✓-6-9285①

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Yucca Mountain Site Characterization Project

Misty Echo Tunnel Dynamics Experiment—Data Report

Volume 2: Appendices

J. S. Phillips, B. A. Luke, J. W. Long, J. G. Lee

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

"Prepared by Yucca Mountain Site Characterization Project (YMSCP) participants as part of the Civilian Radioactive Waste Management Program (CRWM). The YMSCP is managed by the Yucca Mountain Project Office of the U.S. Department of Energy, DOE Field Office, Nevada (DOE/NV). YMSCP work is sponsored by the Office of Geologic Repositories (OGR) of the DOE Office of Civilian Radioactive Waste Management (OCRWM)."

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SAND--89-0972/2

SAND89-0972
Unlimited Release
Printed April 1992

DE92 012615

MISTY ECHO TUNNEL DYNAMICS EXPERIMENT

DATA REPORT

Volume 2: Appendices

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ABSTRACT

Tunnel damage resulting from seismic loading is an important issue for the Yucca Mountain nuclear waste repository. The tunnel dynamics experiment was designed to obtain and document ground motions, permanent displacements, observable changes in fracture patterns, and visible damage at ground motion levels of interest to the Yucca Mountain Project. Even though the maximum free-field loading on this tunnel was 28 g, the damage observed was minor. Fielding details, data obtained, and supporting documentation are reported.

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This work was conducted in support of the Yucca Mountain Project at Quality Level I following procedures approved by the Sandia National Laboratories Nuclear Waste Repository Technology Department. This work applies to WBS element 1.2.4.1.2.

ACKNOWLEDGEMENT

This experiment was a cooperative effort of many individuals and organizations. Additional personnel involved in the fielding of the ground motion experiment were C. D. Lucas of Sandia National Laboratories (SNL) Division 9325 and Jose Loya of EG&G. The tunnel convergence measurements were made by K. Mann, S. Luker, and B. Bellman, all of Science Applications International Corp. The borehole inspection work was performed with the assistance of A. M. Richardson of Parsons Brinckerhoff Quade & Douglas, Inc., and D. Charlton of EG&G. Photographs were taken by C. Serna and L. Arnold of the SNL Photo Lab. Much of the coordination work for fielding this effort was handled by R. W. Donohoe of SNL Division 9323.

All aspects of this experiment could not have succeeded without the positive support of the Defense Nuclear Agency and the support contractors at the Nevada Test Site. The work of all involved in this support was done in a professional and timely manner. The help of all involved, especially J. LaComb and D. Taunton and his staff were greatly appreciated.

A special note of thanks goes to A. J. Chabai and R. C. Bass both of SNL Division 9311 and C. W. Smith of SNL Division 9312 for their valuable input in the planning stages of the ground motion experiment.

FOREWORD

The Yucca Mountain Site Characterization Project (YMP), which is managed by the Nevada Operations Office of the U. S. Department of Energy, is examining the feasibility of siting a repository for commercial high-level nuclear wastes at Yucca Mountain, on and adjacent to the Nevada Test Site (NTS). This work, intended to extend our understanding of the behavior of underground openings subjected to seismic loading, was funded jointly by the YMP and the Military Applications Weapons Test Program. This report summarizes one aspect of the Weapons Test Seismic Investigation project that was conducted in FY 89.

Volume 1 CONTENTS

<u>Section</u>	<u>Page</u>
1.0 Introduction	1
2.0 Experiment Description	5
2.1 Location and General Description	5
2.2 Tunnel Configuration	5
2.2.1 Construction Details	5
2.2.2 Material Properties Description	6
2.2.2.1 General	6
2.2.2.2 TDE Vicinity	7
2.3 Experiment Configuration	7
2.3.1 Ground Motion	7
2.3.2 Surveys	8
2.3.3 Tunnel Convergence	9
2.3.4 Borehole Inspection	10
2.3.5 Photography	10
2.3.6 High-Speed Photography	11
3.0 Presentation and Discussion of Data	117
3.1 Ground Motion Data	117
3.2 Surveys	123
3.2.1 Permanent Displacements	123
3.2.2 Cross Section Measurements	124
3.3 Tunnel Convergence	125
3.4 Data Consistency	126
3.5 Borehole Inspection	127
3.6 Photography	128
3.6.1 Documentary Photography	128
3.6.2 High-Speed Photography	131
4.0 Summary, Conclusions, and Recommendations	315
4.1 Summary	315
4.2 Conclusions	316
4.3 Recommendations	317
5.0 References	319
6.0 Distribution	321

Volume 1 FIGURES

Figure		Page
Figure 1-1.	General Layout of Tunnels in the Vicinity of the MISTY ECHO Working Point	4
Figure 2-1.	Tunnel Construction Details for the Primary TDE Location - Station 56+00 U12N South Extension Drift	17
Figure 2-2.	Overall View of TDE at Station 56+00 Before Construction of Experiment	19
Figure 2-3.	Left Rib of U12N South Extension Drift at Station 56+00	21
Figure 2-4.	Tunnel Construction Details for the Secondary TDE Location - Station 2+84 U12n.22 Bypass Drift	23
Figure 2-5.	Overall View of U12n.22 Bypass Drift Near Station 2+84	25
Figure 2-6.	Stratigraphy in the Vicinity of MISTY ECHO	27
Figure 2-7.	Tunnel Level Geologic Map of Southern N-Tunnel	28
Figure 2-8.	Stratigraphy in the Immediate Vicinity of the TDE	29
Figure 2-9.	Cross Section and Layout of the TDE Ground Motion Experiment - Station 56+00 (Looking away from portal) ..	30
Figure 2-10.	Gage Mount Area on Right Rib, Lining Removed, Mounting Bolts in Place	31
Figure 2-11.	Gage Mount Area on Left Rib, Lining Removed, Mounting Bolts in Place	33
Figure 2-12.	Gage Mount Area on Back, Lining Removed, Mounting Bolts in Place	35
Figure 2-13.	Gage Mount Area on Invert, Lining Removed, Mounting Bolts in Place	37
Figure 2-14.	Right Rib Gage Mount Area with Mounting Plate in Place	39
Figure 2-15.	Left Rib Gage Mount Area with Mounting Plate in Place ..	41
Figure 2-16.	Back Gage Mount Area with Mounting Plate in Place	43
Figure 2-17.	Invert Gage Mount Area with Mounting Plate in Place	45
Figure 2-18.	Gages for Station 3700-2, Left Rib - View of Transverse, and Vertical Gages	47
Figure 2-19.	Gages for Station 3700-2, Left Rib - View of Transverse and Radial Gages	49
Figure 2-20.	Gages for Station 3700-2, Left Rib - View of Transverse, Vertical, and Radial Gages	51
Figure 2-21.	Gages for Station 3700-4, Right Rib - View of Transverse, Vertical, and Radial Gages	53
Figure 2-22.	Gages for Station 3700-4, Right Rib - View of Transverse and Vertical Gages	55
Figure 2-23.	Gages for Station 3700-4, Right Rib - View of Radial, Transverse, and Vertical Gages	57
Figure 2-24.	Gages for Station 3700-5, Invert - View of Radial, Transverse, and Vertical Gages and Waterproof Canister	59
Figure 2-25.	Completed Mounting of Station 3700-4, Right Rib	61
Figure 2-26.	Completed Mounting of Station 3700-2, Left Rib	63
Figure 2-27.	Completed Mounting of Station 3700-1, Back	65
Figure 2-28.	Completed Mounting of Station 3700-5, Invert	67
Figure 2-29.	Drillhole Used for Installation of the Free-Field Measurements, Station 3700-3	69

Volume 1 FIGURES (continued)

Figure		Page
Figure 2-30.	Gages for Station 3700-3, Free-field - View of Radial, Vertical, and Transverse Gages	71
Figure 2-31.	Gages for Station 3700-3, Free-field - View of Gages and Electrical Connections Inside Canister.....	73
Figure 2-32.	Final Assembly of Gage Canister Used for Station 3700-3, Free-field	75
Figure 2-33.	Schematic of the Timing and Control System Used for the TDE Ground Motion Data Acquisition	77
Figure 2-34.	Schematic of the TDE Data Acquisition System - Stations 3700-1, 3700-2 and 3700-3	78
Figure 2-35.	Schematic of the TDE Data Acquisition System - Stations 3700-4 and 3700-5	79
Figure 2-36.	Front View of Equipment Rack Used to Record Ground Motions in the TDE (Note shock isolation mounting of rack)	81
Figure 2-37.	Rear View of the Equipment Rack Used to Record Ground Motions in the TDE	83
Figure 2-38.	Location of Survey Markers Used in the TDE	85
Figure 2-39.	Cross Section at Station 56+18, U12N South Extension Drift Showing Extensometer Anchor Holes and Boreholes for Visual Inspection	86
Figure 2-40.	Cross Section at Station 2+84, U12n.22 Bypass Drift Showing Extensometer Anchor Holes and Boreholes for Visual Inspection	87
Figure 2-41.	Invert Anchor 1TE1, Station 56+18, Primary Location	89
Figure 2-42.	Back Anchor 1TE2, Station 56+18, Primary Location	91
Figure 2-43.	Left Rib Anchors (1TE3 and 1TE5) and Inspection Borehole 1B1, Station 56+18, Primary Location	93
Figure 2-44.	Right Rib Anchors (1TE4 and 1TE6) and Inspection Borehole 1B2, Station 56+18, Primary Location	95
Figure 2-45.	Invert Anchor 2TE1, Station 2+84, Secondary Location ...	97
Figure 2-46.	Back Anchor 2TE2, Station 2+84, Secondary Location	99
Figure 2-47.	Left Rib Anchors (2TE3 and 2TE5) and Inspection Borehole 2B1, Station 2+84, Secondary Location	101
Figure 2-48.	Right Rib Anchors (2TE4 and 2TE6) and Inspection Borehole 2B2, Station 2+84, Secondary Location	103
Figure 2-49.	Tape Extensometer Used for Tunnel Convergence Measurements	105
Figure 2-50.	Side View of the Borehole Scanner Used in the TDE (Numbers correspond to items listed in Table 2-5)	107
Figure 2-51.	End View of the Borehole Scanner Used in the TDE (Numbers correspond to items listed in Table 2-5).....	109
Figure 2-52.	Front View of Borehole Video System Console (Numbers correspond to items listed in Table 2-4)	111
Figure 2-53.	Rear View of Borehole Video System Console (Numbers correspond to items listed in Table 2-4)	113
Figure 2-54.	Elevation view of the High-speed Camera Experiment.....	117
Figure 3-1.	Radial Acceleration and Velocity Data from Station 3700-2 using 7.5% Discriminators - MISTY ECHO	140
Figure 3-2.	Radial Acceleration and Velocity Data from Station 3700-3 using 7.5% Discriminators - MISTY ECHO	141
Figure 3-3.	Radial Acceleration and Velocity Data from Station 3700-2 using 15% Discriminators - MISTY ECHO	142

Volume 1 FIGURES (continued)

<u>Figure</u>		<u>Page</u>
Figure 3-4.	Radial Acceleration and Velocity Data from Station 3700-3 using 15% Discriminators - MISTY ECHO	143
Figure 3-5.	Radial Acceleration and Velocity Data from Station 3700-1 using 7.5% Discriminators - MISTY ECHO	144
Figure 3-6.	Radial Acceleration and Velocity Data from Station 3700-1 using 15% Discriminators - MISTY ECHO	145
Figure 3-7.	Vertical Acceleration and Velocity Data from Station 3700-1 using 7.5% Discriminators - MISTY ECHO	146
Figure 3-8.	Vertical Acceleration and Velocity Data from Station 3700-1 using 15% Discriminators - MISTY ECHO	147
Figure 3-9.	Transverse Acceleration and Velocity Data from Station 3700-1 using 7.5% Discriminators - MISTY ECHO	148
Figure 3-10.	Transverse Acceleration and Velocity Data from Station 3700-1 using 7.5% Discriminators - MISTY ECHO	149
Figure 3-11.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-1 - Vertical Motion	150
Figure 3-12.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-1 - Radial Motion	151
Figure 3-13.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-1 - Transverse Motion	152
Figure 3-14.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-2 - Vertical Motion	153
Figure 3-15.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-2 - Radial Motion	154
Figure 3-16.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-2 - Transverse Motion	155
Figure 3-17.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-3 - Vertical Motion	156
Figure 3-18.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-3 - Radial Motion	157
Figure 3-19.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-3 - Transverse Motion	158
Figure 3-20.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-4 - Vertical Motion	159
Figure 3-21.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-4 - Radial Motion	160
Figure 3-22.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-4 - Transverse Motion	161
Figure 3-23.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-5 - Vertical Motion	162
Figure 3-24.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-5 - Radial Motion	163
Figure 3-25.	Ratio of Signal-to-Noise versus Frequency for the Raw Data, Station 3700-5 - Transverse Motion	164
Figure 3-26.	Comparison of Vertical Free-field and Tunnel Wall Accelerations	165
Figure 3-27.	Comparison of Vertical Free-Field and Tunnel Wall Velocities	166
Figure 3-28.	Comparison of Vertical Free-Field and Tunnel Wall Displacements	167
Figure 3-29.	Comparison of Radial Free-Field and Tunnel Wall Accelerations	168
Figure 3-30.	Comparison of Radial Free-Field and Tunnel Wall Velocities	169

Volume 1 FIGURES (continued)

<u>Figure</u>		<u>Page</u>
Figure 3-31.	Comparison of Radial Free-Field and Tunnel Wall Displacements	170
Figure 3-32.	Comparison of Transverse Free-Field and Tunnel Wall Accelerations	171
Figure 3-33.	Comparison of Transverse Free-Field and Tunnel Wall Velocities	172
Figure 3-34.	Comparison of Transverse Free-Field and Tunnel Wall Displacements	173
Figure 3-35.	Ratios of Tunnel Wall/Free-Field PSRVs for Vertical Motions	174
Figure 3-36.	Ratios of Tunnel Wall/Free-Field PSRVs for Radial Motions	175
Figure 3-37.	Ratios of Tunnel Wall/Free-Field PSRVs for Transverse Motions	176
Figure 3-38.	Three-Dimensional Hodograph for the Initial 2 s of Motion - Free-Field Measurement (Note: Each square represents a change in time of 0.1 s)	177
Figure 3-39.	Three-Dimensional Hodograph for the Initial 2 s of Motion - Left Rib Measurement (Note: Each square represents a change in time of 0.1 s)	178
Figure 3-40.	Three-Dimensional Hodograph for the Initial 2 s of Motion - Right Rib Measurement (Note: Each square represents a change in time of 0.1 s)	179
Figure 3-41.	Three-Dimensional Hodograph for the Initial 2 s of Motion - Tunnel Back Measurement (Note: Each square represents a change in time of 0.1 s)	180
Figure 3-42.	Three-Dimensional Hodograph for the Initial 2 s of Motion - Tunnel Invert Measurement (Note: Each square represents a change in time of 0.1 s)	181
Figure 3-43.	Outward Displacements of Survey Markers on the Ribs	182
Figure 3-44.	Lateral Displacements of Survey Markers on the Ribs	183
Figure 3-45.	Vertical Displacement of Survey Markers on the Ribs	184
Figure 3-46.	Vector Displacement of Survey Markers on the Ribs	185
Figure 3-47.	Convergence Measurements Made at the Primary Location, Station 56+18	186
Figure 3-48.	Convergence Measurements Made at the Secondary Location, U12n.22 Bypass, Station 2+84	187
Figure 3-49.	Pre-Shot Convergence Measurements Made at the Primary Location, Station 56+18	188
Figure 3-50.	Pre-Shot Convergence Measurements Made at the Secondary Location, U12n.22 Bypass, Station 2+84	189
Figure 3-51.	Post-Shot Convergence Measurements Made at the Primary Location, Station 56+18	190
Figure 3-52.	Comparison of Permanent Displacements of Gage-Mounting Bolts and Residual Displacements Taken from Ground Motion Time Histories	191
Figure 3-53.	Comparison of Permanent Displacements of Gage-Mounting Bolts and Tunnel Convergence Measurements	192
Figure 3-54.	Results of Pre-Shot Borehole Inspections	193
Figure 3-55.	Results of Post-Shot Borehole Inspections	194
Figure 3-56.	Layout of Documentary Photography at the Primary Tunnel Section of the TDE, Left Rib	195
Figure 3-57.	Layout of Documentary Photography at the Primary Tunnel Section of the TDE, Right Rib	196

Volume 1 FIGURES (continued)

<u>Figure</u>		<u>Page</u>
Figure 3-58.	Overall View of the TDE Taken at Station 56+20 - Pre-Test	197
Figure 3-59.	Overall View of the TDE Taken at Station 56+20 - Post-Test	199
Figure 3-60.	Overall View of the TDE Taken at Station 55+80 - Pre-Test	201
Figure 3-61.	Overall View of the TDE Taken at Station 55+80 - Post-Test	203
Figure 3-62.	Right Rib, Invert-to-Spring Line from 55+80 to ~55+90 - Pre-Test	205
Figure 3-63.	Right Rib, Spring Line-to-Vent Line from 55+80 to ~55+90 - Pre-Test	207
Figure 3-64.	Tunnel Back, Right Rib Side of Vent Line from 55+80 to ~55+90 - Pre-Test	209
Figure 3-65.	Left Rib, Spring Line-to-Vent Line from 55+80 to ~55+90 - Pre-Test	211
Figure 3-66.	Left Rib, Invert-to-Spring Line from 55+80 to ~55+90 - Pre-Test	213
Figure 3-67.	Right Rib, Invert-to-Spring Line from 55+80 to ~55+90 - Post-Test	215
Figure 3-68.	Right Rib, Spring Line-to-Vent Line from 55+80 to ~55+90 - Post-Test	217
Figure 3-69.	Tunnel Back, Right Rib Side of Vent Line from 55+80 to ~55+90 - Post-Test	219
Figure 3-70.	Left Rib, Spring Line-to-Vent Line from 55+80 to ~55+90 - Post-Test	221
Figure 3-71.	Tunnel Back - Left Rib Side of Vent Line from 55+80 to ~55+90 - Post-Test	223
Figure 3-72.	Left Rib, Invert-to-Spring Line from 55+80 to ~55+90 - Post-Test	225
Figure 3-73.	Right Rib, Invert-to-Spring Line from 55+90 to ~56+00 - Pre-Test	227
Figure 3-74.	Right Rib, Spring Line-to-Vent Line from 55+90 to ~56+00 - Pre-Test	229
Figure 3-75.	Tunnel Back, Right Rib Side of Vent Line from 55+90 to ~56+00 - Pre-Test	231
Figure 3-76.	Left Rib, Spring Line-to-Vent Line from 55+90 to ~56+00 - Pre-Test	233
Figure 3-77.	Left Rib, Invert-to-Spring Line from 55+90 to ~56+00 - Pre-Test	235
Figure 3-78.	Right Rib, Invert-to-Spring Line from 55+90 to ~56+00 - Post-Test	237
Figure 3-79.	Right Rib, Spring Line-to-Vent Line from 55+90 to ~56+00 - Post-Test	239
Figure 3-80.	Tunnel Back, Right Rib Side of Vent Line from 55+90 to ~56+00 - Post-Test	241
Figure 3-81.	Left Rib, Spring Line-to-Vent Line from 55+90 to ~56+00 - Post-Test	243
Figure 3-82.	Tunnel Back - Left Rib Side of Vent Line from 55+90 to ~56+00 - Post-Test	245
Figure 3-83.	Left Rib, Invert-to-Spring Line from 55+90 to ~56+00 - Post-Test	247
Figure 3-84.	Close-up of Damage to Left Rib from 55+90 to ~56+00 - Post-Test	249

Volume 1 FIGURES (continued)

<u>Figure</u>		<u>Page</u>
Figure 3-85.	Right Rib, Invert-to-Spring Line from 56+00 to ~56+10 - Pre-Test	251
Figure 3-86.	Right Rib, Spring Line-to-Vent Line from 56+00 to ~56+10 - Pre-Test	253
Figure 3-87.	Tunnel Back, Right Rib Side of Vent Line from 56+00 to ~56+10 - Pre-Test	255
Figure 3-88.	Left Rib, Spring Line-to-Vent Line from 56+00 to ~56+10 - Pre-Test	257
Figure 3-89.	Left Rib, Invert-to-Spring Line from 56+00 to ~56+10 - Pre-Test	259
Figure 3-90.	Right Rib, Invert-to-Spring Line from 56+00 to ~56+10 - Post-Test	261
Figure 3-91.	Right Rib, Spring Line-to-Vent Line from 56+00 to ~56+10 - Post-Test	263
Figure 3-92.	Tunnel Back, Right Rib Side of Vent Line from 56+00 to ~56+10 - Post-Test	265
Figure 3-93.	Left Rib, Spring Line-to-Vent Line from 56+00 to ~56+10 - Post-Test	267
Figure 3-94.	Tunnel Back, Left Rib Side of Vent Line from 56+00 to ~56+10 - Post-Test	269
Figure 3-95.	Left Rib, Invert-to-Spring Line from 56+00 to ~56+10 - Post-Test	271
Figure 3-96.	Close-up of Damage to Left Rib from 56+00 to ~56+10 - Post-Test	273
Figure 3-97.	Right Rib, Invert-to-Spring Line from 56+10 to ~56+20 - Pre-Test	275
Figure 3-98.	Right Rib, Spring Line-to-Vent Line from 56+10 to ~56+20 - Pre-Test	277
Figure 3-99.	Tunnel Back, Right Rib Side of Vent Line from 56+10 to ~56+20 - Pre-Test	279
Figure 3-100.	Left Rib, Spring Line-to-Vent Line from 56+10 to ~56+20 - Pre-Test	281
Figure 3-101.	Left Rib, Invert-to-Spring Line from 56+10 to ~56+20 - Pre-Test	283
Figure 3-102.	Right Rib, Invert-to-Spring Line from 56+10 to ~56+20 - Post-Test	285
Figure 3-103.	Right Rib, Spring Line-to-Vent Line from 56+10 to ~56+20 - Post-Test	287
Figure 3-104.	Tunnel Back, Right Rib Side of Vent Line from 56+10 to ~56+20 - Post-Test	289
Figure 3-105.	Left Rib, Spring Line-to-Vent Line from 56+10 to ~56+20 - Post-Test	291
Figure 3-106.	Tunnel Back, Left Rib Side of Vent Line from 56+10 to ~56+20 - Post-Test	293
Figure 3-107.	Left Rib, Invert-to-Spring Line from 56+10 to ~56+20 - Post-Test	295
Figure 3-108.	Close-up of Damage to Left Rib from 56+10 to ~56+20 - Post-Test	297
Figure 3-109.	Rock Fragments that Spalled into Borehole 1B1 During the Explosion	299
Figure 3-110.	Overall View of the Secondary Location of the TDE Looking Toward the Portal - Pre-Test	301
Figure 3-111.	Overall View of the Secondary Location of the TDE Looking Away from the Portal - Post-Test	303

Volume 1 FIGURES (concluded)

<u>Figure</u>		<u>Page</u>
Figure 3-112.	Stress Relief Fracture Near Secondary Location - Pre-Test	305
Figure 3-113.	Stress Relief Fracture Near Secondary Location - Post-Test	307
Figure 3-114.	Comparison of Radial Displacement Digitized from the High-speed Photography and the Radial Displacement Derived from the Acceleration Measured at Station 3700-2	309
Figure 3-115.	Comparison of Radial Velocity Derived from the High-speed Photography and the Radial Velocity Derived from the Acceleration Measured at Station 3700-2	310
Figure 3-116.	Still Photograph of the Left Rib at Time of Detonation (Taken from the high-speed photography experiment)	311
Figure 3-117.	Still Photograph of the Left Rib 350 ms After Detonation (Taken from the high-speed photography experiment)	313
Figure 4-1.	Comparison of PSRV Response Spectra Calculated for Design Basis Earthquake Ground Motions (Blume, 1985) and Free-field Ground Motions Measured in the TDE.	318

Volume 1 TABLES

<u>Table</u>		<u>Page</u>
Table 2-1.	Description of Stratigraphic Units Present in the Vicinity of MISTY ECHO	12
Table 2-2.	Media Properties in the Vicinity of the TDE	13
Table 2-3.	MISTY ECHO TDE Ground Motion Equipment Inventory List	14
Table 2-4.	Borehole Video System Equipment Inventory List	15
Table 2-5.	Borehole Scanner Parts List	16
Table 3-1.	Low Pass Filter Cutoff Frequencies Used in Processing MISTY ECHO Ground Motion Data	133
Table 3-2.	Arrival Times and Peak Amplitudes Determined from the TDE Ground Motion Data	134
Table 3-3.	Ratio of Tunnel Wall Motion to Free-Field Motions ..	135
Table 3-4.	Permanent Displacements of Rock Bolts Used as Survey Markers	136
Table 3-5.	Permanent Displacements of Gage Mounting Bolts	137
Table 3-6.	Tunnel Convergence Calculated from Relative Motion of Gage Mounts	138
Table 3-7.	Tunnel Convergence Calculated from Relative Motion of Rock Bolts Used as Survey Markers	139

Volume 2 CONTENTS

APPENDIX A: Ground Motion Data	A-1
APPENDIX B: Ground Motion Data Processing Techniques.....	B-1
APPENDIX C: Tunnel Convergence Experiment Tape Extensometer Calibrations and Data.....	C-1
APPENDIX D: Information from, and Candidate Information for, the Site and Engineering Property Data Base and the Reference Information Base.....	D-1

Volume 2 FIGURES

<u>Figure</u>	<u>Page</u>
Figure A-1. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Vertical Motion, 10s Time Scale.....	A-3
Figure A-2. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Vertical Motion, 2s Time Scale.....	A-4
Figure A-3. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Radial Motion, 10s Time Scale.....	A-5
Figure A-4. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Radial Motion, 2s Time Scale.....	A-6
Figure A-5. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Transverse Motion, 10s Time Scale.....	A-7
Figure A-6. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Transverse Motion, 2s Time Scale.....	A-8
Figure A-7. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Vertical Motion, 10s Time Scale.....	A-9
Figure A-8. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Vertical Motion, 2s Time Scale.....	A-10
Figure A-9. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Radial Motion, 10s Time Scale.....	A-11
Figure A-10. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Radial Motion, 2s Time Scale.....	A-12
Figure A-11. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Transverse Motion, 10s Time Scale.....	A-13
Figure A-12. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Transverse Motion, 2s Time Scale.....	A-14
Figure A-13. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Vertical Motion, 10s Time Scale.....	A-15
Figure A-14. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Vertical Motion, 2s Time Scale.....	A-16
Figure A-15. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Radial Motion, 10s Time Scale.....	A-17
Figure A-16. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Radial Motion, 2s Time Scale.....	A-18

Volume 2 FIGURES (continued)

<u>Figure</u>		<u>Page</u>
Figure A-17.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Transverse Motion, 10s Time Scale.....	A-19
Figure A-18.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Transverse Motion, 2s Time Scale.....	A-20
Figure A-19.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Vertical Motion, 10s Time Scale.....	A-21
Figure A-20.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Vertical Motion, 2s Time Scale.....	A-22
Figure A-21.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Radial Motion, 10s Time Scale.....	A-23
Figure A-22.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Radial Motion, 2s Time Scale.....	A-24
Figure A-23.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Transverse Motion, 10s Time Scale.....	A-25
Figure A-24.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Transverse Motion, 2s Time Scale.....	A-26
Figure A-25.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Vertical Motion, 10s Time Scale.....	A-27
Figure A-26.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Vertical Motion, 2s Time Scale.....	A-28
Figure A-27.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Radial Motion, 10s Time Scale.....	A-29
Figure A-28.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Radial Motion, 2s Time Scale.....	A-30
Figure A-29.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Transverse Motion, 10s Time Scale.....	A-31
Figure A-30.	Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Transverse Motion, 2s Time Scale.....	A-32
Figure A-31.	PSRV Response Spectrum Calculated for Station 3700-1, Tunnel Back, Vertical Motion.....	A-33
Figure A-32.	PSRV Response Spectrum Calculated for Station 3700-1, Tunnel Back, Radial Motion.....	A-34
Figure A-33.	PSRV Response Spectrum Calculated for Station 3700-1, Tunnel Back, Transverse Motion.....	A-35
Figure A-34.	PSRV Response Spectrum Calculated for Station 3700-2, Left Rib, Vertical Motion.....	A-36
Figure A-35.	PSRV Response Spectrum Calculated for Station 3700-2, Left Rib, Radial Motion.....	A-37
Figure A-36.	PSRV Response Spectrum Calculated for Station 3700-2, Left Rib, Transverse Motion.....	A-38

Volume 2 FIGURES (continued)

<u>Figure</u>	<u>Page</u>
Figure A-37. PSRV Response Spectrum Calculated for Station 3700-3, Free-field, Vertical Motion.....	A-39
Figure A-38. PSRV Response Spectrum Calculated for Station 3700-3, Free-field, Radial Motion.....	A-40
Figure A-39. PSRV Response Spectrum Calculated for Station 3700-3, Free-field, Transverse Motion.....	A-41
Figure A-40. PSRV Response Spectrum Calculated for Station 3700-4, Right Rib, Vertical Motion.....	A-42
Figure A-41. PSRV Response Spectrum Calculated for Station 3700-4, Right Rib, Radial Motion.....	A-43
Figure A-42. PSRV Response Spectrum Calculated for Station 3700-4, Right Rib, Transverse Motion.....	A-44
Figure A-43. PSRV Response Spectrum Calculated for Station 3700-5, Invert, Vertical Motion.....	A-45
Figure A-44. PSRV Response Spectrum Calculated for Station 3700-5, Invert, Radial Motion.....	A-46
Figure A-45. PSRV Response Spectrum Calculated for Station 3700-5, Invert, Transverse Motion.....	A-47
Figure A-46. Power Density Spectrum Calculated for the Final Data, Station 3700-1, Tunnel Back, Vertical Motion.....	A-48
Figure A-47. Power Density Spectrum Calculated for the Final Data, Station 3700-1, Tunnel Back, Radial Motion.....	A-49
Figure A-48. Power Density Spectrum Calculated for the Final Data, Station 3700-1, Tunnel Back, Transverse Motion.....	A-50
Figure A-49. Power Density Spectrum Calculated for the Final Data, Station 3700-2, Left Rib, Vertical Motion.....	A-51
Figure A-50. Power Density Spectrum Calculated for the Final Data, Station 3700-2, Left Rib, Radial Motion.....	A-52
Figure A-51. Power Density Spectrum Calculated for the Final Data, Station 3700-2, Left Rib, Transverse Motion.....	A-53
Figure A-52. Power Density Spectrum Calculated for the Final Data, Station 3700-3, Free-field, Vertical Motion.....	A-54
Figure A-53. Power Density Spectrum Calculated for the Final Data, Station 3700-3, Free-field, Radial Motion.....	A-55
Figure A-54. Power Density Spectrum Calculated for the Final Data, Station 3700-3, Free-field, Transverse Motion.....	A-56
Figure A-55. Power Density Spectrum Calculated for the Final Data, Station 3700-4, Right Rib, Vertical Motion.....	A-57
Figure A-56. Power Density Spectrum Calculated for the Final Data, Station 3700-4, Right Rib, Radial Motion.....	A-58
Figure A-57. Power Density Spectrum Calculated for the Final Data, Station 3700-4, Right Rib, Transverse Motion.....	A-59
Figure A-58. Power Density Spectrum Calculated for the Final Data, Station 3700-5, Invert, Vertical Motion.....	A-60
Figure A-59. Power Density Spectrum Calculated for the Final Data, Station 3700-5, Invert, Radial Motion.....	A-61
Figure A-60. Power Density Spectrum Calculated for the Final Data, Station 3700-5, Invert, Transverse Motion.....	A-62

Volume 2 FIGURES (continued)

<u>Figure</u>		<u>Page</u>
Figure B-1.	Raw Acceleration Data from Station 3700-1, Tunnel Back, Vertical Motion	C-13
Figure B-2.	Raw Acceleration Data from Station 3700-1, Tunnel Back, Radial Motion	B-14
Figure B-3.	Raw Acceleration Data from Station 3700-1, Tunnel Back, Transverse Motion	B-15
Figure B-4.	Raw Acceleration Data from Station 3700-2, Left Rib, Vertical Motion	B-16
Figure B-5.	Raw Acceleration Data from Station 3700-2, Left Rib, Radial Motion	B-17
Figure B-6.	Raw Acceleration Data from Station 3700-2, Left Rib, Transverse Motion	B-18
Figure B-7.	Raw Acceleration Data from Station 3700-3, Free Field, Vertical Motion	B-19
Figure B-8.	Raw Acceleration Data from Station 3700-3, Free Field, Radial Motion	B-20
Figure B-9.	Raw Acceleration Data from Station 3700-3, Free Field, Transverse Motion	B-21
Figure B-10.	Raw Acceleration Data from Station 3700-4, Right Rib, Vertical Motion	B-22
Figure B-11.	Raw Acceleration Data from Station 3700-4, Right Rib, Radial Motion	B-23
Figure B-12.	Raw Acceleration Data from Station 3700-4, Right Rib, Transverse Motion	B-24
Figure B-13.	Raw Acceleration Data from Station 3700-5, Invert, Vertical Motion	B-25
Figure B-14.	Raw Acceleration Data from Station 3700-5, Invert, Radial Motion	B-26
Figure B-15.	Raw Acceleration Data from Station 3700-5, Invert, Transverse Motion	R-27
Figure B-16.	Expanded View of Initial Transverse Data Recorded at Station 3700-1	B-28
Figure B-17.	Expanded View of Transverse Velocity at Station 3700-1 Before Spike Removal	B-29
Figure B-18.	Expanded View of Transverse Velocity at Station 3700-1 After Spike Removal	B-30
Figure B-19.	Expanded View of Transverse Velocity at Station 3700-1 After Slope Correction	B-31
Figure B-20.	Power Density Spectra of Noise and Data for Transverse Acceleration at Station 3700-1	B-32
Figure B-21.	Power Density Spectra of Noise and Data for Vertical Acceleration at Station 3700-2	B-33
Figure B-22.	Difference Between the Noise and Data Power Spectra Plotted versus Frequency for Vertical Acceleration at Station 3700-2	B-34
Figure B-23.	Transverse Velocity from Station 3700-1 After "Normal" High-pass Filtering at 0.75 Hz	B-35
Figure B-24.	Transverse Displacement from Station 3700-1 After "Normal" High-pass Filtering at 0.75 Hz	B-36
Figure B-25.	Transverse Velocity from Station 3700-1 Showing Signal Superimposed on Low Frequency Noise	B-37
Figure B-26.	Transverse Velocity from Station 3700-1 After "Hand" Correction	B-38

Volume 2 FIGURES (concluded)

<u>Figure</u>	<u>Page</u>
Figure B-27. Transverse Displacement from Station 3700-1 After "Hand" Correction	B-39
Figure B-28. Illustration of Automated Correction Technique	B-40
Figure B-29. Transverse Acceleration from Station 3700-1 After One Pass Through Automated Correction Technique ...	B-41
Figure B-30. Transverse Velocity from Station 3700-1 After One Pass Through Automated Correction Technique	B-42
Figure B-31. Transverse Displacement from Station 3700-1 After One Pass Through Automated Correction Technique ...	B-43
Figure B-32. Numerical Integration of Corrected (i.e., Spike and Slope Removal) Transverse Acceleration from Station 3700-1	B-44
Figure B-33. Difference Between Data Shown In Figure B-32 and Figure B-30	B-45
Figure B-34. Transverse Acceleration from Station 3700-1 After Second Pass Through Automated Correction Technique.....	B-46
Figure B-35. Transverse Velocity from Station 3700-1 After Second Pass Through Automated Correction Technique	B-47
Figure B-36. Transverse Displacement from Station 3700-1 After Second Pass Through Automated Correction Technique.....	B-48
Figure B-37. Velocity Curve Subtracted from Transverse Velocity in the Second Pass Through Automated Correction Technique	B-49
Figure B-38. Final Transverse Acceleration Curve from Station 3700-1	B-50
Figure B-39. Final Transverse Velocity Curve from Station 3700-1	B-51
Figure B-40. Final Transverse Displacement Curve from Station 3700-1	B-52
Figure B-41. Comparison of the Power Density Spectra of the Raw and Final Data for Transverse Acceleration from Station 3700-1	B-53
Figure B-42. Difference of the Power Density Spectra of the Raw and Final Data for Transverse Acceleration from Station 3700-1 Plotted versus Frequency	B-54
Figure B-43. Comparison of the Power Density Spectra of the Raw and Final Data for Vertical Acceleration from Station 3700-1	B-55
Figure B-44. Difference of the Power Density Spectra of the Raw and Final Data for Vertical Acceleration from Station 3700-1 Plotted versus Frequency	B-56
Figure B-45. Difference Between Raw and Final Transverse Accelerations from Station 3700-1	B-57
Figure B-46. Difference Between Raw and Final Transverse Accelerations from Station 3700-3	B-58

Volume 2 TABLES

<u>Table</u>		<u>Page</u>
Table C-1.	Low-pass Filter Limits Used for MISTY ECHO	C-6
Table C-2.	Final Adjustments to Acceleration for MISTY ECHO ...	C-10

APPENDIX A: GROUND MOTION DATA

This appendix contains the final, corrected (as detailed in Appendix C) set of ground motion data. Figures A-1 through A-30 are the time histories plotted on time scales of 10 s and 2 s. The time histories are organized numerically by station number in the following manner:

- Vertical motions are presented first, radial motions next, and transverse motions last.
- Motion data plotted on the 10 s time scale for a particular record is presented first.

Figures A-31 through A-45 contain the 5 % damped PSRVs calculated for the ground motion accelerations. These are presented in the same fashion as the time histories. Power density spectra calculated for these data were organized as the other data presented in this appendix and are shown in Figures A-46 through A-60.

Figure A-1. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Vertical Motion, 10s Time Scale

Figure A-2. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Vertical Motion, 2s Time Scale

Figure A-3. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Radial Motion, 10s Time Scale

Figure A-4. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Radial Motion, 2s Time Scale

Figure A-5. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Transverse Motion, 10s Time Scale

Figure A-6. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-1, Tunnel Back, Transverse Motion, 2s Time Scale

Figure A-7. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Vertical Motion, 10s Time Scale

Figure A-8. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Vertical Motion, 2s Time Scale

Figure A-9. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Radial Motion, 10s Time Scale

Figure A-10. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Radial Motion, 2s Time Scale

Figure A-11. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Transverse Motion, 10s Time Scale

Figure A-12. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-2, Left Rib, Transverse Motion, 2s Time Scale

Figure A-13. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Vertical Motion, 10s Time Scale

Figure A-14. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Vertical Motion, 2s Time Scale

Figure A-15. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Radial Motion, 10s Time Scale

Figure A-16. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Radial Motion, 2s Time Scale

Figure A-17. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Transverse Motion, 10s Time Scale

Figure A-18. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-3, Free-field, Transverse Motion, 2s Time Scale

Figure A-19. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Vertical Motion, 10s Time Scale

Figure A-20. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Vertical Motion, 2s Time Scale

Figure A-21. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Radial Motion, 10s Time Scale

Figure A-22. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Radial Motion, 2s Time Scale

Figure A-23. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Transverse Motion, 10s Time Scale

Figure A-24. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-4, Right Rib, Transverse Motion, 2s Time Scale

Figure A-25. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Vertical Motion, 10s Time Scale

Figure A-26. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Vertical Motion, 2s Time Scale

Figure A-27. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Radial Motion, 10s Time Scale

Figure A-28. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Radial Motion, 2s Time Scale

Figure A-29. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Transverse Motion, 10s Time Scale

Figure A-30. Final Acceleration, Velocity and Displacement Time Histories for Station 3700-5, Invert, Transverse Motion, 2s Time Scale

Figure A-31. PSRV Response Spectrum Calculated for Station 3700-1, Tunnel Back, Vertical Motion

Figure A-32. PSRV Response Spectrum Calculated for Station 3700-1, Tunnel Back, Radial Motion

Figure A-33. PSRV Response Spectrum Calculated for Station 3700-1, Tunnel Back, Transverse Motion

Figure A-34. PSRV Response Spectrum Calculated for Station 3700-2, Left Rib, Vertical Motion

Figure A-35. PSRV Response Spectrum Calculated for Station 3700-2, Left Rib, Radial Motion

Figure A-36. PSRV Response Spectrum Calculated for Station 3700-2, Left Rib, Transverse Motion

Figure A-37. PSRV Response Spectrum Calculated for Station 3700-3, Free-field, Vertical Motion

Figure A-38. PSRV Response Spectrum Calculated for Station 3700-3, Free-field, Radial Motion

Figure A-39. PSRV Response Spectrum Calculated for Station 3700-3, Free-field, Transverse Motion

Figure A-40. PSRV Response Spectrum Calculated for Station 3700-4, Right Rib, Vertical Motion

Figure A-41. PSRV Response Spectrum Calculated for Station 3700-4, Right Rib, Radial Motion

Figure A-42. PSRV Response Spectrum Calculated for Station 3700-4, Right Rib, Transverse Motion

Figure A-43. PSRV Response Spectrum Calculated for Station 3700-5, Invert, Vertical Motion

Figure A-44. PSRV Response Spectrum Calculated for Station 3700-E, Invert, Radial Motion

Figure A-45. PSRV Response Spectrum Calculated for Station 3700-5, Invert, Transverse Motion

Figure A-46. Power Density Spectrum Calculated for the Final Data, Station 3700-1, Tunnel Back, Vertical Motion

Figure A-47. Power Density Spectrum Calculated for the Final Data, Station 3700-1, Tunnel Back, Radial Motion

Figure A-48. Power Density Spectrum Calculated for the Final Data, Station 3700-1, Tunnel Back, Transverse Motion

Figure A-49. Power Density Spectrum Calculated for the Final Data, Station 3700-2, Left Rib, Vertical Motion

Figure A-50. Power Density Spectrum Calculated for the Final Data, Station 3700-2, Left Rib, Radial Motion

Figure A-51. Power Density Spectrum Calculated for the Final Data, Station 3700-2, Left Rib, Transverse Motion

Figure A-52. Power Density Spectrum Calculated for the Final Data, Station 3700-3, Free-field, Vertical Motion

Figure A-53. Power Density Spectrum Calculated for the Final Data, Station 3700-3, Free-field, Radial Motion

Figure A-54. Power Density Spectrum Calculated for the Final Data, Station 3700-3, Free-field, Transverse Motion

Figure A-55. Power Density Spectrum Calculated for the Final Data, Station 3700-4, Right Rib, Vertical Motion

Figure A-56. Power Density Spectrum Calculated for the Final Data, Station 3700-4, Right Rib, Radial Motion

Figure A-57. Power Density Spectrum Calculated for the Final Data, Station 3700-4, Right Rib, Transverse Motion

Figure A-58. Power Density Spectrum Calculated for the Final Data, Station 3700-5, Invert, Vertical Motion

Figure A-59. Power Density Spectrum Calculated for the Final Data, Station 3700-5, Invert, Radial Motion

Figure A-60. Power Density Spectrum Calculated for the Final Data, Station 3700-5, Invert, Transverse Motion

Appendix B: Ground Motion Data Processing Techniques

CONTENTS

B.1	INTRODUCTION	B-2
B.2	DATA CORRECTION	B-2
B.3	USE OF STANDARD TECHNIQUES	B-3
B.4	DEVELOPMENT OF SOLUTIONS	B-5
B.5	ANALYSIS OF SOLUTION	B-8
B.6	SUMMARY	B-9
B.7	REFERENCES	B-10

B.1 INTRODUCTION:

A large body of UNE ground motion data has been collected for the Yucca Mountain Project (YMP) over the last 12 years. These data have been collected to document the characteristics (frequency content, amplitude, signal duration) of UNE ground motions near the repository site. In general, the characteristics of the data in this data set have been similar. This similarity has allowed the data processing techniques (see Long, 1988 TP-82 for a description) to become "fine tuned" to this specific type of ground motion data. The objectives of the MISTY ECHO Tunnel Dynamics Experiment, and thus the corresponding data recorded, were quite different from the normal situation. These differences were manifested in frequency content, amplitude, and signal duration. MISTY ECHO data contained higher frequencies (over 100 Hz vs less than 100 Hz for normal data), larger amplitudes (over 30 g vs less than 0.05 g), and shorter signal duration (10 s vs 60 s). Raw acceleration time histories recorded for MISTY ECHO are shown in Figures B-1 through B-15.

Under normal conditions this data set would go through several operations in processing. The first step is to digitize the data at 500 samples/s. (This sample rate is adequate to preserve frequencies to about 200 Hz.) The second step is to purge spurious signals from the data.³⁶ These "raw" data are then filtered using Finite Impulse Response (FIR) filters. Low-pass filtering is accomplished first, the sample rate is decreased to 200 samples/s, and the data are high-pass filtered. After filtering, these accelerations are zero averaged and integrated in the frequency domain to yield velocities. The velocities are corrected (trend removal and zero averaged) and integrated in the frequency domain to yield displacements. These displacements are corrected (zero averaged and parabolic correction) and the final data set consisting of filtered accelerations, corrected velocities, and corrected displacements are saved.

The initial attempt to process the MISTY ECHO data followed the above process with the appropriate modifications for frequency content (e.g., an initial sample rate of 1 kHz). This attempt failed for reasons that will become apparent in subsequent discussions. Section B.2 describes the data corrections made to the raw data set. The results and problems in processing the data by the standard techniques are discussed in Section B.3. Solutions to the processing problems are developed and tested in Section B.4. The techniques used to produce the final data set are analyzed in Section B.5, and summarized in Section B.6.

B.2 DATA CORRECTION:

The tangential acceleration recorded at Station 3700-1 (Figure B-3) has been selected to illustrate the problems and demonstrate the techniques used to process these data. There is a noticeable noise spike on this time history

36. Spurious signals may originate from several sources, including the acquisition system, recording system, or in the transmission link. See Phillips, Stearns and Long (1990) for a discussion of noise sources and noise removal techniques.

at 1 second.³⁷ Although not noticeable in Figure B-3, a noise spike, similar to the spike at 1 second, occurs near zero time. The time scale of the data was expanded to determine if there were any other such spikes in this record in the time domain of major motions (0.1 s to 0.3 s). This expansion is shown in Figure B-16. This plot shows that there are no obvious noise spikes in this section of the time history. These noise spikes were eliminated by interpolating new values for any point less than $-10. \text{ m/s}^2$ or greater than $10. \text{ m/s}^2$ during the two time periods 0.0 to 0.1 s and 0.9 to 1.1 s.

At the same time, the gage orientation in the header record was changed from "AT" (indicating acceleration tangential), to "A-262.3" (indicating acceleration and the orientation of the gage in degrees with respect to shot point). The orientation was not supplied to the data reduction personnel at the time the data were digitized.

Two additional problems were still present in the data. The first was the existence of noise spikes at zero time which were not completely eliminated by the previously-mentioned purges, or were not affected at all because they occurred just before zero time. The specific erroneous amplitudes were identified and replaced with either the preceding or the succeeding amplitude. This had the effect of eliminating the sudden shift at zero time which may be seen by comparing the before and after plots of velocity in Figures B-17 and B-18 respectively.

The second problem was the change in slope of the velocity baseline (see Figure B-18) close to zero time, but prior to signal arrival. Because this occurs before signal arrival, it is identified as an artifice of the acquisition system. In order to successfully process these data, this problem had to be solved. The technique used was to select two time periods on each side of the change: -0.016 to 0.0 , and 0.02 to 0.18 s (just before signal arrival). These two time periods were averaged for the acceleration record and the difference in the averages determined. The average difference was then subtracted from the acceleration record for all data points prior to zero time. The effect on the velocity record for the example gage can be seen by comparing Figure B-19 with Figure B-18. At this point all known anomalies from the start of digitizing out to 25 seconds after zero time had been removed. The period $-15.$ to $25.$ seconds was chosen for analysis.

B.3 USE OF STANDARD TECHNIQUES:

All 15 records were analyzed to determine the power spectrum of the signals. The low-pass filter limits shown in Table B-1 were determined from plots like the examples shown in Figures B-20 and B-21. Figure B-20 shows the spectrum of the example gage where the data+noise spectrum (solid line) is greater than the noise spectrum (dotted line) for the frequencies shown. This indicates that the data contains frequencies at least up to 500 Hz. Figure B-21 shows another example (3700-2 AV) where the highest frequency apparent in the data is about 350 Hz (intersection of the noise and data+noise spectra). Figure B-22 is a plot of the difference between the data+noise and the noise

37. This spike is identified as noise because there is no ground motion phenomena that would explain a signal of this amplitude, in this time frame.

spectra shown in Figure B-21. Plots of this type were also used in determining the limits in Table B-1.

TABLE B-1

LOW-PASS FILTER LIMITS USED FOR MISTY ECHO

<u>STATION</u>	<u>GAGE</u>	<u>LIMIT IN HERTZ</u>
3700-1	AV	281
	A-262.3	None
	A-352.3	None
3700-2	AV	346
	A-262.3	None
	A-352.3	281
3700-3	AV	100
	A-262.3	161
	A-352.3	161
3700-4	AV	None
	A-262.3	300
	A-352.3	None
3700-5	AV	375
	A-262.3	None
	A-352.3	None

There are two ways the data could be high-pass filtered using the standard filtering program. First, the normal method is to reduce the sample rate prior to filtering. Because of the frequency content of the signals, any reduction in sample rate eliminates definition of the higher frequencies and thus eliminates data. The second method is to high-pass filter the data at the initial sample rate of 1000 points per second. At this sample rate, the lowest frequency attainable from the high-pass filter is 0.75 Hz (see Stearns, S. D., Digital Signal Analysis, 1975, Chap 8., Pg 115). This would eliminate low-frequency noise, but unfortunately it also would eliminate low-frequency data. Figures B-23 and B-24 show the sample record high-pass filtered at 0.75 Hz with no low-pass filtering. All records filtered in this manner show zero residual displacement.³⁸

Because of the problems with the standard high-pass filter discussed above, it was decided to do no high-pass filtering at this time, but to low-pass filter the data at the limits shown in Table B-1. This was done. While the low-pass filter removes high-frequency noise, nothing has been done to

38. As mentioned earlier, the data processing system has been "fine tuned" to the "standard" UNE. An example of this specialization is the fact that the filter code was developed using the assumption that the data are recorded in an elastic material and therefore, no residual displacement would be observed. While these data were recorded in the elastic region, residual displacements were observed (possibly due to localized failures or cavity formation, the ground motions in this experiment are 4 orders of magnitude larger than measured in the "standard" UNE). Therefore, this assumption does not apply to these data. Unsuccessful efforts were made to modify the code to handle residual displacements.

remove the low-frequency noise. This low-frequency noise is illustrated in Figure B-25. Obviously, the low-frequency curve superimposed on the velocity must be removed in order to obtain a usable record.

In years past, data of this sort was processed by estimating the "correct" base line that should exist in the velocity curve and then correcting the acceleration record to attain the desired velocity base line. This was a slow painstaking process, for the slope of the base line had to be changed over many time periods for each record. However, in an attempt to process these data, this method was tried. The time period zero to 10 seconds was selected for analysis because it appeared that the motion had ceased by 10 seconds. The resulting velocity and displacement for the example record is shown in Figures B-26 and B-27. While the velocities shown in Figure B-26 are reasonable, the displacements in Figure B-27 are questionable because of the nonuniqueness of the solution. In addition, because of the amount of individual judgement used in this technique, it is unlikely that two people would derive exactly the same result. It is doubtful that the same individual, repeating the analysis process, could achieve identical results. This lack of reproducibility is a serious limitation to this method.

B.4 DEVELOPMENT OF SOLUTIONS:

When the hand-adjusted method just illustrated was used regularly in years past, the large storage capacity of today's computers did not exist, so the problem could not be easily approached. However, because the entire signal of interest can easily be fit into the large capacity of today's machines, a new approach is possible.

After experimenting with various ideas, one method was determined to produce satisfactory results. This method was developed using judgement, experience and iteration. The criteria used to evaluate this method included observation of the wave shapes, comparison of residual displacements from the time histories and the measured permanent displacements, and comparison of the frequency content of the signals before and after correction. This method is described below.

First a numerical integration of acceleration is done to get velocity. Next, the low frequency noise curve present in the velocity record is defined. This curve is differentiated and the result subtracted from the acceleration record. The major difficulty in the process is in the definition of the curve to be removed from the velocity. This "correction curve," as it will be called, is defined by working backward in time through the velocity curve until a point is reached where the velocity is near zero. This is essential in determining the curve through the main acceleration phase of the signal. The point where the velocity must be at or near zero is selected as the point just before signal arrival at the station. (For all of the MISTY ECHO data the time of 0.18 s was used.)

The last point of velocity time history is used as the initial point selected for the correction curve. Note that in the algorithm, this point is stored as the last point of the correction curve. The second point on the correction curve is determined from a straight-line interpolation between the current point and a point on the velocity curve N points back in time. N was determined by estimating the duration of the main acceleration signal and

converting that time to the number of points using sample rate. In the case of MISTY ECHO, 1 second, or 1000 points, was used.

The example shown in Figure B-28 will help to illustrate the process. The first interpolation would be made between points A1 and B1 and the point generated on the correction curve would be the point prior to A1 in time. The point just generated then becomes A1 and B1 is backed up one point in time on the velocity curve and the next correction curve point interpolated. Point A1 is always taken as the last point generated on the correction curve while point B1 is taken as the next preceding point in time on the velocity curve. Thus it can be seen that each succeeding correction point is very close to its' predecessor and because the B1 points are taken from the oscillating velocity curve, the correction curve follows closely the gradient of the velocity curve but greatly dampens the oscillations.

The point B2 in the diagram is the point before signal arrival. When B1 reaches that point the correction curve has been generated up to the point A2. If the process were to continue, the dashed line in Figure B-28 would be generated as a part of the correction curve. To avoid this, all points on the correction curve from A2 to B2 are interpolated using A2 and B2 as the end points.

Then, using A3 and B3 as starting points, generation of the correction curve continues as before. When point B4 (the first point on the velocity curve) is reached, N is divided by 2 so that interpolation is made from A4 to B5. Each time point B4 is reached, N is again divided by 2 until the entire correction curve has been generated.

After the correction curve is generated, it is differentiated and the result is subtracted from the acceleration curve. The acceleration, velocity, and displacement curves thus generated for the example record are shown as Figures B-29, B-30, and B-31 respectively. There is no discernible change in acceleration (compare Fig. B-29 to Fig. B-3), but in order to see how the velocity curve has been changed, it is necessary to compare it to the straight numerical integration generated within the program. It is shown as Figure B-32. Figure B-33 is a plot of the values actually subtracted from the velocity curve shown in Figure B-32 to attain the velocity shown in Figure B-30. At this point the velocity waveform is discernible in detail. However, from the displacement in Figure B-31, it is obvious that the velocity is only close to what it should be.

Through iteration and evaluation against the criteria listed above, it was found that putting the data through the same process a second time removed most of the remaining low-frequency noise. The results are seen in Figures B-34, B-35, and B-36 for the example record. The amount subtracted from velocity in this pass is shown in Figure B-37. Figures B-35 and B-37 may be compared to Figure B-30 to see the change in velocity. Figure B-36 is close to the final displacement for this gage. Note that prior to signal arrival the background "noise" is clearly visible as displacement deflections, and after the signal has passed (at about 10 s), the signal returns to background deflections. After the signal has passed, the displacement should be constant except for background deflections. In the example case it is not. If there is slope in the displacement, as there is in this case, it may be removed by introducing a relatively slight change in acceleration at the appropriate

point. The point at which the change in slope should occur is a matter of judgement. For these data, the points used were either the starting point of the record, or the positive or negative peak. If it is obvious that the slope is constant throughout the record, the correction is made in the first point of the data record. Because this will always be well before signal arrival, it will have no effect on the actual data. If the displacement is level until the signal arrives, but then acquires a slope for the remainder of the record (as is the case in the example in Figure B-36), something has happened during signal passage to cause the change in slope.

A slight change could be made to any acceleration point and the slope would be changed from that point on, but the question is, which point should be changed? Let us assume that the most important value being determined by these recordings is the peak acceleration. If the change in slope occurred at either the positive or negative peak acceleration, that peak could be lower than the actual acceleration. In a study of this kind it is better to err to the side of conservatism if one is to err at all. Therefore, if a change is to be made in acceleration at this critical point, it is better to subtract a small amount from the negative peak or add a small amount to the positive peak in order to change the slope in the displacement. This is what was done where necessary to produce the final data set.

In the example, it was decided to add -0.319 m/s^2 to the negative peak acceleration, which changed it from -149.3 to -149.6 m/s^2 , an increase of 0.20 per cent in the peak acceleration--a relatively slight change. The results may be seen in Figures B-38 through B-40. While there is no discernable change in acceleration or velocity, the displacement is now level after signal passage. This is the final displacement record for the example gage. The other 14 accelerations were processed in a similar manner and required final adjustments as shown in Table B-2.

TABLE B-2

FINAL ADJUSTMENTS TO ACCELERATION FOR MISTY ECHO

<u>Station</u>	<u>Gage</u>	<u>Adjustments</u>		<u>% Change in Peak</u>
		<u>Amount</u>	<u>Location</u>	
3700-1	AV	0.	N/A	0.
	A-352.3	0.	N/A	0.
	A-262.3	-0.319	Neg Peak	0.20
3700-2	AV	+0.429	-15 Sec	0.
	A-352.3	+0.322	-15 Sec	0.
	A-262.3	0.	N/A	0.
3700-3	AV	-0.337	Neg Peak	0.46
	A-352.3	+0.506	Pos Peak	0.19
	A-262.3	-0.178	Neg Peak	0.43
3700-4	AV	0.	N/A	0.
	A-352.3	+0.475	-15 Sec	0.
	A-262.3	0.	N/A	0.
3700-5	AV	+0.752	-15 Sec	0.
	A-352.3	0.	N/A	0.
	A-262.3	+0.854	-15 Sec	0.

As can be seen from Table B-2, two-thirds of the time no adjustment to the peak values was made, and in the cases where an adjustment was made, it was less than one-half of 1 % of the original peak value.

B.5 ANALYSIS OF SOLUTION:

The primary algorithm used in this method of processing is in essence a high-pass filter and as such must be inspected to determine what effect it has had on the frequency content of the data. Accordingly, an attempt was made to try to determine this effect.

First, the spectral content of the signals after filtering was determined and compared to the spectral content prior to both the low-pass filtering and the high-pass filtering accomplished with the newly-designed filter. Figure B-41 shows the spectrum of the raw data and the spectrum of the filtered data on the same plot for the example record. The ratio of the filtered to unfiltered power density is plotted in Figure B-42. Because no low-pass filtering was done on the example record, the same plots are shown for the vertical gage at Station 3700-1 in Figures B-43 and B-44. This record was low-pass filtered at 281 Hz. The changes in power density at the high-frequency end are all a result of the frequency-domain filtering with the usual low-pass filter. The changes in the low-frequency end are due to the newly-designed Linear Oscillating Numerical Gradient (LONG) high-pass filter.

Second, the difference between the "raw" accelerations and the final output accelerations was plotted on the same scale as the input accelerations for all gages. The plot for the example gage is shown in Figure B-45.

Because the low-pass filter was not used on this record, the differences are due solely to the changes made by the LONG high-pass filter. They appear to be well below the level of the noise when compared to Figure B-3, and in fact are barely discernible when plotted to this scale. The difference plot for the tangential gage at Station 3700-3 is shown in Figure B-46. Here the differences are the sum of the changes made by both the low-pass and high-pass filters and are quite evident. Again, the changes in high frequency are caused by the low-pass filter while the changes in low frequency are caused by the high-pass filter. This record was chosen for Figure B-46 because it illustrated best the changes caused by both filters.

B.6 SUMMARY

The MISTY ECHO data were scrutinized intensely in the analysis process and the best data set is provided herein as the final data for this event. The processing consisted of the following steps:

1. All records were digitized with a 7.5% deviation from the center-band frequency and a digitizing rate of 1000 points per second.
2. All records were digitized with a 15% deviation from the center-band frequency and a digitizing rate of 1000 points per second.
3. Where the 7.5% records were limited, the 15% records were selected for further processing. Where there was no limiting, the 7.5% records were used.
4. Obvious extraneous noise spikes were removed from the records at about zero time and around 1 s.
5. The sudden shift in the acceleration records at zero time was removed by adjusting the records prior to zero time. This could have no effect whatsoever on the actual data signals.
6. A spectral analysis was done on all records to determine the frequency content.
7. Several attempts were made to process these data using previously-proven and accepted procedures.
8. Where the frequency content of the data was determined to be below 500 Hz, the records involved were low-pass filtered using the normal low-pass filter to remove the high-frequency noise.
9. All records were then processed through the LONG high-pass filter developed specifically for this event using a filter length of 1 s and a signal arrival time of 0.18 s.
10. Where there was a slope present in the displacement record, it was removed by applying a correction to the acceleration record either at the first point of acceleration (-15 seconds), or by increasing the absolute amplitude of the positive or negative acceleration peak.

B.7 REFERENCES

Long, J. W., 1988. Procedures for Acquiring, Digitizing, Processing, Storing, and Retrieving Ground Motion Data from Underground Nuclear Explosions, TP-82, Sandia National Laboratories Nuclear Waste Repository Technology Department Technical Procedure (NNA.890501.0198)

Phillips, J. S., S. D. Stearns and J. W. Long, 1990. "Seismic Data Processing using Digital Signal Analysis Techniques", Proceedings of the 36th International Instrumentation Symposium, May 7th - 10th, 1990, Instrumentation Society of America, Research Triangle Park, NB (NNA.910809.0015)

Stearns, S. D., 1975. Digital Signal Analysis, Chapter 8, p. 115, Hayden Book Company, Inc., Rochelle Park, NJ (NNA.900530.0069)

Figure B-1. Raw Acceleration Data from Station 3700-1, Tunnel Back, Vertical Motion

× 15 PER CENT DEVIATION

Figure B-2. Raw Acceleration Data from Station 3700-1, Tunnel Back, Radial Motion

Figure B-3. Raw Acceleration Data from Station 3700-1, Tunnel Back, Transverse Motion

Figure B-4. Raw Acceleration Data from Station 3700-2, Left Rib, Vertical Motion

* 15 PER CENT DEVIATION

Figure B-5. Raw Acceleration Data from Station 3700-2, Left Rib, Radial Motion

* 15 PER CENT DEVIATION

Figure B-6. Raw Acceleration Data from Station 3700-2, Left Rib, Transverse Motion

Figure B-7. Raw Acceleration Data from Station 3700-3, Free Field, Vertical Motion

Figure B-8. Raw Acceleration Data from Station 3700-3, Free Field, Radial Motion

* 15 PER CENT DEVIATION

Figure B-9. Raw Acceleration Data from Station 3700-3, Free Field, Transverse Motion

Figure B-10. Raw Acceleration Data from Station 3700-4, Right Rib, Vertical Motion

Figure B-11. Raw Acceleration Data from Station 3700-4, Right Rib, Radial Motion

Figure B-12. Raw Acceleration Data from Station 3700-4, Right Rib, Transverse Motion

Figure B-13. Raw Acceleration Data from Station 3700-5, Invert, Vertical Motion

Figure B-14. Raw Acceleration Data from Station 3700-5, Invert, Radial Motion

Figure B-15. Raw Acceleration Data from Station 3700-5, Invert, Transverse Motion

Figure B-16. Expanded View of Initial Transverse Data Recorded at Station 3700-1

Figure B-17. Expanded View of Transverse Velocity at Station 3700-1 Before Spike Removal

Figure B-18. Expanded View of Transverse Velocity at Station 3700-1 After Spike Removal

Figure B-19. Expanded View of Transverse Velocity at Station 3700-1 After Slope Correction

Figure B-20. Power Density Spectra of Noise and Data for Transverse Acceleration at Station 3700-1

SOLID LINE-DATA
DOTTED LINE-BACKGROUND NOISE

Figure B-21. Power Density Spectra of Noise and Data for Vertical Acceleration at Station 3700-2.

SOLID LINE-DATA
DOTTED LINE-BACKGROUND NOISE

Figure B-22. Difference Between the Noise and Data Power Spectra Plotted versus Frequency for Vertical Acceleration at Station 3700-2

× 15 PER CENT DEVIATION

Figure B-23. Transverse Velocity from Station 3700-1 After "Normal" High-pass Filtering at 0.75 Hz

Figure B-24. Transverse Displacement from Station 3700-1 After "Normal" High-pass Filtering at 0.75 Hz

Figure B-25. Transverse Velocity from Station 3700-1 Showing Signal Superimposed on Low Frequency Noise

Figure B-26. Transverse Velocity from Station 3700-1 After "Hand" Correction

Figure B-27. Transverse Displacement from Station 3700-1 After "Hand" Correction

Figure B-28. Illustration of Automated Correction Technique

Figure B-29. Transverse Acceleration from Station 3700-1 After One Pass Through Automated Correction Technique

Figure B-30. Transverse Velocity from Station 3700-1 After One Pass Through Automated Correction Technique

Figure B-31. Transverse Displacement from Station 3700-1 After One Pass Through Automated Correction Technique

Figure B-32. Numerical Integration of Corrected (i.e., Spike and Slope Removal) Transverse Acceleration from Station 3700-1

Figure B-33. Difference Between Data Shown In Figure B-32 and Figure B-30

Figure B-34. Transverse Acceleration from Station 3700-1 After Second Pass Through Automated Correction Technique

Figure B-35. Transverse Velocity from Station 3700-1 After Second Pass Through Automated Correction Technique

Figure B-36. Transverse Displacement from Station 3700-1 After Second Pass Through Automated Correction Technique

Figure B-37. Velocity Curve Subtracted from Transverse Velocity in the Second Pass Through Automated Correction Technique

Figure B-38. Final Transverse Acceleration Curve from Station 3700-1

Figure B-39. Final Transverse Velocity Curve from Station 3700-1

Figure B-40. Final Transverse Displacement Curve from Station 3700-1

Figure B-41. Comparison of the Power Density Spectra of the Raw and Final Data for Transverse Acceleration from Station 3700-1

Figure B-42. Difference of the Power Density Spectra of the Raw and Final Data for Transverse Acceleration from Station 3700-1 Plotted versus Frequency

Figure B-43. Comparison of the Power Density Spectra of the Raw and Final Data for Vertical Acceleration from Station 3700-1

Figure B-44. Difference of the Power Density Spectra of the Raw and Final Data for Vertical Acceleration from Station 3700-1 Plotted versus Frequency

Figure B-45. Difference Between Raw and Final Transverse Accelerations from Station 3700-1

Figure B-46. Difference Between Raw and Final Transverse Accelerations from Station 3700-3

Appendix C: Tunnel Convergence Experiment Tape Extensometer Calibrations and Data

This appendix contains information concerning the tape extensometer used in the tunnel convergence measurements of the Tunnel Dynamics Experiment. This information includes extensometer calibration data, logs of the visual inspection performed on the holes drilled for the tape extensometer anchors and the primary extensometer data.

TAPE EXTENSOMETER CALIBRATION DATA FORM

TAPE EXTENSOMETER: Sinco/Tennametrics 50 TAPE EXT Tape Extensometer
Manufacturer Model Type

ID NUMBER: NA SERIAL NUMBER: 820331-2

EXPERIMENT: Evaluating the Effects of Explosively EP#: 0020 REV 0
Generated Loads on Tunnels

ACTIVITY LOCATION: SADC Rock Mech. Lab. DIAL GAGE ID: NA

	MANUFACTURER AND MODEL	MANUFACTURER'S SERIAL NUMBER	CALIBRATION EXPIRES
CALIBRATION			
DIAL GAUGE:	<u>ELE 2P 0.0001"</u>	<u>NA</u>	<u>11/9/89</u>
TEMP. SENSOR:	<u>NA</u>	<u>SATC 107L-8X-0725</u>	<u>5/9/89</u>
<u>NA</u> :	<u>NA</u>	<u>NA</u>	<u>NA</u>

DISPLACEMENT DATA

UNITS: inches

TEST TEMP.: 29 °C (Units)

REFERENCE	READOUT	REFERENCE	READOUT	REFERENCE	READOUT	DATE & TIME
<u>0.0000</u>	<u>1.739</u>	<u>0.3503</u>	<u>1.399</u>	<u>0.3001</u>	<u>1.941</u>	<u>11/11/88 11:00</u>
<u>0.0505</u>	<u>1.689</u>	<u>0.4009</u>	<u>1.341</u>	<u>0.2509</u>	<u>1.990</u>	<u>NA</u>
<u>0.1011</u>	<u>1.637</u>	<u>0.4502</u>	<u>1.289</u>	<u>0.2006</u>	<u>1.541</u>	<u>NA</u>
<u>0.1520</u>	<u>1.587</u>	<u>0.5010</u>	<u>1.239</u>	<u>0.1506</u>	<u>1.588</u>	<u>NA</u>
<u>0.2001</u>	<u>1.542</u>	<u>0.4502</u>	<u>1.290</u>	<u>0.1006</u>	<u>1.640</u>	<u>NA</u>
<u>0.2506</u>	<u>1.490</u>	<u>0.4001</u>	<u>1.342</u>	<u>0.0504</u>	<u>1.691</u>	<u>NA</u>
<u>0.3009</u>	<u>1.440</u>	<u>0.3507</u>	<u>1.392</u>	<u>0.0000</u>	<u>1.742</u>	<u>11/11/88 15:30</u>

DISTANCE DATA

READING NO.	READING	DATE	TEMP. (Units)
<u>1</u>	<u>3'0"</u>	<u>0.620"</u>	<u>11/11/88</u>
<u>2</u>	<u>NA</u>	<u>NA</u>	<u>29 °C</u>
<u>AVERAGE</u>	<u>0.620"</u>	<u>NA</u>	<u>NA</u>

COMMENTS: (initial and date all comments, make reference to logbooks as appropriate) 1. only the beginning and ending dates and times are given. 11/11/88 KM

PERSONNEL:

Print: Kevin Mann Signature: Kevin Mann Date 11/11/88

Print: ROBERT BELMONT Signature: Robert Belmont Date 2/24/89

Figure 9. Calibration Data Form for the Tape Extensometer

TAPE EXTENSOMETER CALIBRATION DATA FORM

TAPE EXTENSOMETER: Sinco/Terrametrics 50 TAPE EXT Tape Extensometer
 Manufacturer Model Type

ID NUMBER: NA SERIAL NUMBER: 820331-2

EXPERIMENT: Evaluating the Effects of Explosively Generated Loads on Tunnels EP#: 0020 REV 0

ACTIVITY LOCATION: SATC Rock Mech. Lab. DIAL GAGE ID: NA

	MANUFACTURER AND MODEL	MANUFACTURER'S SERIAL NUMBER	CALIBRATION EXPIRES
CALIBRATION			
DIAL GAUGE:	<u>ELE 2P 0.0001"</u>	<u>NA</u>	<u>11/9/89</u>
TEMP. SENSOR:	<u>NA</u>	<u>SATC 1076-8X-C725</u>	<u>5/9/89</u>
<u>NA</u> :	<u>NA</u>	<u>NA</u>	<u>NA</u>

DISPLACEMENT DATA

UNITS: inches

TEST TEMP.: 24°C (Units)

REFERENCE	READOUT	REFERENCE	READOUT	REFERENCE	READOUT	DATE & TIME
<u>0.0000</u>	<u>0.762</u>	<u>0.3502</u>	<u>0.408</u>	<u>0.3002</u>	<u>0.958</u>	<u>11/11/88 11:00</u>
<u>0.0506</u>	<u>0.709</u>	<u>0.4009</u>	<u>0.359</u>	<u>0.2507</u>	<u>0.509</u>	<u>NA</u>
<u>0.1001</u>	<u>0.663</u>	<u>0.4509</u>	<u>0.309</u>	<u>0.2005</u>	<u>0.557</u>	<u>NA</u>
<u>0.1503</u>	<u>0.621</u>	<u>0.5007</u>	<u>0.259</u>	<u>0.1509</u>	<u>0.612</u>	<u>NA</u>
<u>0.2009</u>	<u>0.559</u>	<u>0.4505</u>	<u>0.310</u>	<u>0.1006</u>	<u>0.658</u>	<u>NA</u>
<u>0.2503</u>	<u>0.510</u>	<u>0.4005</u>	<u>0.360</u>	<u>0.0500</u>	<u>0.707</u>	<u>NA</u>
<u>0.3002</u>	<u>0.460</u>	<u>0.3506</u>	<u>0.410</u>	<u>0.0003</u>	<u>0.759</u>	<u>11/11/88 15:30</u>

DISTANCE DATA

READING NO.	READING	DATE	TEMP. (Units)
<u>1</u>	<u>NA</u>	<u>NA</u>	<u>NA</u>
<u>2</u>	<u>NA</u>	<u>NA</u>	<u>NA</u>
<u>AVERAGE</u>	<u>NA</u>		

COMMENTS: (initial and date all comments, make reference to logbooks as appropriate) 1. Only the beginning and ending dates and times are given. 11/11/88 km

PERSONNEL:

Print: Kevin Mann Signature: Kevin Mann Date 11/11/88
 Print: ROBERT BELMAN Signature: Robert Belman Date 2/24/89

Figure 9. Calibration Data Form for the Tape Extensometer

TAPE EXTENSOMETER CALIBRATION DATA FORM

TAPE EXTENSOMETER: Sisco/Terrametrics SD TAPE EXT Tape Extensometer
Manufacturer Model Type

ID NUMBER: NA SERIAL NUMBER: 820331-2

EXPERIMENT: Eval. the Effects of Expl. Gen. Loads on Tun. EP#: 0020 REV 0

ACTIVITY LOCATION: SARC Rock Mech. Lab. DIAL GAGE ID: NA

	MANUFACTURER AND MODEL	MANUFACTURER'S SERIAL NUMBER	CALIBRATION EXPIRES
CALIBRATION			
DIAL GAUGE:	<u>ELE 2P 0.0001"</u>	<u>NA</u>	<u>11/9/89</u>
TEMP. SENSOR:	<u>Omega 115KC</u>	<u>0495</u>	<u>5/9/89</u>
<u>NA</u> :	<u>NA</u>	<u>NA</u>	<u>NA</u>

DISPLACEMENT DATA

UNITS: inches TEST TEMP.: 23°C (Units)

REFERENCE	READOUT	REFERENCE	READOUT	REFERENCE	READOUT	DATE & TIME
<u>0.0000</u>	<u>1.790</u>	<u>0.3504</u>	<u>1.388</u>	<u>0.3001</u>	<u>1.139</u>	<u>2/24/89 9:30</u>
<u>0.0506</u>	<u>1.688</u>	<u>0.4006</u>	<u>1.338</u>	<u>0.2504</u>	<u>1.489</u>	<u>NA</u>
<u>0.1009</u>	<u>1.639</u>	<u>0.4507</u>	<u>1.289</u>	<u>0.2005</u>	<u>1.539</u>	<u>NA</u>
<u>0.1503</u>	<u>1.588</u>	<u>0.5005</u>	<u>1.238</u>	<u>0.1503</u>	<u>1.587</u>	<u>NA</u>
<u>0.2006</u>	<u>1.541</u>	<u>0.4501</u>	<u>1.288</u>	<u>0.1004</u>	<u>1.637</u>	<u>NA</u>
<u>0.2502</u>	<u>1.490</u>	<u>0.4005</u>	<u>1.338</u>	<u>0.0502</u>	<u>1.689</u>	<u>NA</u>
<u>0.3002</u>	<u>1.437</u>	<u>0.3503</u>	<u>1.388</u>	<u>0.0003</u>	<u>1.738</u>	<u>2/24/89 16:30</u>

DISTANCE DATA

READING NO.	READING	DATE	TEMP. (Units)
1 <u>3'0"</u>	<u>0.611"</u>	<u>2/24/89</u>	<u>23°C</u>
2	<u>NA</u>	<u>NA</u>	<u>NA</u>
AVERAGE	<u>0.611"</u>		

COMMENTS: (initial and date all comments, make reference to logbooks as appropriate) 1. only the beginning and ending dates and times are given. 2/24/89 17:00 KM

PERSONNEL:

Print: Kevin Mann Signature: Kevin Mann Date 2/24/89
Print: ROBERT BELLMAN Signature: Robert Bellman Date 2/24/89

Figure 9. Calibration Data Form for the Tape Extensometer

TAPE EXTENSOMETER CALIBRATION DATA FORM

TAPE EXTENSOMETER: Sisco/Terrametrics 50 TAPE EXT Type Extensometer
 Manufacturer Model Type

ID NUMBER: NA SERIAL NUMBER: 820881-2

EXPERIMENT: Eval. the Effects of Exp. Gen. Loads on Tun. EP#: 0020 REV 0

ACTIVITY LOCATION: SAFC Rock Mech. Lab DIAL GAGE ID: NA

	MANUFACTURER AND MODEL	MANUFACTURER'S SERIAL NUMBER	CALIBRATION EXPIRES
CALIBRATION			
DIAL GAUGE:	<u>ELE 2P 0.0001"</u>	<u>NA</u>	<u>11/9/89</u>
TEMP. SENSOR:	<u>Omega 1MTC</u>	<u>0995</u>	<u>5/9/89</u>
<u>NA</u> :	<u>NA</u>	<u>NA</u>	<u>NA</u>

DISPLACEMENT DATA

UNITS: inches

TEST TEMP.: 23°C (Units)

REFERENCE	READOUT	REFERENCE	READOUT	REFERENCE	READOUT	DATE & TIME
<u>0.0000</u>	<u>0.775</u>	<u>0.3504</u>	<u>0.423</u>	<u>0.3002</u>	<u>0.475</u>	<u>2/24/89 9:30</u>
<u>0.0506</u>	<u>0.723</u>	<u>0.4006</u>	<u>0.374</u>	<u>0.2502</u>	<u>0.522</u>	<u>NA</u>
<u>0.1005</u>	<u>0.674</u>	<u>0.4506</u>	<u>0.324</u>	<u>0.2004</u>	<u>0.572</u>	<u>NA</u>
<u>0.1506</u>	<u>0.624</u>	<u>0.5005</u>	<u>0.274</u>	<u>0.1500</u>	<u>0.624</u>	<u>NA</u>
<u>0.2005</u>	<u>0.572</u>	<u>0.4501</u>	<u>0.324</u>	<u>0.1005</u>	<u>0.671</u>	<u>NA</u>
<u>0.2506</u>	<u>0.524</u>	<u>0.4002</u>	<u>0.373</u>	<u>0.0507</u>	<u>0.721</u>	<u>NA</u>
<u>0.3003</u>	<u>0.475</u>	<u>0.3505</u>	<u>0.420</u>	<u>0.0003</u>	<u>0.772</u>	<u>2/24/89 16:30</u>

DISTANCE DATA

READING NO.	READING	DATE	TEMP. (Units)
<u>1</u>	<u>NA</u>	<u>NA</u>	<u>NA</u>
<u>2</u>	<u>NA</u>	<u>NA</u>	<u>NA</u>
AVERAGE	<u>NA</u>		

COMMENTS: (initial and date all comments, make reference to logbooks as appropriate) 1. Only the beginning and ending dates and times are given: 2/24/88 17:00 KFM

PERSONNEL:

Print: Kevin Mann Signature: Kevin Mann Date 2/24/89

Print: ROBERT BELMAN Signature: Robert Belman Date 2/24/89

Figure 9. Calibration Data Form for the Tape Extensometer

CALIBRATION RESULTS

DATE	RANGE (in)	ACCURACY ¹ (%)	ACCEPT/REJECT ²
11-11-88	1.239 - 1.739	0.29	ACCEPT
11-11-88	0.259 - 0.762	0.30	ACCEPT
2-24-89	1.238 - 1.740	0.21	ACCEPT
2-24-89	0.274 - 0.775	0.27	ACCEPT

¹ Calculated as described in EP-0020, Rev D

² Acceptability criterion is $\pm 0.5\%$ accuracy

TAPE EXTENSOMETER ANCHOR HOLE INSPECTIONS

HOLE IDENTIFICATION *	POSITION	DEPTH (M)	FEATURE
<u>PRIMARY LOCATION</u>			
1 TE 1	INVERT	.15	End of hole. Hole is full of standing water, precluding visual inspection
1 TE 2	BACK	.08 .30 .58	Shotcrete-rock interface Fracture, 1-2 cm wide, ^{striking} parallel to drift axis, dipping approx. 70° End of hole
1 TE 3	SOUTH RIB	.08 .13 .15 .25 .46	Shotcrete-rock interface Fracture, 2 cm wide Fracture, 0.6-1 cm wide Fracture, 1-2 cm wide End of hole
1 TE 4	NORTH RIB	.05 .15 .13	Shotcrete-rock interface Fracture, 0.2-1 cm wide Possible fracture, < 0.2 cm wide
1 TE 5	SOUTH RIB	.10 .28 .41 .48	Shotcrete-rock interface Fracture, 0.6-1 cm wide Void pocket, 3 cm wide End of hole
1 TE 6	North rib	.04 .25 .30 .49	Shotcrete-rock interface Fracture, 0.6 cm wide Fracture, 0.6-1 cm wide End of hole
<u>SECONDARY LOCATION</u>			
2 TE 1	INVERT	.13 .25 .39	Fracture, 0.6 cm wide, horizontal, ^{striking} parallel to drift Fracture, 0.6 cm wide, horizontal, ^{striking} parallel to drift End of hole
2 TE 2	back	.48	End of hole
2 TE 3	WEST RIB	.13	End of hole
2 TE 4	EAST RIB	.53	End of hole
2 TE 5	WEST RIB	.48	End of hole
2 TE 6	EAST RIB	.48	End of hole

* SEE FIGURES 2-39 & 2-40 IN VOL. 1 FOR LAYOUT OF ANCHORS

NOTE: FRACTURES ARE APPROXIMATELY VERTICAL AND STRIKE PARALLEL TO THE LONGITUDINAL AXIS OF THE DRIFT, EXCEPT WHERE STATED OTHERWISE.

Evaluating the effects of explosively generated loads on tunnels
 EP-0020, Rev 0
 TAPE EXTENSOMETER DATA: Absolute distances between anchors in inches

SITE 1

Date	Day	Anchor Pair				
		12	13	14	34	56
11-15-88	-25	198.58975	108.37800	175.43200	231.87775	221.10075
11-16-88	-24	198.58950	108.38075	175.41825	231.87725	221.10025
11-17-88	-23	198.58950	108.38400	175.42050	231.88075	221.09975
11-18-88	-22	198.58900	108.38500	175.42100	231.87175	221.10325
11-22-88	-18	198.59075	108.39325	175.42950		221.10250
11-29-88	-11	198.59400	108.38750	175.42225		221.10375
12-06-88	-4	198.58875	108.38400	175.41950		221.10250
12-15-88	5	197.09225	106.62100	175.48425	231.40950	220.36700
12-16-88	6	197.08125	106.63075	175.48550	231.41425	220.36125
12-19-88	9	197.05400	106.63100	175.48350	231.41400	220.35825
12-20-88	10	197.05150	106.63100	175.48900	231.41175	220.35600
12-21-88	11	197.05325	106.63050	175.48825	231.41450	220.35925
01-05-89	26	197.03000	106.63000	175.49525	231.43200	220.36575
01-13-89	34	197.01225	106.63900	175.49850	231.43950	220.37125
01-26-89	47	196.99425	106.62850	175.49550	231.43750	220.35825
02-02-89	54	196.98675	106.63125	175.48900	231.43125	220.35350

SITE 2

Date	Day	Anchor Pair						
		12	13	14	25	26	34	56
11-15-88	-25	133.37775	99.49925	105.53125	138.89275	142.06125	137.78475	141.33950
11-16-88	-24	133.95250	99.49575	105.52900	138.89800	142.05225	137.78325	141.33950
11-17-88	-23	133.98275	99.50000	105.53400	138.89815	142.06100	137.78075	141.33950
11-18-88	-22	133.87975	99.49150	105.53450	138.89675	142.06175	137.78300	141.33900
11-22-88	-18	133.87800	99.49725	105.53200	138.89600	142.06125	137.78300	141.34000
11-29-88	-11	133.87450	99.49975	105.53000	138.89750	142.05975	137.78275	141.33550
12-06-88	-4	133.85550	99.48913	105.51475	138.89200	142.05850	137.77675	141.34475
12-15-88	5	133.79175	99.45175	105.45425	138.89325	142.05800	137.78975	141.34225
12-16-88	6	133.79075	99.44650	105.45300	138.89675	142.05850	137.78750	141.34125
12-19-88	9	133.78725	99.45250	105.45275	138.89550	142.05950	137.78675	141.33975
12-20-88	10	133.78275	99.4660	105.45375	138.88775	142.06150	137.78950	141.34075
12-21-88	11	133.78400	99.4530	105.45400	138.88600	142.05650	137.78950	141.33550
01-05-89	26	133.81075	99.46150	105.47400	138.89500	142.05950	137.79200	141.34150
01-13-89	34	133.80650	99.45925	105.46400	138.89185	142.06250	137.78950	141.34400
01-26-89	47	133.85000	99.49500	105.48665	138.89475	142.06225	137.79115	141.34600
02-02-89	54	133.85384	99.51175	105.49325	138.88834	142.05625	137.78775	141.35025

Appendix D

Information from the Reference Information Base Used in this Reports

This report contains no information from the Reference Information Base.

Candidate Information for the Reference Information Base

This report contains no candidate information for the Reference Information Base.

Candidate Information for the Site & Engineering Properties Data Base

This report contains no candidate information for the Site Engineering Properties Data Base.

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