stress_Dy50_Lith.xls
08/28/2007  10:09a         1,066,496 Stress_Dy2_Lith.xls
08/27/2007  03:53p           824,832 Closures_Dy50_Lith.xls
08/10/2007  03:27p             4,046 stress_for_excel.dat
08/28/2007  10:11a         1,092,096 Stress_Sp_Dy0_Lith.xls
08/27/2007  03:45p            26,112 Closure_Th_Lith_Supp.xls
08/10/2007  02:58p                 0 FC145757.tmp
09/17/2007  01:29p            24,064 Closure_Th_Lith.xls
06/29/2007  06:15a            13,731 Str.fin
08/28/2007  05:28p            31,181 bolt_force_km21_50yrdy.pcx
08/10/2007  03:29p            33,870 stress.log
08/10/2007  03:29p         5,636,096 FH152900.tmp
08/28/2007  04:52p            31,035 bolt_force_km21_50.pcx
08/28/2007  07:20a             3,746 bolt_force_km21.log
08/28/2007  07:38a             3,746 bolt_force_km25.log
08/28/2007  05:33p            31,411 bolt_force_km21_0yrdy.pcx
09/19/2007  03:31p               176 listfiles.dat
              76 File(s)    336,244,928 bytes
               2 Dir(s)  184,558,899,200 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Sensitivity on Ko=0.5\Nonlitho\k=0.5\cat_1,3,5_Input

09/19/2007  02:37p    <DIR>          .
09/19/2007  02:39p    <DIR>          ..
05/15/2007  07:39p             3,408 makemovie.fis
05/15/2007  03:11p             3,679 thermoprop.fis
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:39p             2,152 relaxation.fis
05/15/2007  07:39p           203,437 vel_hori_5e-4.tab
```

```
05/15/2007  07:39p           195,677 vel_vert_5e-4.tab
05/15/2007  07:41p               392 initemp.fis
05/15/2007  07:41p             1,628 thermal_50.dat
05/25/2007  03:20p             2,077 setup.fis
07/17/2007  12:59p             3,016 tunnel.dat
07/18/2007  08:59a               659 hiszones_50.fis
07/25/2007  07:58a             2,871 shake.fis
07/18/2007  09:20a             3,820 properties.fis
07/19/2007  08:56a             1,825 driver.dat
07/19/2007  08:58a               987 seismic.dat
09/19/2007  03:32p               173 listfiles.dat
              16 File(s)        426,746 bytes
               2 Dir(s)  184,549,650,432 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Sensitivity on Ko=0.5\Nonlitho\k=0.5\cat_1,3,5_Output

09/19/2007  02:39p    <DIR>          .
09/19/2007  02:39p    <DIR>          ..
07/25/2007  08:49a         8,039,691 gcukm150th.20
07/25/2007  08:04a         3,948,715 gcukm110is.exv
07/25/2007  08:02a         3,790,915 gcukm110is.ini
07/25/2007  08:05a         3,992,275 gcukm110th.0
07/25/2007  08:06a         4,260,463 gcukm110th.1
07/25/2007  08:10a         6,043,803 gcukm110th.10
07/25/2007  08:06a         4,485,299 gcukm110th.2
07/25/2007  08:15a         7,886,403 gcukm110th.20
07/25/2007  08:19a         9,717,955 gcukm110th.30
07/25/2007  08:08a         5,074,023 gcukm110th.5
07/25/2007  08:19a         9,752,251 gcukm110th.50
07/25/2007  08:09a         5,462,667 gcukm110th.7
07/25/2007  05:54p         8,005,715 gcukm130dy.0
07/25/2007  08:20a         3,956,875 gcukm130is.exv
07/25/2007  08:19a         3,790,915 gcukm130is.ini
07/25/2007  08:21a         4,008,499 gcukm130th.0
07/25/2007  08:22a         4,282,231 gcukm130th.1
07/25/2007  08:27a         6,102,363 gcukm130th.10
07/25/2007  08:23a         4,515,131 gcukm130th.2
07/25/2007  08:31a         7,956,555 gcukm130th.20
07/25/2007  08:36a         9,824,395 gcukm130th.30
07/25/2007  08:25a         5,115,447 gcukm130th.5
07/25/2007  08:36a         9,844,075 gcukm130th.50
07/25/2007  08:26a         5,517,699 gcukm130th.7
07/26/2007  02:27a         9,315,431 gcukm150dy.0
07/25/2007  08:37a         3,967,435 gcukm150is.exv
07/25/2007  08:36a         3,790,915 gcukm150is.ini
07/25/2007  08:38a         4,026,619 gcukm150th.0
07/25/2007  08:40a         4,308,415 gcukm150th.1
07/25/2007  08:45a         6,179,955 gcukm150th.10
07/25/2007  08:40a         4,551,899 gcukm150th.2
07/25/2007  11:34a         6,942,023 gcukm110dy.0
07/25/2007  08:53a         9,905,515 gcukm150th.30
07/25/2007  08:42a         5,164,311 gcukm150th.5
07/25/2007  08:54a         9,930,235 gcukm150th.50
```

07/25/2007	08:43a	5,579,667	gcukm150th.7
09/10/2007	02:15p	400	Shortcut to flacw_sp.exe.lnk
08/07/2007	03:04p	39,670	flac.eps
07/25/2007	02:14p	6,946,523	gcukm110dy.50
07/25/2007	09:34p	8,010,215	gcukm130dy.50
07/26/2007	07:21a	9,319,127	gcukm150dy.50
08/07/2007	02:58p	0	FC145808.tmp
08/07/2007	03:06p	49,152	FH150653.tmp
08/07/2007	03:08p	38,642	fs_RMC3_non_ex.bmp
08/07/2007	03:09p	0	FC150924.tmp
08/08/2007	07:34a	25,779	flac.log
08/07/2007	03:11p	39,788	fs_RMC1_non_ex.bmp
08/07/2007	03:13p	36,624	fs_RMC5_non_ex.bmp
08/20/2007	11:19a	24,064	Closure_Th_Nonlith.xls
08/07/2007	03:26p	29,412	cont_RMC3_non_th0.bmp
08/07/2007	04:27p	2,031,616	FH162730.tmp
08/07/2007	03:30p	26,354	cont_RMC3_non_th1.bmp
08/07/2007	03:33p	26,232	cont_RMC3_non_th2.bmp
08/07/2007	03:36p	26,050	cont_RMC3_non_th5.bmp
08/07/2007	03:38p	26,124	cont_RMC3_non_th7.bmp
08/07/2007	03:41p	25,910	cont_RMC3_non_th10.bmp
08/07/2007	03:43p	28,528	cont_RMC3_non_th20.bmp
08/07/2007	03:45p	29,490	cont_RMC3_non_th30.bmp
08/07/2007	03:56p	29,446	Cont_RMC3_non_th50.bmp
08/07/2007	04:21p	5,803	stress_for_excel.dat
08/07/2007	04:23p	3,484	closure_for_excel.dat
08/27/2007	02:11p	1,152,512	Closures_Dy0_nonlith.xls
08/27/2007	02:12p	1,151,488	Closures_Dy2_Nonlith.xls
08/27/2007	02:13p	1,151,488	Closures_Dy50_nonlith.xls
08/20/2007	11:33a	23,552	stresses_Th_Nonlith.xls
08/27/2007	02:18p	1,147,904	Stress_Dy0_Nonlith.xls
08/27/2007	02:21p	2,230,272	Stress_Dy_2_Nonlith.xls
08/20/2007	11:39a	1,211,904	Stress_Dy_50_Nonlith.xls
08/07/2007	04:27p	50,808	stress.log
08/27/2007	02:15p	793,088	Stress_Sp_Dy50_Nonlith.xls
08/08/2007	07:33a	0	FC073258.tmp
08/08/2007	09:13a	38,322	fs_RMC1_dy0_non.bmp
08/08/2007	09:17a	37,896	fs_RMC3_dy0_non.bmp
08/08/2007	09:21a	36,410	fs_RMC5_dy0_non.bmp
08/08/2007	09:27a	36,976	fs_RMC1_dy50_non.bmp
08/08/2007	09:30a	38,178	fs_RMC3_dy50_non.bmp
08/08/2007	09:33a	37,666	fs_RMC5_dy50_non.bmp
08/08/2007	09:38a	199,302	M110dy_crsig1_0.his
08/08/2007	09:38a	199,302	M110dy_spsig1_0.his
08/08/2007	09:38a	273,390	M130dy_crsig1_0.his
08/08/2007	09:38a	273,390	M130dy_spsig1_0.his
08/08/2007	09:38a	364,614	M150dy_crsig1_0.his
08/08/2007	10:13a	364,614	M150dy_spsig1_0.his
08/09/2007	09:08a	1,575,424	Stress_Cr_Dy0_Nonlith.xls
08/09/2007	09:51a	512	eq50_stress_for_excel.dat
08/09/2007	08:55a	0	FC085533.tmp
08/08/2007	10:18a	1,336,832	Stress_Cr_Dy50_Nonlith.xls
08/08/2007	10:38a	199,302	m110dy_vc_0.his
08/08/2007	10:39a	199,302	m110dy_hc_0.his
08/08/2007	10:39a	273,390	m130dy_vc_0.his
08/08/2007	10:39a	273,390	m130dy_hc_0.his

08/08/2007 10:39a 364,614 m150dy_vc_0.his
08/08/2007 12:13p 364,614 m150dy_hc_0.his
08/09/2007 10:15a 378 eq50_closure_for_excel.dat
08/08/2007 12:13p 199,302 m110dy_vc_50.his
08/08/2007 12:13p 199,302 m110dy_hc_50.his
08/08/2007 12:13p 273,390 m130dy_vc_50.his
08/08/2007 12:13p 273,390 m130dy_hc_50.his
08/08/2007 12:13p 364,558 m150dy_vc_50.his
08/08/2007 12:13p 360,466 m150dy_hc_50.his
08/08/2007 12:41p 992,256 Stress_Sp_Dy0_Nonlith.xls
08/07/2007 07:01p 8,007,623 gcukm130dy.2
08/07/2007 03:22p 6,942,323 gcukm110dy.2
08/07/2007 11:52p 9,316,535 gcukm150dy.2
08/09/2007 08:58a 38,520 fs_RMC1_dy2_non.bmp
08/09/2007 09:00a 39,300 fs_RMC3_dy2_non.bmp
08/09/2007 09:02a 1,736,704 FH090152.tmp
08/09/2007 09:03a 43,854 fs_RMC5_dy2_non.bmp
08/09/2007 09:34a 0 FC093422.tmp
08/09/2007 09:34a 199,246 M110dy_crsig1_2.his
08/09/2007 09:34a 199,246 M110dy_spsig1_2.his
08/09/2007 09:34a 273,446 M130dy_crsig1_2.his
08/09/2007 09:34a 273,446 M130dy_spsig1_2.his
08/09/2007 09:34a 364,614 M150dy_crsig1_2.his
08/09/2007 09:51a 364,614 M150dy_spsig1_2.his
08/09/2007 09:51a 1,743,892 FH095127.tmp
08/09/2007 09:55a 0 FC095549.tmp
08/09/2007 09:56a 199,302 M110dy_crsig1_50.his
08/09/2007 09:56a 199,302 M110dy_spsig1_50.his
08/09/2007 10:16a 1,744,160 FH101620.tmp
08/09/2007 09:56a 273,390 M130dy_crsig1_50.his
08/09/2007 09:56a 273,390 M130dy_spsig1_50.his
08/09/2007 09:56a 364,558 M150dy_crsig1_50.his
08/09/2007 10:16a 364,558 M150dy_spsig1_50.his
08/09/2007 10:16a 199,246 m110dy_vc_2.his
08/09/2007 10:16a 199,246 m110dy_hc_2.his
08/09/2007 10:16a 273,446 m130dy_vc_2.his
08/09/2007 10:16a 273,446 m130dy_hc_2.his
08/09/2007 10:16a 364,614 m150dy_vc_2.his
08/09/2007 10:16a 360,466 m150dy_hc_2.his
09/19/2007 03:32p 7,396 listfiles.dat
09/10/2007 02:20p 8,589 closure_km15.log
09/10/2007 02:19p 1,353 closure_for_excel_A.dat
09/10/2007 02:19p 0 FC151955.tmp
09/10/2007 02:16p 8,589 closure_km11.log
135 File(s) 298,577,125 bytes
2 Dir(s) 184,540,332,032 bytes free

Volume in drive D is New Volume
Volume Serial Number is 683C-0946

Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Sensitivity on Ko=0.5\Nonlitho\k=0.5\cat_1,3,5_sup_Input

09/19/2007 02:39p <DIR> .
09/19/2007 02:39p <DIR> ..
08/07/2007 12:35p 3,679 thermoprop.fis
03/20/2007 10:08p 1,592 boltprop.fis

```
08/07/2007  02:32p             1,865 driver.dat
07/18/2007  08:59a               659 hiszones_50.fis
05/15/2007  07:41p               392 initemp.fis
05/15/2007  07:39p             3,408 makemovie.fis
06/22/2007  04:32p               630 bolt.dat
05/15/2007  07:39p             2,152 relaxation.fis
08/07/2007  02:33p               987 seismic.dat
05/25/2007  03:20p             2,077 setup.fis
07/25/2007  08:19a             2,871 shake.fis
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:41p             1,628 thermal_50.dat
07/18/2007  09:20a             3,820 properties.fis
05/15/2007  07:39p             3,041 tunnel_b.dat
05/15/2007  07:39p           203,437 vel_hori_5e-4.tab
05/15/2007  07:39p           195,677 vel_vert_5e-4.tab
09/19/2007  03:33p               177 listfiles.dat
              18 File(s)        429,037 bytes
               2 Dir(s)  184,540,393,472 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD1\Sensitivity on Ko=0.5\Nonlitho\k=0.5\cat_1,3,5_sup_Output

09/19/2007  02:40p    <DIR>          .
09/19/2007  02:39p    <DIR>          ..
08/07/2007  02:39p         5,298,295 gcskm110th.2
08/07/2007  02:33p         3,790,915 gcskm110is.ini
08/07/2007  02:34p         3,900,235 gcskm110is.exv
08/07/2007  02:35p         4,239,631 gcskm110is.sup
08/07/2007  02:37p         4,359,735 gcskm110th.0
08/07/2007  02:38p         4,854,499 gcskm110th.1
08/28/2007  07:42a               400 Shortcut to flacw_sp.exe.lnk
08/07/2007  02:40p         6,352,931 gcskm110th.5
08/07/2007  02:42p         7,200,215 gcskm110th.7
08/07/2007  02:44p         8,242,727 gcskm110th.10
08/07/2007  02:48p        11,452,959 gcskm110th.20
08/07/2007  02:52p        14,656,335 gcskm110th.30
08/07/2007  02:52p        14,684,503 gcskm110th.50
08/07/2007  02:52p         3,790,915 gcskm130is.ini
08/07/2007  02:53p         3,899,755 gcskm130is.exv
08/07/2007  02:54p         3,951,427 gcskm130th.0
08/07/2007  02:55p         4,222,639 gcskm130th.1
08/07/2007  02:56p         4,460,579 gcskm130th.2
08/07/2007  02:57p         5,060,391 gcskm130th.5
08/07/2007  02:58p         5,462,643 gcskm130th.7
08/07/2007  03:00p         6,046,803 gcskm130th.10
08/07/2007  03:04p         7,901,499 gcskm130th.20
08/07/2007  03:08p         9,755,227 gcskm130th.30
08/07/2007  03:08p         9,784,483 gcskm130th.50
08/07/2007  03:08p         3,790,915 gcskm150is.ini
08/07/2007  03:09p         3,895,915 gcskm150is.exv
08/07/2007  03:10p         4,194,151 gcskm150is.sup
08/07/2007  03:12p         4,473,231 gcskm150th.0
08/07/2007  03:13p         4,970,587 gcskm150th.1
08/07/2007  03:14p         5,414,383 gcskm150th.2
```

```
08/07/2007  03:15p         6,465,563 gcskm150th.5
08/07/2007  03:17p         7,258,415 gcskm150th.7
08/07/2007  03:19p         8,300,063 gcskm150th.10
08/07/2007  03:23p        11,505,111 gcskm150th.20
08/07/2007  03:27p        14,712,807 gcskm150th.30
08/07/2007  03:27p        14,756,527 gcskm150th.50
08/07/2007  11:09p        13,113,703 gcskm110dy.0
08/08/2007  06:51a        13,117,375 gcskm110dy.50
08/08/2007  10:12a         8,005,715 gcskm130dy.0
08/08/2007  01:32p         8,011,019 gcskm130dy.50
08/08/2007  09:15p        13,112,899 gcskm150dy.0
08/09/2007  04:57a        13,118,179 gcskm150dy.50
06/29/2007  06:15a            13,731 Str.fin
08/28/2007  07:19a               658 find_for.fis
08/28/2007  07:47a               810 bolt_forces_for_excel.dat
08/28/2007  07:48a             3,746 bolt_force_km11.log
08/28/2007  04:56p            30,777 bolt_force_km11_50.pcx
08/28/2007  07:42a             3,746 bolt_force_km15.log
08/28/2007  05:43p            30,315 bolt_force_km11_0yrdy.pcx
08/28/2007  05:47p            30,935 bolt_force_km11_50yrdy.pcx
09/19/2007  03:34p               178 listfiles.dat
              51 File(s)    311,701,195 bytes
               2 Dir(s)  184,540,393,472 bytes free
```

List of Files in Attachment II (DVD 2)

```
Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\GRC

09/19/2007  03:35p    <DIR>          .
09/19/2007  02:57p    <DIR>          ..
09/19/2007  09:21a            28,160 ground reaction curves_EmplDrift.xls
09/19/2007  03:35p               124 listfiles.dat
               2 File(s)         28,284 bytes
               2 Dir(s)  184,540,389,376 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5\Input

09/19/2007  03:35p    <DIR>          .
09/19/2007  02:24p    <DIR>          ..
05/15/2007  07:39p             2,152 relaxation.fis
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:39p             3,408 makemovie.fis
03/20/2007  10:08p               659 hiszones_50.fis
05/15/2007  07:39p           203,437 vel_hori_5e-4.tab
05/15/2007  07:39p           195,677 vel_vert_5e-4.tab
05/15/2007  07:41p               392 initemp.fis
05/15/2007  07:41p             1,628 thermal_50.dat
05/25/2007  03:20p             2,077 setup.fis
07/17/2007  12:59p             3,016 tunnel.dat
```

```
07/18/2007  09:28a             3,820 properties.fis
07/19/2007  09:23a             2,427 driver.dat
07/19/2007  09:27a             1,453 seismic.dat
07/25/2007  08:25a             3,679 thermoprop.fis
07/25/2007  08:26a             2,871 shake.fis
09/19/2007  03:35p               143 listfiles.dat
              16 File(s)        427,784 bytes
               2 Dir(s)  184,540,377,088 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5\Output

09/19/2007  03:36p    <DIR>          .
09/19/2007  02:24p    <DIR>          ..
07/25/2007  09:29a         9,815,347 gcuku150th.50
07/25/2007  02:18p         6,945,719 gcukl110dy.50
07/25/2007  08:28a         3,965,035 gcukl110is.exv
07/25/2007  08:26a         3,790,915 gcukl110is.ini
07/25/2007  08:28a         4,017,163 gcukl110th.0
07/25/2007  08:29a         4,286,359 gcukl110th.1
07/25/2007  08:34a         6,080,283 gcukl110th.10
07/25/2007  08:30a         4,511,699 gcukl110th.2
07/25/2007  08:38a         7,923,891 gcukl110th.20
07/25/2007  08:42a         9,763,003 gcukl110th.30
07/25/2007  08:32a         5,100,927 gcukl110th.5
07/25/2007  08:42a         9,800,827 gcukl110th.50
07/25/2007  08:33a         5,497,635 gcukl110th.7
07/25/2007  11:32p         9,315,431 gcukl150dy.0
07/26/2007  03:56a         9,319,931 gcukl150dy.50
07/25/2007  08:43a         4,001,515 gcukl150is.exv
07/25/2007  08:42a         3,790,915 gcukl150is.ini
07/25/2007  08:44a         4,059,235 gcukl150th.0
07/25/2007  08:45a         4,338,511 gcukl150th.1
07/25/2007  08:50a         6,208,035 gcukl150th.10
07/25/2007  08:46a         4,581,491 gcukl150th.2
07/25/2007  08:54a         8,067,771 gcukl150th.20
07/25/2007  08:58a         9,935,611 gcukl150th.30
07/25/2007  08:48a         5,194,407 gcukl150th.5
07/25/2007  08:59a         9,960,835 gcukl150th.50
07/25/2007  08:49a         5,609,259 gcukl150th.7
07/25/2007  04:43p         6,941,219 gcuku110dy.0
07/25/2007  07:08p         6,945,719 gcuku110dy.50
07/25/2007  08:59a         3,882,955 gcuku110is.exv
07/25/2007  08:59a         3,790,915 gcuku110is.ini
07/25/2007  09:00a         3,931,555 gcuku110th.0
07/25/2007  09:01a         4,187,143 gcuku110th.1
07/25/2007  09:05a         5,954,355 gcuku110th.10
07/25/2007  09:02a         4,410,467 gcuku110th.2
07/25/2007  09:09a         7,795,947 gcuku110th.20
07/25/2007  09:13a         9,626,995 gcuku110th.30
07/25/2007  09:03a         4,994,151 gcuku110th.5
07/25/2007  09:13a         9,653,731 gcuku110th.50
07/25/2007  09:04a         5,376,747 gcuku110th.7
07/26/2007  08:21a         9,315,431 gcuku150dy.0
```

07/26/2007 12:47p 9,319,931 gcuku150dy.50
07/25/2007 09:14a 3,877,195 gcuku150is.exv
07/25/2007 09:13a 3,790,915 gcuku150is.ini
07/25/2007 09:15a 3,935,419 gcuku150th.0
07/25/2007 09:16a 4,215,199 gcuku150th.1
07/25/2007 09:21a 6,067,587 gcuku150th.10
07/25/2007 09:17a 4,458,683 gcuku150th.2
07/25/2007 09:25a 7,926,315 gcuku150th.20
07/25/2007 09:29a 9,793,651 gcuku150th.30
07/25/2007 09:18a 5,064,039 gcuku150th.5
07/25/2007 11:53a 6,942,023 gcukl110dy.0
07/25/2007 09:19a 5,470,323 gcuku150th.7
08/10/2007 02:19p 400 Shortcut to flacw_sp.exe.lnk
07/16/2007 08:06a 774 Ps3d.fis
09/19/2007 03:36p 144 listfiles.dat
08/10/2007 02:22p 787 ydisp_gcukl1_exv
08/24/2007 07:41a 38,400 fs_EmpDrt.xls
08/10/2007 02:24p 787 ydisp_gcukl5_exv
08/10/2007 03:29p 787 ydisp_gcuku1_exv
08/10/2007 03:30p 787 ydisp_gcuku5_exv
08/11/2007 12:24p 2,296 stress_for_excel.dat
08/11/2007 11:21a 255 eq_closure_for_excel.dat
08/11/2007 10:13a 1,353 closure_for_excel.dat
08/11/2007 10:08a 8,589 closure_ku11.log
08/11/2007 10:10a 8,589 closure_ku15.log
08/11/2007 10:12a 8,589 closure_kl15.log
08/11/2007 10:13a 8,589 closure_kl11.log
08/11/2007 11:15a 364,614 U150dy_vc_50.his
08/11/2007 11:15a 364,614 U150dy_hc_50.his
08/11/2007 11:15a 364,614 U150dy_vc_0.his
08/11/2007 11:17a 364,614 U150dy_hc_0.his
08/11/2007 11:17a 199,246 U110dy_vc_50.his
08/11/2007 11:17a 199,246 U110dy_hc_50.his
08/11/2007 11:17a 199,246 U110dy_vc_0.his
08/11/2007 11:19a 199,246 U110dy_hc_0.his
08/11/2007 11:19a 199,246 L110dy_vc_50.his
08/11/2007 11:19a 199,246 L110dy_hc_50.his
08/11/2007 11:19a 199,302 L110dy_vc_0.his
08/11/2007 11:21a 199,302 L110dy_hc_0.his
08/11/2007 11:21a 364,614 L150dy_vc_50.his
08/11/2007 11:21a 364,614 L150dy_hc_50.his
08/11/2007 11:21a 364,614 L150dy_vc_0.his
08/11/2007 11:22a 364,614 L150dy_hc_0.his
08/11/2007 12:31p 534 eq_stress_for_excel.dat
08/11/2007 12:18p 16,932 stress_ku11.log
08/11/2007 12:20p 16,932 stress_ku15.log
08/11/2007 12:22p 16,932 stress_kl15.log
08/11/2007 12:24p 16,932 stress_kl11.log
08/11/2007 12:28p 199,302 L110dy_crsig1_0.his
08/11/2007 12:28p 199,302 L110dy_spsig1_0.his
08/11/2007 12:28p 364,614 L150dy_crsig1_0.his
08/11/2007 12:28p 364,614 L150dy_spsig1_0.his
08/11/2007 12:28p 199,246 L110dy_crsig1_50.his
08/11/2007 12:28p 199,246 L110dy_spsig1_50.his
08/11/2007 12:28p 364,614 L150dy_crsig1_50.his
08/11/2007 12:31p 364,614 L150dy_spsig1_50.his

```
08/11/2007  12:31p           199,246 U110dy_crsig1_0.his
08/11/2007  12:31p           199,246 U110dy_spsig1_0.his
08/11/2007  12:31p           364,614 U150dy_crsig1_0.his
08/11/2007  12:31p           364,614 U150dy_spsig1_0.his
08/11/2007  12:31p           199,246 U110dy_crsig1_50.his
08/11/2007  12:31p           199,246 U110dy_spsig1_50.his
08/11/2007  12:31p           364,614 U150dy_crsig1_50.his
08/11/2007  12:32p           364,614 U150dy_spsig1_50.his
08/11/2007  02:12p            37,298 kl11_SS_0.pcx
08/11/2007  02:16p            37,663 kl11_SS_50.pcx
08/11/2007  02:58p            39,766 ku11_SS_0.pcx
08/11/2007  03:03p            41,263 ku11_SS_50.pcx
08/11/2007  03:12p            36,722 kl15_SS_0.pcx
08/11/2007  03:17p            36,205 kl15_SS_50.pcx
08/11/2007  03:22p            36,205 ku15_SS_0.pcx
08/11/2007  03:27p            39,147 ku15_SS_50.pcx
07/16/2007  08:06a             1,625 MCFOS.FIS
08/13/2007  07:27a             1,336 FSindex_for_excel.dat
08/11/2007  04:54p            10,270 fs_kl15_3m.log
08/13/2007  07:21a            11,323 fs_ku15_3m.log
08/13/2007  07:25a            10,270 fs_ku11_3m.log
08/13/2007  07:27a            10,270 fs_kl11_3m.log
             118 File(s)    333,071,095 bytes
               2 Dir(s)  184,540,291,072 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_25+75NL\Input

09/19/2007  03:37p    <DIR>          .
09/19/2007  02:20p    <DIR>          ..
03/20/2007  11:16p               658 temphis_50.tab
03/21/2007  12:48a               659 hiszones_50.fis
03/21/2007  12:48a               392 initemp.fis
03/21/2007  01:44a             3,408 makemovie.fis
03/21/2007  12:48a             2,154 relaxation.fis
03/21/2007  12:48a             2,070 setup.fis
03/21/2007  12:48a             2,874 shake.fis
08/14/2007  12:28p               452 Shortcut to flacw_sp.exe.lnk
07/14/2007  02:52p             3,823 properties.fis
03/20/2007  11:16p             1,518 thermal_50.dat
08/14/2007  09:53a             3,679 thermoprop.fis
03/21/2007  12:48a             3,018 tunnel.dat
03/21/2007  01:44a           203,437 vel_hori_5e-4.tab
03/21/2007  01:44a           195,677 vel_vert_5e-4.tab
08/14/2007  12:26p             2,430 driver_mn.dat
08/14/2007  12:28p               854 seismic_mn.dat
09/19/2007  03:37p               151 listfiles.dat
              17 File(s)        427,254 bytes
               2 Dir(s)  184,540,385,280 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_25+75NL\Output
```

```
09/19/2007  03:37p    <DIR>          .
09/19/2007  02:20p    <DIR>          ..
08/14/2007  12:52p         3,790,855 gcuku150is.ini
08/14/2007  12:30p         3,964,991 gcukl110is.exv
08/14/2007  12:29p         3,790,855 gcukl110is.ini
08/14/2007  12:30p         3,980,515 gcukl110th.0
08/14/2007  12:31p         4,098,459 gcukl110th.1
08/14/2007  12:37p         6,539,975 gcukl110th.100
08/14/2007  12:33p         4,846,943 gcukl110th.25
08/14/2007  12:34p         5,358,547 gcukl110th.40
08/14/2007  07:23p         9,316,583 gcukl150dy.100
08/14/2007  12:45p         4,001,471 gcukl150is.exv
08/14/2007  12:44p         3,790,855 gcukl150is.ini
08/14/2007  12:46p         4,017,547 gcukl150th.0
08/14/2007  12:46p         4,150,107 gcukl150th.1
08/14/2007  12:52p         6,667,727 gcukl150th.100
08/14/2007  12:48p         4,910,183 gcukl150th.25
08/14/2007  12:50p         5,447,491 gcukl150th.40
08/14/2007  09:39p         6,942,371 gcuku110dy.100
08/14/2007  12:37p         3,882,911 gcuku110is.exv
08/14/2007  12:37p         3,790,855 gcuku110is.ini
08/14/2007  12:38p         3,898,435 gcuku110th.0
08/14/2007  12:38p         4,008,819 gcuku110th.1
08/14/2007  12:44p         6,413,543 gcuku110th.100
08/14/2007  12:40p         4,756,799 gcuku110th.25
08/14/2007  12:41p         5,268,403 gcuku110th.40
08/15/2007  01:47a         9,316,583 gcuku150dy.100
08/14/2007  12:53p         3,877,151 gcuku150is.exv
08/14/2007  03:16p         6,942,371 gcukl110dy.100
08/14/2007  12:53p         3,893,227 gcuku150th.0
08/14/2007  12:54p         4,021,755 gcuku150th.1
08/14/2007  01:00p         6,523,247 gcuku150th.100
08/14/2007  12:56p         4,775,279 gcuku150th.25
08/14/2007  12:57p         5,306,035 gcuku150th.40
08/15/2007  01:21p               400 Shortcut to flacw_sp.exe.lnk
08/15/2007  01:26p               741 closure_for_excel.dat
08/16/2007  07:42a             1,840 flac.log
09/19/2007  03:37p               152 listfiles.dat
08/15/2007  01:21p             4,769 closure_ku11.log
08/15/2007  01:23p             4,769 closure_ku15.log
08/15/2007  01:25p             4,769 closure_kl15.log
08/15/2007  01:27p             4,769 closure_kl11.log
08/15/2007  02:31p               532 eq_closure_for_excel.dat
08/16/2007  08:03a             1,477 stress_for_excel.dat
08/15/2007  02:34p           364,614 U150dy_vc_100.his
08/15/2007  02:34p           364,614 U150dy_hc_100.his
08/15/2007  02:34p           364,614 L150dy_vc_100.his
08/15/2007  02:34p           364,614 L150dy_hc_100.his
08/15/2007  02:34p           199,246 U110dy_vc_100.his
08/15/2007  02:35p           199,246 U110dy_hc_100.his
08/15/2007  02:35p           199,246 L110dy_vc_100.his
08/15/2007  02:35p           199,246 L110dy_hc_100.his
08/16/2007  07:54a             9,224 stress_kl11.log
08/16/2007  08:00a             9,224 stress_kl15.log
08/16/2007  08:02a             9,224 stress_ku15.log
```

```
08/16/2007  08:04a           9,224 stress_ku11.log
08/16/2007  09:16a             554 eq_stress_for_excel.dat
08/16/2007  09:19a         199,246 L110dy_crsig1_100.his
08/16/2007  09:19a         199,246 L110dy_spsig1_100.his
08/16/2007  09:19a         364,614 L150dy_crsig1_100.his
08/16/2007  09:19a         364,614 L150dy_spsig1_100.his
08/16/2007  09:19a         199,246 U110dy_crsig1_100.his
08/16/2007  09:19a         199,246 U110dy_spsig1_100.his
08/16/2007  09:19a         364,614 U150dy_crsig1_100.his
08/16/2007  09:19a         364,614 U150dy_spsig1_100.his
              63 File(s)    166,863,436 bytes
               2 Dir(s)  184,540,381,184 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_50+50NL\Input

09/19/2007  03:38p    <DIR>          .
09/19/2007  02:18p    <DIR>          ..
03/21/2007  12:48a             392 initemp.fis
03/21/2007  12:48a             659 hiszones_50.fis
08/14/2007  11:25a           2,430 driver_mn.dat
03/21/2007  01:44a           3,408 makemovie.fis
07/14/2007  02:52p           3,823 properties.fis
03/21/2007  12:48a           2,154 relaxation.fis
08/14/2007  11:27a             854 seismic_mn.dat
03/21/2007  12:48a           2,070 setup.fis
03/21/2007  12:48a           2,874 shake.fis
03/21/2007  12:48a           1,926 temphis_50.tab
03/21/2007  12:48a           1,515 thermal_50.dat
08/14/2007  09:53a           3,679 thermoprop.fis
03/21/2007  12:48a           3,018 tunnel.dat
03/21/2007  01:44a         203,437 vel_hori_5e-4.tab
03/21/2007  01:44a         195,677 vel_vert_5e-4.tab
09/19/2007  03:38p             151 listfiles.dat
              16 File(s)        428,067 bytes
               2 Dir(s)  184,540,377,088 bytes free

Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_50+50NL\Output

09/19/2007  03:39p    <DIR>          .
09/19/2007  02:18p    <DIR>          ..
08/14/2007  12:30p       6,355,399 gcuku150th.58
08/14/2007  11:30a       3,964,991 gcukl110is.exv
08/14/2007  11:29a       3,790,855 gcukl110is.ini
08/14/2007  11:32a       4,098,547 gcukl110th.1
08/14/2007  11:34a       4,514,431 gcukl110th.10
08/14/2007  11:45a       7,398,791 gcukl110th.100
08/14/2007  11:32a       4,174,155 gcukl110th.2
08/14/2007  11:35a       4,857,691 gcukl110th.20
08/14/2007  11:36a       5,195,911 gcukl110th.30
08/14/2007  11:33a       4,317,315 gcukl110th.5
```

08/14/2007	11:39a	5,975,879	gcukl110th.50
08/14/2007	11:39a	6,082,303	gcukl110th.52
08/14/2007	11:40a	6,271,879	gcukl110th.58
08/14/2007	11:41a	6,354,111	gcukl110th.60
08/14/2007	11:41a	6,505,383	gcukl110th.65
08/14/2007	11:42a	6,657,167	gcukl110th.70
08/14/2007	11:43a	6,811,463	gcukl110th.75
08/14/2007	11:44a	6,965,767	gcukl110th.80
08/14/2007	07:55p	9,324,011	gcukl150dy.100
08/14/2007	12:01p	4,001,471	gcukl150is.exv
08/14/2007	12:00p	3,790,855	gcukl150is.ini
08/14/2007	12:03p	4,150,147	gcukl150th.1
08/14/2007	12:05p	4,622,479	gcukl150th.10
08/14/2007	12:19p	7,778,495	gcukl150th.100
08/14/2007	12:03p	4,246,419	gcukl150th.2
08/14/2007	12:06p	4,977,835	gcukl150th.20
08/14/2007	12:07p	5,337,223	gcukl150th.30
08/14/2007	12:04p	4,407,723	gcukl150th.5
08/14/2007	12:11p	6,207,407	gcukl150th.50
08/14/2007	12:12p	6,331,471	gcukl150th.52
08/14/2007	12:13p	6,532,639	gcukl150th.58
08/14/2007	12:13p	6,639,063	gcukl150th.60
08/14/2007	12:14p	6,813,015	gcukl150th.65
08/14/2007	12:15p	6,973,367	gcukl150th.70
08/14/2007	12:16p	7,141,775	gcukl150th.75
08/14/2007	12:17p	7,309,687	gcukl150th.80
08/14/2007	10:30p	6,949,799	gcuku110dy.100
08/14/2007	11:46a	3,882,911	gcuku110is.exv
08/14/2007	11:45a	3,790,855	gcuku110is.ini
08/14/2007	11:47a	4,008,403	gcuku110th.1
08/14/2007	11:49a	4,402,615	gcuku110th.10
08/14/2007	11:59a	7,211,375	gcuku110th.100
08/14/2007	11:47a	4,077,459	gcuku110th.2
08/14/2007	11:50a	4,739,323	gcuku110th.20
08/14/2007	11:51a	5,063,935	gcuku110th.30
08/14/2007	11:48a	4,213,059	gcuku110th.5
08/14/2007	11:54a	5,825,759	gcuku110th.50
08/14/2007	11:54a	5,927,647	gcuku110th.52
08/14/2007	11:55a	6,110,671	gcuku110th.58
08/14/2007	11:55a	6,187,359	gcuku110th.60
08/14/2007	11:56a	6,331,071	gcuku110th.65
08/14/2007	11:57a	6,483,863	gcuku110th.70
08/14/2007	11:57a	6,632,111	gcuku110th.75
08/14/2007	11:58a	6,777,343	gcuku110th.80
08/15/2007	12:31p	9,324,011	gcuku150dy.100
08/14/2007	12:19p	3,877,151	gcuku150is.exv
08/14/2007	12:19p	3,790,855	gcuku150is.ini
08/14/2007	12:21p	4,027,843	gcuku150th.1
08/14/2007	12:23p	4,486,567	gcuku150th.10
08/14/2007	12:36p	7,556,903	gcuku150th.100
08/14/2007	12:21p	4,122,099	gcuku150th.2
08/14/2007	12:24p	4,839,403	gcuku150th.20
08/14/2007	12:25p	5,190,223	gcuku150th.30
08/14/2007	12:22p	4,275,843	gcuku150th.5
08/14/2007	12:29p	6,032,687	gcuku150th.50
08/14/2007	12:29p	6,156,247	gcuku150th.52

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08/14/2007  03:10p         6,949,799 gcukl110dy.100
08/14/2007  12:31p         6,460,815 gcuku150th.60
08/14/2007  12:32p         6,630,231 gcuku150th.65
08/14/2007  12:33p         6,787,055 gcuku150th.70
08/14/2007  12:34p         6,955,463 gcuku150th.75
08/14/2007  12:34p         7,110,775 gcuku150th.80
08/16/2007  09:15a               400 Shortcut to flacw_sp.exe.lnk
08/15/2007  02:18p             1,043 closure_for_excel.dat
09/19/2007  03:39p               152 listfiles.dat
08/15/2007  02:13p             6,679 closure_ku15.log
08/15/2007  02:15p             6,679 closure_ku11.log
08/15/2007  02:16p             6,679 closure_kl11.log
08/15/2007  02:18p             6,679 closure_kl15.log
08/15/2007  02:31p               532 eq_closure_for_excel.dat
08/15/2007  02:31p           364,614 U150dy_vc_100.his
08/15/2007  02:31p           364,614 U150dy_hc_100.his
08/15/2007  02:31p           364,614 L150dy_vc_100.his
08/15/2007  02:31p           364,614 L150dy_hc_100.his
08/15/2007  02:31p           199,246 U110dy_vc_100.his
08/15/2007  02:31p           199,246 U110dy_hc_100.his
08/15/2007  02:31p           199,246 L110dy_vc_100.his
08/15/2007  02:33p           199,246 L110dy_hc_100.his
08/16/2007  07:39a            13,159 stress_ku11.log
08/16/2007  07:38a             2,001 stress_for_excel.dat
08/16/2007  07:34a            13,159 stress_kl11.log
08/16/2007  07:35a            13,159 stress_kl15.log
08/16/2007  07:37a            13,159 stress_ku15.log
08/16/2007  09:16a               554 eq_stress_for_excel.dat
08/16/2007  09:17a           199,246 L110dy_crsig1_100.his
08/16/2007  09:17a           199,246 L110dy_spsig1_100.his
08/16/2007  09:17a           364,614 L150dy_crsig1_100.his
08/16/2007  09:17a           364,614 L150dy_spsig1_100.his
08/16/2007  09:17a           199,246 U110dy_crsig1_100.his
08/16/2007  09:17a           199,246 U110dy_spsig1_100.his
08/16/2007  09:17a           364,614 U150dy_crsig1_100.his
08/16/2007  09:17a           364,614 U150dy_spsig1_100.his
             102 File(s)    414,661,562 bytes
               2 Dir(s)  184,540,307,456 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_grc\Input

09/19/2007  03:40p    <DIR>          .
09/19/2007  02:20p    <DIR>          ..
07/14/2007  02:52p             3,823 properties.fis
03/20/2007  10:08p               659 hiszones_50.fis
05/15/2007  07:39p             2,152 relaxation.fis
05/15/2007  07:39p             2,087 setup.fis
09/19/2007  03:40p               147 listfiles.dat
07/19/2007  04:05p             3,025 tunnel.dat
08/10/2007  09:47a            12,294 driver_grcmn.dat
               7 File(s)         24,187 bytes
               2 Dir(s)  184,540,356,608 bytes free
```

```
Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_grc\Output

09/19/2007  03:40p    <DIR>          .
09/19/2007  02:20p    <DIR>          ..
08/10/2007  09:51a         3,886,923 gcuklgrc6110is.exv
08/10/2007  09:48a         3,791,091 gcuklgrc2110is.ini
08/10/2007  09:49a         3,920,043 gcuklgrc2110is.exv
08/10/2007  09:49a         3,791,091 gcuklgrc4110is.ini
08/10/2007  09:50a         3,917,643 gcuklgrc4110is.exv
08/10/2007  09:50a         3,791,091 gcuklgrc6110is.ini
08/10/2007  09:27a               454 Shortcut to flacw_sp.exe.lnk
08/10/2007  09:51a         3,791,091 gcuklgrc8110is.ini
08/10/2007  09:51a         3,798,603 gcuklgrc10110is.exv
08/10/2007  09:51a         3,791,163 gcuklgrc10110is.ini
08/10/2007  09:51a         3,852,363 gcuklgrc8110is.exv
08/10/2007  09:51a         3,791,091 gcukugrc2110is.ini
08/10/2007  09:52a         3,874,923 gcukugrc2110is.exv
08/10/2007  09:52a         3,791,091 gcukugrc4110is.ini
08/10/2007  09:52a         3,865,323 gcukugrc4110is.exv
08/10/2007  09:52a         3,791,091 gcukugrc6110is.ini
08/10/2007  09:53a         3,849,483 gcukugrc6110is.exv
08/10/2007  09:53a         3,791,091 gcukugrc8110is.ini
08/10/2007  09:53a         3,791,091 gcuklgrc2150is.ini
08/10/2007  09:53a         3,798,603 gcukugrc10110is.exv
08/10/2007  09:53a         3,791,163 gcukugrc10110is.ini
08/10/2007  09:53a         3,837,483 gcukugrc8110is.exv
08/10/2007  09:54a         3,967,083 gcuklgrc2150is.exv
08/10/2007  09:54a         3,791,091 gcuklgrc4150is.ini
08/10/2007  09:56a         3,947,883 gcuklgrc4150is.exv
08/10/2007  09:56a         3,791,091 gcuklgrc6150is.ini
08/10/2007  09:56a         3,892,203 gcuklgrc6150is.exv
08/10/2007  09:56a         3,791,091 gcuklgrc8150is.ini
08/10/2007  09:57a         3,798,603 gcuklgrc10150is.exv
08/10/2007  09:57a         3,791,163 gcuklgrc10150is.ini
08/10/2007  09:57a         3,853,323 gcuklgrc8150is.exv
08/10/2007  09:57a         3,791,091 gcukugrc2150is.ini
08/10/2007  09:57a         3,879,243 gcukugrc2150is.exv
08/10/2007  09:58a         3,791,091 gcukugrc4150is.ini
08/10/2007  09:58a         3,863,883 gcukugrc4150is.exv
08/10/2007  09:58a         3,791,091 gcukugrc6150is.ini
08/10/2007  09:58a         3,848,043 gcukugrc6150is.exv
08/10/2007  09:58a         3,791,091 gcukugrc8150is.ini
08/10/2007  09:59a         3,798,603 gcukugrc10150is.exv
08/10/2007  09:59a         3,791,163 gcukugrc10150is.ini
08/10/2007  09:59a         3,838,443 gcukugrc8150is.exv
08/10/2007  01:05p                 0 FC140531.tmp
08/10/2007  01:06p                 0 FC140600.tmp
09/19/2007  03:40p               148 listfiles.dat
08/10/2007  01:09p             1,225 ydisp_gcu1kl10
08/10/2007  01:10p             1,225 ydisp_gcu1kl8
08/10/2007  01:12p             1,225 ydisp_gcu1kl6
08/10/2007  01:38p             1,225 ydisp_gcu5ku10
08/10/2007  01:41p            16,384 FH144151.tmp
```

```
08/10/2007  01:20p             1,225 ydisp_gcu1kl4
08/10/2007  01:22p             1,225 ydisp_gcu1kl2
08/10/2007  01:24p             1,225 ydisp_gcu5kl10
08/10/2007  01:24p             1,225 ydisp_gcu5kl8
08/10/2007  01:26p             1,225 ydisp_gcu5kl6
08/10/2007  01:27p             1,225 ydisp_gcu5kl4
08/10/2007  01:30p             1,225 ydisp_gcu5kl2
08/10/2007  01:32p             1,225 ydisp_gcu1ku10
08/10/2007  01:33p             1,387 ydisp_gcu1ku8
08/10/2007  01:34p             1,225 ydisp_gcu1ku6
08/10/2007  01:35p             1,225 ydisp_gcu1ku4
08/10/2007  01:37p             1,225 ydisp_gcu1ku2
08/10/2007  01:39p             1,225 ydisp_cgu5ku8
08/10/2007  01:41p             1,225 ydisp_cgu5ku6
08/10/2007  01:42p             1,406 ydisp_gcu5ku4
08/10/2007  01:43p               787 ydisp_gcu5ku2
              65 File(s)    153,152,199 bytes
               2 Dir(s)  184,540,352,512 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_sup\Input

09/19/2007  03:41p    <DIR>          .
09/19/2007  02:21p    <DIR>          ..
09/19/2007  03:41p               147 listfiles.dat
05/15/2007  07:39p             3,408 makemovie.fis
03/20/2007  10:08p             1,592 boltprop.fis
08/29/2007  01:14p             2,503 driver.dat
03/20/2007  10:08p               659 hiszones_50.fis
05/15/2007  07:41p               392 initemp.fis
06/22/2007  04:32p               630 bolt.dat
07/18/2007  09:28a             3,820 properties.fis
05/15/2007  07:39p             2,152 relaxation.fis
08/29/2007  01:15p             1,453 seismic.dat
05/25/2007  03:20p             2,077 setup.fis
07/25/2007  08:31a             2,871 shake.fis
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:41p             1,628 thermal_50.dat
07/25/2007  08:31a             3,679 thermoprop.fis
05/15/2007  07:39p             3,041 tunnel_b.dat
05/15/2007  07:39p           203,437 vel_hori_5e-4.tab
05/15/2007  07:39p           195,677 vel_vert_5e-4.tab
              18 File(s)        430,111 bytes
               2 Dir(s)  184,540,348,416 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_sup\Output

09/19/2007  03:41p    <DIR>          .
09/19/2007  02:21p    <DIR>          ..
08/07/2007  07:57a         7,414,199 gcskl110th.7
08/07/2007  07:47a         3,790,915 gcskl110is.ini
```

08/07/2007 07:48a 3,917,515 gcskl110is.exv
08/07/2007 07:49a 4,327,471 gcskl110is.sup
08/07/2007 07:51a 4,571,991 gcskl110th.0
08/07/2007 07:52a 5,072,803 gcskl110th.1
08/07/2007 07:53a 5,515,735 gcskl110th.2
08/07/2007 07:55a 6,570,371 gcskl110th.5
08/16/2007 12:02p 400 Shortcut to flacw_sp.exe.lnk
08/07/2007 07:58a 8,456,711 gcskl110th.10
08/07/2007 08:03a 11,667,807 gcskl110th.20
08/07/2007 08:07a 14,883,279 gcskl110th.30
08/07/2007 08:07a 14,929,591 gcskl110th.50
08/07/2007 08:07a 3,790,915 gcskl150is.ini
08/07/2007 08:09a 3,947,755 gcskl150is.exv
08/07/2007 08:10a 4,275,391 gcskl150is.sup
08/07/2007 08:12a 4,544,151 gcskl150th.0
08/07/2007 08:13a 5,043,235 gcskl150th.1
08/07/2007 08:14a 5,486,167 gcskl150th.2
08/07/2007 08:16a 6,539,075 gcskl150th.5
08/07/2007 08:17a 7,368,215 gcskl150th.7
08/07/2007 08:19a 8,410,727 gcskl150th.10
08/07/2007 08:23a 11,625,279 gcskl150th.20
08/07/2007 08:28a 14,828,655 gcskl150th.30
08/07/2007 08:28a 14,874,967 gcskl150th.50
08/07/2007 08:28a 3,790,915 gcsku110is.ini
08/07/2007 08:29a 3,865,195 gcsku110is.exv
08/07/2007 08:30a 4,115,551 gcsku110is.sup
08/07/2007 08:30a 4,216,695 gcsku110th.0
08/07/2007 08:32a 4,793,539 gcsku110th.1
08/07/2007 08:33a 5,310,775 gcsku110th.2
08/07/2007 08:35a 6,375,779 gcsku110th.5
08/07/2007 08:37a 7,224,791 gcsku110th.7
08/07/2007 08:39a 8,268,167 gcsku110th.10
08/07/2007 08:43a 11,487,903 gcsku110th.20
08/07/2007 08:47a 14,704,239 gcsku110th.30
08/07/2007 08:48a 14,744,503 gcsku110th.50
08/07/2007 08:48a 3,790,915 gcsku150is.ini
08/07/2007 08:48a 3,863,755 gcsku150is.exv
08/07/2007 08:49a 4,118,311 gcsku150is.sup
08/07/2007 08:51a 4,378,383 gcsku150th.0
08/07/2007 08:52a 4,874,875 gcsku150th.1
08/07/2007 08:53a 5,315,215 gcsku150th.2
08/07/2007 08:55a 6,368,987 gcsku150th.5
08/07/2007 08:56a 7,179,983 gcsku150th.7
08/07/2007 08:58a 8,224,223 gcsku150th.10
08/07/2007 09:02a 11,445,687 gcsku150th.20
08/07/2007 09:07a 14,652,519 gcsku150th.30
08/07/2007 09:07a 14,690,191 gcsku150th.50
08/07/2007 04:59p 13,113,703 gcskl110dy.0
08/08/2007 12:51a 13,118,179 gcskl110dy.50
08/08/2007 08:44a 13,113,703 gcsku110dy.0
08/08/2007 04:39p 13,118,179 gcsku110dy.50
08/09/2007 12:30a 13,113,703 gcskl150dy.0
08/09/2007 08:21a 13,118,179 gcskl150dy.50
08/09/2007 04:13p 13,112,899 gcsku150dy.0
08/10/2007 12:06a 13,117,375 gcsku150dy.50
06/29/2007 06:15a 13,731 Str.fin

08/16/2007 10:01a 658 find_for.fis
08/16/2007 12:08p 790 bolt_forces_for_excel.dat
09/19/2007 03:41p 148 listfiles.dat
08/20/2007 10:14a 29,635 bolt_force_kl11_0yrdy.pcx
08/20/2007 12:31p 32,174 bolt_force_kl11_50yrdy.pcx
08/16/2007 12:03p 3,746 bolt_force_ku11.log
08/20/2007 12:32p 32,174 bolt_force_ku11_0yrdy.pcx
08/20/2007 12:36p 31,349 bolt_force_ku11_50yrdy.pcx
08/20/2007 01:19p 29,290 bolt_force_kl11_0yr.pcx
08/16/2007 12:04p 3,746 bolt_force_ku15.log
08/20/2007 01:44p 30,744 bolt_force_kl11_50yr.pcx
08/16/2007 12:06p 3,746 bolt_force_kl15.log
08/16/2007 12:08p 3,746 bolt_force_kl11.log
71 File(s) 464,796,013 bytes
2 Dir(s) 184,540,278,784 bytes free

Volume in drive D is New Volume
Volume Serial Number is 683C-0946

Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_sup_25+75NL\Input

09/19/2007 03:42p <DIR> .
09/19/2007 02:14p <DIR> ..
03/21/2007 03:30a 2,874 shake.fis
03/21/2007 02:17a 1,592 boltprop.fis
03/21/2007 02:17a 659 hiszones_50.fis
06/22/2007 04:32p 630 bolt.dat
03/21/2007 03:30a 3,408 makemovie.fis
07/14/2007 02:52p 3,823 properties.fis
03/21/2007 02:17a 2,154 relaxation.fis
03/21/2007 02:17a 2,070 setup.fis
03/21/2007 02:17a 392 initemp.fis
08/14/2007 01:11p 454 Shortcut to flacw_sp.exe.lnk
03/20/2007 11:16p 658 temphis_50.tab
03/20/2007 11:16p 1,518 thermal_50.dat
08/14/2007 09:53a 3,679 thermoprop.fis
03/21/2007 02:17a 3,041 tunnel_b.dat
03/21/2007 03:30a 203,437 vel_hori_5e-4.tab
03/21/2007 03:30a 195,677 vel_vert_5e-4.tab
08/14/2007 01:09p 2,503 driver_bmn.dat
08/14/2007 01:10p 854 seismic_bmn.dat
09/19/2007 03:42p 155 listfiles.dat
19 File(s) 429,578 bytes
2 Dir(s) 184,540,336,128 bytes free

Volume in drive D is New Volume
Volume Serial Number is 683C-0946

Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_sup_25+75NL\Output

09/19/2007 03:42p <DIR> .
09/19/2007 02:14p <DIR> ..
08/14/2007 01:50p 4,118,267 gcsku150is.sup
08/14/2007 01:13p 3,917,471 gcskl110is.exv
08/14/2007 01:11p 3,790,855 gcskl110is.ini
08/14/2007 01:14p 4,327,427 gcskl110is.sup

```
08/14/2007  01:15p         4,343,031 gcskl110th.0
08/14/2007  01:16p         4,584,591 gcskl110th.1
08/14/2007  01:24p         8,742,091 gcskl110th.100
08/14/2007  01:18p         5,877,691 gcskl110th.25
08/14/2007  01:20p         6,770,743 gcskl110th.40
08/15/2007  08:05a        13,114,823 gcskl150dy.100
08/14/2007  01:36p         3,947,711 gcskl150is.exv
08/14/2007  01:35p         3,790,855 gcskl150is.ini
08/14/2007  01:38p         4,275,347 gcskl150is.sup
08/14/2007  01:38p         4,291,863 gcskl150th.0
08/14/2007  01:39p         4,531,695 gcskl150th.1
08/14/2007  01:48p         9,004,555 gcskl150th.100
08/14/2007  01:42p         5,866,267 gcskl150th.25
08/14/2007  01:44p         6,850,903 gcskl150th.40
08/15/2007  05:06p        13,114,823 gcsku110dy.100
08/14/2007  01:24p         3,865,151 gcsku110is.exv
08/14/2007  01:24p         3,790,855 gcsku110is.ini
08/14/2007  01:25p         4,115,507 gcsku110is.sup
08/14/2007  01:26p         4,132,023 gcsku110th.0
08/14/2007  01:27p         4,392,591 gcsku110th.1
08/14/2007  01:35p         8,553,547 gcsku110th.100
08/14/2007  01:29p         5,693,467 gcsku110th.25
08/14/2007  01:31p         6,574,423 gcsku110th.40
08/16/2007  02:06a        13,114,823 gcsku150dy.100
08/14/2007  01:49p         3,863,711 gcsku150is.exv
08/14/2007  01:48p         3,790,855 gcsku150is.ini
08/14/2007  11:03p        13,114,823 gcskl110dy.100
08/14/2007  01:51p         4,133,871 gcsku150th.0
08/14/2007  01:52p         4,373,703 gcsku150th.1
08/14/2007  02:00p         8,773,123 gcsku150th.100
08/14/2007  01:54p         5,695,315 gcsku150th.25
08/14/2007  01:56p         6,614,287 gcsku150th.40
08/16/2007  01:23p               402 Shortcut to flacw_sp.exe.lnk
06/29/2007  06:15a            13,731 Str.fin
08/16/2007  10:01a               658 find_for.fis
08/16/2007  01:26p               505 bolt_forces_for_excel.dat
09/19/2007  03:42p               156 listfiles.dat
08/16/2007  01:23p             2,339 bolt_force_ku11.log
08/16/2007  01:24p             2,339 bolt_force_ku15.log
08/16/2007  01:26p             2,339 bolt_force_kl11.log
08/16/2007  01:25p             2,339 bolt_force_kl15.log
              45 File(s)    219,877,892 bytes
               2 Dir(s)  184,540,332,032 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_sup_50+50NL\Input

09/19/2007  03:43p    <DIR>          .
09/19/2007  02:15p    <DIR>          ..
07/14/2007  02:52p             3,823 properties.fis
03/21/2007  02:17a             1,592 boltprop.fis
08/14/2007  12:43p             2,503 driver_bmn.dat
03/21/2007  02:17a               659 hiszones_50.fis
03/21/2007  02:17a               392 initemp.fis
```

```
03/21/2007  03:30a             3,408 makemovie.fis
06/22/2007  04:32p               630 bolt.dat
03/21/2007  02:17a             2,154 relaxation.fis
08/14/2007  12:44p               854 seismic_bmn.dat
03/21/2007  02:17a             2,070 setup.fis
03/21/2007  03:30a             2,874 shake.fis
03/21/2007  12:48a             1,926 temphis_50.tab
03/21/2007  12:48a             1,515 thermal_50.dat
08/14/2007  09:53a             3,679 thermoprop.fis
03/21/2007  02:17a             3,041 tunnel_b.dat
03/21/2007  03:30a           203,437 vel_hori_5e-4.tab
03/21/2007  03:30a           195,677 vel_vert_5e-4.tab
09/19/2007  03:43p               155 listfiles.dat
              18 File(s)        430,389 bytes
               2 Dir(s)  184,540,332,032 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1,5_sup_50+50NL\Output

09/19/2007  03:43p    <DIR>          .
09/19/2007  02:15p    <DIR>          ..
08/14/2007  02:03p         8,113,303 gcsku150th.50
08/14/2007  12:49p         3,917,471 gcskl110is.exv
08/14/2007  12:48p         3,790,855 gcskl110is.ini
08/14/2007  12:50p         4,327,427 gcskl110is.sup
08/14/2007  12:52p         4,582,455 gcskl110th.1
08/14/2007  12:54p         5,429,035 gcskl110th.10
08/14/2007  01:09p        10,922,623 gcskl110th.100
08/14/2007  12:53p         4,768,719 gcskl110th.2
08/14/2007  12:56p         6,071,535 gcskl110th.20
08/14/2007  12:57p         6,701,067 gcskl110th.30
08/14/2007  12:53p         5,050,055 gcskl110th.5
08/14/2007  01:02p         8,346,703 gcskl110th.50
08/14/2007  01:02p         8,576,247 gcskl110th.52
08/14/2007  01:03p         8,906,007 gcskl110th.58
08/14/2007  01:04p         9,088,887 gcskl110th.60
08/14/2007  01:05p         9,359,903 gcskl110th.65
08/14/2007  01:06p         9,630,911 gcskl110th.70
08/14/2007  01:06p         9,901,063 gcskl110th.75
08/14/2007  01:07p        10,170,343 gcskl110th.80
08/15/2007  06:29a        13,122,259 gcskl150dy.100
08/14/2007  01:30p         3,947,711 gcskl150is.exv
08/14/2007  01:29p         3,790,855 gcskl150is.ini
08/14/2007  01:31p         4,275,347 gcskl150is.sup
08/14/2007  01:33p         4,531,239 gcskl150th.1
08/14/2007  01:35p         5,371,771 gcskl150th.10
08/14/2007  01:50p        10,916,335 gcskl150th.100
08/14/2007  01:34p         4,715,775 gcskl150th.2
08/14/2007  01:37p         6,009,951 gcskl150th.20
08/14/2007  01:38p         6,631,707 gcskl150th.30
08/14/2007  01:35p         4,994,519 gcskl150th.5
08/14/2007  01:42p         8,249,695 gcskl150th.50
08/14/2007  01:43p         8,474,919 gcskl150th.52
08/14/2007  01:44p         8,823,687 gcskl150th.58
```

```
08/14/2007  01:45p         9,010,023 gcskl150th.60
08/14/2007  01:46p         9,312,143 gcskl150th.65
08/14/2007  01:47p         9,587,471 gcskl150th.70
08/14/2007  01:48p         9,867,991 gcskl150th.75
08/14/2007  01:48p        10,152,823 gcskl150th.80
08/15/2007  02:39p        13,122,259 gcsku110dy.100
08/14/2007  01:09p         3,865,151 gcsku110is.exv
08/14/2007  01:09p         3,790,855 gcsku110is.ini
08/14/2007  01:10p         4,115,507 gcsku110is.sup
08/14/2007  01:12p         4,375,719 gcsku110th.1
08/14/2007  01:14p         5,224,891 gcsku110th.10
08/14/2007  01:29p        10,755,631 gcsku110th.100
08/14/2007  01:13p         4,561,119 gcsku110th.2
08/14/2007  01:16p         5,898,495 gcsku110th.20
08/14/2007  01:17p         6,521,979 gcsku110th.30
08/14/2007  01:13p         4,846,775 gcsku110th.5
08/14/2007  01:22p         8,163,295 gcsku110th.50
08/14/2007  01:22p         8,390,247 gcsku110th.52
08/14/2007  01:23p         8,720,007 gcsku110th.58
08/14/2007  01:24p         8,909,799 gcsku110th.60
08/14/2007  01:25p         9,186,863 gcsku110th.65
08/14/2007  01:26p         9,459,599 gcsku110th.70
08/14/2007  01:27p         9,734,071 gcsku110th.75
08/14/2007  01:27p        10,003,351 gcsku110th.80
08/15/2007  10:47p        13,121,455 gcsku150dy.100
08/14/2007  01:51p         3,863,711 gcsku150is.exv
08/14/2007  01:50p         3,790,855 gcsku150is.ini
08/14/2007  01:52p         4,118,267 gcsku150is.sup
08/14/2007  01:53p         4,374,159 gcsku150th.1
08/14/2007  01:56p         5,213,827 gcsku150th.10
08/14/2007  02:10p        10,738,471 gcsku150th.100
08/14/2007  01:54p         4,556,967 gcsku150th.2
08/14/2007  01:57p         5,857,191 gcsku150th.20
08/14/2007  01:58p         6,478,083 gcsku150th.30
08/14/2007  01:55p         4,835,711 gcsku150th.5
08/14/2007  10:18p        13,122,259 gcskl110dy.100
08/14/2007  02:04p         8,339,391 gcsku150th.52
08/14/2007  02:05p         8,683,839 gcsku150th.58
08/14/2007  02:05p         8,869,311 gcsku150th.60
08/14/2007  02:06p         9,159,335 gcsku150th.65
08/14/2007  02:07p         9,431,207 gcsku150th.70
08/14/2007  02:08p         9,717,775 gcsku150th.75
08/14/2007  02:09p         9,986,191 gcsku150th.80
08/16/2007  01:14p               402 Shortcut to flacw_sp.exe.lnk
06/29/2007  06:15a            13,731 Str.fin
08/16/2007  10:01a               658 find_for.fis
08/16/2007  01:19p               693 bolt_forces_for_excel.dat
09/19/2007  03:43p               156 listfiles.dat
08/16/2007  01:14p             3,277 bolt_force_kl11.log
08/16/2007  01:16p             3,277 bolt_force_kl15.log
08/16/2007  01:17p             3,277 bolt_force_ku15.log
08/16/2007  01:19p             3,277 bolt_force_ku11.log
              85 File(s)    563,373,196 bytes
               2 Dir(s)  184,540,266,496 bytes free
```

Volume in drive D is New Volume

Volume Serial Number is 683C-0946

Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1_g10k\Input

```
09/19/2007  03:43p    <DIR>          .
09/19/2007  02:24p    <DIR>          ..
07/18/2007  09:28a             3,820 properties.fis
03/20/2007  10:08p               659 hiszones_50.fis
05/15/2007  07:41p               392 initemp.fis
09/19/2007  03:43p               146 listfiles.dat
05/15/2007  07:39p             3,408 makemovie.fis
08/29/2007  01:28p               625 driver.dat
05/15/2007  07:39p             2,152 relaxation.fis
08/29/2007  01:29p               389 seismic.dat
05/25/2007  03:20p             2,077 setup.fis
06/20/2007  01:34p             2,871 shake.fis
05/15/2007  02:13p               945 temphis_50.tab
05/15/2007  07:41p             1,628 thermal_50.dat
08/20/2007  03:55p             3,679 thermoprop.fis
07/17/2007  12:59p             3,016 tunnel.dat
06/30/2003  10:41a           373,597 vel_hori_1e-4.tab
06/30/2003  10:40a           373,120 vel_vert_1e-4.tab
              16 File(s)        772,524 bytes
               2 Dir(s)  184,539,303,936 bytes free
```

Volume in drive D is New Volume
Volume Serial Number is 683C-0946

Directory of D:\RUD\GCEDLAC_Attachment\DVD2\Nonlitho\cat_1_g10k\Output

```
09/19/2007  03:44p    <DIR>          .
09/19/2007  02:24p    <DIR>          ..
08/20/2007  04:16p         6,080,283 gcukl110th.10
08/21/2007  01:58a         9,852,739 gcukl110dy.50
08/20/2007  04:10p         3,965,035 gcukl110is.exv
08/20/2007  04:08p         3,790,915 gcukl110is.ini
08/20/2007  04:11p         4,017,163 gcukl110th.0
08/20/2007  04:12p         4,286,359 gcukl110th.1
08/20/2007  09:11p         9,848,239 gcukl110dy.0
08/20/2007  04:12p         4,511,699 gcukl110th.2
08/20/2007  04:20p         7,923,891 gcukl110th.20
08/20/2007  04:24p         9,763,003 gcukl110th.30
08/20/2007  04:14p         5,100,927 gcukl110th.5
08/20/2007  04:25p         9,800,827 gcukl110th.50
08/20/2007  04:15p         5,497,635 gcukl110th.7
08/21/2007  08:28a               410 Shortcut to flacw_sp.exe.lnk
08/21/2007  08:26a             2,296 stress_for_excel.dat
08/21/2007  08:29a               255 eq_closure_for_excel.dat
08/21/2007  08:31a               275 eq_stress_for_excel.dat
08/21/2007  08:23a             1,353 closure_for_excel.dat
08/21/2007  08:23a             8,589 closure_kl11.log
08/21/2007  08:27a            16,932 stress_kl11.log
09/19/2007  03:44p               147 listfiles.dat
08/21/2007  08:29a           387,238 L110dy_vc_50.his
08/21/2007  08:29a           387,238 L110dy_hc_50.his
08/21/2007  08:29a           387,238 L110dy_vc_0.his
```

```
08/21/2007  08:30a           387,238 L110dy_hc_0.his
08/21/2007  08:31a           387,238 L110dy_crsig1_0.his
08/21/2007  08:31a           387,238 L110dy_spsig1_0.his
08/21/2007  08:31a           387,238 L110dy_crsig1_50.his
08/21/2007  08:41a           387,238 L110dy_spsig1_50.his
              29 File(s)     87,566,876 bytes
               2 Dir(s)  184,539,299,840 bytes free

 Volume in drive D is New Volume
 Volume Serial Number is 683C-0946

 Directory of D:\RUD\GCEDLAC_Attachment\DVD2\pull test calibration

09/19/2007  03:44p    <DIR>          .
09/19/2007  03:41p    <DIR>          ..
09/17/2007  02:33p             2,250 K003S275.DAT
09/17/2007  01:31p            71,615 k003_s275.sav
09/19/2007  07:40a            57,856 Pull Test Calibration.xls
09/17/2007  01:36p                77 pull_test.txt
09/19/2007  03:44p               142 listfiles.dat
               5 File(s)        131,940 bytes
               2 Dir(s)  184,539,295,744 bytes free
```