OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET

Complete Only Applicable Items

1. QA: QA

2. ☒ Analysis — Check all that apply

Type of Analysis	☒ Engineering	
	☐ Performance Assessment	
	☐ Scientific	
Intended Use of Analysis	☐ Input to Calculation	
	☒ Input to another Analysis or Model	
	☒ Input to Technical Document	
	☐ Input to other Technical Products	

Describe use:

This analysis will support the development of the *Physical and Chemical Environment Model* and the *Water Distribution and Removal Model.*

3. ☒ Model — Check all that apply

Type of Model	☐ Conceptual Model	☐ Abstraction Model
	☒ Mathematical Model	☐ System Model
	☐ Process Model	
Intended Use of Model	☐ Input to Calculation	
	☒ Input to another Model or Analysis	
	☒ Input to Technical Document	
	☐ Input to other Technical Products	

Describe use:

The results from this model will support the development of the *Physical and Chemical Environment Model* and the *Water Distribution and Removal Model.*

4. Title:

Drift Degradation Analysis

5. Document Identifier (including Rev. No. and Change No., if applicable):

ANL-EBS-MD-000027 REV 01

6. Total Attachments:

Fourteen

7. Attachment Numbers - No. of Pages in Each:

I-4, II-7 (plus 2 CDs), III-9, IV-6, V-11, VI-16, VII-2, VIII-5, IX-23, X-30, XI-22, XII-23, XIII-6, XIV-3

	Printed Name	Signature	Date
8. Originator	Dwayne C. Kicker	[signature]	10/31/00
9. Checker	Fei Duan	[signature]	10/31/00
10. Lead/Supervisor	Ernest L. Hardin	[signature]	10/31/00
11. Responsible Manager	Ernest L. Hardin	[signature]	10/31/00

12. Remarks:

Ming Lin provided a significant contribution to the development of Sections 6.3 and 6.4 of this document.

John Kemeny provided support in the analysis of seismic and thermal effects on drift degradation, and in the rock fall frequency assessment (Section 6.4.2).

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET
Complete Only Applicable Items

1. QA: QA

Page: 1 of: 103

2. [X] Analysis — Check all that apply

Type of Analysis:
- [X] Engineering
- [ ] Performance Assessment
- [ ] Scientific

Intended Use of Analysis:
- [ ] Input to Calculation
- [X] Input to another Analysis or Model
- [X] Input to Technical Document
- [ ] Input to other Technical Products

Describe use:

This analysis will support the development of the *Physical and Chemical Environment Model* and the *Water Distribution and Removal Model.*

3. [X] Model — Check all that apply

Type of Model:
- [ ] Conceptual Model
- [ ] Abstraction Model
- [X] Mathematical Model
- [ ] System Model
- [ ] Process Model

Intended Use of Model:
- [ ] Input to Calculation
- [X] Input to another Model or Analysis
- [X] Input to Technical Document
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Describe use:

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD
Complete Only Applicable Items

2. Analysis or Model Title:

Drift Degradation Analysis

3. Document Identifier (including Rev. No. and Change No., if applicable):

ANL-EBS-MD-000027 REV 01

4. Revision/Change No.	5. Description of Revision/Change
00	Initial issue.
00 / 1	The technical product cover sheet was changed to indicate that this document reports the development and use of a model. Section 6.5 on model validation was added. The report was changed to include results for 75°-azimuth emplacement drifts and to provide additional results for emplacement drifts with no backfill. The Document Input Reference System (DIRS) information was removed from document and made part of the records package. The numbering of the attachments has been changed to reflect removal of the DIRS information. Attachment VI is now Attachment I. Table 2 was modified. The description of the use of software routines in Section 3 was changed. The data in Tables 14, 15, 20, 21, 23, 24, and Figure 17 were corrected. Additional attachments were added to document the field observation of key blocks in the Cross Drift, and to document natural analogues for the seismic effect on rock fall.
01	The Tptpln fracture geometry inputs to DRKBA were revised to be consistent with the developed fracture geometry data in ANL-EBS-GE-000006. Output information for the Tptpln was revised throughout the report. The data and information presented in the supporting calculation, CAL-EBS-MD-000010 REV 00, has been updated and merged with this report. Therefore, this revision supersedes calculation CAL-EBS-MD-000010 REV 00. Additional seismic analyses have been included in Attachment V. Information supporting the analysis of drift degradation features, even and processes (FEPS) has been added in Section 6.6. Information supporting the resolution applicable Nuclear Regulatory Commission (NRC) key technical issues has been added in Section 6.7. A brief discussion of the impacts of the small-trace length fracture data on drift degradation has been added in Section 7.2. Attachments VIII through XI were added to include the information that was previously provided in calculation CAL-EBS-MD-000010 REV 00 (note that data for the Tptpln unit has been updated in these attachments). Drift profile figures were moved from Section 6.4.3 to Attachment XII. The calculation of mean input data based on source DTNs identified in Section 4.1 was added as documented in Attachment XIII. An assessment of the joint plane representation in the DRKBA rock fall model was added in Attachment XIV to provide additional bases for Assumption 5.1.

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TABLES

TABLES (Continued)

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TABLES (Continued)

Page

TABLES (Continued)

Page

ACRONYMS

ACC	Records Processing Center accession number
AMR	analysis and modeling report
AP	administrative procedure
CD	compact disc
CRWMS	Civilian Radioactive Waste Management System
DIRS	Document Input Reference System
DLS	Detailed Line Survey
DRKBA	Discrete Region Key Block Analysis
DTN	data tracking number
EBS	Engineered Barrier System
ECRB	Enhanced Characterization of the Repository Block
ESF	Exploratory Studies Facility
FEPs	features, events, and processes
FPGM	full periphery geologic map
g/cc	grams per cubic centimeter
GPa	gigapascal
Hz	Hertz
ICN	Interim Change Notice
km	kilometer
m	meter
m^3 or m^3	cubic meter
M&O	Management and Operating Contractor
MCS	Monte Carlo simulation
MPa	megapascal
NLP	Nevada line procedure
NRC	Nuclear Regulatory Commission
NRG	North Ramp geotechnical borehole
P-wave	primary-wave
Pa	pascal
PGA	peak ground acceleration
QA	quality assurance
QAP	quality administrative procedure

ACROYNMS (Continued)

S-wave	shear-wave
SD	systematic drilling borehole
SNL	Sandia National Laboratories
TBV	to be verified
TCw	Tiva Canyon welded tuff thermal mechanical unit
TDMS	Technical Data Management System
TIC	Technical Information Center
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
UDEC	Universal Distinct Element Code
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
YMP	Yucca Mountain Site Characterization Project
yr	year

1. PURPOSE

The purpose of this analysis and modeling report (AMR) is to analyze the deterioration of the rock mass surrounding the potential repository emplacement drifts, and provide data to the Engineered Barrier System (EBS) post-closure performance assessment. The drift degradation analysis provides data that may modify estimates of seepage into the emplacement drift due to mechanical effects of rock fall during the period of compliance for post-closure performance. This analysis has been developed according to the guidance provided by the *Development Plan for Drift Degradation Analysis* (CRWMS M&O 1999a). The output of this analysis documents expected drift deterioration for the repository design description (CRWMS M&O 2000e, p. 28). The analysis will provide input data to two EBS AMRs: the Physical and Chemical Environment Model, and the Water Distribution and Removal Model.

1.1 BACKGROUND

A probabilistic key block analysis was initially proposed as part of the Exploratory Studies Facility (ESF) design confirmation activities. These plans included an analysis of geotechnical mapping data from the ESF to identify the size of potential key blocks, assess specific key blocks occurring in the field, and conduct a stability analysis on these blocks, if necessary, to confirm the effectiveness of the existing ground support. Large key blocks are significant because they have the potential to increase ground support loads, and if disturbed by a seismic event, could potentially fail if the ground support is not adequate.

As part of this initial planning, technical literature sources were reviewed (see Section 6.5) for the purpose of determining the most appropriate approach to be used in the development of a key block analysis for the Yucca Mountain Site Characterization Project (YMP). As a result, the Discrete Region Key Block Analysis (DRKBA) software was purchased. The DRKBA probabilistic approach is unique and is distinguished from traditional key block analyses in that it assesses the maximum size of key blocks within a given number of simulations and also predicts the number of potential key blocks that will be formed within a referenced length of tunnel. The DRKBA approach also allows for a variety of tunnel and jointing configurations.

It was recognized that this key block analysis has the potential to provide necessary information to support several key project documents, including the Site Recommendation Report and the License Application. The potential users of the key block analysis include the Waste Package Department, the System Engineering Department, the Performance Assessment Department, and the Subsurface Facilities Department.

1.2 OBJECTIVES

The specific objectives of the drift degradation analysis are:

- to model the jointed configuration of the rock mass surrounding the emplacement drift cavity,
- to provide a statistical description of block sizes formed by fractures around the emplacement drifts for the lithologic units of the repository host horizon,

- to estimate changes in drift profiles resulting from progressive deterioration of the emplacement drifts both with and without backfill, and

- to provide an estimate of the time required for significant drift deterioration to occur.

1.3 WORK SCOPE

These activities involve developing models using analytical methods, including both a distinct element numerical code and the DRKBA (key block) numerical code, and performing calculations and statistical analyses to determine the expected quantities, locations, size distributions and frequencies of rock fall, based on the repository design description (CRWMS M&O 2000e, p. 28). Deteriorated drift profiles as a result of rock fall have been determined. This analysis has considered various emplacement drift orientations, with the drift azimuth varied in appropriate increments to examine the effect of orientation on key block size and frequency. This analysis has examined unsupported drifts, and applied static, thermal, and seismic loading conditions.

Revision 0 of this report included analyses with backfill as part of the baseline design. While backfill is no longer part of the baseline design, the backfill results have been included in this report for historical documentation.

1.4 ANALYSIS/MODEL APPLICABILITY

The drift degradation results with seismic consideration, including the drift profiles, are applicable for 5.5-m-diameter emplacement drifts oriented at specified bearings. The specified emplacement drift orientations include both the superseded repository baseline drifts with a drift azimuth of 108° (i.e., a bearing of N72W) (CRWMS M&O 1997a, pp. 22 and 33; Wilkins and Heath 1999), and the current emplacement drift orientation with an azimuth of 252°, or 72° (CRWMS M&O 2000e, p. 28). The current emplacement drift orientation is based on the recommendations of a drift orientation analysis (CRWMS M&O 1999d). The key block analysis is constrained by various joint configuration assumptions as identified in Section 5.

2. QUALITY ASSURANCE

This AMR has been developed in accordance with AP-3.10Q as an implementing document of Work Package 1201213EM1 (CRWMS M&O 1999b). A development plan (CRWMS M&O 1999a) was used, and a Technical Change Request was processed in accordance with AP-2.13Q and AP-3.4Q, respectively. A QAP-2-0 activity evaluation (CRWMS M&O 1999b) was performed for the preparation of this report, which showed that this analysis activity is subject to the controls of the QA program. Note that both the development plan (CRWMS M&O 1999a) and the activity evaluation (CRWMS M&O 1999b) were prepared prior to the issuance of AP-2.21Q. Since the revisions presented in this technical product do not represent a change in work scope, the existing technical product plan and activity evaluation (i.e., CRWMS M&O 1999a and CRMWS M&O 1999b) remain in effect.

There are no QAP-2-3 Classification of Permanent Items and NLP-2-0 Determination of Importance Evaluations directly applicable to the development of this document. Unverified and undetermined data are identified and tracked in accordance with AP-3.15Q.

All electronic data used in the preparation of this AMR were obtained from the Technical Data Management System (TDMS) as appropriate. The preparation of this AMR did not require any prerequisites, special controls (including AP-SV.1Q controls), environmental conditions, processes, or skills. It should be noted that the development plan (CRWMS M&O 1999a) for this activity was developed prior to the issuance of AP-SV.1Q, and therefore does not include a discussion of AP-SV.1Q controls. To ensure accuracy and completeness of the information generated by this report, access to the information on the personal computer used to develop this report is controlled with password protection. The personal computer files are stored on the network 'O' drive, which is backed up daily per project standards. Upon completion of this work, all files are transferred to a CD, appropriately labeled, and verified by examining the file listing. The CD is transmitted to Engineering Document Control for transfer to the Record Processing Center. During the process of checking the document, accuracy and completeness of the data placed in the Records Processing Center is verified against the information contained in this report. Visual checks are conducted on print-outs.

All computer software used in this analysis is identified in Section 3. Qualified codes include Universal Distinct Element Code (UDEC) Version 2.0, UNWEDGE Version 2.3, and DRKBA Version 3.3. Output data/results developed in this AMR have been submitted to the TDMS in accordance with AP-SIII.3Q.

In addition to the procedures cited above, the following procedures are applicable to this document: AP-3.14Q, AP-SI.1Q, and AP-SIII.2Q.

3. COMPUTER SOFTWARE AND MODEL USAGE

The computer software used to develop the drift degradation analysis is identified in this section. The DRKBA rock fall model was developed as part of this AMR, and is validated as documented in Section 6.5.

3.1 QUALIFIED COMPUTER SOFTWARE

UDEC Version 2.0 (CRWMS M&O 1994, software tracking number B00000000-01717-1200-30004) was used in parts of this drift degradation analysis. UDEC was used to analyze the seismic and thermal effects on block movement. The analyses were performed on a computer with a Pentium microprocessor (Dell OptiPlex GXi, CRWMS M&O #116400). UDEC software is appropriate for the applications used in this drift degradation analysis. UDEC was obtained from the Configuration Management in accordance with the applicable M&O procedures. UDEC software was used only within the range of validation as specified in the software qualification documentation, in accordance with AP-SI.1Q. A complete listing of UDEC input files used in this analysis is provided in Attachment II. The outputs are described in Attachment V. A complete listing of output files is also provided in Attachment II.

UNWEDGE Version 2.3 (CRWMS M&O 1998a, software tracking number 30053-2.3-00) was used in parts of this drift degradation analysis. UNWEDGE was used to produce block geometry data based on three fracture sets. UNWEDGE calculations were performed on a computer with a Pentium microprocessor (Dell OptiPlex GXi, CRWMS M&O #116400). UNWEDGE software is appropriate for the applications used in this drift degradation analysis. UNWEDGE was obtained from the Configuration Management in accordance with AP-SI.1Q. UNWEDGE software was used only within the range of validation as specified in the software qualification documentation. A complete listing of UNWEDGE input files used in this analysis is provided in Attachment II. The outputs are described in Attachment IX. A complete listing of output files is also provided in Attachment II.

DRKBA Version 3.3 (CRWMS M&O 2000b, software tracking number 10071-3.3-00) was used in parts of this drift degradation analysis. DRKBA was used to simulate the formation of blocks formed in the rock mass based on tunnel mapping data, and to analyze these blocks to determine if they are stable. DRKBA analyses were performed on a computer with a Pentium microprocessor (Dell OptiPlex GXi, CRWMS M&O #116400). DRKBA software is appropriate for the applications used in this drift degradation analysis. DRKBA was obtained from the Configuration Management in accordance with the applicable M&O procedures. DRKBA software was used only within the range of validation as specified in the software qualification documentation, in accordance with AP-SI.1Q. A complete listing of DRKBA input files used in this analysis is provided in Attachment II. The outputs are described in Section 6. A complete listing of output files is also provided in Attachment II.

3.2 ROUTINES/MACROS

Volume_cal V1.1 is classified as a software macro per AP-SI.1Q and is qualified in Attachment VIII. The macro runs under *Microsoft Excel 97 SR-2*. This macro resides in the *Excel* spreadsheet files *pmn-rock volume per mcs v2.xls, pll-rock volume per mcs v2.xls, pln-rock*

volume per mcs v2.xls (Attachment II). The purpose of this macro is to calculate the total rock fall volume per 24.4 m of drift length (equivalent to the total drift length per one Monte Carlo Simulation in DRKBA analysis). The macro is verified by visual inspection of the calculation results with a hand calculation of the total key block volume per one Monte Carlo simulation. A comparison of the hand calculation and macro calculation results is provided in Attachment VIII, which indicates that the macro *Volume_cal V1.1* provides correct results for the calculation of total volume. *Volume_cal V1.1* is therefore appropriate for the application in this task.

In addition to the above listed items, both *Microsoft Excel 97 SR-2* and *Mathcad 7 Professional* were also used. These software items were used to perform support calculational activities as described in Section 6.3.2, Section 6.3.3, Attachment II, and Attachment III. *Excel* was used to calculate excavation orientation inputs, to assist in the summary of the block size data, and to provide graphical presentation of the block size distribution data. *Mathcad* was used to calculate both excavation orientation and joint description input parameters.

To provide documentation of the analysis in sufficient detail to allow independent repetition of the software in accordance with AP-3.10Q Attachment I, and to ensure compliance with AP-SI.1Q, the minimum information required by AP-SI.1Q Section 5.1.1.2 has been provided:

- Identification of the *Excel* and *Mathcad* files, including the version of the file, are provided in Section 6.3.2, Section 6.3.3, Attachment II, and Attachment III.

- The name and version of the commercial software are provided as described above.

- The inputs, spreadsheet cell contents and equations, and results are provided in Attachment II. This provides sufficient documentation that these standard mathematical calculations provide correct results for the specified range of input parameters. Only standard mathematical functions were used.

4. INPUTS

4.1 DATA AND PARAMETERS

The geotechnical parameters include data and information collected either by field mapping or by laboratory testing. Two sets of geometrical data for joints were used in this analysis. The first set, collected from the Exploratory Studies Facility (ESF) Main Loop (i.e., the North Ramp, Main Drift, and South Ramp), is referred to as the ESF data in this report. The second set, collected from the Enhanced Characterization of the Repository Block (ECRB) Cross Drift, is called the ECRB data. Qualified joint mapping data for the Topopah Spring Tuff crystal poor upper lithophysal zone (Tptpul) and Topopah Spring Tuff crystal poor middle nonlithophysal zone (Tptpmn) lithologic units are available from the ESF data. Qualified joint mapping data for the Tptpul, Tptpmn, Topopah Spring Tuff crystal poor lower lithophysal zone (Tptpll), and Topopah Spring Tuff crystal poor lower nonlithophysal zone (Tptpln) lithologic units are available from the ECRB data.

Mapping data from the ESF being used in the analysis includes both U.S. Geological Survey/U.S. Bureau of Reclamation (USGS/USBR) Full Periphery Geologic Maps (FPGMs) and the Detailed Line Survey (DLS). Developed fracture data, including joint set orientation, joint spacing, joint trace length, and joint offset from the DLS, have been provided by data tracking number (DTN) MO0008SPAFRA06.004. The developed fracture data are based on final, qualified fracture data as listed in Tables 1 and 2. Fracture strike and dip data contained in the electronic files of the FPGMs were used to determine fracture set orientation, while fracture set spacing and trace length data were obtained from the DLS. All fracture spacing information for the primary joint sets has been converted to "true spacing". Details for the determination of fracture set orientations, the identification of joint sets, and fracture spacing and trace length data are provided in Section 6. It should be noted that subsequent studies by the USGS/USBR have generated data on "small-scale" fractures with trace lengths less than 1 m (DTN GS990908314224.009). These data were collected at six locations in the Tptpmn (2 locations), Tptpll (3 locations), and Tptpln (1 location) and thus do not provide a representative data set for the purposes of this analysis. A discussion of the impact of the small trace length fracture data on this analysis is provided in Section 7.2.

The origin of the data for specific joint geometrical parameters is listed in Table 1, with the data sources for FPGMs and DLSs provided in Table 2.

Table 1. Origin of Data for Joint Geometrical Parameters

Lithologic Unit	Origin of Joint Geometrical Parameters		
	Joint Set Orientation	Joint Spacing	Joint Trace Length
Tptpul	ESF FPGM & ECRB FPGM	ESF DLS & ECRB DLS	ESF DLS & ECRB DLS
Tptpmn	ESF FPGM & ECRB FPGM	ESF DLS & ECRB DLS	ESF DLS & ECRB DLS
Tptpll	ECRB FPGM	ECRB DLS	ECRB DLS
Tptpln	ECRB FPGM	ECRB DLS	ECRB DLS

Table 2. Geotechnical Data Sources for the Drift Degradation Analysis[1]

Description of Data	Data Tracking Number	Organizational Responsibility
Fracture geometry for stratigraphic units of the repository horizon	MO0008SPAFRA06.004	M&O/SFD
ESF DLS, Stations 18+00 through 26+00, Rev. 01	GS971108314224.024	USGS/USBR
ESF DLS, Stations 26+00 through 30+00, Rev. 01	GS971108314224.025	USGS/USBR
ESF DLS, Stations 30+00 through 35+00, Rev. 00	GS960708314224.008	USGS/USBR
ESF DLS, Stations 35+00 through 40+00, Rev. 00	GS000608314224.004	USGS/USBR
ESF DLS, Stations 40+00 through 45+00, Rev. 00	GS960708314224.010	USGS/USBR
ESF DLS, Stations 45+00 through 50+00, Rev. 01	GS971108314224.026	USGS/USBR
ESF DLS, Stations 50+00 through 55+00, Rev. 00	GS960908314224.014	USGS/USBR
ESF DLS, Stations 55+00 through 60+00, Rev. 01	GS971108314224.028	USGS/USBR
ESF DLS, Stations 60+00 through 65+00, Rev. 00	GS970208314224.003	USGS/USBR
ESF DLS, Stations 70+00 through 75+00, Rev. 00	GS970808314224.010	USGS/USBR
ESF FPGM, Station 04+00 to 26+00 Revision 1	GS960908314224.020	USGS/USBR
ESF FPGM, Station 26+00 to 30+00 Revision 0	GS000608314224.006	USGS/USBR
ESF FPGM, Station 30+00 to 40+00 Revision 0	GS960908314224.015	USGS/USBR
ESF FPGM, Station 40+00 to 50+00 Revision 0	GS960908314224.016	USGS/USBR
ESF FPGM, Station 50+00 to 55+00 Revision 0	GS960908314224.017	USGS/USBR
ESF FPGM, Station 55+00 to 60+00 Revision 0	GS970108314224.002	USGS/USBR
ESF FPGM, Station 60+00 to 65+00 Revision 0	GS970208314224.004	USGS/USBR
ESF FPGM, Station 65+00 to 70+00 Revision 0	GS970808314224.009	USGS/USBR
ESF FPGM, Station 70+00 to 75+00 Revision 0	GS970808314224.011	USGS/USBR
ECRB DLS, Station 00+00 to 15+00	GS990408314224.001	USGS/USBR
ECRB DLS, Station 15+00 to 26+64	GS990408314224.002	USGS/USBR
ECRB FPGM, Station 00+00 to 10+00	GS990408314224.003	USGS/USBR
ECRB FPGM, Station 10+00 to 15+00	GS990408314224.004	USGS/USBR
ECRB FPGM, Station 15+00 to 20+00	GS990408314224.005	USGS/USBR
ECRB FPGM, Station 20+00 to 26+00	GS990408314224.006	USGS/USBR
ESF FPGM Srike and Dip Data Entry Correction Analysis	MO9904MWDFPG16.000	M&O/SFD
Summary of bulk properties measurements from borehole data	SNL02030193001.027	SNL
Fracture shear strength from NRG-4 & NRG-6	SNL02112293001.003	SNL
Fracture shear strength from SD-9	SNL02112293001.005	SNL
Fracture shear strength from NRG-7/7A and SD-12	SNL02112293001.007	SNL
Intact rock elastic properties from the TSw2 unit from NRG-5	SNL02030193001.012	SNL
Intact rock elastic properties from the TSw2 unit from NRG-6	SNL02030193001.004	SNL
Intact rock elastic properties from the TSw2 unit from NRG-7/7A	SNL02030193001.019	SNL
Intact rock elastic properties from the TSw2 unit from NRG-7/7A	SNL02030193001.020	SNL
Intact rock elastic properties from the TSw2 unit from NRG-7/7A	SNL02030193001.021	SNL
Intact rock elastic properties from the TSw2 unit from SD-9	SNL02030193001.026	SNL
Intact rock elastic properties from the TSw2 unit from SD-12	SNL02030193001.023	SNL

[1]Developed DLS and FPGM data are provided by DTN: MO0008SPAFRA06.004, which is the Technical Product Output of CRWMS M&O (2000d). See Section 7.3 for a discussion of the impacts of verification of this data.

Joint strength parameters, including cohesion and friction angle, were developed in Attachment XIII based on laboratory shear strength test data from core specimens (see Table 2 for source DTNs). Mean value and standard deviation are required as the inputs for the key block analysis (Table 3). The calculation of mean values in Attachment XIII is consistent with CRWMS M&O (1997b, p. 5-143).

Table 3. Inputs for Joint Strength Parameters[1]

Parameter	Cohesion (MPa)	Friction Angle (degree)
Mean	0.86	41
Standard Deviation	0.81	3

[1]Source DTNs provided in Table 2; calculation of the mean values documented in Attachment XIII.

Rock density data and intact rock elastic properties were obtained from the laboratory tests performed on the rock cores from the North Ramp geotechnical (NRG) and the systematic drilling (SD) boreholes (see Table 2 for source DTNs). The development of mean values based on the source DTNs is provided in Attachment XIII. The saturated bulk density (ρ) of 2.41 g/cc for Tptpln unit was used in the analysis. This value was selected for conservatism since the value is the highest of the examined units (CRWMS M&O 1997b, pp. 5-25 and 5-26). Mean elastic rock properties from the TSw2 thermal mechanical unit, including an elastic modulus of 33.03 GPa and a Poisson's ratio of 0.21, were used in this analysis as described in Attachment V. The calculation of mean values in Attachment XIII is consistent with CRWMS M&O (1997b, pp. 5-26, 5-88, and 5-96).

Design basis seismic ground motion parameters are provided by DTN MO0003SEPSDARS.002 for both Category 1 and Category 2 design basis events. A Category 1 design basis event means "those natural and human-induced events that are reasonably likely to occur regularly, moderately frequently, or one or more times before permanent closure of the geologic repository operations area." A Category 2 design basis event is defined as "other natural and man-induced events that are considered unlikely, but sufficiently credible to warrant consideration, taking into account the potential for significant radiological impacts on public health and safety." The return periods for the occurrence of Category 1 and Category 2 design basis events are 1,000 years and 10,000 years, respectively. In addition to the two categories, an intermediate category with a 5,000-year event was also considered in this analysis.

The peak ground accelerations (PGAs) for the horizontal motion in the frequency range of 5 to 10 Hz were selected for this analysis. The values are listed in Table 4. Three levels of seismic events are included: Level 1 corresponding to a 1,000-year event (Category 1), Level 2 corresponding to a 5,000-year event, and Level 3 corresponding to a 10,000-year event (Category 2).

Table 4. Selected Peak Ground Accelerations for Seismic Analysis (DTN: MO0003SEPSDARS.002, TBV-4408)

Seismic Event	Peak Ground Acceleration (g)[1]
Level 1 (1,000-year event, Category 1)	0.14
Level 2 (5,000-year event)	0.30
Level 3 (10,000-year event, Category 2)	0.43

[1]The Level 2 (5,000-year event) PGA value was estimated based on the Category 1 and Category 2 PGA values. See Assumption 5.5.

4.2 CRITERIA

There are no criteria from either requirements documents or System Description Documents that are applicable to this drift degradation analysis. This AMR was prepared to comply with the DOE interim guidance (Dyer 1999) which directs the use of specified Subparts/Sections of the proposed NRC high-level waste rule, 10 CFR Part 63. Relevant requirements for performance assessment from Section 114 of that document are: "Any performance assessment used to demonstrate compliance with Sec. 113(b) shall: (a) Include data related to the geology, hydrology, and geochemistry ... used to define parameters and conceptual models used in the assessment. (b) Account for uncertainties and variabilities in parameter values and provide the technical basis for parameter ranges, probability distributions, or bounding values used in the performance assessment. ... (g) Provide the technical basis for models used in the performance assessment such as comparisons made with outputs of detailed process-level models ... ."

4.3 CODES AND STANDARDS

There are no codes and standards applicable to this drift degradation analysis.

5. ASSUMPTIONS

The following assumptions have been used in this drift degradation analysis. No assumptions listed below require confirmation.

5.1 JOINT REPRESENTATION AS CIRCULAR DISCS

Individual joints within each joint set are represented as circular discs in three-dimensional space with radii drawn from a distribution estimated on the assumption that the radius is equal to twice the mapped trace length. This assumption potentially provides for a more accurate representation of the joint since the mapped joint trace length may actually represent only a portion of the overall joint plane. This is considered conservative based on the sensitivity calculation for joint plane representation provided in Attachment XIV. This assumption is used in Section 6.3.2.

5.2 JOINT POSITION PARAMETER

The positioning parameter required as joint parameter input is assumed to be the offset measured from the center of the trace length to the scan line of the detailed line survey. This is the best available way to represent the positioning parameter since the determination of the true positioning parameter requires the three dimensional information of the joint plane that is not available. This approach is considered conservative because the offset measured from the one dimensional scan line is smaller than the true offset in three dimensional space (the probability of forming a key block is higher with a smaller offset value). This assumption is used in Section 6.3.2.

5.3 NO GROUND SUPPORT CONSIDERED IN THE ANALYSIS

The key block analysis simulated in the DRKBA software does not include a ground support element. All key blocks predicted in this analysis are therefore the blocks that fail in an unsupported opening. This assumption is necessary due to the limitation of the DRKBA program. The assumption apparently will lead to a conservative prediction of key blocks for the pre-closure period and is considered adequate for the post-closure period. The assumption is used in Section 6.3.1.

5.4 SIMULATION OF THE SEISMIC EFFECT WITH JOINT STRENGTH REDUCTION

This analysis uses an alternative method for joint strength reduction to simulate the seismic effect on the occurrence of key blocks. This method is verified using the distinct element code UDEC (see Section 3). The dynamic analysis result was compared to the quasi-static analysis result adopting the alternative method. The process of verification is documented in Attachment V. This assumption is used in Section 6.3.4.

5.5 PGA VALUE FOR A 5000-YEAR SEISMIC EVENT

A PGA value of 0.30 g was assumed for a 5,000-year seismic event. This value is reasonable since it is based on an interpolation from the PGA values provided for 1,000-year and 10,000-year seismic events (DTN: MO0003SEPSDARS.002). This assumption is used in Section 4.1.

5.6 SEISMIC GROUND MOTION FOR UDEC DYNAMIC ANALYSIS

A 10 Hz sinusoidal seismic wave was imposed at the bottom boundary of UDEC mesh for dynamic analysis. The peak ground velocity of 39 cm/sec for a 10,000-year event was simulated in the dynamic analysis. These values are reasonable since they are based on the peak ground velocity values provided by CRWMS M&O (1999e, p. A1-1). These assumptions are used in Attachment V.

5.7 JOINT COHESION USED IN DRKBA ROCK FALL MODEL

The laboratory shear strength tests indicate the mean cohesion value of 0.86 MPa and the standard deviation of 0.81 MPa (Table 3). Due to the wide range of the standard deviation, the joint cohesion used in DRKBA rock fall model is conservatively initialized as 0.1 MPa. This assumption is used in Section 6.3.2.

5.8 SUBCRITICAL CRACK GROWTH PARAMETERS

Subcritical crack growth parameters A and n were used in the analysis of time-dependent and thermal effects on joint cohesion. Conservative values of $n = 25$ and $A = 10^{-5}$ meters/second were assumed based on previous Yucca Mountain studies (Kessler et al. 1996). This assumption is used in Attachment I.

5.9 EMPLACEMENT DRIFT AZIMUTH

Emplacement drifts trending 105° were modeled in this AMR to represent the superseded drift azimuth of 108°. The current, or primary, emplacement drift azimuth of 72° was modeled in this AMR with drifts trending 75°. This 3-degree difference between the modeled and actual drift alignment is acceptable given the variability of joint set orientations captured in the model (see Section 6.3.2). The 3-degree difference does not significantly effect the results from this analysis. This assumption is used in Section 6.3.3.

6. ANALYSIS/MODEL

6.1 INTRODUCTION

Key blocks are formed at the surrounding rock mass of an excavation by the intersection of three or more planes of structural discontinuities as shown in Figure 1. This analysis provides an assessment of the possible formation of key blocks within the repository horizon based on the orientations of discontinuities present in the ESF Main Loop and in the ECRB Cross Drift. Block failure due to seismic and thermal effects has also been analyzed. The corresponding emplacement drift profiles have been developed to depict the drift degradation over time. The drift degradation analysis provides data that may modify estimates of seepage into the emplacement drift due to mechanical effects of rock fall during the period of compliance for post-closure performance. Therefore, in accordance with the screening criteria in AP-3.15Q, Attachment 6, the intended use of this analysis is to provide estimates of Other Factors for the Post-Closure Safety Case. This corresponds to secondary (Level 2) importance in accordance with AP-3.10Q, Attachment 1, Section 6.

6.2 FIELD OBSERVATION OF KEY BLOCKS

Key blocks in the 5-m-diameter Cross Drift are first evident in the crown at about station 10+50 in the Tptpmn unit (note that metric stationing is used throughout the ESF, such that station 10+50 refers to 1050 m from the start of the tunnel). Most of the key blocks in this region are of minor size and typically fall immediately after excavation prior to ground support installation. Key blocks are possible in this area because of the increased presence of the plane of weakness (i.e., a vapor phase parting) in the near horizontal orientation that intersects with two opposing near vertical joint planes. Fallout from these key blocks during excavation is typical of the rock in the middle non-lithophysal zone (Tptpmn) of the TSw2 thermal mechanical unit. The largest resultant void is possibly 0.5 cubic meters at approximately station 11+55 as shown in Figure 2. No unstable key blocks were observed in the field. Documentation of key blocks observed in the Cross Drift is provided in Attachment VI.

While ground support monitoring in the ESF Main Loop has provided long-term evidence indicating stable rock support performance, there are several sections in the ESF where excessive raveling and block fall-out have occurred. These typically correspond to the "3.01X" areas, and most often occurred in fault zones and in the TCw and TSw2 thermal mechanical units. The 3.01X areas refer to sections of the ESF Main Loop that were constructed under Section 3.01X of the Subsurface General Construction specification (CRWMS M&O 1997c, p. 15). The specification indicates that special actions may be necessary to continue excavation in the event that adverse ground conditions prevent normal Tunnel Boring Machine operations. A typical opening profiles in a 3.01X area is shown in Figure 3. This profile is indicative of the worst case ground conditions in the Tptpmn lithologic unit of the ESF Main Loop.

The geometry of various size key blocks based on typical joint sets observed in the ESF is provided in Attachment IX.

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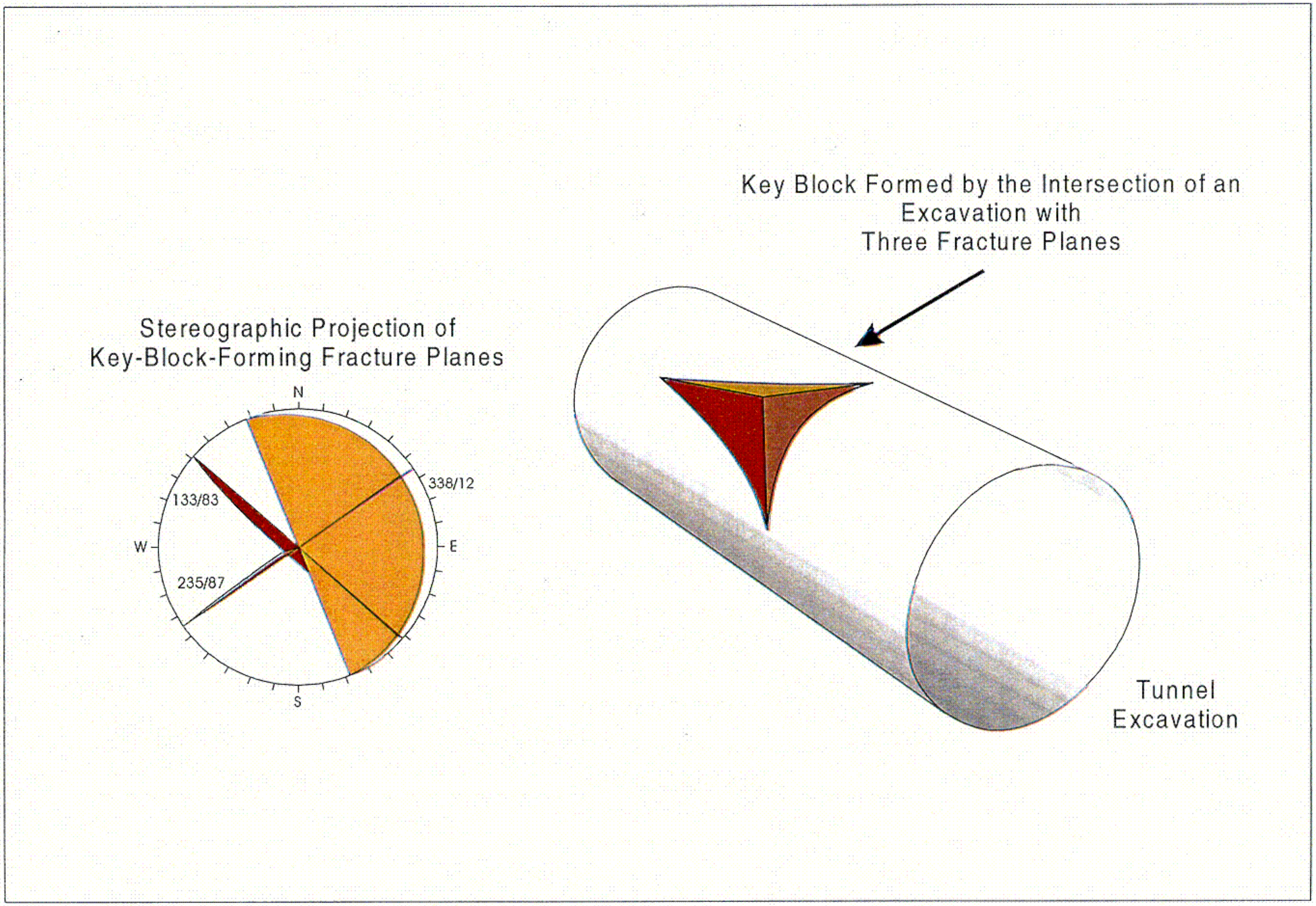

Figure 1. Illustration of a Typical Key Block and Associated Fracture Planes

Figure 2. Evidence of Key Block Occurrence in the ECRB Cross Drift, Station 11+55

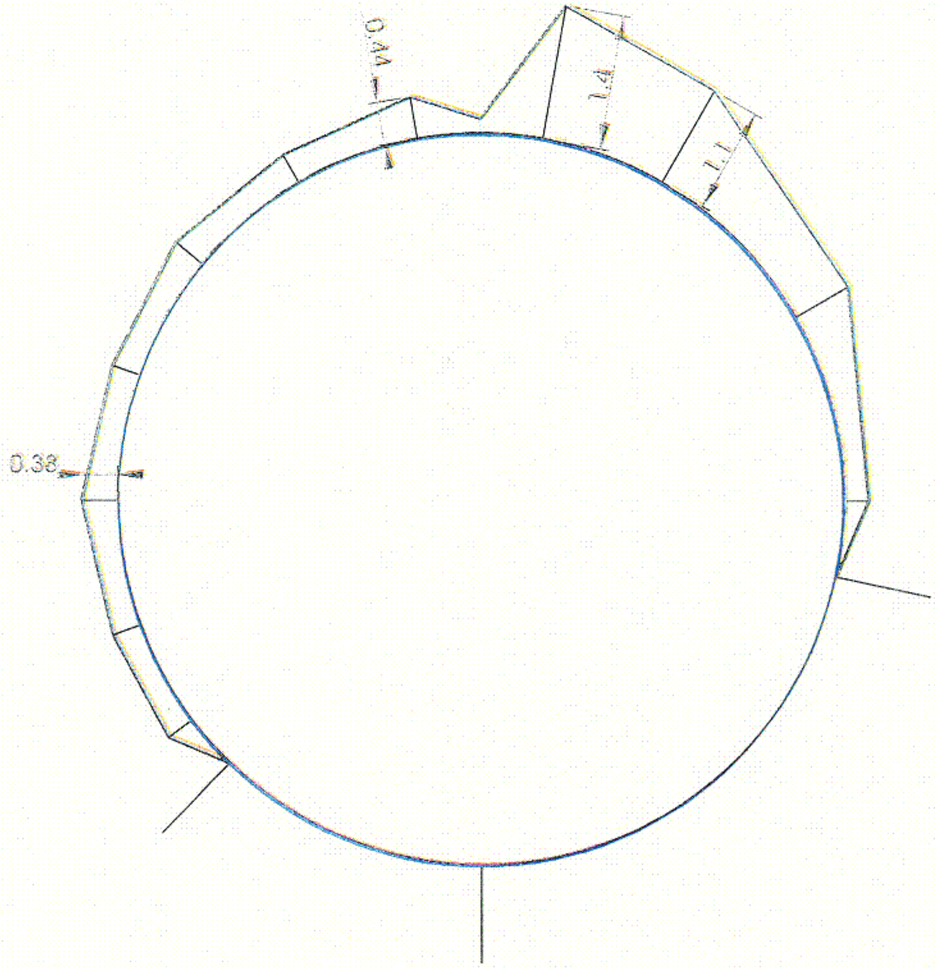

Figure 3. Opening Profile at ESF Station 60+24.70 (Steel Set #1272, Tptpmn Lithostratigraphic Unit) Based on Field Survey Data (dimensions in meters) (CRWMS M&O 1999c, p. 27)

6.3 APPROACH

The approach toward this drift degradation analysis involves the following:

- Prepare a key block model of the rock mass.
- Analyze blocks that have fallen in the field, and their associated joints.
- Collect and assess joint geometrical data and joint frictional properties data from the ESF Main Loop and ECRB Cross Drift to develop the joint modeling inputs for DRKBA.
- Analyze the joint data to assess the potential formation of key blocks using DRKBA, including the maximum block size.

- Analyze the seismic and thermal effects on joint and block movement.

- Analyze the DRKBA block size distribution data for each lithologic unit within the repository host horizon.

- Determine the number and average volume of rock fall per unit length of drift for various levels of seismic hazard.

- Evaluate post-closure frequency of block failure for 10,000 years.

- Analyze the drift profile showing the progressive movement of joints and blocks with time.

6.3.1 DRKBA Approach

DRKBA is a commercially available acquired software product (as described in Section 3). The software simulates structural discontinuities as circular discs placed in the rock mass according to probabilistic distributions determined from tunnel mapping data. Joint planes are simulated by a Monte Carlo technique from probability distributions representing the orientation, spacing, and trace length of the corresponding joint set. DRKBA determines where joint planes intersect to form blocks, and then analyzes these blocks to determine if they are geometrically feasible (i.e., the shape of the block is such that it is physically possible to slide or fall into the tunnel opening). If the blocks are geometrically feasible, DRKBA then determines if they are mechanically stable (i.e., the gravitational forces that cause the block to move into the tunnel opening are less than the frictional forces on the block sliding surfaces). DRKBA does not include a ground support element (see Assumption 5.3).

A probabilistic key block analysis using DRKBA requires four sets of data. The required data are stored in data files having extensions *.mkg*, *.exc*, *.den*, and *.prb*, and contain information for the grid, excavation, rock density, and joint sets, respectively. The make grid file (*.mkg*) includes the information required for building a grid of nodal points for the mesh. The excavation data file (*.exc*) contains the information for defining an excavation in three dimensional space. The density file (*.den*) holds the information for the rock density data. The probabilistic joint data file (*.prb*) includes the required information for generating fracture space from the given fracture probability distributions.

The DRKBA software employs a bipolar Watson distribution for joint orientation data. The principal axis orientation and a concentration factor k are the required inputs for the bipolar Watson distribution. The concentration factor k is an index of the concentration. The larger the value of k, the more the distribution is concentrated towards the principal axis orientation. Joints are represented as circular discs in the DRKBA analysis. Joint radii (see Assumption 5.1), spacings, and positioning are simulated with beta distributions. The beta distribution is a four-parameter distribution with the parameters a, b, p, and q. The parameters a and b represent the ends of the closed interval upon which the beta distribution is defined. The parameters p and q determine the shape of the distribution curve, their values were calculated from the mean and standard deviation of the transformed data. The transformed data were obtained by normalizing the data with the maximum value. The cohesion and friction angle of the joints are simulated as a

bivariate normal distribution. Inputs for the mean and standard deviation of the joint strength parameters are required.

6.3.2 Statistical Representation of Joint Data

Joint sets were identified in CRWMS M&O (2000d, Section 6.4.1) based on clustering of the data from joint normal vectors plotted on stereonets as shown in Figures 4 to 7 (see Section 4, Tables 1 and 2 for data sources). The scatter plots, contour plots, strike rosettes, and major planes are all included in these figures. The major joint plane is expressed using the strike/dip format in these figures. The joint orientation is expressed in dip direction/dip format in Table 5. In addition to the primary joint sets listed in Table 5, a random joint set has also been simulated to account for any joint that is present in the rock mass but not accounted for in the primary sets. The dispersion of the individual joints about their associated joint set axes was modeled by a Watson bipolar distribution for axial data. This probability distribution is characterized by a unit normal vector representing the mean direction about which the data is clustered and a concentration factor k representing the degree to which the data is clustered about the mean direction. The concentration factors were calculated based on the eigenvalues and eigenvectors of the orientation matrix (Fisher, Lewis, and Embleton 1987). The calculated concentration factors are also listed in Table 5. The process to calculate the concentration factors is included in Attachment II (see electronic files *New-K-Tptpul V1.mcd*, *New-K-Tptpmn V1.mcd*, *New-K-Tptpll V1.mcd*, and *New-K-Tptpln V2.mcd.*

Joint radii (see Assumption 5.1), spacings, and positioning (see Assumption 5.2) are simulated with beta distributions. The offset measured from the center of the trace length to the scan line was used as the positioning parameter. The parameters a, b, p and q for each lithologic unit are listed in Tables 6 to 9, with the details for the calculation of each parameter provided in Attachment II (see electronic files *New-Beta-Tptpul V1.xls*, *New-Beta-Tptpmn V1.xls*, *New-Beta-Tptpll V1.xls*, and *New-Beta-Tptpln V2.xls*. Attachment III provides an example for calculating the distribution parameters with the fracture data of the first joint set for Tptpll unit.

Cohesion and friction angle of the joints are simulated with the bivariate normal distribution. Mean and standard deviation for the cohesion and friction angle are presented in Section 4 (see Table 3). Cohesion values were conservatively reduced (Assumption 5.7).

6.3.3 Excavation Modeling

As discussed in Assumption 5.9, the primary excavation in this analysis is a horizontal 5.5-m diameter emplacement drift trending 75° in accordance with the repository design description (CRWMS M&O 2000e, p. 28). Emplacement drifts trending 105° in accordance with the superseded repository baseline design (CRWMS M&O 1997a, pp. 22 and 33; Wilkins and Heath 1999) have also been included. Additionally, a range of emplacement drift orientations with the drift azimuth varying every 15° has been analyzed for the static condition only (i.e., with no seismic or thermal loading).

For each Monte Carlo simulation, a 24.4-m-long (80-ft) tunnel has been modeled in three-dimensional space. A circular tunnel opening both with and without backfill was modeled. For the cases with no backfill, 18 plane equations were used to describe the circumference of the

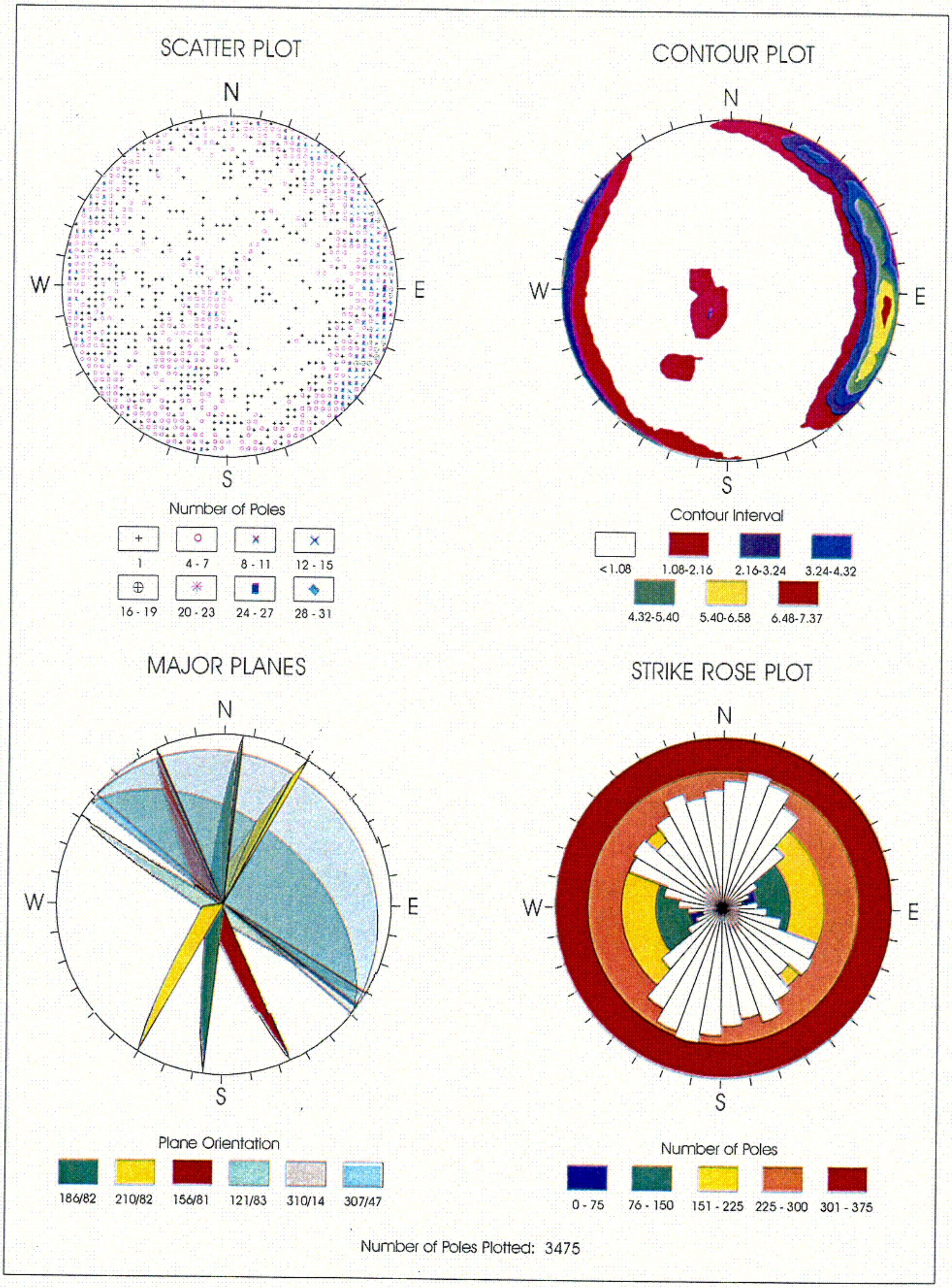

Figure 4. Determination of Primary Joint Sets, Tptpul (CRWMS M&O 2000d, Figure III-1)

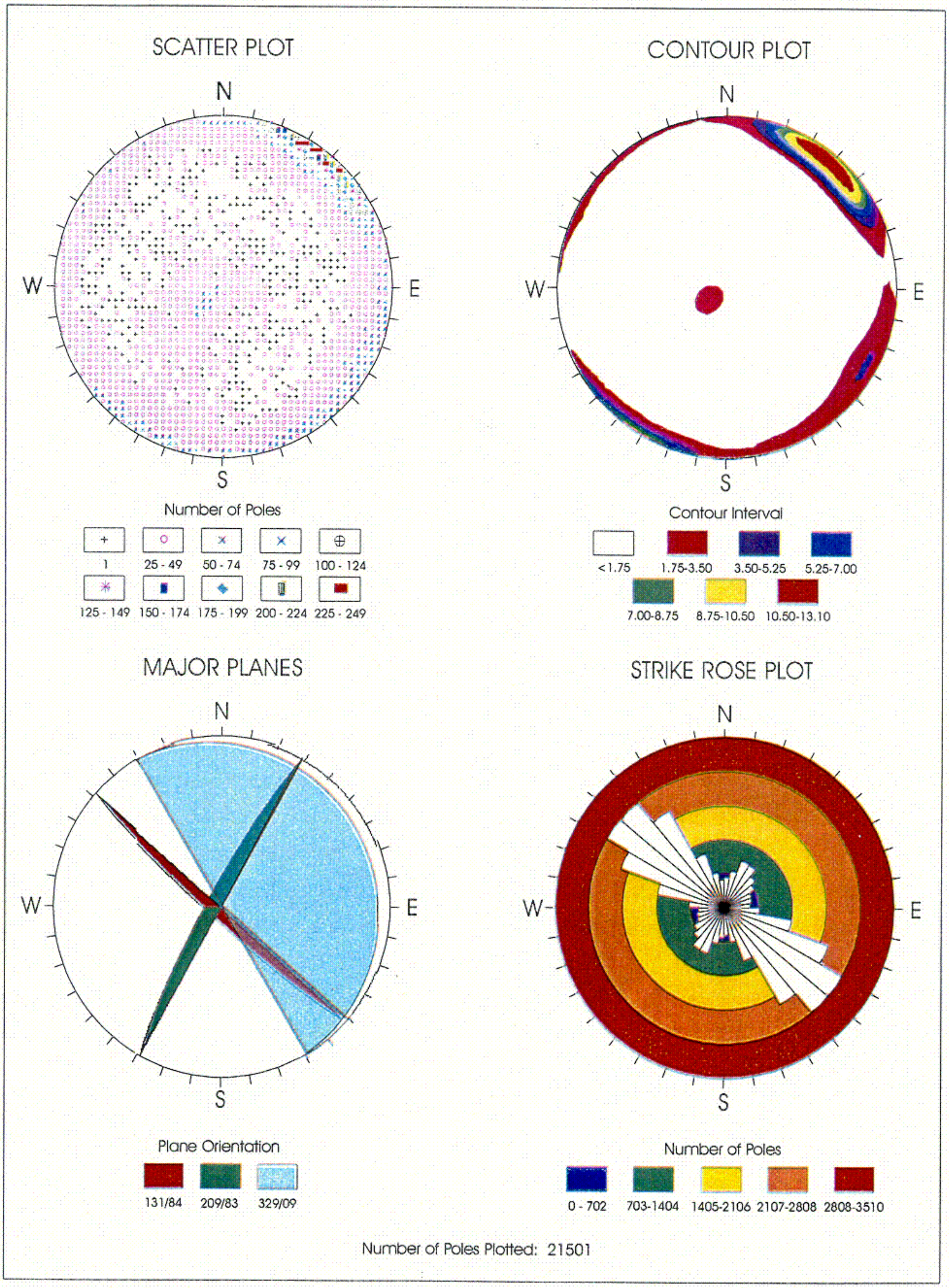

Figure 5. Determination of Primary Joint Sets, Tptpmn (CRWMS M&O 2000d, Figure III-2)

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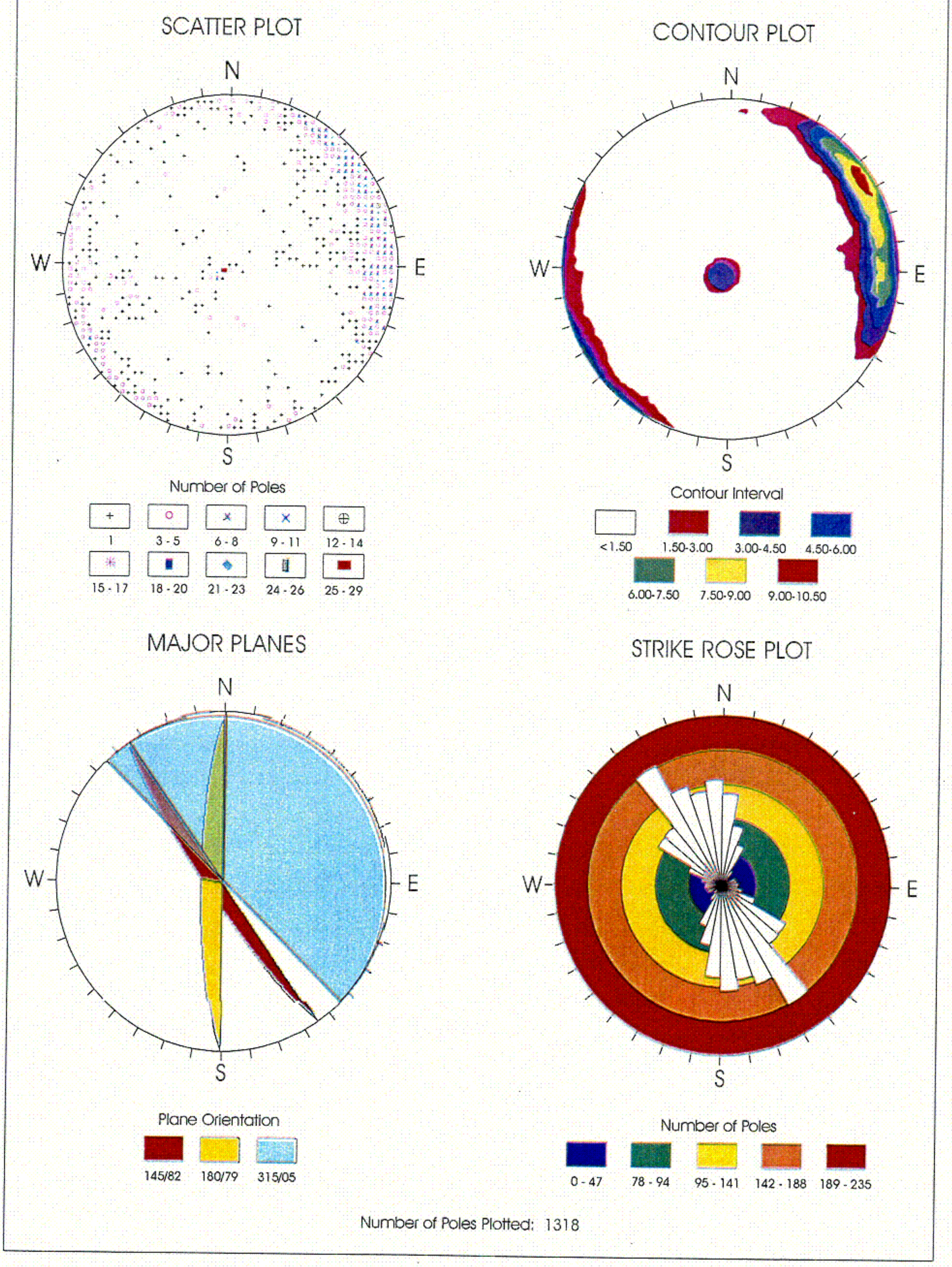

Figure 6. Determination of Primary Joint Sets, Tptpll (CRWMS M&O 2000d, Figure III-3)

C06

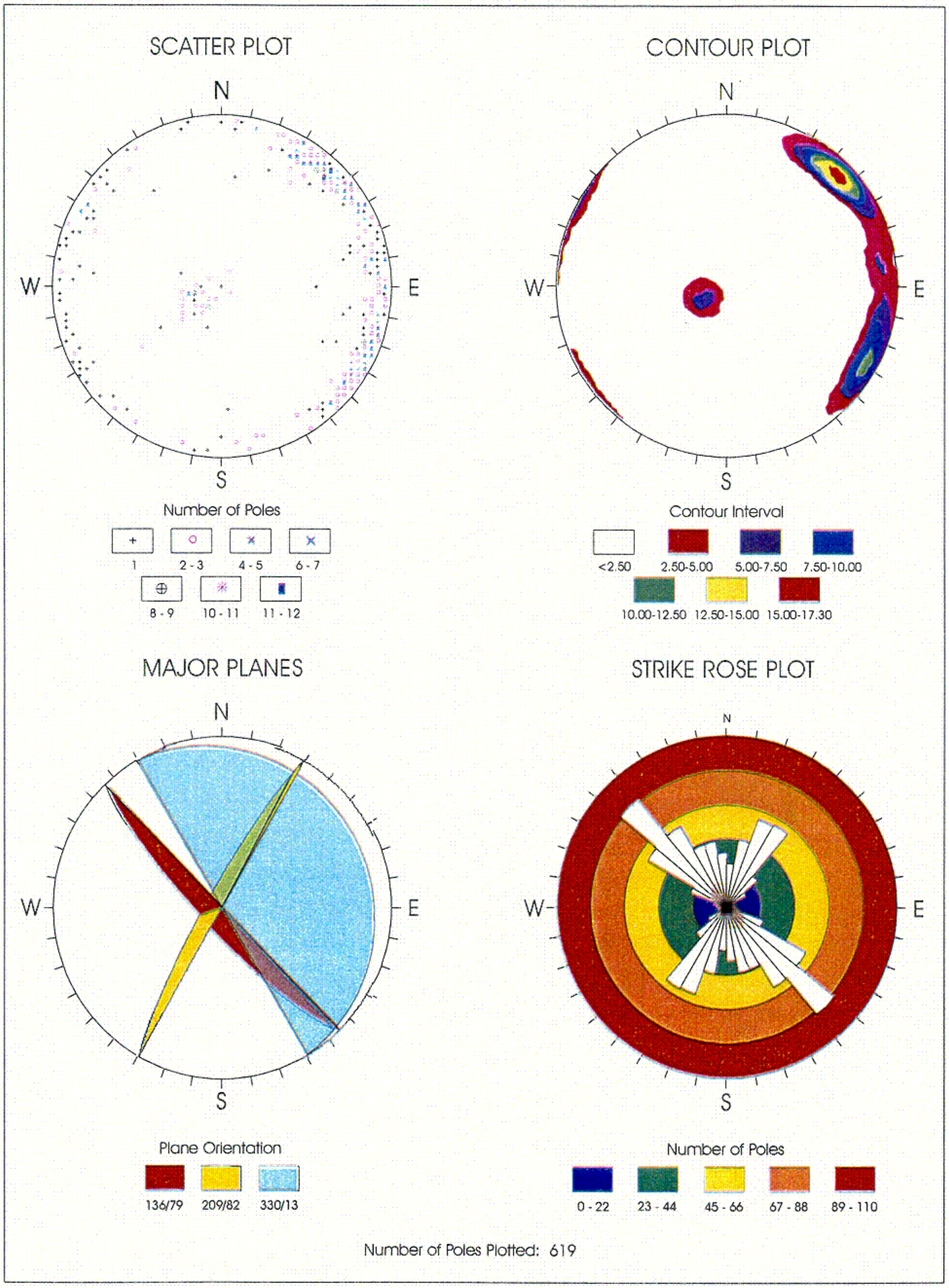

Figure 7. Determination of Primary Joint Sets, Tptpln (CRWMS M&O 2000d, Figure III-4)

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Table 5. Joint Set Orientation Data and Concentration Factors[1]

Lithologic Unit	Joint Set Number	Mean Dip Direction[2] (degrees)	Mean Dip[2] (degrees)	Concentration Factor k
Tptpul	1	276	82	36.648
	2	300	82	20.576
	3	246	81	20.112
	4	211	83	22.425
	5	40	14	16.393
	6	37	47	24.210
	Random	263	70	1.850
Tptpmn	1	221	84	31.586
	2	299	83	26.143
	3	59	9	18.210
	Random	267	79	2.896
Tptpll	1	235	82	27.529
	2	270	79	24.723
	3	45	5	30.375
	Random	230	79	2.497
Tptpln	1	226	79	51.826
	2	299	82	23.304
	3	60	13	49.993
	Random	262	79	3.583

[1]Calculation details provided in Attachment II, files *New-K-Tptpul V1.mcd*, *New-K-Tptpmn V1.mcd*, *New-K-Tptpll V1.mcd*, and *New-K-Tptpln V2.mcd*.
[2]The derivation of the joint set orientation data is shown in Figures 4 through 7.

Table 6. Beta Distribution Parameters for Tptpul Unit[1]

Joint Set Number	Parameters	a (m)	b (m)	p	q
1	Spacing	0.0132	16.3307	0.4223	1.5728
	Radius	2.0000	47.1800	0.2137	1.7194
	Positioning	0.0050	9.1500	0.2216	1.9098
2	Spacing	0.0015	16.3325	0.4073	1.3699
	Radius	2.0000	43.8000	0.3937	4.0620
	Positioning	0.0050	6.8500	0.4098	3.8946
3	Spacing	0.0083	16.4285	0.3545	1.1899
	Radius	2.0000	35.6000	0.3844	2.9909
	Positioning	0.0000	6.7500	0.4169	3.3486
4	Spacing	0.0098	16.0907	0.4500	1.3407
	Radius	1.8400	32.9000	0.3264	2.0332
	Positioning	0.0000	7.0000	0.2718	2.1962
5	Spacing	0.0295	14.3903	0.3171	1.1136
	Radius	2.0800	42.2000	0.4845	1.8767
	Positioning	0.0900	7.4500	0.5098	2.0530
6	Spacing	0.0070	16.4655	0.4063	1.0548
	Radius	2.1200	58.4000	0.5676	1.6409
	Positioning	0.0000	9.1500	0.3000	0.8489
Random	Spacing	0.0100	15.8700	0.6101	1.5645
	Radius	1.6400	58.0600	0.2448	2.0376
	Positioning	0.0000	9.1500	0.2186	1.6597

[1]Calculation details provided in Attachment II, file *New-Beta-Tptpul V1.xls*.

Table 7. Beta Distribution Parameters for Tptpmn Unit[1]

Joint Set Number	Parameters	a (m)	b (m)	p	q
1	Spacing	0.0008	13.9199	0.2322	5.1372
	Radius	1.8200	108.0000	0.6554	20.7171
	Positioning	0.0000	9.1500	0.7569	10.2825
2	Spacing	0.0033	16.5306	0.4098	3.0879
	Radius	1.6400	141.0600	0.2024	7.2515
	Positioning	0.0000	9.1500	0.3292	4.0327
3	Spacing	0.0018	15.2606	0.2010	5.2988
	Radius	0.3200	101.6000	0.5503	8.5360
	Positioning	0.0150	9.1500	0.6369	4.6763
Random	Spacing	0.0100	15.1900	0.5279	7.6008
	Radius	1.3000	60.6000	0.6333	9.2812
	Positioning	0.0000	9.1500	0.5735	7.6186

[1]Calculation details provided in Attachment II, file *New-Beta-Tptpmn V1.xls*.

Table 8. Beta Distribution Parameters for Tptpll Unit[1]

Joint Set Number	Parameters	a (m)	b (m)	p	q
1	Spacing	0.0123	15.7210	0.3070	1.1475
	Radius	1.9000	47.0000	0.3332	1.7478
	Positioning	0.0000	8.2500	0.3443	1.5890
2	Spacing	0.1339	13.6172	0.7050	1.7231
	Radius	2.0400	32.8000	0.1833	0.7549
	Positioning	0.0050	7.2000	0.2507	1.0294
3	Spacing	0.0293	13.7779	0.1385	0.5149
	Radius	3.0800	90.0000	0.1378	0.8908
	Positioning	0.1800	9.1500	0.3089	1.0130
Random	Spacing	0.0500	16.4900	0.5816	1.6822
	Radius	1.7200	53.2400	0.2378	2.3364
	Positioning	0.0000	9.1500	0.2141	2.0886

[1]Calculation details provided in Attachment II, file *New-Beta-Tptpll V1.xls*.

Table 9. Beta Distribution Parameters for Tptpln Unit[1]

Joint Set Number	Parameters	a (m)	b (m)	p	q
1	Spacing	0.0094	14.9637	0.1695	1.6013
	Radius	1.9800	29.6000	0.2850	0.9917
	Positioning	0.0150	5.6500	0.2812	1.0604
2	Spacing	0.0417	13.3921	0.2965	1.3043
	Radius	1.8800	51.6000	0.1993	1.1523
	Positioning	0.0600	8.1000	0.1983	0.8379
3	Spacing	0.0230	12.9674	0.2935	1.0515
	Radius	2.0200	10.6000	0.0993	0.6935
	Positioning	0.2150	1.5500	0.9565	2.0600
Random	Spacing	0.0300	10.5800	0.7008	2.1191
	Radius	1.7800	31.7000	0.1814	0.6253
	Positioning	0.0150	7.0750	0.2266	0.9275

[1]Calculation details provided in Attachment II, file *New-Beta-Tptpln V2.xls*.

circular tunnel, and 2 plane equations were used to describe each end of the tunnel. For the cases with backfill, a simplified tunnel geometry was used to model the opening above the backfill material as described in Section 6.4.2. The backfilled opening was modeled using 15 plane equations to describe the opening perimeter, and 2 plane equations to describe the end of the tunnel. The selection for the length of the tunnel modeled and the number of planes for simulation of the circular opening were based on the computer run time and the accuracy of the simulation. Calculations for the plane equations are included in Attachment II (electronic files *exca vectors V1.xls* and *exca vectors-backfill V1.xls*). The region around the excavation has been modeled with a grid consisting of 681,472 nodes. The nodes are spaced 0.3 m (1 ft) apart, with each node representing 0.028 cubic meters (1 cubic foot) of the rock mass.

6.3.4 Seismic Consideration

Natural analogues for the effect of seismic events on rock fall are provided in Attachment VII. Underground openings are constrained by the surrounding medium, and it is unlikely that underground openings could move to any significant extent independently of the medium or be subjected to vibration amplification. Two potential causes of block movement during seismic events were observed. The first is related to the differential acceleration in the rock blocks surrounding the tunnel due to seismic excitation (Dowding 1979, p. 19). The second cause is the increase of the tangential force from seismic loading along the sliding surfaces of the rock block (Kaiser, McCreath, and Tannant 1996, p. 8-3).

A high-frequency seismic wave is required for the possibility of block movement due to differential acceleration (Dowding 1979, p. 19). For a case with shear wave velocity of 2000 m/sec intersecting a 5.5-m diameter drift in the repository host rock, the frequency which would produce the differential acceleration was calculated to be approximately 90 Hz. This frequency of concern is very high compared to the principal frequencies (1 to 10 Hz) with major earthquakes. Block movement due to differential acceleration is therefore not considered in this analysis.

With a relatively high ratio of wave length to opening diameter, the surrounding rock mass and the opening itself move nearly as a rigid body with free-field acceleration. A simplified quasi-static approach was used in this analysis to account for the increase of the force along the sliding surfaces. Due to the limitation of DRKBA, seismic loads can not be directly applied to the opening in the numerical simulation. An alternative method with reduction of joint strength parameters was used to account for the seismic effect (see Assumption 5.4). The reduced joint strength parameters are listed in Table 10. This method was verified based on the test runs using the distinct element code UDEC (see Section 3). Justification of this method is provided in Attachment V. Notice that joint cohesion is conservatively scaled down to 0.1 MPa from 0.86 MPa listed in Table 3 (see Assumption 5.7).

Table 10. Reduced Joint Strength Parameters to Account for Seismic Effect (Attachment V)

Loading Case	Joint Cohesion (Pa)	Joint Friction Angle (degree)
Static	99,873	41
Seismic level 1	21,282	34
Seismic level 2	10,920	24
Seismic level 3	10,776	18

6.3.5 Thermal and Fracture-Degradation Consideration

The induced thermal stress and the potential degradation of joint mechanical properties are the concerns for the thermal effect to the block movement. Due to the lateral confinement of the rock, the predicted thermal stress is highest in the horizontal direction. The high horizontal thermal stress provides the locking effect for the blocks formed by the predominant vertical joint sets during the heating period. Due to the limitation of the applying external loads using DRKBA, this locking effect was conservatively ignored in this analysis.

The degradation of joint mechanical properties due to time effect was developed by Kemeny (1991). This approach was used to develop the degradation of joint cohesion based on the site-specific parameters. Figure 8 shows the developed cohesion degradation curve. As shown in this figure, the reduction of joint cohesion is predicted to occur mainly during the first two hundred years. Detailed descriptions for this approach are provided in Attachment I.

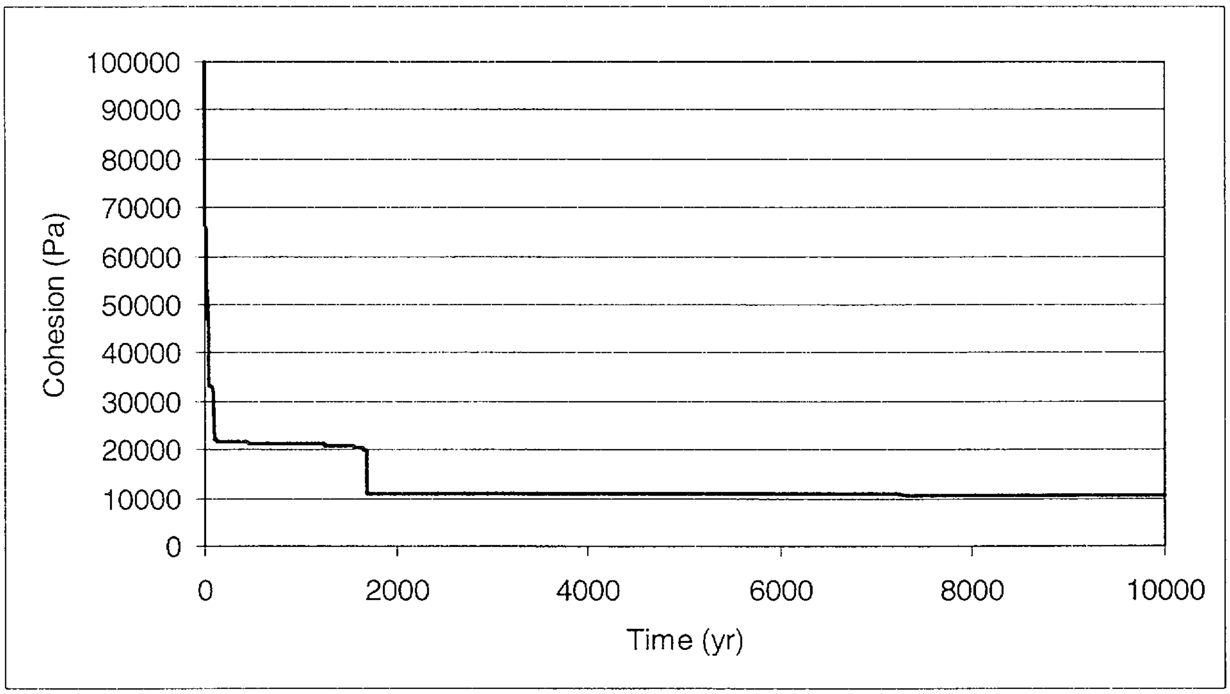


Figure 8. Degradation of Joint Cohesion with Respect to Time
(Attachment I; Attachment II, file *Cohesion Degradation V1.xls*)

6.4 ANALYSIS RESULTS

The prediction of key blocks forming at the emplacement drifts located in the four lithologic units is presented in this section. The results are presented for both a static key block assessment and a quasi-static key block assessment to account for seismic, thermal, and time effects on key blocks.

In the DRKBA analysis, random joint patterns are generated with joint centers positioned in three-dimensional space, considering each joint set in sequence for each Monte Carlo simulation. The forming of key blocks is therefore different in each Monte Carlo simulation. Test runs were conducted to determine an adequate number of Monte Carlo simulations for the analyses as described in Attachment IV. Based on the test run results, 200 Monte Carlo simulations are adequate for the Tptpmn unit and 400 Monte Carlo simulations are adequate for the rest of the units.

6.4.1 Prediction of Key Block Size and Distribution

6.4.1.1 Static Condition

A range of drift orientations with the drift azimuth varied in 15° increments is considered in the static analyses. Figures 9 through 12 present the key block analysis results in the format of cumulative frequency of occurrence for each lithologic unit. The DRKBA input and output files are contained in the compact discs (CDs) provided in Attachment II. The cumulative frequencies of occurrence corresponding to 50, 75, 90, 95 and 98 percentile block volume for each unit are listed in Tables 11 to 14. The maximum block sizes predicted from the analyses are also presented in this table. Corresponding graphs are presented in Figures 13 to 16. The predicted block size is generally small. The 95 percentile block ranges from 1.03 to 4.21 m^3 for the Tptpul unit, 1.35 to 3.70 m^3 for the Tptpmn unit, 0.55 to 8.88 m^3 for the Tptpll unit, and 0.61 to 3.50 m^3 for the Tptpln unit. For the orientation closest to the superseded repository baseline design (i.e., an azimuth of 105° as discussed in Section 6.3.3), the 98 percentile block is 2.25 m^3 for Tptpul unit, 4.57 m^3 for Tptpmn unit, 5.56 m^3 for Tptpll unit, and 1.77 m^3 for Tptpln unit.

The maximum key block sizes for the range of tunnel orientations evaluated are shown in Figure 17. The orientations predicted for the higher maximum key block sizes are in general parallel to the major high-angle joint sets (major joint set orientations are listed in Table 5). The maximum key block size predicted in this analyses for the emplacement drift is 66 m^3 when the drift is oriented at an azimuth of 150° in Tptpll unit. Maximum key block sizes are in general less than 9 m^3 when the drift is oriented in between 75° azimuth and 105° azimuth. The lowest maximum block size of 0.75 m^3 is found in Tptpll when the drift is oriented at an azimuth of 90°.

The predicted numbers of key blocks per unit length of emplacement drift are listed in Table 15. The number of key blocks formed in the lithophysal rock (i.e., the Tptpul and Tptpll units) and in the Tptpln unit was predicted to be scarce. The number of blocks predicted per 1 km of drift range from 12 to 20 for the Tptpul unit, 1 to 6 for Tptpll unit, 2 to 12 for Tptpln unit. Key blocks are most predominant in the Tptpmn unit, the number of blocks ranging from 26 to 63 per 1 km of drift. The orientations that are predicted to have a higher number of blocks are in general parallel to the major high-angle joint sets. This trend is consistent with that observed for the prediction of the maximum block size.

6.4.1.2 Quasi-Static Seismic Analysis Results

The results for quasi-static analysis with the consideration of seismic effects on rock fall are presented in this section. The method used for the quasi-static analysis to simulate the seismic effect is described in Section 6.3.4. Three levels of earthquake representing 1,000-year event

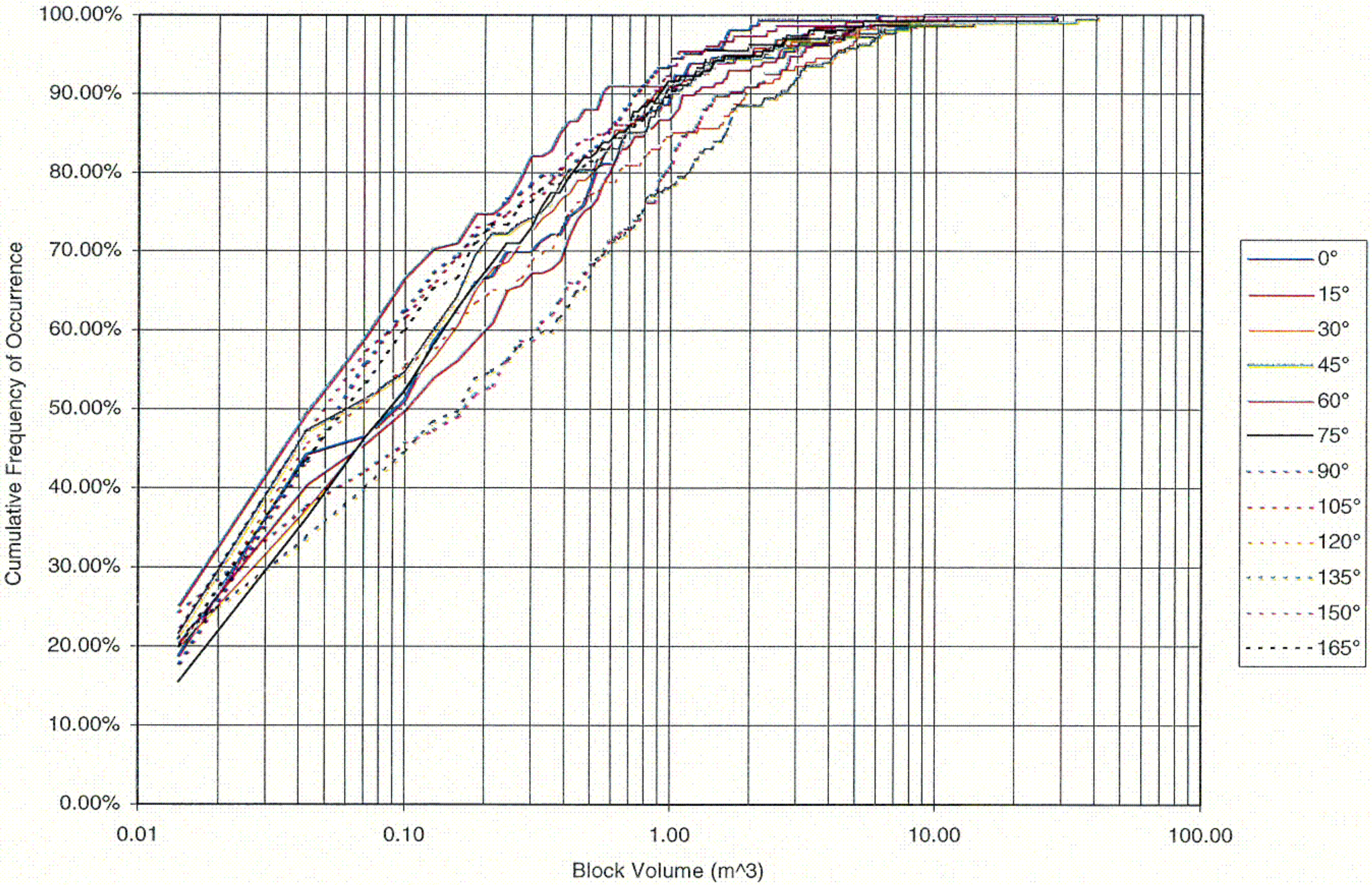


Figure 9. Cumulative Block Size Distribution for Various Drift Orientations in the Tptpul Unit, Static Condition (Attachment II, file *Tpulaa res V1.xls*)

C08

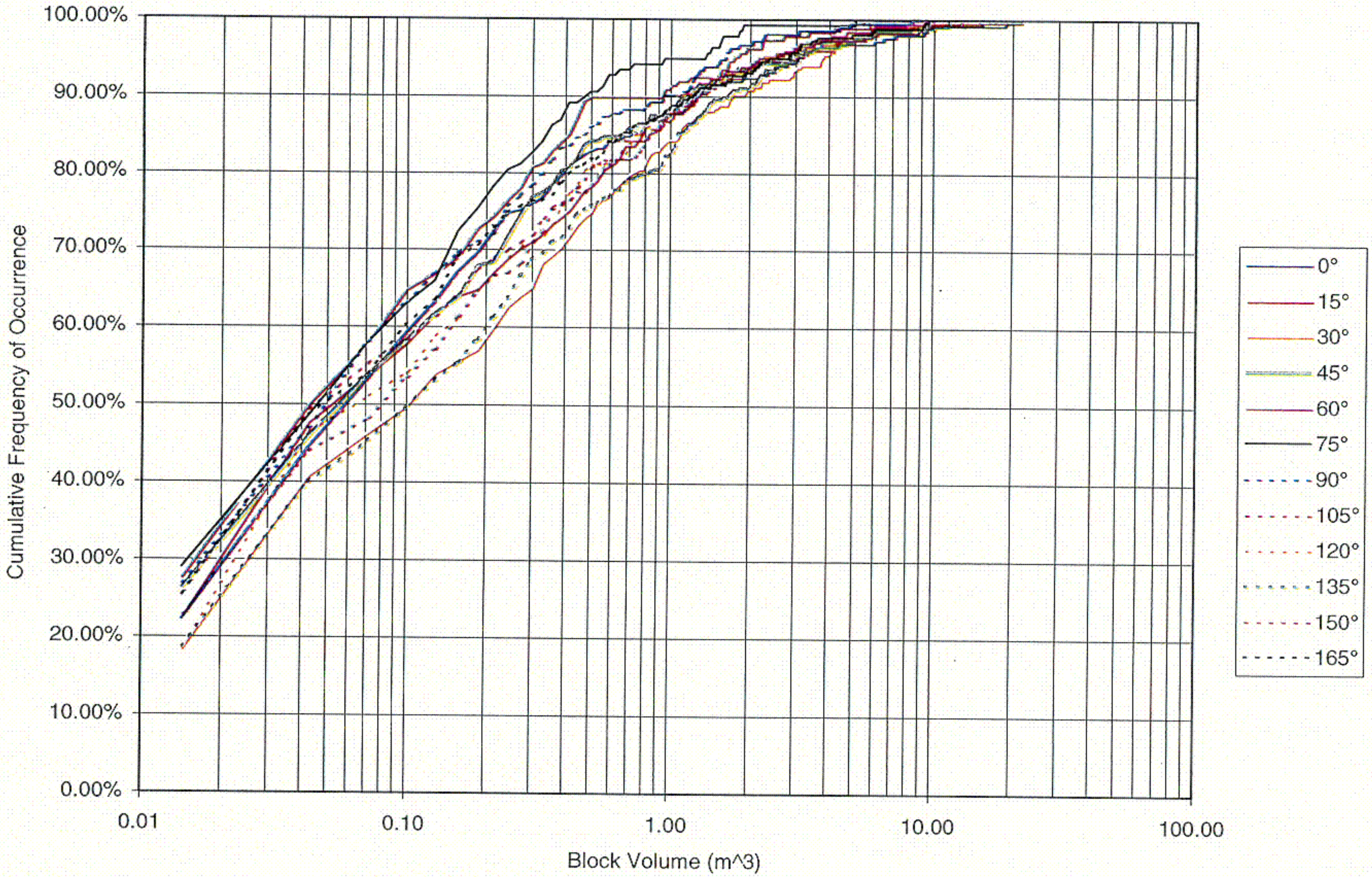


Figure 10. Cumulative Block Size Distribution for Various Drift Orientations in the Tptpmn Unit, Static Condition (Attachment II, file *Tpmnaa res V1.xls*)

C09

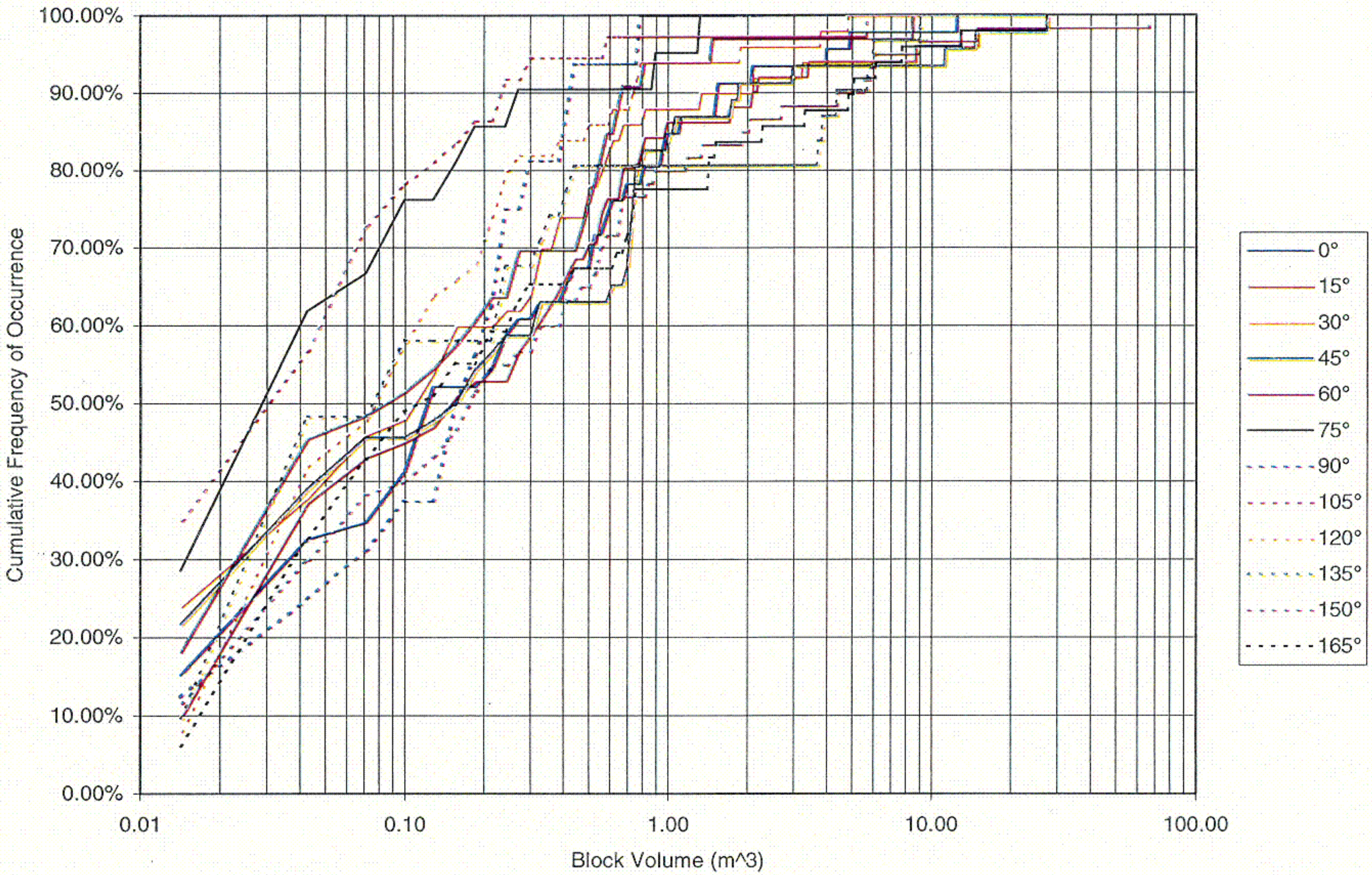


Figure 11. Cumulative Block Size Distribution for Various Drift Orientations in the Tptpll Unit, Static Condition (Attachment II, file *Tpllaa res V1.xls*)

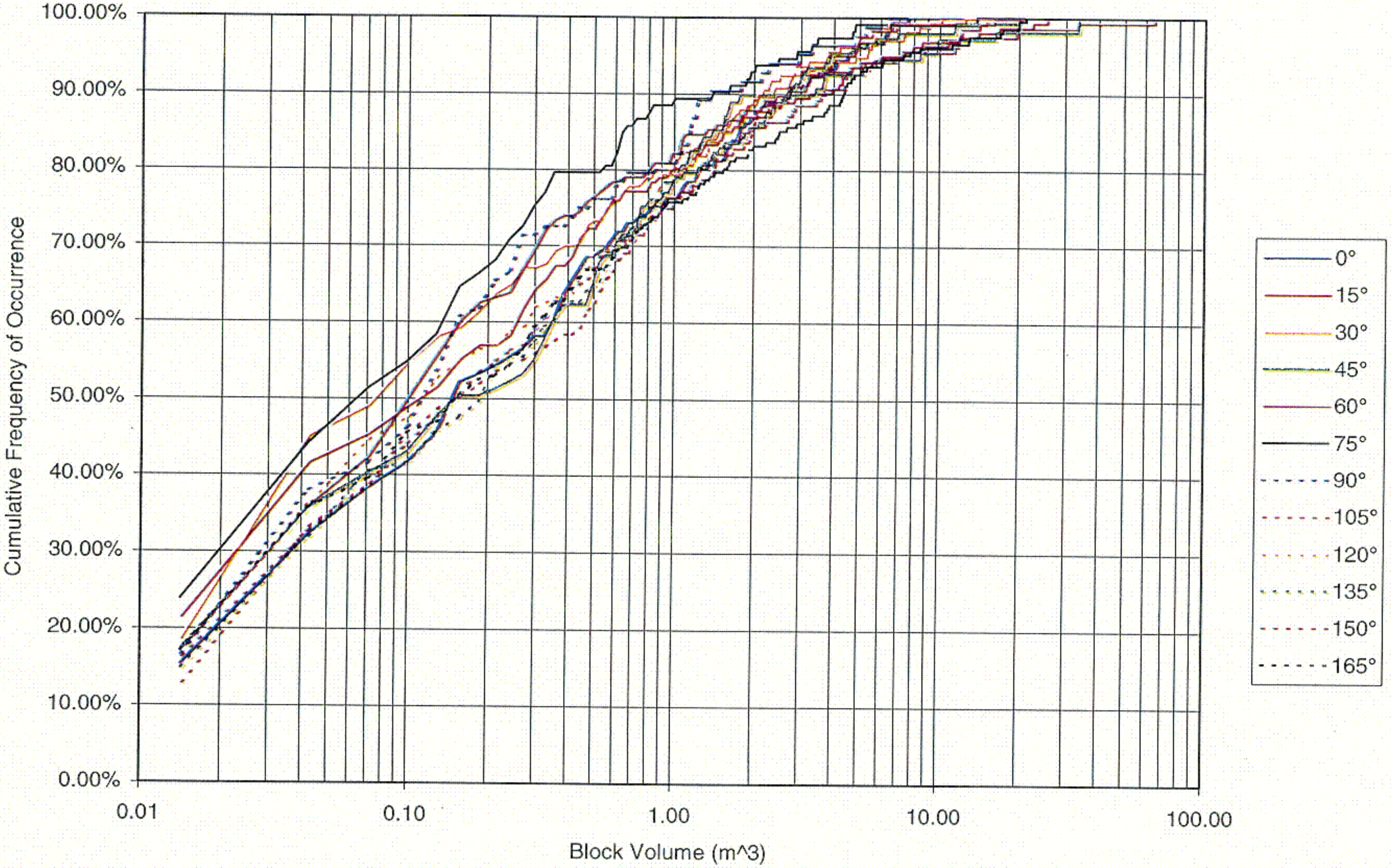


Figure 12. Cumulative Block Size Distribution for Various Drift Orientations in the Tptpln Unit, Static Condition (Attachment II, file *Tplnaa res V2.xls*)

C//

Table 11. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpul Unit, Static Condition (Attachment II, file *Tpulaa res V1.xls*)

Cumulative Frequency of Occurrence (%)	Drift Orientation (Azimuth in degree)											
	0	15	30	45	60	75	90	105	120	135	150	165
50	0.07	0.10	0.07	0.04	0.04	0.07	0.04	0.04	0.04	0.16	0.16	0.04
75	0.41	0.44	0.33	0.33	0.21	0.30	0.21	0.24	0.38	0.78	0.75	0.24
90	0.98	1.20	0.84	0.95	0.52	0.89	0.72	0.84	1.88	2.59	1.63	0.98
95	2.65	2.51	1.51	2.22	2.02	2.19	1.09	1.03	4.09	4.21	3.07	1.35
98	6.98	4.54	4.88	6.13	3.41	3.27	1.63	2.25	5.05	6.30	4.60	4.15
maximum	27.42	10.86	7.55	14.14	6.02	8.93	5.93	6.95	16.41	40.42	8.37	28.44

Table 12. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpmn Unit, Static Condition (Attachment II, file *Tpmnaa res V1.xls*)

Cumulative Frequency of Occurrence (%)	Drift Orientation (Azimuth in degree)											
	0	15	30	45	60	75	90	105	120	135	150	165
50	0.04	0.04	0.10	0.04	0.04	0.04	0.04	0.04	0.04	0.10	0.07	0.04
75	0.24	0.38	0.50	0.27	0.21	0.16	0.21	0.33	0.35	0.44	0.33	0.24
90	1.18	1.20	1.68	1.15	0.92	0.47	0.92	1.18	1.03	1.63	1.23	1.20
95	3.04	2.93	3.70	2.85	1.71	1.35	1.60	2.45	2.17	3.04	2.11	2.79
98	7.12	5.68	5.76	5.90	3.30	1.80	2.25	4.57	4.86	5.65	5.71	4.86
maximum	19.86	9.84	17.34	11.34	12.64	5.00	8.20	9.19	10.89	19.33	21.39	9.47

Table 13. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpll Unit, Static Condition (Attachment II, file *Tpllaa res V1.xls*)

Cumulative Frequency of Occurrence (%)	Drift Orientation (Azimuth in degree)											
	0	15	30	45	60	75	90	105	120	135	150	165
50	0.10	0.13	0.10	0.16	0.07	0.01	0.16	0.01	0.07	0.07	0.16	0.10
75	0.58	0.55	0.47	0.72	0.47	0.07	0.27	0.07	0.21	0.38	0.64	0.72
90	1.51	2.02	2.05	1.83	0.64	0.24	0.41	0.21	0.72	4.32	5.48	5.03
95	3.95	8.57	8.62	11.14	1.43	0.86	0.75	0.55	1.83	5.96	8.88	7.66
98	12.42	12.70	27.34	27.20	8.37	1.29	0.75	5.56	4.71	8.96	14.71	27.17
maximum	12.42	27.31	27.34	27.20	8.37	1.29	0.75	5.56	4.71	8.96	65.99	27.17

Table 14. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpln Unit, Static Condition (Attachment II, file *Tplnaa res V2.xls*)

Cumulative Frequency of Occurrence (%)	Drift Orientation (Azimuth in degree)											
	0	15	30	45	60	75	90	105	120	135	150	165
50	0.13	0.10	0.07	0.13	0.10	0.04	0.10	0.13	0.10	0.18	0.16	0.13
75	0.81	0.55	0.52	0.72	0.67	0.27	0.47	0.86	0.81	0.78	0.69	0.89
90	2.70	3.19	2.31	3.38	2.08	1.37	1.35	2.62	2.02	2.65	2.31	4.32
95	4.46	5.93	5.22	8.42	3.58	2.87	2.93	3.98	3.67	3.87	3.33	7.26
98	6.33	13.80	7.29	16.21	8.25	4.66	5.22	5.45	6.07	6.90	5.56	16.86
maximum	7.52	25.05	12.25	33.40	16.95	13.75	6.33	14.71	9.93	20.23	47.95	21.14

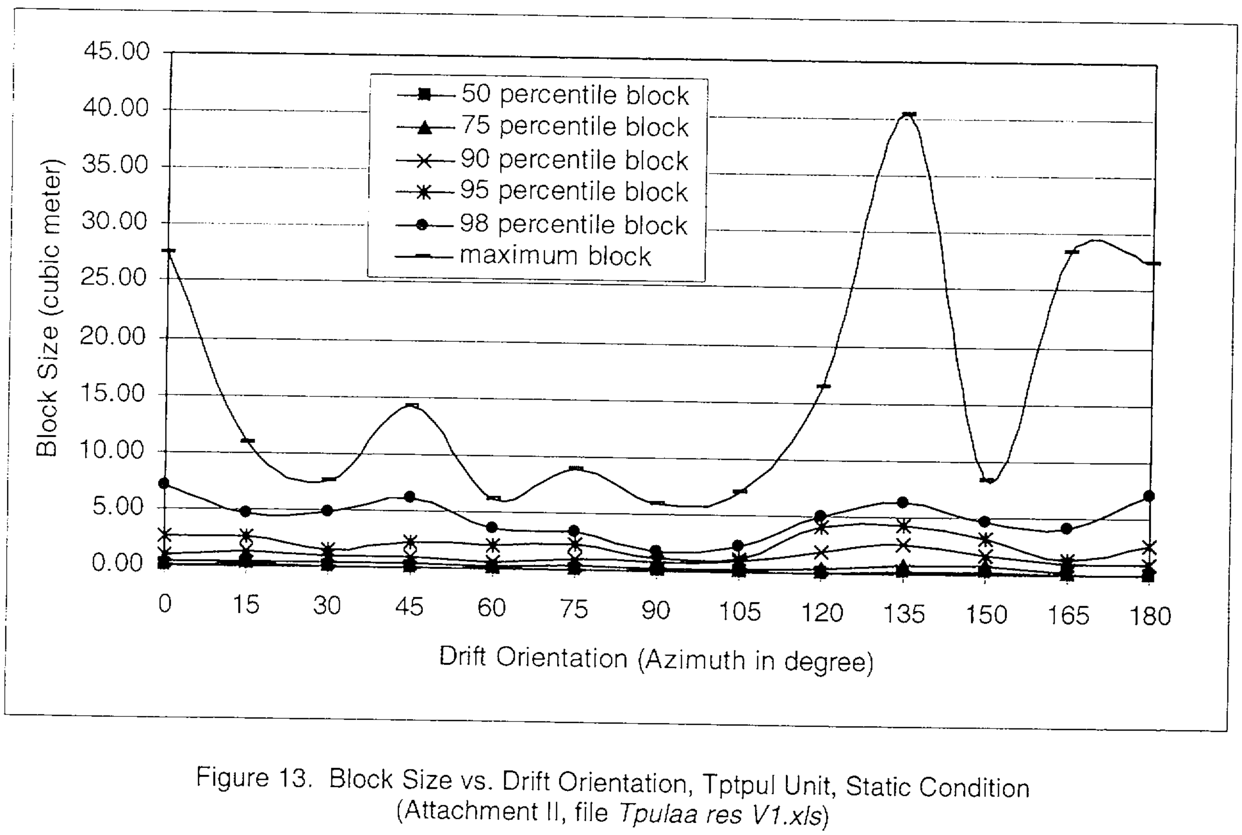


Figure 13. Block Size vs. Drift Orientation, Tptpul Unit, Static Condition (Attachment II, file *Tpulaa res V1.xls*)

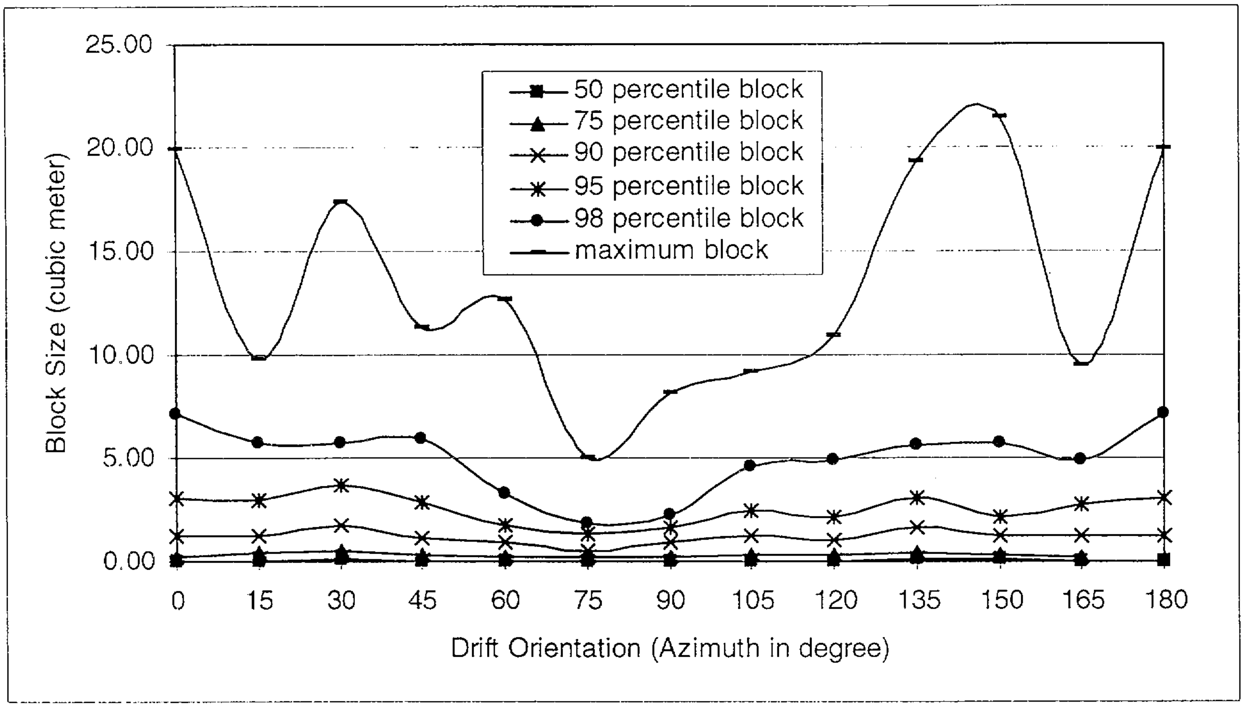


Figure 14. Block Size vs. Drift Orientation, Tptpmn Unit, Static Condition
(Attachment II, file *Tpmnaa res V1.xls*)

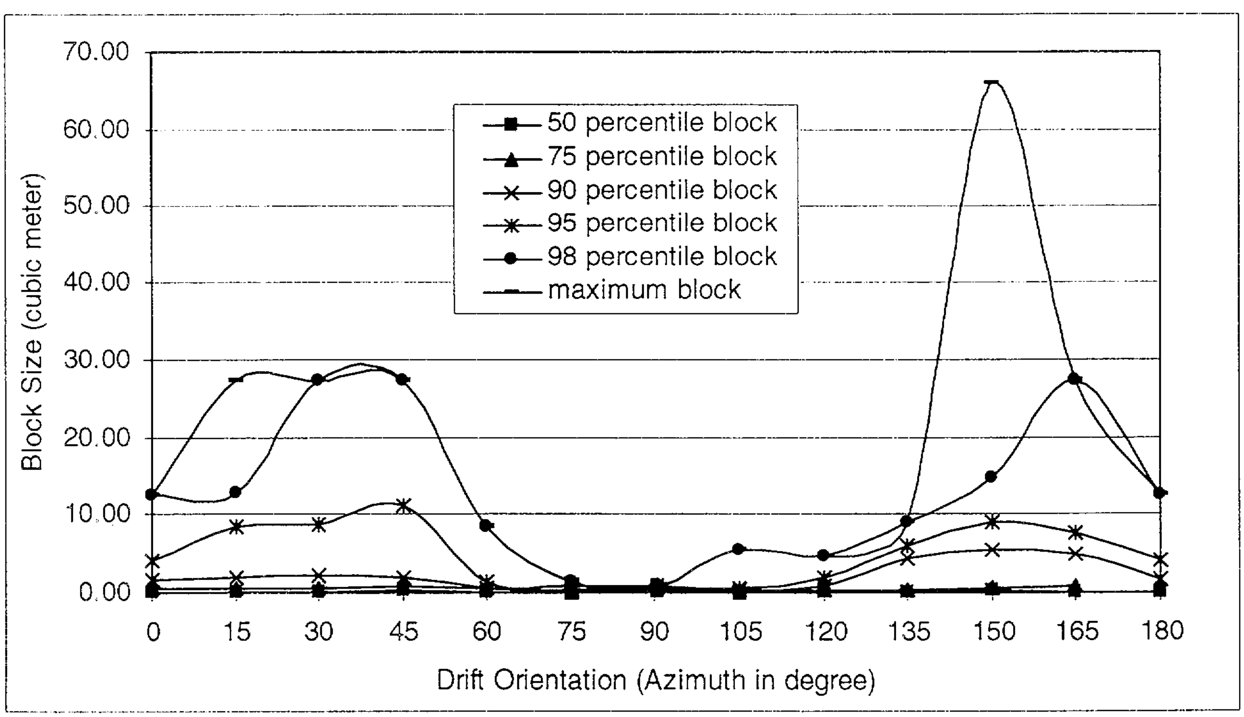


Figure 15. Block Size vs. Drift Orientation, Tptpll Unit, Static Condition
(Attachment II, file *Tpllaa res V1.xls*)

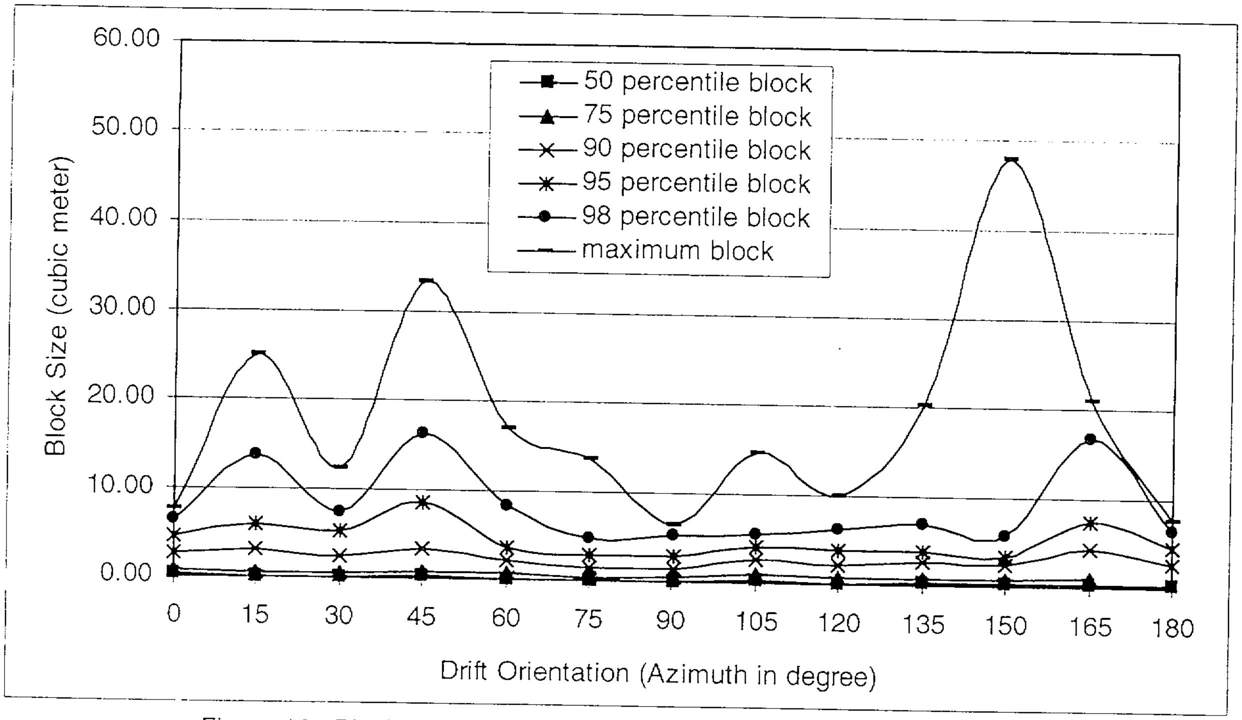


Figure 16. Block Size vs. Drift Orientation, Tptpln Unit, Static Condition (Attachment II, file *Tplnaa res V2.xls*)

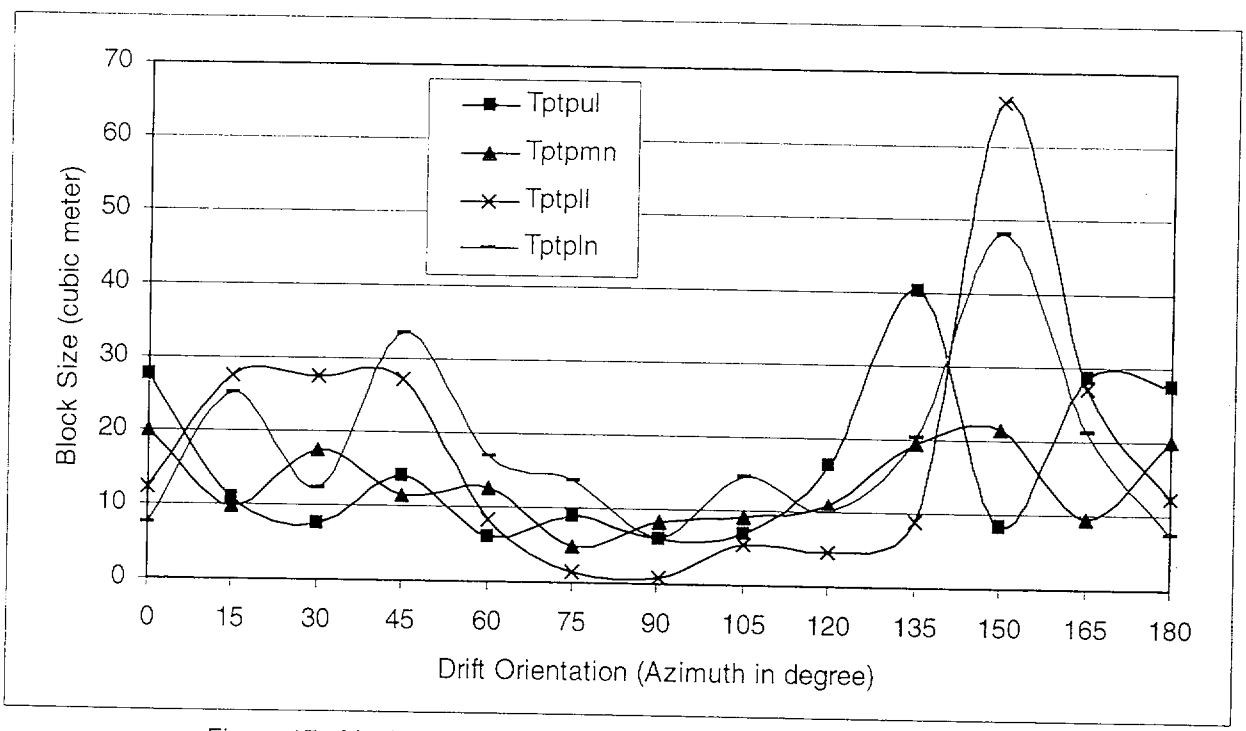


Figure 17. Maximum Block Size vs. Drift Orientation, Static Condition (Attachment II, file *Res sum V2.xls*)

Table 15. Predicted Number of Key Blocks per Unit Length (km) along Emplacement Drift, Static Condition (Attachment II, file *Res sum V2.xls*)

Lithologic Unit	Drift Orientation (Azimuth in degree)											
	0	15	30	45	60	75	90	105	120	135	150	165
Tptpul	14	19	13	15	14	16	17	16	19	22	18	14
Tptpmn	51	46	59	36	39	28	44	41	58	70	62	53
Tptpll	5	5	5	5	3	2	2	4	5	3	6	5
Tptpln	19	17	18	11	14	12	9	13	17	16	15	21

(Level 1), 5,000-year event (Level 2), and 10,000-year event (Level 3) are considered. An emplacement drift orientation with an azimuth of 75° is the primary orientation for the quasi-static analysis. Additionally, an emplacement drift orientation with an azimuth of 105° has been analyzed. The inputs and outputs related to the quasi-static analysis are contained in the CDs provided in Attachment II.

105°-Azimuth Emplacement Drift Orientation–The seismic results for 5.5-m-diameter emplacement drifts oriented with a tunnel azimuth of 105° are provided in this subsection. The analyses do not include backfill.

Figures 18 through 21 present the key block size distribution for each lithologic unit respectively. In addition to the results from the three levels of earthquake events, static results are also included for comparison. The cumulative frequencies of occurrence corresponding to 50, 75, 90, 95 and 98 percentile block volume for each unit are listed in Tables 16 to 19. The maximum block sizes predicted from the analyses are included in these tables. Corresponding graphs are presented in Figures 22 to 25. The analysis results indicate that the seismic effect on the rock fall size distribution is relatively minor.

The predicted numbers of key blocks per unit length of drift are listed in Table 20. Static results are also included for comparison. The comparison shows that there is an insignificant impact for a 1,000-year event earthquake (Level 1) on the number of rock falls, and only a minor impact for both a 5000-year event earthquake (Level 2) and a 10,000-year event (Level 3). The number of key blocks predicted for Tptpll unit remains scarce, as there was no change in the number of blocks regardless of the level of seismic event.

The predicted average volume of rock fall per unit length of drift is listed in Table 21. The trend for the average volume of rock fall per kilometer is similar to that for the predicted number of key blocks per kilometer.

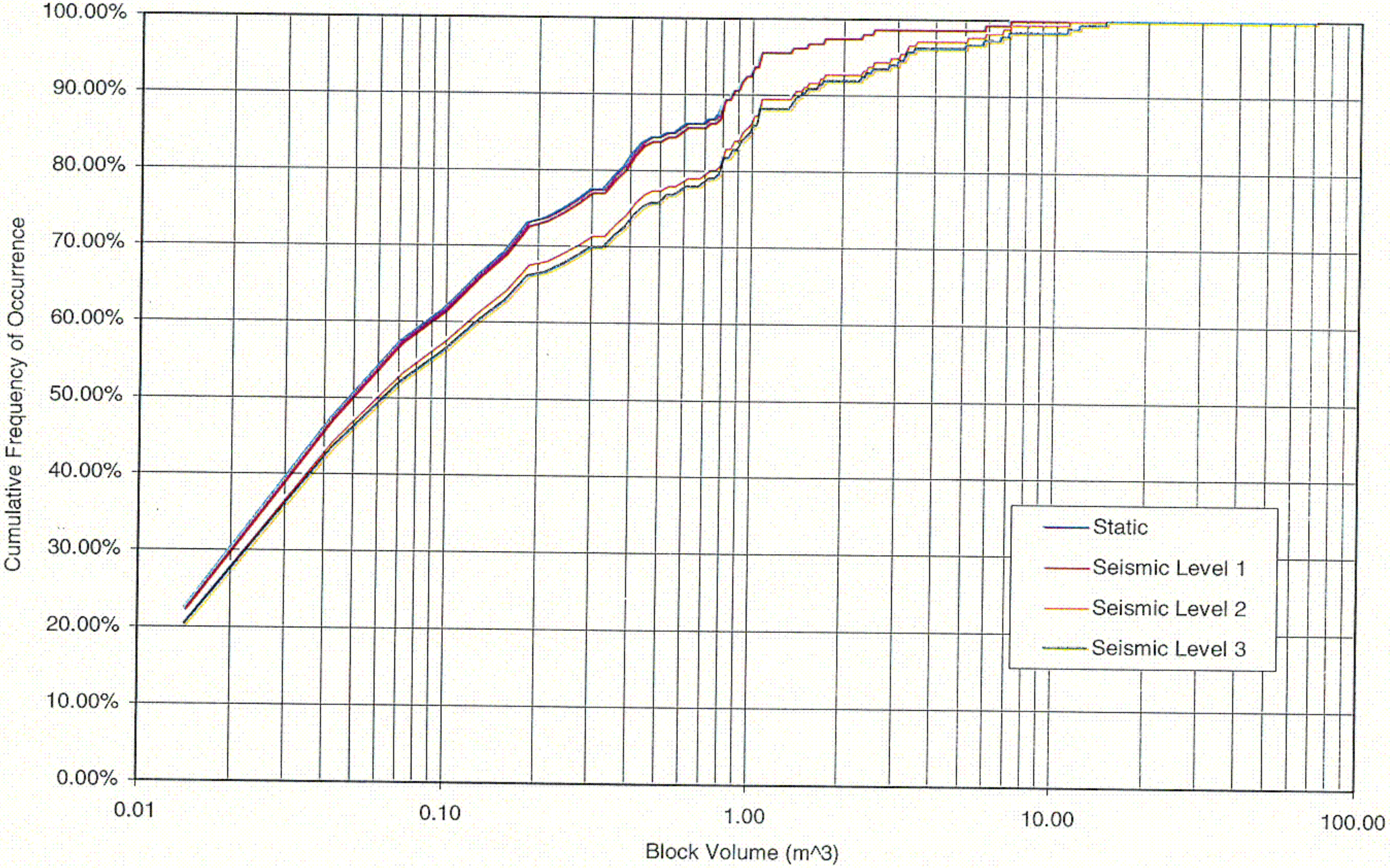
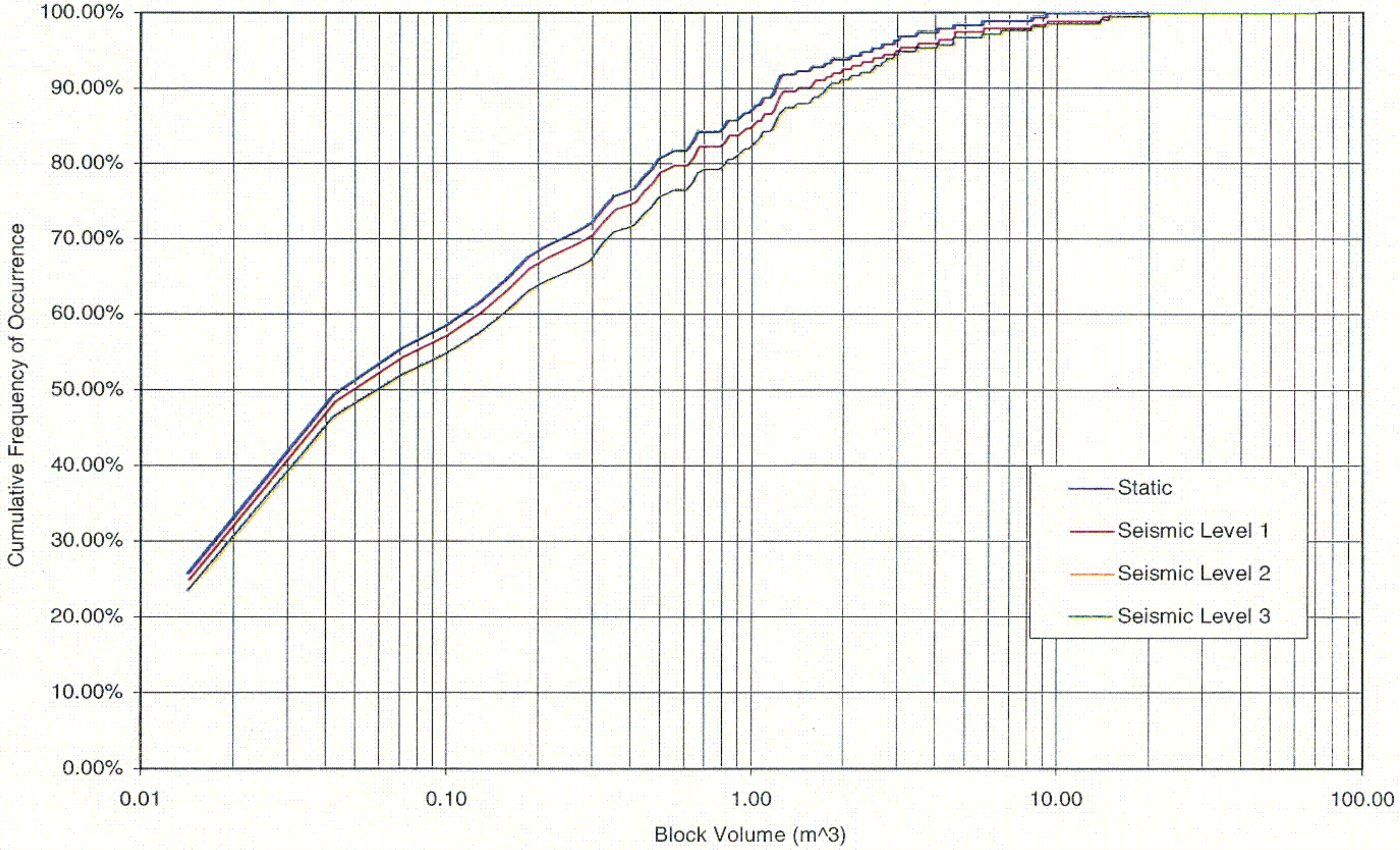
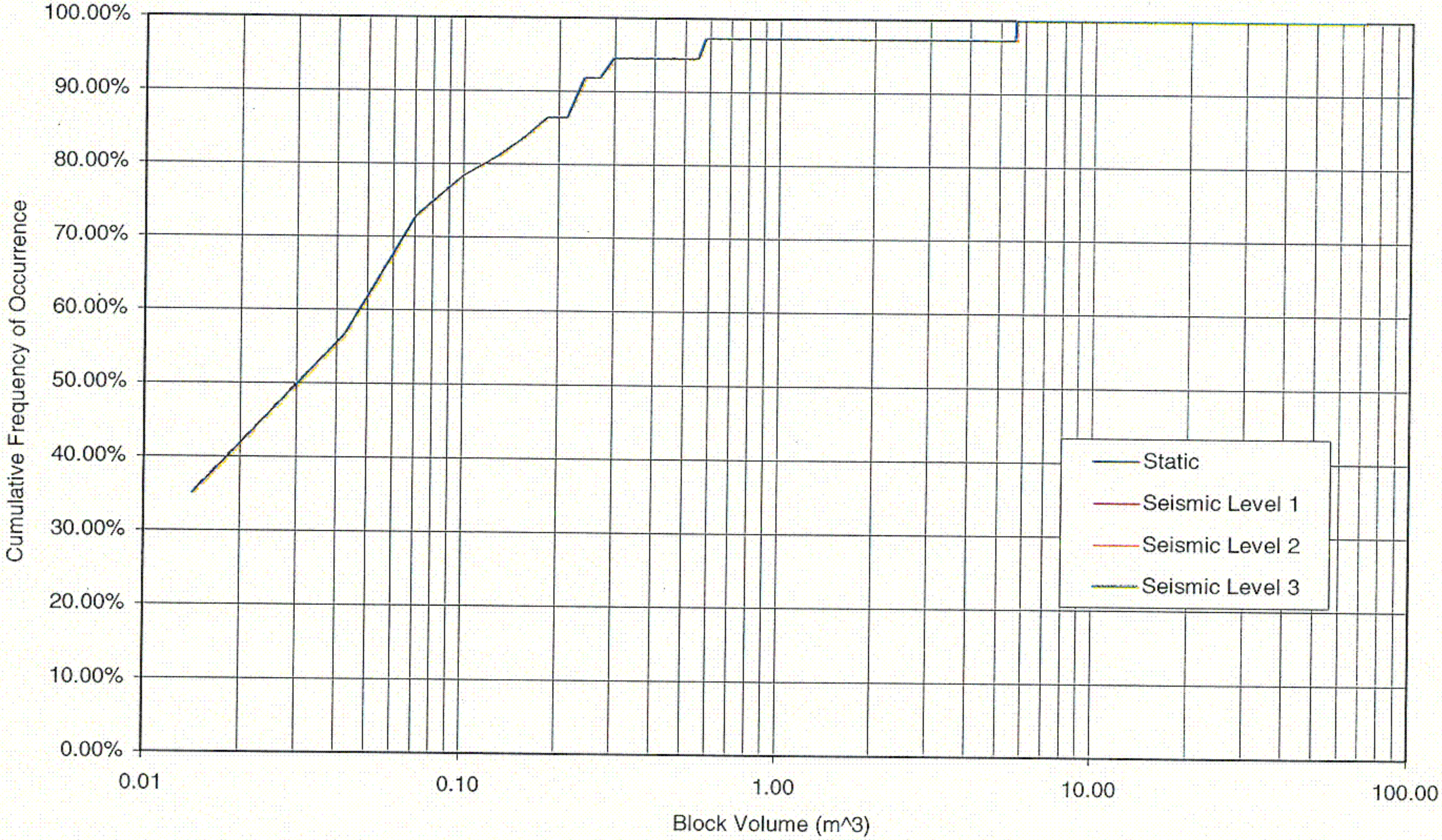


Figure 18. Cumulative Key Block Size Distribution for Seismic Consideration in the Tptpul Unit, 105°-Azimuth (Attachment II, file *Tpulse res V1.xls*)



NOTE: The seismic level 2 and seismic level 3 distribution curves are identical.

Figure 19. Cumulative Key Block Size Distribution for Seismic Consideration in the Tptpmn Unit, 105°-Azimuth (Attachment II, file *Tpmnse res V1.xls*)



NOTE: The static, seismic level 1, seismic level 2, and seismic level 3 distribution curves are identical.

Figure 20. Cumulative Key Block Size Distribution for Seismic Consideration in the Tptpll Unit, 105°-Azimuth (Attachment II, file *Tpllse res V1.xls*)

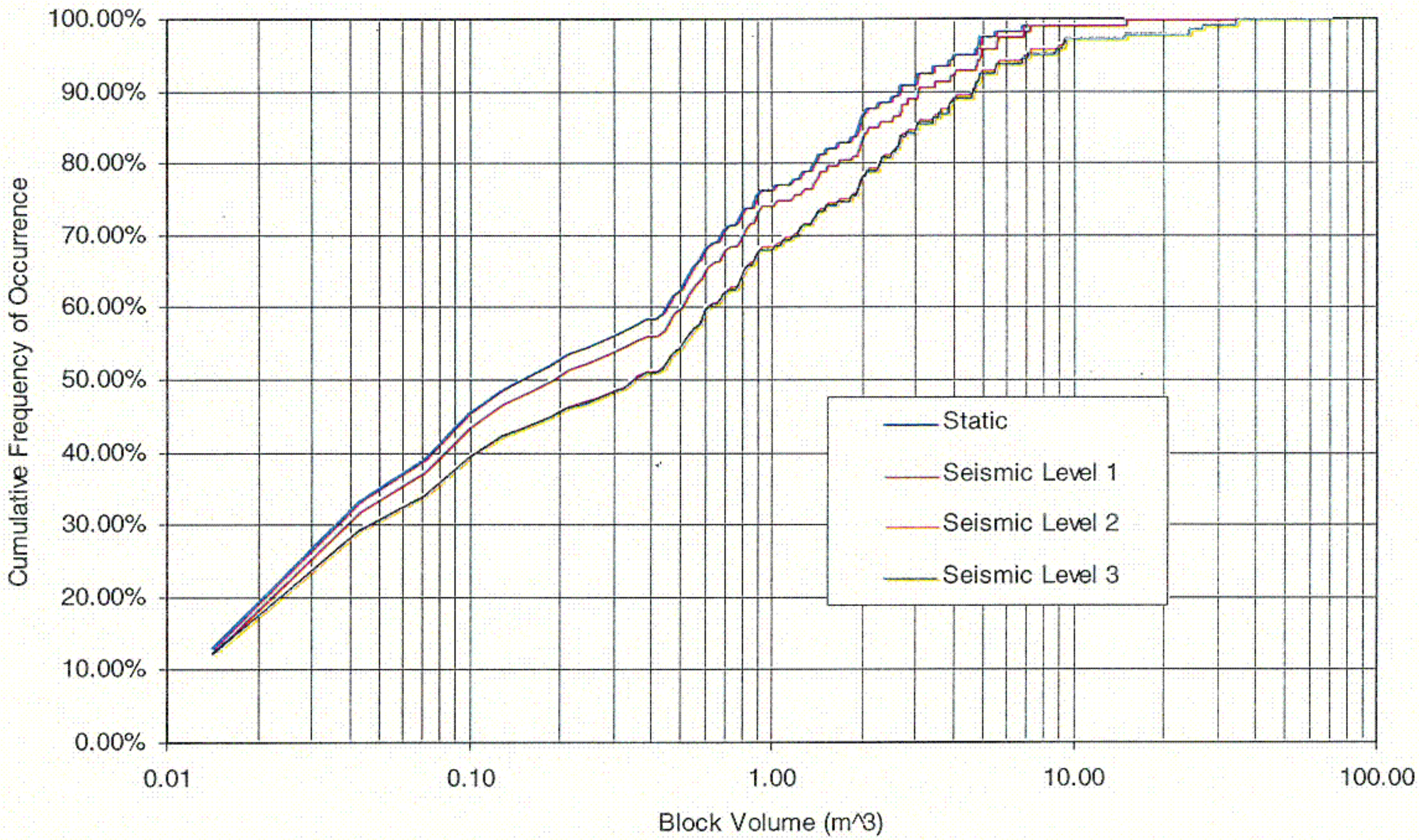


Figure 21. Cumulative Key Block Size Distribution for Seismic Consideration in the Tptpln Unit, 105°-Azimuth (Attachment II, file *Tpln seismic 105 res V2.xls*)

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Table 16. Block Volume (in cubic meter) Corresponding to Various Level of Predicted Cumulative Frequency of Occurrence, 105°-Azimuth Emplacement Drift in Tptpul Unit, with Seismic Consideration (Attachment II, file *Tpulse res V1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Static Plus Seismic		
		Level 1	Level 2	Level 3
50%	0.04	0.04	0.04	0.04
75%	0.24	0.24	0.38	0.41
90%	0.84	0.84	1.32	1.43
95%	1.03	1.03	2.79	3.13
98%	2.25	2.25	5.73	6.95
maximum	6.95	6.95	10.86	14.54

Table 17. Block Volume (in cubic meter) Corresponding to Various Level of Predicted Cumulative Frequency of Occurrence, 105°-Azimuth Emplacement Drift in Tptpmn Unit, with Seismic Consideration (Attachment II, file *Tpmnse res V1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Static Plus Seismic		
		Level 1	Level 2	Level 3
50%	0.04	0.04	0.04	0.04
75%	0.33	0.41	0.47	0.47
90%	1.18	1.37	1.74	1.74
95%	2.45	2.90	3.44	3.44
98%	4.57	5.68	8.25	8.25
maximum	9.19	19.89	19.89	19.89

Table 18. Block Volume (in cubic meter) Corresponding to Various Level of Predicted Cumulative Frequency of Occurrence, 105°-Azimuth Emplacement Drift in Tptpll Unit, with Seismic Consideration (Attachment II, file *Tpllse res V1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Static Plus Seismic		
		Level 1	Level 2	Level 3
50%	0.01	0.01	0.01	0.01
75%	0.07	0.07	0.07	0.07
90%	0.21	0.21	0.21	0.21
95%	0.55	0.55	0.55	0.55
98%	5.56	5.56	5.56	5.56
maximum	5.56	5.56	5.56	5.56

Table 19. Block Volume (in cubic meter) Corresponding to Various Level of Predicted Cumulative Frequency of Occurrence, 105°-Azimuth Emplacement Drift in Tptpln Unit, with Seismic Consideration (Attachment II, file *Tpln seismic 105 res V2.xls*)

Cumulative Frequency of Occurrence (%)	Static	Static Plus Seismic		
		Level 1	**Level 2**	**Level 3**
50%	0.13	0.18	0.33	0.33
75%	0.86	1.15	1.63	1.80
90%	2.62	2.99	4.60	4.66
95%	3.98	4.83	6.73	7.04
98%	5.45	6.73	24.00	24.00
maximum	14.71	14.71	34.22	34.22

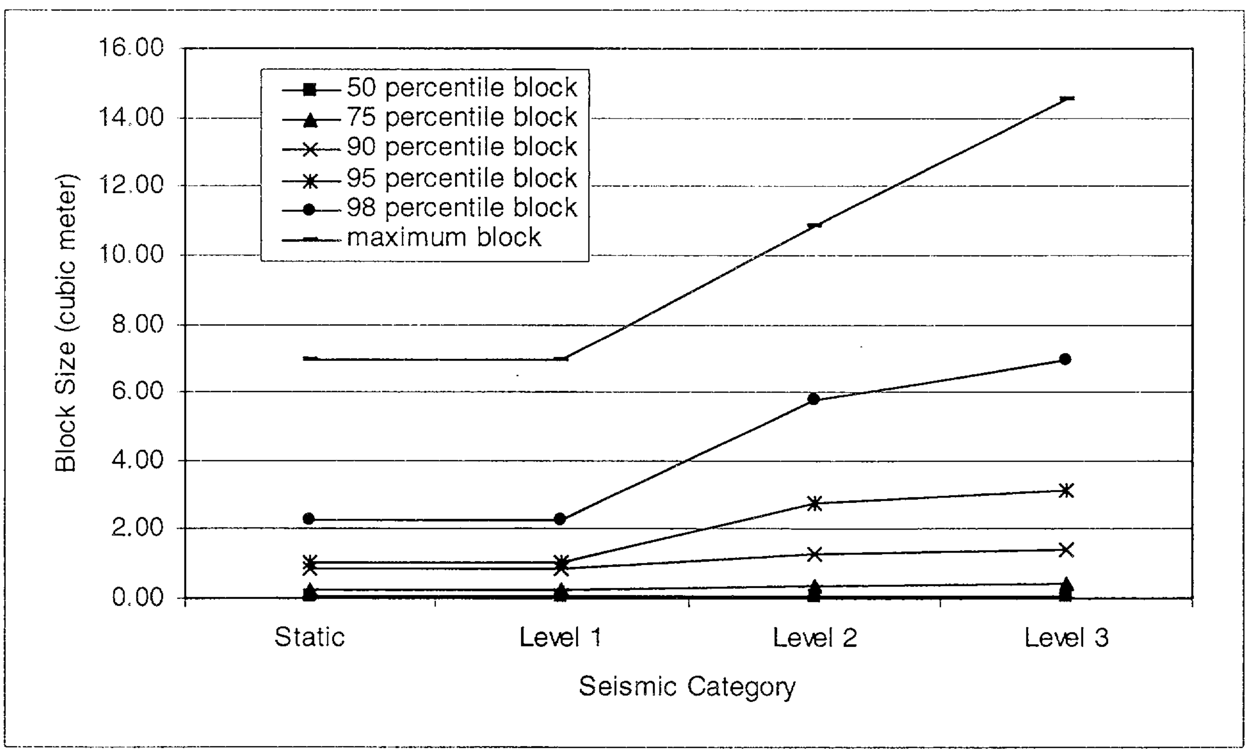


Figure 22. Block Size vs. Seismic Category, Tptpul Unit, 105°-Azimuth (Attachment II, file *Tpulse res V1.xls*)

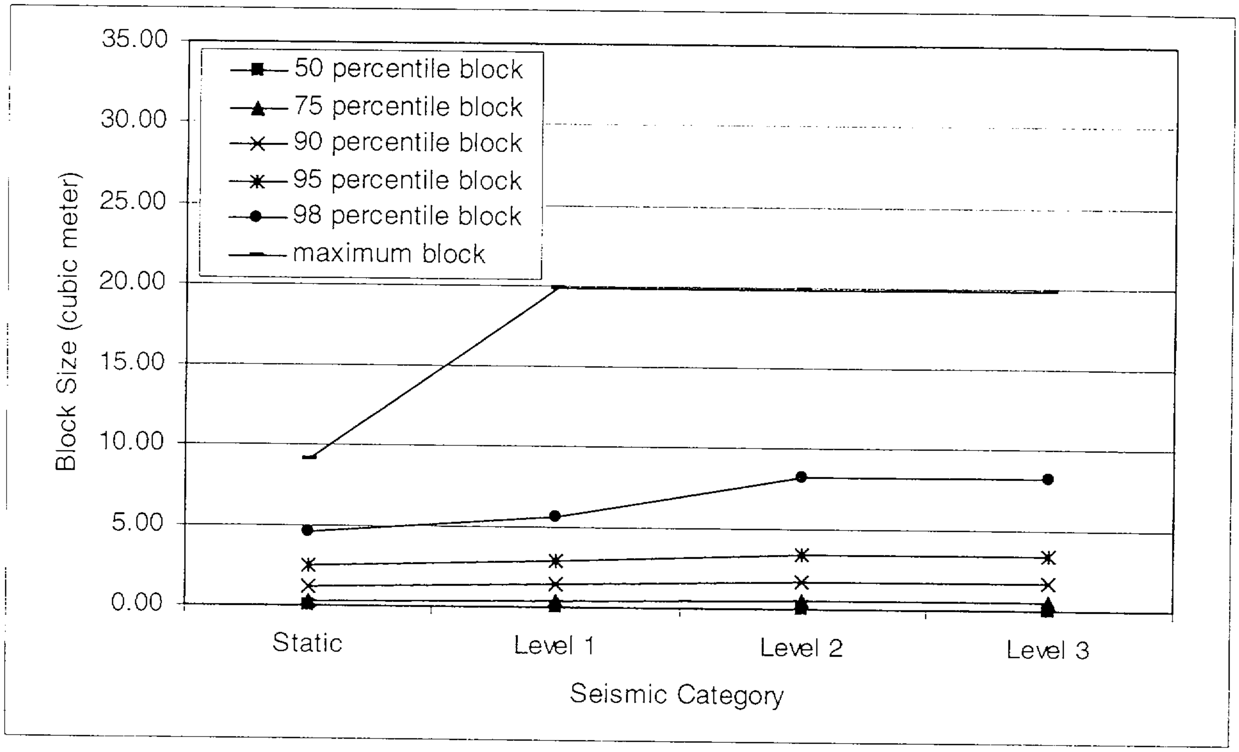


Figure 23. Block Size vs. Seismic Category, Tptpmn Unit, 105°-Azimuth
(Attachment II, file *Tpmnse res V1.xls*)

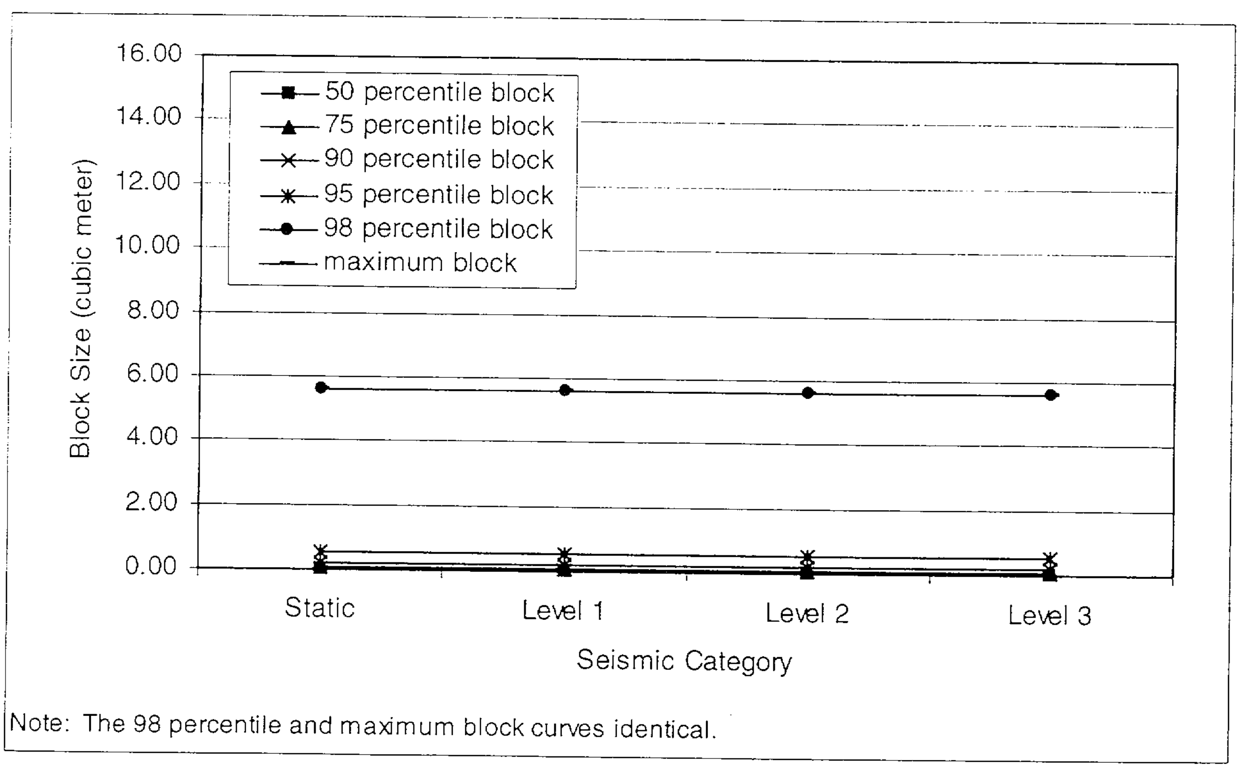


Figure 24. Block Size vs. Seismic Category, Tptpll Unit, 105°-Azimuth
(Attachment II, file *Tpllse res V1.xls*)

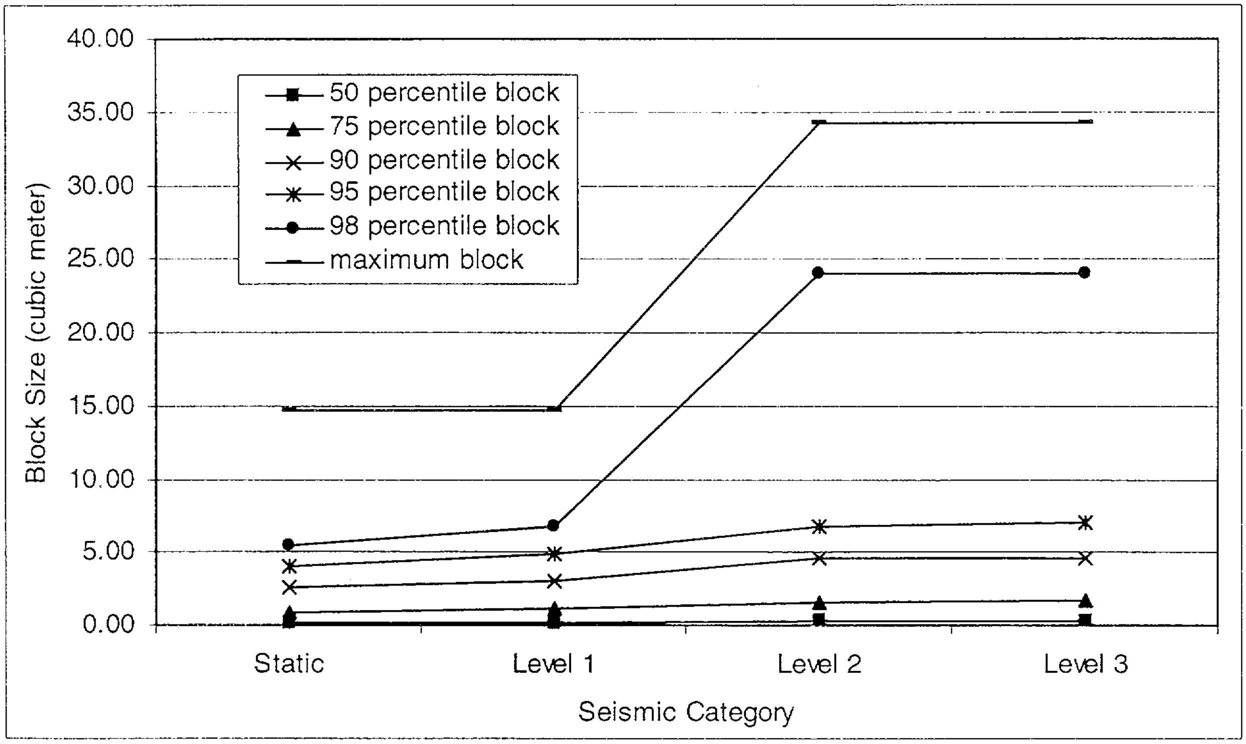


Figure 25. Block Size vs. Seismic Category, Tptpln Unit, 105°-Azimuth (Attachment II, file *Tpln seismic 105 res V2.xls*)

Table 20. Predicted Number of Key Blocks per Unit Length (km) along 105°-Azimuth Emplacement Drift, with Seismic Consideration (Attachment II, file *Res sum V2.xls*)

Lithologic Unit	**Static**	**Static Plus Seismic**		
		Level 1	**Level 2**	**Level 3**
Tptpul	16	17	19	19
Tptpmn	41	42	44	44
Tptpll	4	4	4	4
Tptpln	13	13	15	15

Table 21. Predicted Average Volume of Key Blocks per Unit Length along 105°-Azimuth Emplacement Drift, with Seismic Consideration (Attachment II, file *Total vol seis 105 v2.xls*)

Lithologic Unit	**Static (m^3/km)**	**Static Plus Seismic (m^3/km)**		
		Level 1	**Level 2**	**Level 3**
Tptpul	5.4	5.5	10.4	13.4
Tptpmn	19.8	28.4	35.6	35.6
Tptpll	0.9	0.9	0.9	0.9
Tptpln	11.6	13.8	26.8	27.7

75°-Azimuth Emplacement Drift Orientation–The seismic results for 5.5-m-diameter emplacement drifts oriented with a tunnel azimuth of 75° are provided in this subsection and in Attachment X.

Similar to Figures 18 through 21 for the 105° drift orientation, Figures 26 through 29 present the key block size distribution for a 75° drift orientation. The cumulative frequencies of occurrence corresponding to 50, 75, 90, 95 and 98 percentile block volume for each unit are listed in Tables 22 to 25. The maximum block sizes predicted from the analyses are included in these tables. The maximum block sizes predicted for Tptpul and Tptpmn units under a Level 3 seismic event are approximately 2 to 5 times the sizes for the static condition. For Tptpll unit, seismic events appear to have no impact on block size. These results are generally consistent with the results of the 105° drift orientation.

The predicted numbers of key blocks per unit length of drift are listed in Table 26. Similar to the results of 105° drift orientation, the results show that there is an insignificant impact for a 1,000-year event earthquake (Level 1) on the number of rock falls, and only a minor impact for both a 5000-year event earthquake (Level 2) and a 10,000-year event (Level 3). The number of key blocks predicted for the Tptpll unit remains scarce, as there was no change in the number of blocks regardless of the level of seismic event. The predicted average volume of rock fall per unit length of drift is listed in Table 27. The trend for the average volume of rock fall per kilometer is similar to that for the predicted number of key blocks per kilometer. The predicted block numbers and volume for the 75°-azimuth orientation are considerably less that those for 105°-azimuth orientation in the Tptpmn and Tptpll units. A more detailed assessment of the volume of failed rock for a 75°-azimuth emplacement drift orientation is provided in Attachment XI.

Table 22. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, 75°-Azimuth Emplacement Drift in Tptpul Unit, with Seismic Consideration (Attachment II, file *tpul seismic 75 res v1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Static Plus Seismic (m^3)		
		Level 1	Level 2	Level 3
50%	0.07	0.07	0.10	0.10
75%	0.30	0.33	0.38	0.41
90%	0.89	0.92	1.57	2.28
95%	2.19	2.42	4.88	8.93
98%	3.27	4.88	15.19	24.45
maximum	8.93	36.17	36.17	36.17

Table 23. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, 75°-Azimuth Emplacement Drift in Tptpmn Unit, with Seismic Consideration (Attachment II, file *tpmn seismic 75 res v1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Static Plus Seismic (m^3)		
		Level 1	Level 2	Level 3
50%	0.04	0.04	0.04	0.04
75%	0.16	0.18	0.24	0.24
90%	0.47	0.55	1.03	1.03
95%	1.35	1.51	1.77	1.77
98%	1.80	4.23	4.23	4.23
maximum	5.00	6.16	14.00	14.00

Table 24. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, 75°-Azimuth Emplacement Drift in Tptpll Unit, with Seismic Consideration (Attachment II, file *tpll seismic 75 res v1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Static Plus Seismic (m^3)		
		Level 1	Level 2	Level 3
50%	0.01	0.01	0.01	0.01
75%	0.07	0.07	0.07	0.13
90%	0.24	0.24	0.24	0.24
95%	0.86	0.86	0.86	0.86
98%	1.29	1.29	1.29	1.29
maximum	1.29	1.29	1.29	1.29

Table 25. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, 75°-Azimuth Emplacement Drift in Tptpln Unit, with Seismic Consideration (Attachment II, file *tpln seismic 75 res v2.xls*)

Cumulative Frequency of Occurrence (%)	Static	Static Plus Seismic (m^3)		
		Level 1	Level 2	Level 3
50%	0.04	0.04	0.07	0.07
75%	0.27	0.30	0.33	0.33
90%	1.37	1.60	2.45	2.00
95%	2.87	2.96	4.77	4.66
98%	4.66	4.66	14.63	14.63
maximum	13.75	13.75	57.33	57.33

Table 26. Predicted Number of Key Blocks per Unit Length (km) along 75°-Azimuth Emplacement Drift, with Seismic Consideration (Attachment II, file *Res sum V2.xls*)

Lithologic Unit	Static	Static Plus Seismic		
		Level 1	Level 2	Level 3
Tptpul	16	16	17	18
Tptpmn	28	29	32	32
Tptpll	2	2	2	2
Tptpln	12	12	12	12

Table 27. Predicted Average Volume of Key Blocks per Unit Length along 75°-Azimuth Emplacement Drift, with Seismic Consideration (Attachment II, file *Total vol seis 75 v2.xls*)

Lithologic Unit	Static (m^3/km)	Static Plus Seismic (m^3/km)		
		Level 1	Level 2	Level 3
Tptpul	7.2	10.9	20.3	27.5
Tptpmn	6.8	9.0	14.4	14.4
Tptpll	0.4	0.4	0.4	0.4
Tptpln	6.4	6.7	19.7	19.8

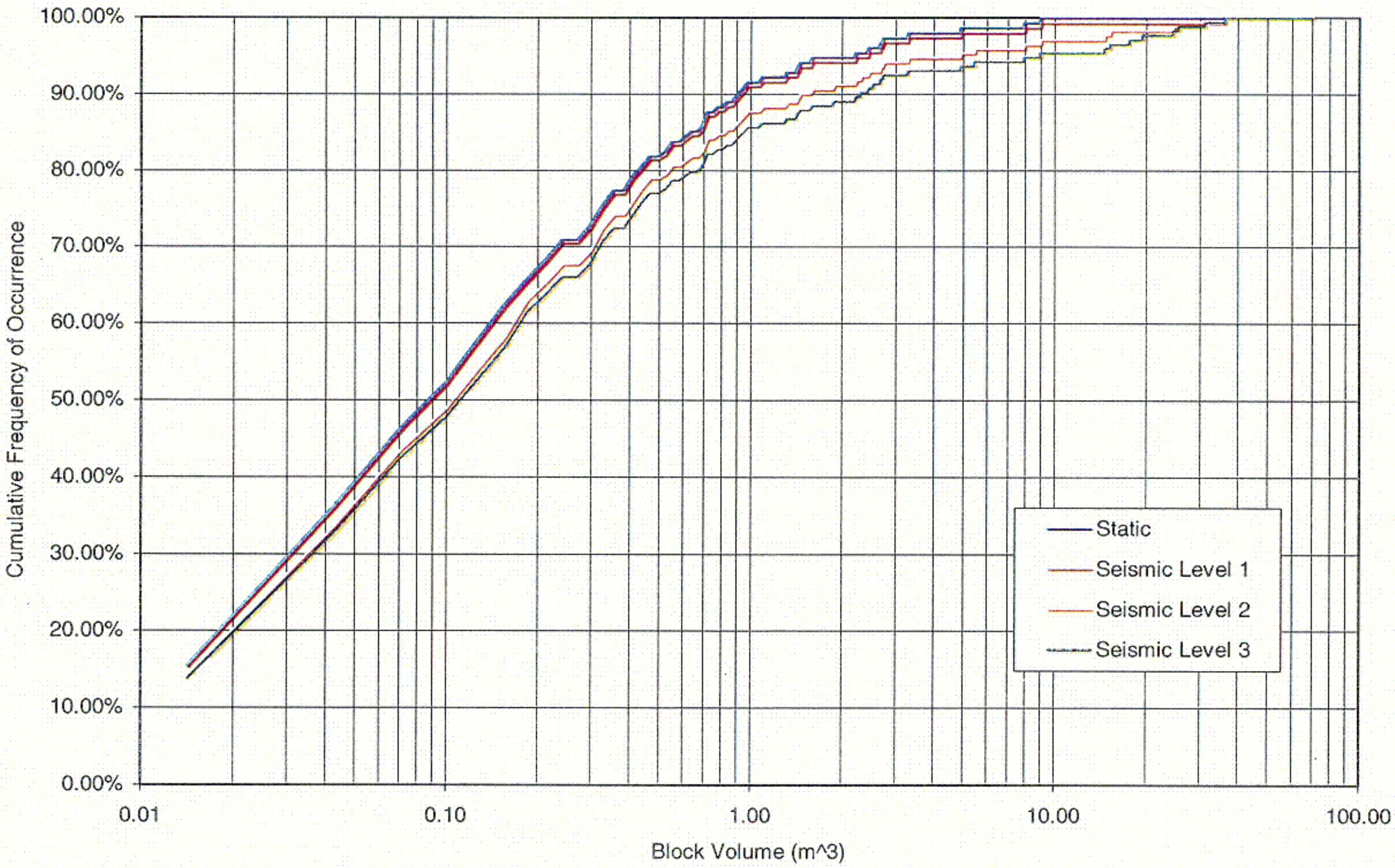
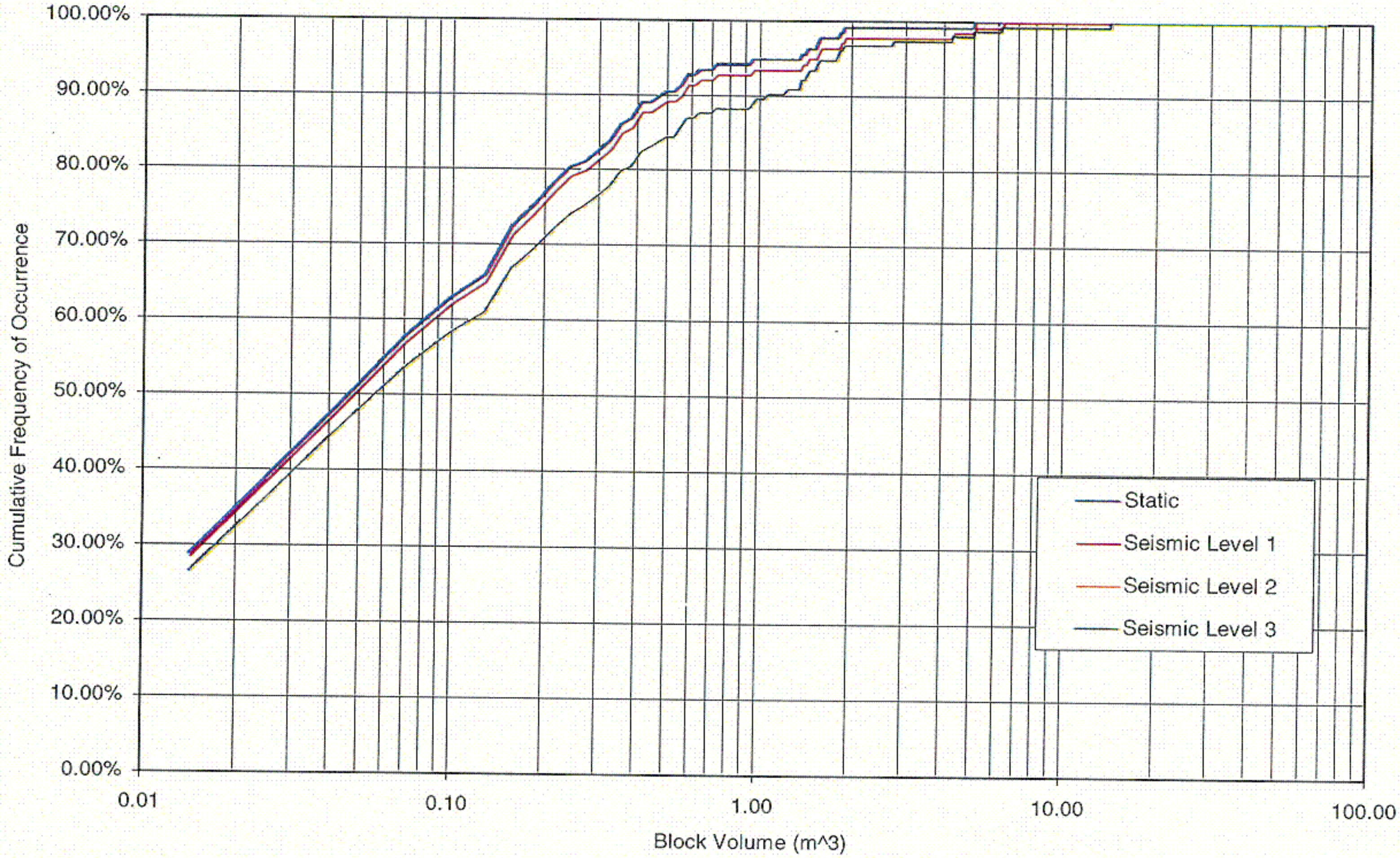
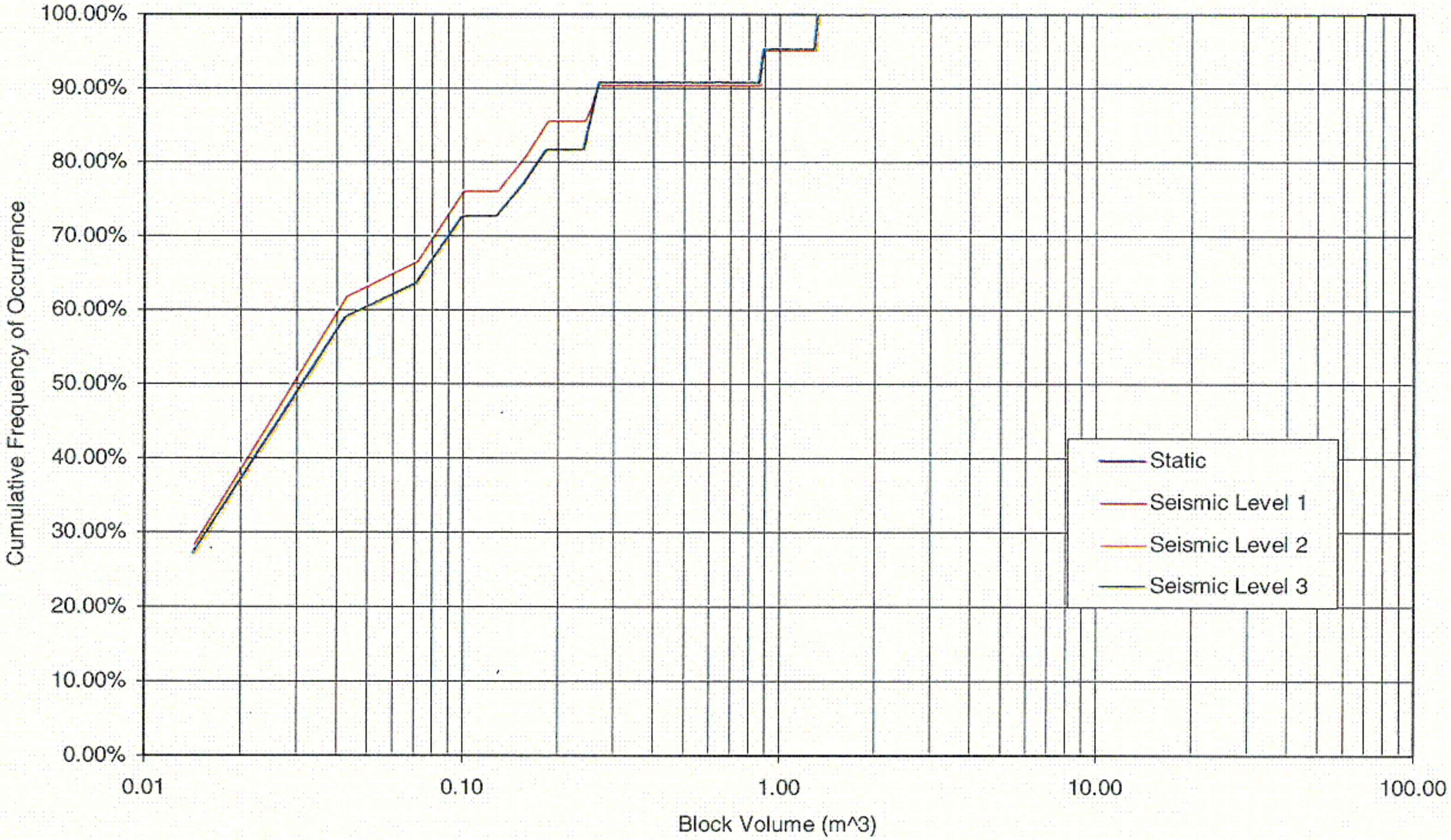


Figure 26. Cumulative Key Block Size Distribution for Seismic Consideration in the Tptpul Unit, 75°-Azimuth (Attachment II, file *tpul seismic 75 res v1.xls*)



NOTE: The seismic level 2 and seismic level 3 distribution curves are identical.

Figure 27. Cumulative Key Block Size Distribution for Seismic Consideration in the Tptpmn Unit, 75°-Azimuth (Attachment II, file *tpmn seismic 75 res v1.xls*)



NOTE: The static, seismic level 1, and seismic level 2 distribution curves are identical.

Figure 28. Cumulative Key Block Size Distribution for Seismic Consideration in the Tptpll Unit, 75°-Azimuth (Attachment II, file *tpll seismic 75 res v1.xls*)

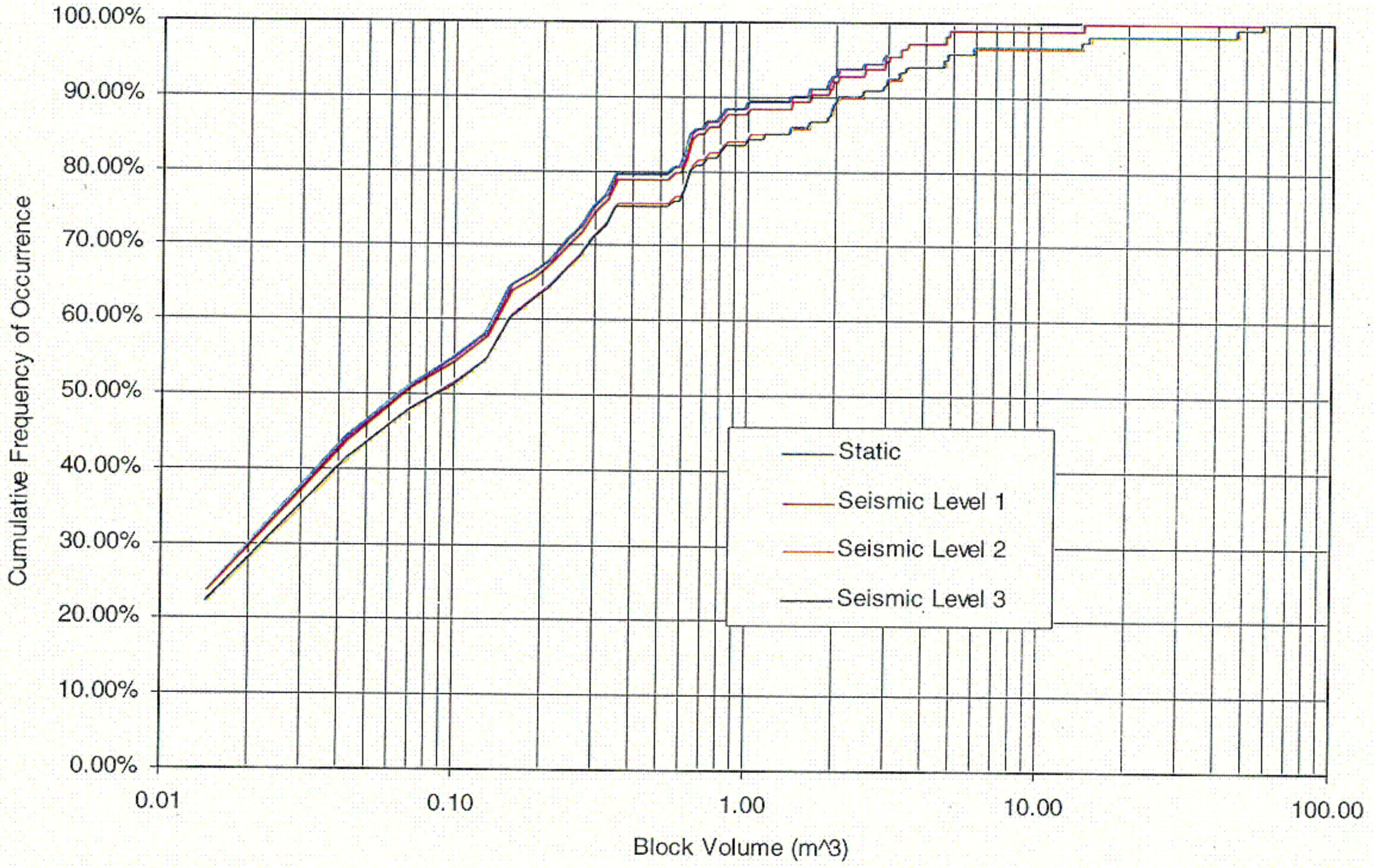


Figure 29. Cumulative Key Block Size Distribution for Seismic Consideration in the Tptpln Unit, 75°-Azimuth (Attachment II, file *tpln seismic 75 res v2.xls*)

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6.4.2 Rock Fall Related to Time-Dependent and Thermal Effects

The results for the analysis with the consideration of time-dependent and thermal effects are presented in this section. The analysis uses an approach that accounts for the time-dependent and thermal effect with joint cohesion degradation. The development and justification of this approach is described in Section 6.3.5 and Attachment I.

Four different times are selected for the analysis: 0 years (static condition), 200 years, 2,000 years, and 10,000 years. The corresponding joint cohesion for each time is listed in Table 28. The reduction of joint cohesion is predicted to be very small in the period between years 2,000 and 10,000.

105°-Azimuth Emplacement Drift Orientation With Backfill–Backfill, which was formerly part of the engineering barrier system at the post-closure period, is included in the analysis for the consideration of time-dependent and thermal effects. The backfill configuration and the simplified opening geometry used in the analysis are presented in Figure 30. It is apparent that the blocks that form around the springline area will no longer occur in the analysis with backfill.

The predicted number of key blocks per kilometer of drift for the 105° orientation is listed in Table 29. Only minor increases of key blocks are predicted between year 200 and year 2,000. No change is predicted from year 2,000 to year 10,000. The predicted average volume of rock fall per unit length of drift is listed in Table 30. The results indicate that time-dependent and thermal effects have a minor impact on rock fall.

105°-Azimuth Emplacement Drift Orientation Without Backfill–The analysis results for 5.5-m-diameter emplacement drifts oriented with a tunnel azimuth of 105° without backfill are provided in this subsection. The cumulative frequencies of occurrence corresponding to 50, 75, 90, 95, and 98 percentile block volume for each unit are listed in Tables 31 to 34 and shown in Figures 31 to 34. The maximum block sizes predicted from the analyses are included in these tables. The predicted number of key blocks per kilometer of drift for this orientation is listed in Table 35. The predicted average volume of rock fall per unit length of drift is listed in Table 36. The results in general are consistent with the case with backfill.

75°-Azimuth Emplacement Drift Orientation Without Backfill–The analysis results for 5.5-m-diameter emplacement drifts oriented with a tunnel azimuth of 75° without backfill are provided in this subsection. The cumulative frequencies of occurrence corresponding to 50, 75, 90, 95, and 98 percentile plus the maximum block volume for each unit are listed in Tables 37 to 40 and shown in Figures 35 to 38. The predicted number of key blocks per kilometer of drift for the 75° azimuth orientation is listed in Table 41. The predicted average volume of rock fall per unit length of drift is listed in Table 42. The predicted block numbers and volume for the 75° azimuth orientation are considerably less that those for 105° azimuth orientation in the Tptpmn and Tptpll units.

Table 28. Reduced Joint Cohesion to Account for Time-Dependent and Thermal Effects (see Figure 8)

Period (year)	Joint Cohesion (Pa)
0 (Static)	99,873
200	21,674
2,000	10,988
10,000	10,776

Table 29. Predicted Number of Key Blocks per Unit Length (km) along 105°-Azimuth Emplacement Drift, with Time-Dependent and Thermal Consideration, with Backfill (Attachment II, file *Res sum V2.xls*)

Lithologic Unit	Static	Year 200	Year 2000	Year 10000
Tptpul	16	16	16	16
Tptpmn	41	40	43	43
Tptpll	4	4	4	4
Tptpln	13	13	14	14

Table 30. Predicted Average Volume of Key Blocks per Unit Length (km) along 105°-Azimuth Emplacement Drift, with Time-Dependent and Thermal Consideration, with Backfill (Attachment II, file *Total vol tm 105 backfill v2.xls*)

Lithologic Unit	Static	Year 200	Year 2000	Year 10000
Tptpul	5.4	5.6	9.7	9.7
Tptpmn	19.8	17.4	20.9	20.9
Tptpll	0.9	0.9	1.0	1.0
Tptpln	11.6	14.0	20.7	20.7

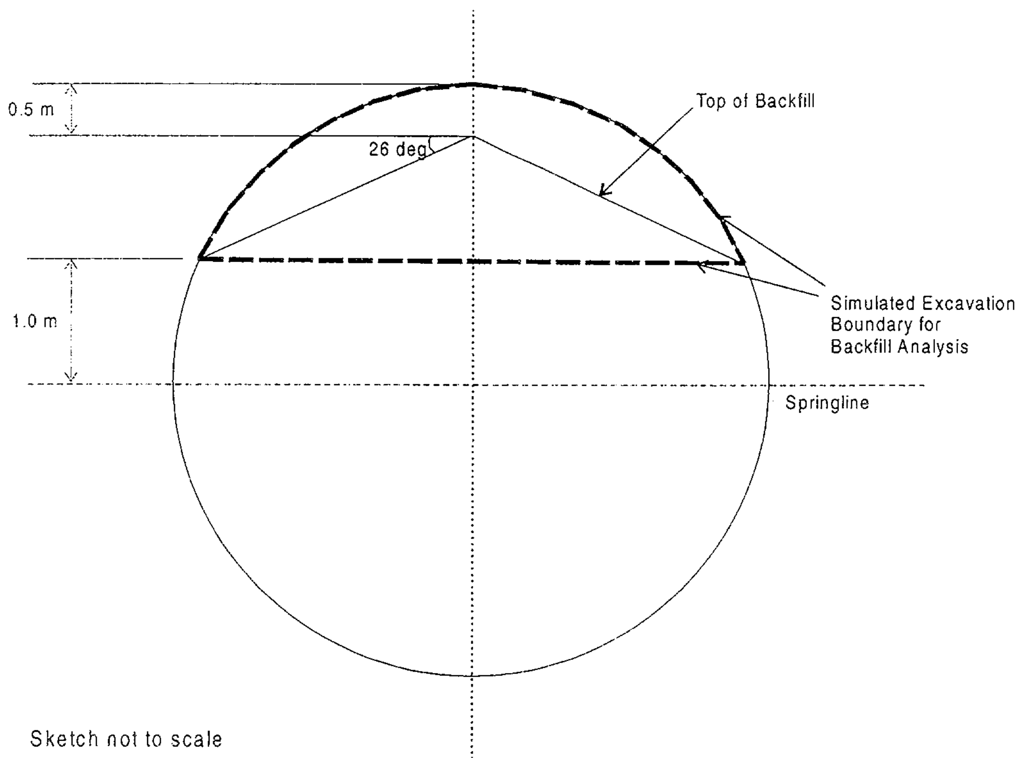


Figure 30. Backfill Configuration and Simplified Opening Geometry
(based on CRWMS M&O 2000f, p. 15)

Table 31. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpul Unit, with Time-dependent and Thermal Consideration, No Backfill, Drift Orientation: 105° Azimuth
(Attachment II, file *tpul tm 105 res v1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Year 200	Year 2000	Year 10000
50%	0.04	0.04	0.04	0.04
75%	0.24	0.24	0.35	0.35
90%	0.84	0.84	1.03	1.03
95%	1.03	1.03	2.99	2.99
98%	2.25	2.25	5.73	5.73
maximum	6.95	6.95	10.86	10.86

Table 32. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpmn Unit, with Time-dependent and Thermal Consideration, No Backfill, Drift Orientation: 105° Azimuth (Attachment II, file *tpmn tm 105 res v1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Year 200	Year 2000	Year 10000
50%	0.04	0.04	0.04	0.04
75%	0.33	0.41	0.47	0.47
90%	1.18	1.37	1.71	1.71
95%	2.45	2.90	3.02	3.02
98%	4.57	5.68	6.56	6.56
maximum	9.19	19.89	19.89	19.89

Table 33. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpll Unit, with Time-dependent and Thermal Consideration, No Backfill, Drift Orientation: 105° Azimuth (Attachment II, file *tpll tm 105 res v1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Year 200	Year 2000	Year 10000
50%	0.01	0.01	0.01	0.01
75%	0.07	0.07	0.07	0.07
90%	0.21	0.21	0.21	0.21
95%	0.55	0.55	0.55	0.55
98%	5.56	5.56	5.56	5.56
maximum	5.56	5.56	5.56	5.56

Table 34. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpln Unit, with Time-dependent and Thermal Consideration, No Backfill, Drift Orientation: 105° Azimuth (Attachment II, file *tpln tm 105 res v2.xls*)

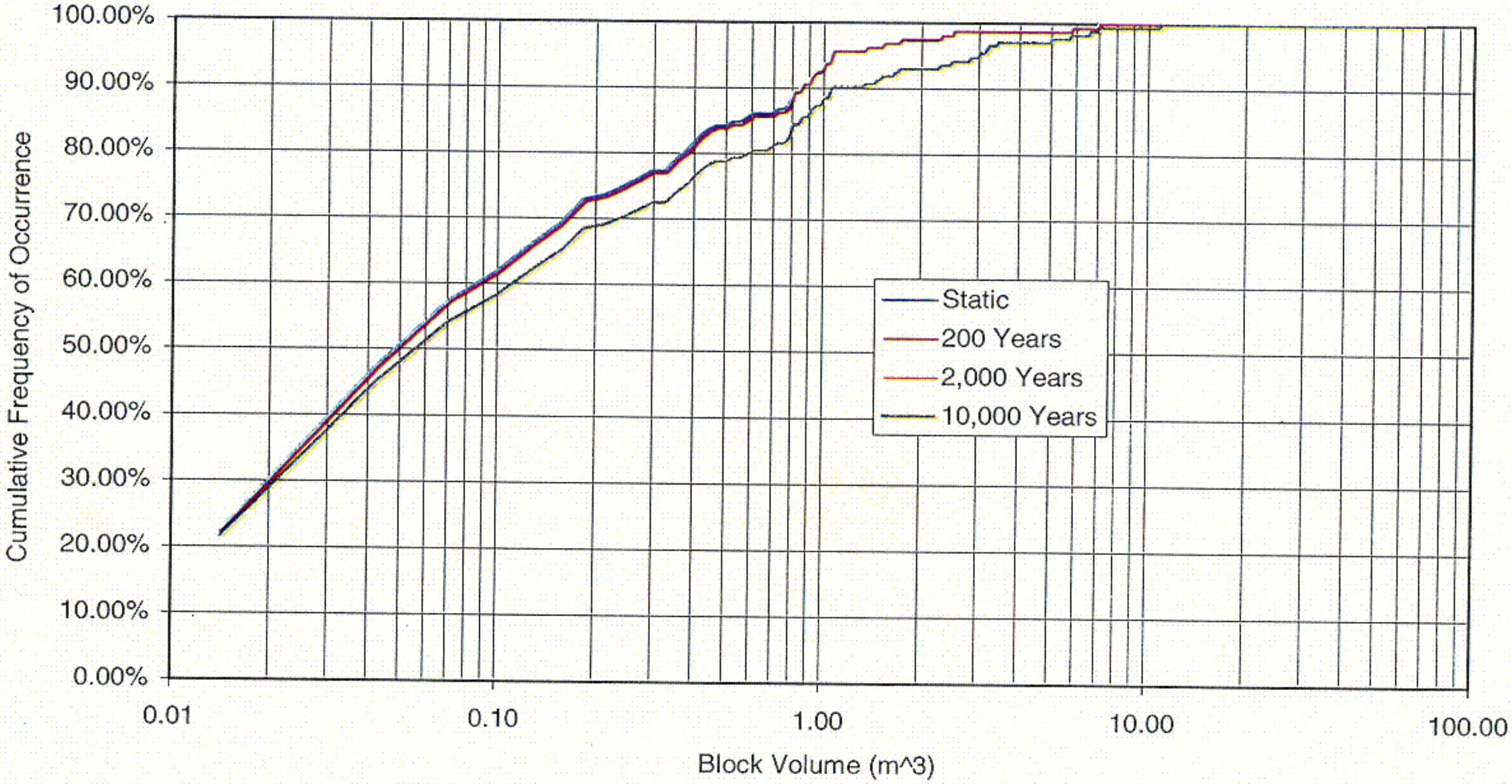
Cumulative Frequency of Occurrence (%)	Static	Year 200	Year 2000	Year 10000
50%	0.13	0.18	0.27	0.27
75%	0.86	1.15	1.37	1.37
90%	2.62	2.99	3.87	3.87
95%	3.98	4.83	5.51	5.51
98%	5.45	6.73	14.71	14.71
maximum	14.71	14.71	34.22	34.22

Table 35. Predicted Number of Key Blocks per Unit Length (km) along Emplacement Drift, with Time-Dependent and Thermal Consideration, No Backfill, Drift Orientation: 105° Azimuth (Attachment II, file *Res sum V2.xls*)

Lithologic Unit	Static	Year 200	Year 2000	Year 10000
Tptpul	16	17	18	18
Tptpmn	41	42	44	44
Tptpll	4	4	4	4
Tptpln	13	13	14	14

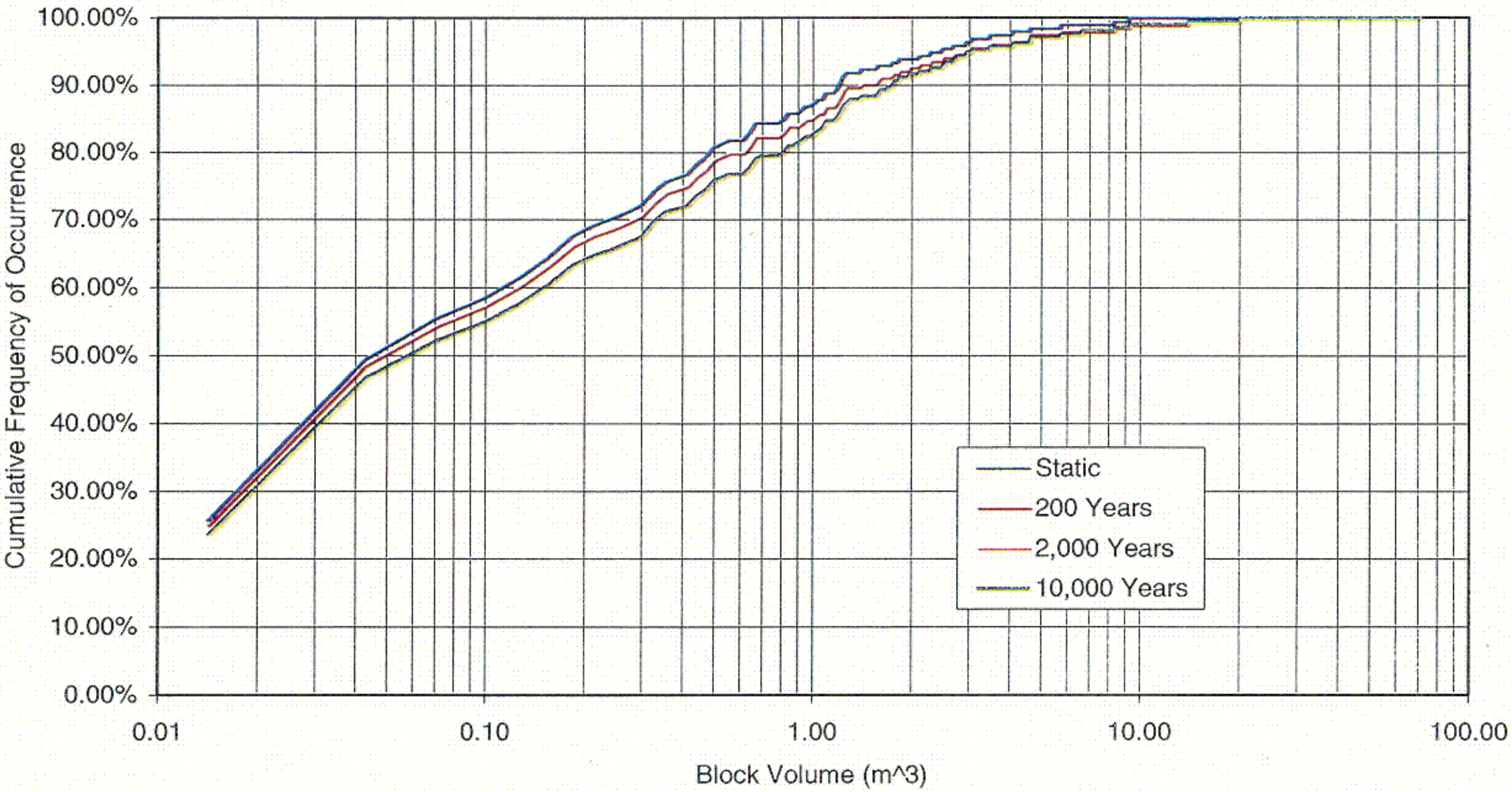
Table 36. Predicted Average Volume of Key Blocks per Unit Length (km) along Emplacement Drift, with Time-Dependent and Thermal Consideration, No Backfill, Drift Orientation: 105° Azimuth (Attachment II, file *Total vol tm 105 v2.xls*)

Lithologic Unit	Static	Year 200	Year 2000	Year 10000
Tptpul	5.4	5.5	9.8	9.8
Tptpmn	19.8	28.4	32.5	32.5
Tptpll	0.9	0.9	0.9	0.9
Tptpln	11.6	13.8	22.0	22.0



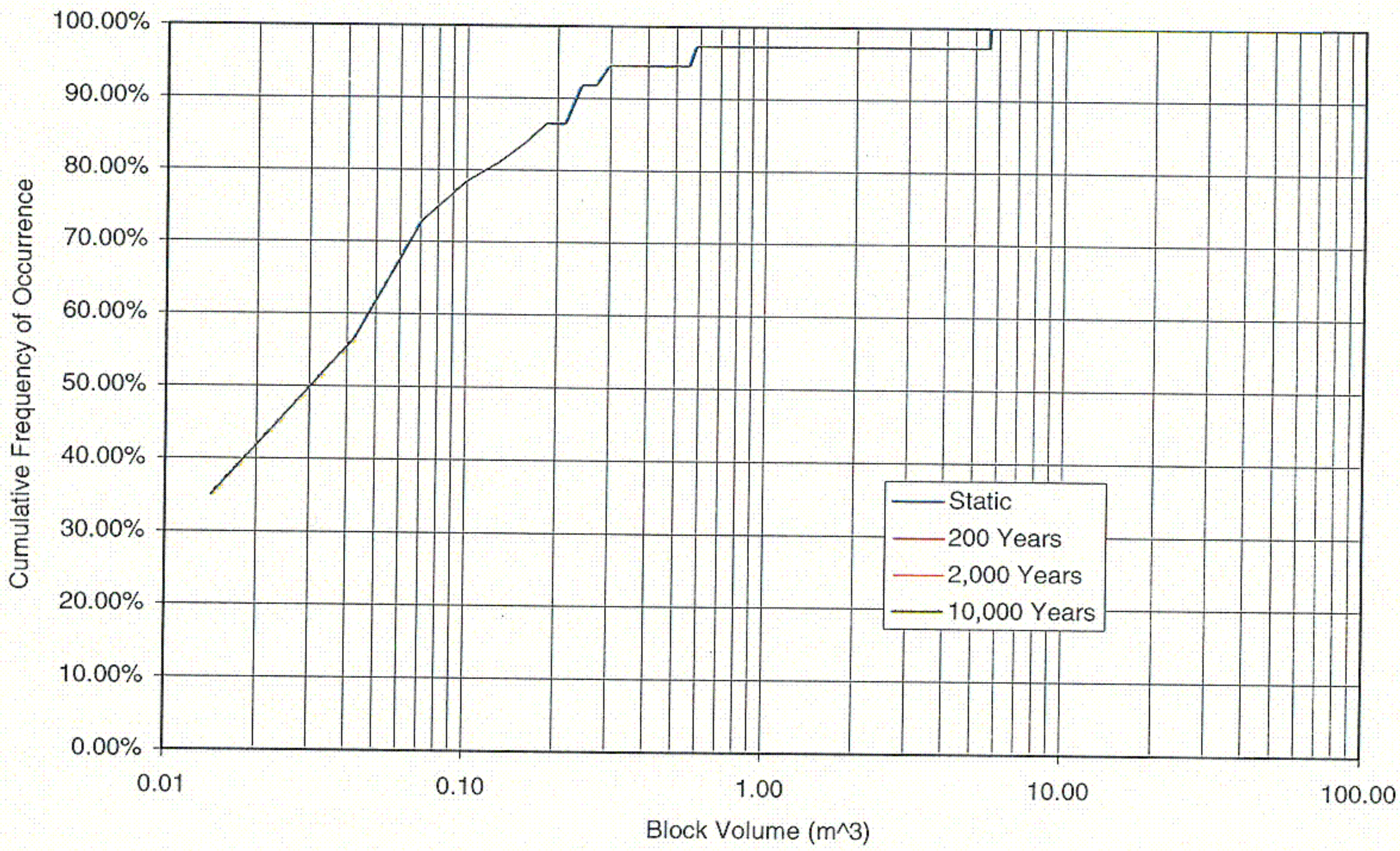
Note: The 2,000 year and 10,000 year distribution curves are identical.

Figure 31. Cumulative Key Block Size Distribution With Time-dependent and Thermal Consideration in the Tptpul Unit, No Backfill, Drift Orientation: 105° Azimuth (Attachment II, file *tpul tm 105 res v1.xls*)



Note: The 2,000 year and 10,000 year distribution curves are identical.

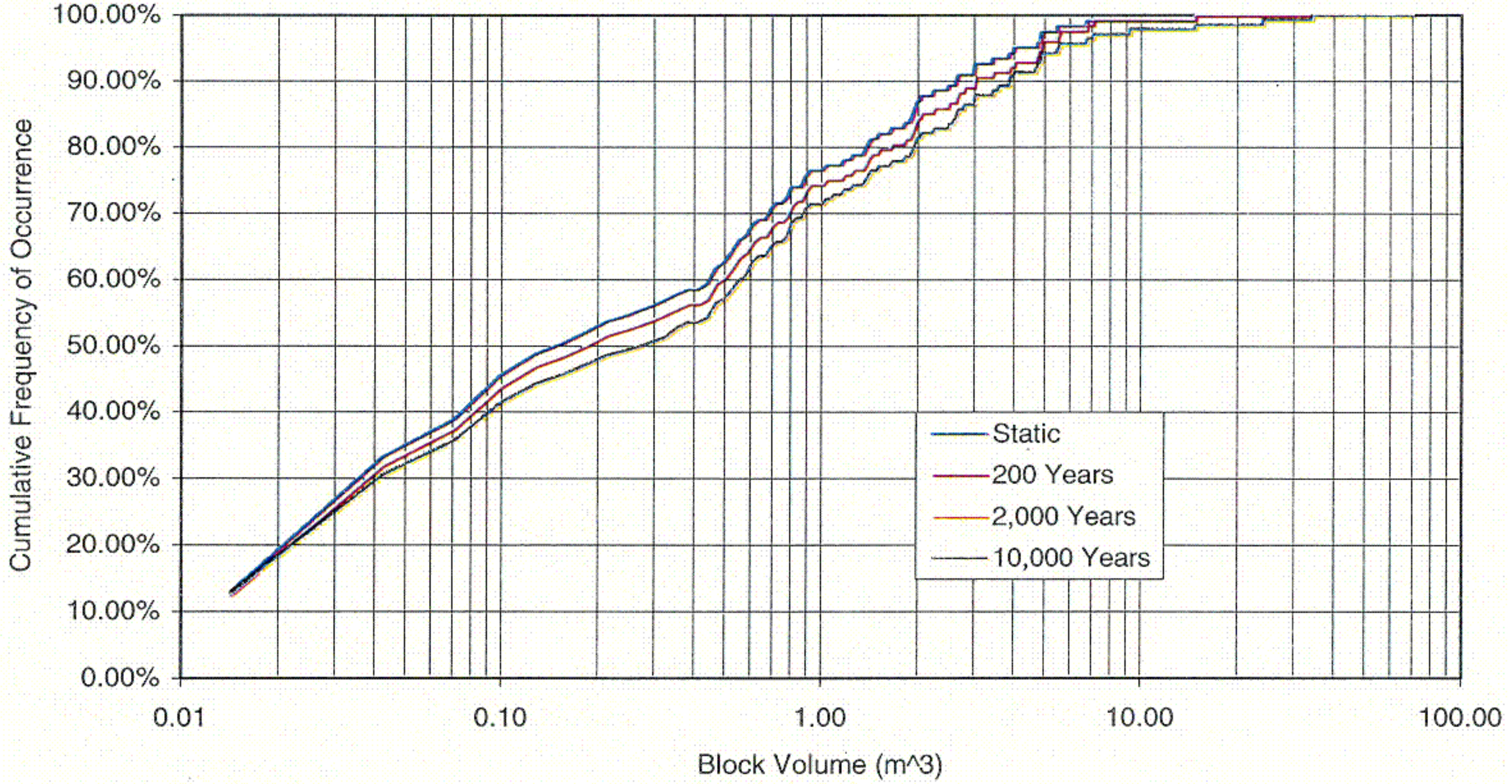
Figure 32. Cumulative Key Block Size Distribution With Time-dependent and Thermal Consideration in the Tptpmn Unit, No Backfill, Drift Orientation: 105° Azimuth (Attachment II, file *tpmn tm 105 res v1.xls*)



Note: The static, 200 year, 2,000 year, and 10,000 year distribution curves are identical.

Figure 33. Cumulative Key Block Size Distribution With Time-dependent and Thermal Consideration in the Tptpll Unit, No Backfill, Drift Orientation: 105° Azimuth (Attachment II, file *tpll tm 105 res v1.xls*)

C22



NOTE: The 2,000 year and 10,000 year distribution curves are identical.

Figure 34. Cumulative Key Block Size Distribution With Time-dependent and Thermal Consideration in the Tptpln Unit, No Backfill, Drift Orientation: 105° Azimuth (Attachment II, file *tpln tm 105 res v2.xls*)

C23

Table 37. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpul Unit, with Time-dependent and Thermal Consideration, No Backfill, Drift Orientation: 75° Azimuth (Attachment II, file *tpul tm 75 res v1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Year 200	Year 2000	Year 10000
50%	0.07	0.07	0.07	0.07
75%	0.30	0.33	0.33	0.33
90%	0.89	0.92	0.95	0.95
95%	2.19	2.42	2.65	2.65
98%	3.27	4.88	7.91	7.91
maximum	8.93	36.17	36.17	36.17

Table 38. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpmn Unit, with Time-dependent and Thermal Consideration, No Backfill, Drift Orientation: 75° Azimuth (Attachment II, file *tpmn tm 75 res v1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Year 200	Year 2000	Year 10000
50%	0.04	0.04	0.04	0.04
75%	0.16	0.18	0.21	0.21
90%	0.47	0.52	0.61	0.61
95%	1.35	1.40	1.51	1.51
98%	1.80	1.85	5.00	5.00
maximum	5.00	5.00	14.00	14.00

Table 39. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpll Unit, with Time-dependent and Thermal Consideration, No Backfill, Drift Orientation: 75° Azimuth (Attachment II, file *tpll tm 75 res v1.xls*)

Cumulative Frequency of Occurrence (%)	Static	Year 200	Year 2000	Year 10000
50%	0.01	0.01	0.01	0.01
75%	0.07	0.07	0.07	0.07
90%	0.24	0.24	0.24	0.24
95%	0.86	0.86	0.86	0.86
98%	1.29	1.29	1.29	1.29
maximum	1.29	1.29	1.29	1.29

Table 40. Block Volume (in cubic meter) Corresponding to Various Levels of Predicted Cumulative Frequency of Occurrence, Emplacement Drift in Tptpln Unit, with Time-dependent and Thermal Consideration, No Backfill, Drift Orientation: 75° Azimuth
(Attachment II, file *tpln tm 75 res v2.xls*)

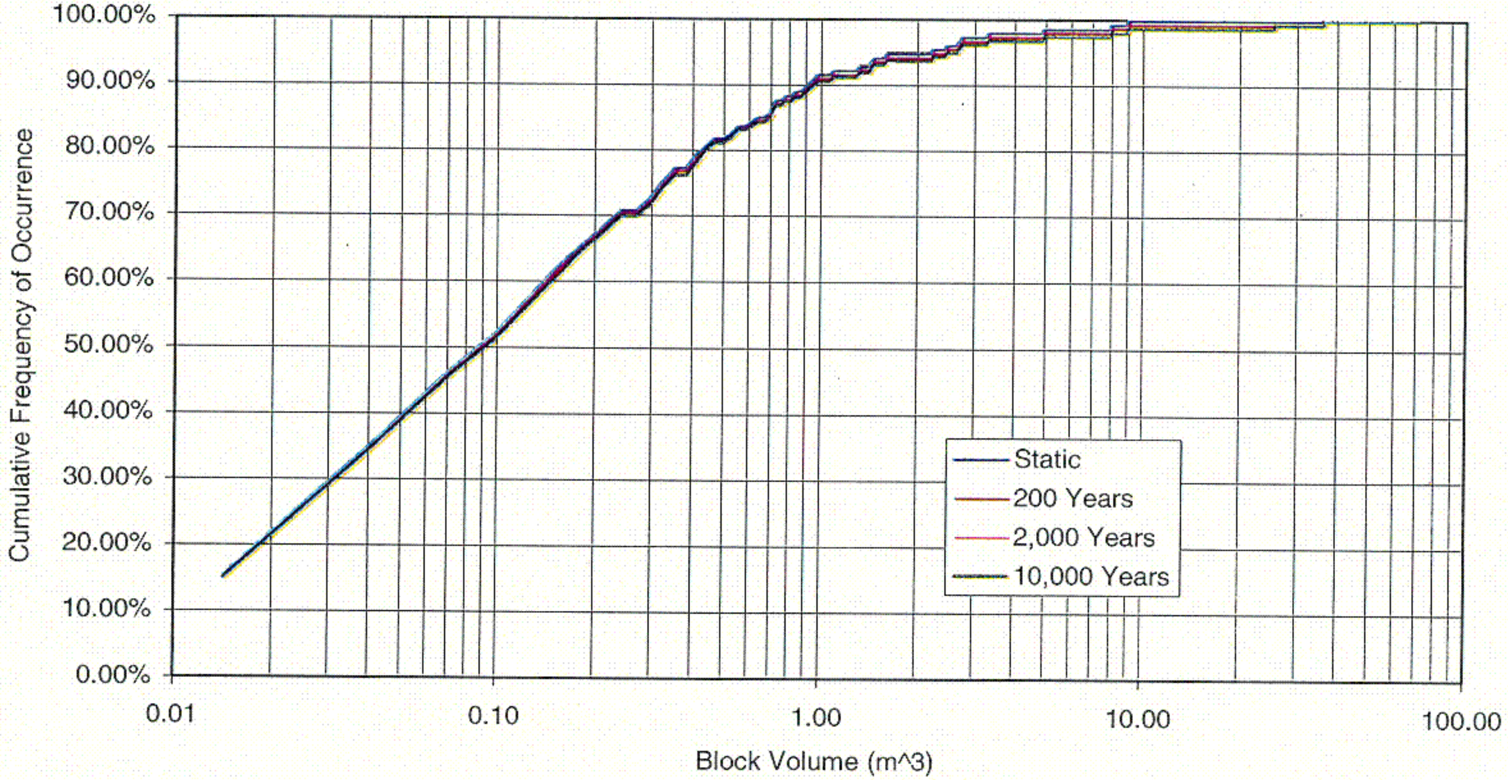
Cumulative Frequency of Occurrence (%)	Static	Year 200	Year 2000	Year 10000
50%	0.04	0.04	0.07	0.07
75%	0.27	0.30	0.30	0.30
90%	1.37	1.60	1.91	1.91
95%	2.87	2.96	3.27	3.27
98%	4.66	4.66	4.77	4.77
maximum	13.75	13.75	57.33	57.33

Table 41. Predicted Number of Key Blocks per Unit Length (km) along Emplacement Drift, with Time-Dependent and Thermal Consideration, No Backfill, Drift Orientation: 75° Azimuth
(Attachment II, file *Res sum V2.xls*)

Lithologic Unit	Static	Year 200	Year 2000	Year 10000
Tptpul	16	16	16	16
Tptpmn	28	28	30	30
Tptpll	2	2	2	2
Tptpln	12	12	12	12

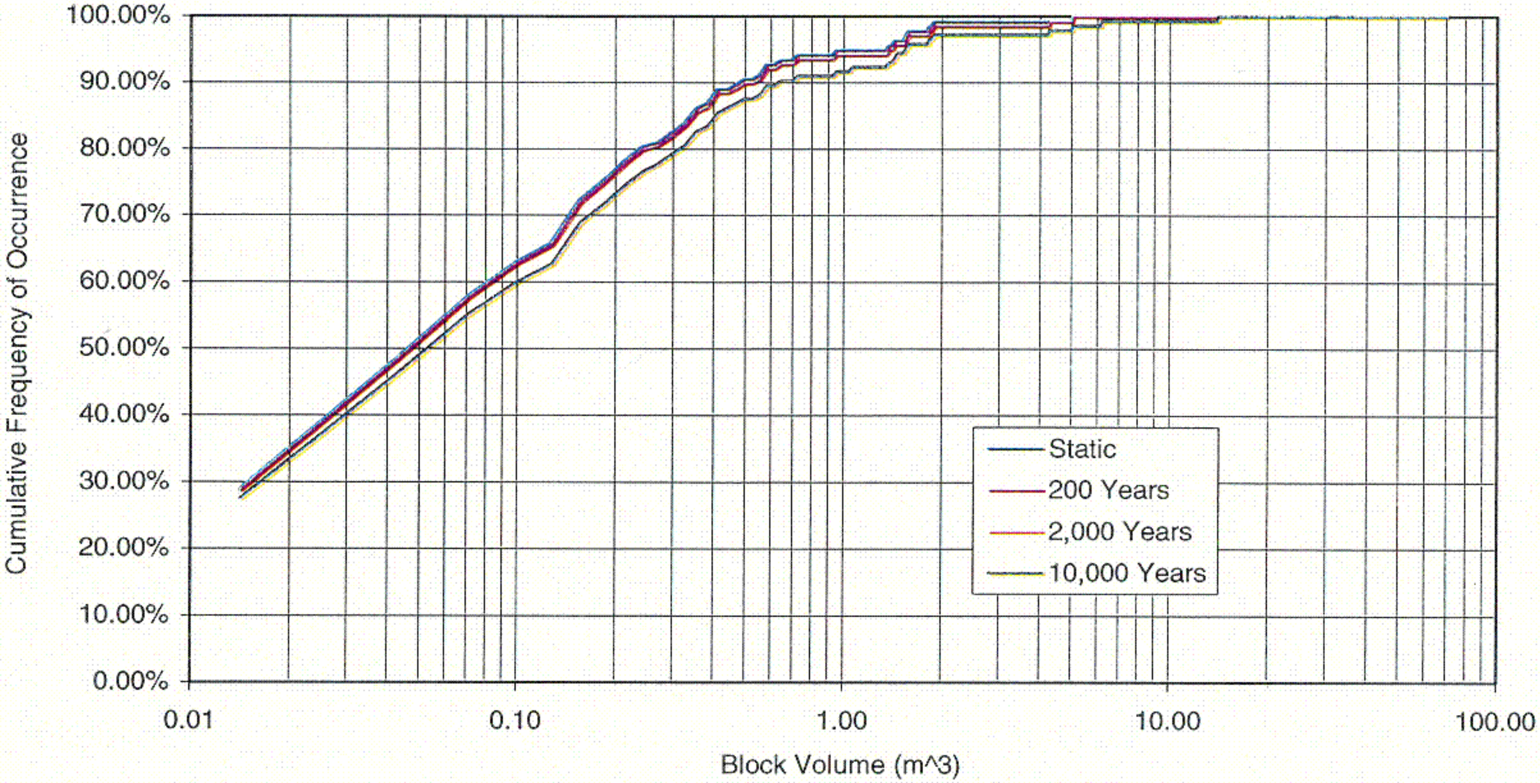
Table 42. Predicted Average Volume of Key Blocks per Unit Length (km) along Emplacement Drift, with Time-Dependent and Thermal Consideration, No Backfill, Drift Orientation: 75° Azimuth
(Attachment II, file *Total vol tm 75 v2.xls*)

Lithologic Unit	Static	Year 200	Year 2000	Year 10000
Tptpul	7.2	10.9	13.6	13.6
Tptpmn	6.8	7.7	12.5	12.5
Tptpll	0.4	0.4	0.4	0.4
Tptpln	6.4	6.7	12.8	12.8



NOTE: The 2,000 year and 10,000 year distribution curves are identical.

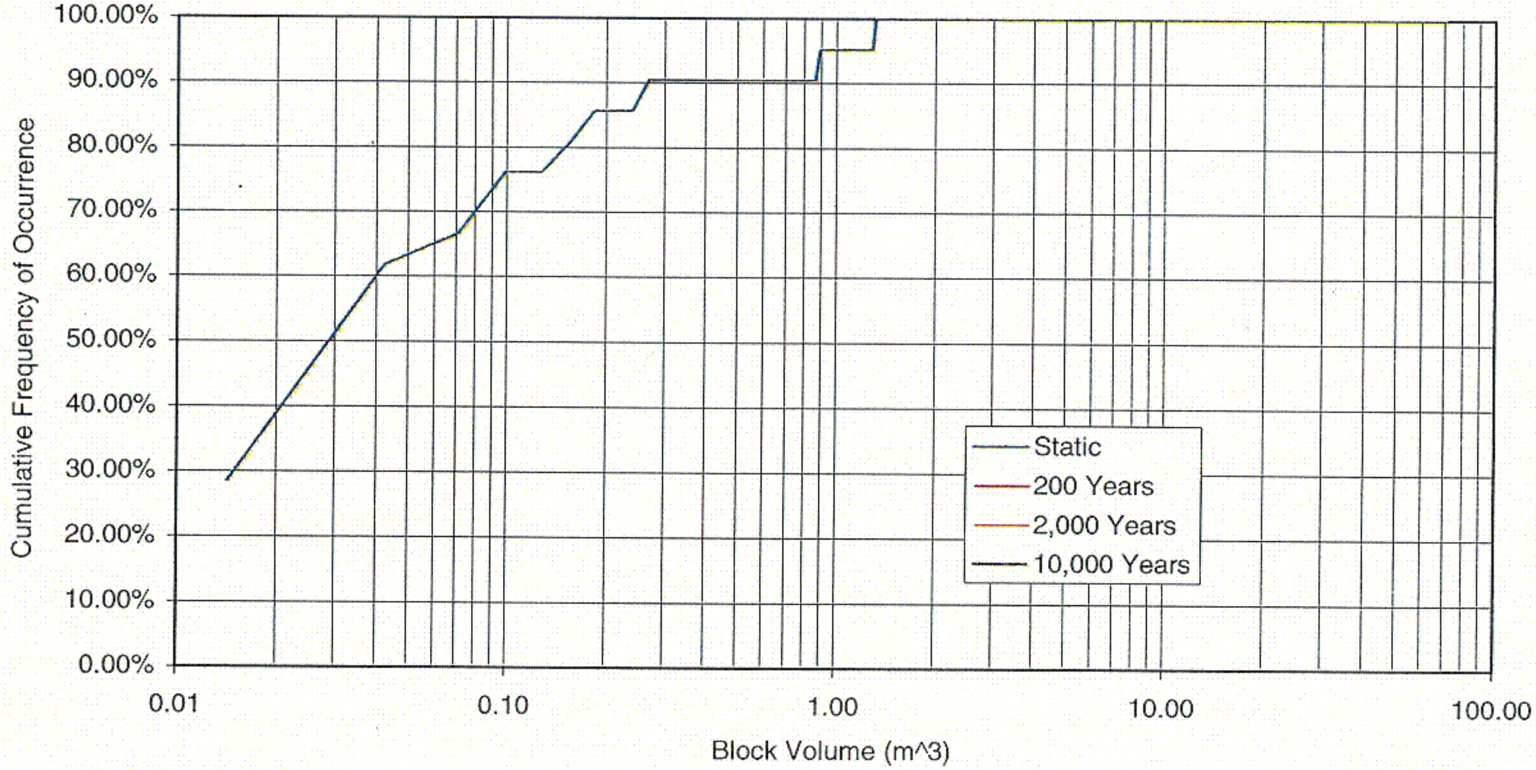
Figure 35. Cumulative Key Block Size Distribution With Time-dependent and Thermal Consideration in the Tptpul Unit, No Backfill, Drift Orientation: 75° Azimuth (Attachment II, file *tpul tm 75 res v1.xls*)



NOTE: The 2,000 year and 10,000 year distribution curves are identical.

Figure 36. Cumulative Key Block Size Distribution With Time-dependent and Thermal Consideration in the Tptpmn Unit, No Backfill, Drift Orientation: 75° Azimuth (Attachment II, file *tpmn tm 75 res v1.xls*)

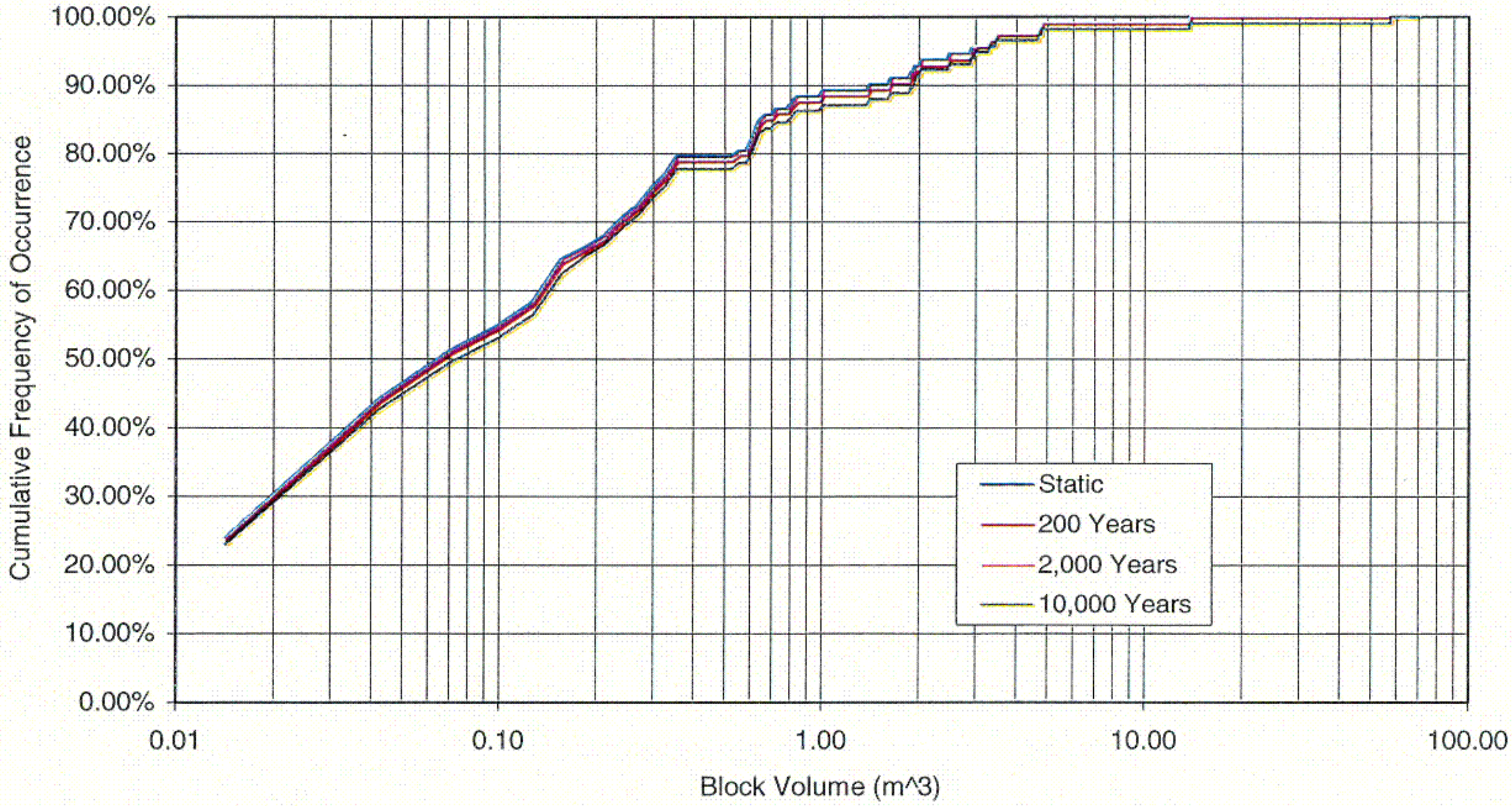
C25



NOTE: The Static , 200 year, 2,000 year and 10,000 year distribution curves are identical.

Figure 37. Cumulative Key Block Size Distribution With Time-dependent and Thermal Consideration in the Tptpll Unit, No Backfill, Drift Orientation: 75° Azimuth (Attachment II, file *tpll tm 75 res v1.xls*)

C26



NOTE: The 2,000 years and 10,000 years distribution curves are identical.

Figure 38. Cumulative Key Block Size Distribution With Time-dependent and Thermal Consideration in the Tptpln Unit, No Backfill, Drift Orientation: 75° Azimuth (Attachment II, file *tpln tm 75 res v2.xls*)

C27

6.4.3 Drift Profile Prediction

The key block approach applied in this analysis has provided an assessment of existing fracture data to determine probable occurrences of rock blocks that would fall into the tunnel opening in the absence of ground support. The DRKBA approach applied considers progressive block failure, such that when an initial key block fails and is removed, then an additional failure surface may open up allowing other blocks to fall. Progressive block failure continues until the crown becomes geometrically and mechanically stable, and no additional blocks can fall. The final progressive failure surface provides the basis for the drift profile predictions presented in this section.

A statistical distribution of the deteriorated drift profiles is shown in Figures 39 and 40 for the Tptpmn and Tptpll units respectively, including both a 75 percentile profile and a worst case profile. To determine the statistical distribution of drift profiles, the total volume of failed rock per Monte Carlo simulation was first determined (see Attachment XI). The total volumes were rank-ordered, such that the 75 percentile profile for a particular unit indicates that 75% of the drift length within that unit will have less rock fall volume. That is, 75% of the drift length within the unit will have less drift profile deterioration.

With the nature of probabilistic analysis, the drift profile predicted in the DRKBA rock fall model varies along the axis of the tunnel. To select the most conservative profile, or the worst case cross section, the cross section views along the drift axis were first created. The most conservative profile was then selected based on visual inspection of all the cross sections. Notice that the profile selected represents the worst case in a small section of the tunnel and, in fact, rock fall does not occur in many areas of the tunnel. To clarify the potential confusion, the extent of the drift affected by the rock fall is provided in Table 43 along with the rock fall volume per Monte Carlo simulation.

The Tptpmn (Figure 39) represents the unit within the repository horizon in which key blocks are most predominant. The Tptpll (Figure 40) represents the rock unit with the greatest areal extent in the repository horizon. Figures 39 and 40 show profiles as a function of seismic loading. It should be noted that the seismic loading includes a conservative reduction in joint cohesion to account for thermal and time dependent effects (see Attachment V).

Worst case drift profiles for each of the stratigraphic units modeled, with various loading scenarios and configurations, are provided in Attachment XII. Also included in Attachment XII is the total volume of rock fall in the worst case cross section area where rock fall occurs. For two worst-case drift profiles that are similar, the rock fall volume provides a three-dimensional indication of the total rock fall area. The rock fall volume provides a volumetric description of the profile, thus providing a sense of the extent of rock fall along the drift axis.

It should be noted that for a given drift profile, the DRKBA code is indifferent to the volume of the failed blocks relative to the volume of the opening. The effect of rubble (i.e., failed blocks) in the opening and the subsequent bulking of the rubble pile has not been considered in the development of drift profiles.

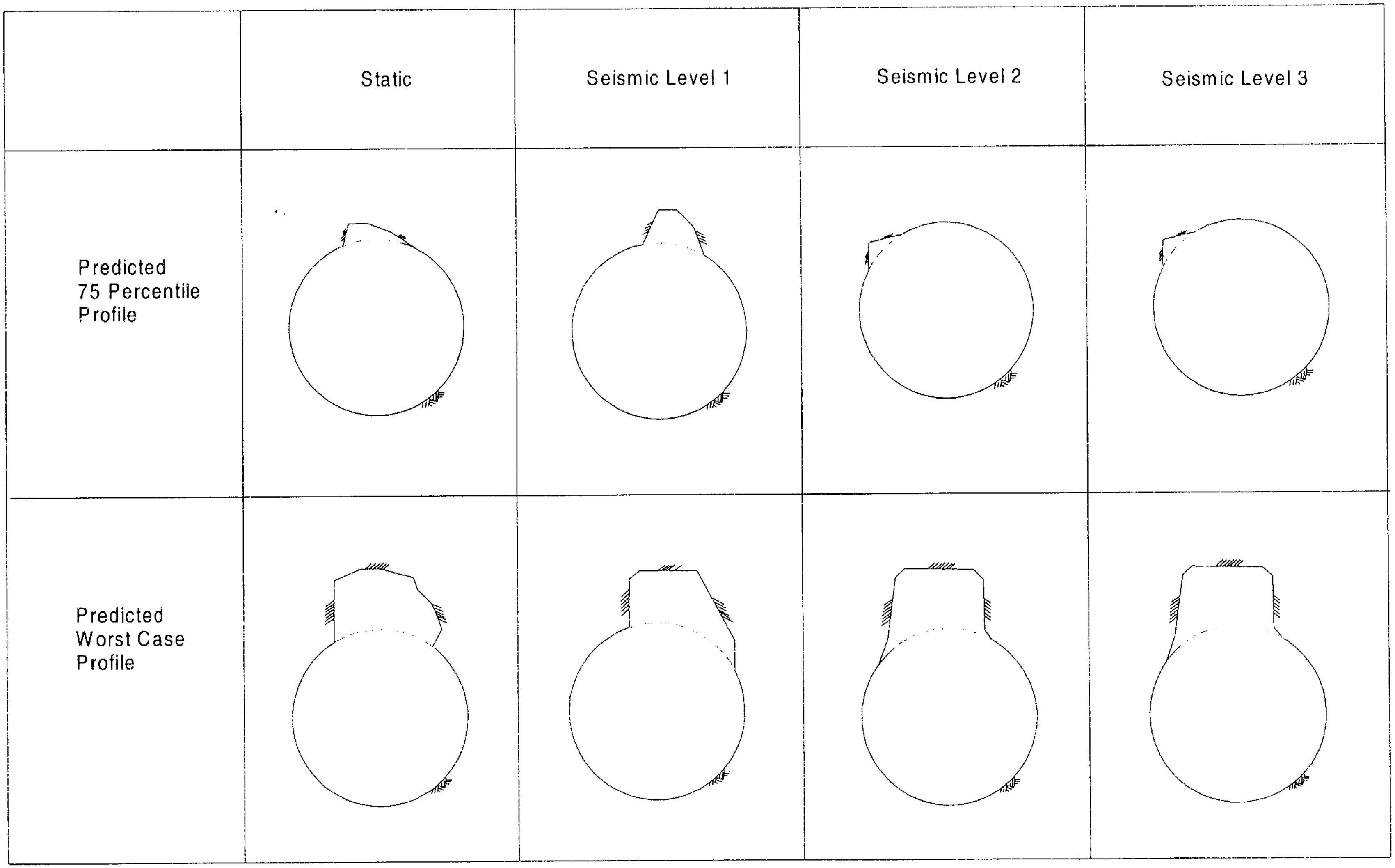


Figure 39. Emplacement Drift Profiles for the Tptpmn Unit, No Backfill, Drift Orientation: 75° Azimuth
(Attachment II, Table II-3)

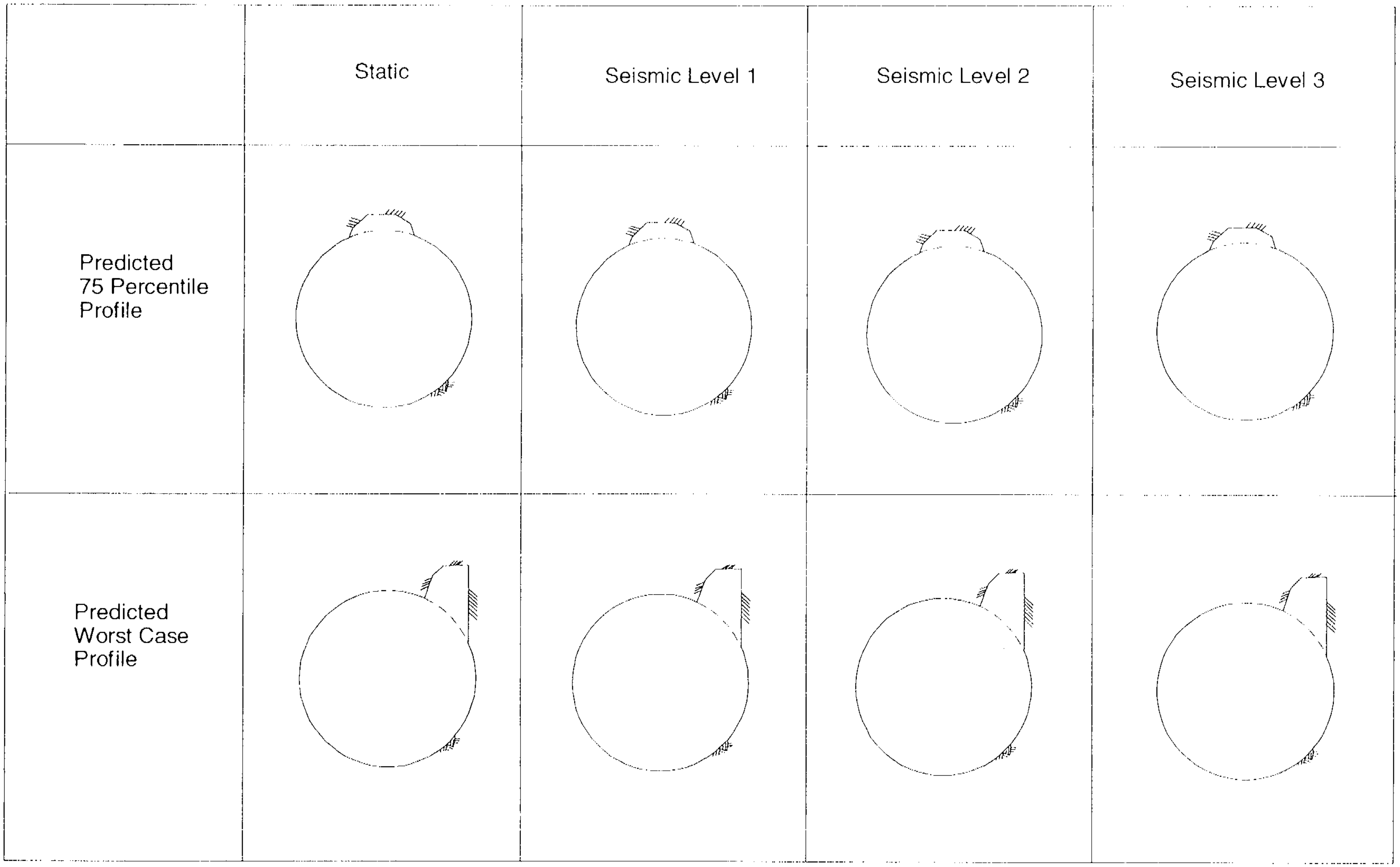


Figure 40. Emplacement Drift Profiles for the Tptpll Unit, No Backfill, Drift Orientation: 75° Azimuth (Attachment II, Table II-3)

Table 43. Rock Fall Information for Deteriorated Drift Profiles

Lithologic Unit	Loading Condition	75 Percentile Profiles[1]		Worst Case Profiles[1]		Percentage of Drift Length Affected by Rock Fall[2] (%)
		Monte Carlo Simulation Number	Total Rock Fall Volume for the Associated Monte Carlo Simulation (m^3)	Monte Carlo Simulation Number	Total Rock Fall Volume for the Associated Monte Carlo Simulation (m^3)	
Tptpmn	Static	181	0.74	193	5.72	6.2
	Seismic Level 1	25	0.79	4	6.21	6.7
	Seismic Level 2	132	0.88	183	14.51	8.1
	Seismic Level 3	132	0.88	183	14.51	8.1
Tptpll	Static	56	0.51	62	0.91	0.4
	Seismic Level 1	56	0.51	62	0.91	0.4
	Seismic Level 2	56	0.51	62	0.91	0.4
	Seismic Level 3	56	0.51	62	0.91	0.4

[1]Attachment II, file *Summary of rock volume per mcs V1.xls*
[2]Attachment II, file *Total vol seis 75 v2.xls*

6.5 MODEL VALIDATION

The DRKBA rock fall model involved the use of probabilistic key block theory through the numerical code, DRKBA V3.3 (see Section 3.1). This method is based on an industry accepted approach for analyzing geotechnical problems. Prior to initially purchasing the DRKBA software, technical literature sources were reviewed for the purpose of determining the most appropriate approach to be used in the development of a key block analysis for the YMP. In summary, the issue of key block analysis in underground excavations located in jointed rock masses has been considered in a number of design situations. Deterministic methods of block theory in rock engineering were advanced by Warburton (1981) and Goodman and Shi (1985). The UNWEDGE software (CRWMS M&O 1998a) is an example of a deterministic method that calculates the maximum block size given the spacing and orientation of three joint sets, and the excavation size and orientation. Subsequently Hoerger and Young (1990), Tyler, Trueman, and Pine (1991), Kuszmaul and Goodman (1995) and Stone et al. (1996) have been orientated towards probabilistic risk assessment of key block failure. Stone et al. (1996) reports on the use of DRKBA. These latest methods are considered suitable for the analysis of densely jointed and faulted rock masses (i.e., greater than three joint sets) where planar joint surfaces can reasonably be assumed. These conditions typically exist at the YMP.

In general, the static key block results presented are representative of the observed key block occurrence in the ESF Main Loop and ECRB Cross Drift. The results from the rock fall model have shown that key blocks are most predominant in the Tptpmn unit, which agrees with field observations.

The ECRB Cross Drift, with a diameter of 5.0 m, is most comparable to the modeled emplacement drifts, which have a diameter of 5.5 m. The Cross Drift passed through four

lithologic units, including the Tptpul unit (primarily from stations 0+00 to 10+15), the Tptpmn unit (primarily from stations 10+15 to 14+44), the Tptpll unit (stations 14+44 to 23+26), and the Tptpln unit (stations 23+26 to 25+85) (Mongano et al. 1999, pp. 105-106). A comparison of the field-observed key blocks, or rock fall areas, to the results from the DRKBA rock fall model is shown in Table 44.

As shown in Table 44, the number of key blocks occurring in the Cross Drift per kilometer is generally in good agreement with the DRKBA rock fall model. The primary key block forming unit is the Tptpmn. Field observations in the Tptpmn unit showed 40 blocks per kilometer, while 36 blocks per kilometer were simulated in the DRKBA model. It is believed that there were more blocks observed in the field than simulated in the model for the following reasons:

- Many of the observed blocks were very small and likely failed due to excavation-induced stresses (i.e., the rotation of the TBM potentially "plucked" small blocks from the face). The key block model would not simulate these blocks.

- Some of the observed blocks are associated with intensely fractured areas. The exposed fracture planes may be due to raveling of the rock within intensely fractured areas, rather than a structurally-controlled key block failure. The key block model would not simulate these failure methods.

The DRKBA rock fall model predicts approximately 14 key blocks per kilometer in the Tptpul and Tptpln units, which is significantly less than the predicted number of blocks for the Tptpmn unit. Field observations are consistent with this trend, with 3 blocks per kilometer observed in the Tptpul unit, and 8 blocks per kilometer observed in the Tptpln unit. For the Tptpll unit, the rock fall model indicated a relatively small number of key blocks per kilometer, which generally agrees with field observations since no key blocks occurred in this unit.

The size of key block observed in the Cross Drift is generally less than 0.5 m^3, as indicated in Table 44. An example of one of the larger key blocks in the Cross Drift is shown in Figure 2. In the DRKBA Tptpmn rock fall model with a tunnel azimuth of 45° (i.e., an azimuth similar to the Cross Drift in the Tptpmn unit), 75% of the blocks simulated were less than 0.27 m^3, and 90% of the blocks simulated were less than 1.15 m^3 (see Table 12). The maximum size block observed in the Cross Drift is captured within this range.

The seismic component of the DRKBA rock fall model involves a quasi-static method of reducing the joint strength parameters to account for the seismic effect. This method was verified based on the test runs using the dynamic functions of the distinct element code UDEC as described in Attachment V. The comparison between the results from the dynamic and quasi-static analyses shows a consistent prediction of block failure at the opening roof. The seismic effect on both the size and number of blocks in the rock fall model is relatively minor. This is consistent with the natural analogues presented in Attachment VII.

The field observation of key block occurrence in the ESF and the consistent prediction of blocks based on an alternative numerical solution provide an adequate level of confidence for use of the model.

Table 44. Comparison of DRKBA Rock Fall Model to Field Observations

Lithologic Unit	Field Observation from ECRB Cross Drift				Results from DRKBA Rock Fall Model			
	Excavation		Key Block Occurrence		Excavation		Key Block Occurrence	
	Diameter (m)	Azimuth[1] (degree)	Number[2] (blocks per km)	Size[3] (m^3)	Diameter (m)	Azimuth[4] (degree)	Number[5] (blocks per km)	Size[6] (m^3)
Tptpul	5.0	49 to 74	3	< 0.5	5.5	45, 60, 75	14 to 16	0.52 to 0.95
Tptpmn	5.0	49	40	< 0.5	5.5	45	36	1.15
Tptpll	5.0	49	0	—	5.5	45	5	1.83
Tptpln	5.0	49 to 109	8	< 0.5	5.5	45, 60, 75, 90, 105	9 to 14	1.35 to 3.38

[1]Azimuth corresponds to values provided by CRWMS M&O (1998b, p. 10) minus 180 degrees.
[2]Observed number of blocks per km documented in Attachment VI.
[3]Field block size estimated based on field observation.
[4]DRKBA static rock fall modeled in 15-degree increments as described in Section 6.4.1.1.
[5]Values taken from Table 15.
[6]Values taken from the 90th percentile row in Tables 11 through 14.

6.6 DRIFT DEGRADATION FEATURES, EVENTS, AND PROCESSES (FEPS)

Features, events, and processes (FEPs) related to drift degradation have been extracted from the EBS FEPs (CRWMS M&O 2000g, Section 6.2) and are listed in Table 45. Considerations for inclusion in or exclusion from the Total System Performance Assessment (TSPA) are identified in Table 45, along with references to appropriate sections in this report that address the FEPs consideration. The considerations for inclusion or exclusion presented in Table 45 are not necessarily compatible with TSPA considerations as listed in CRWMS M&O (2000g, Section 6.2). TSPA final considerations are based on input from other analyses and models, while the FEPS considerations in Table 45 are based only on this analysis of drift degradation.

Table 45. Drift Degradation FEPs[1]

YMP FEP #	FEP Name	Database Rev 00 EBS FEP Description [Other PMRs]	Considerations for Inclusion in TSPA (Reference to section in this report)	Considerations for Exclusion from TSPA (Reference to section in this report)
1.1.02.00.00	Excavation/ construction	This FEP is concerned with the effects associated with excavation/construction of the underground regions of the repository on the long-term behavior of the engineered and natural barriers. Excavation-related effects include changes to rock properties due to boring and blasting and chemical changes to the rock and incoming groundwater due to potential explosives residue. Excavation and other construction activities could also directly cause groundwater chemistry changes within the tunnel due to the impact of such contaminants as diesel exhaust, explosives residues, or other organic contaminants (Secondary FEP 1.1.02.00.03). Finally, oxidizing water introduced into the repository during excavation/ construction could impact repository conditions/ performance (Secondary FEP 1.1.02.00.04).	N/A	Rock fall models are based on observation of rock characteristics in the as-built (post-excavation) condition, so that excavation effects, if any, are considered. Other effects of excavation on rock mass response are minor (Section 6).
2.1.07.01.00	Rockfall (large block)	Rock falls may occur that are large enough to mechanically tear or rupture waste packages.	N/A	Rock fall models are based on site characterization data. Probabilistic descriptions of rock size and rock fall frequency are provided for use in engineering design analyses (Section 6.4). The consequences based on TSPA evaluations were assessed to be low (CRWMS M&O 2000g, Section 6.2.30).

Table 45. Drift Degradation FEPs[1] (Continued)

YMP FEP #	FEP Name	Database Rev 00 EBS FEP Description [Other PMRs]	Considerations for Inclusion in TSPA (Reference to section in this report)	Considerations for Exclusion from TSPA (Reference to section in this report)
2.1.07.02.00	Mechanical degradation or collapse of drift	Partial or complete collapse of the drifts, as opposed to discrete rock fall, could occur as a result of seismic activity, thermal effects, stresses related to excavation, or possibly other mechanisms. Drift collapse could affect stability of the engineered barriers and waste packages. Drift collapse may be localized as stopping at faults or other geologic features. Rock fall of small blocks may produce rubble throughout part or all of the tunnel.	N/A	Rock fall models are based on site characterization data, and extend to conditions that can represent drift collapse. Probabilistic descriptions of rock size and rock fall frequency are provided for use in engineering design analyses that include seismic, thermal, and time-dependent effects (Section 6.4). The effects of rubble would be similar to analyzed cases involving larger blocks. The drift degradation analysis has indicated that rock fall is limited to relatively small portions of the overall tunnel length (Section 6.4.3), with a limited amount of rock fall volume, or rubble (Attachment XI). The consequences based on TSPA evaluations were assessed to be low (CRWMS M&O 2000g, Section 6.2.31).
2.1.11.07.00	Thermally-induced stress changes in waste and EBS	Thermally-induced stress changes in the waste and EBS may affect performance of the repository. Relevant processes include rock fall, drift stability, changes in physical properties of the disturbed rock zone around the repository, and changes in the physical properties of the surrounding rock.	N/A	Probabilistic descriptions of rock size and rock fall frequency, for conditions representing elevated stress and temperature, are provided for use in engineering design analyses (Section 6.4). No credit is taken for ground support (which could be impacted by thermal stress especially in the post-closure period) in rock fall models.

[1]FEP numbers, names, and descriptions are consistent with CRWMS M&O (2000g, Section 6.2).

Table 46. Key Technical Issues Addressed in the Drift Degradation Analysis (Continued)

Issue Resolution Status Report/ Key Technical Issue	Subissue	Component	Acceptance Criterion	Approach and Section Reference
Repository Design and Thermal-Mechanical Effects (NRC 1999a) (continued)	Subissue 3: Thermal-mechanical effects on underground facility design and performance (continued)	Component 2 (continued)	Acceptance Criterion 7 (continued)	area around an individual emplacement drift as well as over the entire repository as functions of ground motions (Section 6.4.3 and Attachment XII). The rock fall model currently does not assess the probability of simultaneous fall of multiple blocks.
		Component 3: Consideration of thermal-mechanical effects on flow into emplacement drifts	Acceptance Criterion 3: Time-dependent changes in size and shape of the emplacement drifts due to thermally induced ground movements (rock deformations, collapse, and other changes that may affect the integrity and geometrical configuration of underground openings) are estimated taking into account uncertainties in the context of their impacts on the performance.	The drift degradation analysis estimates time-dependent changes in the size and shape of the emplacement drifts due to thermally induced ground movements (Section 6.3.5 and Attachment XII).
Structural Deformation and Seismicity (NRC 1999b)	Subissue 3: Fracturing	N/A	Acceptance Criterion 1: Data and Model Justification - Sufficient field, borehole, and underground excavation data are acquired to adequately support conceptual models, assumptions, and boundary conditions of numerical abstractions of fracture data and fracture models of ambient and perturbed conditions.	<u>Fracture Aperture Distribution</u> Fracture aperture is not a critical factor for rock fall, and was not considered in the rock fall analyses in the drift degradation analysis. Fracture geometry and the fracture frictional properties are the parameters that contribute to rock fall (Section 4.1). <u>Fracture Connectivity Across Stratal Boundaries</u> The rock fall analyses in the drift degradation analysis consider the joint trace length from field mapping data to model the extent of the fracture planes (see additional discussion under Subissue 3: Fracturing, Acceptance Criterion 4). Multiple fracture planes may contribute to the formation of one rock block. The connectivity, or intersections of the fracture planes is considered in the rock fall analyses within stratal boundaries. Since the fracture geometry varies according to lithostratigraphic unit, rock fall data were

Table 46. Key Technical Issues Addressed in the Drift Degradation Analysis (Continued)

Issue Resolution Status Report/ Key Technical Issue	Subissue	Component	Acceptance Criterion	Approach and Section Reference
Structural Deformation and Seismicity (NRC 1999b)	Subissue 3: Fracturing	N/A	Acceptance Criterion 1 (continued)	determined for each lithostratigraphic unit to accurately characterize potential rock block development within each unit. Therefore, it was not necessary to consider fracture connectivity across stratal boundaries in the rock fall analyses.
			Acceptance Criterion 2: Data Uncertainty and Verification - Parameter values, assumed ranges, probability distributions, and bounding assumptions used to determine fracture distributions and properties of ambient and perturbed conditions are technically defensible and reasonably account for uncertainties and variabilites.	<u>Boundary Conditions of Numerical Abstractions of Fracture Data, Models, and Modifications under Ambient and Thermally Perturbed Conditions</u> The drift degradation analysis has examined the effects of seismic and thermal loading on rock fall (Sections 6.3.4 and 6.3.5). This approach considered a significant reduction in joint cohesion in response to thermal loading, and the subsequent effect on rock fall. Seismic loading in the drift degradation analysis was examined using a quasi-static approach involving a significant reduction in the joint friction angle to simulate the effect of increased force along rock block sliding surfaces in response to a seismic event. Both seismic and thermal loading were shown to have minimal effects on rock fall development (Section 7.1). Although the mechanical behavior of fractures under seismic and thermal loads are not well understood at this time, the relatively large reduction of fracture strength parameters provide reasonable bounding scenarios.

Table 46. Key Technical Issues Addressed in the Drift Degradation Analysis (Continued)

Issue Resolution Status Report/ Key Technical Issue	Subissue	Component	Acceptance Criterion	Approach and Section Reference
Structural Deformation and Seismicity (NRC 1999b)	Subissue 3: Fracturing	N/A	Acceptance Criterion 3: Model Uncertainty - Alternative modeling approaches for fracture distribution and properties of fractures consistent with available data and current geologic understanding are investigated and results and limitations are appropriately considered in abstractions for process and PA models of ambient and perturbed repository conditions.	Continuity of Consideration of Fracture Data and Alternative Fracture Models Abstracted in the US DOE Process Level and Performance Assessment Models The drift degradation analysis uses a continuous and traceable approach incorporating all of the ESF-mapped fracture data (Section 4.1). Analysis of the mapped fracture data is summarized in CRWMS M&O (2000d). Predominant fracture sets were identified, and fracture spacing and trace length data were provided in this fracture report.
			Acceptance Criterion 4: Model Verification - Results of abstractions of fracture data and fracture models incorporated in process models and TSPA models are verified by comparison with output of sensitivity studies, natural analogs, and empirical observations, as appropriate.	The drift degradation analysis has considered the variability in joint set orientation, spacing, and trace length through the use of the numerical code, DRKBA (Sections 6.3.1 and 6.3.2). Statistical distributions of fracture data were input into DRKBA. Beta distributions were used to represent the fracture spacing and trace lengths, whereas Watson bi-polar distributions were used to model the joint set orientations. The concentration factor, k, in the Watson bi-polar distribution, determined from the mapped fracture data, represents the degree to which the orientation data is clustered about the mean orientation. DRKBA examines the variation of fracture geometry through multiple Monte Carlo simulations of the fractured rock mass, where fracture patterns are generated based on the statistical distributions of the fracture data.

7. CONCLUSIONS

7.1 SUMMARY

A statistical description of the probable block sizes formed by fractures around the emplacement drifts has been developed for each of the lithologic units of the repository host horizon. A range of drift orientations with the drift azimuth varied in 15° increments has been considered in the static analysis. For the quasi-static seismic analysis, and the time-dependent and thermal effects analysis, two drift orientations have been considered: a drift azimuth of 105° and the current emplacement drift azimuth of 75° (see Assumption 5.9). The change in drift profile resulting from progressive deterioration of the emplacement drifts has been assessed both with and without backfill. Drift profiles have been determined for four different time increments, including static (i.e., upon excavation), 200 years, 2,000 years, and 10,000 years. The effect of seismic events on rock fall has been analyzed. Block size distributions and drift profiles have been determined for three seismic levels, including a 1,000-year event, a 5,000-year event, and a 10,000-year event. Data developed in this modeling and analysis activity have been entered into the TDMS (DTN: MO0010RDDAAMRR.002).

The following conclusions have resulted from this drift degradation analysis:

- The available fracture data are suitable for supporting a detailed key block analysis of the repository host horizon rock mass. The available data from the north-south Main Drift and the east-west Cross Drift (Section 4.1) provide a sufficient representative fracture sample of the repository emplacement drift horizon. However, the Tptpln fracture data are only available from a relatively small section of the Cross Drift, resulting in a smaller fracture sample size compared to the other lithologic units. This results in a lower degree of confidence that the key block data based on the Tptpln data set is actually representative of the overall Tptpln key block population.

- The seismic effect on the rock fall size distribution for all events analyzed is relatively minor (Section 6.4.1.2, 75°-azimuth emplacement drift orientation).

- The analysis of thermal and time-dependent effects on rock fall in this study is based on a reduction in the joint cohesion. Joint cohesion has been conservatively reduced from a laboratory test value of 0.86 MPa to a value of 0.01 MPa after 10,000 years (Sections 6.3.2 and 6.3.4). The results from this analysis indicate that time-dependent and thermal effects have a minor impact on rock fall (Section 6.4.2, 75°-azimuth emplacement drift orientation without backfill).

- Both the 75 percentile and the worst-case drift degradation profiles have been provided in this analysis for the current emplacement drift azimuth of approximately 75° (Section 6.4.3). Most of the emplacement drift openings were not affected by rock fall. For the current emplacement drift alignment, the highest percentage of drift affected by rock fall was 8% in the Tptpmn unit (Table 43). The Tptpmn unit produced the highest frequency of key blocks per kilometer compared to the other lithologic units (Tables 26 and 41).

- This key block analysis has shown that the current drift alignment is relatively favorable in terms of reducing the potential maximum size rock block compared to most drift orientations (Figure 17).

7.2 ASSESSMENT

This analysis involved the use of the distinct element code, UDEC, and probabilistic key block theory through the numerical code, DRKBA. These methods are based on industry accepted approaches for analyzing geotechnical problems. In general, the static key block results presented are representative of the observed key block occurrence in the ESF. The results of this study have shown that key blocks are most predominant in the Tptpmn unit, which agrees with field observations. The size of key blocks observed in the field is generally less than 1 m^3, which agrees with the simulated distribution of block sizes presented in this study.

The representativeness of the DRKBA rock fall model is affected by how well the fracture data inputs describe the actual fracture conditions at the emplacement drift horizon. The natural variability of fractures within a rock mass always represents uncertainty in the design of structures in rock. The vast amount of fracture data collected at the YMP provides a very good representation of the range of fractures anticipated at the emplacement drift horizon. The range of fracture variability from tunnel mapping has been captured in the rock fall model through multiple Monte Carlo simulations of the rock mass.

The small trace length fracture data (DTN GS990908314224.009), which were collected at six locations in the Cross Drift over a total distance of 30 m, were not considered to be a representative data set for this analysis. Based on field observations, the small trace length fractures do not contribute to block development, and are not appropriate for the DRKBA rock fall model. The effect of small trace length fractures on block development, if any, would be to either decrease the maximum block size, or decrease the probability of occurrence of the maximum block. The impact of not considering this data is that the block size distributions presented in this analysis could potentially be more conservative. Over time, the small trace length fractures may contribute toward raveling, or surficial degradation of the rock mass.

To account for uncertainties associated with seismic, thermal, and time-dependent effects on rock fall, a conservative reduction of joint strength parameters has been included in the model.

7.3 TBV IMPACT

TBV-4408 is the result of using unqualified vibratory ground motion parameters in the seismic analysis (DTN MO0003SEPSDARS.002). When these data are qualified, an assessment of the impacts to this study as a result of any changes to the data would be required.

Developed fracture geometry data are provided by DTN MO0008SPAFRA06.004, which is the Technical Product Output of CRWMS M&O (2000d). These data are currently unqualified because of the unqualified status of the software product used to develop these data (CRWMS M&O 2000d, Section 7). When these data are qualified, an assessment of the impacts to this study as a result of any changes to the data would be required.

This document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System (DIRS) database.

7.4 RECOMMENDATIONS

The following recommendations have resulted from this drift degradation analysis:

- While this analysis has shown that a relatively small percentage of the repository host horizon will be affected by block failure, an extensive field mapping program during repository construction is recommended to help locate potential areas of key block failure.

- The data collected from the small trace length fracture study should be further analyzed to assess its effect on drift degradation in terms of raveling, or surficial degradation of the rock mass. As demonstrated in this analysis, the Tptpll unit is generally not affected by structurally controlled key block failure. Therefore, raveling, or surficial degradation could be the primary means of drift degradation in the Tptpll unit.

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AP-17.1Q, Revision 1, ICN 2. *Record Source Responsibilities for Inclusionary Records*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19991217.0505.

AP-SI.1Q, Revision 2, ICN 4, ECN 1. *Software Management*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20001019.0023.

AP-SIII.2Q, Revision 0, ICN 3. *Qualification of Unqualified Data and Documentation of the Rationale for Accepted Data*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20001002.0152.

AP-SIII.3Q, Revision 0, ICN 3. *Submittal and Incorporation of Data to the Technical Data Management System*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000418.0808.

NLP-2-0, Revision 5, ICN 1. *Determination of Importance Evaluations*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000713.0360.

QAP-2-0, Revision 5. *Conduct of Activities*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980826.0209.

QAP-2-3, Revision 10. *Classification of Permanent Items*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990316.0006.

AP-SV.1Q, Revision 0, ICN 2. *Control of the Electronic Management of Data*. Las Vegas, Nevada: U.S. Department of Energy, Yucca Mountain Site Characterization Office. ACC: MOL.20000831.0065.

8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

GS971108314224.024. Revision 1 of Detailed Line Survey Data, Station 18+00 to Station 26+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/03/1997.

GS971108314224.025. Revision 1 of Detailed Line Survey Data, Station 26+00 to Station 30+00, North Ramp and Main Drift, Exploratory Studies Facility. Submittal date: 12/03/1997.

GS960708314224.008. Provisional Results: Geotechnical Data for Station 30+00 to Station 35+00, Main Drift of the ESF. Submittal date: 08/05/1996.

GS000608314224.004. Provisional Results: Geotechnical Data for Station 35+00 to Station 40+00, Main Drift of the ESF. Submittal date: 06/20/2000.

GS960708314224.010. Provisional Results: Geotechnical Data for Station 40+00 to Station 45+00, Main Drift of the ESF. Submittal date: 08/05/1996.

GS971108314224.026. Revision 1 of Detailed Line Survey Data, Station 45+00 to Station 50+00, Main Drift, Exploratory Studies Facility. Submittal date: 12/03/1997.

GS960908314224.014. Provisional Results - ESF Main Drift, Station 50+00 to Station 55+00. Submittal date: 09/09/1996.

GS971108314224.028. Revision 1 of Detailed Line Survey Data, Station 55+00 to Station 60+00, Main Drift and South Ramp, Exploratory Studies Facility. Submittal date: 12/03/1997.

GS970208314224.003. Geotechnical Data for Station 60+00 to Station 65+00, South Ramp of the ESF. Submittal date: 02/12/1997.

GS970808314224.010. Provisional Results: Geotechnical Data for Station 70+00 to Station 75+00, South Ramp of the ESF. Submittal date: 08/25/1997.

GS960908314224.020. Analysis Report: Geology of the North Ramp - Stations 4+00 to 28+00 and Data: Detailed Line Survey and Full Periphery Geotechnical Map - Alcoves 3 (UPCA) and 4 (LPCA), and Comparative Geologic Cross Section - Stations 0+60 to 28+00. Submittal date: 09/09/1996.

GS000608314224.006. Provisional Results: Geotechnical Data for Station 26+00 to 30+00, North Ramp and Main Drift of the ESF, Full Periphery Geotechnical Maps (Drawings OA-46-222 through OA-46-226) and Rock Mass Quality Ratings Report. Submittal date: 06/28/2000.

GS960908314224.015. Provisional Results: Geotechnical Data for Station 30+00 to 40+00, Main Drift of the ESF, Full Periphery Geotechnical Maps and Rock Mass Quality Ratings Report. Submittal date: 09/09/1996.

GS960908314224.016. Provisional Results: Geotechnical Data for Station 40+00 to 50+00, Main Drift of the ESF, Full Periphery Geotechnical Maps and Rock Mass Quality Ratings Report. Submittal date: 09/09/1996.

GS960908314224.017. Provisional Results: Geotechnical Data for Station 50+00 to 55+00, Main Drift of the ESF, Full Periphery Geotechnical Maps and Rock Mass Quality Ratings Report. Submittal date: 09/09/1996.

GS970108314224.002. Provisional Results: Geotechnical Data for Station 55+00 to 60+00, Main Drift of the ESF, Full Periphery Geotechnical Maps (Drawings OA-46-257 through OA-46-262) and Rock Mass Quality Ratings Report. Submittal date: 01/31/1997.

GS970208314224.004. Geotechnical Data for Station 60+00 to 65+00, South Ramp of the ESF. Submittal date: 02/12/1997.

GS970808314224.009. Provisional Results: Geotechnical Data for Station 65+00 to 70+00, South Ramp of the ESF, Full Periphery Geotechnical Maps (Drawings OA-46-269 through OA-46-274) and Rock Mass Quality Ratings Report. Submittal date: 08/18/1997.

GS970808314224.011. Provisional Results: Geotechnical Data for Station 70+00 to 75+00, South Ramp of the ESF. Submittal date: 08/25/1997.

GS990408314224.001. Detailed Line Survey Data for Stations 00+00.89 to 14+95.18, ECRB Cross Drift. Submittal date: 09/09/1999.

GS990408314224.002. Detailed Line Survey Data for Stations 15+00.85 to 26+63.85, ECRB Cross Drift. Submittal date: 09/09/1999.

GS990408314224.003. Full-periphery Geologic Maps for Station -0+10 to 10+00, ECRB Cross Drift. Submittal date: 09/09/1999.

GS990408314224.004. Full-periphery Geologic Maps for Station 10+00 to 15+00, ECRB Cross Drift. Submittal date: 09/09/1999.

GS990408314224.005. Full-periphery Geologic Maps for Station 15+00 to 20+00, ECRB Cross Drift. Submittal date: 09/09/1999.

GS990408314224.006. Full-periphery Geologic Maps for Station 20+00 to 26+81, ECRB Cross Drift. Submittal date: 09/09/1999.

GS990908314224.009. Detailed Line Survey Data for Horizontal and Vertical Traverses, ECRB. Submittal date: 09/16/1999.

MO0003SEPSDARS.002. Preliminary Seismic Design Acceleration Response Spectra for the Repository Level (Point B). Submittal date: 03/30/2000. URN-0203

MO0008SPAFRA06.004. Fracture Geometry Data for the Lithostratigraphic Units of the Repository Host Horizon. Submittal date: 08/28/2000.

MO9904MWDFPG16.000. Full Periphery Geotechnical Mapping Srike and Dip Data Entry Correction Analysis. Submittal date: 04/06/1999.

SNL02030193001.027. Summary of Bulk Property Measurements Including Saturated Bulk Density for NRG-2, NRG-2A, NRG-2B, NRG-3, NRG-4, NRG-5, NRG-6, NRG-7/7A, SD-9, and SD-12. Submittal date: 08/14/1996.

SNL02112293001.003. Results from Shear Stress Experiments on Natural Fractures from NRG-4 and NRG-6. Submittal date: 03/13/1995.

SNL02112293001.005. Mechanical Properties of Fractures in Specimens from Drillhole USW SD-9. Submittal date: 07/15/1996.

SNL02112293001.007. Mechanical Properties of Fractures in Specimens from Drillholes USW-NRG-7/7A and USW SD-12. Submittal date: 08/08/1996.

SNL02030193001.004. Mechanical Properties Data for Drillhole USW NRG-6 Samples from Depth 462.3 ft. to 1085.0 ft. Submittal date: 08/05/1993.

SNL02030193001.012. Mechanical Properties Data for Drillhole UE25 NRG-5 Samples from Depth 847.2 ft. to 896.5 ft. Submittal date: 12/02/1993.

SNL02030193001.019. Mechanical Properties Data for Drillhole USW NRG-7/7A Samples from Depth 507.4 ft. to 881.0 ft. Submittal date: 06/29/1994.

SNL02030193001.020. Mechanical Properties Data for Drillhole USW NRG-7/7A Samples from Depth 554.7 ft. to 1450.1 ft. Submittal date: 07/25/1994.

SNL02030193001.021. Mechanical Properties Data (Ultrasonic Velocities, Static Elastic Properties, Triaxial Strength, Dry Bulk Density, and Porosity) for Drillhole USW NRG-7/7A Samples from Depth 345.0 ft. to 1408.6 ft. Submittal date: 02/16/1995.

SNL02030193001.023. Mechanical Properties Data (Ultrasonic Velocities, Static Elastic Properties, Unconfined Strength, Triaxial Strength, Dry Bulk Density, and Porosity) for Drillhole USW SD-12 Samples from Depth 16.1 ft. to 1300.3 ft. Submittal date: 08/02/1995.

SNL02030193001.026. Mechanical Properties Data (Ultrasonic Velocities, Elastic Moduli and Fracture Strength) for Drillhole USW SD-9. Submittal date: 02/22/1996.

ATTACHMENT I

TIME DEPENDENT AND THERMAL EFFECTS ON JOINT COHESION

TIME-DEPENDENT AND THERMAL EFFECTS ON JOINT COHESION

The site-specific time-dependent behavior of joint strength parameters for the host rock is not available at this time. An approach based on the time-dependent degradation work by Kemeny (1991) is used in this study. The approach assumes that the degradation occurs mainly due to the reduction of joint cohesion. Joint cohesion exists due to the asperities along the joint surface. These asperities may shear off with time and they may shear off due to the increased shear stress caused by the thermal effect. By using the numerical analysis results for the thermally induced shear stress and some site-specific data, the joint cohesion degradation with time can be quantified based on the approach reported by Kemeny and Cook (1986).

The equation for the mode II stress intensity factor (K_{II}) for a single asperity under shear and normal stresses can be expressed in the following (Kemeny and Cook 1986):

$$K_{II} = \frac{(\tau - \sigma_n \tan(\phi))2w}{\sqrt{\pi a(t)}} \qquad \text{(Eq. I-1)}$$

Where τ is the shear stress, σ_n is the normal stress, and ϕ is the friction angle. The geometrical parameters w and a are shown in Figure I-1.

Crack growth occurs when K_{II} is equal to K_{IIC}. Equation I-1 can be re-written based on the Mohr-Coulomb relationship as:

$$C_0 = \frac{K_{IIC}\sqrt{\pi a(t)}}{2w} \qquad \text{(Eq. I-2)}$$

where C_0 is the joint cohesion.

A cohesion of 0.1 MPa is predicted using the parameters $K_{IIC} = 0.5$ MPa $(m)^{0.5}$ and a_0 is equal to 0.0127 m. These parameters are therefore used as the initial parameters before time-dependent crack growth occurs. As the asperity size decreases due to time-dependent crack growth, the cohesion will decrease as given by Equation I-2.

The time-dependent crack growth can be expressed using the following equation (Kemeny 1991):

$$\frac{d(a(t))}{dt} = A\left[\frac{K_{II}}{K_{IIC}}\right]^n \qquad \text{(Eq. I-3)}$$

Combining Equations I-1 and I-3, the time-dependent crack growth can be written as:

$$\frac{d(a(t))}{dt} = 2^n A\pi^{-n/2}\left[\frac{w(\tau - \sigma_n \tan(\phi))}{\sqrt{a(t)}K_{IIC}}\right]^n \qquad \text{(Eq. I-4)}$$

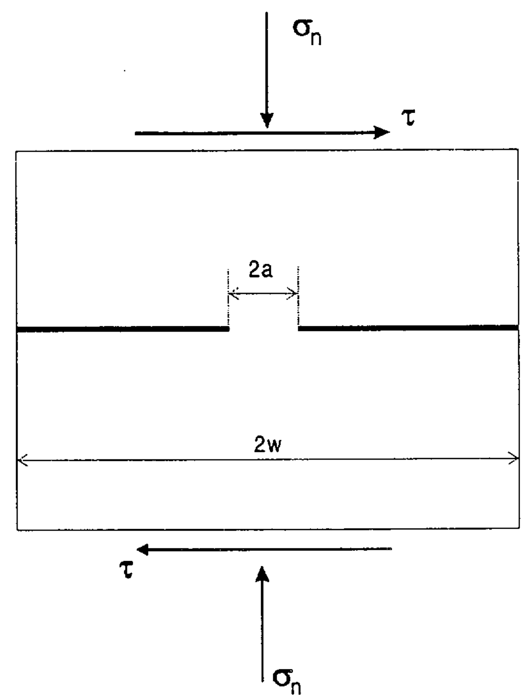


Figure I-1. Parameters Used for Calculation of Mode II Stress Intensity Factor

where A and n are subcritical crack growth parameters. Previous Yucca Mountain studies have used $n = 25$ and A ranging from 10^{-6} to 10^{-4} m/s (Kessler and McGuire 1996). A value for A of 10^{-5} m/s is used in this analysis (Assumption 5.8).

The effective shear stress, (τ - σ_n tanϕ), is time-dependent due to the thermal loading by the canisters. The thermal loading can cause horizontal stresses as high as 50 MPa in the backs of the underground drifts, decreasing the stability of some joints and increasing the stability of others. On average, it is found that the effective shear stress along the joints (τ - σ_n tanϕ) increases by as much as 16% in the time period where heating of the rock occurs. The function used to describe the additional effective shear stress due to thermal heating is as follows:

$$f(t) = 1 + 0.00001044556 * e^{(120-t)/50} t^2 \qquad \text{(Eq. I-5)}$$

This function is presented graphically in Figure I-2. The figure shows that the shear stresses are increased by approximately 10% in the period between 50 and 200 years. Adding this function to Equation I-4, the time-dependent crack growth expression is now:

$$\frac{d(a(t))}{dt} = 31536000 * 2^n A\pi^{-n/2} \left[\frac{w(\tau - \sigma_n \tan(\phi))(1 + 0.00001044556 * e^{(120-t)/50} t^2)}{\sqrt{a(t)} K_{IIC}} \right]^n$$

(Eq. I-6)

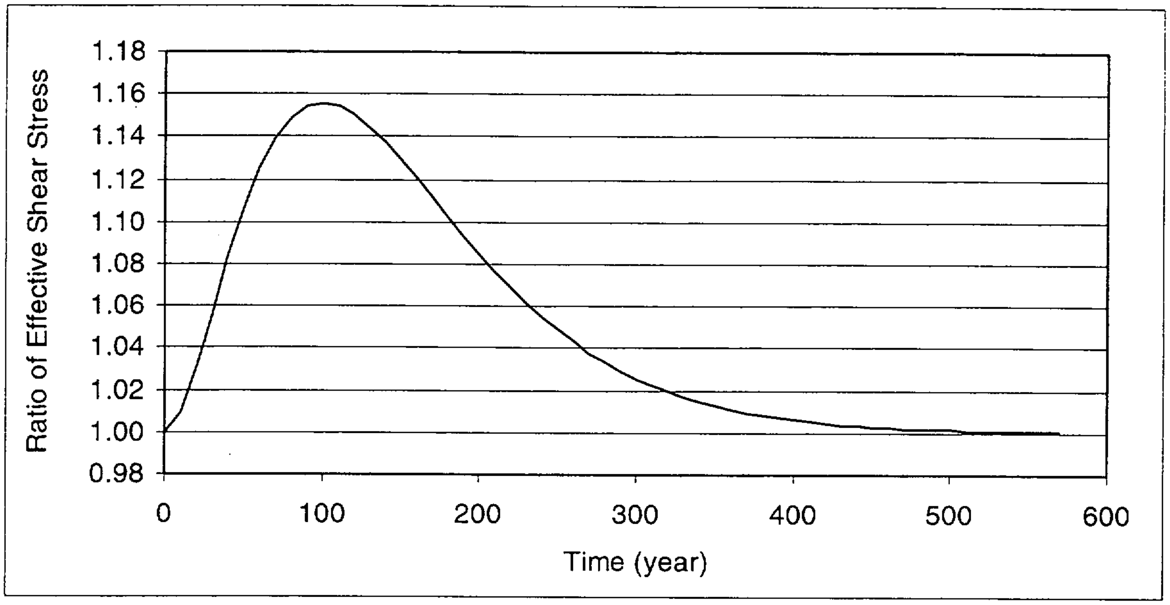


Figure I-2. Function of the Additional Shear Stress Due to Thermal Loading

The nonlinear differential equation was solved numerically using MathCAD. The calculation results in an asperity vs. time relationship. This relationship is then used in conjunction with Equation I-2 to obtain the cohesion values for various time.

Numerical analysis made for the in situ stress state give a range of effective shear stresses (τ - σ_n tanϕ) that range from 0.04 to 0.06 MPa. Calculations were made with effective shear stresses of 0.04, 0.0425, 0.045, 0.0475, 0.05, 0.0525, 0.055, 0.0575, and 0.06 MPa, and the results were averaged. This approach results in a stepped cohesion reduction over time as shown in Figure 8.

ATTACHMENT II

DRIFT DEGRADATION ANALYSIS COMPUTER FILES

DRIFT DEGRADATION ANALYSIS COMPUTER FILES

This attachment provides a list of computer files for the drift degradation analysis. The list is separated into the following directories on the CDs included in this attachment:

- *DRKBA Inputs and Outputs* — includes all of the input and output files for the probabilistic key block software, DRKBA
- *UNWEDGE Inputs and Outputs* — includes all of the input and output information for the software, UNWEDGE
- *UDEC Inputs and Outputs* — includes all of the input and output information for the distinct element program, UDEC
- *Calculation Files* — includes other calculation files.

The input and output files for DRKBA for each case share similar file extensions. Table II-1 explains the type of file and the associated file extension. Table II-2 lists the sub-directories for all the cases run in DRKBA. The subdirectory *Profile* includes all the DXF files for drift profile plots shown in Section 6.4.3 and in Attachment XII. The file name and the associated drift degradation profiles are listed in Table II-3.

UNWEDGE files are listed in Table II-4. UDEC files are listed in Table II-5. Calculation files using the software EXCEL 97 and MathCAD Version 8 are listed in Table II-6.

Table II-1. File Extension Associated with DRKBA Input and Output Files

File Extension	Description of File
ANA	Input Summary File
MKG	Input Grid File
EXC	Input Excavation File
DEN	Input Density File
PRB	Input Joint Data File
KBO	Output File for Key Block Information
BSD	Output File for Block Size Distribution

Table II-2. List of DRKBA Input and Output Files

Directory	Brief Description
Runpul\k003aa	Tptpul, 0° Azimuth, Static Condition
Runpul\k004aa	Tptpul, 15° Azimuth, Static Condition
Runpul\k005aa	Tptpul, 30° Azimuth, Static Condition
Runpul\k006aa	Tptpul, 45° Azimuth, Static Condition
Runpul\k007aa	Tptpul, 60° Azimuth, Static Condition
Runpul\k008aa	Tptpul, 75° Azimuth, Static Condition
Runpul\k009aa	Tptpul, 90° Azimuth, Static Condition
Runpul\k010aa	Tptpul, 105° Azimuth, Static Condition
Runpul\k011aa	Tptpul, 120° Azimuth, Static Condition
Runpul\k012aa	Tptpul, 135° Azimuth, Static Condition
Runpul\k013aa	Tptpul, 150° Azimuth, Static Condition

Table II-2. List of DRKBA Input and Output Files (Continued)

Directory	Brief Description
Runpul\k014aa	Tptpul, 165° Azimuth, Static Condition
Runpmn\k017aa	Tptpmn, 0° Azimuth, Static Condition
Runpmn\k018aa	Tptpmn, 15° Azimuth, Static Condition
Runpmn\k019aa	Tptpmn, 30° Azimuth, Static Condition
Runpmn\k020aa	Tptpmn, 45° Azimuth, Static Condition
Runpmn\k021aa	Tptpmn, 60° Azimuth, Static Condition
Runpmn\k022aa	Tptpmn, 75° Azimuth, Static Condition
Runpmn\k023aa	Tptpmn, 90° Azimuth, Static Condition
Runpmn\k024aa	Tptpmn, 105° Azimuth, Static Condition
Runpmn\k025aa	Tptpmn, 120° Azimuth, Static Condition
Runpmn\k026aa	Tptpmn, 135° Azimuth, Static Condition
Runpmn\k027aa	Tptpmn 150° Azimuth, Static Condition
Runpmn\k028aa	Tptpmn, 165° Azimuth, Static Condition
Runpll\k031aa	Tptpll, 0° Azimuth, Static Condition
Runpll\k032aa	Tptpll, 15° Azimuth, Static Condition
Runpll\k033aa	Tptpll, 30° Azimuth, Static Condition
Runpll\k034aa	Tptpll, 45° Azimuth, Static Condition
Runpll\k035aa	Tptpll, 60° Azimuth, Static Condition
Runpll\k036aa	Tptpll, 75° Azimuth, Static Condition
Runpll\k037aa	Tptpll, 90° Azimuth, Static Condition
Runpll\k038aa	Tptpll, 105° Azimuth, Static Condition
Runpll\k039aa	Tptpll, 120° Azimuth, Static Condition
Runpll\k040aa	Tptpll, 135° Azimuth, Static Condition
Runpll\k041aa	Tptpll, 150° Azimuth, Static Condition
Runpll\k042aa	Tptpll, 165° Azimuth, Static Condition
Runpln\k045aa	Tptpln, 0° Azimuth, Static Condition
Runpln\k046aa	Tptpln, 15° Azimuth, Static Condition
Runpln\k047aa	Tptpln, 30° Azimuth, Static Condition
Runpln\k048aa	Tptpln, 45° Azimuth, Static Condition
Runpln\k049aa	Tptpln, 60° Azimuth, Static Condition
Runpln\k050aa	Tptpln, 75° Azimuth, Static Condition
Runpln\k051aa	Tptpln, 90° Azimuth, Static Condition
Runpln\k052aa	Tptpln, 105° Azimuth, Static Condition
Runpln\k053aa	Tptpln, 120° Azimuth, Static Condition
Runpln\k054aa	Tptpln, 135° Azimuth, Static Condition
Runpln\k055aa	Tptpln, 150° Azimuth, Static Condition
Runpln\k056aa	Tptpln, 165° Azimuth, Static Condition
seismic\k010aa\cat1	Tptpul, 105° Azimuth, Seismic, Level 1
seismic\k010aa\cat2	Tptpul, 105° Azimuth, Seismic, Level 2
seismic\k010aa\cat3	Tptpul, 105° Azimuth, Seismic, Level 3
seismic\k024aa\cat1	Tptpmn, 105° Azimuth, Seismic, Level 1
seismic\k024aa\cat2	Tptpmn, 105° Azimuth, Seismic, Level 2
seismic\k024aa\cat3	Tptpmn, 105° Azimuth, Seismic, Level 3
seismic\k038aa\cat1	Tptpll, 105° Azimuth, Seismic, Level 1
seismic\k038aa\cat2	Tptpll, 105° Azimuth, Seismic, Level 2
seismic\k038aa\cat3	Tptpln, 105° Azimuth, Seismic, Level 3
seismic\k052aa\cat1	Tptpln, 105° Azimuth, Seismic, Level 1
seismic\k052aa\cat2	Tptpln, 105° Azimuth, Seismic, Level 2
seismic\k052aa\cat3	Tptpln, 105° Azimuth, Seismic, Level 3
Time-dep\k010aa\yr200	Tptpul, 105° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k010aa\yr10k	Tptpul, 105° Azimuth, Time-dependent and Thermal, 10000 yr
Time-dep\k024aa\yr200	Tptpmn, 105° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k024aa\yr10k	Tptpmn, 105° Azimuth, Time-dependent and Thermal, 10000 yr

Table II-2. List of DRKBA Input and Output Files (Continued)

Directory	Brief Description
Time-dep\k038aa\yr200	Tptpll, 105° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k038aa\yr10k	Tptpll, 105° Azimuth, Time-dependent and Thermal, 10000 yr
Time-dep\k052aa\yr200	Tptpln, 105° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k052aa\yr10k	Tptpln, 105° Azimuth, Time-dependent and Thermal, 10000 yr
Seismic\k008aa\cat1	Tptpul, 75° Azimuth, Seismic, Level 1
Seismic\k008aa\cat2	Tptpul, 75° Azimuth, Seismic, Level 2
Seismic\k008aa\cat3	Tptpul, 75° Azimuth, Seismic, Level 3
Seismic\k022aa\cat1	Tptpmn, 75° Azimuth, Seismic, Level 1
Seismic\k022aa\cat2	Tptpmn, 75° Azimuth, Seismic, Level 2
Seismic\k022aa\cat3	Tptpmn, 75° Azimuth, Seismic, Level 3
Seismic\k036aa\cat1	Tptpll, 75° Azimuth, Seismic, Level 1
Seismic\k036aa\cat2	Tptpll, 75° Azimuth, Seismic, Level 2
Seismic\k036aa\cat3	Tptpln, 75° Azimuth, Seismic, Level 3
Seismic\k050aa\cat1	Tptpln, 75° Azimuth, Seismic, Level 1
Seismic\k050aa\cat2	Tptpln, 75° Azimuth, Seismic, Level 2
Seismic\k050aa\cat3	Tptpln, 75° Azimuth, Seismic, Level 3
Time-dep\k008aa\yr200	Tptpul, 75° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k008aa\yr10k	Tptpul, 75° Azimuth, Time-dependent and Thermal, 10000 yr
Time-dep\k022aa\yr200	Tptpmn, 75° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k022aa\yr10k	Tptpmn, 75° Azimuth, Time-dependent and Thermal, 10000 yr
Time-dep\k036aa\yr200	Tptpll, 75° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k036aa\yr10k	Tptpll, 75° Azimuth, Time-dependent and Thermal, 10000 yr
Time-dep\k050aa\yr200	Tptpln, 75° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k050aa\yr10k	Tptpln, 75° Azimuth, Time-dependent and Thermal, 10000 yr
Time-dep\k010aa\yr200	Tptpul, 105° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k010aa\yr10k	Tptpul, 105° Azimuth, Time-dependent and Thermal, 10000 yr
Time-dep\k024aa\yr200	Tptpmn, 105° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k024aa\yr10k	Tptpmn, 105° Azimuth, Time-dependent and Thermal, 10000 yr
Time-dep\k038aa\yr200	Tptpll, 105° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k038aa\yr10k	Tptpll, 105° Azimuth, Time-dependent and Thermal, 10000 yr
Time-dep\k052aa\yr200	Tptpln, 105° Azimuth, Time-dependent and Thermal, 200 yr
Time-dep\k052aa\yr10k	Tptpln, 105° Azimuth, Time-dependent and Thermal, 10000 yr

Table II-3. List of DRKBA Output Files for Degradation Profile

Directory\File Name	Brief Description
Profile\k010c1fs.dxf	Tptpul, Static and Seismic Level 1, Time-Dependent and Thermal, 200 Yr, 105° Azimuth, Without Backfill, Worst Case Profile
Profile\k010n2fs.dxf	Tptpul, Seismic Level 2, 105° Azimuth, Worst Case Profile
Profile\k010n3fs.dxf	Tptpul, Seismic Level 3, 105° Azimuth, Worst Case Profile
Profile\k024stfs.dxf	Tptpmn, Static, 105° Azimuth, Worst Case Profile
Profile\k024n1fs.dxf	Tptpmn, Seismic Level 1, Seismic Level 2, and Seismic Level 3, Time-Dependent and Thermal, 200, 2000 and 10000 Yr, 105° Azimuth, Without Backfill, Worst Case Profile
Profile\k038c2fs.dxf	Tptpll, Static, Seismic Level 1, Seismic Level 2, and Seismic Level 3, Time-Dependent and Thermal, 200, 2000 and 10000 Yr, 105° Azimuth, Without Backfill, Worst Case Profile
Profile\k052c0fs.dxf	Tptpln, Static, 105° Azimuth, Worst Case Profile
Profile\k052c1fs.dxf	Tptpln, Seismic Level 1, Time-Dependent and Thermal, 200 Yr, 105° Azimuth, Without Backfill, Worst Case Profile

Table II-3. List of DRKBA Output Files for Degradation Profile (Continued)

Directory\File Name	Brief Description
Profile\k052c2fs.dxf	Tptpln, Seismic Level 2 and Seismic Level 3, Time-Dependent and Thermal, 2000 and 10000 Yr, 105° Azimuth, Without Backfill, Worst Case Profile
Profile\k010y1fs.dxf	Tptpul, Time-Dependent and Thermal, 200 Yr, 105° Azimuth, With Backfill, Worst Case Profile
Profile\k010y3fs.dxf	Tptpul, Time-Dependent and Thermal, 2000 and 10000 Yr, 105° Azimuth, With Backfill, Worst Case Profile
Profile\k024y3fs.dxf	Tptpmn, Time-Dependent and Thermal, 200, 2000 and 10000 Yr, 105° Azimuth, With Backfill, Worst Case Profile
Profile\k038y3fs.dxf	Tptpll, Time-Dependent and Thermal, 200, 2000 and 10000 Yr, 105° Azimuth, With Backfill, Worst Case Profile
Profile\k008c1fs.dxf	Tptpul, Static and Seismic Level 1, Time-Dependent and Thermal, 200 ,2000 and 10000 Yr, 75° Azimuth, Without Backfill, Worst Case Profile
Profile\k008c2fs.dxf	Tptpul, Seismic Level 2 and Seismic Level 3, 75° Azimuth, Worst Case Profile
Profile\k022c0fs.dxf	Tptpmn, Static, 75° Azimuth, Worst Case Profile
Profile\k022c1fs.dxf	Tptpmn, Seismic Level 1, 75° Azimuth, Worst Case Profile
Profile\k022c2fs.dxf	Tptpmn, Seismic Level 2 and Seismic Level 3, 75° Azimuth, Worst Case Profile
Profile\k036c1fs.dxf	Tptpll, Static, Seismic Level 1, Seismic Level 2, and Seismic Level 3, Time-Dependent and Thermal, 200, 2000 and 10000 Yr, 75° Azimuth, Without Backfill, Worst Case Profile
Profile\k050c1fs.dxf	Tptpln, Static, Seismic Level 1, Seismic Level 2, and Seismic Level 3, Time-Dependent and Thermal, 200, 2000 and 10000 Yr, 75° Azimuth, Without Backfill, Worst Case Profile
Profile\k050c2fs.dxf	Tptpln, Seismic Level 1 and 2, Time-Dependent and Thermal, 2000 and 10000 Yr, 75° Azimuth, Without Backfill, Worst Case Profile
Profile\k022t1fs.dxf	Tptpmn, Time-Dependent and Thermal, 200 Yr, 75° Azimuth, Without Backfill, Worst Case Profile
Profile\k010t2fs.dxf	Tptpul, Time-Dependent and Thermal, 2000 and 10000 Yr, 105° Azimuth, Without Backfill, Worst Case Profile
Profile\k022m0fs.dxf	Tptpmn, Static, 75° Azimuth, 75 Percentile Profile
Profile\k022m1fs.dxf	Tptpmn, Seismic Level 1, 75° Azimuth, 75 Percentile Profile
Profile\k022m2fs.dxf	Tptpmn, Seismic Level 2 and 3, 75° Azimuth, 75 Percentile Profile
Profile\k036m1fs.dxf	Tptpll, Static, Seismic Level 1, Seismic Level 2, and Seismic Level 3, 75° Azimuth, 75 Percentile Profile

Table I-4. List of UNWEDGE Input and Output Files

File Name	Brief Description
1mt.weg	UNWEDGE input and output information for a 1 MT rock block
2mt.weg	UNWEDGE input and output information for a 2 MT rock block
4mt.weg	UNWEDGE input and output information for a 4 MT rock block
5mt.weg	UNWEDGE input and output information for a 5 MT rock block
8mt.weg	UNWEDGE input and output information for a 8 MT rock block
15mt.weg	UNWEDGE input and output information for a 15 MT rock block
19mt.weg	UNWEDGE input and output information for a 19 MT rock block
30mt.weg	UNWEDGE input and output information for a 30 MT rock block
36mt.weg	UNWEDGE input and output information for a 36 MT rock block
52mt.weg	UNWEDGE input and output information for a 52 MT rock block

Table II-5. List of UDEC Input and Output Files

File Name	Brief Description
Case1.dat	Input file for initial consolidation state, case 1
Case1-d.dat	Input file for dynamic analysis, case 1
Case1-s.dat	Input file for quasi-static analysis, case1
Case1-1.sav	Output file for initial consolidation state, case 1
Case1-d.sav	Output file for dynamic analysis, case 1
Case1-s.sav	Output file for quasi-static analysis, case 1
Case2.dat	Input file for initial consolidation state, case 2
Case2-d.dat	Input file for dynamic analysis, case 2
Case2-s.dat	Input file for quasi-static analysis, case2
Case2-1.sav	Output file for initial consolidation state, case 2
Case2-d.sav	Output file for dynamic analysis, case 2
Case2-s.sav	Output file for quasi-static analysis, case 2
Case3-d.dat	Input file for dynamic analysis, case 3
Case3-d.sav	Output file for dynamic analysis, case 3
Case4-d.dat	Input file for dynamic analysis, case 4
Case4-d.sav	Output file for dynamic analysis, case 4

Table II-6. List of the Calculation Files

File Name	Software	Brief Description
Cohesion Degradation V1 .xls	EXCEL 97	Cohesion degradation due to time and thermal effect
Exca vectors V1.xls	EXCEL 97	Calculation of the plane equations to describe the 5.5-m-diameter excavation opening
Exca vectors-backfill V1.xls	EXCEL 97	Calculation of the plane equations to describe the 5.5-m-diameter excavation opening with backfill
New_Beta_Tptpll V1.xls	EXCEL 97	Beta Distribution Parameters (a, b, p, q) for joint spacing, trace length, and location for Tptpll
New_Beta_Tptpln V2.xls	EXCEL 97	Beta Distribution Parameters (a, b, p, q) for joint spacing, trace length, and location for Tptpln
New_Beta_Tptpmn V1.xls	EXCEL 97	Beta Distribution Parameters (a, b, p, q) for joint spacing, trace length, and location for Tptpmn
New_Beta_Tptpul V1.xls	EXCEL 97	Beta Distribution Parameters (a, b, p, q) for joint spacing, trace length, and location for Tptpul
New-K-Tptpll V1.mcd	MathCAD 8	Calculation of K factor of joint orientation for Tptpll
New-K-Tptpln V2.mcd	MathCAD 8	Calculation of K factor of joint orientation for Tptpln
New-K-Tptpmn V1.mcd	MathCAD 8	Calculation of K factor of joint orientation for Tptpmn
New-K-Tptpul V1.mcd	MathCAD 8	Calculation of K factor of joint orientation for Tptpul
Orient-Tptpll V1.xls	EXCEL 97	Calculation of the components for the Orientation Matrix for Tptpll
Orient-Tptpln V2.xls	EXCEL 97	Calculation of the components for the Orientation Matrix for Tptpln
Orient-Tptpmn V1.xls	EXCEL 97	Calculation of the components for the Orientation Matrix for Tptpmn
Orient-Tptpul V1.xls	EXCEL 97	Calculation of the components for the Orientation Matrix for Tptpul
Res sum V2.xls	EXCEL 97	Summary of maximum key block size results
Thermal curve V1.xls	EXCEL 97	Ratio of effective shear stress for thermal effect
Time thermal cohesion degradation V1.mcd	MathCAD 8	Cohesion degradation due to time and thermal effect
Total vol tm 75 v2.xls	EXCEL 97	Total key block volume calculation, time-dependent and thermal, 75° Azimuth, Without Backfill
Total vol seis 75 v2.xls	EXCEL 97	Total key block volume calculation, seismic, 75° Azimuth, Without Backfill
Total vol tm 105 backfill v2.xls	EXCEL 97	Total key block volume calculation, time-dependent and thermal, 105° Azimuth, With Backfill
Total vol tm 105 v2.xls	EXCEL 97	Total key block volume calculation, time-dependent and thermal, 105° Azimuth, Without Backfill

Table II-6. List of the Calculation Files (Continued)

File Name	Software	Brief Description
Total vol seis 105 v2.xls	EXCEL 97	Total key block volume calculation, seismic, 105° Azimuth, Without Backfill
Tpllaa res V1.xls	EXCEL 97	Processed key block size distribution output file, Tptpll, Static
Tpllse res V1.xls	EXCEL 97	Processed key block size distribution output file, Tptpll, Seismic
Tplltm res V1.xls	EXCEL 97	Processed key block size distribution output file, Tptpll, Time-dependent and thermal
Tplnaa res V2.xls	EXCEL 97	Processed key block size distribution output file, Tptpln, Static
Tpln seismic 105 res V2.xls	EXCEL 97	Processed key block size distribution output file, Tptpln, Seismic
Tpln tm 105 res V2.xls	EXCEL 97	Processed key block size distribution output file, Tptpln, Time-dependent and thermal
Tpmnaa res V1.xls	EXCEL 97	Processed key block size distribution output file, Tptpmn, Static
Tpmnse res V1.xls	EXCEL 97	Processed key block size distribution output file, Tptpmn, Seismic
Tpmntm res V1.xls	EXCEL 97	Processed key block size distribution output file, Tptpmn, Time-dependent and thermal
Tpulaa res V1.xls	EXCEL 97	Processed key block size distribution output file, Tptpul, Static
Tpulse res V1.xls	EXCEL 97	Processed key block size distribution output file, Tptpul, Seismic
Tpultm res V1.xls	EXCEL 97	Processed key block size distribution output file, Tptpul, Time-dependent and thermal
tpul tm 75 res v1.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpul, 75 degree azimuth, time-dependent and thermal, no backfill
tpmn tm 75 res v1.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpmn, 75 degree azimuth, time-dependent and thermal, no backfill
tpll tm 75 res v1.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpll, 75 degree azimuth, time-dependent and thermal, no backfill
tpln tm 75 res v2.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpln, 75 degree azimuth, time-dependent and thermal, no backfill
tpul tm 105 res v1.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpul, 105 degree azimuth, time-dependent and thermal, no backfill
tpmn tm 105 res v1.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpmn, 105 degree azimuth, time-dependent and thermal, no backfill
tpll tm 105 res v1.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpll, 105 degree azimuth, time-dependent and thermal, no backfill
tpln tm bf 105 res v2.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpln, 105 degree azimuth, time-dependent and thermal, no backfill
tpul seismic 75 res v1.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpul, 75 degree azimuth, seismic, no backfill
tpmn seismic 75 res v1.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpmn, 75 degree azimuth, seismic, no backfill
tpll seismic 75 res v1.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpll, 75 degree azimuth, seismic, no backfill
tpln seismic 75 res v2.xls	EXCEL 97	Rock blocks accumulated percentage of occurrence, Tptpln, 75 degree azimuth, seismic, no backfill
z-length cal v1.xls	EXCEL 97	Basis for z-length calculation formula
pmn-rock volume per mcs v2.xls	EXCEL 97	Calculation of block volume, 75 degree azimuth, Tptpmn
pll-rock volume per mcs v2.xls	EXCEL 97	Calculation of block volume, 75 degree azimuth, Tptpll
pln-rock volume per mcs v2.xls	EXCEL 97	Calculation of block volume, 75 degree azimuth, Tptpln
Summary of rock volume per mcs V1.xls	EXCEL 97	Summary of block volume results
Joint strength.xls	EXCEL 97	Calculation of mean joint cohesion and friction angle

ATTACHMENT III

CALCULATION EXAMPLE FOR JOINT PARAMETERS USED IN DRKBA ANALYSIS (Tptpll, Joint Set 1)

CALCULATION EXAMPLE FOR JOINT PARAMETERS USED IN DRKBA ANALYSIS (Tptpll, Joint Set 1)

An example is provided in this attachment to describe the process of calculating the required joint geometrical parameters. These parameters include the concentration factor k of a bipolar Watson distribution for joint set orientation and a, b, p, and q parameters of the beta distribution for joint radii, spacings, and positioning. The first joint set identified in the Tptpll unit is used as the example.

The joint spacing, radii (two times the mapped trace lengths), and positioning (offset) were first sorted in the fracture database. The parameters a and b represent the ends of the closed interval upon which the beta distribution is defined. The smallest and largest joint parameters observed were assigned as a and b parameters. The values of p and q were calculated based on the technique presented by Derman, Gleser, and Ingram (1973, pp. 398-403). In order to determine p and q, the joint data were transformed to the unit interval [0,1] by interpolation between the smallest and largest values encountered. The parameters p and q were then calculated from the mean and standard deviation of the transformed data by means of the following equations:

$$p = \mu\,[\,\mu(1-\mu)/\sigma^2 - 1\,]$$
$$q = (1-\mu)\,[\,\mu(1-\mu)/\sigma^2 - 1\,]$$

where μ is the mean of the transformed data and σ^2 is the variance of the transformed data. The calculations are included in Table III-1.

To calculate the concentration factor, the orientation matrix of the joint data has to be first determined (Fisher, Lewis, and Embleton 1987, pp. 33 and 175-176). The orientation matrix T is defined in the following:

$$T = \begin{bmatrix} \sum x_i^2 & \sum x_i y_i & \sum x_i z_i \\ \sum x_i y_i & \sum y_i^2 & \sum y_i z_i \\ \sum x_i z_i & \sum y_i z_i & \sum z_i^2 \end{bmatrix}$$

where (x_i, y_i, z_i) is the unit normal vector of a joint plane and i ranges from 1 to n (the number of fractures collected in the joint sets). The components of the orientation matrix are calculated in Table III-2.

The solution for the concentration factor k can be approximated based on the largest eigenvalue (τ_3) of the orientation matrix T (Fisher, Lewis, and Embleton 1987, pp. 175-176). The solution is:

$$k = \begin{cases} 3.75 \times (3\tau_3 - 1) & 0.333 < \tau_3 \le 0.38 \\ 3.34 \times (3\tau_3 - 1) & 0.38 < \tau_3 \le 0.65 \\ 0.7 + 1/(1 - \tau_3) & 0.65 < \tau_3 \le 0.99 \\ 1/(1 - \tau_3) & \tau_3 \ge 0.99 \end{cases}$$

Calculations of the eigenvalues and k factor were conducted using Mathcad and are presented in Table III-3.

Table III-1. Calculation of the a, b, p, and q parameters for Joint Spacing, Radii, and Positioning (Tptpll, Joint Set 1, "New-Beta-Tptpll V1.xls")

Joint Set #1	Dip=	82	Dip Direction =	235					
	Sorted Joint Spacing (m)	**Sorted Trace Length (m)**	**Joint Offset (m)**	**Joint Offset (all positive, m)**	**Sorted Joint Offset (m)**	**Joint Radius (m)**	**Transformed Spacing**	**Transformed Radius**	**Transformed Offset**
	15.72	23.50	-0.09	0.09	8.25	47.00	1.0000	1.0000	1.0000
	15.69	18.94	1.70	1.70	7.03	37.88	0.9981	0.7978	0.8521
	15.05	15.01	0.65	0.65	5.35	30.02	0.9573	0.6235	0.6485
	13.52	14.10	-1.21	1.21	5.35	28.20	0.8599	0.5831	0.6485
	13.43	13.50	1.60	1.60	5.30	27.00	0.8540	0.5565	0.6424
	12.99	13.40	-0.80	0.80	5.30	26.80	0.8260	0.5521	0.6424
	12.74	13.40	-0.49	0.49	5.25	26.80	0.8103	0.5521	0.6364
	11.27	13.30	7.03	7.03	5.25	26.60	0.7167	0.5477	0.6364
	11.06	13.30	1.10	1.10	4.80	26.60	0.7035	0.5477	0.5818
	10.62	12.50	-0.38	0.38	4.80	25.00	0.6752	0.5122	0.5818
	10.20	12.40	8.25	8.25	4.78	24.80	0.6488	0.5078	0.5788
	7.83	12.40	-0.80	0.80	4.75	24.80	0.4974	0.5078	0.5758
	7.53	11.20	-0.71	0.71	4.70	22.40	0.4783	0.4545	0.5691
	6.27	10.79	-0.11	0.11	4.40	21.58	0.3981	0.4364	0.5333
	5.80	10.50	0.18	0.18	4.11	21.00	0.3686	0.4235	0.4976
	5.72	10.45	0.51	0.51	4.00	20.90	0.3634	0.4213	0.4848
	5.06	10.40	4.70	4.70	3.95	20.80	0.3215	0.4191	0.4788
	4.94	9.95	1.36	1.36	3.90	19.90	0.3138	0.3991	0.4727
	4.86	9.40	5.25	5.25	3.80	18.80	0.3087	0.3747	0.4606
	4.80	8.60	2.29	2.29	3.21	17.20	0.3048	0.3392	0.3891
	4.60	8.50	1.06	1.06	3.15	17.00	0.2922	0.3348	0.3818
	4.37	8.49	2.03	2.03	2.80	16.98	0.2774	0.3344	0.3394
	4.33	8.40	0.40	0.40	2.70	16.80	0.2750	0.3304	0.3273
	4.32	8.40	-0.33	0.33	2.45	16.80	0.2744	0.3304	0.2970
	4.32	8.40	-0.33	0.33	2.29	16.80	0.2742	0.3304	0.2770
	3.94	8.00	0.10	0.10	2.03	16.00	0.2499	0.3126	0.2455
	3.77	7.30	0.58	0.58	1.80	14.60	0.2392	0.2816	0.2182
	3.75	7.10	-0.03	0.03	1.70	14.20	0.2378	0.2727	0.2061
	3.15	6.98	-0.35	0.35	1.60	13.96	0.1996	0.2674	0.1939
	3.15	5.75	0.85	0.85	1.36	11.50	0.1996	0.2129	0.1642
	3.12	5.67	0.95	0.95	1.30	11.34	0.1978	0.2093	0.1576
	2.61	5.40	2.80	2.80	1.21	10.80	0.1653	0.1973	0.1467
	2.57	4.90	4.00	4.00	1.10	9.80	0.1626	0.1752	0.1327
	2.43	4.50	-0.35	0.35	1.06	9.00	0.1538	0.1574	0.1279
	2.39	3.80	4.75	4.75	1.05	7.60	0.1513	0.1264	0.1273
	2.18	3.78	0.40	0.40	0.95	7.56	0.1381	0.1255	0.1152
	2.13	3.40	4.40	4.40	0.85	6.80	0.1349	0.1086	0.1030
	2.05	3.40	3.80	3.80	0.80	6.80	0.1299	0.1086	0.0970
	1.93	3.40	0.20	0.20	0.80	6.80	0.1218	0.1086	0.0970
	1.88	3.30	3.15	3.15	0.80	6.60	0.1186	0.1042	0.0964

Table III-1. Calculation of the a, b, p, and q parameters for Joint Spacing, Radii, and Positioning (Tptpll, Joint Set 1, "New-Beta-Tptpll V1.xls") (Continued)

	Sorted Joint Spacing (m)	Sorted Trace Length (m)	Joint Offset (m)	Joint Offset (all positive, m)	Sorted Joint Offset (m)	Joint Radius (m)	Transformed Spacing	Transformed Radius	Transformed Offset
	1.74	3.16	3.21	3.21	0.75	6.32	0.1098	0.0980	0.0909
	1.68	3.10	0.48	0.48	0.72	6.20	0.1060	0.0953	0.0867
	1.65	2.94	0.15	0.15	0.72	5.88	0.1042	0.0882	0.0867
	1.64	2.75	0.31	0.31	0.71	5.50	0.1034	0.0798	0.0861
	1.51	2.52	-0.02	0.02	0.69	5.04	0.0953	0.0696	0.0830
	1.47	2.50	0.57	0.57	0.65	5.00	0.0929	0.0687	0.0788
	1.40	2.47	0.47	0.47	0.64	4.94	0.0884	0.0674	0.0770
	1.40	2.28	4.78	4.78	0.64	4.56	0.0884	0.0590	0.0770
	1.35	2.28	0.50	0.50	0.62	4.56	0.0853	0.0590	0.0752
	1.32	2.25	3.95	3.95	0.60	4.50	0.0834	0.0576	0.0727
	1.27	2.19	-0.38	0.38	0.60	4.38	0.0803	0.0550	0.0721
	1.25	2.15	-0.32	0.32	0.60	4.30	0.0790	0.0532	0.0721
	1.22	2.11	-0.16	0.16	0.58	4.22	0.0771	0.0514	0.0697
	1.22	2.10	0.00	0.00	0.57	4.20	0.0771	0.0510	0.0691
	1.21	2.10	5.30	5.30	0.57	4.20	0.0765	0.0510	0.0685
	1.21	1.69	0.62	0.62	0.51	3.38	0.0764	0.0328	0.0618
	1.17	1.67	1.30	1.30	0.51	3.34	0.0740	0.0319	0.0612
	1.02	1.62	1.80	1.80	0.50	3.24	0.0639	0.0297	0.0606
	0.99	1.61	-0.50	0.50	0.50	3.22	0.0620	0.0293	0.0606
	0.96	1.60	-0.50	0.50	0.50	3.20	0.0603	0.0288	0.0606
	0.94	1.58	0.75	0.75	0.49	3.16	0.0589	0.0279	0.0588
	0.83	1.56	-0.15	0.15	0.48	3.12	0.0520	0.0271	0.0576
	0.76	1.54	-0.23	0.23	0.48	3.08	0.0476	0.0262	0.0576
	0.72	1.51	-0.25	0.25	0.47	3.02	0.0451	0.0248	0.0570
	0.71	1.51	0.72	0.72	0.47	3.02	0.0444	0.0248	0.0570
	0.69	1.50	0.80	0.80	0.46	3.00	0.0432	0.0244	0.0558
	0.64	1.50	2.70	2.70	0.43	3.00	0.0401	0.0244	0.0521
	0.60	1.50	2.45	2.45	0.42	3.00	0.0375	0.0244	0.0509
	0.60	1.49	5.35	5.35	0.40	2.98	0.0375	0.0239	0.0485
	0.51	1.48	0.26	0.26	0.40	2.96	0.0319	0.0235	0.0479
	0.49	1.48	-0.51	0.51	0.38	2.96	0.0306	0.0235	0.0455
	0.46	1.48	-0.37	0.37	0.38	2.96	0.0287	0.0235	0.0455
	0.38	1.46	4.11	4.11	0.37	2.92	0.0231	0.0226	0.0448
	0.36	1.45	-0.60	0.60	0.35	2.90	0.0223	0.0222	0.0418
	0.33	1.45	-0.43	0.43	0.35	2.90	0.0200	0.0222	0.0418
	0.32	1.43	-0.69	0.69	0.33	2.86	0.0196	0.0213	0.0400
	0.28	1.43	0.13	0.13	0.33	2.86	0.0168	0.0213	0.0400
	0.25	1.39	-0.32	0.32	0.33	2.78	0.0149	0.0195	0.0394
	0.25	1.37	0.64	0.64	0.33	2.74	0.0149	0.0186	0.0394
	0.24	1.32	-0.57	0.57	0.32	2.64	0.0143	0.0164	0.0388
	0.22	1.30	0.48	0.48	0.32	2.60	0.0130	0.0155	0.0388
	0.20	1.30	-0.60	0.60	0.31	2.60	0.0118	0.0155	0.0376

Table III-1. Calculation of the a, b, p, and q parameters for Joint Spacing, Radii, and Positioning (Tptpll, Joint Set 1, "New-Beta-Tptpll V1.xls") (Continued)

	Sorted Joint Spacing (m)	Sorted Trace Length (m)	Joint Offset (m)	Joint Offset (all positive, m)	Sorted Joint Offset (m)	Joint Radius (m)	Transformed Spacing	Transformed Radius	Transformed Offset
	0.18	1.29	-0.145	0.145	0.295	2.58	0.0105	0.0151	0.0358
	0.14	1.27	-0.47	0.47	0.295	2.54	0.0078	0.0142	0.0358
	0.10	1.27	-0.235	0.235	0.26	2.54	0.0055	0.0142	0.0315
	0.10	1.27	-0.6	0.6	0.25	2.54	0.0055	0.0142	0.0303
	0.07	1.25	-0.295	0.295	0.25	2.5	0.0036	0.0133	0.0303
	0.06	1.24	-0.635	0.635	0.235	2.48	0.0030	0.0129	0.0285
	0.01	1.24	-0.05	0.05	0.225	2.48	0.0000	0.0129	0.0273
		1.19	0.05	0.05	0.2	2.38		0.0106	0.0242
		1.16	0.2	0.2	0.2	2.32		0.0093	0.0242
		1.15	0.46	0.46	0.175	2.3		0.0089	0.0212
		1.14	0.33	0.33	0.16	2.28		0.0084	0.0194
		1.09	0.295	0.295	0.15	2.18		0.0062	0.0182
		1.08	1.05	1.05	0.15	2.16		0.0058	0.0182
		1.08	3.9	3.9	0.145	2.16		0.0058	0.0176
		1.07	5.25	5.25	0.125	2.14		0.0053	0.0152
		1.04	5.3	5.3	0.11	2.08		0.0040	0.0133
		1.03	4.8	4.8	0.1	2.06		0.0035	0.0121
		1.03	4.8	4.8	0.085	2.06		0.0035	0.0103
		1.01	5.35	5.35	0.05	2.02		0.0027	0.0061
		1.01	0.715	0.715	0.05	2.02		0.0027	0.0061
		1	0.25	0.25	0.025	2		0.0022	0.0030
		0.98	-0.325	0.325	0.025	1.96		0.0013	0.0030
		0.95	-0.42	0.42	0	1.9		0.0000	0.0000
Mean	3.33	4.56	—	—	1.47	9.12	0.2111	0.1601	0.1781
Std. Dev.	4.09	4.71	—	—	1.84	9.42	0.2605	0.2089	0.2234
Min.	0.01	0.95	—	—	0.00	1.90	—	—	—
Max.	15.72	23.50	—	—	8.25	47.00	—	—	—
p	—						0.3070	0.3332	0.3443
q	—						1.1475	1.7478	1.5890

Table III-2. Calculation of the Components for the Orientation Matrix ("Orient-Tptpll V1.xls")

Station (m)	Azimuth	Dip	Dip Vector Component			Strike Vector Component			Pole Vector Component			xi*xi	xi*yi	xi*zi	yi*yi	yi*zi	zi*zi
			xd	yd	zd	xs	ys	zs	xi	yi	zi						
5751.02	139	75	-0.195	-0.170	-0.966	-0.656	0.755	0.000	0.729	0.634	-0.259	0.5314	0.4620	-0.1887	0.4016	-0.1640	0.0670
5753.70	136	84	-0.075	-0.073	-0.995	-0.695	0.719	0.000	0.715	0.691	-0.105	0.5118	0.4942	-0.0748	0.4773	-0.0722	0.0109
5761.50	137	72	-0.226	-0.211	-0.951	-0.682	0.731	0.000	0.696	0.649	-0.309	0.4838	0.4512	-0.2149	0.4207	-0.2004	0.0955
5761.72	145	72	-0.253	-0.177	-0.951	-0.574	0.819	0.000	0.779	0.546	-0.309	0.6069	0.4250	-0.2407	0.2976	-0.1686	0.0955
5791.33	148	90	0.000	0.000	-1.000	-0.530	0.848	0.000	0.848	0.530	0.000	0.7192	0.4494	0.0000	0.2808	0.0000	0.0000
5791.92	151	84	-0.091	-0.051	-0.995	-0.485	0.875	0.000	0.870	0.482	-0.105	0.7566	0.4194	-0.0909	0.2325	-0.0504	0.0109
5798.94	133	77	-0.153	-0.165	-0.974	-0.731	0.682	0.000	0.665	0.713	-0.225	0.4416	0.4735	-0.1495	0.5078	-0.1603	0.0506
5800.50	144	85	-0.071	-0.051	-0.996	-0.588	0.809	0.000	0.806	0.586	-0.087	0.6495	0.4719	-0.0702	0.3429	-0.0510	0.0076
5805.57	152	76	-0.214	-0.114	-0.970	-0.469	0.883	0.000	0.857	0.456	-0.242	0.7340	0.3903	-0.2073	0.2075	-0.1102	0.0585
5813.05	155	76	-0.219	-0.102	-0.970	-0.423	0.906	0.000	0.879	0.410	-0.242	0.7733	0.3606	-0.2127	0.1682	-0.0992	0.0585
5820.95	159	81	-0.146	-0.056	-0.988	-0.358	0.934	0.000	0.922	0.354	-0.156	0.8502	0.3264	-0.1442	0.1253	-0.0554	0.0245
5828.98	144	84	-0.085	-0.061	-0.995	-0.588	0.809	0.000	0.805	0.585	-0.105	0.6474	0.4703	-0.0841	0.3417	-0.0611	0.0109
5829.00	156	79	-0.174	-0.078	-0.982	-0.407	0.914	0.000	0.897	0.399	-0.191	0.8042	0.3580	-0.1711	0.1594	-0.0762	0.0364
5841.23	149	85	-0.075	-0.045	-0.996	-0.515	0.857	0.000	0.854	0.513	-0.087	0.7292	0.4381	-0.0744	0.2632	-0.0447	0.0076
5845.47	143	81	-0.125	-0.094	-0.988	-0.602	0.799	0.000	0.789	0.594	-0.156	0.6222	0.4689	-0.1234	0.3533	-0.0930	0.0245
5846.00	151	83	-0.107	-0.059	-0.993	-0.485	0.875	0.000	0.868	0.481	-0.122	0.7536	0.4177	-0.1058	0.2315	-0.0586	0.0149
5846.52	135	77	-0.159	-0.159	-0.974	-0.707	0.707	0.000	0.689	0.689	-0.225	0.4747	0.4747	-0.1550	0.4747	-0.1550	0.0506
5848.49	132	88	-0.023	-0.026	-0.999	-0.743	0.669	0.000	0.669	0.743	-0.035	0.4472	0.4967	-0.0233	0.5516	-0.0259	0.0012
5848.89	140	75	-0.198	-0.166	-0.966	-0.643	0.766	0.000	0.740	0.621	-0.259	0.5475	0.4594	-0.1915	0.3855	-0.1607	0.0670
5851.55	144	74	-0.223	-0.162	-0.961	-0.588	0.809	0.000	0.778	0.565	-0.276	0.6048	0.4394	-0.2144	0.3192	-0.1557	0.0760
5858.65	133	77	-0.153	-0.165	-0.974	-0.731	0.682	0.000	0.665	0.713	-0.225	0.4416	0.4735	-0.1495	0.5078	-0.1603	0.0506
5864.74	326	85	0.072	0.049	-0.996	0.559	-0.829	0.000	-0.826	-0.557	-0.087	0.6821	0.4601	0.0720	0.3103	0.0486	0.0076
1445.49	330	80	0.150	0.087	-0.985	0.500	-0.866	0.000	-0.853	-0.492	-0.174	0.7274	0.4200	0.1481	0.2425	0.0855	0.0302
1506.35	132	80	-0.116	-0.129	-0.985	-0.743	0.669	0.000	0.659	0.732	-0.174	0.4342	0.4823	-0.1144	0.5356	-0.1271	0.0302
1512.14	132	87	-0.035	-0.039	-0.999	-0.743	0.669	0.000	0.668	0.742	-0.052	0.4465	0.4959	-0.0350	0.5508	-0.0388	0.0027
1652.91	152	76	-0.214	-0.114	-0.970	-0.469	0.883	0.000	0.857	0.456	-0.242	0.7340	0.3903	-0.2073	0.2075	-0.1102	0.0585
1803.20	161	72	-0.292	-0.101	-0.951	-0.326	0.946	0.000	0.899	0.310	-0.309	0.8086	0.2784	-0.2779	0.0959	-0.0957	0.0955
1818.45	129	71	-0.205	-0.253	-0.946	-0.777	0.629	0.000	0.595	0.735	-0.326	0.3541	0.4372	-0.1937	0.5399	-0.2392	0.1060
1823.58	133	89	-0.012	-0.013	-1.000	-0.731	0.682	0.000	0.682	0.731	-0.017	0.4650	0.4986	-0.0119	0.5347	-0.0128	0.0003
1825.00	137	84	-0.076	-0.071	-0.995	-0.682	0.731	0.000	0.727	0.678	-0.105	0.5290	0.4933	-0.0760	0.4600	-0.0709	0.0109
1851.69	338	87	0.049	0.020	-0.999	0.375	-0.927	0.000	-0.926	-0.374	-0.052	0.8573	0.3464	0.0485	0.1399	0.0196	0.0027
1867.62	136	84	-0.075	-0.073	-0.995	-0.695	0.719	0.000	0.715	0.691	-0.105	0.5118	0.4942	-0.0748	0.4773	-0.0722	0.0109
1870.81	325	82	0.114	0.080	-0.990	0.574	-0.819	0.000	-0.811	-0.568	-0.139	0.6580	0.4607	0.1129	0.3226	0.0790	0.0194
1883.72	145	78	-0.170	-0.119	-0.978	-0.574	0.819	0.000	0.801	0.561	-0.208	0.6420	0.4495	-0.1666	0.3148	-0.1166	0.0432
1900.24	158	88	-0.032	-0.013	-0.999	-0.375	0.927	0.000	0.927	0.374	-0.035	0.8586	0.3469	-0.0323	0.1402	-0.0131	0.0012
1917.12	148	77	-0.191	-0.119	-0.974	-0.530	0.848	0.000	0.826	0.516	-0.225	0.6828	0.4267	-0.1859	0.2666	-0.1162	0.0506
1928.54	155	83	-0.110	-0.052	-0.993	-0.423	0.906	0.000	0.900	0.419	-0.122	0.8092	0.3773	-0.1096	0.1760	-0.0511	0.0149
1941.70	147	80	-0.146	-0.095	-0.985	-0.545	0.839	0.000	0.826	0.536	-0.174	0.6822	0.4430	-0.1434	0.2877	-0.0931	0.0302
1941.98	159	82	-0.130	-0.050	-0.990	-0.358	0.934	0.000	0.924	0.355	-0.139	0.8547	0.3281	-0.1287	0.1259	-0.0494	0.0194
1975.74	129	84	-0.066	-0.081	-0.995	-0.777	0.629	0.000	0.626	0.773	-0.105	0.3917	0.4837	-0.0654	0.5974	-0.0808	0.0109

Table III-2. Calculation of the Components for the Orientation Matrix ("Orient-Tptpll V1.xls") (Continued)

Station (m)	Azimuth	Dip	Dip Vector Component			Strike Vector Component			Pole Vector Component			xi*xi	xi*yi	xi*zi	yi*yi	yi*zi	zi*zi
			xd	yd	zd	xs	ys	zs	xi	yi	zi						
1978.20	147	88	-0.029	-0.019	-0.999	-0.545	0.839	0.000	0.838	0.544	-0.035	0.7025	0.4562	-0.0293	0.2963	-0.0190	0.0012
2038.81	140	84	-0.080	-0.067	-0.995	-0.643	0.766	0.000	0.762	0.639	-0.105	0.5804	0.4870	-0.0796	0.4087	-0.0668	0.0109
2062.13	140	82	-0.107	-0.089	-0.990	-0.643	0.766	0.000	0.759	0.637	-0.139	0.5755	0.4829	-0.1056	0.4052	-0.0886	0.0194
2062.35	142	80	-0.137	-0.107	-0.985	-0.616	0.788	0.000	0.776	0.606	-0.174	0.6022	0.4705	-0.1348	0.3676	-0.1053	0.0302
2100.12	323	82	0.111	0.084	-0.990	0.602	-0.799	0.000	-0.791	-0.596	-0.139	0.6255	0.4713	0.1101	0.3552	0.0829	0.0194
2119.70	330	77	0.195	0.112	-0.974	0.500	-0.866	0.000	-0.844	-0.487	-0.225	0.7120	0.4111	0.1898	0.2373	0.1096	0.0506
2141.65	148	88	-0.030	-0.018	-0.999	-0.530	0.848	0.000	0.848	0.530	-0.035	0.7183	0.4488	-0.0296	0.2805	-0.0185	0.0012
2142.92	152	87	-0.046	-0.025	-0.999	-0.469	0.883	0.000	0.882	0.469	-0.052	0.7775	0.4134	-0.0461	0.2198	-0.0245	0.0027
2145.08	138	82	-0.103	-0.093	-0.990	-0.669	0.743	0.000	0.736	0.663	-0.139	0.5416	0.4876	-0.1024	0.4391	-0.0922	0.0194
2153.01	157	87	-0.048	-0.020	-0.999	-0.391	0.921	0.000	0.919	0.390	-0.052	0.8450	0.3587	-0.0481	0.1523	-0.0204	0.0027
2156.20	136	81	-0.113	-0.109	-0.988	-0.695	0.719	0.000	0.710	0.686	-0.156	0.5048	0.4875	-0.1111	0.4707	-0.1073	0.0245
2158.80	148	78	-0.176	-0.110	-0.978	-0.530	0.848	0.000	0.830	0.518	-0.208	0.6881	0.4300	-0.1725	0.2687	-0.1078	0.0432
2159.05	152	75	-0.229	-0.122	-0.966	-0.469	0.883	0.000	0.853	0.453	-0.259	0.7274	0.3868	-0.2207	0.2056	-0.1174	0.0670
2160.29	149	74	-0.236	-0.142	-0.961	-0.515	0.857	0.000	0.824	0.495	-0.276	0.6789	0.4079	-0.2271	0.2451	-0.1365	0.0760
2161.48	153	85	-0.078	-0.040	-0.996	-0.454	0.891	0.000	0.888	0.452	-0.087	0.7879	0.4014	-0.0774	0.2045	-0.0394	0.0076
2162.18	146	88	-0.029	-0.020	-0.999	-0.559	0.829	0.000	0.829	0.559	-0.035	0.6865	0.4630	-0.0289	0.3123	-0.0195	0.0012
2163.60	140	88	-0.027	-0.022	-0.999	-0.643	0.766	0.000	0.766	0.642	-0.035	0.5861	0.4918	-0.0267	0.4127	-0.0224	0.0012
2177.30	140	83	-0.093	-0.078	-0.993	-0.643	0.766	0.000	0.760	0.638	-0.122	0.5781	0.4851	-0.0927	0.4070	-0.0778	0.0149
2179.00	140	79	-0.146	-0.123	-0.982	-0.643	0.766	0.000	0.752	0.631	-0.191	0.5655	0.4745	-0.1435	0.3981	-0.1204	0.0364
2180.00	137	79	-0.140	-0.130	-0.982	-0.682	0.731	0.000	0.718	0.669	-0.191	0.5154	0.4806	-0.1370	0.4482	-0.1277	0.0364
2197.90	138	74	-0.205	-0.184	-0.961	-0.669	0.743	0.000	0.714	0.643	-0.276	0.5103	0.4595	-0.1969	0.4137	-0.1773	0.0760
2198.85	130	73	-0.188	-0.224	-0.956	-0.766	0.643	0.000	0.615	0.733	-0.292	0.3779	0.4503	-0.1797	0.5367	-0.2142	0.0855
2198.95	145	78	-0.170	-0.119	-0.978	-0.574	0.819	0.000	0.801	0.561	-0.208	0.6420	0.4495	-0.1666	0.3148	-0.1166	0.0432
2199.56	160	80	-0.163	-0.059	-0.985	-0.342	0.940	0.000	0.925	0.337	-0.174	0.8564	0.3117	-0.1607	0.1135	-0.0585	0.0302
2200.85	135	78	-0.147	-0.147	-0.978	-0.707	0.707	0.000	0.692	0.692	-0.208	0.4784	0.4784	-0.1438	0.4784	-0.1438	0.0432
2211.19	150	84	-0.091	-0.052	-0.995	-0.500	0.866	0.000	0.861	0.497	-0.105	0.7418	0.4283	-0.0900	0.2473	-0.0520	0.0109
2212.03	140	87	-0.040	-0.034	-0.999	-0.643	0.766	0.000	0.765	0.642	-0.052	0.5852	0.4911	-0.0400	0.4120	-0.0336	0.0027
2223.24	145	74	-0.226	-0.158	-0.961	-0.574	0.819	0.000	0.787	0.551	-0.276	0.6200	0.4341	-0.2170	0.3040	-0.1520	0.0760
2223.31	135	80	-0.123	-0.123	-0.985	-0.707	0.707	0.000	0.696	0.696	-0.174	0.4849	0.4849	-0.1209	0.4849	-0.1209	0.0302
2223.83	150	72	-0.268	-0.155	-0.951	-0.500	0.866	0.000	0.824	0.476	-0.309	0.6784	0.3917	-0.2545	0.2261	-0.1469	0.0955
2225.20	154	82	-0.125	-0.061	-0.990	-0.438	0.899	0.000	0.890	0.434	-0.139	0.7922	0.3864	-0.1239	0.1884	-0.0604	0.0194
2225.30	157	80	-0.160	-0.068	-0.985	-0.391	0.921	0.000	0.907	0.385	-0.174	0.8218	0.3488	-0.1574	0.1481	-0.0668	0.0302
2227.06	142	84	-0.082	-0.064	-0.995	-0.616	0.788	0.000	0.784	0.612	-0.105	0.6142	0.4798	-0.0819	0.3749	-0.0640	0.0109
2231.44	155	74	-0.250	-0.116	-0.961	-0.423	0.906	0.000	0.871	0.406	-0.276	0.7590	0.3539	-0.2401	0.1650	-0.1120	0.0760
2231.94	135	86	-0.049	-0.049	-0.998	-0.707	0.707	0.000	0.705	0.705	-0.070	0.4976	0.4976	-0.0492	0.4976	-0.0492	0.0049
2233.17	326	85	0.072	0.049	-0.996	0.559	-0.829	0.000	-0.826	-0.557	-0.087	0.6821	0.4601	0.0720	0.3103	0.0486	0.0076
2234.51	335	86	0.063	0.029	-0.998	0.423	-0.906	0.000	-0.904	-0.422	-0.070	0.8174	0.3812	0.0631	0.1777	0.0294	0.0049
2234.57	331	87	0.046	0.025	-0.999	0.485	-0.875	0.000	-0.873	-0.484	-0.052	0.7629	0.4229	0.0457	0.2344	0.0253	0.0027
2235.60	158	88	-0.032	-0.013	-0.999	-0.375	0.927	0.000	0.927	0.374	-0.035	0.8586	0.3469	-0.0323	0.1402	-0.0131	0.0012
2236.07	159	83	-0.114	-0.044	-0.993	-0.358	0.934	0.000	0.927	0.356	-0.122	0.8586	0.3296	-0.1129	0.1265	-0.0433	0.0149

Table III-2. Calculation of the Components for the Orientation Matrix ("Orient-Tptpll V1.xls") (Continued)

Station (m)	Azimuth	Dip	Dip Vector Component			Strike Vector Component			Pole Vector Component			xi*xi	xi*yi	xi*zi	yi*yi	yi*zi	zi*zi
			xd	yd	zd	xs	ys	zs	xi	yi	zi						
2237.60	143	72	-0.247	-0.186	-0.951	-0.602	0.799	0.000	0.760	0.572	-0.309	0.5769	0.4347	-0.2347	0.3276	-0.1769	0.0955
2238.32	130	74	-0.177	-0.211	-0.961	-0.766	0.643	0.000	0.618	0.736	-0.276	0.3818	0.4550	-0.1703	0.5422	-0.2030	0.0760
2238.93	160	80	-0.163	-0.059	-0.985	-0.342	0.940	0.000	0.925	0.337	-0.174	0.8564	0.3117	-0.1607	0.1135	-0.0585	0.0302
2239.66	135	86	-0.049	-0.049	-0.998	-0.707	0.707	0.000	0.705	0.705	-0.070	0.4976	0.4976	-0.0492	0.4976	-0.0492	0.0049
2239.84	137	88	-0.026	-0.024	-0.999	-0.682	0.731	0.000	0.731	0.682	-0.035	0.5342	0.4982	-0.0255	0.4646	-0.0238	0.0012
2241.74	146	82	-0.115	-0.078	-0.990	-0.559	0.829	0.000	0.821	0.554	-0.139	0.6740	0.4546	-0.1143	0.3066	-0.0771	0.0194
2242.39	148	88	-0.030	-0.018	-0.999	-0.530	0.848	0.000	0.848	0.530	-0.035	0.7183	0.4488	-0.0296	0.2805	-0.0185	0.0012
2244.81	134	87	-0.036	-0.038	-0.999	-0.719	0.695	0.000	0.694	0.718	-0.052	0.4812	0.4983	-0.0363	0.5160	-0.0376	0.0027
2245.19	318	72	0.230	0.207	-0.951	0.669	-0.743	0.000	-0.707	-0.636	-0.309	0.4995	0.4498	0.2184	0.4050	0.1967	0.0955
2247.40	138	84	-0.078	-0.070	-0.995	-0.669	0.743	0.000	0.739	0.665	-0.105	0.5462	0.4918	-0.0773	0.4428	-0.0696	0.0109
2247.64	158	81	-0.145	-0.059	-0.988	-0.375	0.927	0.000	0.916	0.370	-0.156	0.8386	0.3388	-0.1433	0.1369	-0.0579	0.0245
2253.99	322	76	0.191	0.149	-0.970	0.616	-0.788	0.000	-0.765	-0.597	-0.242	0.5846	0.4568	0.1850	0.3569	0.1445	0.0585
2255.23	137	89	-0.013	-0.012	-1.000	-0.682	0.731	0.000	0.731	0.682	-0.017	0.5347	0.4986	-0.0128	0.4650	-0.0119	0.0003
2259.62	148	72	-0.262	-0.164	-0.951	-0.530	0.848	0.000	0.807	0.504	-0.309	0.6505	0.4065	-0.2492	0.2540	-0.1557	0.0955
2265.50	151	75	-0.226	-0.125	-0.966	-0.485	0.875	0.000	0.845	0.468	-0.259	0.7137	0.3956	-0.2187	0.2193	-0.1212	0.0670
2265.70	157	78	-0.191	-0.081	-0.978	-0.391	0.921	0.000	0.900	0.382	-0.208	0.8107	0.3441	-0.1872	0.1461	-0.0795	0.0432
2267.78	133	78	-0.142	-0.152	-0.978	-0.731	0.682	0.000	0.667	0.715	-0.208	0.4450	0.4772	-0.1387	0.5118	-0.1487	0.0432
2278.54	134	85	-0.061	-0.063	-0.996	-0.719	0.695	0.000	0.692	0.717	-0.087	0.4789	0.4959	-0.0603	0.5135	-0.0625	0.0076
2279.31	138	84	-0.078	-0.070	-0.995	-0.669	0.743	0.000	0.739	0.665	-0.105	0.5462	0.4918	-0.0773	0.4428	-0.0696	0.0109
2295.21	140	78	-0.159	-0.134	-0.978	-0.643	0.766	0.000	0.749	0.629	-0.208	0.5615	0.4711	-0.1558	0.3953	-0.1307	0.0432
2299.20	150	83	-0.106	-0.061	-0.993	-0.500	0.866	0.000	0.860	0.496	-0.122	0.7389	0.4266	-0.1048	0.2463	-0.0605	0.0149
2316.88	138	81	-0.116	-0.105	-0.988	-0.669	0.743	0.000	0.734	0.661	-0.156	0.5387	0.4851	-0.1148	0.4368	-0.1034	0.0245
2320.70	147	82	-0.117	-0.076	-0.990	-0.545	0.839	0.000	0.831	0.539	-0.139	0.6897	0.4479	-0.1156	0.2909	-0.0751	0.0194
2322.65	138	80	-0.129	-0.116	-0.985	-0.669	0.743	0.000	0.732	0.659	-0.174	0.5356	0.4823	-0.1271	0.4342	-0.1144	0.0302
											SUM	66.132	45.475	-10.228	34.551	-7.382	3.317

Table III-3. Calculation of the Concentration Factor k for Joint Orientation ("New-Tptpll V1.mcd")

K Factor Calculation for Watson Bipolar Distribution:
(xx, xy,xz,yy,yz,zz calculated in EXCEL workseet
Orient-Tptpll.xls)

Tptpll, Joint Set 1

$xx := 66.1322$

$xy := 45.4751$

$xz := -10.2284$

$yy := 34.5513$

$yz := -7.3818$

$zz := 3.3167$

$$T := \begin{bmatrix} xx & xy & xz \\ xy & yy & yz \\ xz & yz & zz \end{bmatrix}$$

$c := \mathrm{eigenvals}(T)$ $\quad c = \begin{bmatrix} 2.217 \\ 1.66 \\ 100.124 \end{bmatrix}$

$n := c_0 + c_1 + c_2$

$cn := \frac{c}{n}$ $\quad cn = \begin{bmatrix} 0.021 \\ 0.016 \\ 0.963 \end{bmatrix}$ $\quad \tau 3 := \max(cn)$

$K1 := 3.75 \cdot (3\,\tau 3 - 1)$ $\quad K2 := 3.34 \cdot (3\,\tau 3 - 1)$

$K3 := 0.7 + \frac{1}{(1 - \tau 3)}$ $\quad K4 := \frac{1}{(1 - \tau 3)}$

$$K := \begin{vmatrix} K1 \text{ if } 0.333 < \tau 3 \le 0.36 \\ K2 \text{ if } 0.38 < \tau 3 \le 0.65 \\ K3 \text{ if } 0.65 < \tau 3 \le 0.99 \\ K4 \text{ if } \tau 3 \ge 0.99 \end{vmatrix}$$

$K = 27.529$

ATTACHMENT IV

DETERMINATION OF THE NUMBER OF DRKBA MONTE CARLO SIMULATIONS

DETERMINATION OF THE NUMBER OF DRKBA MONTE CARLO SIMULATIONS

In the DRKBA analysis, random joint patterns are generated with joint centers positioned in three-dimensional space, considering each joint set in sequence for each Monte Carlo simulation. The forming of key blocks is therefore different in each Monte Carlo simulation. To determine the adequate number of Monte Carlo simulations for the analyses, test runs were first conducted. The criteria used to determine the adequate number of Monte Carlo simulations include (1) consistent prediction of the block size distribution and (2) consistent prediction of the maximum block size. The predicted number of blocks per 10 simulations was also evaluated, but was not condsidered to be a primary factor in determining the required number of Monte Carlo simulations.

Test runs were first conducted for the Tptpln unit with 200, 400, and 600 Monte Carlo simulations. Figure IV-1 shows the block size distribution curves in the form of cumulative frequency of occurrence. The prediction of block size distribution for 400 simulations is similar to the results from 600 simulations as indicated in Figure IV-1. However, for the case of 200 simulations, a larger block size was predicted for the same level of cumulative frequency of occurrence compared to the cases with 400 and 600 simulations. The predicted numbers of blocks per 10 simulations for the three cases are presented in Figures IV-2. The results are in good agreement for all three cases. The maximum block sizes predicted for the three cases are identical as shown in Figure IV-3. It was determined that 400 simulations are adequate for the DRKBA analyses in Tptpln unit based on the results of these three test runs.

For the Tptpmn unit, tests runs with 100, 200, and 400 Monte Carlo simulations were conducted. Figure IV-4 shows the block size distribution curves for the three cases. The prediction of block size distribution for 200 simulations is similar to the results from 400 simulations. The predicted numbers of blocks per 10 simulations for the three cases are presented in Figures IV-5. The results show and increasing number of blocks for higher number of simulations. The maximum block sizes predicted for the three cases are shown in Figure IV-6. The maximum blocks predicted for 200 and 400 simulations are identical, while the maximum block size for the 100 simulation is significantly smaller. It was determined that 200 simulations are adequate for the DRKBA analyses for Tptpmn unit.

The predicted number of key block per simulation for Tptpul and Tptpll are in general similar to that of the Tptpln unit. Therefore, 400 simulations are also used for the analyses conducted in Tptpul and Tptpll units.

C28

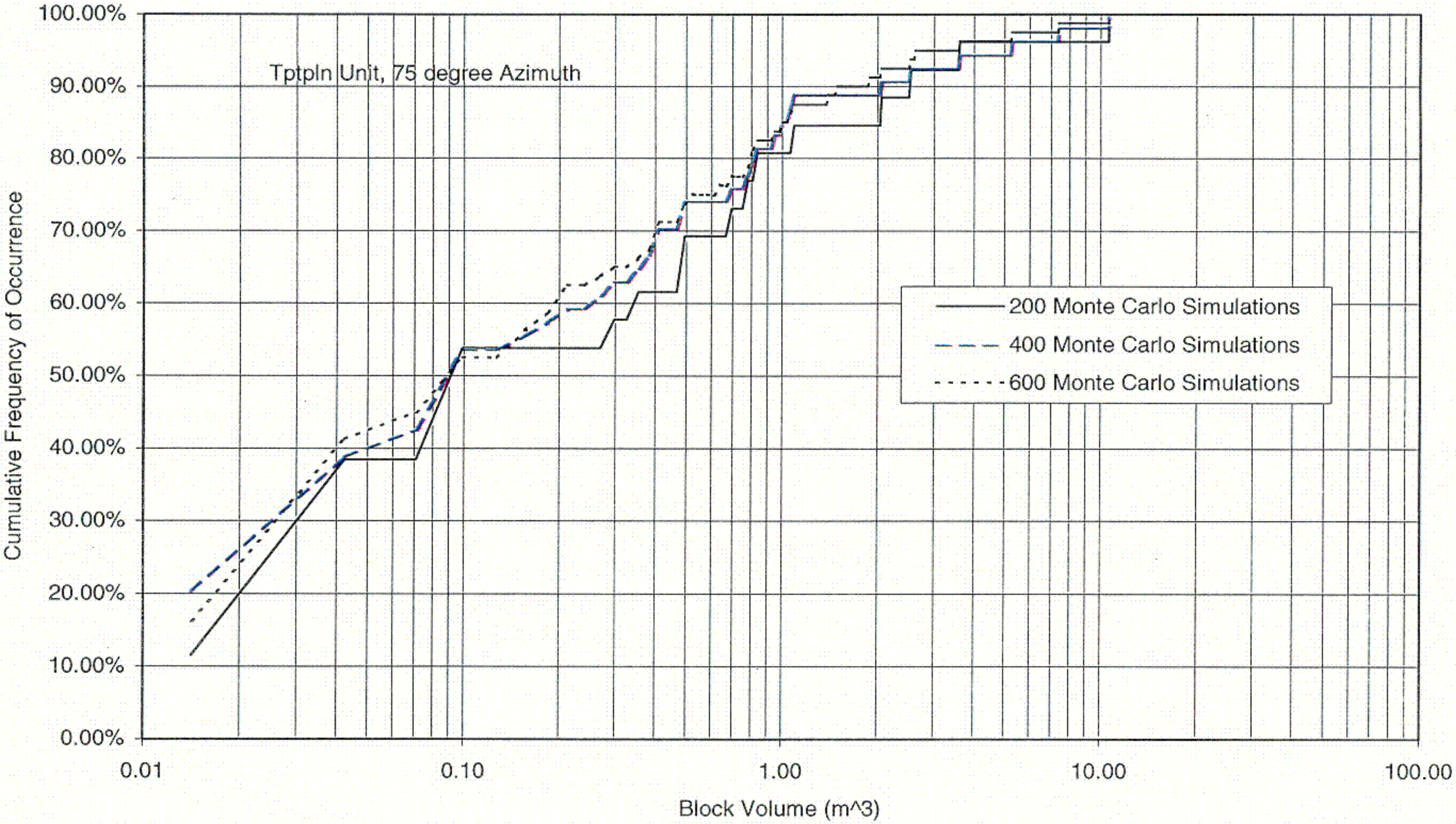


Figure IV-1. Block Size Distributions for the Test Runs, Tptpln Unit

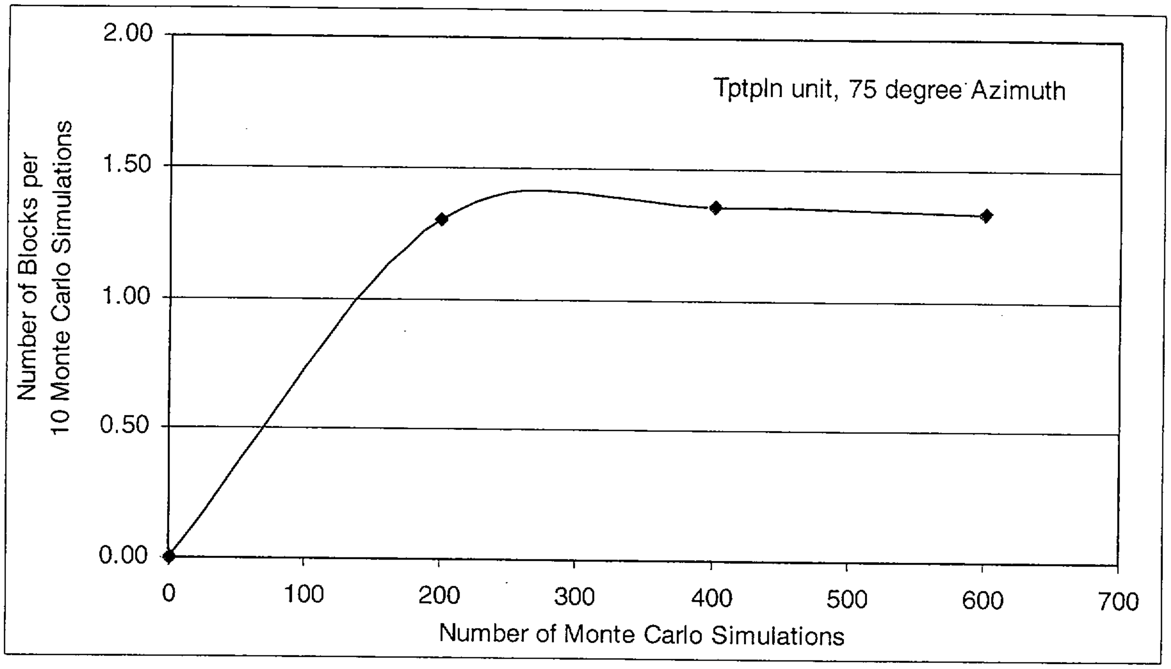


Figure IV-2. Predicted Number of Key Blocks Per 10 Monte Carlo Simulations, Tptpln Unit

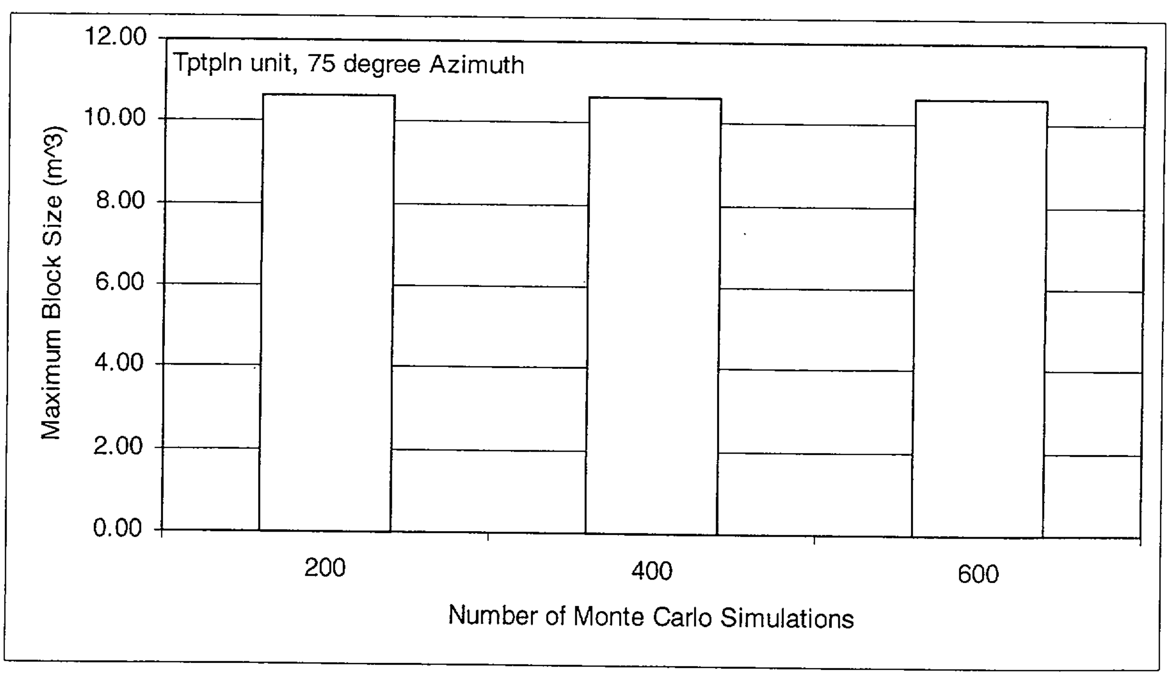


Figure IV-3. Predicted Number of Maximum Block Size, Tptpln Unit

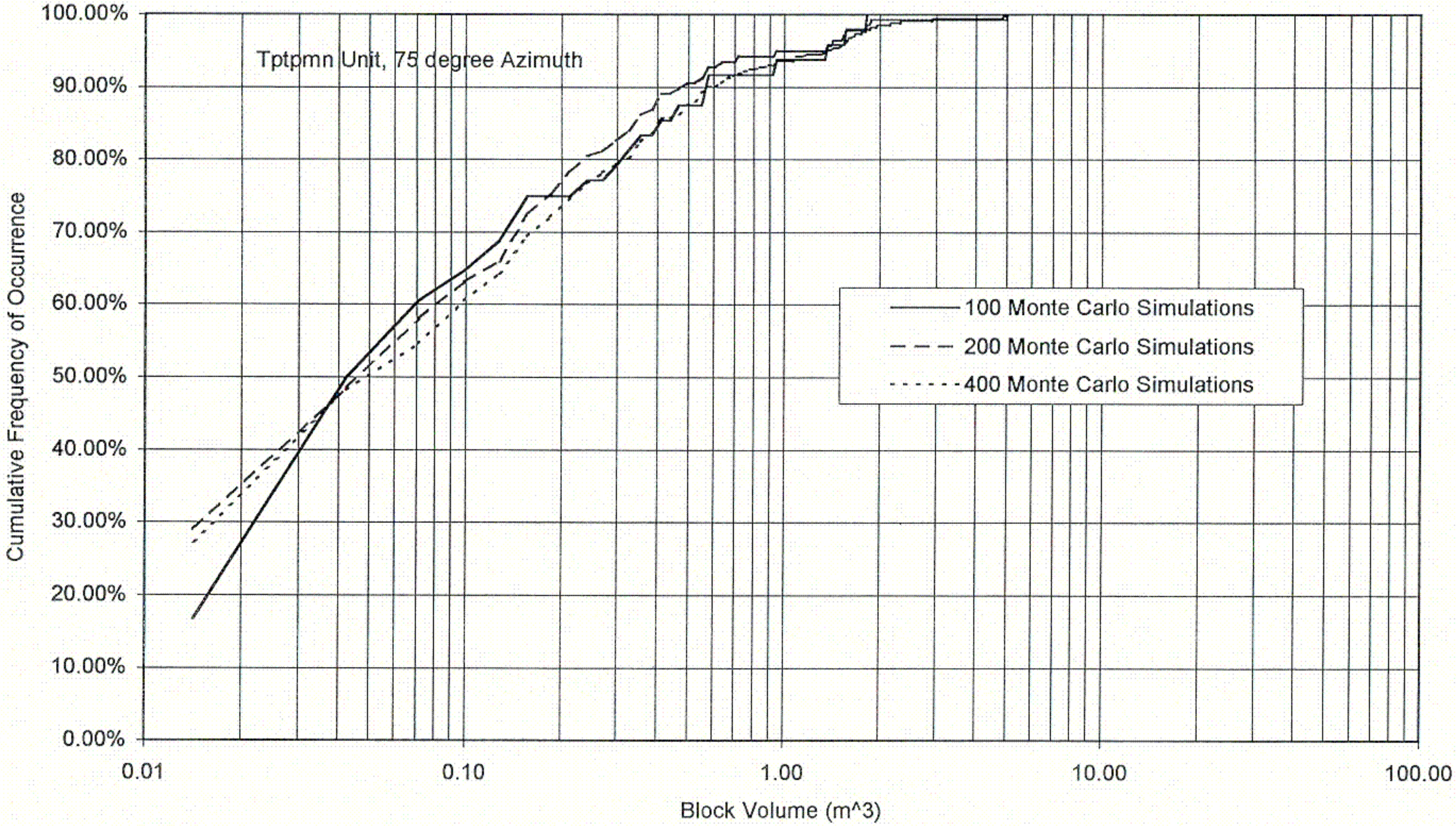


Figure IV-4. Block Size Distributions for the Test Runs, Tptpmn Unit

C29

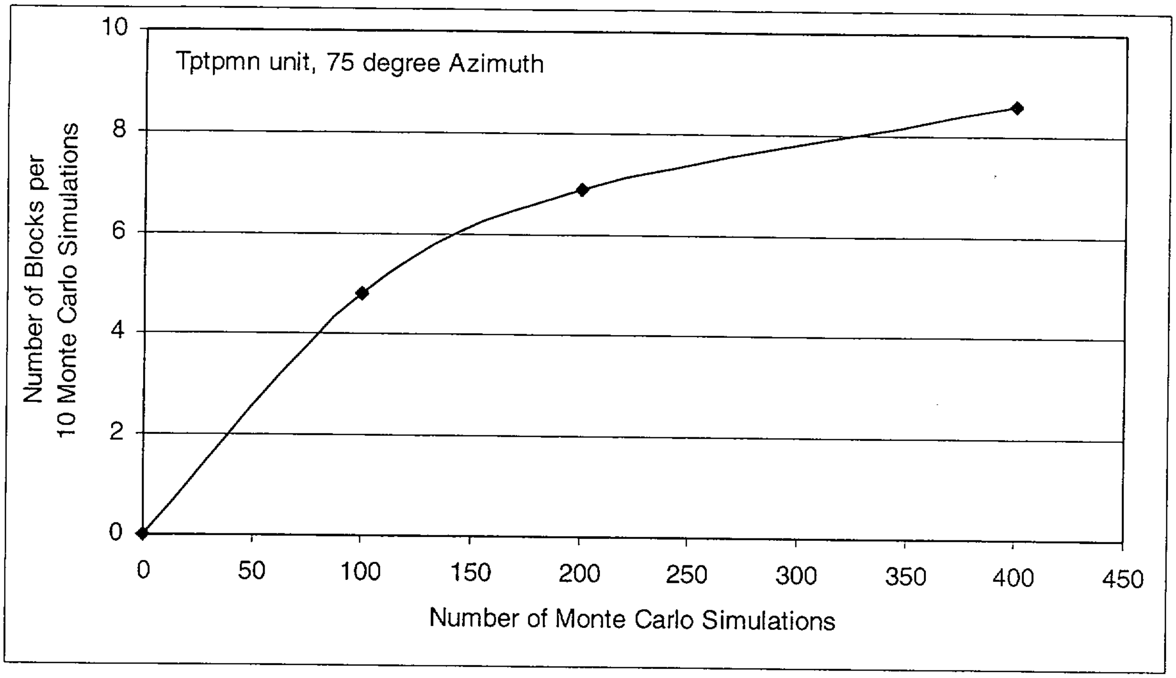


Figure IV-5. Predicted Number of Key Blocks Per 10 Monte Carlo Simulations, Tptpmn Unit

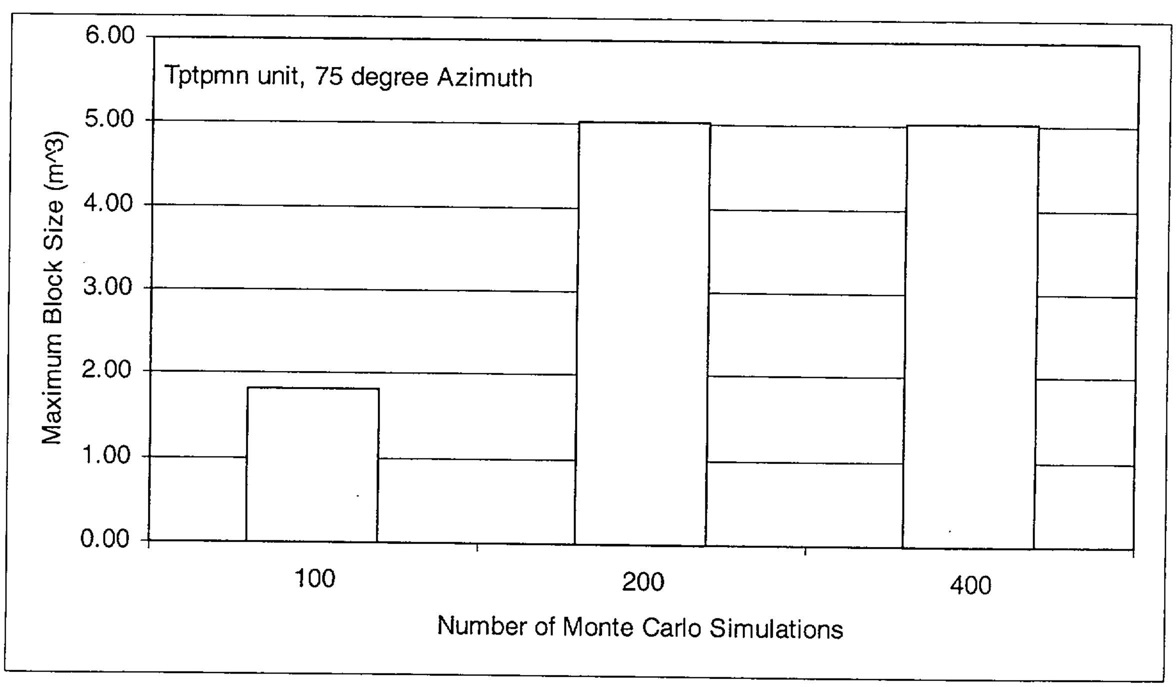


Figure IV-6. Predicted Number of Maximum Block Size, Tptpmn Unit

ATTACHMENT V

QUASI-STATIC APPROACH FOR SIMULATION OF SEISMIC EFFECT

QUASI-STATIC APPROACH FOR SIMULATION OF SEISMIC EFFECT

V.1 INTRODUCTION

The probabilistic key block analysis code DRKBA considers only gravity load in its assessment of mechanical stability of key blocks. Due to this limitation, seismic loads can not be directly applied to the opening in the DRKBA analysis. An alternative method that applies a reduction of joint strength parameters was used to account for the seismic effect.

The following equation was used to calculate the reduced friction angle in the alternative method:

$$\Delta\phi = a\tan(PGA/1g) \qquad \text{(Eq. V-1)}$$

where *PGA* is the peak ground acceleration of the shear wave with unit in g.

This method is illustrated by the simple examples presented in Figure V-1. The stable joint plane example is presented in Figure V-1a. In this example, the alternative method (i.e., with a reduced friction angle) predicts a stable condition, which is the same as the approach with the seismic load included. The unstable joint plane example is presented in Figure V-1b. The alternative reduced friction angle method is capable of predicting the unstable joint condition as shown.

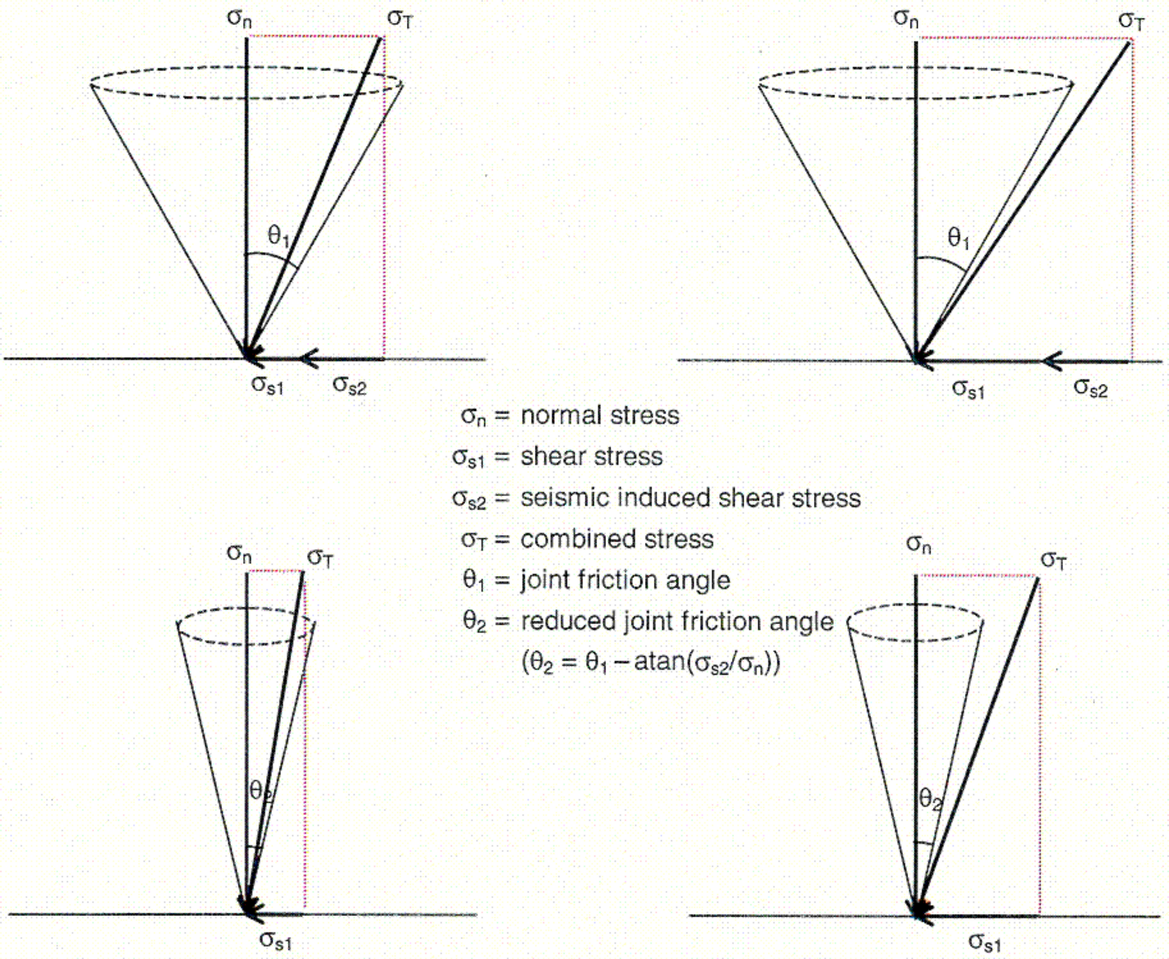
V.2 VERIFICATION WITH DYNAMIC AND QUASI-STATIC MODELING USING UDEC

The alternative method was also verified using numerical simulation of a dynamic analysis against a quasi-static analysis. The numerical simulation was completed using the distinct element code UDEC (CRWMS M&O 1994). Two cases subjected to seismic loads, one which results in unstable blocks and another which results in stable blocks, were simulated and are presented in this attachment.

V.2.1 CASE 1 WITH UNSTABLE BLOCKS

The mesh used for the Case 1 analysis is presented in Figure V-2. The fracture geometry resembles a typical cross section in the highly fractured Tptpmn unit. Two joint sets, one near horizontal and one near vertical, are simulated. The joint spacings for the near horizontal joint set and the near vertical joint set are 0.7 m and 0.5 m respectively. The dip angle for these two sets are 83° and 13° respectively. Due to the dynamic and static nature of the analysis, the boundary conditions differ for these two analyses. The boundary conditions imposed for these two analyses are listed in Table V-1. The material properties used in the analysis and their sources are listed in Table V-2.

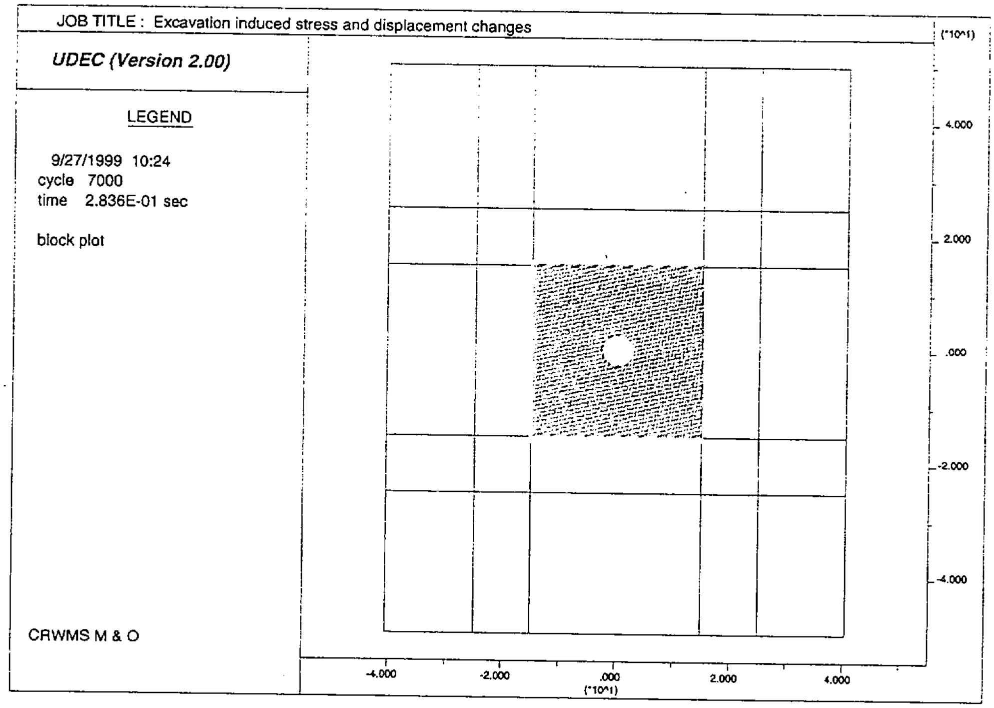
The initial consolidation and excavation were first simulated as a typical static analysis. In the dynamic analysis, the cohesion value was reduced from 0.1 MPa to 0.01 MPa. The initial friction angle value of 41° was not changed in the dynamic analysis. The reduction of cohesion



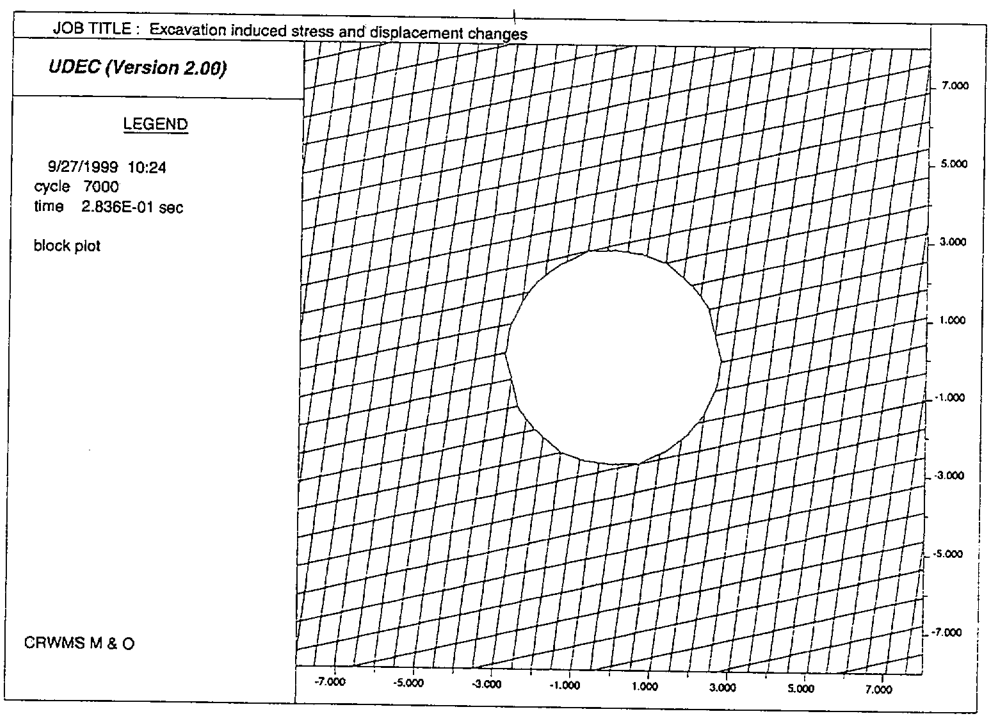
a. Stable Condition

b. Unstable Condition

Figure V-1. Illustrative Examples for the Alternative Method to Account for Seismic Effect



(a) UDEC Mesh



(b) Blow-out of the mesh around opening

Figure V-2. Distinct Element Mesh for UDEC Analysis, Case 1

Table V-1. Boundary Conditions of Cases 1 and 2 for UDEC Analyses

Boundary	Dynamic Analysis	Quasi-Static Analysis
Left	X free, Y fixed	X fixed
Right	X free, Y fixed	X fixed
Top	X and Y Viscous with overburden surcharge	Pressure boundary with overburden surcharge
Bottom	X and Y Viscous with shear wave velocity imposed	Y fixed

Note: The X-axis is in the horizontal direction and the Y-axis is in the vertical direction.

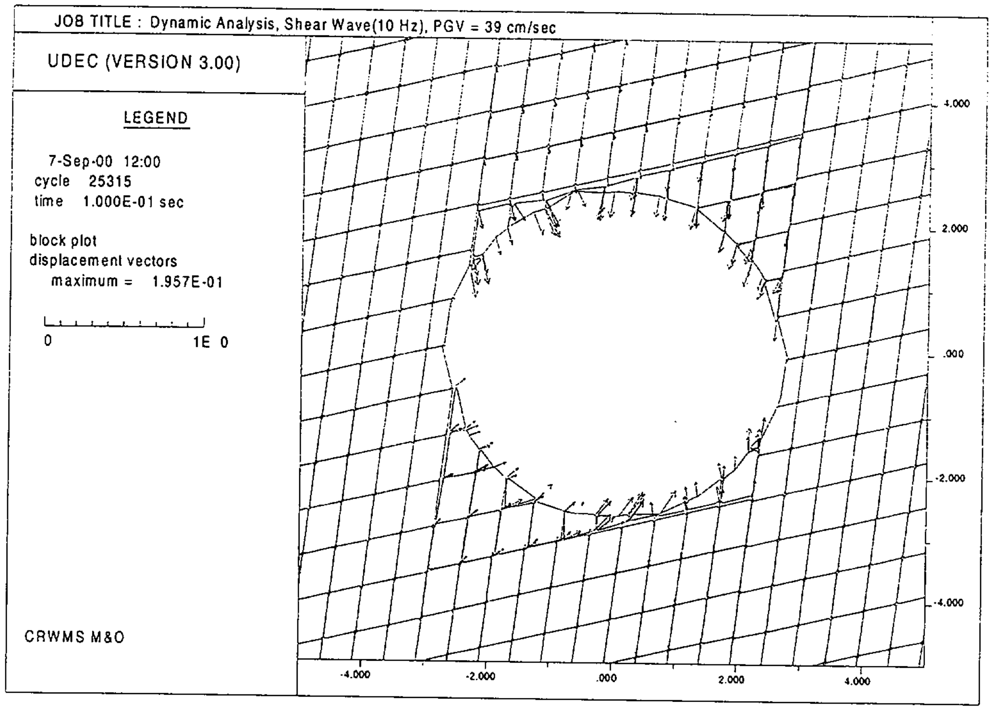
Table V-2. Material Properties Used in UDEC Analyses

Material Property and Unit	Value	Source[1]
Rock Mass Elastic Modulus (GPa)	33.03	Section 4.1
Rock Mass Poisson's Ratio	0.21	Section 4.1
Rock Mass Density (g/cc)	2.41	Section 4.1
Initial Joint Cohesion (MPa)	0.1	Assumption 5.7
Initial Joint Friction Angle (degree)	41	Section 4.1

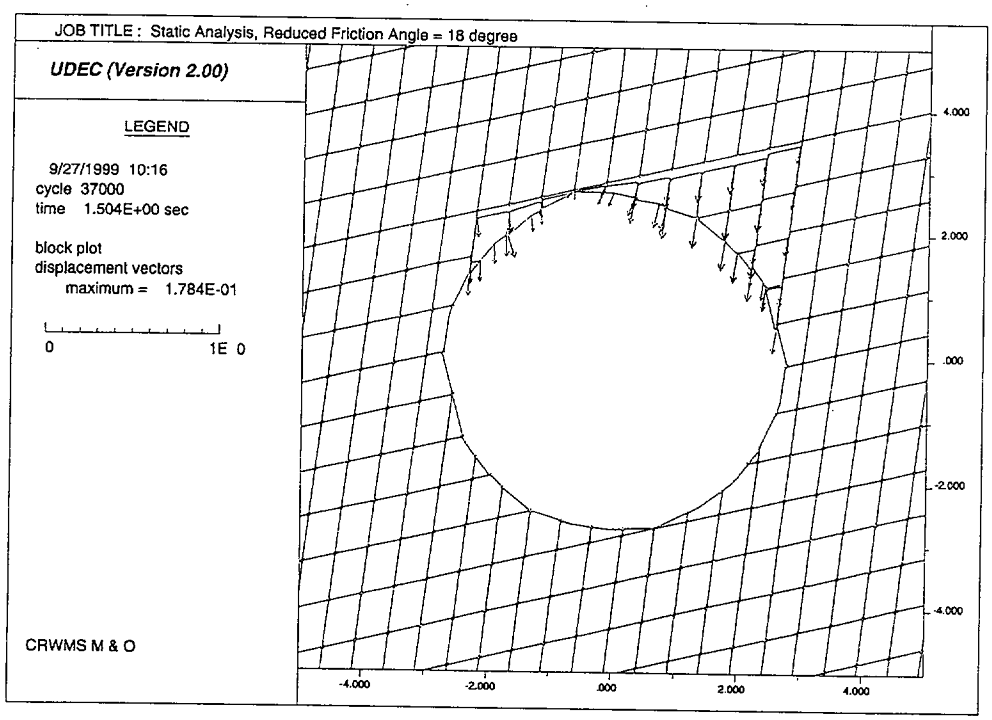
[1]DTNs for the source data are provided in Table 2.

is included to ensure a conservative result, and is based on the time-dependent analysis described in Attachment I. The dynamic boundaries were then imposed for the dynamic analysis with a 10 Hz sinusoidal shear wave at the bottom boundary. The frequency of 10 Hz was selected to represent a conservative principle earthquake frequency (see Section 6.3.4). The peak ground velocity of 39 cm/sec (10,000-year event, Assumption 5.6) was simulated as the peak velocity in the sinusoidal wave. The block movements around the opening after one full cycle of shear wave (duration of 0.1 second) are shown in Figure V-3a. Blocks over the upper-right hand corner show large movement downward, also the lower-left hand corner show floor heaving due to blocks' upward movement.

As for the quasi-static analysis using the alternative method, joint cohesion and friction angle were reduced from 0.1 MPa and 41° to 0.01 MPa and 18° to account for seismic effect. The reduction of friction angle was calculated based on Equation V-1 with PGA = 0.43 g for a 10,000-year event earthquake. The reduction of cohesion is included to ensure a conservative result, and is based on the time-dependent analysis described in Attachment I. The cohesion



(a) Dynamic Analysis Result for Case 1



(b) Quasi-Static Analysis Result for Case 1

Figure V-3. Prediction of Block Movements from UDEC Analysis, Case 1

versus time relationship is shown in Figure 8. A cohesion value at year 1,000 was selected based on Figure 8 corresponding to a 1,000-year event earthquake. Similarly, cohesion values for a 5,000-year event and a 10,000-year event were selected based on Figure 8. The block movements predicted from the quasi-static analysis are presented in Figure V-3b. The comparison between the results from the dynamic and quasi-static analyses shows a consistent prediction of block failure at the opening roof. The floor heaving observed from the dynamic analysis result was not predicted in the quasi-static analysis. Since the objective of this analysis is related to the rock fall, this discrepancy is therefore ignored.

V.2.2 CASE 2 WITH STABLE BLOCKS

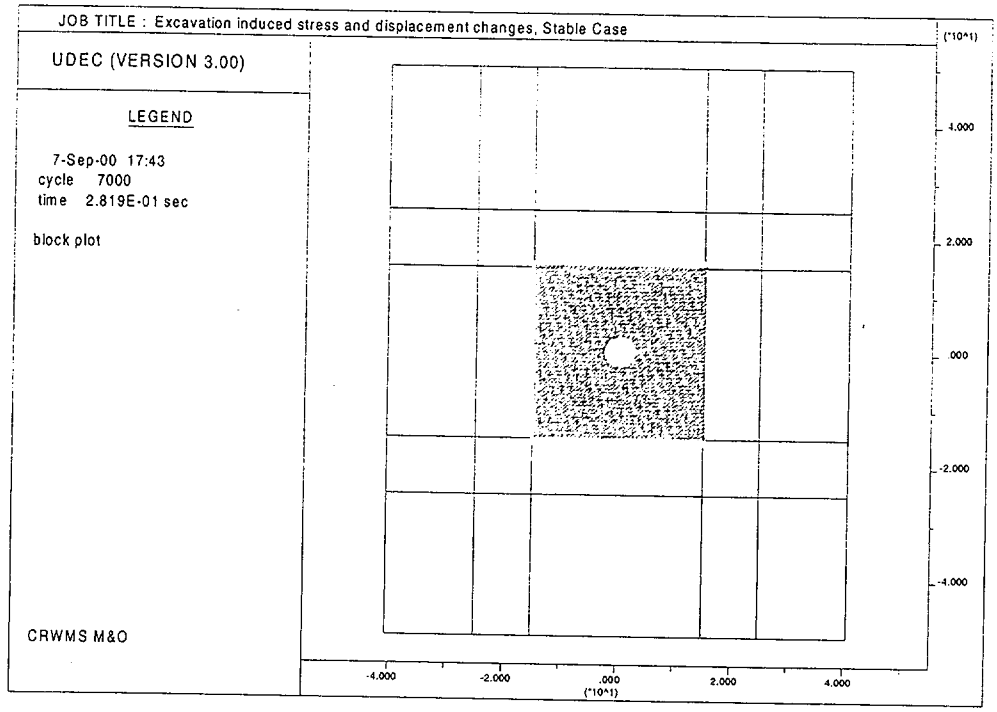
The mesh used for the Case 2 analysis is presented in Figure V-4. The fracture geometry resembles that of Case 1 but with a less dipping vertical set. Two joint sets, with dip angles of 40° and 3° and spacings of 0.7 m and 0.5 m, were simulated. The boundary conditions and material properties used in the analysis are the same as those for Case 1 as listed in Tables V-1 and V-2.

Same as in Case 1, the modeling process for this case included the initial consolidation and excavation. In the Case 2 dynamic analysis, the cohesion value was reduced from 0.1 MPa to 0.01 MPa. The initial friction angle value of 41° was not changed in the dynamic analysis. The reduction of cohesion is included to ensure a conservative result, and is based on the time-dependent analysis described in Attachment I. The dynamic boundaries were then imposed for the dynamic analysis with a 10 Hz sinusoidal shear wave at the bottom boundary. The peak ground velocity of 39 cm/sec (10,000-year event, Assumption 5.6) was simulated as the peak velocity in the sinusoidal wave. Figure V-5a shows the stable ground condition after the dynamic excitation with relative minor movement at the lower left corner of the opening.

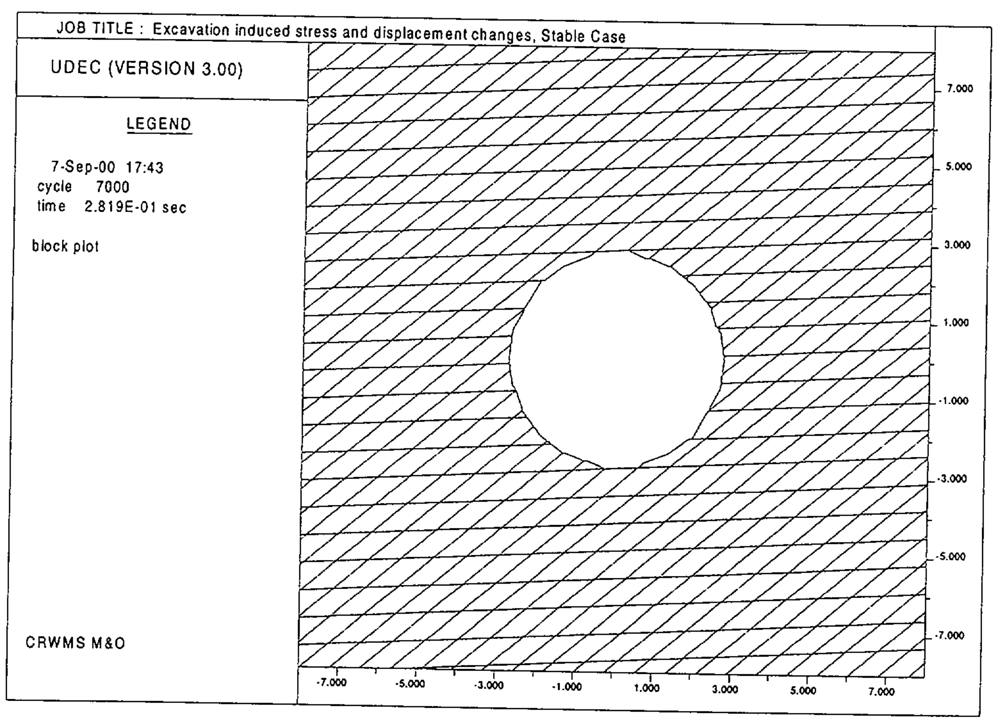
As for the quasi-static analysis, joint cohesion and friction angle were also reduced from 0.1 MPa and 41° to 0.01 MPa and 18° to account for seismic effect. Consistent with the dynamic analysis result, the stable ground condition was also predicted for the quasi-static analysis. The displacements of the blocks for this analysis are shown in Figure V-5b.

V.3 CONSIDERATION OF OTHER COMPONENTS OF SEISMIC MOTION

Equation V-1 and the seismic analyses for Cases 1 and 2 consider only the in-plane shear-wave (S-wave) component (horizontal direction) of the seismic motion. The out-of-plane S-wave and the primary-wave (P-wave, vertical direction) components were not included. Additional UDEC analyses were conducted to include both the S-wave and the P-wave components to investigate the effect on block stability with the additional components. Cases 1 and 2 were modified to accommodate the additional P-wave component. In addition to the horizontal sinusoidal motion, a sinusoidal excitation with vertical P-wave peak ground velocity of 22 cm/sec, corresponding to a vertical wave with PGA of 0.44 g (CRWMS M&O 1999e), was also included in the model. Both the P-wave and S-wave components were simulated with a frequency of 10 Hz. The material properties for these additional analyses are the same as Cases 1 and 2. The boundary conditions for these analyses, as listed in Table V-3, were modified to accommodate the P-wave component.

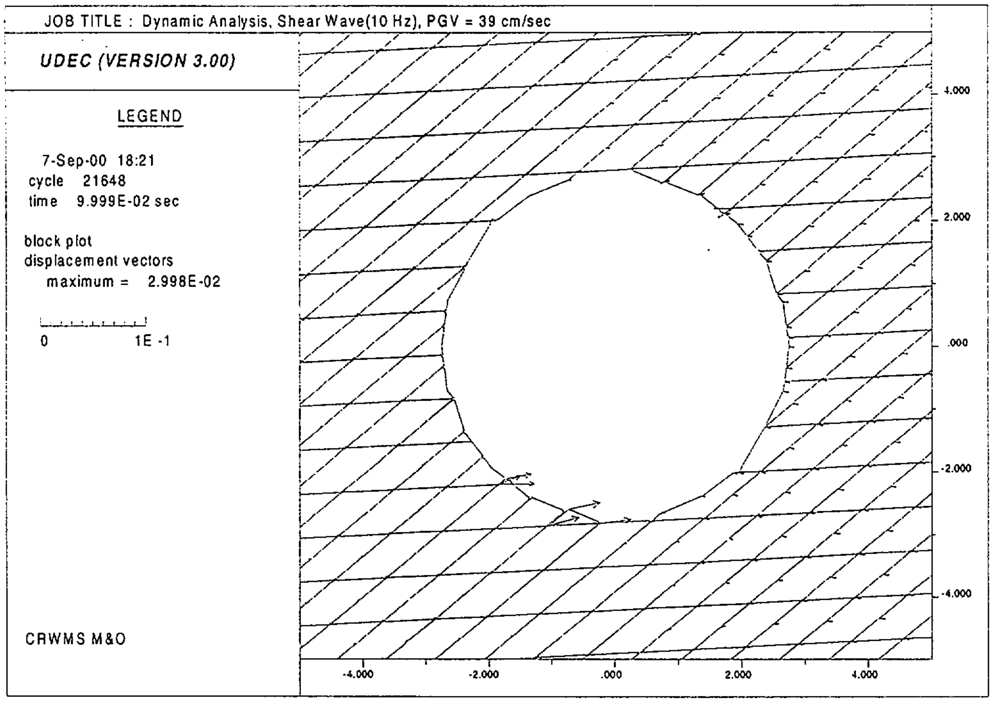


(a) UDEC Mesh for Case 2

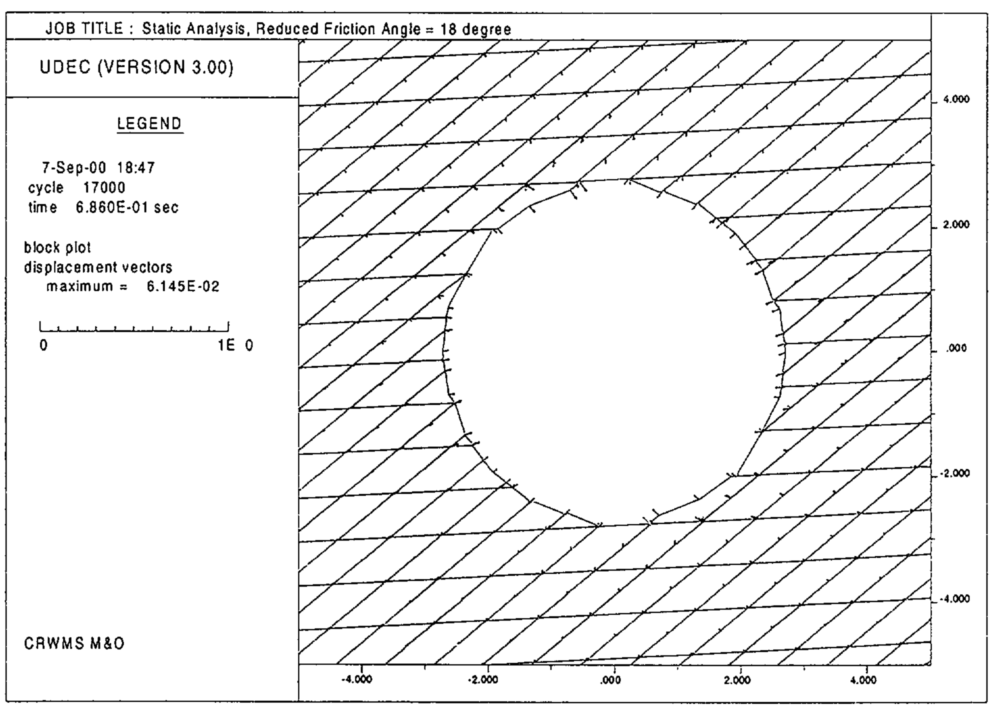


(b) Blow-out of the mesh around opening

Figure V-4. Distinct Element Mesh for UDEC Analysis, Case 2



(a) Dynamic Analysis Result for Case 2



(b) Quasi-Static Analysis Result for Case 2

Figure V-5. Prediction of Block Movements from UDEC Analysis, Case 2

Table V-3. Boundary Conditions of Cases 3 and 4 for UDEC Analyses

Boundary	Dynamic Analysis
Left	X free
Right	X free
Top	X and Y Viscous with overburden surcharge
Bottom	X and Y Viscous with P- and S-wave velocities imposed

Note: The X-axis is in the horizontal direction and the Y-axis is in the vertical direction.

The result for block sliding for the modified Case 1, which is now referred to as Case 3, is presented in Figure V-6. The result is almost identical to the result for the S-wave-only case presented in Figure V-3a, with slightly larger displacement for the sliding blocks. The result for the modified Case 2, which is now called Case 4, is presented in Figure V-7. The result is almost identical to the result for the S-wave-only case presented in Figure V-5a with a stable ground condition around the opening. The results presented in Figures V-6 and V-7 provide the rationale for using only the S-wave component in the quasi-static approach.

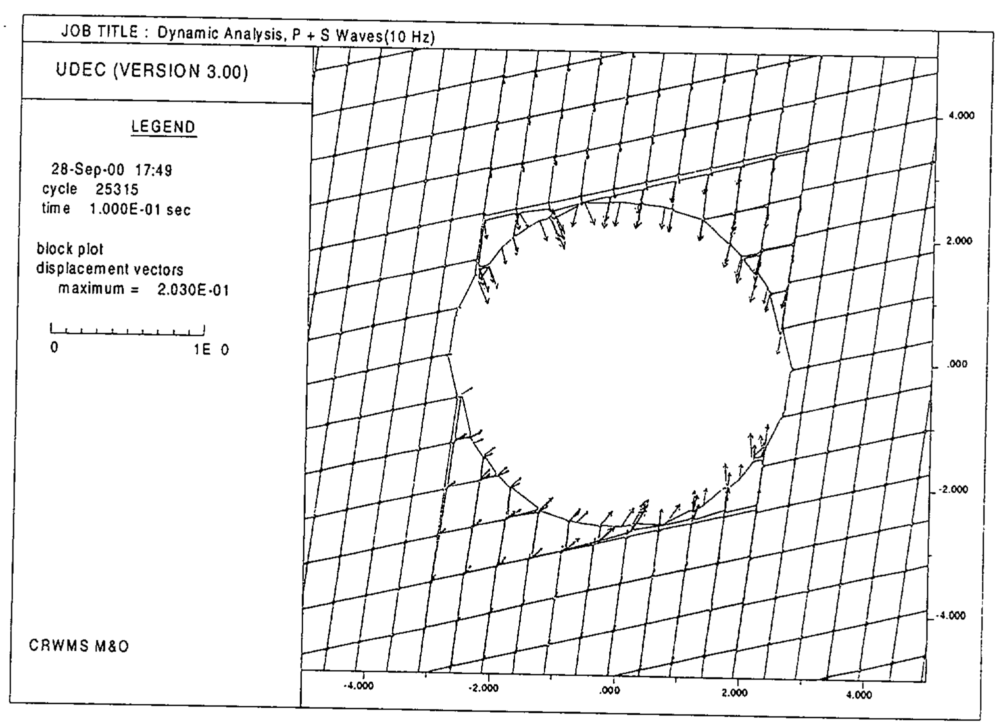


Figure V-6. Prediction of Block Movements from UDEC Analysis, Case 3

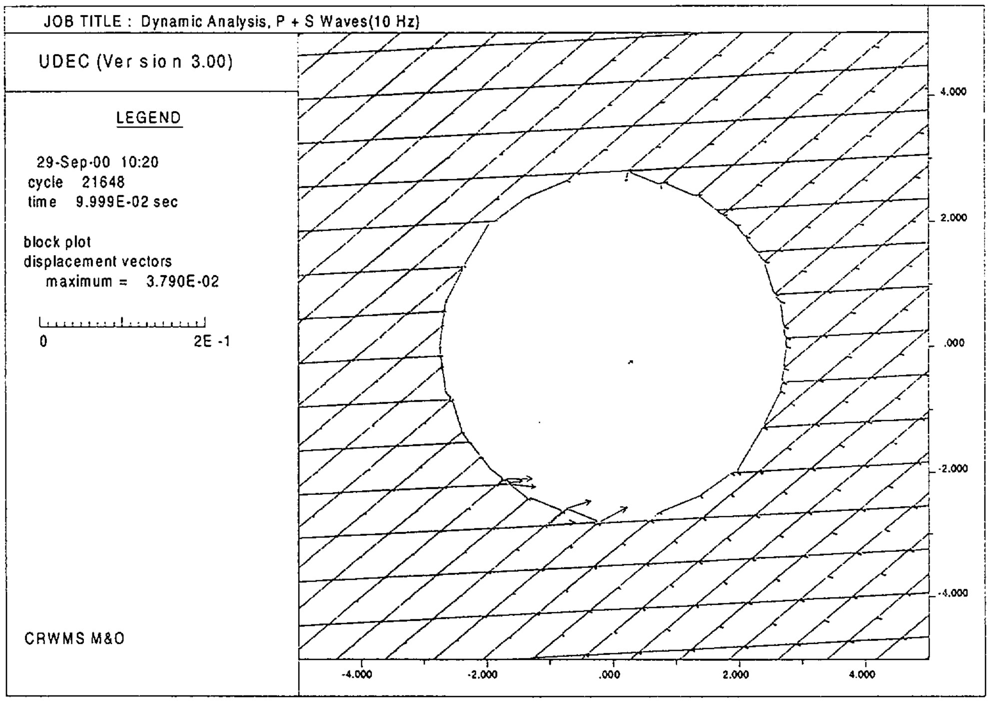


Figure V-7. Prediction of Block Movements from UDEC Analysis, Case 4

ATTACHMENT VI

FIELD OBSERVATION OF KEY BLOCKS IN THE CROSS DRIFT

FIELD OBSERVATION OF KEY BLOCKS IN THE CROSS DRIFT

This attachment documents the observation of key blocks in the ECRB Cross Drift, including the Tptpul unit (stations 0+00 to 10+15), the Tptpmn unit (stations 10+15 to 14+44), the Tptpll unit (stations 14+44 to 23+26), and the Tptpln unit (stations 23+26 to 25+85) (Mongano et al. 1999, pp. 105-106). Additional descriptions of key blocks in the Cross Drift are provided in Sections 6.2 and 6.5. Portions of the full periphery geologic maps (FPGMs) containing key blocks are presented in Figures VI-1 through VI-14. An explanation of symbols on the FPGMs is provided in Figure VI-1. The potential key blocks are identified on these maps as exposed fracture faces bounded by joints. The number of blocks per kilometer observed in the Cross Drift (Table VI-1) was determined by identifying the number of key blocks in each lithologic unit as indicated in Figures VI-2 through VI-14 over the total length of drift in the unit.

Table VI-1. Number of Key Blocks Observed in the Cross Drift

Lithologic Unit	Metric Stationing[1] (m)	Length of Drift[2] (km)	Number of Blocks[3]	Blocks per Kilometer
Tptpul	0+00 to 10+15	1.02	3	3
Tptpmn	10+15 to 14+44	0.43	17	40
Tptpll	14+44 to 23+26	0.88	0	0
Tptpln	23+26 to 25+85	0.26	2	8

[1]Source: Mongano et al. (1999, pp. 105-106).
[2]Based on metric stationing as defined in Section 6.2 (e.g., for the Tptpmn unit, length = 1444 m - 1015 m / 1000 = 0.43 km).
[3]The observation of key blocks is documented in Figures VI-2 through VI-14.

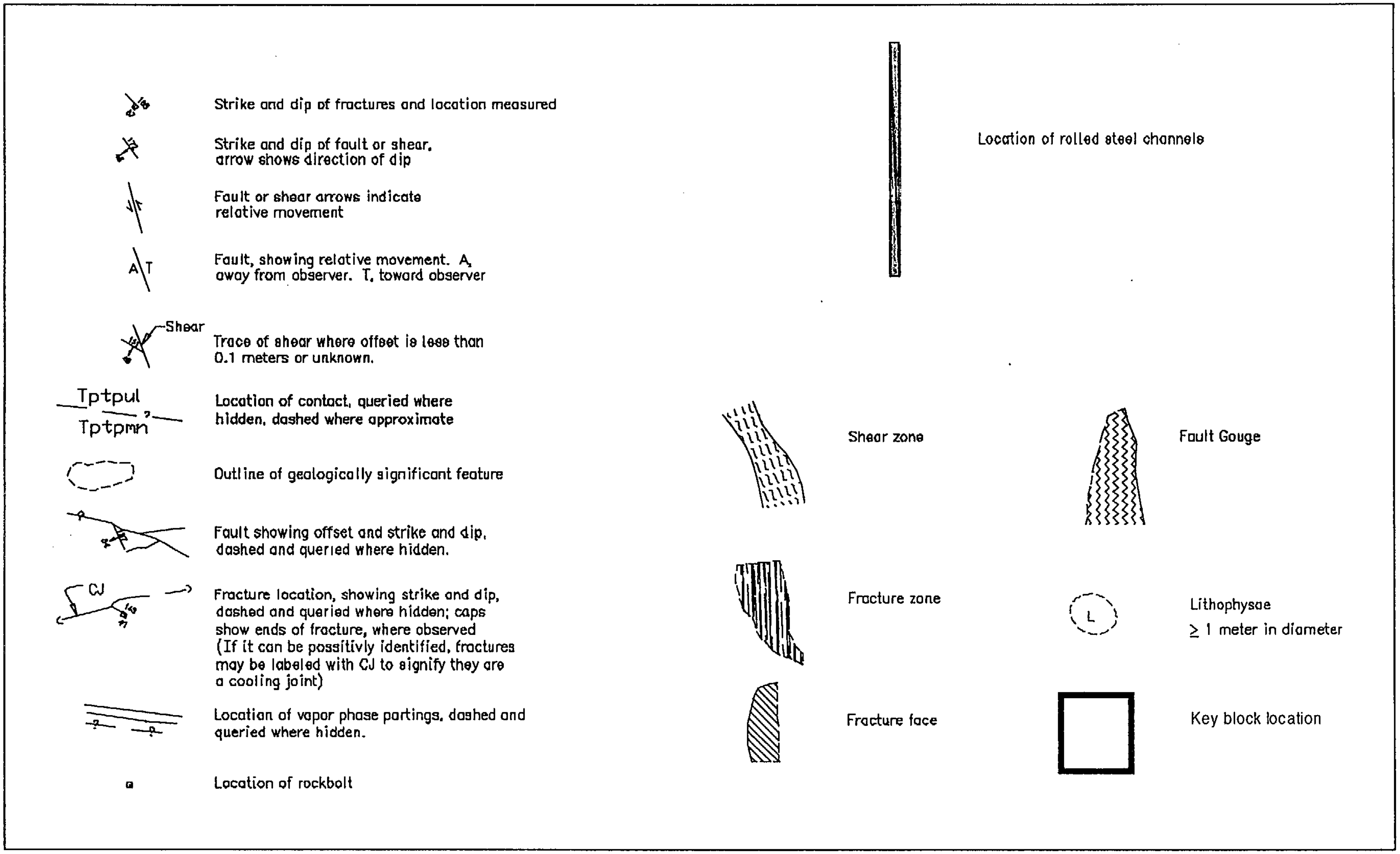


Figure VI-1. Explanation of Symbols on Full Periphery Geologic Maps

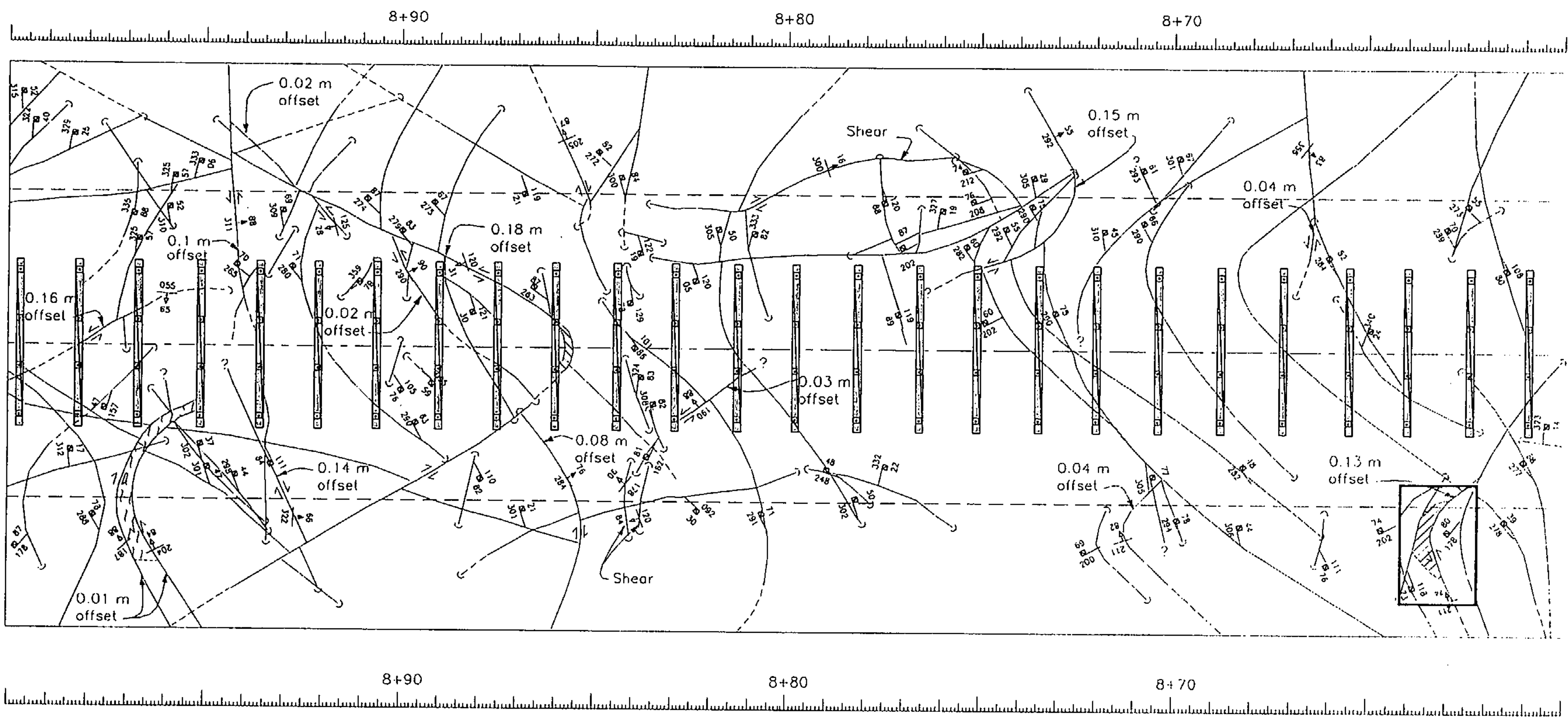


Figure VI-2. Key Block Location, Tptpul Unit, Cross Drift Stations 8+60 to 9+00

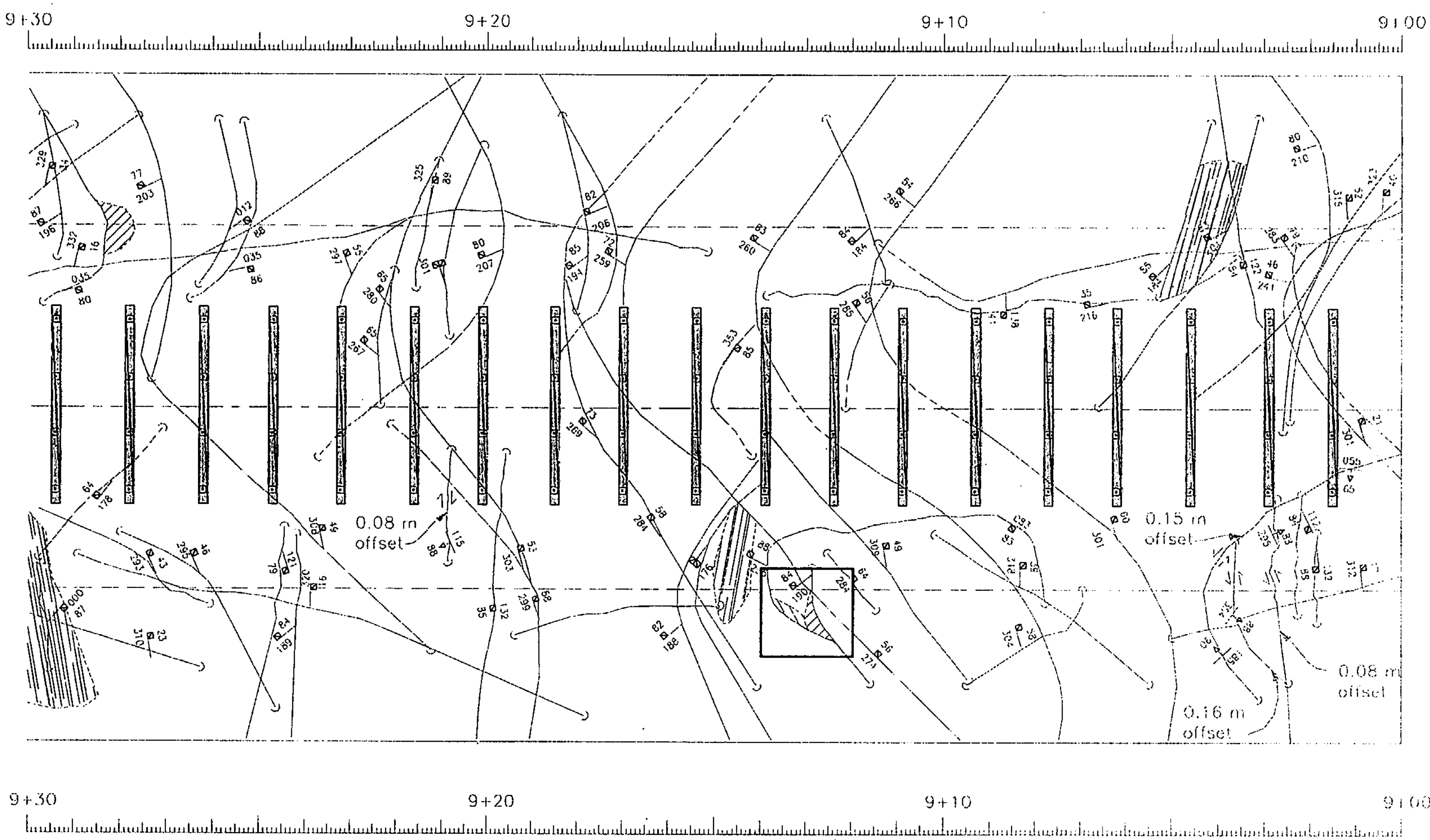


Figure VI-3. Key Block Location, Tptpul Unit, Cross Drift Stations 9+00 to 9+30

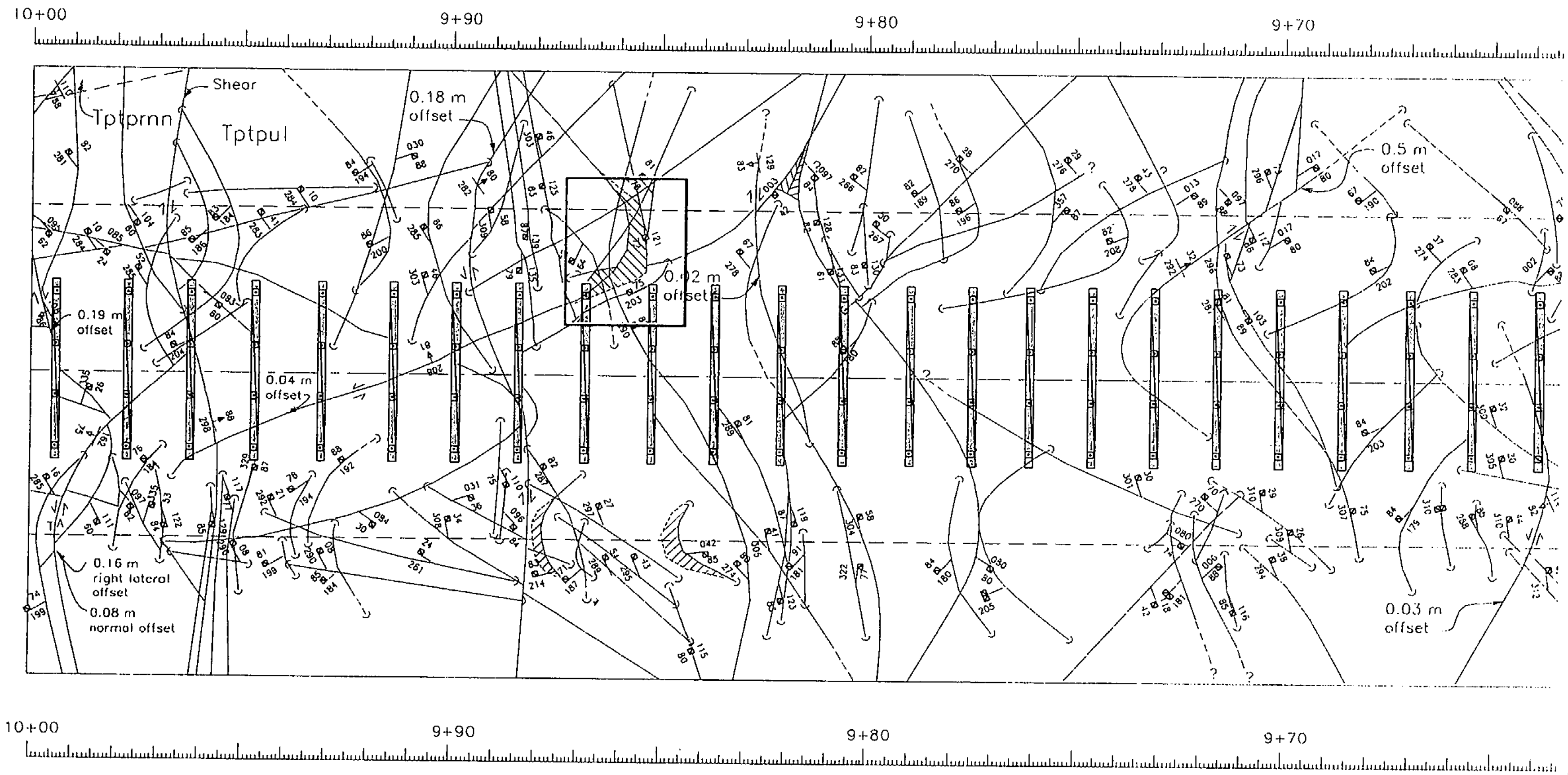


Figure VI-4. Key Block Location, Tptpul Unit, Cross Drift Stations 9+64 to 10+00

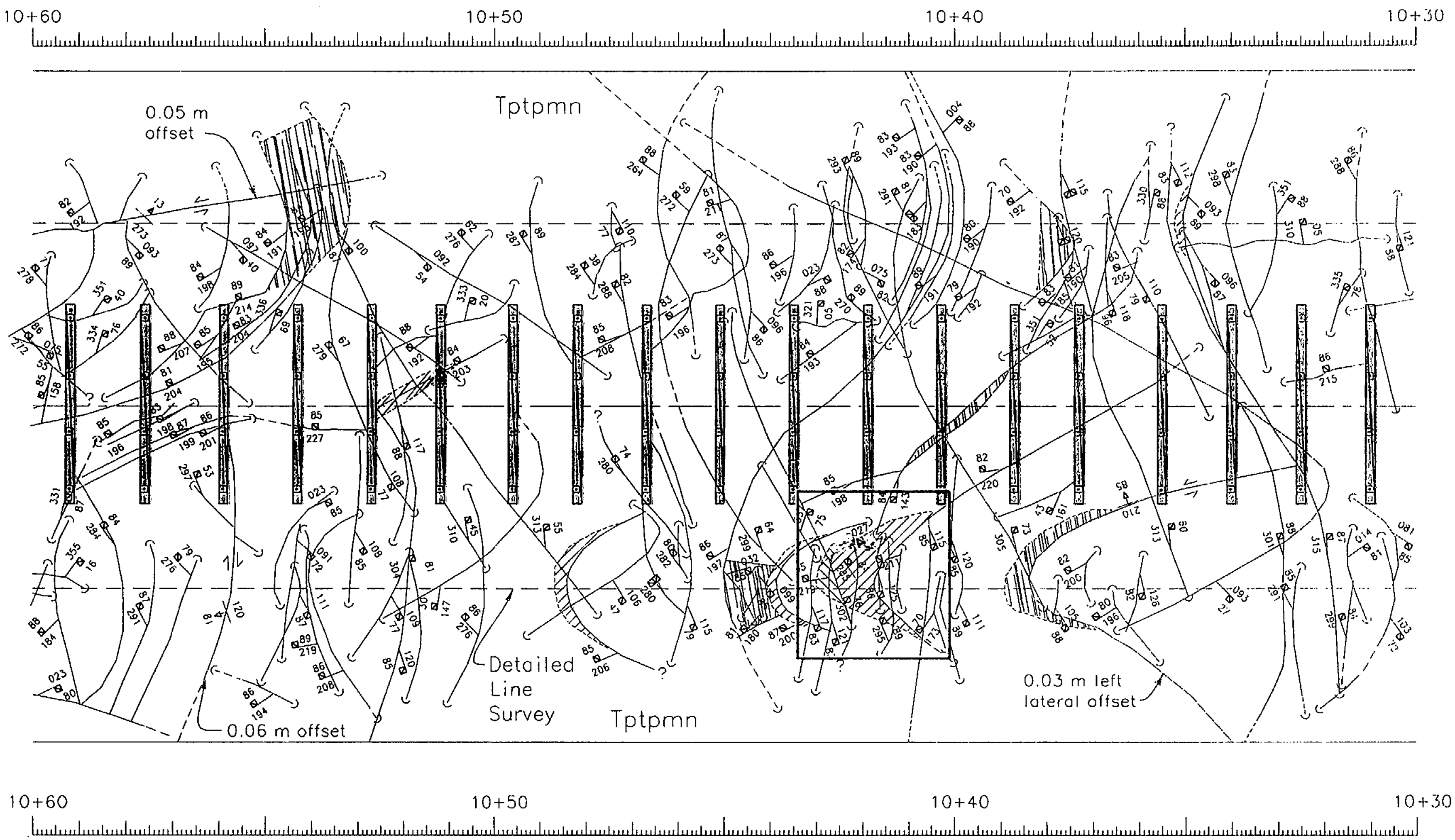


Figure VI-5. Key Block Location, Tptpmn Unit, Cross Drift Stations 10+30 to 10+60

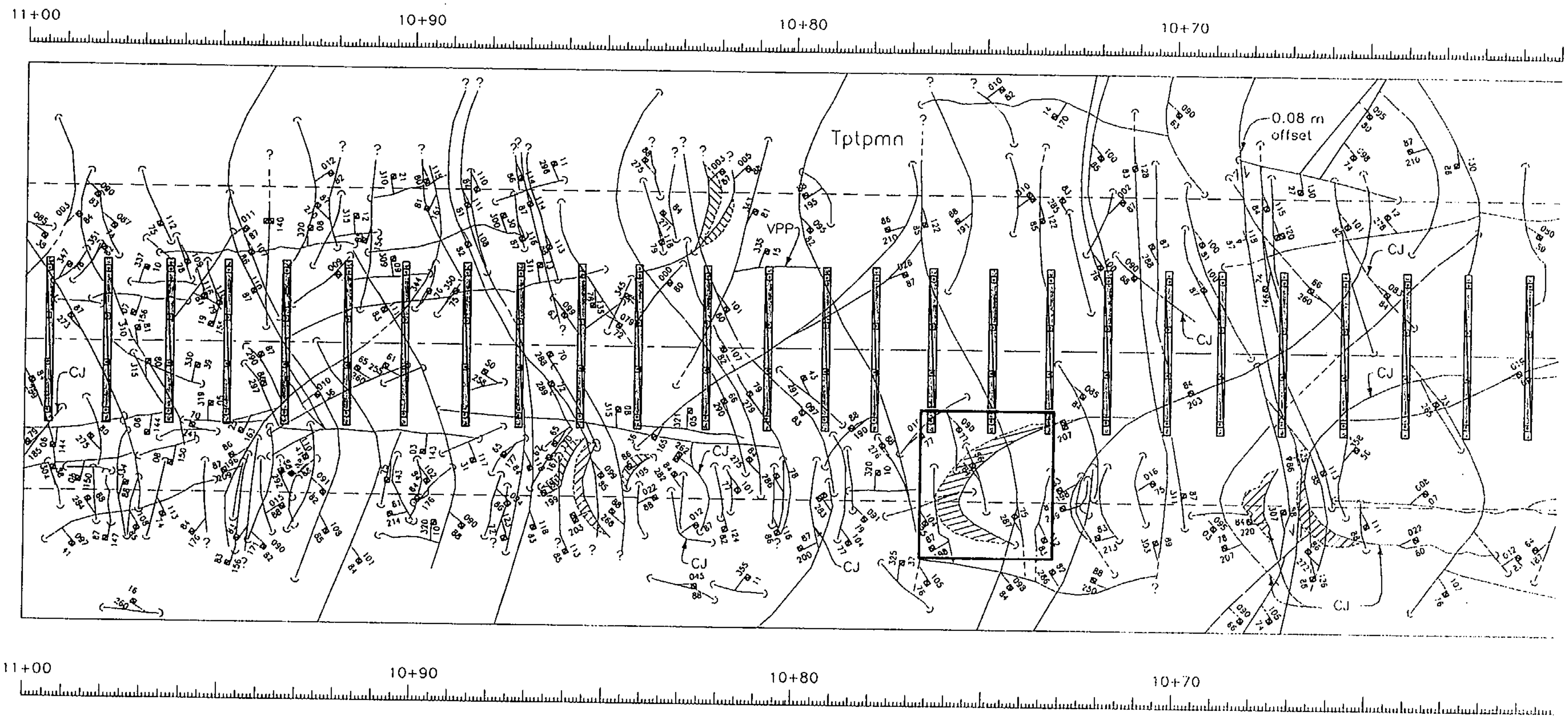


Figure VI-6. Key Block Location, Tptpmn Unit, Cross Drift Stations 10+60 to 11+00

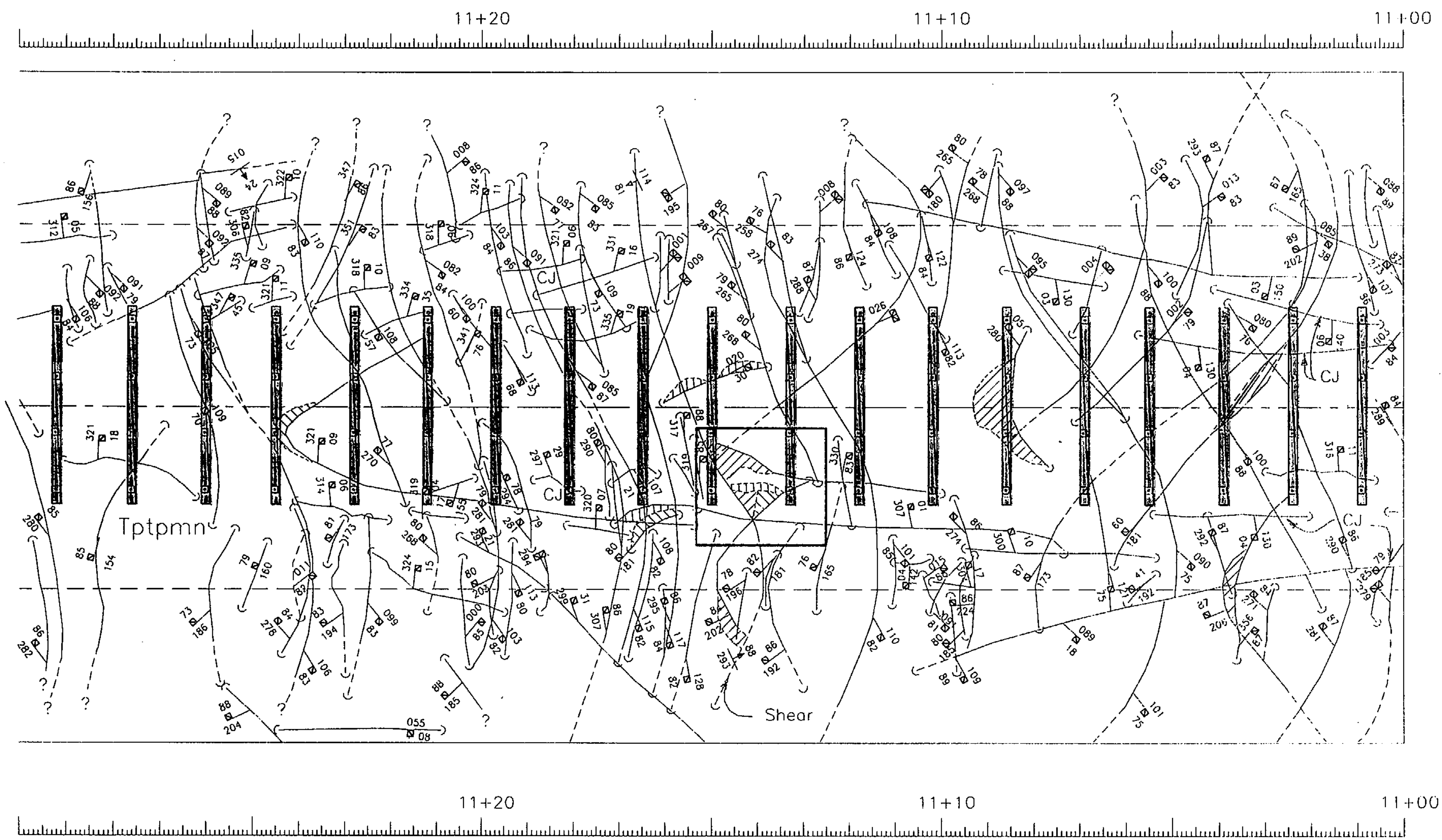


Figure VI-7. Key Block Location, Tptpmn Unit, Cross Drift Stations 11+00 to 11+30

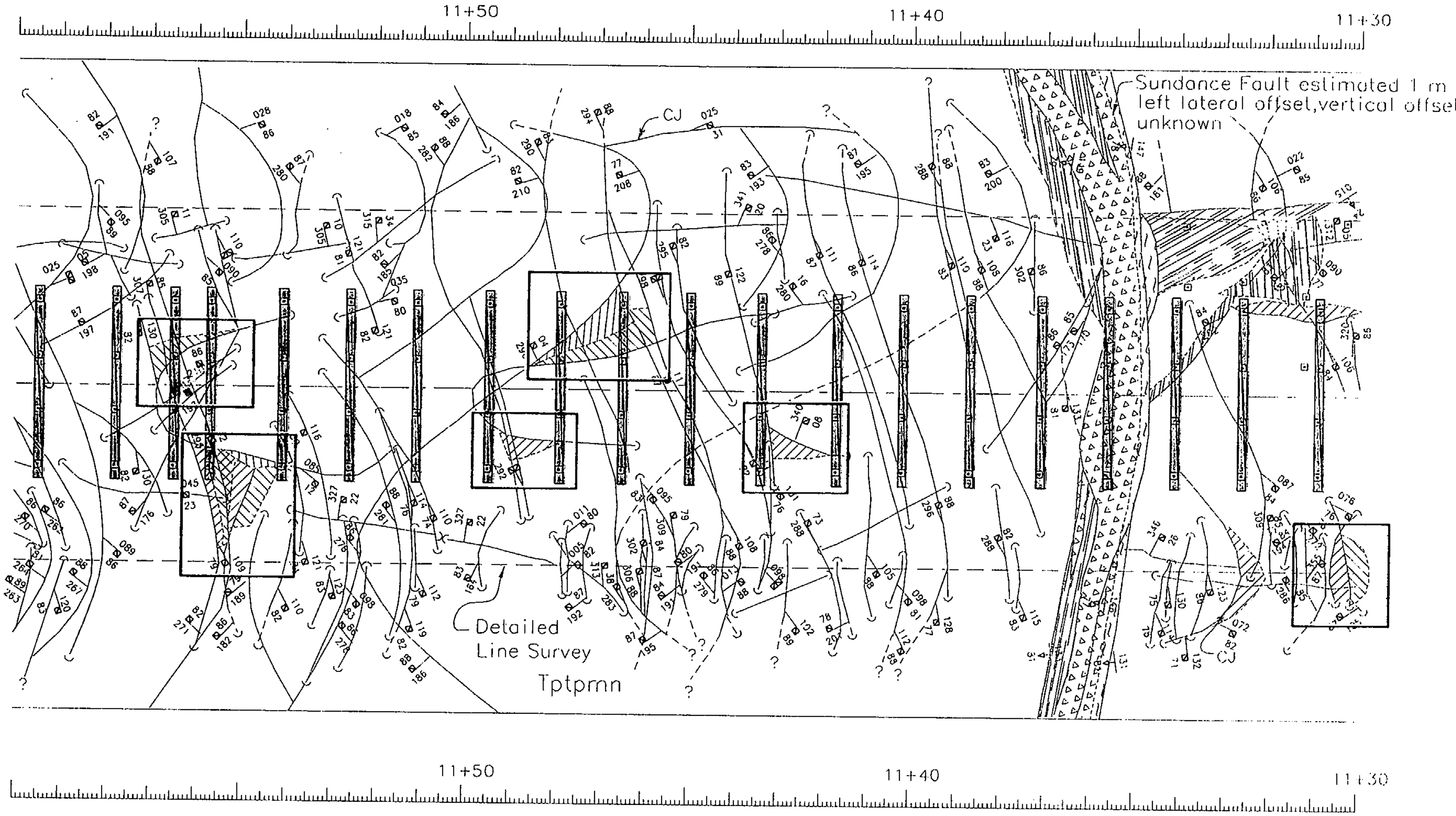


Figure VI-8. Key Block Location, Tptpmn Unit, Cross Drift Stations 11+30 to 11+60

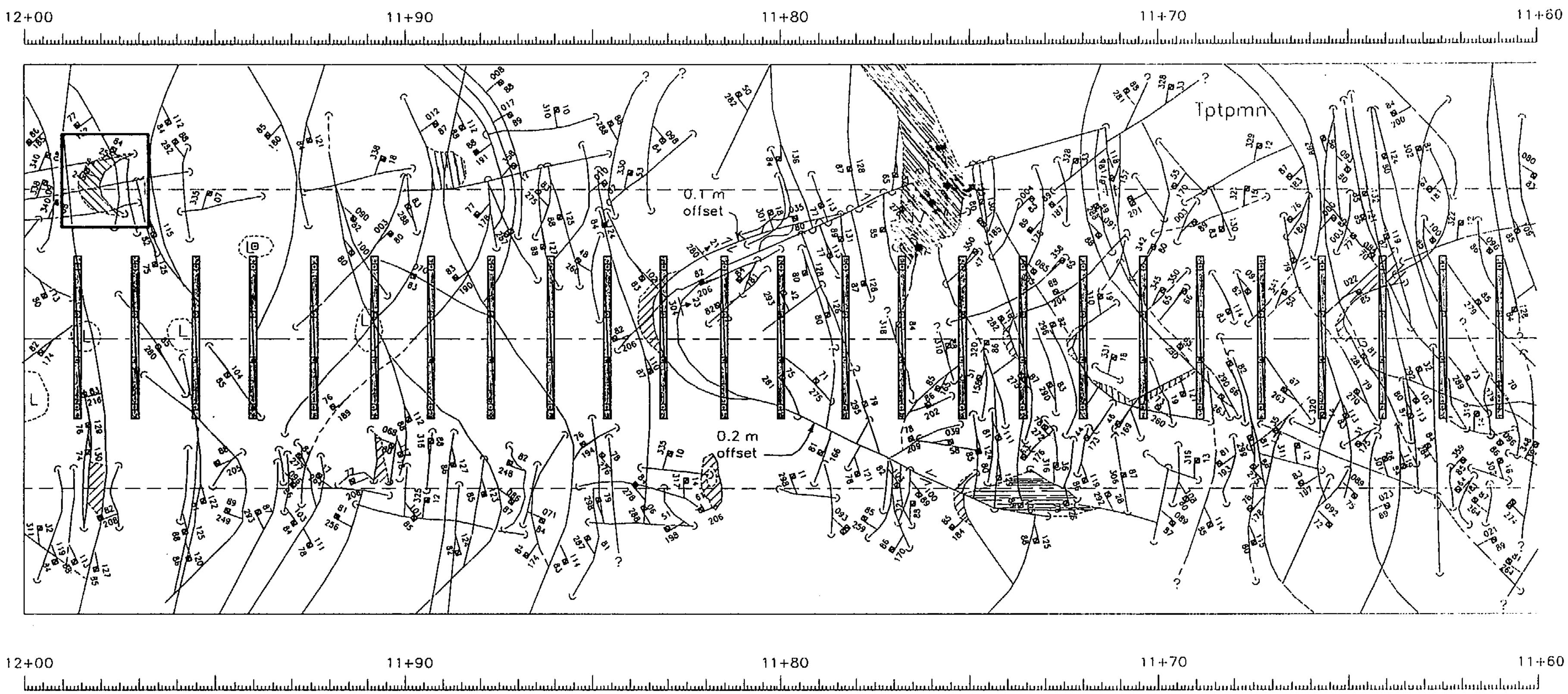


Figure VI-9. Key Block Location, Tptpmn Unit, Cross Drift Stations 11+60 to 12+00

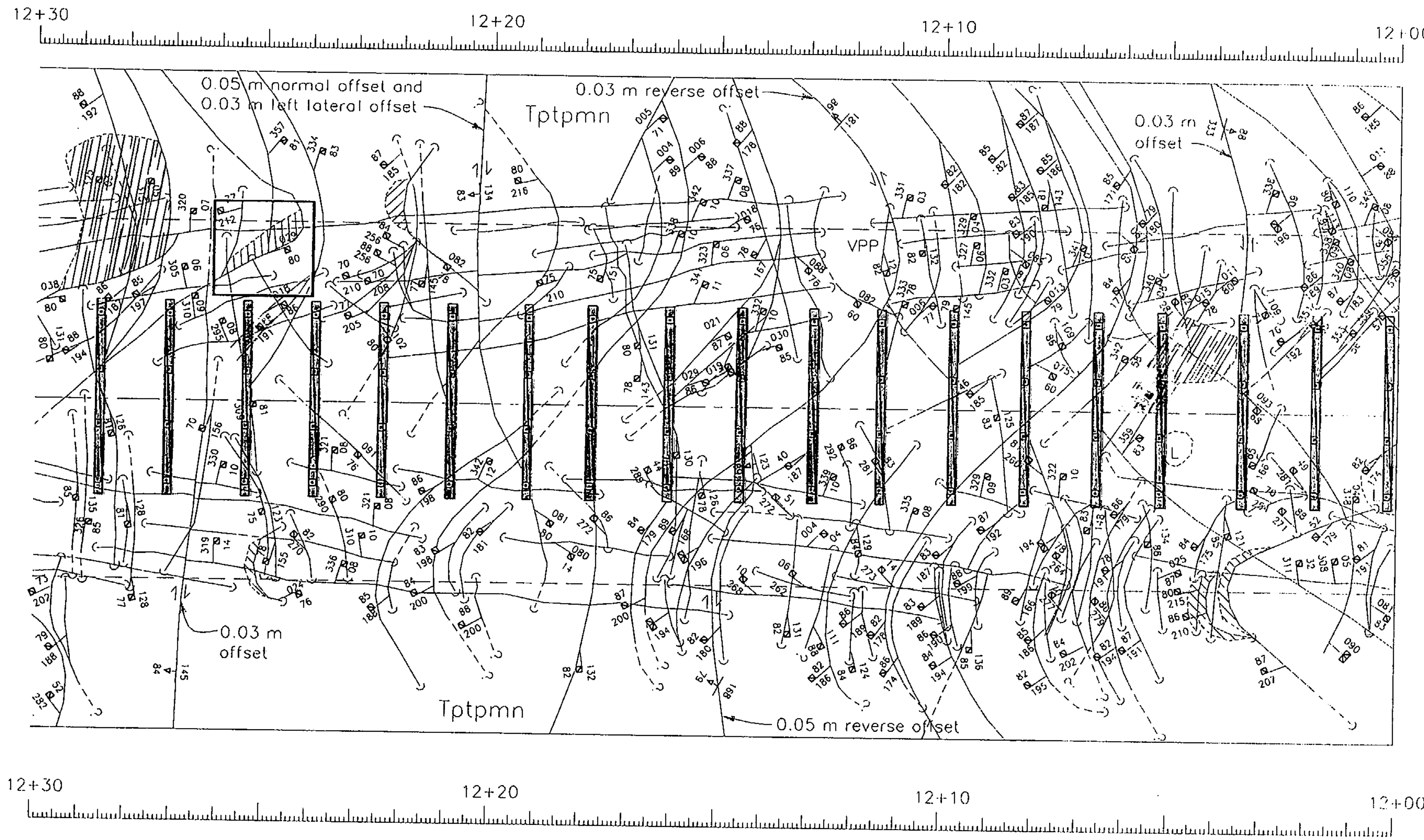


Figure VI-10. Key Block Location, Tptpmn Unit, Cross Drift Stations 12+00 to 12+30

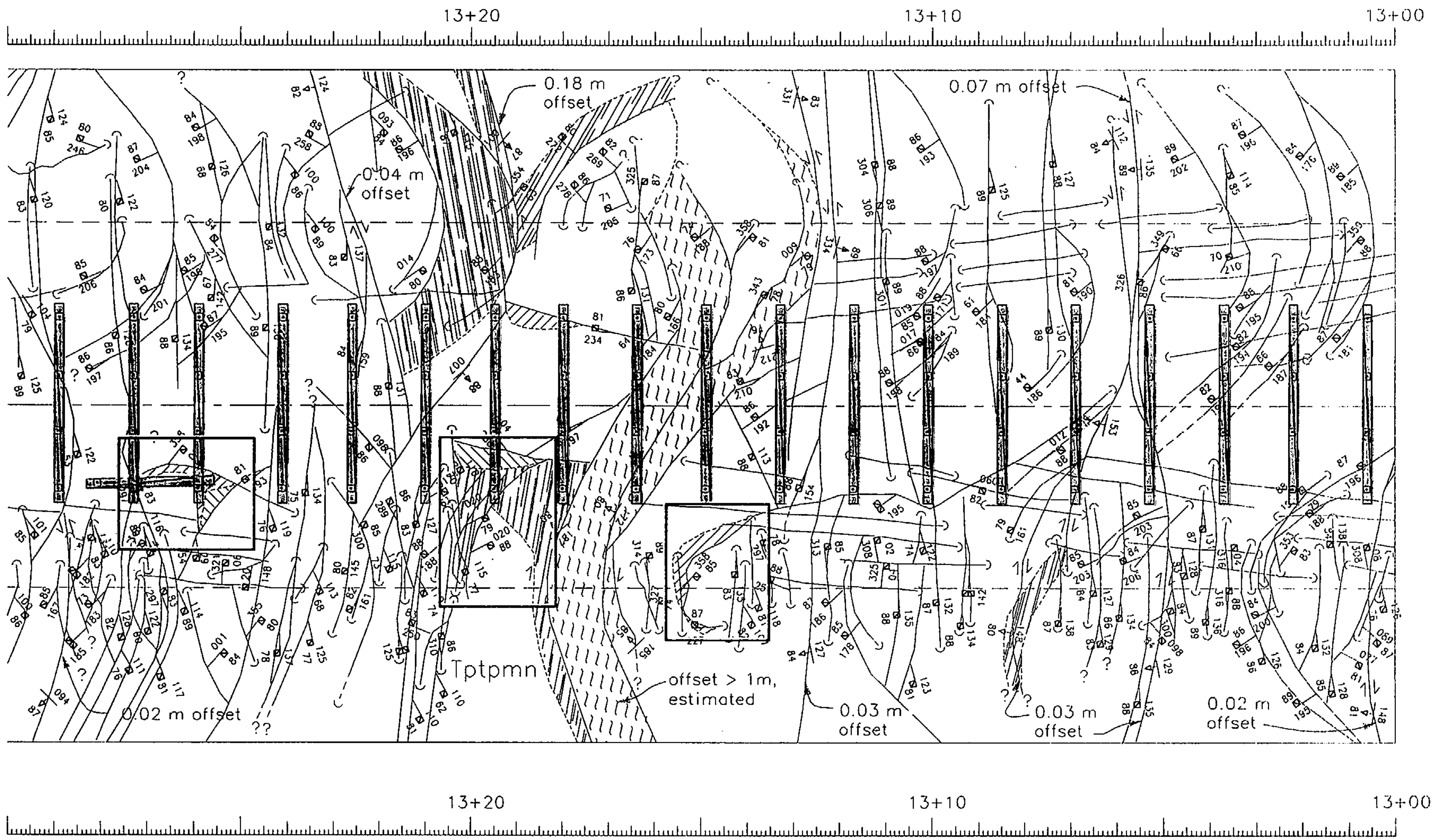


Figure VI-11. Key Block Location, Tptpmn Unit, Cross Drift Stations 13+00 to 13+30

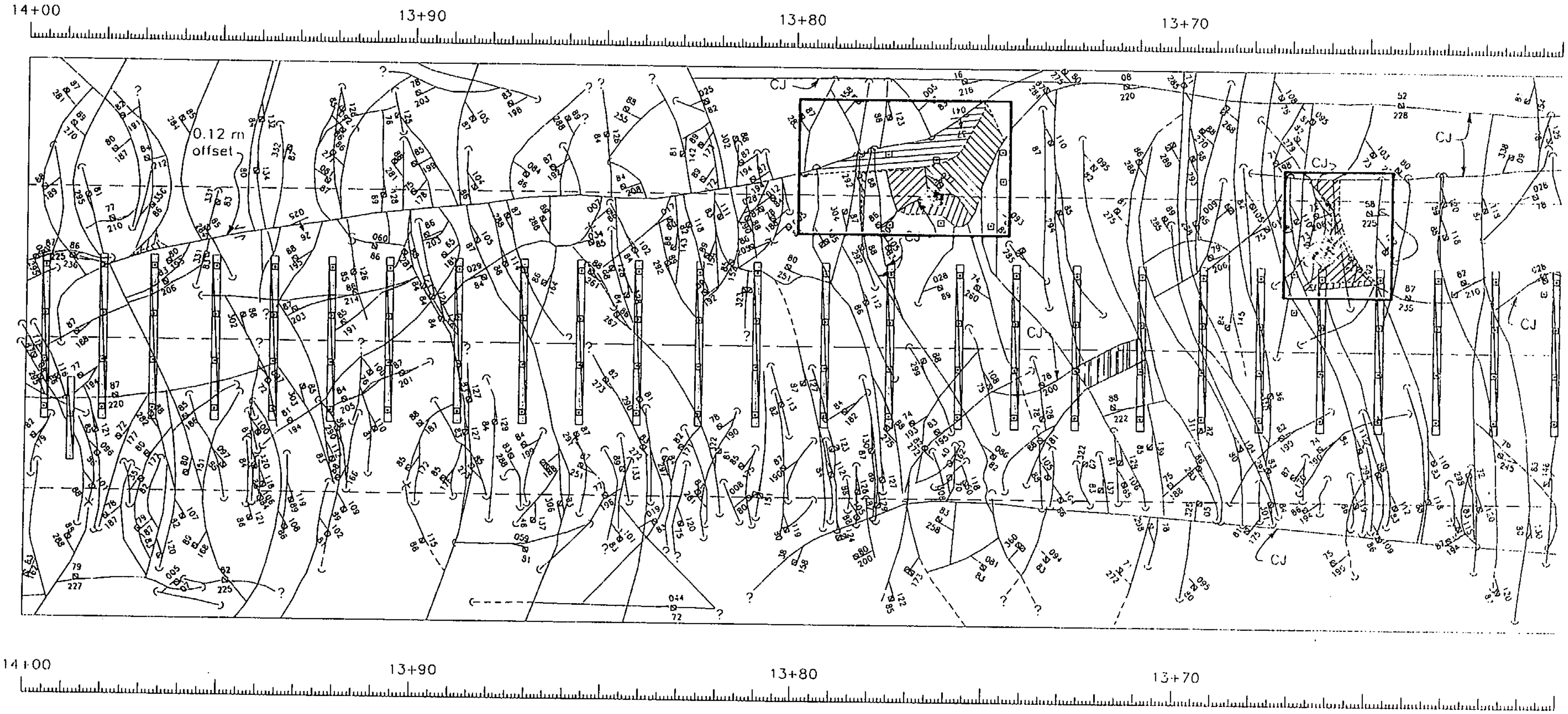


Figure VI-12. Key Block Location, Tptpmn Unit, Cross Drift Stations 13+60 to 14+00

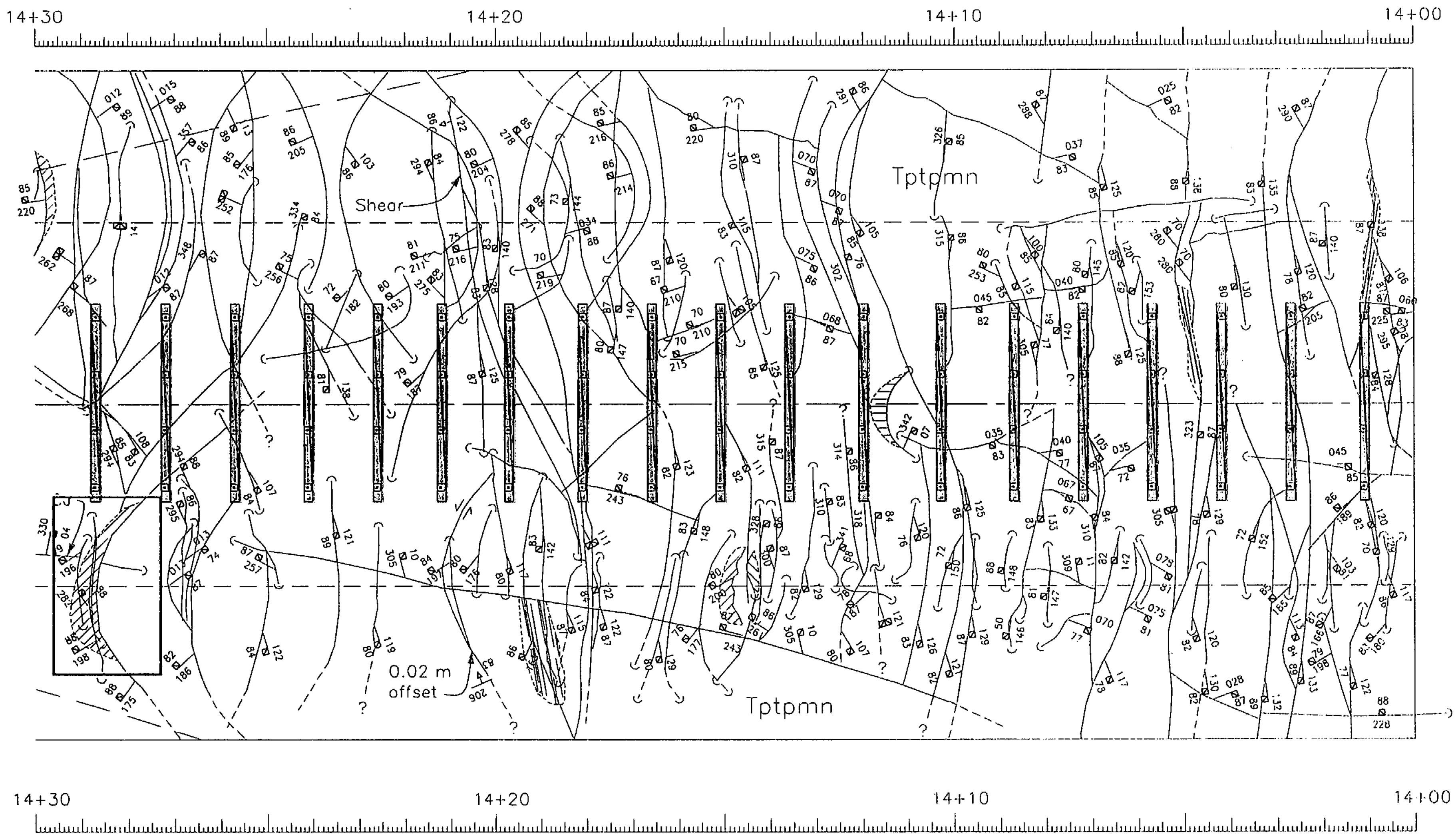


Figure VI-13. Key Block Location, Tptpmn Unit, Cross Drift Stations 14+00 to 14+30

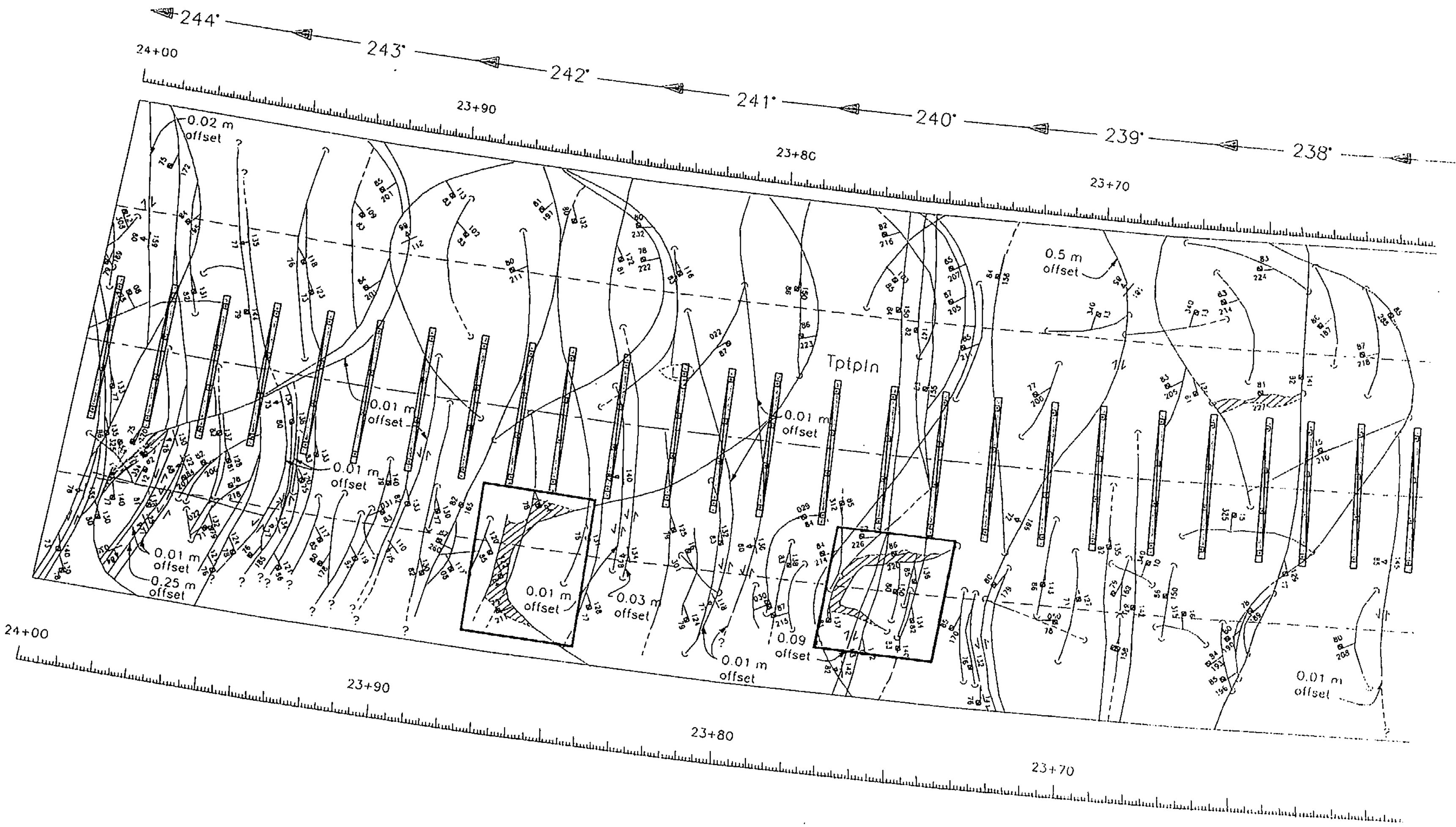


Figure VI-14. Key Block Location, Tptpln Unit, Cross Drift Stations 23+65 to 24+00

ATTACHMENT VII

NATURAL AND MAN-MADE ANALOGUES OF THE EFFECT OF SEISMIC EVENTS ON ROCK FALL

NATURAL AND MAN-MADE ANALOGUES OF THE EFFECT OF SEISMIC EVENTS ON ROCK FALL

VII.1 ANALOGUES OF MAJOR EARTHQUAKES

On July 28, 1976, a magnitude 7.8 earthquake occurred in Tang-Shan, China, a city with both substantial mining and industrial facilities. Surface intensities at Tang-Shan were such that in the area where the strongest shaking occurred, 80% to 90% of the surface structures collapsed. However, for important engineered structures immediately below the surface, there was generally no serious damage regardless of the depth or size of the structure (Wang 1985, p. 741).

The USGS reported in the lessons and conclusions of the Alaskan earthquake on March 28, 1964 that no significant damage was reported to underground facilities, including mines and tunnels, as a result of the earthquake, although some rocks were shaken loose in places. Included in this analysis were studies of the coal mines in the Matanuska Valley which were undamaged, the railroad tunnels near Whittier, the tunnel and penstocks at the Eklutna hydroelectric project, and the Chugach Electric Association tunnel between Cooper Lake and Kenai Lake. There were also no reports of damage to the oil and gas wells in and along Cook Inlet. The reports of no damage from the Alaskan earthquake are significant. This earthquake was one of the largest (magnitude = 8.5) to occur in this country, and surface damage was extreme (Pratt et al. 1978, p. 32).

VII.2 ANALOGUE OF A RECENT EARTHQUAKE

Tunnels in the epicentral region of the Kobe, Japan earthquake (January 16, 1995; magnitude = 6.9) experienced no major damage (partial or total collapse) for peak ground accelerations measured at the surface of approximately 0.6 g (Savino et al. 1999).

VII.3 ANALOGUE OF A SITE-SPECIFIC EARTHQUAKE

On June 29, 1992, a magnitude 5.6 earthquake occurred at Little Skull Mountain about 20 km from Yucca Mountain. Within days of the earthquake, a team of scientists examined the interior of the tunnel 125 meters deep in the epicentral region of the earthquake. The team reported no evidence of damage in the tunnel that could be associated with the earthquake (Savino et al. 1999).

ATTACHMENT VIII

VERIFICATION OF EXCEL 97 MACRO VOLUME_CAL V1.1

VERIFICATION OF EXCEL 97 MACRO VOLUME_CAL V1.1

VIII.1 MACRO IDENTIFICATION

Macro name: *Volume_cal V1.1*. Macro version: 1.1. Initial issue of macro. The macro runs under *Excel 97 SR-2*. This macro resides in the *Excel* spreadsheet files *pmn-rock volume per mcs v2.xls, pll-rock volume per mcs v2.xls, pln-rock volume per mcs v2.xls* (Attachment II).

VIII.2 MACRO PURPOSE AND VALIDATION

The purpose of this macro is to calculate the total rock fall volume per 24.4 m of drift length (equivalent to the total drift length per one Monte Carlo Simulation in DRKBA analysis). The inputs are the key block output file (with extension *.kbo*, see Attachment II) from DRKBA. This *.kbo* output file contains the information of the volume of every key block identified for the entire Monte Carlo simulations. The DRKBA output file was first read in the *Excel* spreadsheet. The macro then looped through each key block as presented in each row of the spreadsheet. Logic for identification of the Monte Carlo simulation and the addition formula was applied to each key block to calculate the total rock fall per one Monte Carlo Simulation. Notice that the volume reported in DRKBA output file is in ft^3. The macro calculates the total volume in ft^3 and then converts to m^3.

The macro *Volume_cal V1.1* is verified by visual inspection of the calculation results with a hand calculation of the total key block volume per one Monte Carlo simulation. Table VIII-1 provides the results of the hand calculations of Monte Carlo simulations 48, 56, and 223 for Tptpmn, Tptpll, and Tptpln respectively. The individual key block volume in the simulation is included in the table. A comparison of the hand calculation and macro calculation result, as shown in Table VIII-1, indicates that the macro *Volume_cal V1.1* provides correct results for the calculation of total volume.

A listing of the macro source code is provided in Figure VIII-1. The formula used in macro *Volume_cal V1.1* consists only of simple addition. The macro is therefore applicable with no specific range of input parameters.

Table VIII-1. Comparison of the Calculation Results

Lithologic Unit	Monte Carlo Simulation Number	Individual key block volume (ft^3)	Total volume per one Monte Carlo Simulation from Hand Calculation (ft^3) (i.e., summation of individual key block volumes)	Total volume per one Monte Carlo Simulation from Macro (ft^3)	Total volume per one Monte Carlo Simulation from Hand Calculation (m^3)	Total volume per one Monte Carlo Simulation from Macro (m^3)
Tptpmn	48	1 2 4 2 2 3 11 34 2 13 56 9	139	139	3.94	3.94
Tptpll	56	4 7 1 1 2 2 1	18	18	0.51	0.51
Tptpln	223	34 8 29 36 262 186 1 2 10	568	568	16.10	16.10

```
Sub Volume_cal()
'
' V1.1
' Macro1 Macro
' Macro recorded 02/16/2000 by YMP
'

'

Dim i As Integer, i1 As Integer, i2 As Integer, i3 As Integer, ik As Integer
Dim ic1 As Integer, ic2 As Integer, ic3 As Integer, ic4 As Integer
Dim testflag As Integer

    Range("M1").Select
    ActiveCell.FormulaR1C1 = "Total Volume in a MCS (ft^3)"
    Range("M1").Select
    Selection.Copy
    Range("N1").Select
    ActiveSheet.Paste
    Application.CutCopyMode = False
    ActiveCell.FormulaR1C1 = "Total Volume in a MCS (m^3)"

    Range("P1").Select
    ActiveCell.FormulaR1C1 = "MCS Number"
    Range("Q1").Select
    ActiveCell.FormulaR1C1 = "Total Volume in a MCS (m^3)-condensed"

    Columns("Q:Q").ColumnWidth = 10

    Range("M1:R1").Select
    With Selection
        .HorizontalAlignment = xlCenter
        .VerticalAlignment = xlCenter
        .WrapText = True
        .Orientation = 0
        .ShrinkToFit = False
        .MergeCells = False
    End With

     ic1 = 2
    Do While Cells(ic1, 1).Value <> ""
        ic1 = ic1 + 1
    Loop
    ic1 = ic1 - 1

    ik = 2
    testflag = 0
```

Figure VIII-1. Listing of the Visual Basic Source Code for Macro *Volume_cal V 1.1*

```
 For i = 2 To ic1 - 1

If (testflag = 0) Then
    i1 = i
    vol = Cells(i1, 7).Value
End If



If (Cells(i + 1, 2).Value <> Cells(i, 2)) Then

Cells(i1, 13).Value = vol
Cells(i1, 14).Value = vol / (3.28 ^ 3)
testflag = 0

Cells(ik, 16).Value = Cells(i, 2).Value
Cells(ik, 17).Value = vol / (3.28 ^ 3)

ik = ik + 1

  If (i = ic1 - 1) Then
    Cells(ic1, 13).Value = Cells(ic1, 7).Value
    Cells(ic1, 14).Value = Cells(ic1, 7).Value / (3.28 ^ 3)
  End If

Else

vol = vol + Cells(i + 1, 7).Value
testflag = 1

End If

Next i

Range("Q2:Q300 ").Select
Selection.NumberFormat = "0.00"
Range("N2:N300").Select
Selection.NumberFormat = "0.00"

End Sub
```

Figure VIII-1. Listing of the Visual Basic Source Code for Macro *Volume_cal V 1.1* (Continued)

ATTACHMENT IX

BLOCK SIZE GEOMETRY

BLOCK SIZE GEOMETRY

The geometry of various sizes of key blocks is provided in this attachment. The geometry of blocks can vary based on the orientations of joints and the number of joints that form the key block. Due to the limitation of the post-processing capability of DRKBA, the geometry of the blocks predicted in the probabilistic analysis using DRKBA is not available. An alternative approach, which uses the qualified software UNWEDGE (CRWMS M&O 1998a) to calculate the block geometry based on three dominant joint sets, was adopted in this assessment.

The three joint sets, two sub-vertical and one sub-horizontal, which are typical for the joint sets observed in the ESF as indicated in Table 5, were used as inputs to UNWEDGE to predict the block geometry. In order to obtain the geometry for the various block sizes, the joint orientations were adjusted with a trial-and-error process. The mean joint set data for the Tptpll unit were used as the starting point for the trial-and-error process. The adjustment of the joint orientation is justified because the variation of joint orientation within each joint set was considered in the key block analysis. The joint set orientations used to obtain the block geometry are listed in Table IX-1. The joint orientation adjustment was first made in 5-degree increments of the joint dip direction to determine the trend of the block size value corresponding to the joint orientation. The 5-degree increment range containing the desired block size was then selected for finer adjustments in 1-degree increments to determine the joint orientation for a particular block size.

Notice that the geometry of rock blocks can not be uniquely defined due to the stochastic nature of joint geometry and occurrence. The block geometry calculated based on rock blocks forming with the predominant sub-vertical joint sets and the sub-horizontal set is considered the most likely geometry. The blocks that form by joints categorized in the random joint set are not considered in this assessment.

Table IX-1. The Joint Set Orientation Used to Predict the Block Geometry[1]

Rock Block Tonnage (MT[2])	Joint Set 1		Joint Set 2		Joint Set 3	
	Dip	Dip Direction	Dip	Dip Direction	Dip	Dip Direction
1	82	239	79	250	5	35
2	82	232	79	250	5	25
4	82	225	79	280	5	25
5	82	220	79	290	5	25
8	82	214	79	290	5	25
15	82	206	79	290	5	25
19	82	205	79	290	5	25
30	82	202	79	290	5	25
36	82	201	79	290	5	25
52	82	200	79	290	5	25

[1]The joint set orientations are based on typical values presented in Table 5 and were determined by a trial-and-error process to correspond to the associated rock block tonnage.

[2]MT = metric tons.

The block geometry results presented in this attachment are based on 5.5-m-diameter emplacement drifts oriented with a tunnel azimuth of 75°. The block geometries were calculated according to the approach described above. The apex (i.e., block height) and Z-length (i.e., the maximum extent of block along tunnel axis) are summarized in Table IX-2 for various block sizes. Outputs from UNWEDGE, including perspective and cross-section views for each of the block sizes listed in Table IX-1, are provided in Figures IX-1 to IX-20. The block tonnage output from UNWEDGE is rounded to the nearest integer number. The UNWEDGE inputs for the block geometry assessment are listed in Table IX-1 and in Attachment II.

Table IX-2. The Apex and Z-Length for Various Block Sizes

Block Size (MT)	Apex (m)	Z-Length (m)
1	1.65	2.44
2	1.46	3.30
4	1.32	4.23
5	1.28	5.38
8	1.29	7.82
15	1.31	13.65
19	1.31	15.96
30	1.30	24.79
36	1.29	28.94
52	1.27	40.49

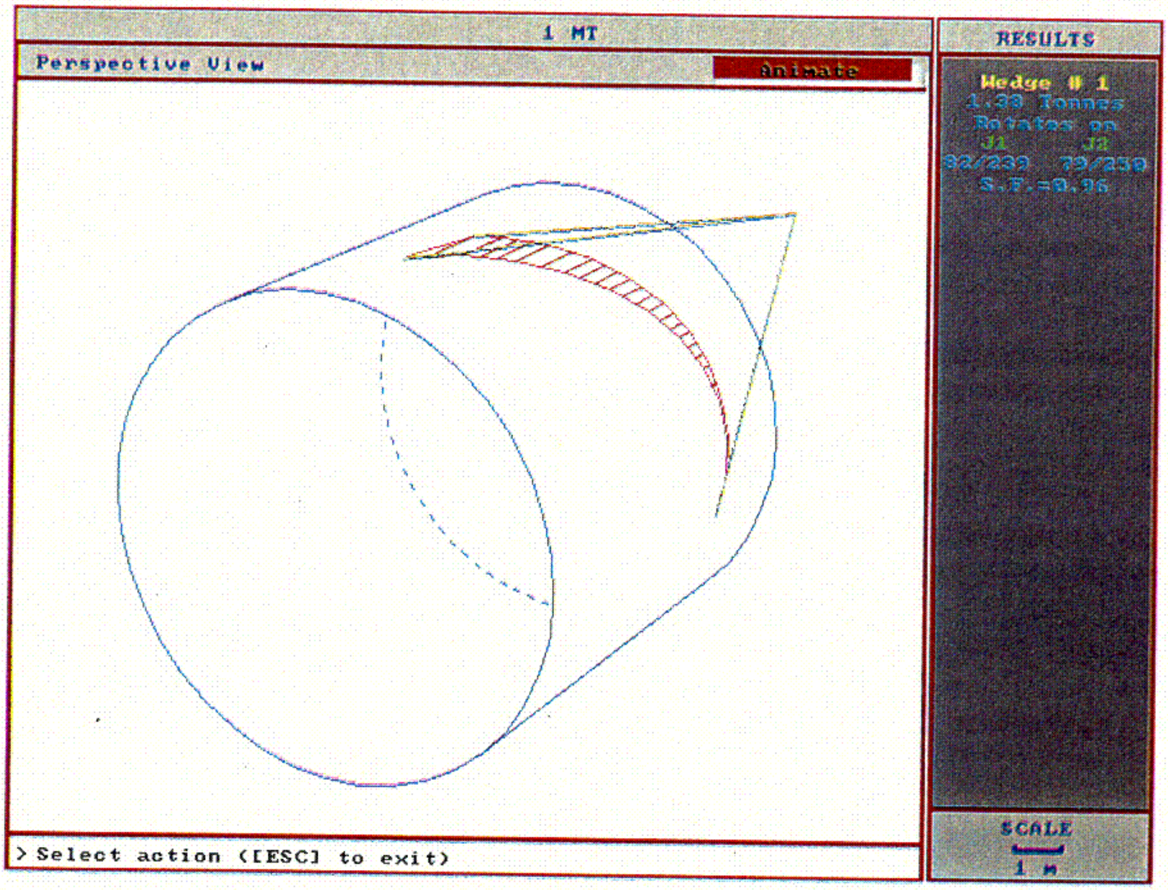


Figure IX-1. Perspective View of 1 MT Block

C31

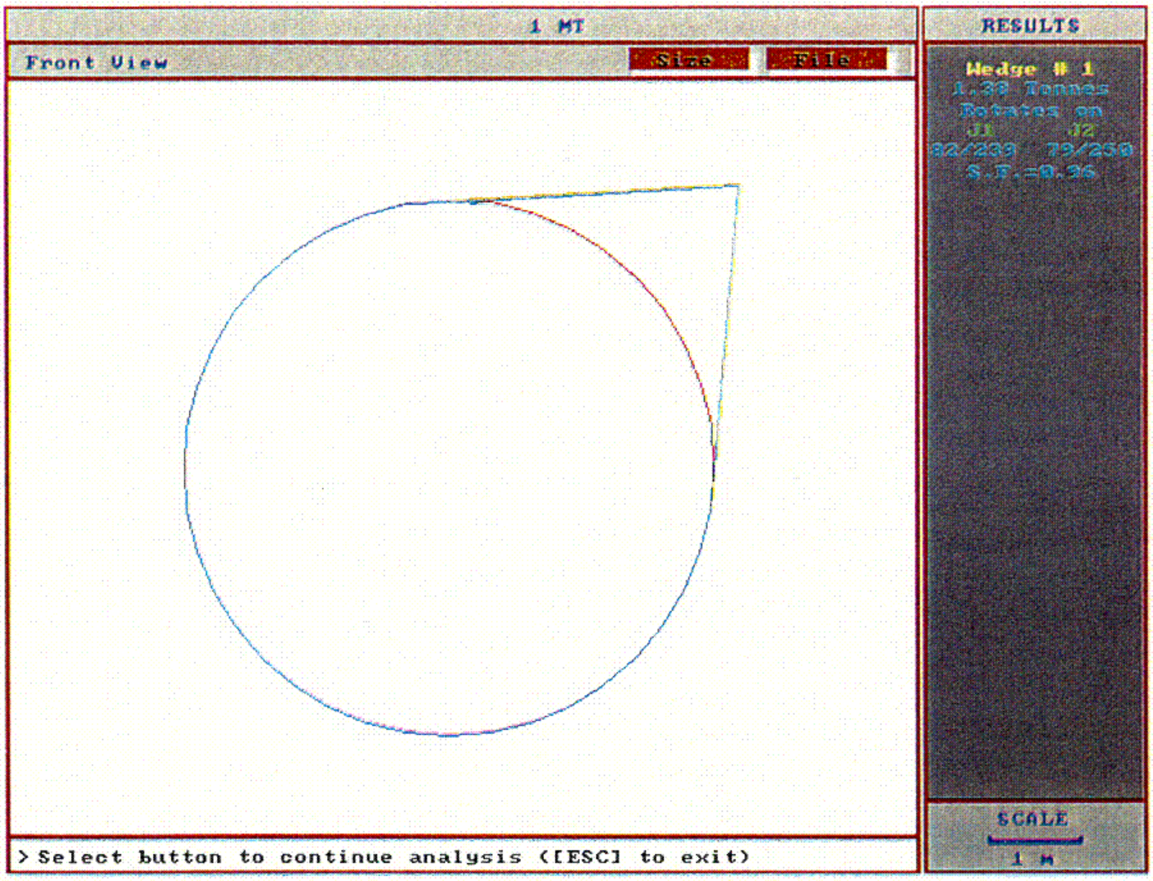


Figure IX-2. Cross-Sectional View of 1 MT Block

C32

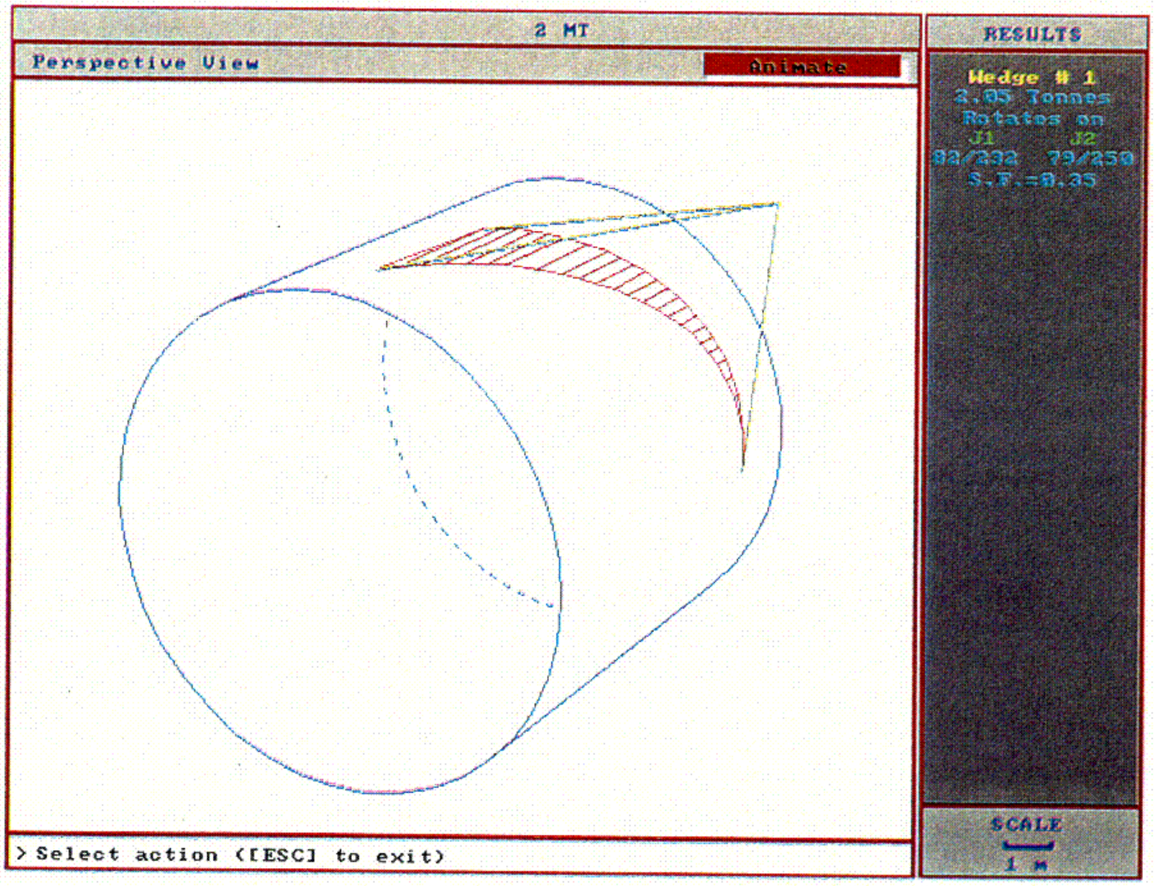


Figure IX-3. Perspective View of 2 MT Block

C33

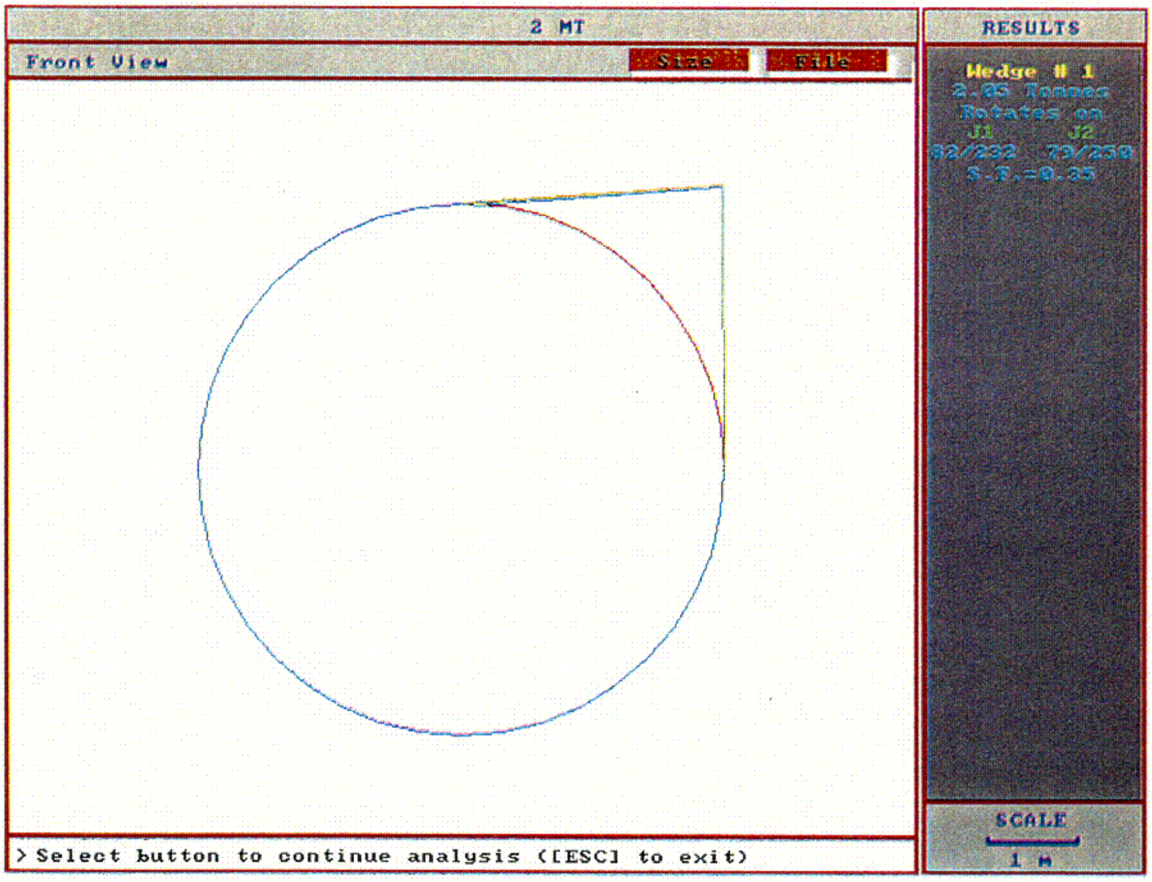


Figure IX-4. Cross-Sectional View of 2 MT Block

C34

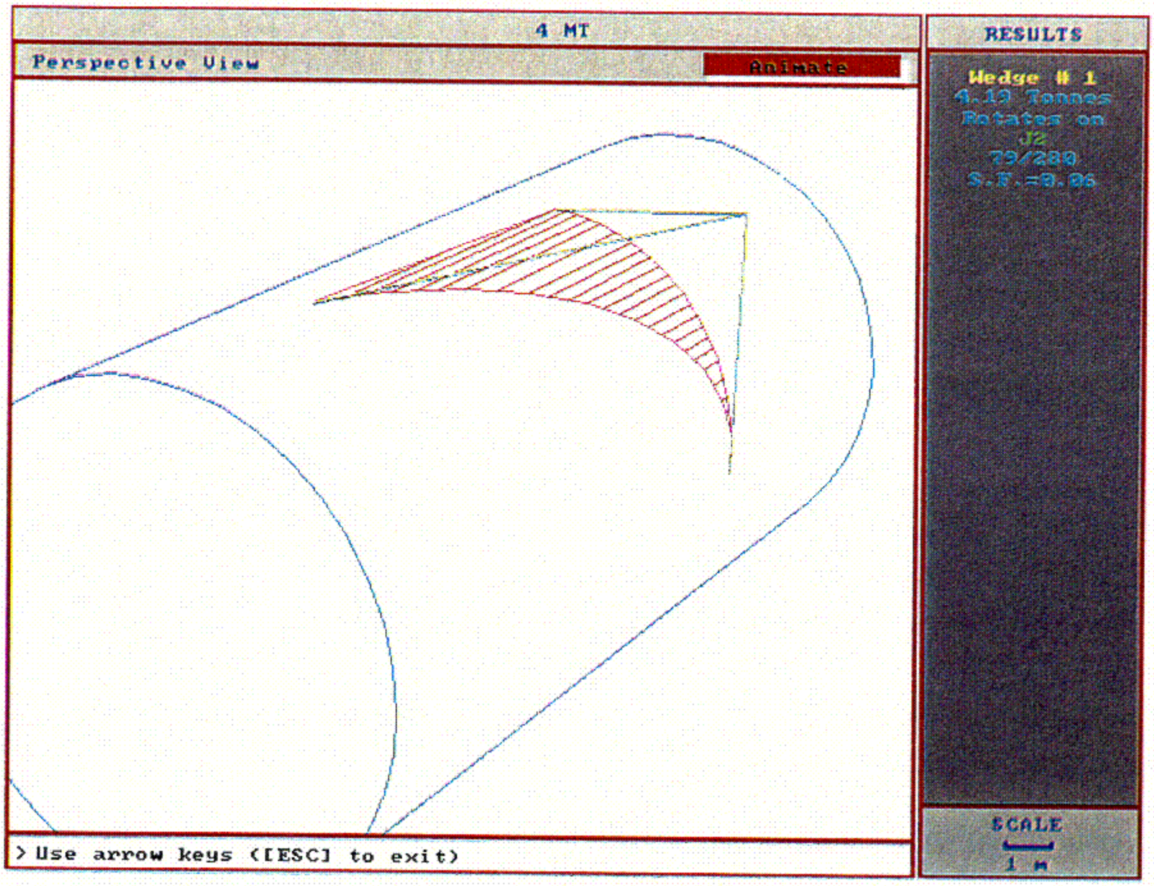


Figure IX-5. Perspective View of 4 MT Block

C35

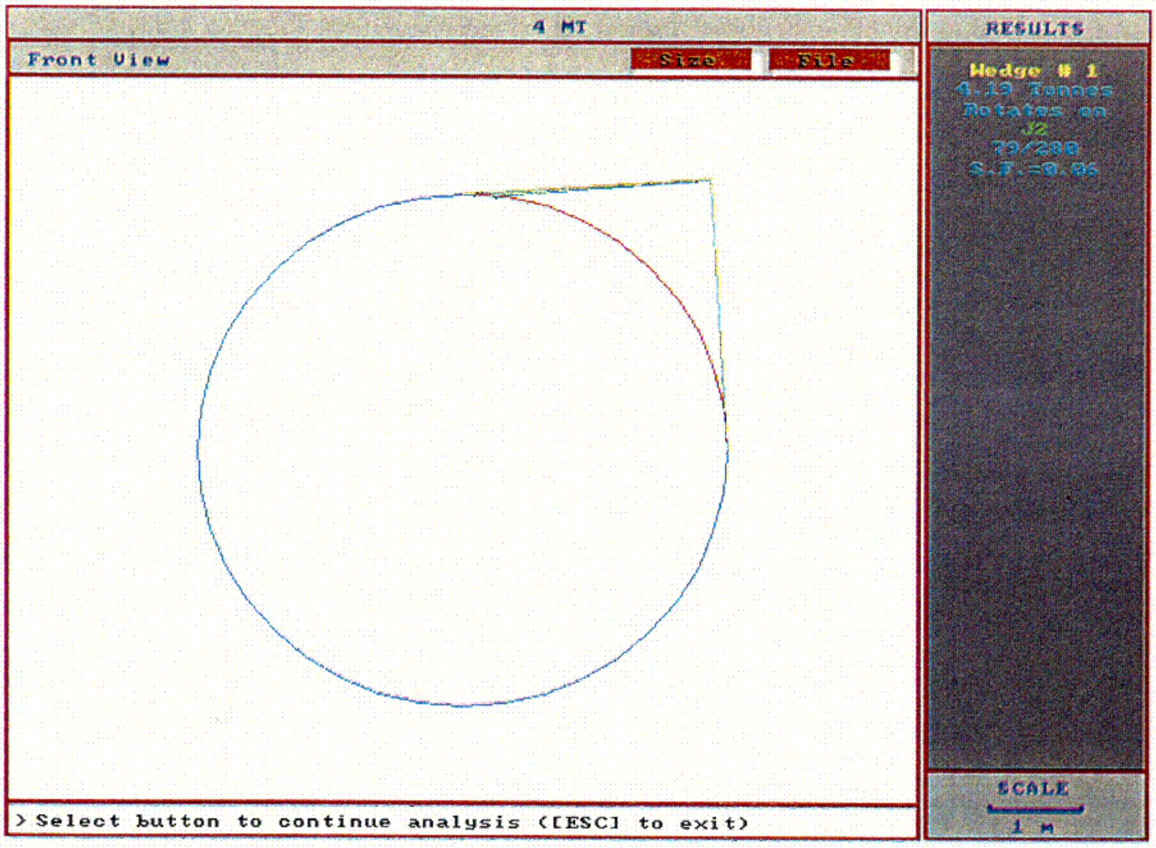


Figure IX-6. Cross-Sectional View of 4 MT Block

C36

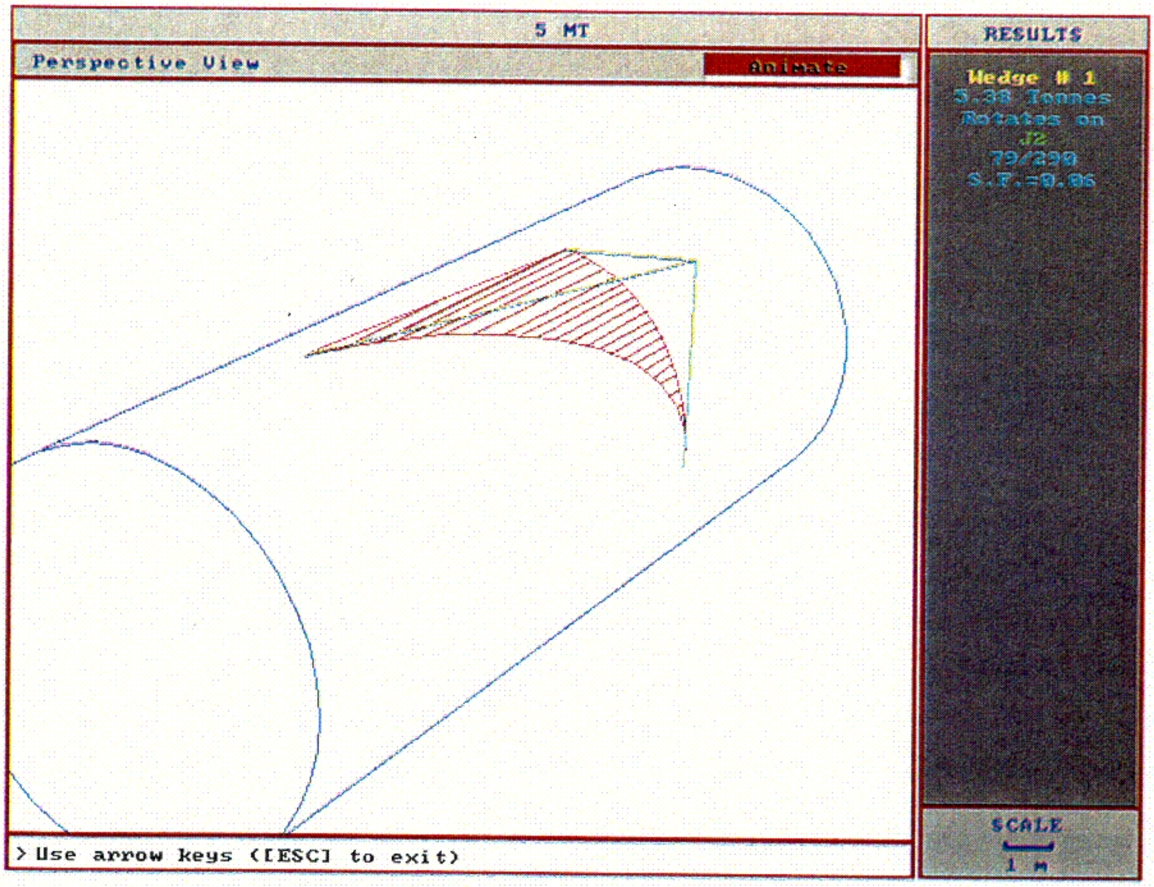


Figure IX-7. Perspective View of 5 MT Block

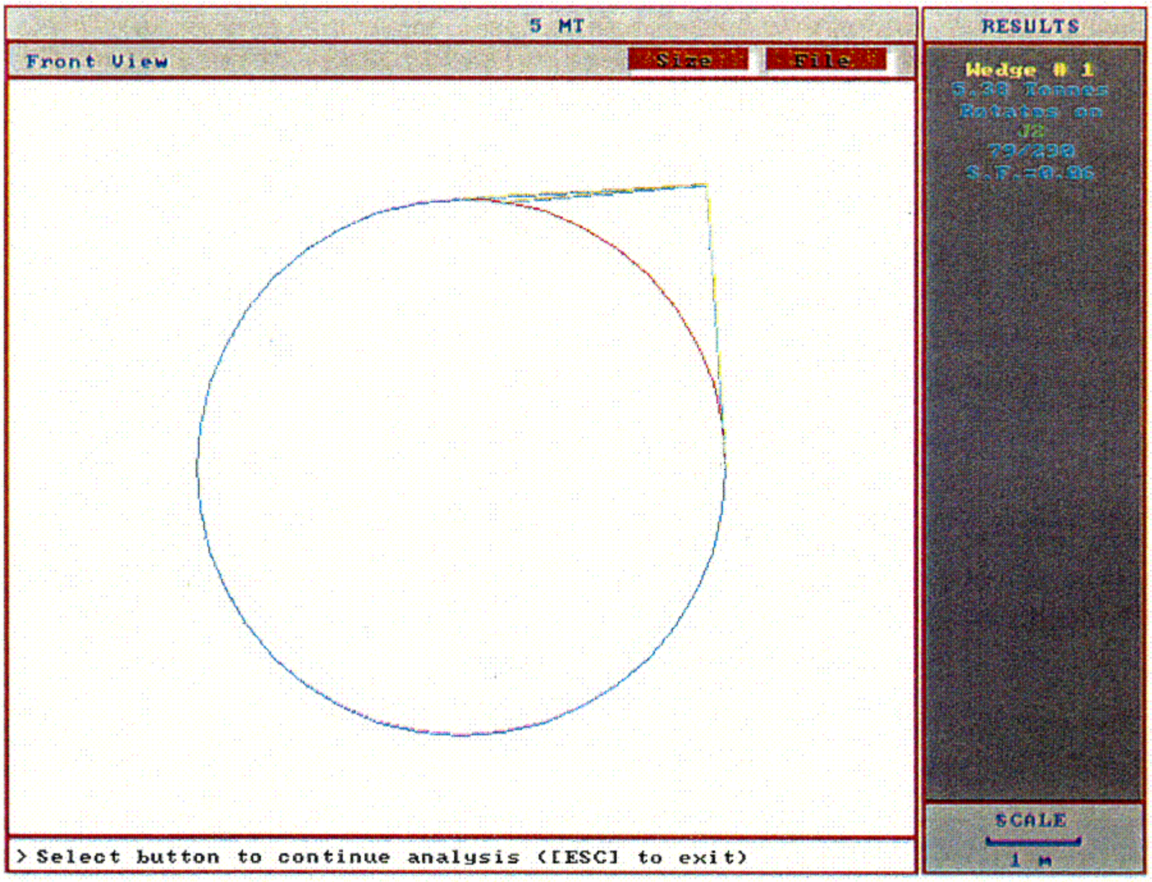


Figure IX-8. Cross-Sectional View of 5 MT Block

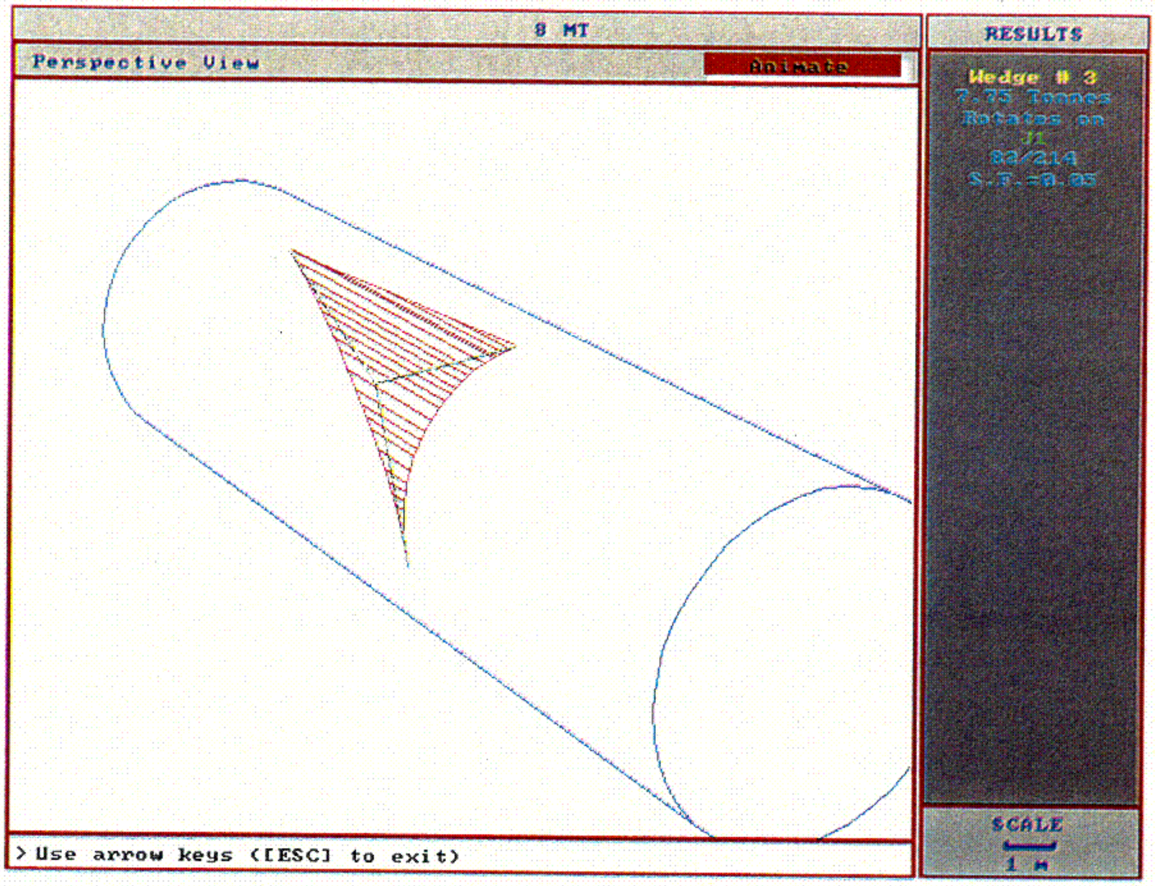


Figure IX-9. Perspective View of 8 MT Block

C39

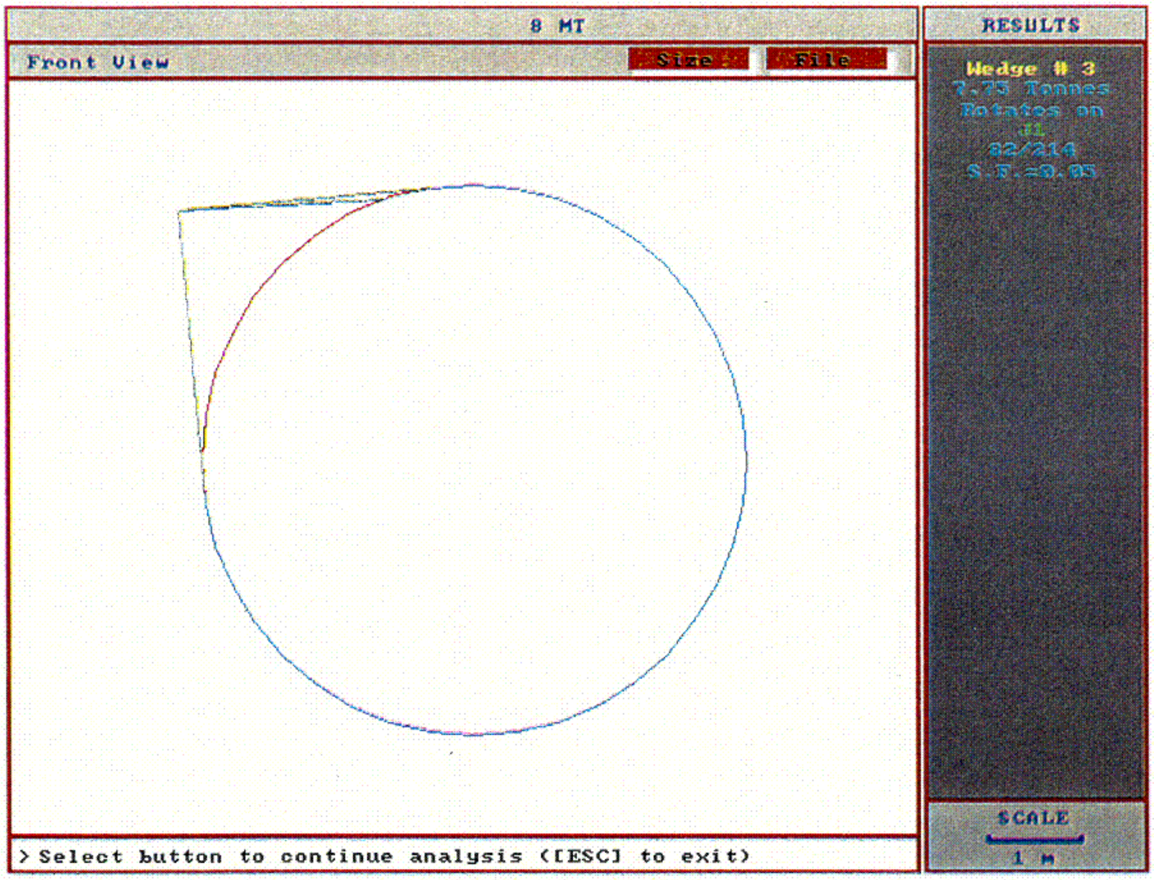


Figure IX-10. Cross-Sectional View of 8 MT Block

C40

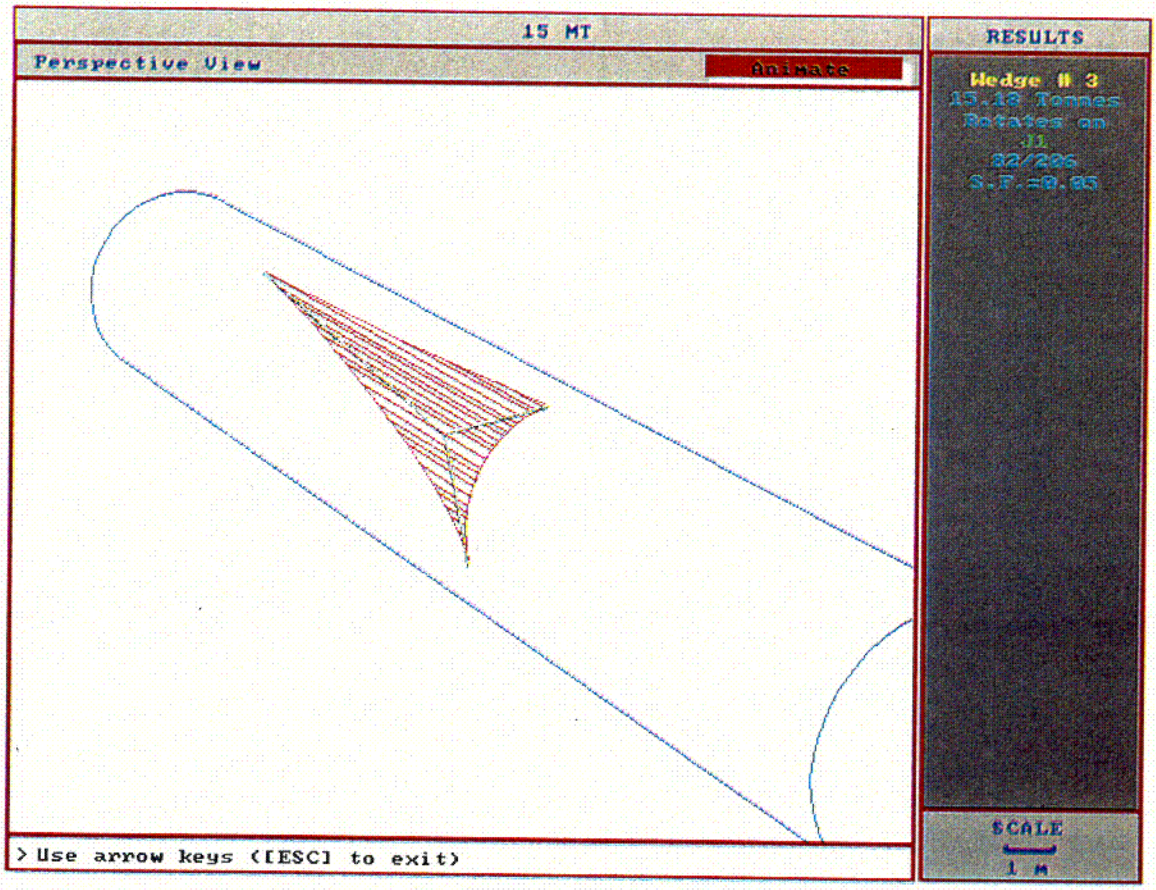


Figure IX-11. Perspective View of 15 MT Block

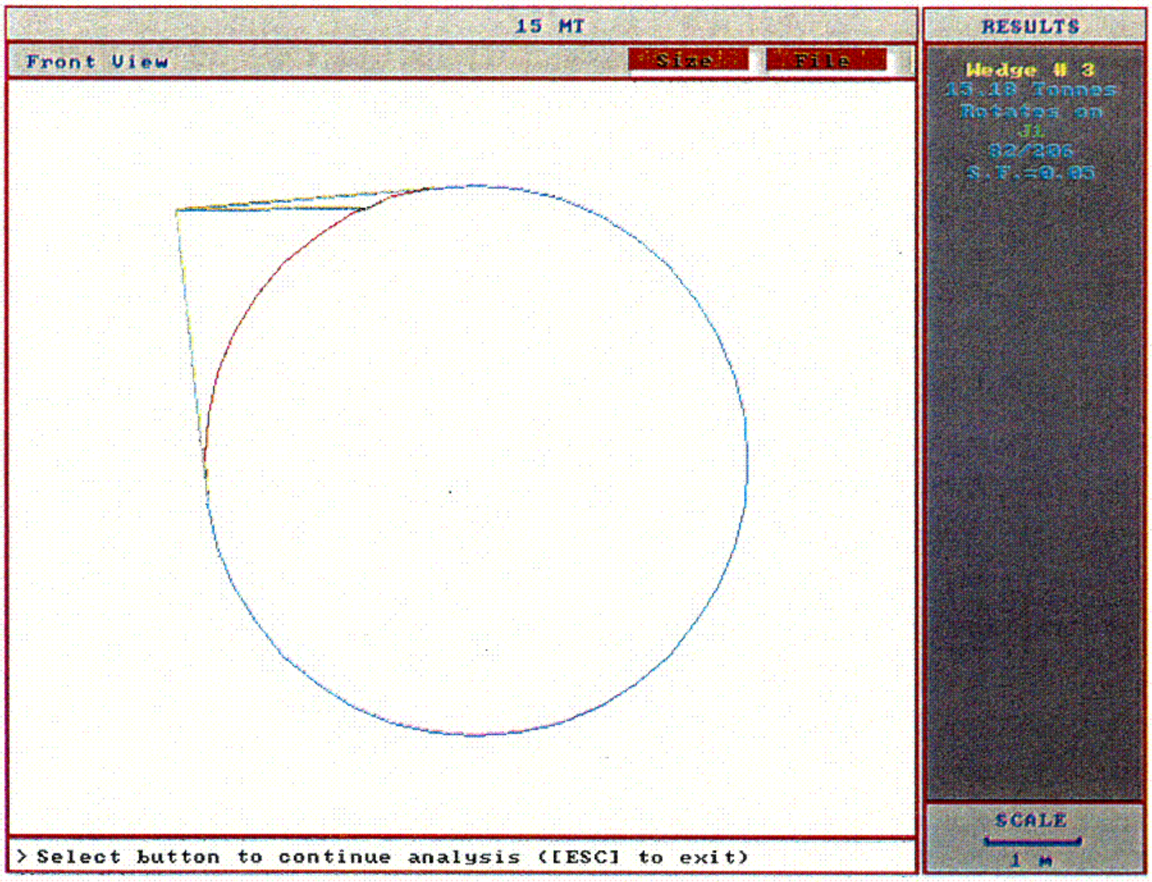


Figure IX-12. Cross-Sectional View of 15 MT Block

C42

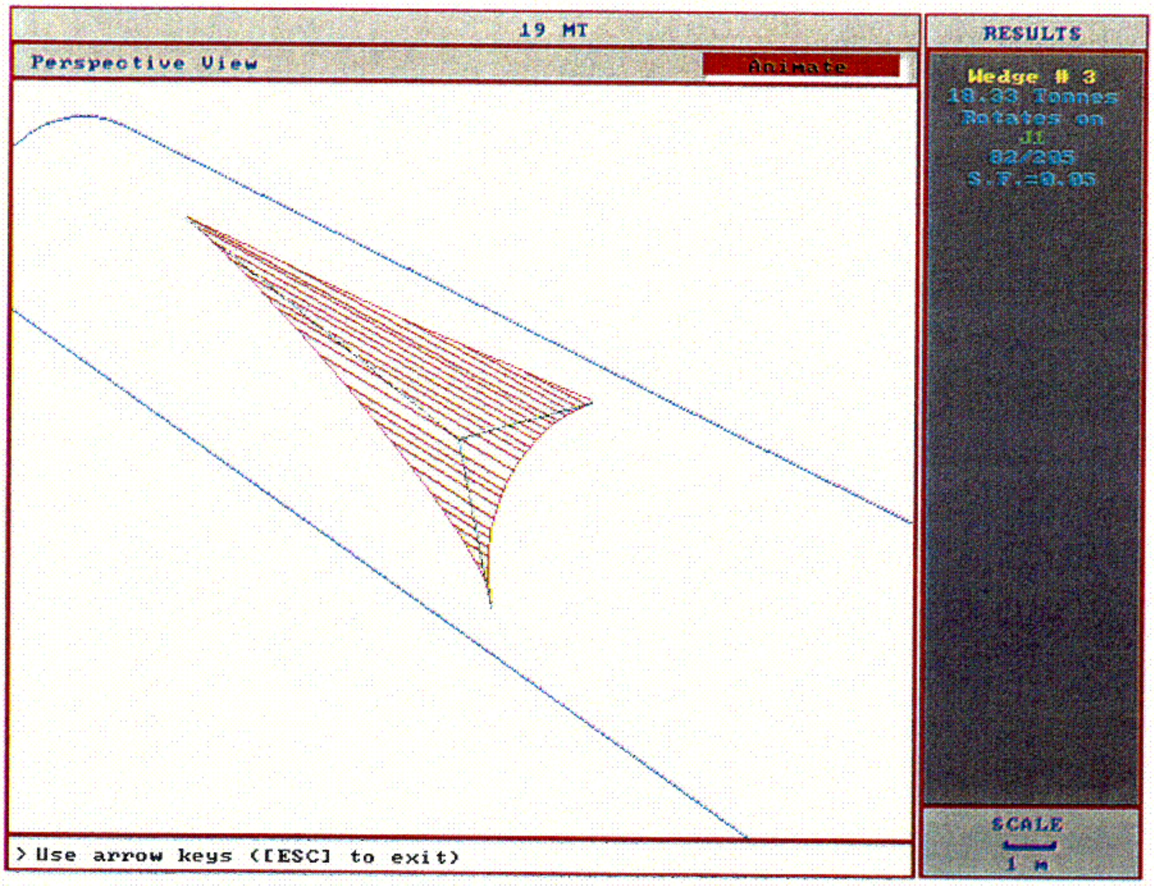


Figure IX-13. Perspective View of 19 MT Block

C43

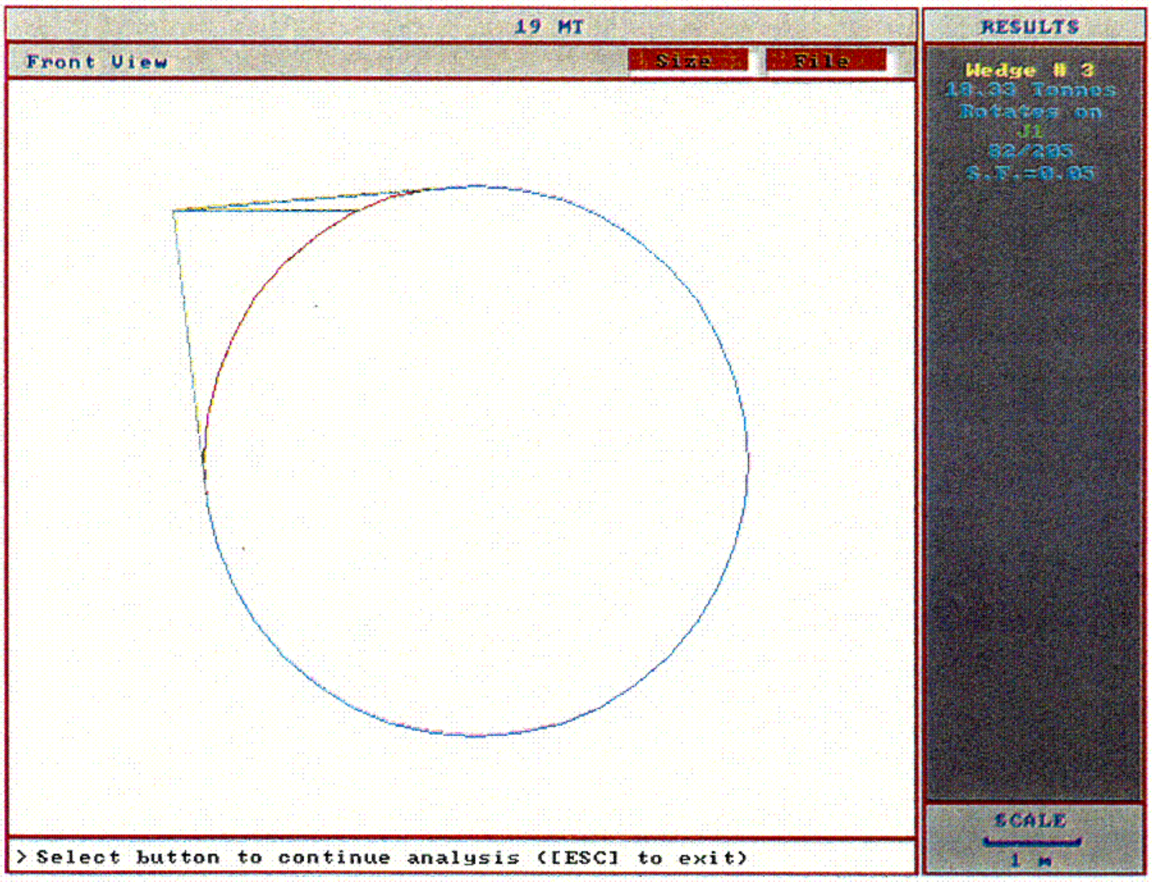


Figure IX-14. Cross-Sectional View of 19 MT Block

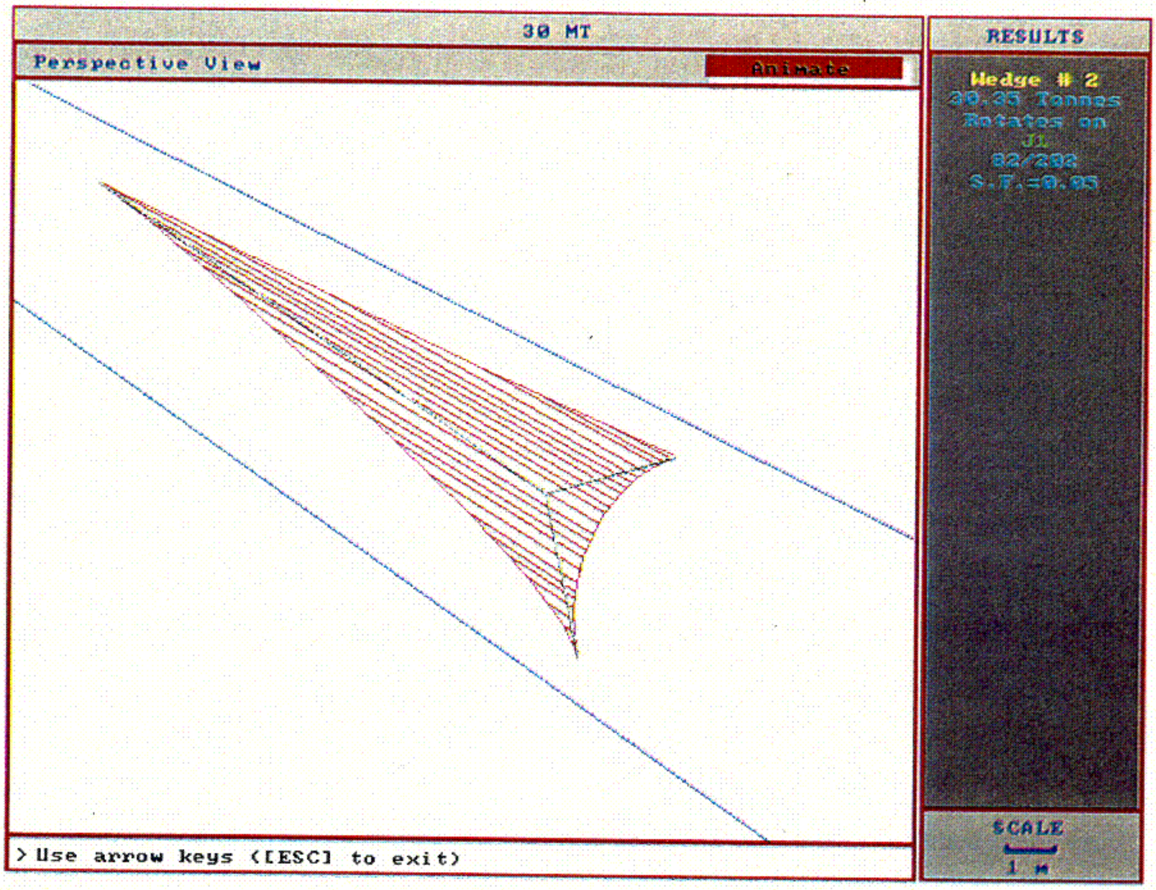


Figure IX-15. Perspective View of 30 MT Block

C45

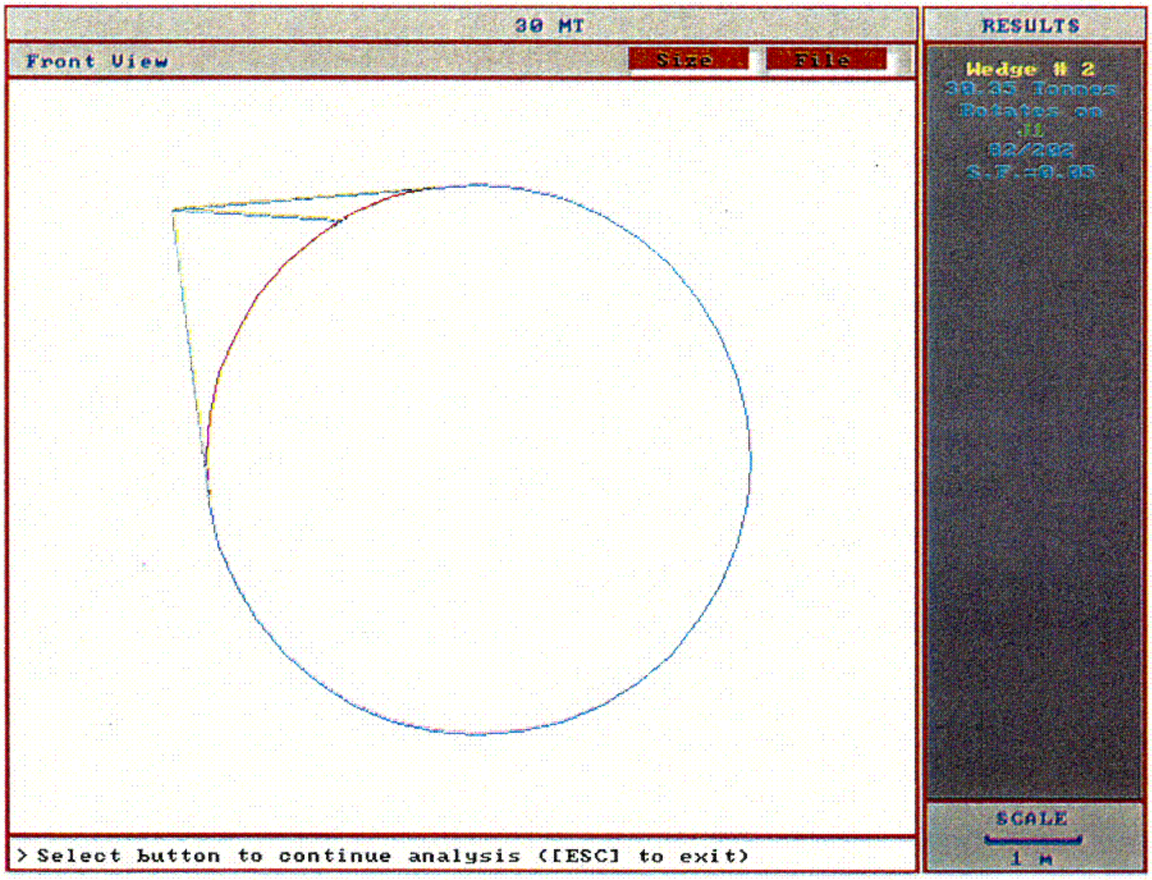


Figure IX-16. Cross-Sectional View of 30 MT Block

C46

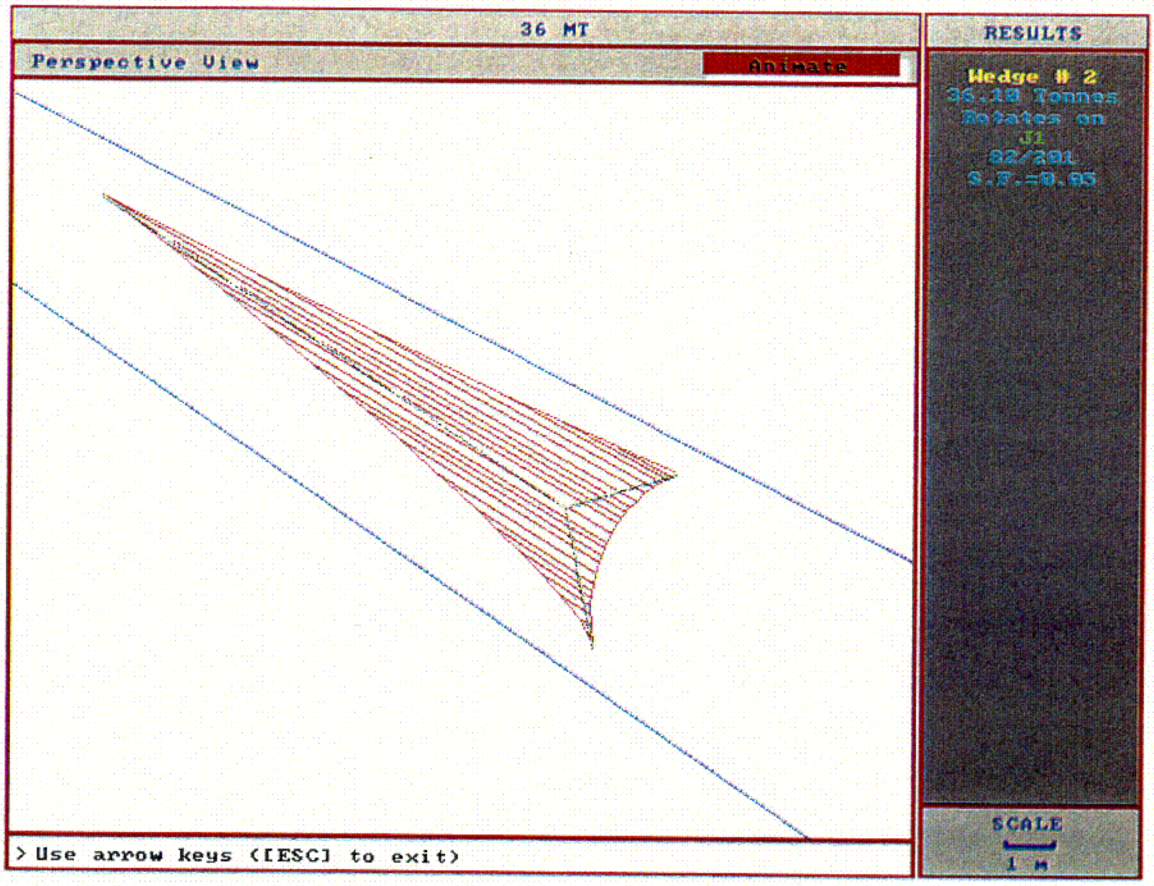


Figure IX-17. Perspective View of 36 MT Block

C47

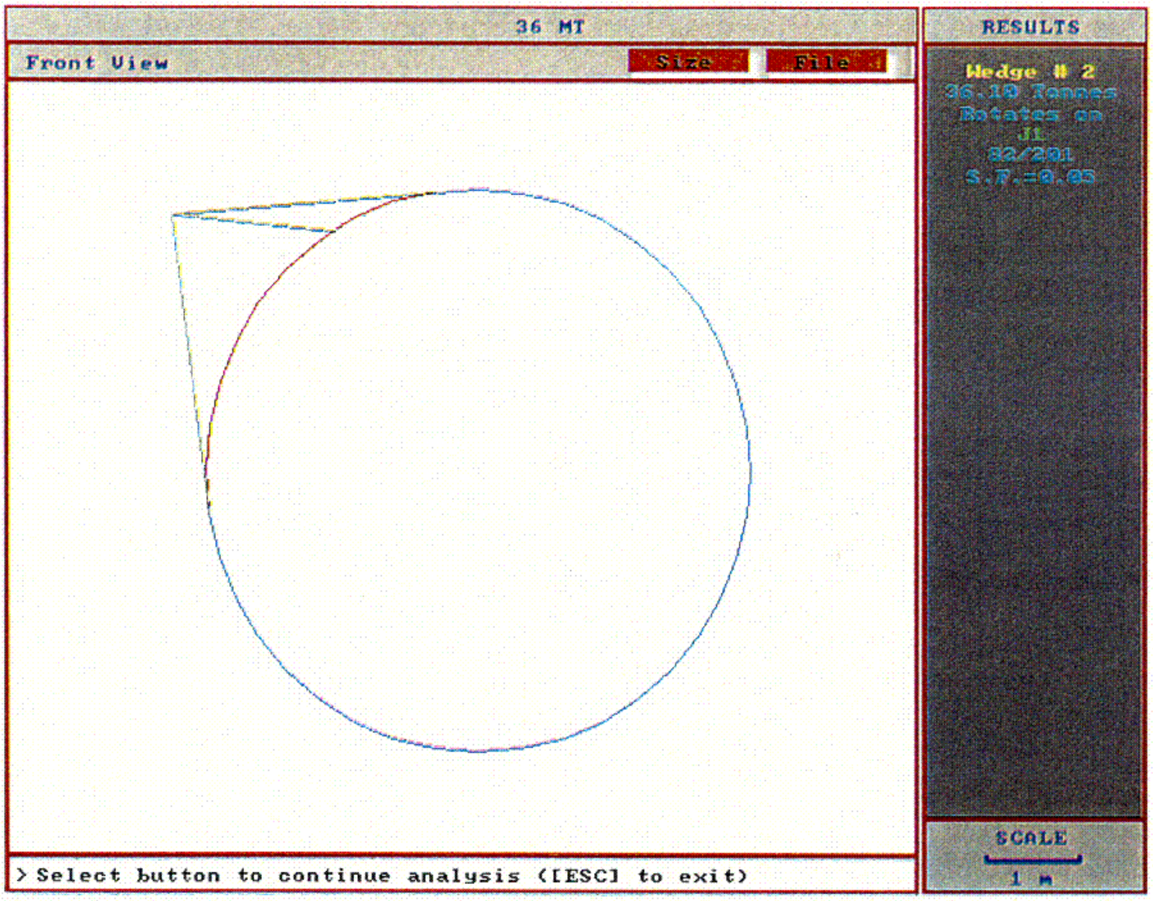


Figure IX-18. Cross-Sectional View of 36 MT Block

C48

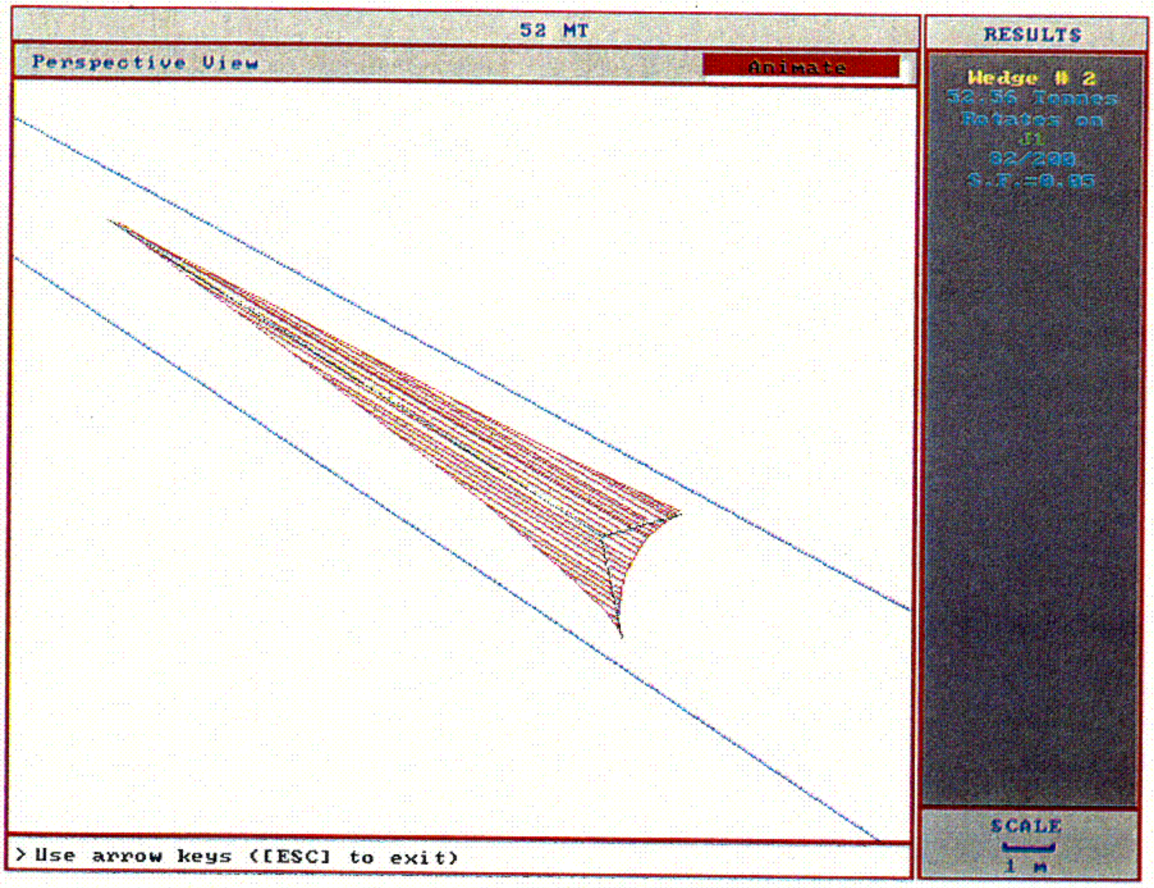


Figure IX-19. Perspective View of 52 MT Block

C49

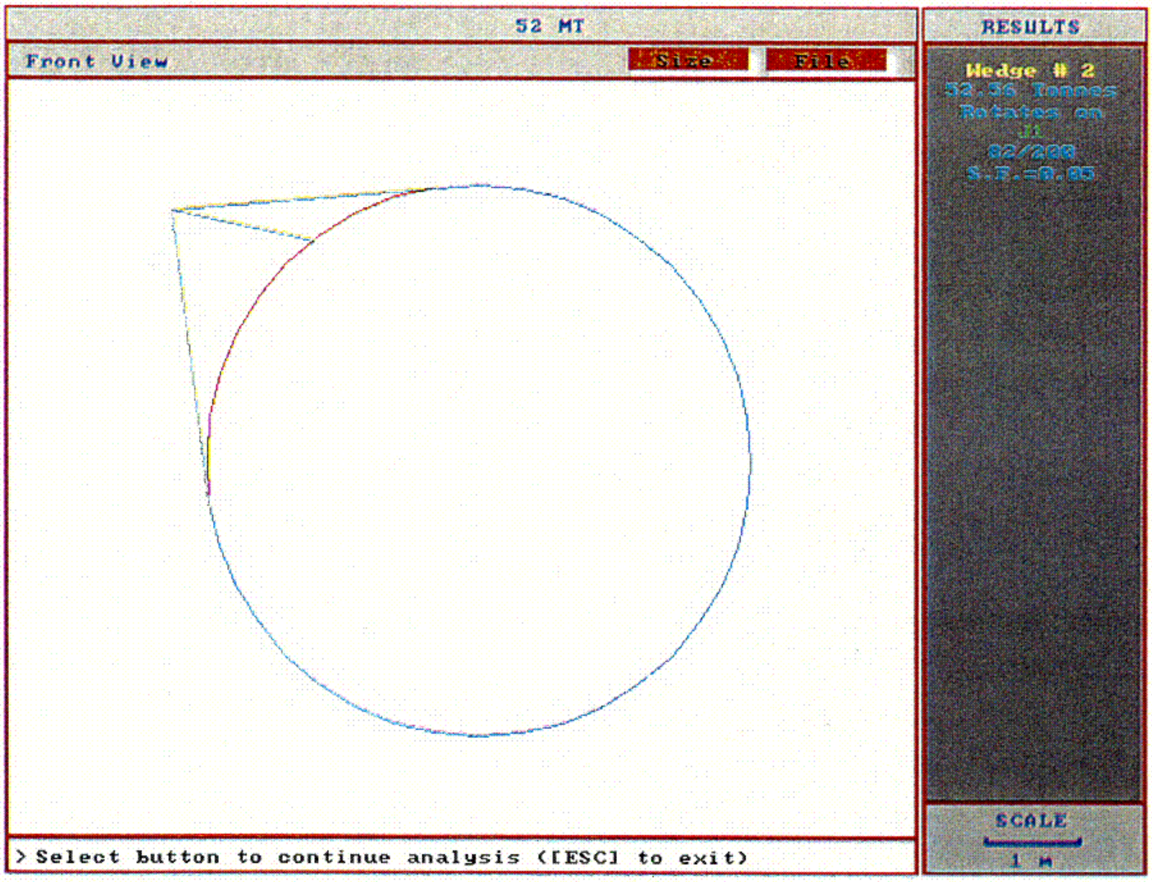


Figure IX-20. Cross-Sectional View of 52 MT Block

C50

ATTACHMENT X

BLOCK SIZE PROBABILITY OF OCCURRENCE DATA

BLOCK SIZE PROBABILITY OF OCCURRENCE DATA

Block size probability data as described in Sections 6.3.4 and 6.4.1 are presented in this attachment, including both static and static plus seismic results. The results are based on 5.5-m-diameter emplacement drifts with a tunnel azimuth of 75°. These results do not include backfill. These results are taken from DRKBA output files (*K022AA.bsd*, *K036AA.bsd*, *K050AA.bsd*) and calculation files (*tpmn seismic 75 res v1.xls*, *tpll seismic 75 res v1.xls*, *tpln seismic 75 res v2.xls*) provided in Attachment II. Block size probability data are provided for the Tptpmn unit (Table X-1), the Tptpll unit (Table X-2), and the Tptpln unit (Table X-3).

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
0.5	0.01	0.03	40	0.290	40	0.286	41	0.266	41	0.266
1.5	0.04	0.10	67	0.486	67	0.479	70	0.455	70	0.455
2.5	0.07	0.17	80	0.580	80	0.571	83	0.539	83	0.539
3.5	0.10	0.24	87	0.630	87	0.621	90	0.584	90	0.584
4.5	0.13	0.31	91	0.659	91	0.650	94	0.610	94	0.610
5.5	0.16	0.38	100	0.725	100	0.714	103	0.669	103	0.669
6.5	0.18	0.44	104	0.754	104	0.743	107	0.695	107	0.695
7.5	0.21	0.51	108	0.783	108	0.771	111	0.721	111	0.721
8.5	0.24	0.58	111	0.804	111	0.793	114	0.740	114	0.740
9.5	0.27	0.65	112	0.812	112	0.800	116	0.753	116	0.753
10.5	0.30	0.72	114	0.826	114	0.814	118	0.766	118	0.766
11.5	0.33	0.78	116	0.841	116	0.829	120	0.779	120	0.779
12.5	0.35	0.85	119	0.862	119	0.850	123	0.799	123	0.799
13.5	0.38	0.92	120	0.870	120	0.857	124	0.805	124	0.805
14.5	0.41	0.99	123	0.891	123	0.879	127	0.825	127	0.825
15.5	0.44	1.06	123	0.891	123	0.879	128	0.831	128	0.831
16.5	0.47	1.13	124	0.899	124	0.886	129	0.838	129	0.838
17.5	0.50	1.19	125	0.906	125	0.893	130	0.844	130	0.844
18.5	0.52	1.26	125	0.906	125	0.893	130	0.844	130	0.844
19.5	0.55	1.33	126	0.913	126	0.900	132	0.857	132	0.857
20.5	0.58	1.40	128	0.928	128	0.914	134	0.870	134	0.870
21.5	0.61	1.47	128	0.928	128	0.914	134	0.870	134	0.870
22.5	0.64	1.54	129	0.935	129	0.921	135	0.877	135	0.877
23.5	0.67	1.60	129	0.935	129	0.921	135	0.877	135	0.877
24.5	0.69	1.67	129	0.935	129	0.921	135	0.877	135	0.877
25.5	0.72	1.74	130	0.942	130	0.929	136	0.883	136	0.883
26.5	0.75	1.81	130	0.942	130	0.929	136	0.883	136	0.883
27.5	0.78	1.88	130	0.942	130	0.929	136	0.883	136	0.883
28.5	0.81	1.94	130	0.942	130	0.929	136	0.883	136	0.883

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
29.5	0.84	2.01	130	0.942	130	0.929	136	0.883	136	0.883
30.5	0.86	2.08	130	0.942	130	0.929	136	0.883	136	0.883
31.5	0.89	2.15	130	0.942	130	0.929	136	0.883	136	0.883
32.5	0.92	2.22	130	0.942	130	0.929	136	0.883	136	0.883
33.5	0.95	2.29	131	0.949	131	0.936	137	0.890	137	0.890
34.5	0.98	2.35	131	0.949	131	0.936	138	0.896	138	0.896
35.5	1.01	2.42	131	0.949	131	0.936	138	0.896	138	0.896
36.5	1.03	2.49	131	0.949	131	0.936	138	0.896	138	0.896
37.5	1.06	2.56	131	0.949	131	0.936	139	0.903	139	0.903
38.5	1.09	2.63	131	0.949	131	0.936	139	0.903	139	0.903
39.5	1.12	2.70	131	0.949	131	0.936	139	0.903	139	0.903
40.5	1.15	2.76	131	0.949	131	0.936	139	0.903	139	0.903
41.5	1.18	2.83	131	0.949	131	0.936	139	0.903	139	0.903
42.5	1.20	2.90	131	0.949	131	0.936	139	0.903	139	0.903
43.5	1.23	2.97	131	0.949	131	0.936	140	0.909	140	0.909
44.5	1.26	3.04	131	0.949	131	0.936	140	0.909	140	0.909
45.5	1.29	3.11	131	0.949	131	0.936	140	0.909	140	0.909
46.5	1.32	3.17	131	0.949	131	0.936	140	0.909	140	0.909
47.5	1.35	3.24	131	0.949	131	0.936	140	0.909	140	0.909
48.5	1.37	3.31	132	0.957	132	0.943	142	0.922	142	0.922
49.5	1.40	3.38	132	0.957	132	0.943	142	0.922	142	0.922
50.5	1.43	3.45	133	0.964	133	0.950	143	0.929	143	0.929
51.5	1.46	3.51	133	0.964	133	0.950	144	0.935	144	0.935
52.5	1.49	3.58	133	0.964	133	0.950	144	0.935	144	0.935
53.5	1.51	3.65	133	0.964	133	0.950	144	0.935	144	0.935
54.5	1.54	3.72	134	0.971	134	0.957	145	0.942	145	0.942
55.5	1.57	3.79	135	0.978	135	0.964	146	0.948	146	0.948
56.5	1.60	3.86	135	0.978	135	0.964	146	0.948	146	0.948
57.5	1.63	3.92	135	0.978	135	0.964	146	0.948	146	0.948
58.5	1.66	3.99	135	0.978	135	0.964	146	0.948	146	0.948
59.5	1.68	4.06	135	0.978	135	0.964	146	0.948	146	0.948
60.5	1.71	4.13	135	0.978	135	0.964	146	0.948	146	0.948
61.5	1.74	4.20	135	0.978	135	0.964	146	0.948	146	0.948
62.5	1.77	4.27	135	0.978	135	0.964	146	0.948	146	0.948
63.5	1.80	4.33	135	0.978	135	0.964	147	0.955	147	0.955
64.5	1.83	4.40	136	0.986	136	0.971	148	0.961	148	0.961
65.5	1.85	4.47	136	0.986	136	0.971	148	0.961	148	0.961
66.5	1.88	4.54	137	0.993	137	0.979	149	0.968	149	0.968
67.5	1.91	4.61	137	0.993	137	0.979	149	0.968	149	0.968
68.5	1.94	4.67	137	0.993	137	0.979	149	0.968	149	0.968

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft³	m³	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
69.5	1.97	4.74	137	0.993	137	0.979	149	0.968	149	0.968
70.5	2.00	4.81	137	0.993	137	0.979	149	0.968	149	0.968
71.5	2.02	4.88	137	0.993	137	0.979	149	0.968	149	0.968
72.5	2.05	4.95	137	0.993	137	0.979	149	0.968	149	0.968
73.5	2.08	5.02	137	0.993	137	0.979	149	0.968	149	0.968
74.5	2.11	5.08	137	0.993	137	0.979	149	0.968	149	0.968
75.5	2.14	5.15	137	0.993	137	0.979	149	0.968	149	0.968
76.5	2.17	5.22	137	0.993	137	0.979	149	0.968	149	0.968
77.5	2.19	5.29	137	0.993	137	0.979	149	0.968	149	0.968
78.5	2.22	5.36	137	0.993	137	0.979	149	0.968	149	0.968
79.5	2.25	5.43	137	0.993	137	0.979	149	0.968	149	0.968
80.5	2.28	5.49	137	0.993	137	0.979	149	0.968	149	0.968
81.5	2.31	5.56	137	0.993	137	0.979	149	0.968	149	0.968
82.5	2.34	5.63	137	0.993	137	0.979	149	0.968	149	0.968
83.5	2.36	5.70	137	0.993	137	0.979	149	0.968	149	0.968
84.5	2.39	5.77	137	0.993	137	0.979	149	0.968	149	0.968
85.5	2.42	5.83	137	0.993	137	0.979	149	0.968	149	0.968
86.5	2.45	5.90	137	0.993	137	0.979	149	0.968	149	0.968
87.5	2.48	5.97	137	0.993	137	0.979	149	0.968	149	0.968
88.5	2.51	6.04	137	0.993	137	0.979	149	0.968	149	0.968
89.5	2.53	6.11	137	0.993	137	0.979	149	0.968	149	0.968
90.5	2.56	6.18	137	0.993	137	0.979	149	0.968	149	0.968
91.5	2.59	6.24	137	0.993	137	0.979	149	0.968	149	0.968
92.5	2.62	6.31	137	0.993	137	0.979	149	0.968	149	0.968
93.5	2.65	6.38	137	0.993	137	0.979	149	0.968	149	0.968
94.5	2.68	6.45	137	0.993	137	0.979	149	0.968	149	0.968
95.5	2.70	6.52	137	0.993	137	0.979	149	0.968	149	0.968
96.5	2.73	6.59	137	0.993	137	0.979	150	0.974	150	0.974
97.5	2.76	6.65	137	0.993	137	0.979	150	0.974	150	0.974
98.5	2.79	6.72	137	0.993	137	0.979	150	0.974	150	0.974
99.5	2.82	6.79	137	0.993	137	0.979	150	0.974	150	0.974
100.5	2.85	6.86	137	0.993	137	0.979	150	0.974	150	0.974
101.5	2.87	6.93	137	0.993	137	0.979	150	0.974	150	0.974
102.5	2.90	6.99	137	0.993	137	0.979	150	0.974	150	0.974
103.5	2.93	7.06	137	0.993	137	0.979	150	0.974	150	0.974
104.5	2.96	7.13	137	0.993	137	0.979	150	0.974	150	0.974
105.5	2.99	7.20	137	0.993	137	0.979	150	0.974	150	0.974
106.5	3.02	7.27	137	0.993	137	0.979	150	0.974	150	0.974
107.5	3.04	7.34	137	0.993	137	0.979	150	0.974	150	0.974
108.5	3.07	7.40	137	0.993	137	0.979	150	0.974	150	0.974

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft³	m³	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
109.5	3.10	7.47	137	0.993	137	0.979	150	0.974	150	0.974
110.5	3.13	7.54	137	0.993	137	0.979	150	0.974	150	0.974
111.5	3.16	7.61	137	0.993	137	0.979	150	0.974	150	0.974
112.5	3.19	7.68	137	0.993	137	0.979	150	0.974	150	0.974
113.5	3.21	7.75	137	0.993	137	0.979	150	0.974	150	0.974
114.5	3.24	7.81	137	0.993	137	0.979	150	0.974	150	0.974
115.5	3.27	7.88	137	0.993	137	0.979	150	0.974	150	0.974
116.5	3.30	7.95	137	0.993	137	0.979	150	0.974	150	0.974
117.5	3.33	8.02	137	0.993	137	0.979	150	0.974	150	0.974
118.5	3.36	8.09	137	0.993	137	0.979	150	0.974	150	0.974
119.5	3.38	8.16	137	0.993	137	0.979	150	0.974	150	0.974
120.5	3.41	8.22	137	0.993	137	0.979	150	0.974	150	0.974
121.5	3.44	8.29	137	0.993	137	0.979	150	0.974	150	0.974
122.5	3.47	8.36	137	0.993	137	0.979	150	0.974	150	0.974
123.5	3.50	8.43	137	0.993	137	0.979	150	0.974	150	0.974
124.5	3.53	8.50	137	0.993	137	0.979	150	0.974	150	0.974
125.5	3.55	8.56	137	0.993	137	0.979	150	0.974	150	0.974
126.5	3.58	8.63	137	0.993	137	0.979	150	0.974	150	0.974
127.5	3.61	8.70	137	0.993	137	0.979	150	0.974	150	0.974
128.5	3.64	8.77	137	0.993	137	0.979	150	0.974	150	0.974
129.5	3.67	8.84	137	0.993	137	0.979	150	0.974	150	0.974
130.5	3.70	8.91	137	0.993	137	0.979	150	0.974	150	0.974
131.5	3.72	8.97	137	0.993	137	0.979	150	0.974	150	0.974
132.5	3.75	9.04	137	0.993	137	0.979	150	0.974	150	0.974
133.5	3.78	9.11	137	0.993	137	0.979	150	0.974	150	0.974
134.5	3.81	9.18	137	0.993	137	0.979	150	0.974	150	0.974
135.5	3.84	9.25	137	0.993	137	0.979	150	0.974	150	0.974
136.5	3.87	9.32	137	0.993	137	0.979	150	0.974	150	0.974
137.5	3.89	9.38	137	0.993	137	0.979	150	0.974	150	0.974
138.5	3.92	9.45	137	0.993	137	0.979	150	0.974	150	0.974
139.5	3.95	9.52	137	0.993	137	0.979	150	0.974	150	0.974
140.5	3.98	9.59	137	0.993	137	0.979	150	0.974	150	0.974
141.5	4.01	9.66	137	0.993	137	0.979	150	0.974	150	0.974
142.5	4.04	9.72	137	0.993	137	0.979	150	0.974	150	0.974
143.5	4.06	9.79	137	0.993	137	0.979	150	0.974	150	0.974
144.5	4.09	9.86	137	0.993	137	0.979	150	0.974	150	0.974
145.5	4.12	9.93	137	0.993	137	0.979	150	0.974	150	0.974
146.5	4.15	10.00	137	0.993	137	0.979	150	0.974	150	0.974
147.5	4.18	10.07	137	0.993	137	0.979	150	0.974	150	0.974
148.5	4.21	10.13	137	0.993	137	0.979	150	0.974	150	0.974

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft³	m³	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
149.5	4.23	10.20	137	0.993	137	0.979	150	0.974	150	0.974
150.5	4.26	10.27	137	0.993	138	0.986	151	0.981	151	0.981
151.5	4.29	10.34	137	0.993	138	0.986	151	0.981	151	0.981
152.5	4.32	10.41	137	0.993	138	0.986	151	0.981	151	0.981
153.5	4.35	10.48	137	0.993	138	0.986	151	0.981	151	0.981
154.5	4.37	10.54	137	0.993	138	0.986	151	0.981	151	0.981
155.5	4.40	10.61	137	0.993	138	0.986	151	0.981	151	0.981
156.5	4.43	10.68	137	0.993	138	0.986	151	0.981	151	0.981
157.5	4.46	10.75	137	0.993	138	0.986	151	0.981	151	0.981
158.5	4.49	10.82	137	0.993	138	0.986	151	0.981	151	0.981
159.5	4.52	10.88	137	0.993	138	0.986	151	0.981	151	0.981
160.5	4.54	10.95	137	0.993	138	0.986	151	0.981	151	0.981
161.5	4.57	11.02	137	0.993	138	0.986	151	0.981	151	0.981
162.5	4.60	11.09	137	0.993	138	0.986	151	0.981	151	0.981
163.5	4.63	11.16	137	0.993	138	0.986	151	0.981	151	0.981
164.5	4.66	11.23	137	0.993	138	0.986	151	0.981	151	0.981
165.5	4.69	11.29	137	0.993	138	0.986	151	0.981	151	0.981
166.5	4.71	11.36	137	0.993	138	0.986	151	0.981	151	0.981
167.5	4.74	11.43	137	0.993	138	0.986	151	0.981	151	0.981
168.5	4.77	11.50	137	0.993	138	0.986	151	0.981	151	0.981
169.5	4.80	11.57	137	0.993	138	0.986	151	0.981	151	0.981
170.5	4.83	11.64	137	0.993	138	0.986	151	0.981	151	0.981
171.5	4.86	11.70	137	0.993	138	0.986	151	0.981	151	0.981
172.5	4.88	11.77	137	0.993	138	0.986	151	0.981	151	0.981
173.5	4.91	11.84	137	0.993	138	0.986	151	0.981	151	0.981
174.5	4.94	11.91	137	0.993	138	0.986	151	0.981	151	0.981
175.5	4.97	11.98	137	0.993	138	0.986	151	0.981	151	0.981
176.5	5.00	12.04	137	0.993	138	0.986	151	0.981	151	0.981
177.5	5.03	12.11	138	1.000	139	0.993	152	0.987	152	0.987
178.5	5.05	12.18	138	1.000	139	0.993	152	0.987	152	0.987
179.5	5.08	12.25	138	1.000	139	0.993	152	0.987	152	0.987
180.5	5.11	12.32	138	1.000	139	0.993	152	0.987	152	0.987
181.5	5.14	12.39	138	1.000	139	0.993	152	0.987	152	0.987
182.5	5.17	12.45	138	1.000	139	0.993	152	0.987	152	0.987
183.5	5.20	12.52	138	1.000	139	0.993	152	0.987	152	0.987
184.5	5.22	12.59	138	1.000	139	0.993	152	0.987	152	0.987
185.5	5.25	12.66	138	1.000	139	0.993	152	0.987	152	0.987
186.5	5.28	12.73	138	1.000	139	0.993	152	0.987	152	0.987
187.5	5.31	12.80	138	1.000	139	0.993	152	0.987	152	0.987
188.5	5.34	12.86	138	1.000	139	0.993	152	0.987	152	0.987

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft³	m³	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
189.5	5.37	12.93	138	1.000	139	0.993	152	0.987	152	0.987
190.5	5.39	13.00	138	1.000	139	0.993	152	0.987	152	0.987
191.5	5.42	13.07	138	1.000	139	0.993	152	0.987	152	0.987
192.5	5.45	13.14	138	1.000	139	0.993	152	0.987	152	0.987
193.5	5.48	13.21	138	1.000	139	0.993	152	0.987	152	0.987
194.5	5.51	13.27	138	1.000	139	0.993	152	0.987	152	0.987
195.5	5.54	13.34	138	1.000	139	0.993	152	0.987	152	0.987
196.5	5.56	13.41	138	1.000	139	0.993	152	0.987	152	0.987
197.5	5.59	13.48	138	1.000	139	0.993	152	0.987	152	0.987
198.5	5.62	13.55	138	1.000	139	0.993	152	0.987	152	0.987
199.5	5.65	13.61	138	1.000	139	0.993	152	0.987	152	0.987
200.5	5.68	13.68	138	1.000	139	0.993	152	0.987	152	0.987
201.5	5.71	13.75	138	1.000	139	0.993	152	0.987	152	0.987
202.5	5.73	13.82	138	1.000	139	0.993	152	0.987	152	0.987
203.5	5.76	13.89	138	1.000	139	0.993	152	0.987	152	0.987
204.5	5.79	13.96	138	1.000	139	0.993	152	0.987	152	0.987
205.5	5.82	14.02	138	1.000	139	0.993	152	0.987	152	0.987
206.5	5.85	14.09	138	1.000	139	0.993	152	0.987	152	0.987
207.5	5.88	14.16	138	1.000	139	0.993	152	0.987	152	0.987
208.5	5.90	14.23	138	1.000	139	0.993	152	0.987	152	0.987
209.5	5.93	14.30	138	1.000	139	0.993	152	0.987	152	0.987
210.5	5.96	14.37	138	1.000	139	0.993	152	0.987	152	0.987
211.5	5.99	14.43	138	1.000	139	0.993	152	0.987	152	0.987
212.5	6.02	14.50	138	1.000	139	0.993	152	0.987	152	0.987
213.5	6.05	14.57	138	1.000	139	0.993	152	0.987	152	0.987
214.5	6.07	14.64	138	1.000	139	0.993	152	0.987	152	0.987
215.5	6.10	14.71	138	1.000	139	0.993	152	0.987	152	0.987
216.5	6.13	14.77	138	1.000	139	0.993	152	0.987	152	0.987
217.5	6.16	14.84	138	1.000	139	0.993	152	0.987	152	0.987
218.5	6.19	14.91	138	1.000	140	1.000	153	0.994	153	0.994
219.5	6.22	14.98	138	1.000	140	1.000	153	0.994	153	0.994
220.5	6.24	15.05	138	1.000	140	1.000	153	0.994	153	0.994
221.5	6.27	15.12	138	1.000	140	1.000	153	0.994	153	0.994
222.5	6.30	15.18	138	1.000	140	1.000	153	0.994	153	0.994
223.5	6.33	15.25	138	1.000	140	1.000	153	0.994	153	0.994
224.5	6.36	15.32	138	1.000	140	1.000	153	0.994	153	0.994
225.5	6.39	15.39	138	1.000	140	1.000	153	0.994	153	0.994
226.5	6.41	15.46	138	1.000	140	1.000	153	0.994	153	0.994
227.5	6.44	15.53	138	1.000	140	1.000	153	0.994	153	0.994
228.5	6.47	15.59	138	1.000	140	1.000	153	0.994	153	0.994

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft³	m³	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
229.5	6.50	15.66	138	1.000	140	1.000	153	0.994	153	0.994
230.5	6.53	15.73	138	1.000	140	1.000	153	0.994	153	0.994
231.5	6.56	15.80	138	1.000	140	1.000	153	0.994	153	0.994
232.5	6.58	15.87	138	1.000	140	1.000	153	0.994	153	0.994
233.5	6.61	15.93	138	1.000	140	1.000	153	0.994	153	0.994
234.5	6.64	16.00	138	1.000	140	1.000	153	0.994	153	0.994
235.5	6.67	16.07	138	1.000	140	1.000	153	0.994	153	0.994
236.5	6.70	16.14	138	1.000	140	1.000	153	0.994	153	0.994
237.5	6.73	16.21	138	1.000	140	1.000	153	0.994	153	0.994
238.5	6.75	16.28	138	1.000	140	1.000	153	0.994	153	0.994
239.5	6.78	16.34	138	1.000	140	1.000	153	0.994	153	0.994
240.5	6.81	16.41	138	1.000	140	1.000	153	0.994	153	0.994
241.5	6.84	16.48	138	1.000	140	1.000	153	0.994	153	0.994
242.5	6.87	16.55	138	1.000	140	1.000	153	0.994	153	0.994
243.5	6.90	16.62	138	1.000	140	1.000	153	0.994	153	0.994
244.5	6.92	16.69	138	1.000	140	1.000	153	0.994	153	0.994
245.5	6.95	16.75	138	1.000	140	1.000	153	0.994	153	0.994
246.5	6.98	16.82	138	1.000	140	1.000	153	0.994	153	0.994
247.5	7.01	16.89	138	1.000	140	1.000	153	0.994	153	0.994
248.5	7.04	16.96	138	1.000	140	1.000	153	0.994	153	0.994
249.5	7.07	17.03	138	1.000	140	1.000	153	0.994	153	0.994
250.5	7.09	17.10	138	1.000	140	1.000	153	0.994	153	0.994
251.5	7.12	17.16	138	1.000	140	1.000	153	0.994	153	0.994
252.5	7.15	17.23	138	1.000	140	1.000	153	0.994	153	0.994
253.5	7.18	17.30	138	1.000	140	1.000	153	0.994	153	0.994
254.5	7.21	17.37	138	1.000	140	1.000	153	0.994	153	0.994
255.5	7.23	17.44	138	1.000	140	1.000	153	0.994	153	0.994
256.5	7.26	17.50	138	1.000	140	1.000	153	0.994	153	0.994
257.5	7.29	17.57	138	1.000	140	1.000	153	0.994	153	0.994
258.5	7.32	17.64	138	1.000	140	1.000	153	0.994	153	0.994
259.5	7.35	17.71	138	1.000	140	1.000	153	0.994	153	0.994
260.5	7.38	17.78	138	1.000	140	1.000	153	0.994	153	0.994
261.5	7.40	17.85	138	1.000	140	1.000	153	0.994	153	0.994
262.5	7.43	17.91	138	1.000	140	1.000	153	0.994	153	0.994
263.5	7.46	17.98	138	1.000	140	1.000	153	0.994	153	0.994
264.5	7.49	18.05	138	1.000	140	1.000	153	0.994	153	0.994
265.5	7.52	18.12	138	1.000	140	1.000	153	0.994	153	0.994
266.5	7.55	18.19	138	1.000	140	1.000	153	0.994	153	0.994
267.5	7.57	18.26	138	1.000	140	1.000	153	0.994	153	0.994
268.5	7.60	18.32	138	1.000	140	1.000	153	0.994	153	0.994

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
269.5	7.63	18.39	138	1.000	140	1.000	153	0.994	153	0.994
270.5	7.66	18.46	138	1.000	140	1.000	153	0.994	153	0.994
271.5	7.69	18.53	138	1.000	140	1.000	153	0.994	153	0.994
272.5	7.72	18.60	138	1.000	140	1.000	153	0.994	153	0.994
273.5	7.74	18.66	138	1.000	140	1.000	153	0.994	153	0.994
274.5	7.77	18.73	138	1.000	140	1.000	153	0.994	153	0.994
275.5	7.80	18.80	138	1.000	140	1.000	153	0.994	153	0.994
276.5	7.83	18.87	138	1.000	140	1.000	153	0.994	153	0.994
277.5	7.86	18.94	138	1.000	140	1.000	153	0.994	153	0.994
278.5	7.89	19.01	138	1.000	140	1.000	153	0.994	153	0.994
279.5	7.91	19.07	138	1.000	140	1.000	153	0.994	153	0.994
280.5	7.94	19.14	138	1.000	140	1.000	153	0.994	153	0.994
281.5	7.97	19.21	138	1.000	140	1.000	153	0.994	153	0.994
282.5	8.00	19.28	138	1.000	140	1.000	153	0.994	153	0.994
283.5	8.03	19.35	138	1.000	140	1.000	153	0.994	153	0.994
284.5	8.06	19.42	138	1.000	140	1.000	153	0.994	153	0.994
285.5	8.08	19.48	138	1.000	140	1.000	153	0.994	153	0.994
286.5	8.11	19.55	138	1.000	140	1.000	153	0.994	153	0.994
287.5	8.14	19.62	138	1.000	140	1.000	153	0.994	153	0.994
288.5	8.17	19.69	138	1.000	140	1.000	153	0.994	153	0.994
289.5	8.20	19.76	138	1.000	140	1.000	153	0.994	153	0.994
290.5	8.23	19.82	138	1.000	140	1.000	153	0.994	153	0.994
291.5	8.25	19.89	138	1.000	140	1.000	153	0.994	153	0.994
292.5	8.28	19.96	138	1.000	140	1.000	153	0.994	153	0.994
293.5	8.31	20.03	138	1.000	140	1.000	153	0.994	153	0.994
294.5	8.34	20.10	138	1.000	140	1.000	153	0.994	153	0.994
295.5	8.37	20.17	138	1.000	140	1.000	153	0.994	153	0.994
296.5	8.40	20.23	138	1.000	140	1.000	153	0.994	153	0.994
297.5	8.42	20.30	138	1.000	140	1.000	153	0.994	153	0.994
298.5	8.45	20.37	138	1.000	140	1.000	153	0.994	153	0.994
299.5	8.48	20.44	138	1.000	140	1.000	153	0.994	153	0.994
300.5	8.51	20.51	138	1.000	140	1.000	153	0.994	153	0.994
301.5	8.54	20.58	138	1.000	140	1.000	153	0.994	153	0.994
302.5	8.57	20.64	138	1.000	140	1.000	153	0.994	153	0.994
303.5	8.59	20.71	138	1.000	140	1.000	153	0.994	153	0.994
304.5	8.62	20.78	138	1.000	140	1.000	153	0.994	153	0.994
305.5	8.65	20.85	138	1.000	140	1.000	153	0.994	153	0.994
306.5	8.68	20.92	138	1.000	140	1.000	153	0.994	153	0.994
307.5	8.71	20.98	138	1.000	140	1.000	153	0.994	153	0.994
308.5	8.74	21.05	138	1.000	140	1.000	153	0.994	153	0.994

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
309.5	8.76	21.12	138	1.000	140	1.000	153	0.994	153	0.994
310.5	8.79	21.19	138	1.000	140	1.000	153	0.994	153	0.994
311.5	8.82	21.26	138	1.000	140	1.000	153	0.994	153	0.994
312.5	8.85	21.33	138	1.000	140	1.000	153	0.994	153	0.994
313.5	8.88	21.39	138	1.000	140	1.000	153	0.994	153	0.994
314.5	8.91	21.46	138	1.000	140	1.000	153	0.994	153	0.994
315.5	8.93	21.53	138	1.000	140	1.000	153	0.994	153	0.994
316.5	8.96	21.60	138	1.000	140	1.000	153	0.994	153	0.994
317.5	8.99	21.67	138	1.000	140	1.000	153	0.994	153	0.994
318.5	9.02	21.74	138	1.000	140	1.000	153	0.994	153	0.994
319.5	9.05	21.80	138	1.000	140	1.000	153	0.994	153	0.994
320.5	9.08	21.87	138	1.000	140	1.000	153	0.994	153	0.994
321.5	9.10	21.94	138	1.000	140	1.000	153	0.994	153	0.994
322.5	9.13	22.01	138	1.000	140	1.000	153	0.994	153	0.994
323.5	9.16	22.08	138	1.000	140	1.000	153	0.994	153	0.994
324.5	9.19	22.15	138	1.000	140	1.000	153	0.994	153	0.994
325.5	9.22	22.21	138	1.000	140	1.000	153	0.994	153	0.994
326.5	9.25	22.28	138	1.000	140	1.000	153	0.994	153	0.994
327.5	9.27	22.35	138	1.000	140	1.000	153	0.994	153	0.994
328.5	9.30	22.42	138	1.000	140	1.000	153	0.994	153	0.994
329.5	9.33	22.49	138	1.000	140	1.000	153	0.994	153	0.994
330.5	9.36	22.55	138	1.000	140	1.000	153	0.994	153	0.994
331.5	9.39	22.62	138	1.000	140	1.000	153	0.994	153	0.994
332.5	9.42	22.69	138	1.000	140	1.000	153	0.994	153	0.994
333.5	9.44	22.76	138	1.000	140	1.000	153	0.994	153	0.994
334.5	9.47	22.83	138	1.000	140	1.000	153	0.994	153	0.994
335.5	9.50	22.90	138	1.000	140	1.000	153	0.994	153	0.994
336.5	9.53	22.96	138	1.000	140	1.000	153	0.994	153	0.994
337.5	9.56	23.03	138	1.000	140	1.000	153	0.994	153	0.994
338.5	9.59	23.10	138	1.000	140	1.000	153	0.994	153	0.994
339.5	9.61	23.17	138	1.000	140	1.000	153	0.994	153	0.994
340.5	9.64	23.24	138	1.000	140	1.000	153	0.994	153	0.994
341.5	9.67	23.31	138	1.000	140	1.000	153	0.994	153	0.994
342.5	9.70	23.37	138	1.000	140	1.000	153	0.994	153	0.994
343.5	9.73	23.44	138	1.000	140	1.000	153	0.994	153	0.994
344.5	9.76	23.51	138	1.000	140	1.000	153	0.994	153	0.994
345.5	9.78	23.58	138	1.000	140	1.000	153	0.994	153	0.994
346.5	9.81	23.65	138	1.000	140	1.000	153	0.994	153	0.994
347.5	9.84	23.71	138	1.000	140	1.000	153	0.994	153	0.994
348.5	9.87	23.78	138	1.000	140	1.000	153	0.994	153	0.994

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
349.5	9.90	23.85	138	1.000	140	1.000	153	0.994	153	0.994
350.5	9.93	23.92	138	1.000	140	1.000	153	0.994	153	0.994
351.5	9.95	23.99	138	1.000	140	1.000	153	0.994	153	0.994
352.5	9.98	24.06	138	1.000	140	1.000	153	0.994	153	0.994
353.5	10.01	24.12	138	1.000	140	1.000	153	0.994	153	0.994
354.5	10.04	24.19	138	1.000	140	1.000	153	0.994	153	0.994
355.5	10.07	24.26	138	1.000	140	1.000	153	0.994	153	0.994
356.5	10.09	24.33	138	1.000	140	1.000	153	0.994	153	0.994
357.5	10.12	24.40	138	1.000	140	1.000	153	0.994	153	0.994
358.5	10.15	24.47	138	1.000	140	1.000	153	0.994	153	0.994
359.5	10.18	24.53	138	1.000	140	1.000	153	0.994	153	0.994
360.5	10.21	24.60	138	1.000	140	1.000	153	0.994	153	0.994
361.5	10.24	24.67	138	1.000	140	1.000	153	0.994	153	0.994
362.5	10.26	24.74	138	1.000	140	1.000	153	0.994	153	0.994
363.5	10.29	24.81	138	1.000	140	1.000	153	0.994	153	0.994
364.5	10.32	24.87	138	1.000	140	1.000	153	0.994	153	0.994
365.5	10.35	24.94	138	1.000	140	1.000	153	0.994	153	0.994
366.5	10.38	25.01	138	1.000	140	1.000	153	0.994	153	0.994
367.5	10.41	25.08	138	1.000	140	1.000	153	0.994	153	0.994
368.5	10.43	25.15	138	1.000	140	1.000	153	0.994	153	0.994
369.5	10.46	25.22	138	1.000	140	1.000	153	0.994	153	0.994
370.5	10.49	25.28	138	1.000	140	1.000	153	0.994	153	0.994
371.5	10.52	25.35	138	1.000	140	1.000	153	0.994	153	0.994
372.5	10.55	25.42	138	1.000	140	1.000	153	0.994	153	0.994
373.5	10.58	25.49	138	1.000	140	1.000	153	0.994	153	0.994
374.5	10.60	25.56	138	1.000	140	1.000	153	0.994	153	0.994
375.5	10.63	25.63	138	1.000	140	1.000	153	0.994	153	0.994
376.5	10.66	25.69	138	1.000	140	1.000	153	0.994	153	0.994
377.5	10.69	25.76	138	1.000	140	1.000	153	0.994	153	0.994
378.5	10.72	25.83	138	1.000	140	1.000	153	0.994	153	0.994
379.5	10.75	25.90	138	1.000	140	1.000	153	0.994	153	0.994
380.5	10.77	25.97	138	1.000	140	1.000	153	0.994	153	0.994
381.5	10.80	26.03	138	1.000	140	1.000	153	0.994	153	0.994
382.5	10.83	26.10	138	1.000	140	1.000	153	0.994	153	0.994
383.5	10.86	26.17	138	1.000	140	1.000	153	0.994	153	0.994
384.5	10.89	26.24	138	1.000	140	1.000	153	0.994	153	0.994
385.5	10.92	26.31	138	1.000	140	1.000	153	0.994	153	0.994
386.5	10.94	26.38	138	1.000	140	1.000	153	0.994	153	0.994
387.5	10.97	26.44	138	1.000	140	1.000	153	0.994	153	0.994
388.5	11.00	26.51	138	1.000	140	1.000	153	0.994	153	0.994

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
389.5	11.03	26.58	138	1.000	140	1.000	153	0.994	153	0.994
390.5	11.06	26.65	138	1.000	140	1.000	153	0.994	153	0.994
391.5	11.09	26.72	138	1.000	140	1.000	153	0.994	153	0.994
392.5	11.11	26.79	138	1.000	140	1.000	153	0.994	153	0.994
393.5	11.14	26.85	138	1.000	140	1.000	153	0.994	153	0.994
394.5	11.17	26.92	138	1.000	140	1.000	153	0.994	153	0.994
395.5	11.20	26.99	138	1.000	140	1.000	153	0.994	153	0.994
396.5	11.23	27.06	138	1.000	140	1.000	153	0.994	153	0.994
397.5	11.26	27.13	138	1.000	140	1.000	153	0.994	153	0.994
398.5	11.28	27.20	138	1.000	140	1.000	153	0.994	153	0.994
399.5	11.31	27.26	138	1.000	140	1.000	153	0.994	153	0.994
400.5	11.34	27.33	138	1.000	140	1.000	153	0.994	153	0.994
401.5	11.37	27.40	138	1.000	140	1.000	153	0.994	153	0.994
402.5	11.40	27.47	138	1.000	140	1.000	153	0.994	153	0.994
403.5	11.43	27.54	138	1.000	140	1.000	153	0.994	153	0.994
404.5	11.45	27.60	138	1.000	140	1.000	153	0.994	153	0.994
405.5	11.48	27.67	138	1.000	140	1.000	153	0.994	153	0.994
406.5	11.51	27.74	138	1.000	140	1.000	153	0.994	153	0.994
407.5	11.54	27.81	138	1.000	140	1.000	153	0.994	153	0.994
408.5	11.57	27.88	138	1.000	140	1.000	153	0.994	153	0.994
409.5	11.60	27.95	138	1.000	140	1.000	153	0.994	153	0.994
410.5	11.62	28.01	138	1.000	140	1.000	153	0.994	153	0.994
411.5	11.65	28.08	138	1.000	140	1.000	153	0.994	153	0.994
412.5	11.68	28.15	138	1.000	140	1.000	153	0.994	153	0.994
413.5	11.71	28.22	138	1.000	140	1.000	153	0.994	153	0.994
414.5	11.74	28.29	138	1.000	140	1.000	153	0.994	153	0.994
415.5	11.77	28.36	138	1.000	140	1.000	153	0.994	153	0.994
416.5	11.79	28.42	138	1.000	140	1.000	153	0.994	153	0.994
417.5	11.82	28.49	138	1.000	140	1.000	153	0.994	153	0.994
418.5	11.85	28.56	138	1.000	140	1.000	153	0.994	153	0.994
419.5	11.88	28.63	138	1.000	140	1.000	153	0.994	153	0.994
420.5	11.91	28.70	138	1.000	140	1.000	153	0.994	153	0.994
421.5	11.94	28.76	138	1.000	140	1.000	153	0.994	153	0.994
422.5	11.96	28.83	138	1.000	140	1.000	153	0.994	153	0.994
423.5	11.99	28.90	138	1.000	140	1.000	153	0.994	153	0.994
424.5	12.02	28.97	138	1.000	140	1.000	153	0.994	153	0.994
425.5	12.05	29.04	138	1.000	140	1.000	153	0.994	153	0.994
426.5	12.08	29.11	138	1.000	140	1.000	153	0.994	153	0.994
427.5	12.11	29.17	138	1.000	140	1.000	153	0.994	153	0.994
428.5	12.13	29.24	138	1.000	140	1.000	153	0.994	153	0.994

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
429.5	12.16	29.31	138	1.000	140	1.000	153	0.994	153	0.994
430.5	12.19	29.38	138	1.000	140	1.000	153	0.994	153	0.994
431.5	12.22	29.45	138	1.000	140	1.000	153	0.994	153	0.994
432.5	12.25	29.52	138	1.000	140	1.000	153	0.994	153	0.994
433.5	12.28	29.58	138	1.000	140	1.000	153	0.994	153	0.994
434.5	12.30	29.65	138	1.000	140	1.000	153	0.994	153	0.994
435.5	12.33	29.72	138	1.000	140	1.000	153	0.994	153	0.994
436.5	12.36	29.79	138	1.000	140	1.000	153	0.994	153	0.994
437.5	12.39	29.86	138	1.000	140	1.000	153	0.994	153	0.994
438.5	12.42	29.92	138	1.000	140	1.000	153	0.994	153	0.994
439.5	12.45	29.99	138	1.000	140	1.000	153	0.994	153	0.994
440.5	12.47	30.06	138	1.000	140	1.000	153	0.994	153	0.994
441.5	12.50	30.13	138	1.000	140	1.000	153	0.994	153	0.994
442.5	12.53	30.20	138	1.000	140	1.000	153	0.994	153	0.994
443.5	12.56	30.27	138	1.000	140	1.000	153	0.994	153	0.994
444.5	12.59	30.33	138	1.000	140	1.000	153	0.994	153	0.994
445.5	12.62	30.40	138	1.000	140	1.000	153	0.994	153	0.994
446.5	12.64	30.47	138	1.000	140	1.000	153	0.994	153	0.994
447.5	12.67	30.54	138	1.000	140	1.000	153	0.994	153	0.994
448.5	12.70	30.61	138	1.000	140	1.000	153	0.994	153	0.994
449.5	12.73	30.68	138	1.000	140	1.000	153	0.994	153	0.994
450.5	12.76	30.74	138	1.000	140	1.000	153	0.994	153	0.994
451.5	12.79	30.81	138	1.000	140	1.000	153	0.994	153	0.994
452.5	12.81	30.88	138	1.000	140	1.000	153	0.994	153	0.994
453.5	12.84	30.95	138	1.000	140	1.000	153	0.994	153	0.994
454.5	12.87	31.02	138	1.000	140	1.000	153	0.994	153	0.994
455.5	12.90	31.08	138	1.000	140	1.000	153	0.994	153	0.994
456.5	12.93	31.15	138	1.000	140	1.000	153	0.994	153	0.994
457.5	12.95	31.22	138	1.000	140	1.000	153	0.994	153	0.994
458.5	12.98	31.29	138	1.000	140	1.000	153	0.994	153	0.994
459.5	13.01	31.36	138	1.000	140	1.000	153	0.994	153	0.994
460.5	13.04	31.43	138	1.000	140	1.000	153	0.994	153	0.994
461.5	13.07	31.49	138	1.000	140	1.000	153	0.994	153	0.994
462.5	13.10	31.56	138	1.000	140	1.000	153	0.994	153	0.994
463.5	13.12	31.63	138	1.000	140	1.000	153	0.994	153	0.994
464.5	13.15	31.70	138	1.000	140	1.000	153	0.994	153	0.994
465.5	13.18	31.77	138	1.000	140	1.000	153	0.994	153	0.994
466.5	13.21	31.84	138	1.000	140	1.000	153	0.994	153	0.994
467.5	13.24	31.90	138	1.000	140	1.000	153	0.994	153	0.994
468.5	13.27	31.97	138	1.000	140	1.000	153	0.994	153	0.994

Table X-1. Block Size Probability of Occurrence Data for the Tptpmn Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
469.5	13.29	32.04	138	1.000	140	1.000	153	0.994	153	0.994
470.5	13.32	32.11	138	1.000	140	1.000	153	0.994	153	0.994
471.5	13.35	32.18	138	1.000	140	1.000	153	0.994	153	0.994
472.5	13.38	32.25	138	1.000	140	1.000	153	0.994	153	0.994
473.5	13.41	32.31	138	1.000	140	1.000	153	0.994	153	0.994
474.5	13.44	32.38	138	1.000	140	1.000	153	0.994	153	0.994
475.5	13.46	32.45	138	1.000	140	1.000	153	0.994	153	0.994
476.5	13.49	32.52	138	1.000	140	1.000	153	0.994	153	0.994
477.5	13.52	32.59	138	1.000	140	1.000	153	0.994	153	0.994
478.5	13.55	32.65	138	1.000	140	1.000	153	0.994	153	0.994
479.5	13.58	32.72	138	1.000	140	1.000	153	0.994	153	0.994
480.5	13.61	32.79	138	1.000	140	1.000	153	0.994	153	0.994
481.5	13.63	32.86	138	1.000	140	1.000	153	0.994	153	0.994
482.5	13.66	32.93	138	1.000	140	1.000	153	0.994	153	0.994
483.5	13.69	33.00	138	1.000	140	1.000	153	0.994	153	0.994
484.5	13.72	33.06	138	1.000	140	1.000	153	0.994	153	0.994
485.5	13.75	33.13	138	1.000	140	1.000	153	0.994	153	0.994
486.5	13.78	33.20	138	1.000	140	1.000	153	0.994	153	0.994
487.5	13.80	33.27	138	1.000	140	1.000	153	0.994	153	0.994
488.5	13.83	33.34	138	1.000	140	1.000	153	0.994	153	0.994
489.5	13.86	33.41	138	1.000	140	1.000	153	0.994	153	0.994
490.5	13.89	33.47	138	1.000	140	1.000	153	0.994	153	0.994
491.5	13.92	33.54	138	1.000	140	1.000	153	0.994	153	0.994
492.5	13.95	33.61	138	1.000	140	1.000	153	0.994	153	0.994
493.5	13.97	33.68	138	1.000	140	1.000	153	0.994	153	0.994
494.5	14.00	33.75	138	1.000	140	1.000	153	0.994	153	0.994
495.5	14.03	33.81	138	1.000	140	1.000	154	1.000	154	1.000

Table X-2. Block Size Probability of Occurrence Data for the Tptpll Unit

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
0.5	0.01	0.03	6	0.286	6	0.286	6	0.286	6	0.273
1.5	0.04	0.10	13	0.619	13	0.619	13	0.619	13	0.591
2.5	0.07	0.17	14	0.667	14	0.667	14	0.667	14	0.636
3.5	0.10	0.24	16	0.762	16	0.762	16	0.762	16	0.727
4.5	0.13	0.31	16	0.762	16	0.762	16	0.762	16	0.727
5.5	0.16	0.38	17	0.810	17	0.810	17	0.810	17	0.773
6.5	0.18	0.44	18	0.857	18	0.857	18	0.857	18	0.818
7.5	0.21	0.51	18	0.857	18	0.857	18	0.857	18	0.818
8.5	0.24	0.58	18	0.857	18	0.857	18	0.857	18	0.818
9.5	0.27	0.65	19	0.905	19	0.905	19	0.905	20	0.909
10.5	0.30	0.72	19	0.905	19	0.905	19	0.905	20	0.909
11.5	0.33	0.78	19	0.905	19	0.905	19	0.905	20	0.909
12.5	0.35	0.85	19	0.905	19	0.905	19	0.905	20	0.909
13.5	0.38	0.92	19	0.905	19	0.905	19	0.905	20	0.909
14.5	0.41	0.99	19	0.905	19	0.905	19	0.905	20	0.909
15.5	0.44	1.06	19	0.905	19	0.905	19	0.905	20	0.909
16.5	0.47	1.13	19	0.905	19	0.905	19	0.905	20	0.909
17.5	0.50	1.19	19	0.905	19	0.905	19	0.905	20	0.909
18.5	0.52	1.26	19	0.905	19	0.905	19	0.905	20	0.909
19.5	0.55	1.33	19	0.905	19	0.905	19	0.905	20	0.909
20.5	0.58	1.40	19	0.905	19	0.905	19	0.905	20	0.909
21.5	0.61	1.47	19	0.905	19	0.905	19	0.905	20	0.909
22.5	0.64	1.54	19	0.905	19	0.905	19	0.905	20	0.909
23.5	0.67	1.60	19	0.905	19	0.905	19	0.905	20	0.909
24.5	0.69	1.67	19	0.905	19	0.905	19	0.905	20	0.909
25.5	0.72	1.74	19	0.905	19	0.905	19	0.905	20	0.909
26.5	0.75	1.81	19	0.905	19	0.905	19	0.905	20	0.909
27.5	0.78	1.88	19	0.905	19	0.905	19	0.905	20	0.909
28.5	0.81	1.94	19	0.905	19	0.905	19	0.905	20	0.909
29.5	0.84	2.01	19	0.905	19	0.905	19	0.905	20	0.909
30.5	0.86	2.08	19	0.905	19	0.905	19	0.905	20	0.909
31.5	0.89	2.15	20	0.952	20	0.952	20	0.952	21	0.955
32.5	0.92	2.22	20	0.952	20	0.952	20	0.952	21	0.955
33.5	0.95	2.29	20	0.952	20	0.952	20	0.952	21	0.955
34.5	0.98	2.35	20	0.952	20	0.952	20	0.952	21	0.955
35.5	1.01	2.42	20	0.952	20	0.952	20	0.952	21	0.955
36.5	1.03	2.49	20	0.952	20	0.952	20	0.952	21	0.955
37.5	1.06	2.56	20	0.952	20	0.952	20	0.952	21	0.955
38.5	1.09	2.63	20	0.952	20	0.952	20	0.952	21	0.955

Table X-2. Block Size Probability of Occurrence Data for the Tptpll Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
39.5	1.12	2.70	20	0.952	20	0.952	20	0.952	21	0.955
40.5	1.15	2.76	20	0.952	20	0.952	20	0.952	21	0.955
41.5	1.18	2.83	20	0.952	20	0.952	20	0.952	21	0.955
42.5	1.20	2.90	20	0.952	20	0.952	20	0.952	21	0.955
43.5	1.23	2.97	20	0.952	20	0.952	20	0.952	21	0.955
44.5	1.26	3.04	20	0.952	20	0.952	20	0.952	21	0.955
45.5	1.29	3.11	20	0.952	20	0.952	20	0.952	21	0.955
46.5	1.32	3.17	21	1.000	21	1.000	21	1.000	22	1.000

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
0.5	0.01	0.03	27	0.239	27	0.237	27	0.225	27	0.223
1.5	0.04	0.10	50	0.442	50	0.439	50	0.417	50	0.413
2.5	0.07	0.17	58	0.513	58	0.509	58	0.483	58	0.479
3.5	0.10	0.24	62	0.549	62	0.544	62	0.517	62	0.512
4.5	0.13	0.31	66	0.584	66	0.579	66	0.550	66	0.545
5.5	0.16	0.38	73	0.646	73	0.640	73	0.608	73	0.603
6.5	0.18	0.44	75	0.664	75	0.658	76	0.633	76	0.628
7.5	0.21	0.51	77	0.681	77	0.675	78	0.650	78	0.645
8.5	0.24	0.58	80	0.708	80	0.702	81	0.675	81	0.669
9.5	0.27	0.65	82	0.726	82	0.719	83	0.692	83	0.686
10.5	0.30	0.72	85	0.752	85	0.746	86	0.717	86	0.711
11.5	0.33	0.78	87	0.770	87	0.763	88	0.733	88	0.727
12.5	0.35	0.85	90	0.796	90	0.789	91	0.758	91	0.752
13.5	0.38	0.92	90	0.796	90	0.789	91	0.758	91	0.752
14.5	0.41	0.99	90	0.796	90	0.789	91	0.758	91	0.752
15.5	0.44	1.06	90	0.796	90	0.789	91	0.758	91	0.752
16.5	0.47	1.13	90	0.796	90	0.789	91	0.758	91	0.752
17.5	0.50	1.19	90	0.796	90	0.789	91	0.758	91	0.752
18.5	0.52	1.26	90	0.796	90	0.789	91	0.758	91	0.752
19.5	0.55	1.33	91	0.805	91	0.798	92	0.767	92	0.760
20.5	0.58	1.40	91	0.805	91	0.798	92	0.767	92	0.760
21.5	0.61	1.47	93	0.823	93	0.816	94	0.783	94	0.777
22.5	0.64	1.54	96	0.850	96	0.842	97	0.808	97	0.802
23.5	0.67	1.60	97	0.858	97	0.851	98	0.817	98	0.810
24.5	0.69	1.67	97	0.858	97	0.851	98	0.817	98	0.810
25.5	0.72	1.74	98	0.867	98	0.860	99	0.825	99	0.818
26.5	0.75	1.81	98	0.867	98	0.860	99	0.825	99	0.818
27.5	0.78	1.88	98	0.867	98	0.860	99	0.825	99	0.818
28.5	0.81	1.94	99	0.876	99	0.868	100	0.833	100	0.826
29.5	0.84	2.01	100	0.885	100	0.877	101	0.842	101	0.835
30.5	0.86	2.08	100	0.885	100	0.877	101	0.842	101	0.835
31.5	0.89	2.15	100	0.885	100	0.877	101	0.842	101	0.835
32.5	0.92	2.22	100	0.885	100	0.877	101	0.842	101	0.835
33.5	0.95	2.29	100	0.885	100	0.877	101	0.842	101	0.835
34.5	0.98	2.35	100	0.885	100	0.877	101	0.842	101	0.835
35.5	1.01	2.42	101	0.894	101	0.886	102	0.850	102	0.843
36.5	1.03	2.49	101	0.894	101	0.886	102	0.850	102	0.843
37.5	1.06	2.56	101	0.894	101	0.886	102	0.850	102	0.843
38.5	1.09	2.63	101	0.894	101	0.886	102	0.850	102	0.843

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
39.5	1.12	2.70	101	0.894	101	0.886	102	0.850	102	0.843
40.5	1.15	2.76	101	0.894	101	0.886	102	0.850	103	0.851
41.5	1.18	2.83	101	0.894	101	0.886	102	0.850	103	0.851
42.5	1.20	2.90	101	0.894	101	0.886	102	0.850	103	0.851
43.5	1.23	2.97	101	0.894	101	0.886	102	0.850	103	0.851
44.5	1.26	3.04	101	0.894	101	0.886	102	0.850	103	0.851
45.5	1.29	3.11	101	0.894	101	0.886	102	0.850	103	0.851
46.5	1.32	3.17	101	0.894	101	0.886	102	0.850	103	0.851
47.5	1.35	3.24	101	0.894	101	0.886	102	0.850	103	0.851
48.5	1.37	3.31	101	0.894	101	0.886	102	0.850	103	0.851
49.5	1.40	3.38	102	0.903	102	0.895	103	0.858	104	0.860
50.5	1.43	3.45	102	0.903	102	0.895	103	0.858	104	0.860
51.5	1.46	3.51	102	0.903	102	0.895	103	0.858	104	0.860
52.5	1.49	3.58	102	0.903	102	0.895	103	0.858	104	0.860
53.5	1.51	3.65	102	0.903	102	0.895	103	0.858	104	0.860
54.5	1.54	3.72	102	0.903	102	0.895	103	0.858	104	0.860
55.5	1.57	3.79	102	0.903	102	0.895	103	0.858	104	0.860
56.5	1.60	3.86	102	0.903	102	0.895	103	0.858	104	0.860
57.5	1.63	3.92	103	0.912	103	0.904	104	0.867	105	0.868
58.5	1.66	3.99	103	0.912	103	0.904	104	0.867	105	0.868
59.5	1.68	4.06	103	0.912	103	0.904	104	0.867	105	0.868
60.5	1.71	4.13	103	0.912	103	0.904	104	0.867	105	0.868
61.5	1.74	4.20	103	0.912	103	0.904	104	0.867	105	0.868
62.5	1.77	4.27	103	0.912	103	0.904	104	0.867	105	0.868
63.5	1.80	4.33	103	0.912	103	0.904	104	0.867	105	0.868
64.5	1.83	4.40	103	0.912	103	0.904	104	0.867	105	0.868
65.5	1.85	4.47	103	0.912	103	0.904	104	0.867	105	0.868
66.5	1.88	4.54	104	0.920	104	0.912	105	0.875	106	0.876
67.5	1.91	4.61	104	0.920	104	0.912	105	0.875	106	0.876
68.5	1.94	4.67	105	0.929	105	0.921	106	0.883	107	0.884
69.5	1.97	4.74	105	0.929	105	0.921	107	0.892	108	0.893
70.5	2.00	4.81	105	0.929	105	0.921	107	0.892	108	0.893
71.5	2.02	4.88	106	0.938	106	0.930	108	0.900	109	0.901
72.5	2.05	4.95	106	0.938	106	0.930	108	0.900	109	0.901
73.5	2.08	5.02	106	0.938	106	0.930	108	0.900	109	0.901
74.5	2.11	5.08	106	0.938	106	0.930	108	0.900	109	0.901
75.5	2.14	5.15	106	0.938	106	0.930	108	0.900	109	0.901
76.5	2.17	5.22	106	0.938	106	0.930	108	0.900	109	0.901
77.5	2.19	5.29	106	0.938	106	0.930	108	0.900	109	0.901
78.5	2.22	5.36	106	0.938	106	0.930	108	0.900	109	0.901

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
79.5	2.25	5.43	106	0.938	106	0.930	108	0.900	109	0.901
80.5	2.28	5.49	106	0.938	106	0.930	108	0.900	109	0.901
81.5	2.31	5.56	106	0.938	106	0.930	108	0.900	109	0.901
82.5	2.34	5.63	106	0.938	106	0.930	108	0.900	109	0.901
83.5	2.36	5.70	106	0.938	106	0.930	108	0.900	109	0.901
84.5	2.39	5.77	106	0.938	106	0.930	108	0.900	109	0.901
85.5	2.42	5.83	106	0.938	106	0.930	108	0.900	109	0.901
86.5	2.45	5.90	106	0.938	106	0.930	108	0.900	109	0.901
87.5	2.48	5.97	107	0.947	107	0.939	109	0.908	110	0.909
88.5	2.51	6.04	107	0.947	107	0.939	109	0.908	110	0.909
89.5	2.53	6.11	107	0.947	107	0.939	109	0.908	110	0.909
90.5	2.56	6.18	107	0.947	107	0.939	109	0.908	110	0.909
91.5	2.59	6.24	107	0.947	107	0.939	109	0.908	110	0.909
92.5	2.62	6.31	107	0.947	107	0.939	109	0.908	110	0.909
93.5	2.65	6.38	107	0.947	107	0.939	109	0.908	110	0.909
94.5	2.68	6.45	107	0.947	107	0.939	109	0.908	110	0.909
95.5	2.70	6.52	107	0.947	107	0.939	109	0.908	110	0.909
96.5	2.73	6.59	107	0.947	107	0.939	109	0.908	110	0.909
97.5	2.76	6.65	107	0.947	107	0.939	109	0.908	110	0.909
98.5	2.79	6.72	107	0.947	107	0.939	109	0.908	110	0.909
99.5	2.82	6.79	107	0.947	107	0.939	109	0.908	110	0.909
100.5	2.85	6.86	107	0.947	107	0.939	109	0.908	110	0.909
101.5	2.87	6.93	107	0.947	107	0.939	109	0.908	110	0.909
102.5	2.90	6.99	108	0.956	108	0.947	110	0.917	111	0.917
103.5	2.93	7.06	108	0.956	108	0.947	110	0.917	111	0.917
104.5	2.96	7.13	108	0.956	108	0.947	110	0.917	111	0.917
105.5	2.99	7.20	108	0.956	109	0.956	111	0.925	112	0.926
106.5	3.02	7.27	108	0.956	109	0.956	111	0.925	112	0.926
107.5	3.04	7.34	108	0.956	109	0.956	111	0.925	112	0.926
108.5	3.07	7.40	108	0.956	109	0.956	111	0.925	112	0.926
109.5	3.10	7.47	108	0.956	109	0.956	111	0.925	112	0.926
110.5	3.13	7.54	108	0.956	109	0.956	111	0.925	112	0.926
111.5	3.16	7.61	108	0.956	109	0.956	111	0.925	112	0.926
112.5	3.19	7.68	108	0.956	109	0.956	111	0.925	112	0.926
113.5	3.21	7.75	108	0.956	109	0.956	111	0.925	112	0.926
114.5	3.24	7.81	108	0.956	109	0.956	111	0.925	112	0.926
115.5	3.27	7.88	108	0.956	109	0.956	111	0.925	112	0.926
116.5	3.30	7.95	109	0.965	110	0.965	112	0.933	113	0.934
117.5	3.33	8.02	109	0.965	110	0.965	112	0.933	113	0.934
118.5	3.36	8.09	109	0.965	110	0.965	112	0.933	113	0.934

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft³	m³	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
119.5	3.38	8.16	109	0.965	110	0.965	112	0.933	113	0.934
120.5	3.41	8.22	109	0.965	110	0.965	112	0.933	113	0.934
121.5	3.44	8.29	109	0.965	110	0.965	112	0.933	113	0.934
122.5	3.47	8.36	110	0.973	111	0.974	113	0.942	114	0.942
123.5	3.50	8.43	110	0.973	111	0.974	113	0.942	114	0.942
124.5	3.53	8.50	110	0.973	111	0.974	113	0.942	114	0.942
125.5	3.55	8.56	110	0.973	111	0.974	113	0.942	114	0.942
126.5	3.58	8.63	110	0.973	111	0.974	113	0.942	114	0.942
127.5	3.61	8.70	110	0.973	111	0.974	113	0.942	114	0.942
128.5	3.64	8.77	110	0.973	111	0.974	113	0.942	114	0.942
129.5	3.67	8.84	110	0.973	111	0.974	113	0.942	114	0.942
130.5	3.70	8.91	110	0.973	111	0.974	113	0.942	114	0.942
131.5	3.72	8.97	110	0.973	111	0.974	113	0.942	114	0.942
132.5	3.75	9.04	110	0.973	111	0.974	113	0.942	114	0.942
133.5	3.78	9.11	110	0.973	111	0.974	113	0.942	114	0.942
134.5	3.81	9.18	110	0.973	111	0.974	113	0.942	114	0.942
135.5	3.84	9.25	110	0.973	111	0.974	113	0.942	114	0.942
136.5	3.87	9.32	110	0.973	111	0.974	113	0.942	114	0.942
137.5	3.89	9.38	110	0.973	111	0.974	113	0.942	114	0.942
138.5	3.92	9.45	110	0.973	111	0.974	113	0.942	114	0.942
139.5	3.95	9.52	110	0.973	111	0.974	113	0.942	114	0.942
140.5	3.98	9.59	110	0.973	111	0.974	113	0.942	114	0.942
141.5	4.01	9.66	110	0.973	111	0.974	113	0.942	114	0.942
142.5	4.04	9.72	110	0.973	111	0.974	113	0.942	114	0.942
143.5	4.06	9.79	110	0.973	111	0.974	113	0.942	114	0.942
144.5	4.09	9.86	110	0.973	111	0.974	113	0.942	114	0.942
145.5	4.12	9.93	110	0.973	111	0.974	113	0.942	114	0.942
146.5	4.15	10.00	110	0.973	111	0.974	113	0.942	114	0.942
147.5	4.18	10.07	110	0.973	111	0.974	113	0.942	114	0.942
148.5	4.21	10.13	110	0.973	111	0.974	113	0.942	114	0.942
149.5	4.23	10.20	110	0.973	111	0.974	113	0.942	114	0.942
150.5	4.26	10.27	110	0.973	111	0.974	113	0.942	114	0.942
151.5	4.29	10.34	110	0.973	111	0.974	113	0.942	114	0.942
152.5	4.32	10.41	110	0.973	111	0.974	113	0.942	114	0.942
153.5	4.35	10.48	110	0.973	111	0.974	113	0.942	114	0.942
154.5	4.37	10.54	110	0.973	111	0.974	113	0.942	114	0.942
155.5	4.40	10.61	110	0.973	111	0.974	113	0.942	114	0.942
156.5	4.43	10.68	110	0.973	111	0.974	113	0.942	114	0.942
157.5	4.46	10.75	110	0.973	111	0.974	113	0.942	114	0.942
158.5	4.49	10.82	110	0.973	111	0.974	113	0.942	114	0.942

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft³	m³	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
159.5	4.52	10.88	110	0.973	111	0.974	113	0.942	114	0.942
160.5	4.54	10.95	110	0.973	111	0.974	113	0.942	114	0.942
161.5	4.57	11.02	110	0.973	111	0.974	113	0.942	114	0.942
162.5	4.60	11.09	110	0.973	111	0.974	113	0.942	114	0.942
163.5	4.63	11.16	110	0.973	111	0.974	113	0.942	114	0.942
164.5	4.66	11.23	110	0.973	111	0.974	113	0.942	114	0.942
165.5	4.69	11.29	111	0.982	112	0.982	114	0.950	115	0.950
166.5	4.71	11.36	111	0.982	112	0.982	114	0.950	115	0.950
167.5	4.74	11.43	111	0.982	112	0.982	114	0.950	115	0.950
168.5	4.77	11.50	111	0.982	112	0.982	114	0.950	115	0.950
169.5	4.80	11.57	112	0.991	113	0.991	115	0.958	116	0.959
170.5	4.83	11.64	112	0.991	113	0.991	115	0.958	116	0.959
171.5	4.86	11.70	112	0.991	113	0.991	115	0.958	116	0.959
172.5	4.88	11.77	112	0.991	113	0.991	115	0.958	116	0.959
173.5	4.91	11.84	112	0.991	113	0.991	115	0.958	116	0.959
174.5	4.94	11.91	112	0.991	113	0.991	115	0.958	116	0.959
175.5	4.97	11.98	112	0.991	113	0.991	115	0.958	116	0.959
176.5	5.00	12.04	112	0.991	113	0.991	115	0.958	116	0.959
177.5	5.03	12.11	112	0.991	113	0.991	115	0.958	116	0.959
178.5	5.05	12.18	112	0.991	113	0.991	115	0.958	116	0.959
179.5	5.08	12.25	112	0.991	113	0.991	115	0.958	116	0.959
180.5	5.11	12.32	112	0.991	113	0.991	115	0.958	116	0.959
181.5	5.14	12.39	112	0.991	113	0.991	115	0.958	116	0.959
182.5	5.17	12.45	112	0.991	113	0.991	115	0.958	116	0.959
183.5	5.20	12.52	112	0.991	113	0.991	115	0.958	116	0.959
184.5	5.22	12.59	112	0.991	113	0.991	115	0.958	116	0.959
185.5	5.25	12.66	112	0.991	113	0.991	115	0.958	116	0.959
186.5	5.28	12.73	112	0.991	113	0.991	115	0.958	116	0.959
187.5	5.31	12.80	112	0.991	113	0.991	115	0.958	116	0.959
188.5	5.34	12.86	112	0.991	113	0.991	115	0.958	116	0.959
189.5	5.37	12.93	112	0.991	113	0.991	115	0.958	116	0.959
190.5	5.39	13.00	112	0.991	113	0.991	115	0.958	116	0.959
191.5	5.42	13.07	112	0.991	113	0.991	115	0.958	116	0.959
192.5	5.45	13.14	112	0.991	113	0.991	115	0.958	116	0.959
193.5	5.48	13.21	112	0.991	113	0.991	115	0.958	116	0.959
194.5	5.51	13.27	112	0.991	113	0.991	115	0.958	116	0.959
195.5	5.54	13.34	112	0.991	113	0.991	115	0.958	116	0.959
196.5	5.56	13.41	112	0.991	113	0.991	115	0.958	116	0.959
197.5	5.59	13.48	112	0.991	113	0.991	115	0.958	116	0.959
198.5	5.62	13.55	112	0.991	113	0.991	115	0.958	116	0.959

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft³	m³	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
199.5	5.65	13.61	112	0.991	113	0.991	115	0.958	116	0.959
200.5	5.68	13.68	112	0.991	113	0.991	115	0.958	116	0.959
201.5	5.71	13.75	112	0.991	113	0.991	115	0.958	116	0.959
202.5	5.73	13.82	112	0.991	113	0.991	115	0.958	116	0.959
203.5	5.76	13.89	112	0.991	113	0.991	115	0.958	116	0.959
204.5	5.79	13.96	112	0.991	113	0.991	115	0.958	116	0.959
205.5	5.82	14.02	112	0.991	113	0.991	115	0.958	116	0.959
206.5	5.85	14.09	112	0.991	113	0.991	115	0.958	116	0.959
207.5	5.88	14.16	112	0.991	113	0.991	115	0.958	116	0.959
208.5	5.90	14.23	112	0.991	113	0.991	115	0.958	116	0.959
209.5	5.93	14.30	112	0.991	113	0.991	116	0.967	117	0.967
210.5	5.96	14.37	112	0.991	113	0.991	116	0.967	117	0.967
211.5	5.99	14.43	112	0.991	113	0.991	116	0.967	117	0.967
212.5	6.02	14.50	112	0.991	113	0.991	116	0.967	117	0.967
213.5	6.05	14.57	112	0.991	113	0.991	116	0.967	117	0.967
214.5	6.07	14.64	112	0.991	113	0.991	116	0.967	117	0.967
215.5	6.10	14.71	112	0.991	113	0.991	116	0.967	117	0.967
216.5	6.13	14.77	112	0.991	113	0.991	116	0.967	117	0.967
217.5	6.16	14.84	112	0.991	113	0.991	116	0.967	117	0.967
218.5	6.19	14.91	112	0.991	113	0.991	116	0.967	117	0.967
219.5	6.22	14.98	112	0.991	113	0.991	116	0.967	117	0.967
220.5	6.24	15.05	112	0.991	113	0.991	116	0.967	117	0.967
221.5	6.27	15.12	112	0.991	113	0.991	116	0.967	117	0.967
222.5	6.30	15.18	112	0.991	113	0.991	116	0.967	117	0.967
223.5	6.33	15.25	112	0.991	113	0.991	116	0.967	117	0.967
224.5	6.36	15.32	112	0.991	113	0.991	116	0.967	117	0.967
225.5	6.39	15.39	112	0.991	113	0.991	116	0.967	117	0.967
226.5	6.41	15.46	112	0.991	113	0.991	116	0.967	117	0.967
227.5	6.44	15.53	112	0.991	113	0.991	116	0.967	117	0.967
228.5	6.47	15.59	112	0.991	113	0.991	116	0.967	117	0.967
229.5	6.50	15.66	112	0.991	113	0.991	116	0.967	117	0.967
230.5	6.53	15.73	112	0.991	113	0.991	116	0.967	117	0.967
231.5	6.56	15.80	112	0.991	113	0.991	116	0.967	117	0.967
232.5	6.58	15.87	112	0.991	113	0.991	116	0.967	117	0.967
233.5	6.61	15.93	112	0.991	113	0.991	116	0.967	117	0.967
234.5	6.64	16.00	112	0.991	113	0.991	116	0.967	117	0.967
235.5	6.67	16.07	112	0.991	113	0.991	116	0.967	117	0.967
236.5	6.70	16.14	112	0.991	113	0.991	116	0.967	117	0.967
237.5	6.73	16.21	112	0.991	113	0.991	116	0.967	117	0.967
238.5	6.75	16.28	112	0.991	113	0.991	116	0.967	117	0.967

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
239.5	6.78	16.34	112	0.991	113	0.991	116	0.967	117	0.967
240.5	6.81	16.41	112	0.991	113	0.991	116	0.967	117	0.967
241.5	6.84	16.48	112	0.991	113	0.991	116	0.967	117	0.967
242.5	6.87	16.55	112	0.991	113	0.991	116	0.967	117	0.967
243.5	6.90	16.62	112	0.991	113	0.991	116	0.967	117	0.967
244.5	6.92	16.69	112	0.991	113	0.991	116	0.967	117	0.967
245.5	6.95	16.75	112	0.991	113	0.991	116	0.967	117	0.967
246.5	6.98	16.82	112	0.991	113	0.991	116	0.967	117	0.967
247.5	7.01	16.89	112	0.991	113	0.991	116	0.967	117	0.967
248.5	7.04	16.96	112	0.991	113	0.991	116	0.967	117	0.967
249.5	7.07	17.03	112	0.991	113	0.991	116	0.967	117	0.967
250.5	7.09	17.10	112	0.991	113	0.991	116	0.967	117	0.967
251.5	7.12	17.16	112	0.991	113	0.991	116	0.967	117	0.967
252.5	7.15	17.23	112	0.991	113	0.991	116	0.967	117	0.967
253.5	7.18	17.30	112	0.991	113	0.991	116	0.967	117	0.967
254.5	7.21	17.37	112	0.991	113	0.991	116	0.967	117	0.967
255.5	7.23	17.44	112	0.991	113	0.991	116	0.967	117	0.967
256.5	7.26	17.50	112	0.991	113	0.991	116	0.967	117	0.967
257.5	7.29	17.57	112	0.991	113	0.991	116	0.967	117	0.967
258.5	7.32	17.64	112	0.991	113	0.991	116	0.967	117	0.967
259.5	7.35	17.71	112	0.991	113	0.991	116	0.967	117	0.967
260.5	7.38	17.78	112	0.991	113	0.991	116	0.967	117	0.967
261.5	7.40	17.85	112	0.991	113	0.991	116	0.967	117	0.967
262.5	7.43	17.91	112	0.991	113	0.991	116	0.967	117	0.967
263.5	7.46	17.98	112	0.991	113	0.991	116	0.967	117	0.967
264.5	7.49	18.05	112	0.991	113	0.991	116	0.967	117	0.967
265.5	7.52	18.12	112	0.991	113	0.991	116	0.967	117	0.967
266.5	7.55	18.19	112	0.991	113	0.991	116	0.967	117	0.967
267.5	7.57	18.26	112	0.991	113	0.991	116	0.967	117	0.967
268.5	7.60	18.32	112	0.991	113	0.991	116	0.967	117	0.967
269.5	7.63	18.39	112	0.991	113	0.991	116	0.967	117	0.967
270.5	7.66	18.46	112	0.991	113	0.991	116	0.967	117	0.967
271.5	7.69	18.53	112	0.991	113	0.991	116	0.967	117	0.967
272.5	7.72	18.60	112	0.991	113	0.991	116	0.967	117	0.967
273.5	7.74	18.66	112	0.991	113	0.991	116	0.967	117	0.967
274.5	7.77	18.73	112	0.991	113	0.991	116	0.967	117	0.967
275.5	7.80	18.80	112	0.991	113	0.991	116	0.967	117	0.967
276.5	7.83	18.87	112	0.991	113	0.991	116	0.967	117	0.967
277.5	7.86	18.94	112	0.991	113	0.991	116	0.967	117	0.967
278.5	7.89	19.01	112	0.991	113	0.991	116	0.967	117	0.967

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
279.5	7.91	19.07	112	0.991	113	0.991	116	0.967	117	0.967
280.5	7.94	19.14	112	0.991	113	0.991	116	0.967	117	0.967
281.5	7.97	19.21	112	0.991	113	0.991	116	0.967	117	0.967
282.5	8.00	19.28	112	0.991	113	0.991	116	0.967	117	0.967
283.5	8.03	19.35	112	0.991	113	0.991	116	0.967	117	0.967
284.5	8.06	19.42	112	0.991	113	0.991	116	0.967	117	0.967
285.5	8.08	19.48	112	0.991	113	0.991	116	0.967	117	0.967
286.5	8.11	19.55	112	0.991	113	0.991	116	0.967	117	0.967
287.5	8.14	19.62	112	0.991	113	0.991	116	0.967	117	0.967
288.5	8.17	19.69	112	0.991	113	0.991	116	0.967	117	0.967
289.5	8.20	19.76	112	0.991	113	0.991	116	0.967	117	0.967
290.5	8.23	19.82	112	0.991	113	0.991	116	0.967	117	0.967
291.5	8.25	19.89	112	0.991	113	0.991	116	0.967	117	0.967
292.5	8.28	19.96	112	0.991	113	0.991	116	0.967	117	0.967
293.5	8.31	20.03	112	0.991	113	0.991	116	0.967	117	0.967
294.5	8.34	20.10	112	0.991	113	0.991	116	0.967	117	0.967
295.5	8.37	20.17	112	0.991	113	0.991	116	0.967	117	0.967
296.5	8.40	20.23	112	0.991	113	0.991	116	0.967	117	0.967
297.5	8.42	20.30	112	0.991	113	0.991	116	0.967	117	0.967
298.5	8.45	20.37	112	0.991	113	0.991	116	0.967	117	0.967
299.5	8.48	20.44	112	0.991	113	0.991	116	0.967	117	0.967
300.5	8.51	20.51	112	0.991	113	0.991	116	0.967	117	0.967
301.5	8.54	20.58	112	0.991	113	0.991	116	0.967	117	0.967
302.5	8.57	20.64	112	0.991	113	0.991	116	0.967	117	0.967
303.5	8.59	20.71	112	0.991	113	0.991	116	0.967	117	0.967
304.5	8.62	20.78	112	0.991	113	0.991	116	0.967	117	0.967
305.5	8.65	20.85	112	0.991	113	0.991	116	0.967	117	0.967
306.5	8.68	20.92	112	0.991	113	0.991	116	0.967	117	0.967
307.5	8.71	20.98	112	0.991	113	0.991	116	0.967	117	0.967
308.5	8.74	21.05	112	0.991	113	0.991	116	0.967	117	0.967
309.5	8.76	21.12	112	0.991	113	0.991	116	0.967	117	0.967
310.5	8.79	21.19	112	0.991	113	0.991	116	0.967	117	0.967
311.5	8.82	21.26	112	0.991	113	0.991	116	0.967	117	0.967
312.5	8.85	21.33	112	0.991	113	0.991	116	0.967	117	0.967
313.5	8.88	21.39	112	0.991	113	0.991	116	0.967	117	0.967
314.5	8.91	21.46	112	0.991	113	0.991	116	0.967	117	0.967
315.5	8.93	21.53	112	0.991	113	0.991	116	0.967	117	0.967
316.5	8.96	21.60	112	0.991	113	0.991	116	0.967	117	0.967
317.5	8.99	21.67	112	0.991	113	0.991	116	0.967	117	0.967
318.5	9.02	21.74	112	0.991	113	0.991	116	0.967	117	0.967

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
319.5	9.05	21.80	112	0.991	113	0.991	116	0.967	117	0.967
320.5	9.08	21.87	112	0.991	113	0.991	116	0.967	117	0.967
321.5	9.10	21.94	112	0.991	113	0.991	116	0.967	117	0.967
322.5	9.13	22.01	112	0.991	113	0.991	116	0.967	117	0.967
323.5	9.16	22.08	112	0.991	113	0.991	116	0.967	117	0.967
324.5	9.19	22.15	112	0.991	113	0.991	116	0.967	117	0.967
325.5	9.22	22.21	112	0.991	113	0.991	116	0.967	117	0.967
326.5	9.25	22.28	112	0.991	113	0.991	116	0.967	117	0.967
327.5	9.27	22.35	112	0.991	113	0.991	116	0.967	117	0.967
328.5	9.30	22.42	112	0.991	113	0.991	116	0.967	117	0.967
329.5	9.33	22.49	112	0.991	113	0.991	116	0.967	117	0.967
330.5	9.36	22.55	112	0.991	113	0.991	116	0.967	117	0.967
331.5	9.39	22.62	112	0.991	113	0.991	116	0.967	117	0.967
332.5	9.42	22.69	112	0.991	113	0.991	116	0.967	117	0.967
333.5	9.44	22.76	112	0.991	113	0.991	116	0.967	117	0.967
334.5	9.47	22.83	112	0.991	113	0.991	116	0.967	117	0.967
335.5	9.50	22.90	112	0.991	113	0.991	116	0.967	117	0.967
336.5	9.53	22.96	112	0.991	113	0.991	116	0.967	117	0.967
337.5	9.56	23.03	112	0.991	113	0.991	116	0.967	117	0.967
338.5	9.59	23.10	112	0.991	113	0.991	116	0.967	117	0.967
339.5	9.61	23.17	112	0.991	113	0.991	116	0.967	117	0.967
340.5	9.64	23.24	112	0.991	113	0.991	116	0.967	117	0.967
341.5	9.67	23.31	112	0.991	113	0.991	116	0.967	117	0.967
342.5	9.70	23.37	112	0.991	113	0.991	116	0.967	117	0.967
343.5	9.73	23.44	112	0.991	113	0.991	116	0.967	117	0.967
344.5	9.76	23.51	112	0.991	113	0.991	116	0.967	117	0.967
345.5	9.78	23.58	112	0.991	113	0.991	116	0.967	117	0.967
346.5	9.81	23.65	112	0.991	113	0.991	116	0.967	117	0.967
347.5	9.84	23.71	112	0.991	113	0.991	116	0.967	117	0.967
348.5	9.87	23.78	112	0.991	113	0.991	116	0.967	117	0.967
349.5	9.90	23.85	112	0.991	113	0.991	116	0.967	117	0.967
350.5	9.93	23.92	112	0.991	113	0.991	116	0.967	117	0.967
351.5	9.95	23.99	112	0.991	113	0.991	116	0.967	117	0.967
352.5	9.98	24.06	112	0.991	113	0.991	116	0.967	117	0.967
353.5	10.01	24.12	112	0.991	113	0.991	116	0.967	117	0.967
354.5	10.04	24.19	112	0.991	113	0.991	116	0.967	117	0.967
355.5	10.07	24.26	112	0.991	113	0.991	116	0.967	117	0.967
356.5	10.09	24.33	112	0.991	113	0.991	116	0.967	117	0.967
357.5	10.12	24.40	112	0.991	113	0.991	116	0.967	117	0.967
358.5	10.15	24.47	112	0.991	113	0.991	116	0.967	117	0.967

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
359.5	10.18	24.53	112	0.991	113	0.991	116	0.967	117	0.967
360.5	10.21	24.60	112	0.991	113	0.991	116	0.967	117	0.967
361.5	10.24	24.67	112	0.991	113	0.991	116	0.967	117	0.967
362.5	10.26	24.74	112	0.991	113	0.991	116	0.967	117	0.967
363.5	10.29	24.81	112	0.991	113	0.991	116	0.967	117	0.967
364.5	10.32	24.87	112	0.991	113	0.991	116	0.967	117	0.967
365.5	10.35	24.94	112	0.991	113	0.991	116	0.967	117	0.967
366.5	10.38	25.01	112	0.991	113	0.991	116	0.967	117	0.967
367.5	10.41	25.08	112	0.991	113	0.991	116	0.967	117	0.967
368.5	10.43	25.15	112	0.991	113	0.991	116	0.967	117	0.967
369.5	10.46	25.22	112	0.991	113	0.991	116	0.967	117	0.967
370.5	10.49	25.28	112	0.991	113	0.991	116	0.967	117	0.967
371.5	10.52	25.35	112	0.991	113	0.991	116	0.967	117	0.967
372.5	10.55	25.42	112	0.991	113	0.991	116	0.967	117	0.967
373.5	10.58	25.49	112	0.991	113	0.991	116	0.967	117	0.967
374.5	10.60	25.56	112	0.991	113	0.991	116	0.967	117	0.967
375.5	10.63	25.63	112	0.991	113	0.991	116	0.967	117	0.967
376.5	10.66	25.69	112	0.991	113	0.991	116	0.967	117	0.967
377.5	10.69	25.76	112	0.991	113	0.991	116	0.967	117	0.967
378.5	10.72	25.83	112	0.991	113	0.991	116	0.967	117	0.967
379.5	10.75	25.90	112	0.991	113	0.991	116	0.967	117	0.967
380.5	10.77	25.97	112	0.991	113	0.991	116	0.967	117	0.967
381.5	10.80	26.03	112	0.991	113	0.991	116	0.967	117	0.967
382.5	10.83	26.10	112	0.991	113	0.991	116	0.967	117	0.967
383.5	10.86	26.17	112	0.991	113	0.991	116	0.967	117	0.967
384.5	10.89	26.24	112	0.991	113	0.991	116	0.967	117	0.967
385.5	10.92	26.31	112	0.991	113	0.991	116	0.967	117	0.967
386.5	10.94	26.38	112	0.991	113	0.991	116	0.967	117	0.967
387.5	10.97	26.44	112	0.991	113	0.991	116	0.967	117	0.967
388.5	11.00	26.51	112	0.991	113	0.991	116	0.967	117	0.967
389.5	11.03	26.58	112	0.991	113	0.991	116	0.967	117	0.967
390.5	11.06	26.65	112	0.991	113	0.991	116	0.967	117	0.967
391.5	11.09	26.72	112	0.991	113	0.991	116	0.967	117	0.967
392.5	11.11	26.79	112	0.991	113	0.991	116	0.967	117	0.967
393.5	11.14	26.85	112	0.991	113	0.991	116	0.967	117	0.967
394.5	11.17	26.92	112	0.991	113	0.991	116	0.967	117	0.967
395.5	11.20	26.99	112	0.991	113	0.991	116	0.967	117	0.967
396.5	11.23	27.06	112	0.991	113	0.991	116	0.967	117	0.967
397.5	11.26	27.13	112	0.991	113	0.991	116	0.967	117	0.967
398.5	11.28	27.20	112	0.991	113	0.991	116	0.967	117	0.967

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
399.5	11.31	27.26	112	0.991	113	0.991	116	0.967	117	0.967
400.5	11.34	27.33	112	0.991	113	0.991	116	0.967	117	0.967
401.5	11.37	27.40	112	0.991	113	0.991	116	0.967	117	0.967
402.5	11.40	27.47	112	0.991	113	0.991	116	0.967	117	0.967
403.5	11.43	27.54	112	0.991	113	0.991	116	0.967	117	0.967
404.5	11.45	27.60	112	0.991	113	0.991	116	0.967	117	0.967
405.5	11.48	27.67	112	0.991	113	0.991	116	0.967	117	0.967
406.5	11.51	27.74	112	0.991	113	0.991	116	0.967	117	0.967
407.5	11.54	27.81	112	0.991	113	0.991	116	0.967	117	0.967
408.5	11.57	27.88	112	0.991	113	0.991	116	0.967	117	0.967
409.5	11.60	27.95	112	0.991	113	0.991	116	0.967	117	0.967
410.5	11.62	28.01	112	0.991	113	0.991	116	0.967	117	0.967
411.5	11.65	28.08	112	0.991	113	0.991	116	0.967	117	0.967
412.5	11.68	28.15	112	0.991	113	0.991	116	0.967	117	0.967
413.5	11.71	28.22	112	0.991	113	0.991	116	0.967	117	0.967
414.5	11.74	28.29	112	0.991	113	0.991	116	0.967	117	0.967
415.5	11.77	28.36	112	0.991	113	0.991	116	0.967	117	0.967
416.5	11.79	28.42	112	0.991	113	0.991	116	0.967	117	0.967
417.5	11.82	28.49	112	0.991	113	0.991	116	0.967	117	0.967
418.5	11.85	28.56	112	0.991	113	0.991	116	0.967	117	0.967
419.5	11.88	28.63	112	0.991	113	0.991	116	0.967	117	0.967
420.5	11.91	28.70	112	0.991	113	0.991	116	0.967	117	0.967
421.5	11.94	28.76	112	0.991	113	0.991	116	0.967	117	0.967
422.5	11.96	28.83	112	0.991	113	0.991	116	0.967	117	0.967
423.5	11.99	28.90	112	0.991	113	0.991	116	0.967	117	0.967
424.5	12.02	28.97	112	0.991	113	0.991	116	0.967	117	0.967
425.5	12.05	29.04	112	0.991	113	0.991	116	0.967	117	0.967
426.5	12.08	29.11	112	0.991	113	0.991	116	0.967	117	0.967
427.5	12.11	29.17	112	0.991	113	0.991	116	0.967	117	0.967
428.5	12.13	29.24	112	0.991	113	0.991	116	0.967	117	0.967
429.5	12.16	29.31	112	0.991	113	0.991	116	0.967	117	0.967
430.5	12.19	29.38	112	0.991	113	0.991	116	0.967	117	0.967
431.5	12.22	29.45	112	0.991	113	0.991	116	0.967	117	0.967
432.5	12.25	29.52	112	0.991	113	0.991	116	0.967	117	0.967
433.5	12.28	29.58	112	0.991	113	0.991	116	0.967	117	0.967
434.5	12.30	29.65	112	0.991	113	0.991	116	0.967	117	0.967
435.5	12.33	29.72	112	0.991	113	0.991	116	0.967	117	0.967
436.5	12.36	29.79	112	0.991	113	0.991	116	0.967	117	0.967
437.5	12.39	29.86	112	0.991	113	0.991	116	0.967	117	0.967
438.5	12.42	29.92	112	0.991	113	0.991	116	0.967	117	0.967

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
439.5	12.45	29.99	112	0.991	113	0.991	116	0.967	117	0.967
440.5	12.47	30.06	112	0.991	113	0.991	116	0.967	117	0.967
441.5	12.50	30.13	112	0.991	113	0.991	116	0.967	117	0.967
442.5	12.53	30.20	112	0.991	113	0.991	116	0.967	117	0.967
443.5	12.56	30.27	112	0.991	113	0.991	116	0.967	117	0.967
444.5	12.59	30.33	112	0.991	113	0.991	116	0.967	117	0.967
445.5	12.62	30.40	112	0.991	113	0.991	116	0.967	117	0.967
446.5	12.64	30.47	112	0.991	113	0.991	116	0.967	117	0.967
447.5	12.67	30.54	112	0.991	113	0.991	116	0.967	117	0.967
448.5	12.70	30.61	112	0.991	113	0.991	116	0.967	117	0.967
449.5	12.73	30.68	112	0.991	113	0.991	116	0.967	117	0.967
450.5	12.76	30.74	112	0.991	113	0.991	116	0.967	117	0.967
451.5	12.79	30.81	112	0.991	113	0.991	116	0.967	117	0.967
452.5	12.81	30.88	112	0.991	113	0.991	116	0.967	117	0.967
453.5	12.84	30.95	112	0.991	113	0.991	116	0.967	117	0.967
454.5	12.87	31.02	112	0.991	113	0.991	116	0.967	117	0.967
455.5	12.90	31.08	112	0.991	113	0.991	116	0.967	117	0.967
456.5	12.93	31.15	112	0.991	113	0.991	116	0.967	117	0.967
457.5	12.95	31.22	112	0.991	113	0.991	116	0.967	117	0.967
458.5	12.98	31.29	112	0.991	113	0.991	116	0.967	117	0.967
459.5	13.01	31.36	112	0.991	113	0.991	116	0.967	117	0.967
460.5	13.04	31.43	112	0.991	113	0.991	116	0.967	117	0.967
461.5	13.07	31.49	112	0.991	113	0.991	116	0.967	117	0.967
462.5	13.10	31.56	112	0.991	113	0.991	116	0.967	117	0.967
463.5	13.12	31.63	112	0.991	113	0.991	116	0.967	117	0.967
464.5	13.15	31.70	112	0.991	113	0.991	116	0.967	117	0.967
465.5	13.18	31.77	112	0.991	113	0.991	116	0.967	117	0.967
466.5	13.21	31.84	112	0.991	113	0.991	116	0.967	117	0.967
467.5	13.24	31.90	112	0.991	113	0.991	116	0.967	117	0.967
468.5	13.27	31.97	112	0.991	113	0.991	116	0.967	117	0.967
469.5	13.29	32.04	112	0.991	113	0.991	116	0.967	117	0.967
470.5	13.32	32.11	112	0.991	113	0.991	116	0.967	117	0.967
471.5	13.35	32.18	112	0.991	113	0.991	116	0.967	117	0.967
472.5	13.38	32.25	112	0.991	113	0.991	116	0.967	117	0.967
473.5	13.41	32.31	112	0.991	113	0.991	116	0.967	117	0.967
474.5	13.44	32.38	112	0.991	113	0.991	116	0.967	117	0.967
475.5	13.46	32.45	112	0.991	113	0.991	116	0.967	117	0.967
476.5	13.49	32.52	112	0.991	113	0.991	116	0.967	117	0.967
477.5	13.52	32.59	112	0.991	113	0.991	116	0.967	117	0.967
478.5	13.55	32.65	112	0.991	113	0.991	116	0.967	117	0.967

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft³	m³	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
479.5	13.58	32.72	112	0.991	113	0.991	116	0.967	117	0.967
480.5	13.61	32.79	112	0.991	113	0.991	116	0.967	117	0.967
481.5	13.63	32.86	112	0.991	113	0.991	116	0.967	117	0.967
482.5	13.66	32.93	112	0.991	113	0.991	116	0.967	117	0.967
483.5	13.69	33.00	112	0.991	113	0.991	116	0.967	117	0.967
484.5	13.72	33.06	112	0.991	113	0.991	116	0.967	117	0.967
485.5	13.75	33.13	112	0.991	113	0.991	116	0.967	117	0.967
486.5	13.78	33.20	113	1.000	114	1.000	117	0.975	118	0.975
487.5	13.80	33.27	113	1.000	114	1.000	117	0.975	118	0.975
488.5	13.83	33.34	113	1.000	114	1.000	117	0.975	118	0.975
489.5	13.86	33.41	113	1.000	114	1.000	117	0.975	118	0.975
490.5	13.89	33.47	113	1.000	114	1.000	117	0.975	118	0.975
491.5	13.92	33.54	113	1.000	114	1.000	117	0.975	118	0.975
492.5	13.95	33.61	113	1.000	114	1.000	117	0.975	118	0.975
493.5	13.97	33.68	113	1.000	114	1.000	117	0.975	118	0.975
494.5	14.00	33.75	113	1.000	114	1.000	117	0.975	118	0.975
495.5	14.03	33.81	113	1.000	114	1.000	117	0.975	118	0.975
496.5	14.06	33.88	113	1.000	114	1.000	117	0.975	118	0.975
497.5	14.09	33.95	113	1.000	114	1.000	117	0.975	118	0.975
498.5	14.12	34.02	113	1.000	114	1.000	117	0.975	118	0.975
499.5	14.14	34.09	113	1.000	114	1.000	117	0.975	118	0.975
500.5	14.17	34.16	113	1.000	114	1.000	117	0.975	118	0.975
501.5	14.20	34.22	113	1.000	114	1.000	117	0.975	118	0.975
502.5	14.23	34.29	113	1.000	114	1.000	117	0.975	118	0.975
503.5	14.26	34.36	113	1.000	114	1.000	117	0.975	118	0.975
504.5	14.29	34.43	113	1.000	114	1.000	117	0.975	118	0.975
505.5	14.31	34.50	113	1.000	114	1.000	117	0.975	118	0.975
506.5	14.34	34.57	113	1.000	114	1.000	117	0.975	118	0.975
507.5	14.37	34.63	113	1.000	114	1.000	117	0.975	118	0.975
508.5	14.40	34.70	113	1.000	114	1.000	117	0.975	118	0.975
509.5	14.43	34.77	113	1.000	114	1.000	117	0.975	118	0.975
510.5	14.46	34.84	113	1.000	114	1.000	117	0.975	118	0.975
511.5	14.48	34.91	113	1.000	114	1.000	117	0.975	118	0.975
512.5	14.51	34.97	113	1.000	114	1.000	117	0.975	118	0.975
513.5	14.54	35.04	113	1.000	114	1.000	117	0.975	118	0.975
514.5	14.57	35.11	113	1.000	114	1.000	117	0.975	118	0.975
515.5	14.60	35.18	113	1.000	114	1.000	117	0.975	118	0.975
516.5	14.63	35.25	113	1.000	114	1.000	117	0.975	118	0.975
517.5	14.65	35.32	113	1.000	114	1.000	118	0.983	119	0.983

Table X-3. Block Size Probability of Occurrence Data for the Tptpln Unit (Continued)

Block Size			Cumulative Block Size Data							
			static		seismic, level 1		seismic, level 2		seismic, level 3	
ft^3	m^3	MT	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)	Number of Blocks	Frequency (CDF)
1653.5	46.83	112.85	113	1.000	114	1.000	119	0.992	120	0.992
2025.5	57.36	138.24	113	1.000	114	1.000	120	1.000	121	1.000

ATTACHMENT XI

VOLUME OF FAILED ROCK

VOLUME OF FAILED ROCK

The volume of failed rock per DRKBA simulation (i.e., a drift length of 24.4 m) is provided in this attachment based on 5.5-m-diameter emplacement drifts orientated with a tunnel azimuth of 75° in accordance with the current repository layout. These results do not include backfill. Both static and static plus seismic results are provided. To obtain the total volume per simulation, the DRKBA key block output files were read in *Excel* spreadsheets and a macro, *Volume_cal V1.1*, was prepared to automatically calculate the total volume. The *Excel* spreadsheet routines that contain the calculation macro are *pmn-rock volume per mcs v2.xls, pll-rock volume per mcs v2.xls,* and *pln-rock volume per mcs v2.xls* (Attachment II). The descriptions and verification of the macro embedded in these *Excel* routines are provided in Attachment VIII. The results are presented in Figures XI-1 to XI-24, for the Tptpmn, Tptpll, and Tptpln units, respectively. Block volume results are provided for those units that contain the emplacement drifts. The Tptpul, which is not currently part of the repository horizon, was not included in this attachment.

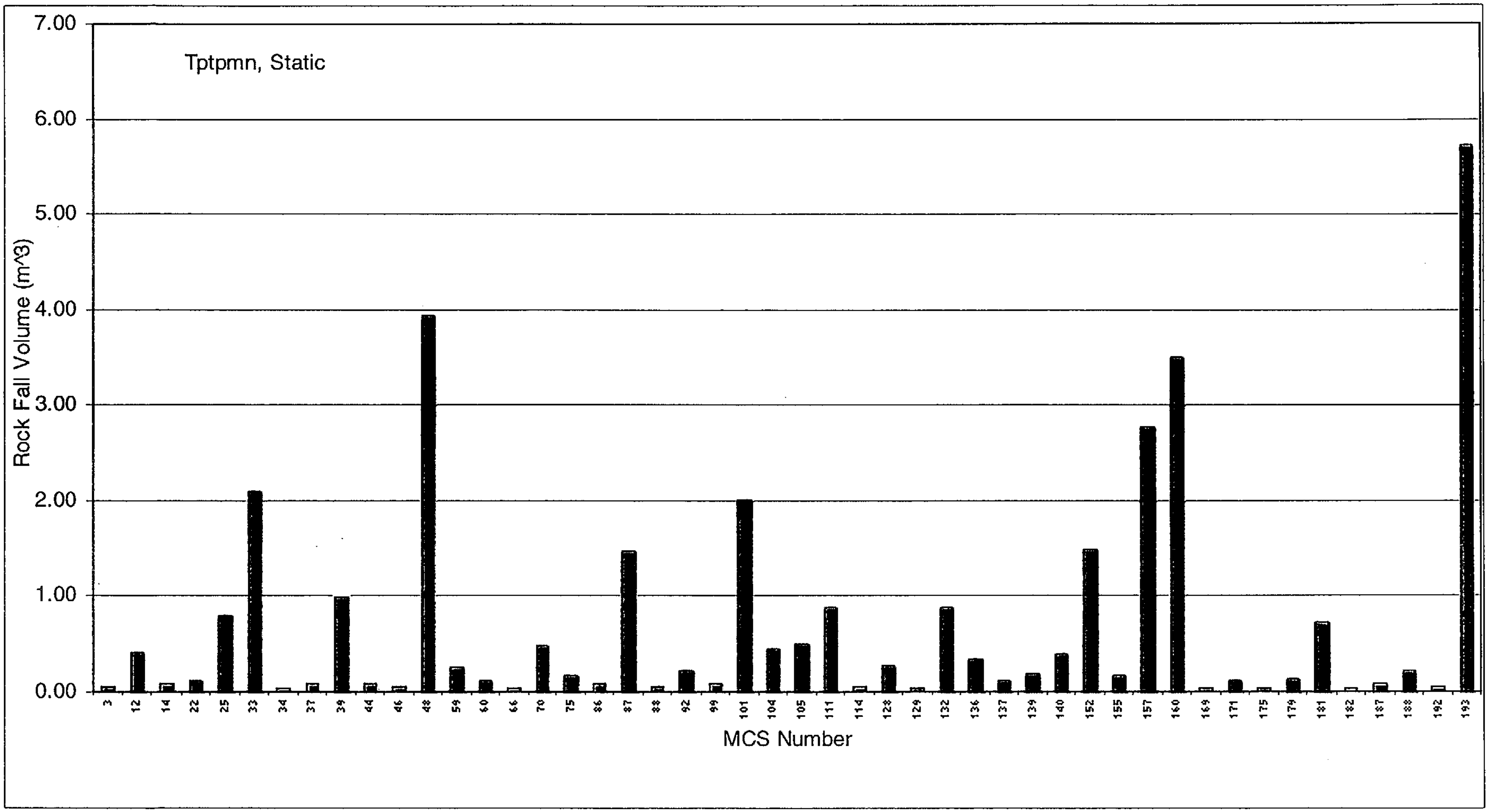


Figure XI-1. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpmn, Static Condition

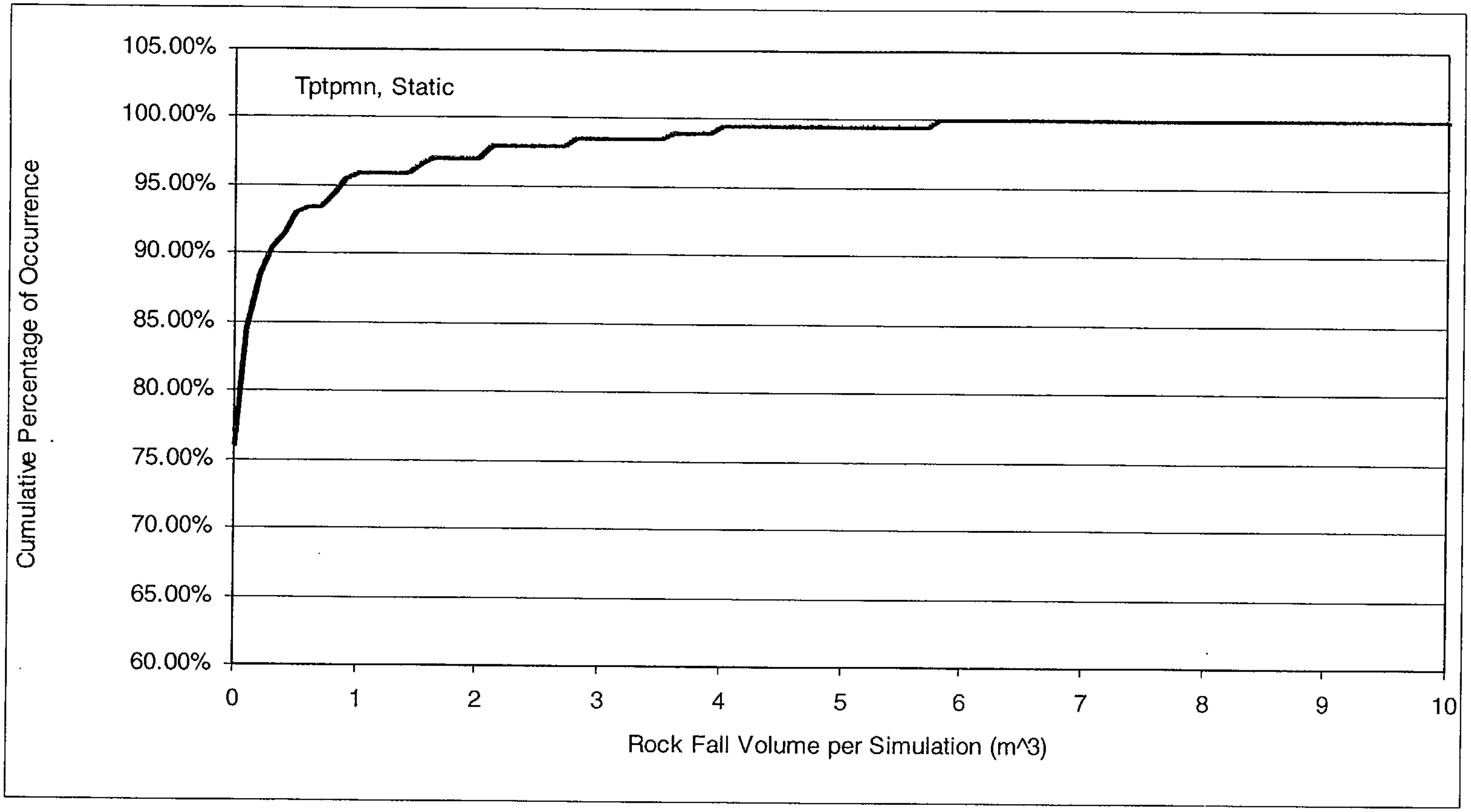


Figure XI-2. Cumulative Rock Fall Volume Distribution, Tptpmn, Static Condition

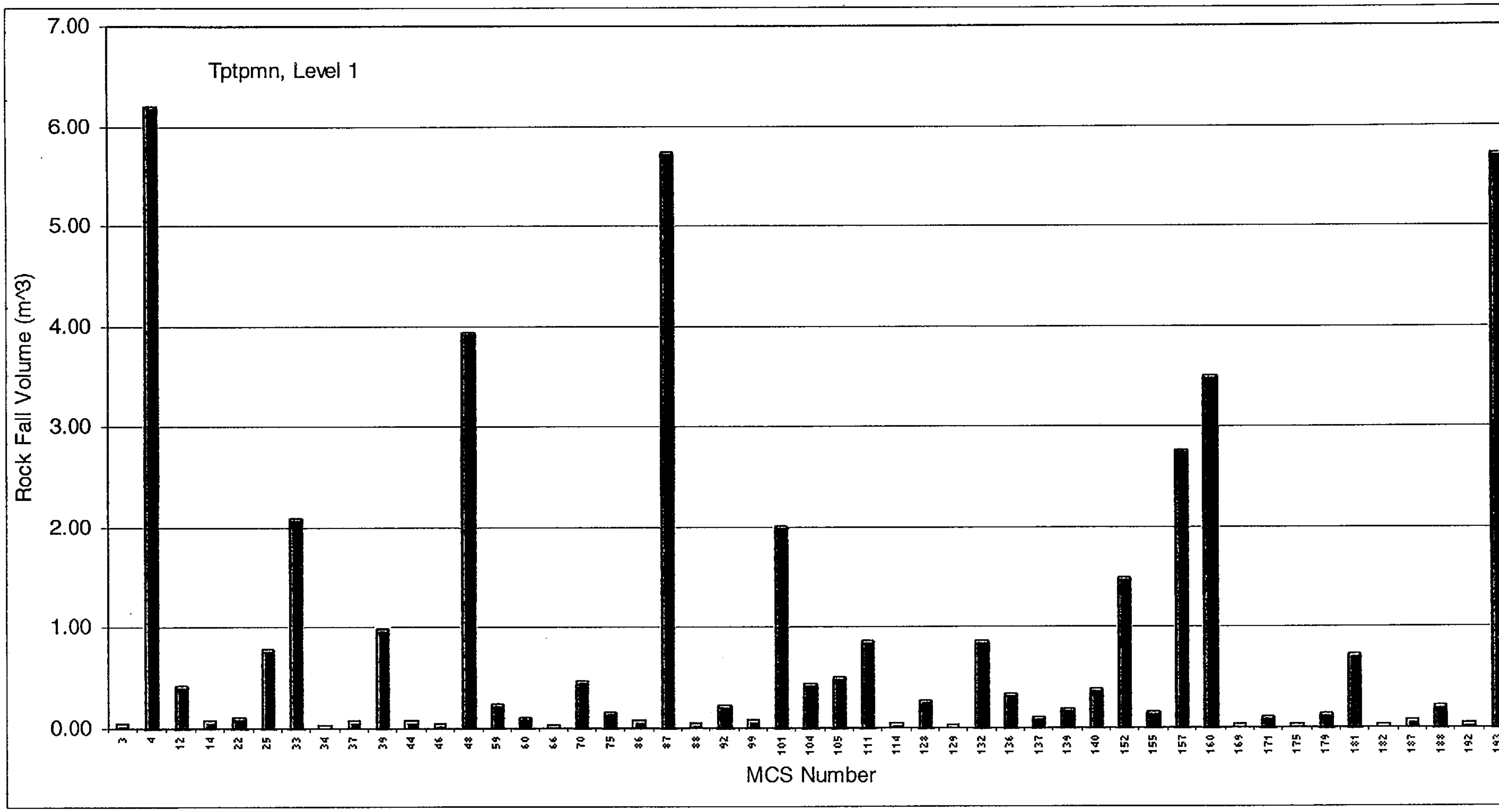


Figure XI-3. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpmn, Seismic Level 1

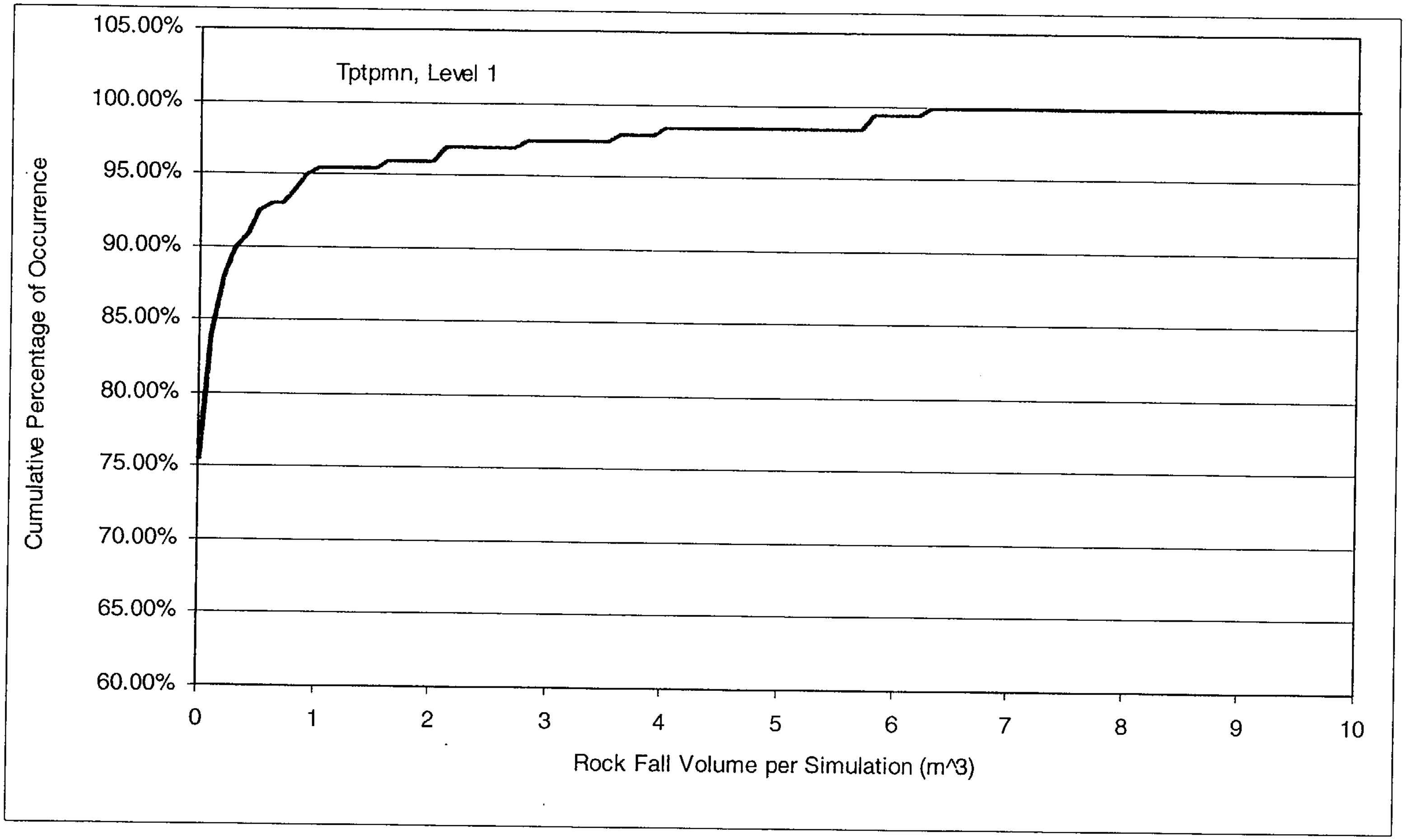


Figure XI-4. Cumulative Rock Fall Volume Distribution, Tptpmn, Seismic Level 1

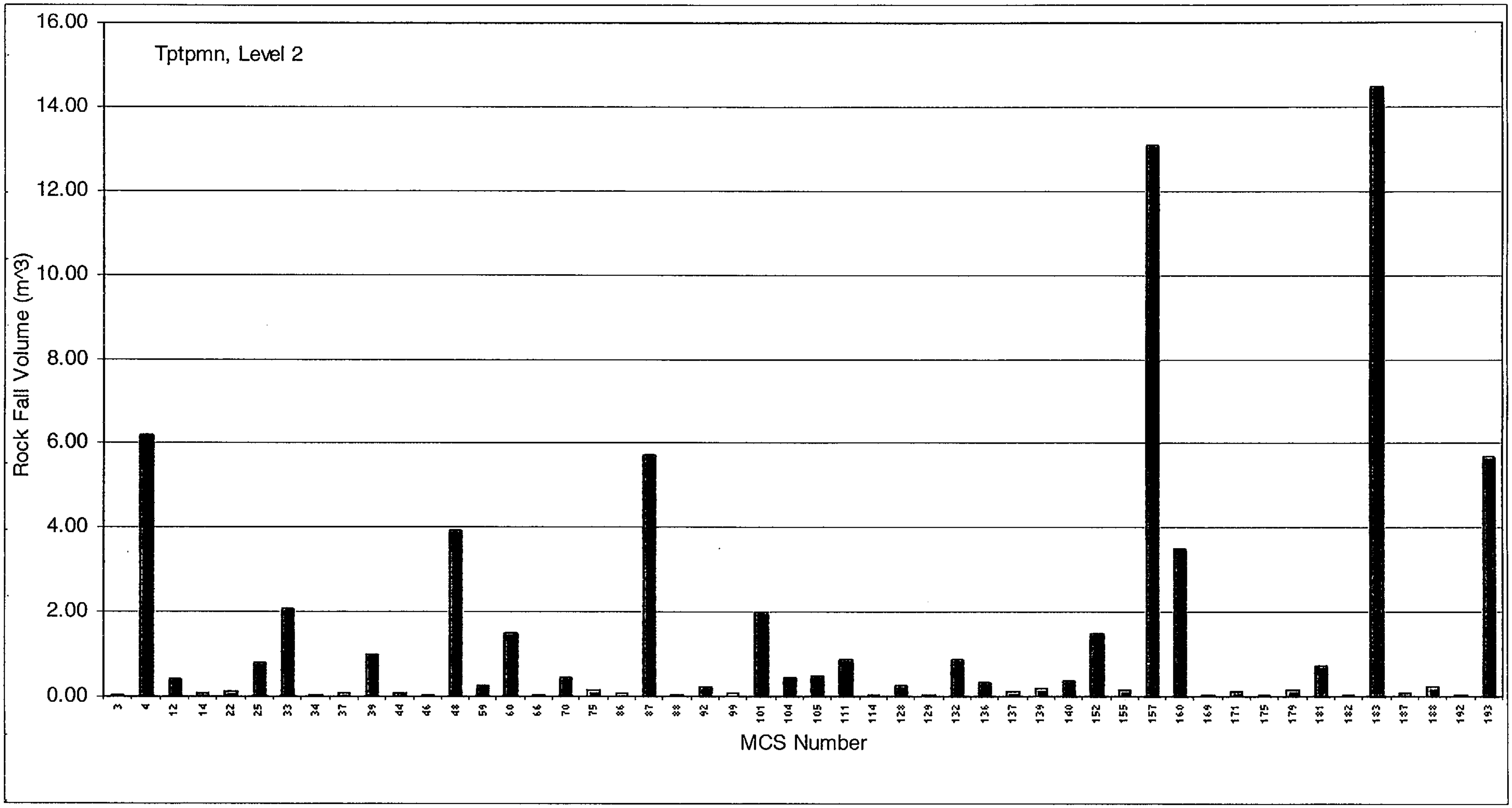


Figure XI-5. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpmn, Seismic Level 2

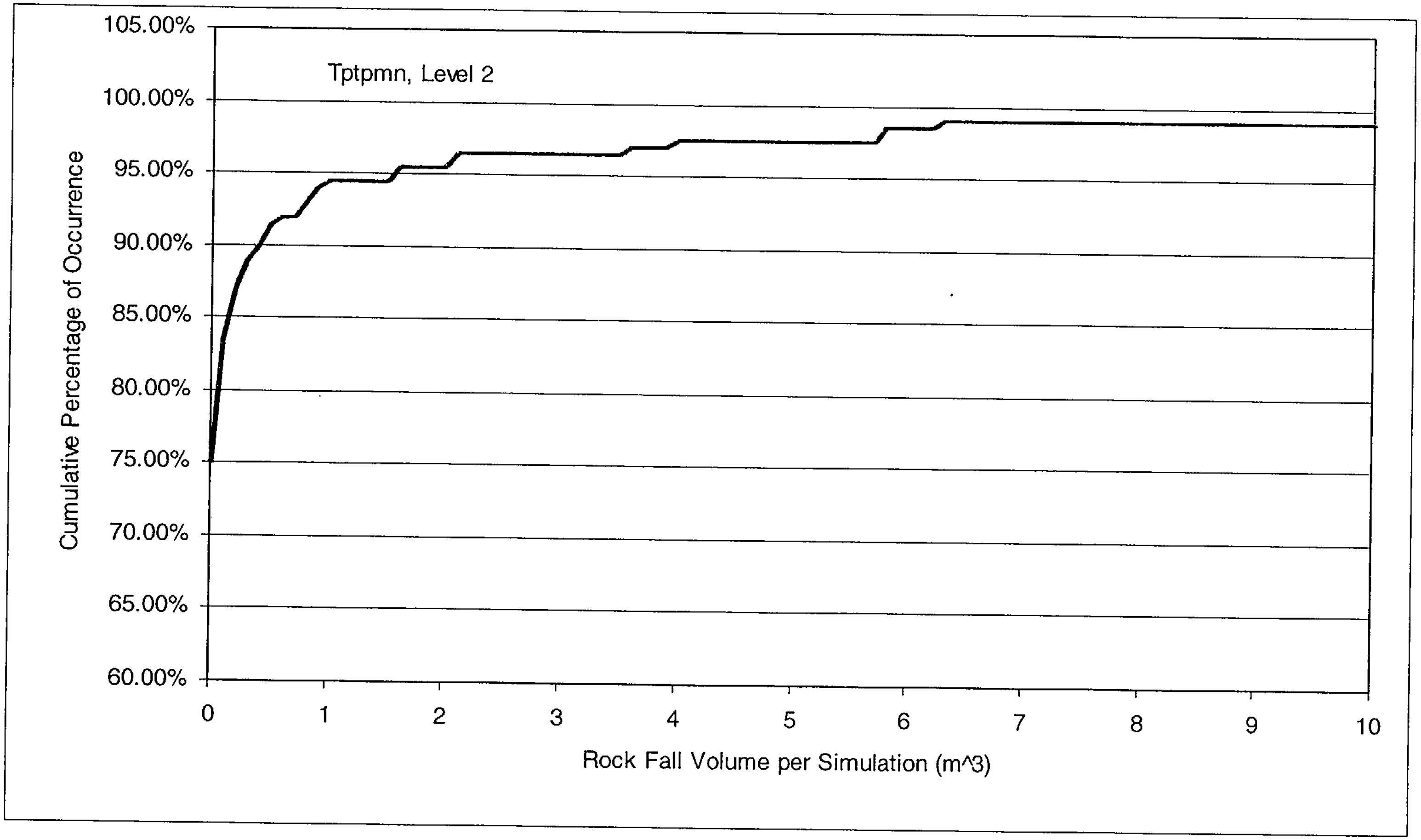


Figure XI-6. Cumulative Rock Fall Volume Distribution, Tptpmn, Seismic Level 2

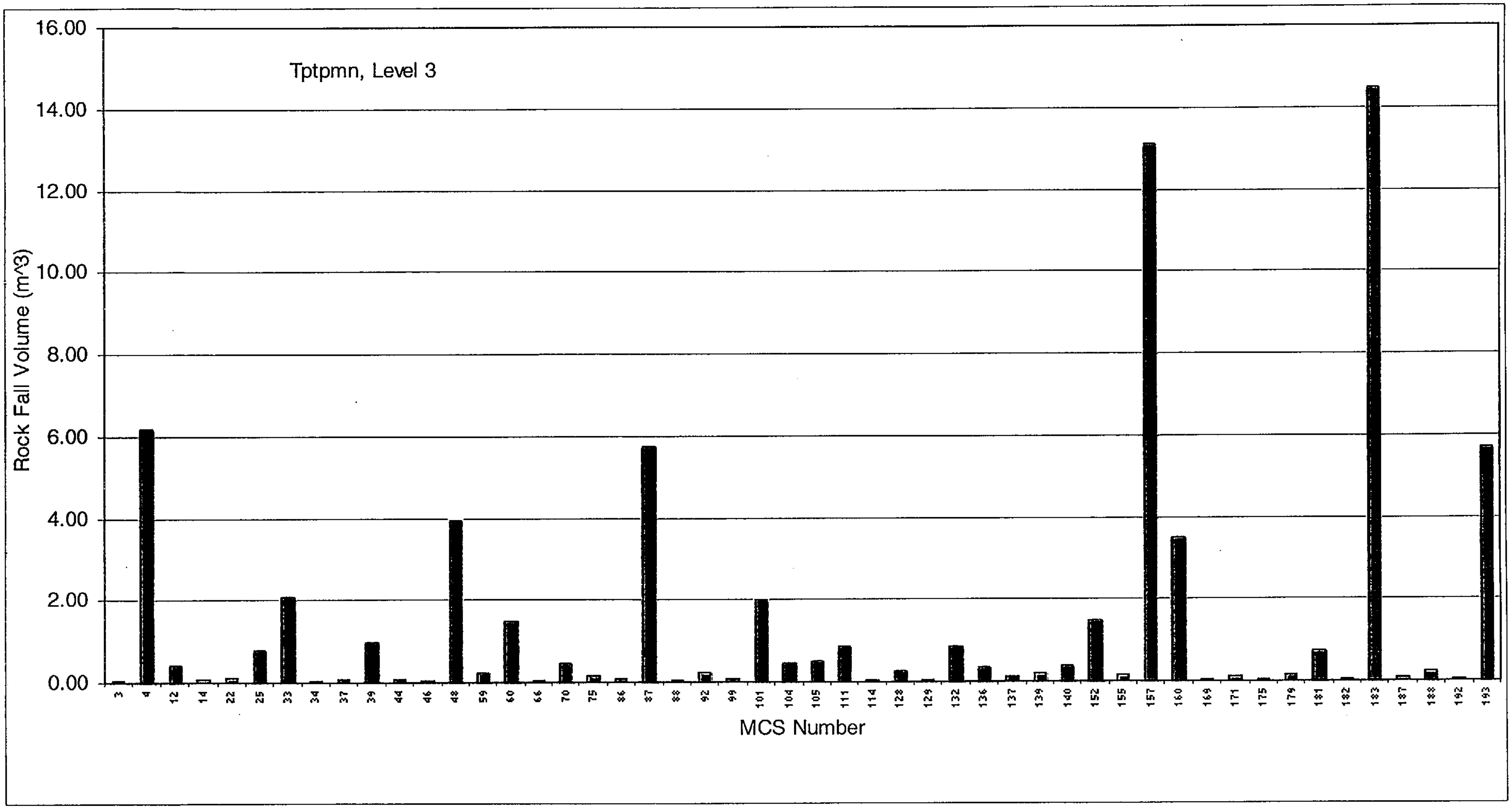


Figure XI-7. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpmn, Seismic Level 3

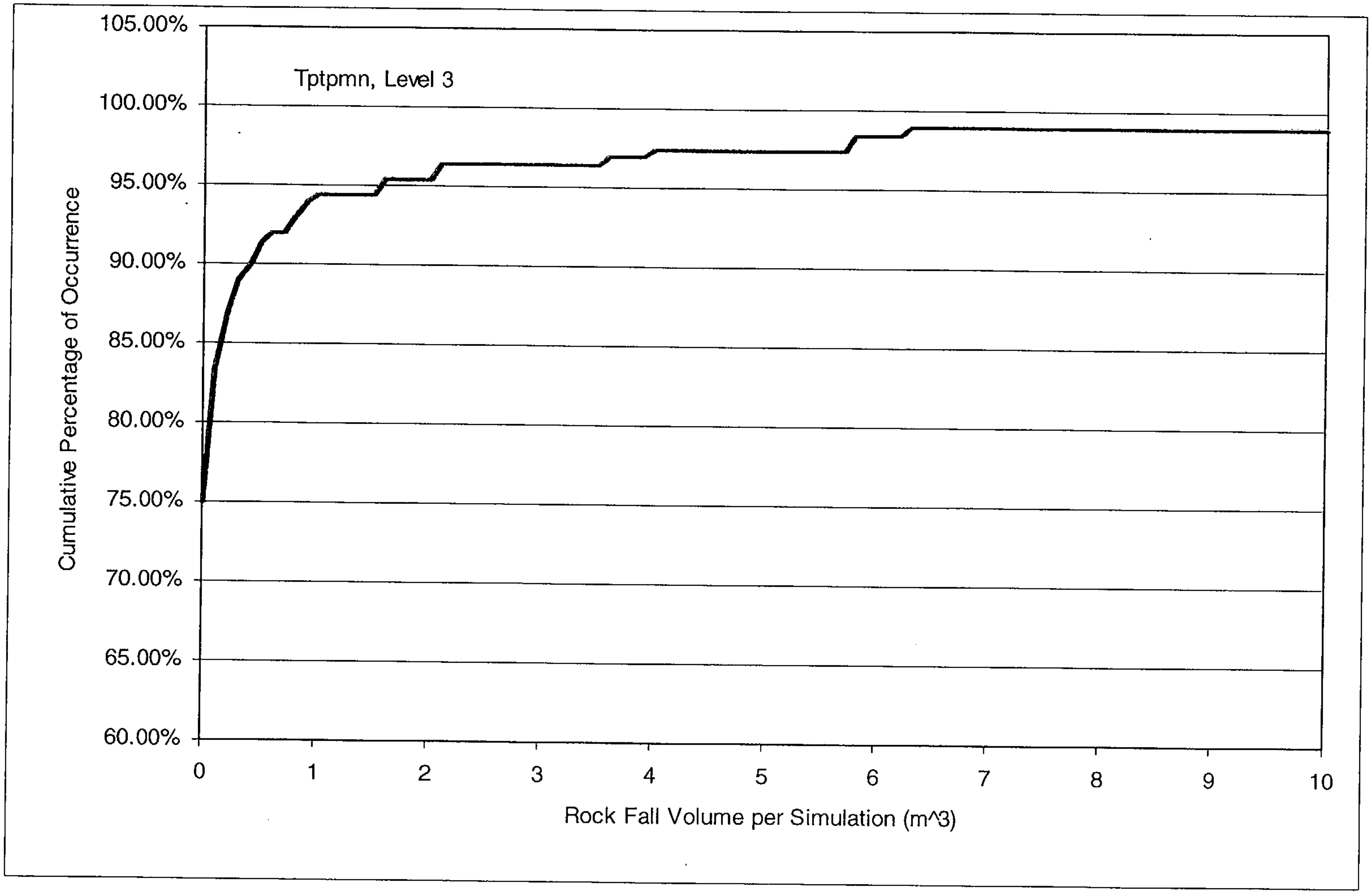


Figure XI-8. Cumulative Rock Fall Volume Distribution, Tptpmn, Seismic Level 3

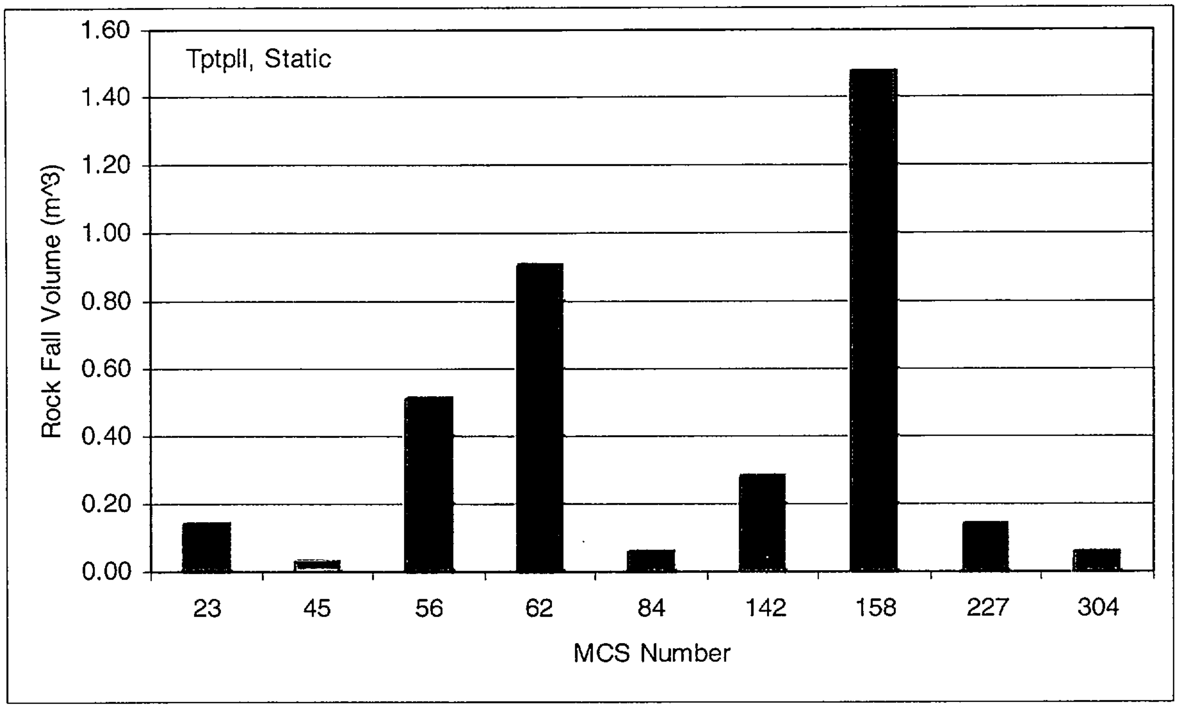


Figure XI-9. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpll, Static Condition

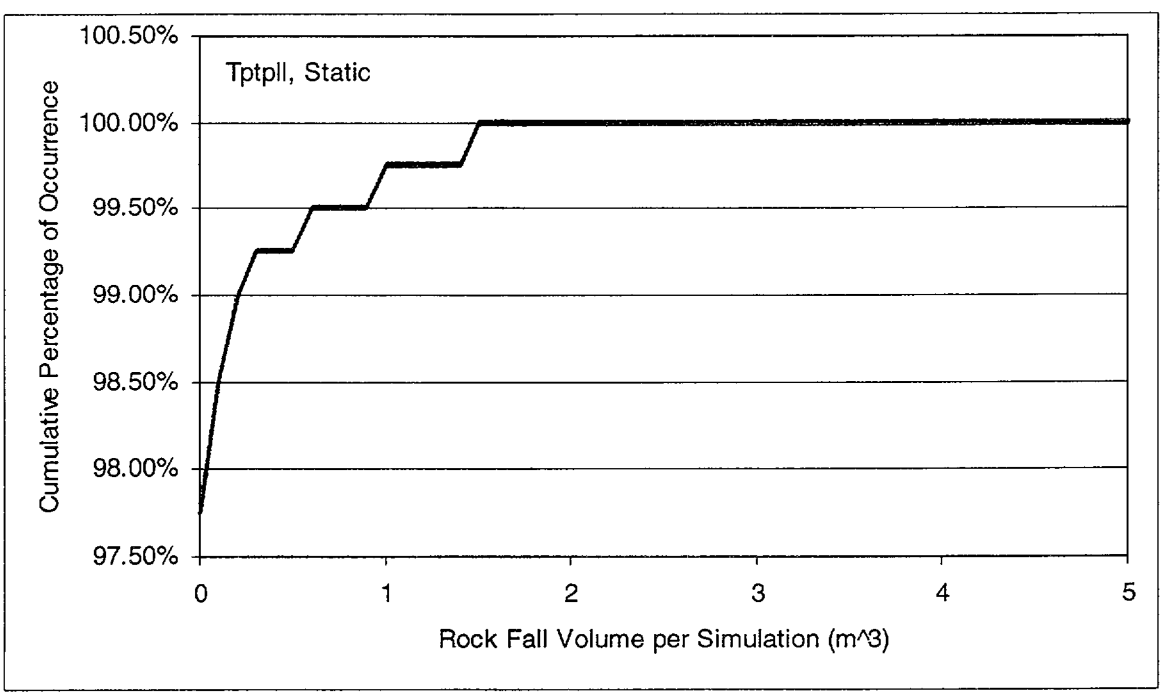


Figure XI-10. Cumulative Rock Fall Volume Distribution, Tptpll, Static Condition

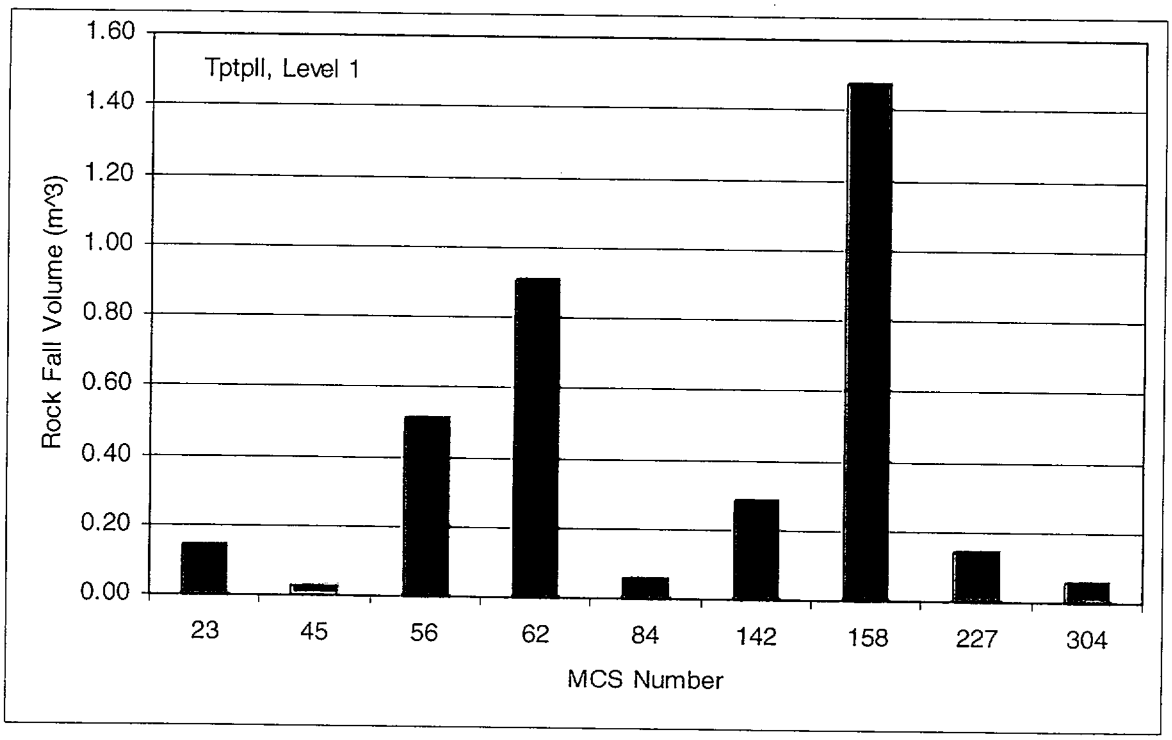


Figure XI-11. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpll, Seismic Level 1

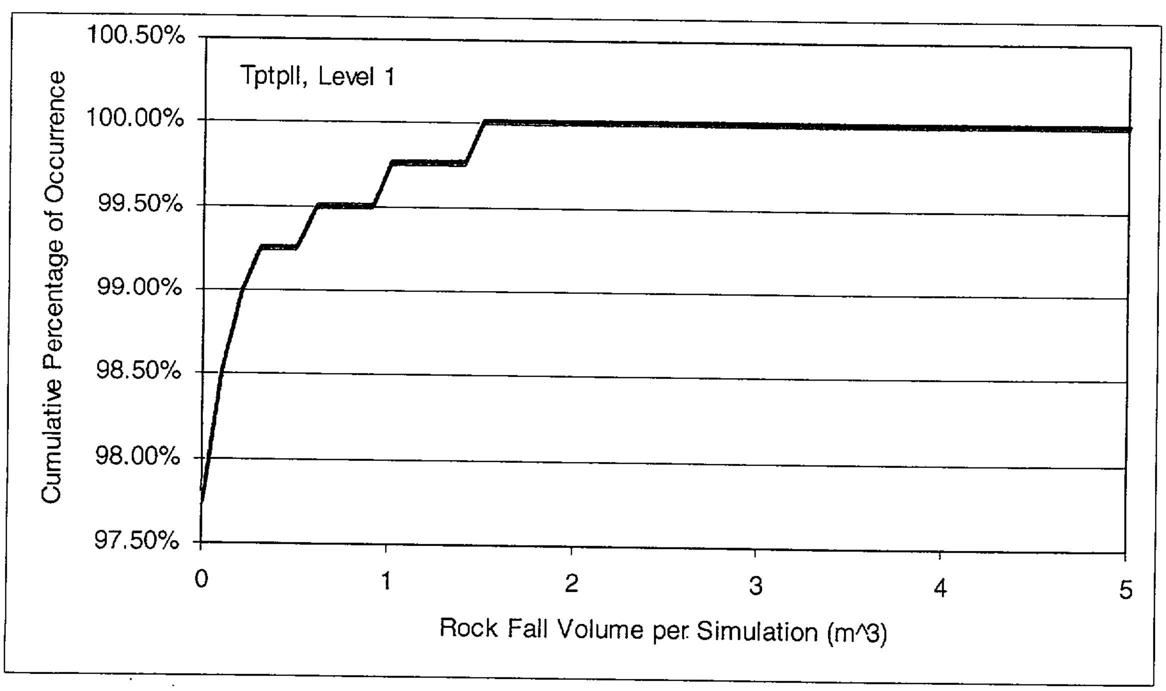


Figure XI-12. Cumulative Rock Fall Volume Distribution, Tptpll, Seismic Level 1

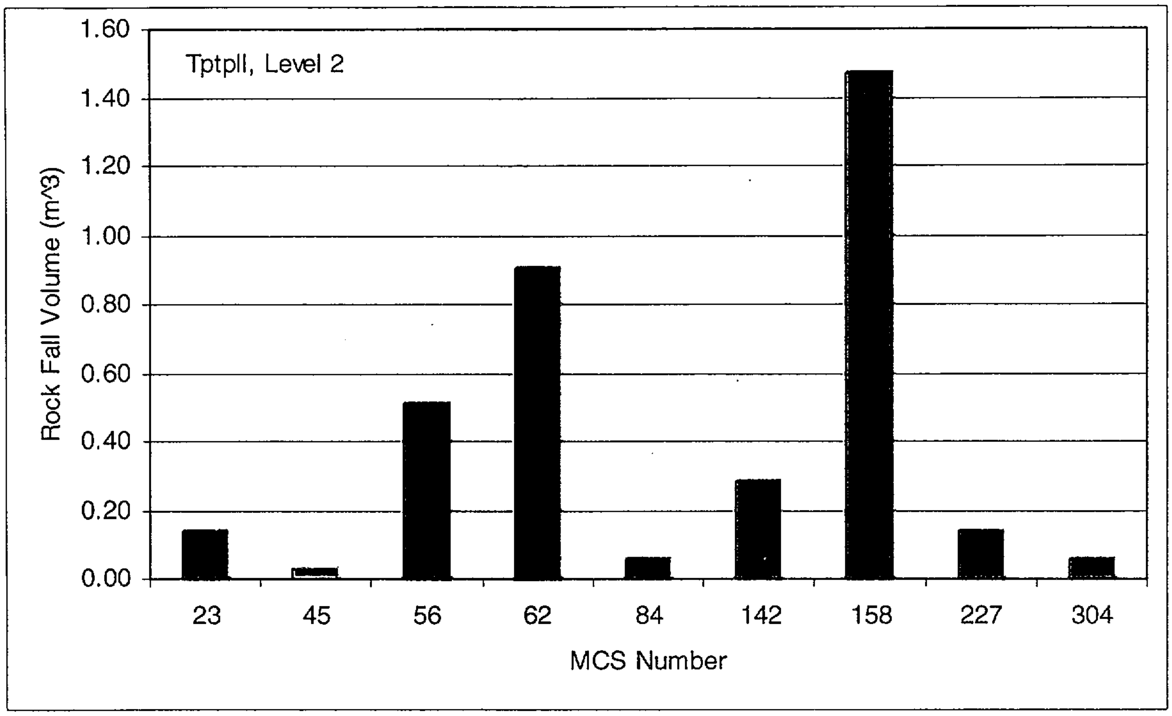


Figure XI-13. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpll, Seismic Level 2

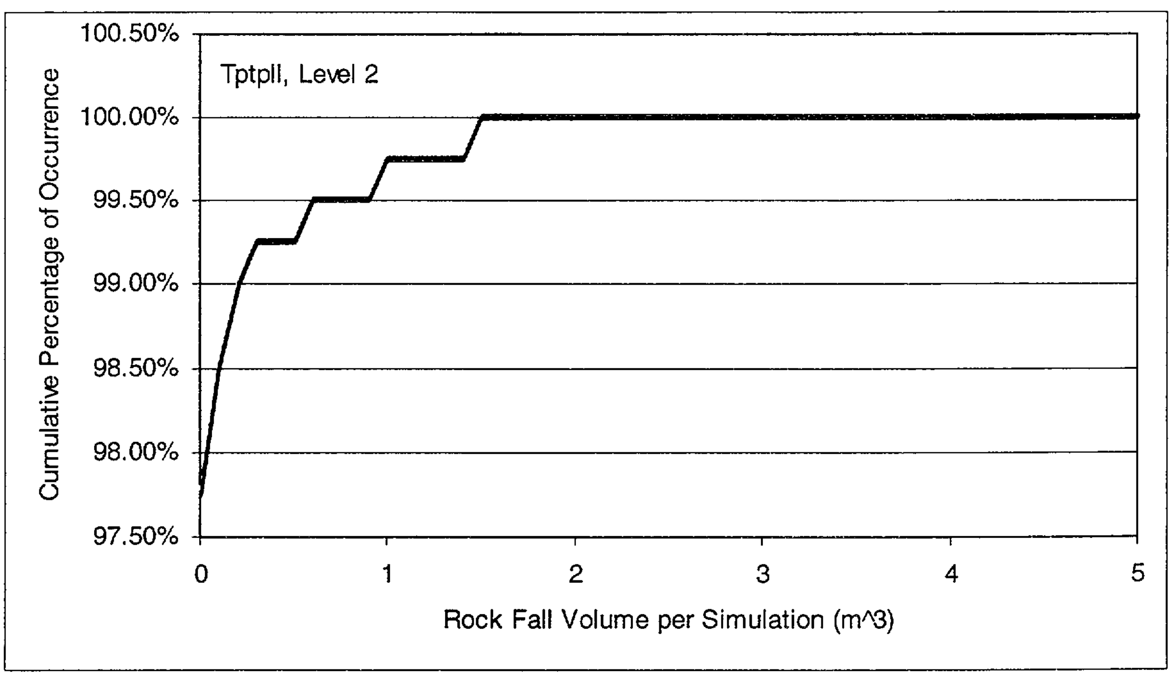


Figure XI-14. Cumulative Rock Fall Volume Distribution, Tptpll, Seismic Level 2

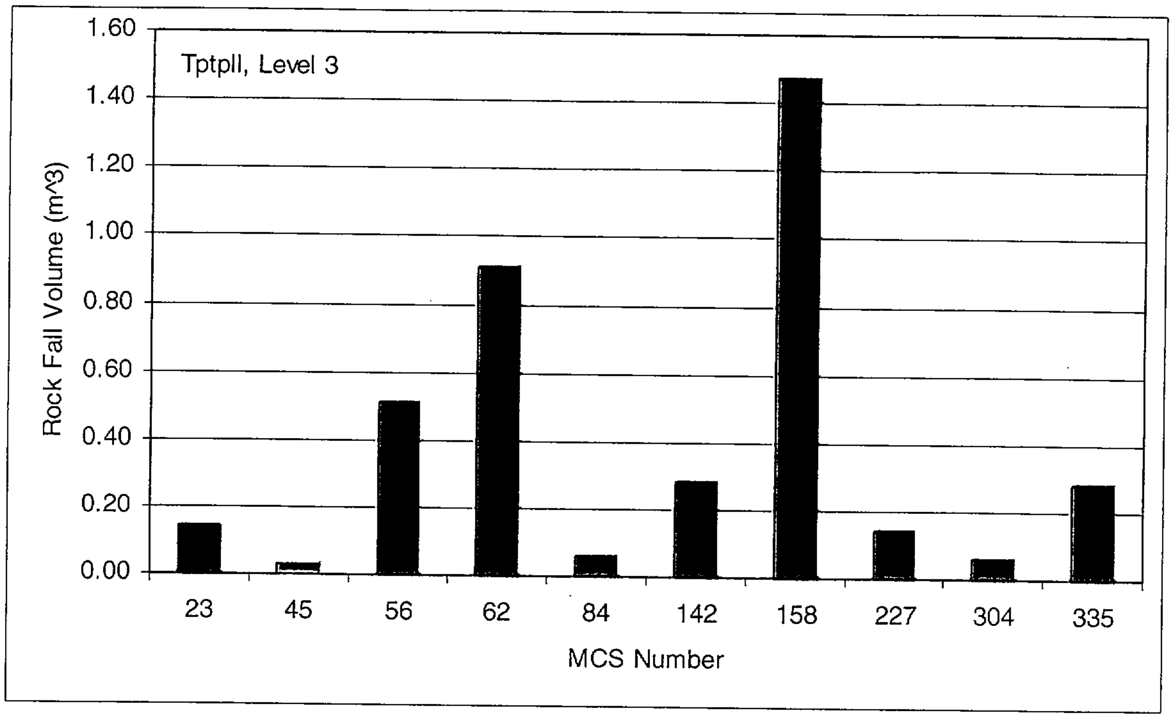


Figure XI-15. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpll, Seismic Level 3

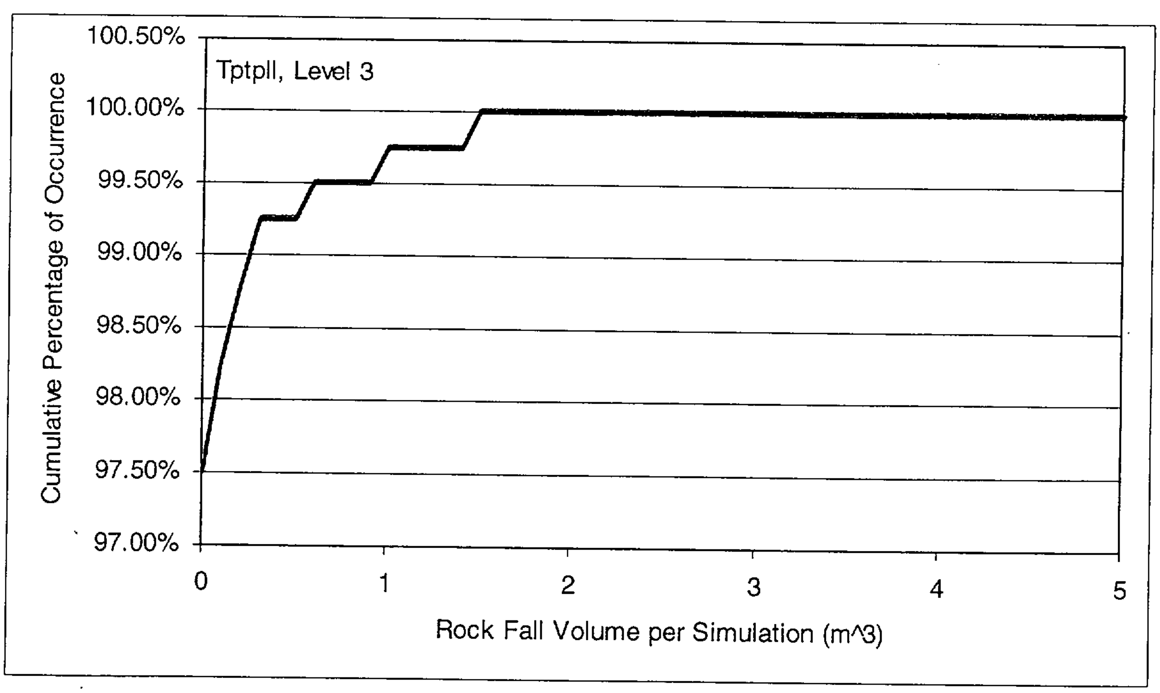


Figure XI-16. Cumulative Rock Fall Volume Distribution, Tptpll, Seismic Level 3

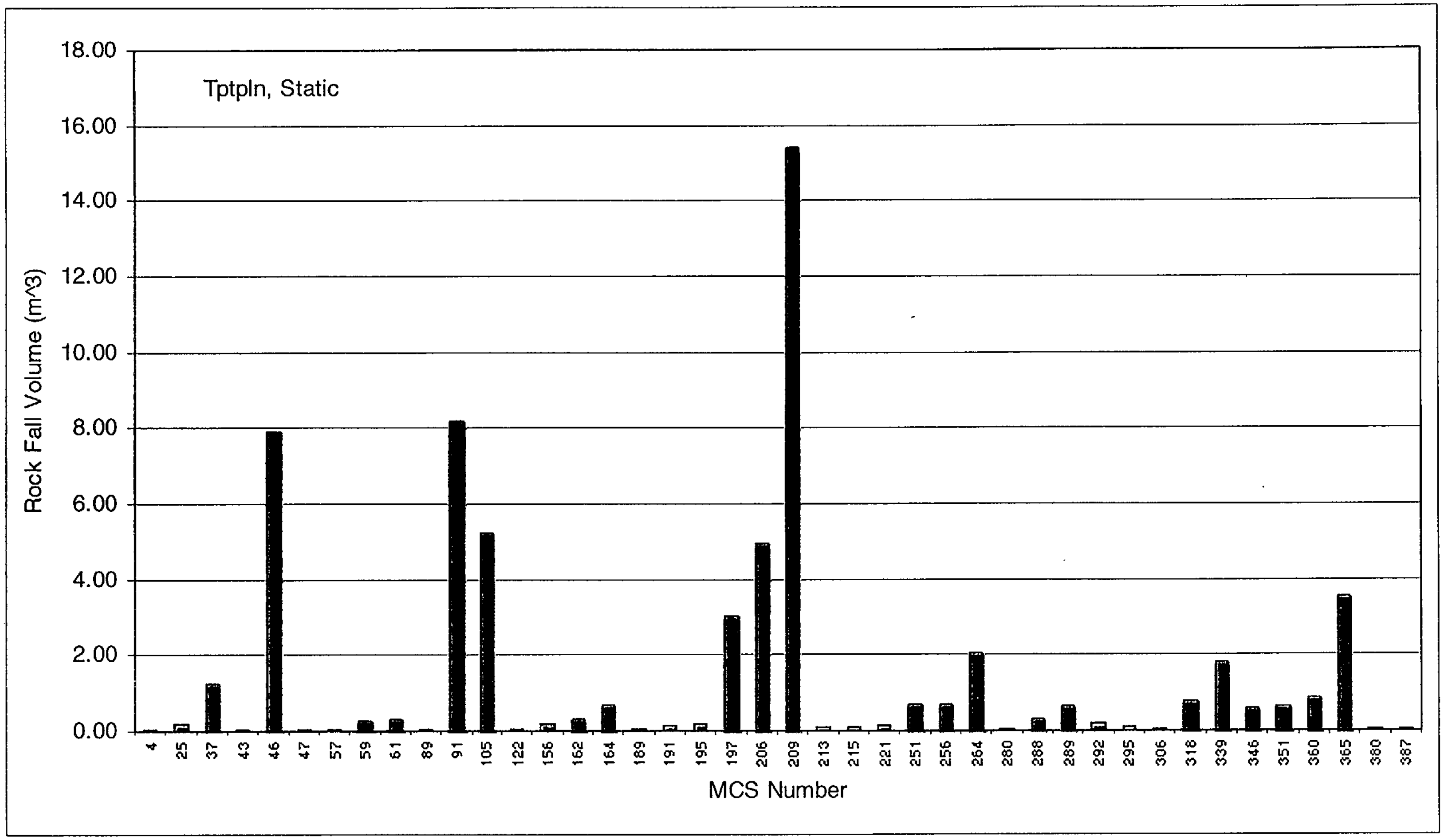


Figure XI-17. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpln, Static Condition

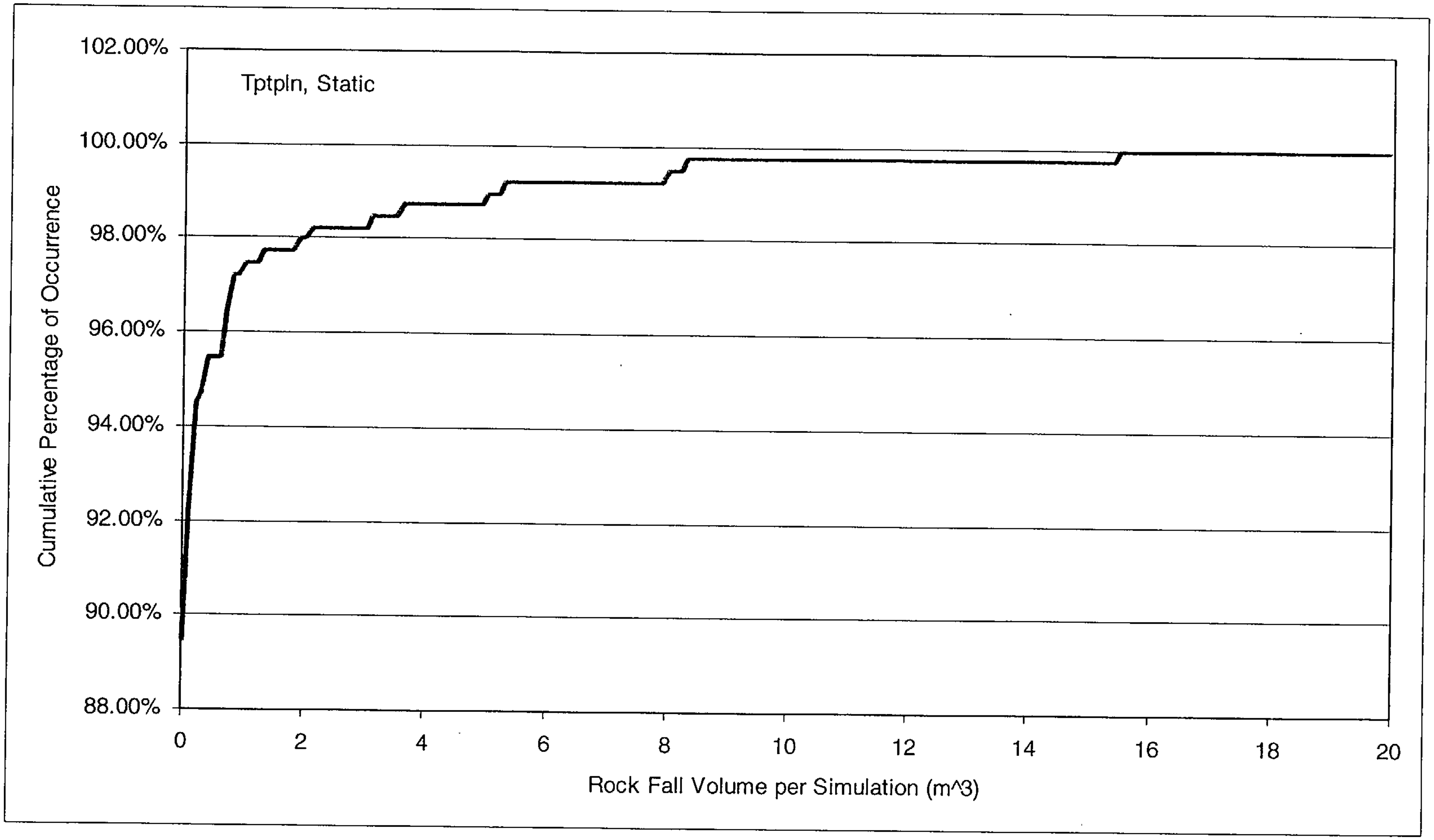


Figure XI-18. Cumulative Rock Fall Volume Distribution, Tptpln, Static Condition

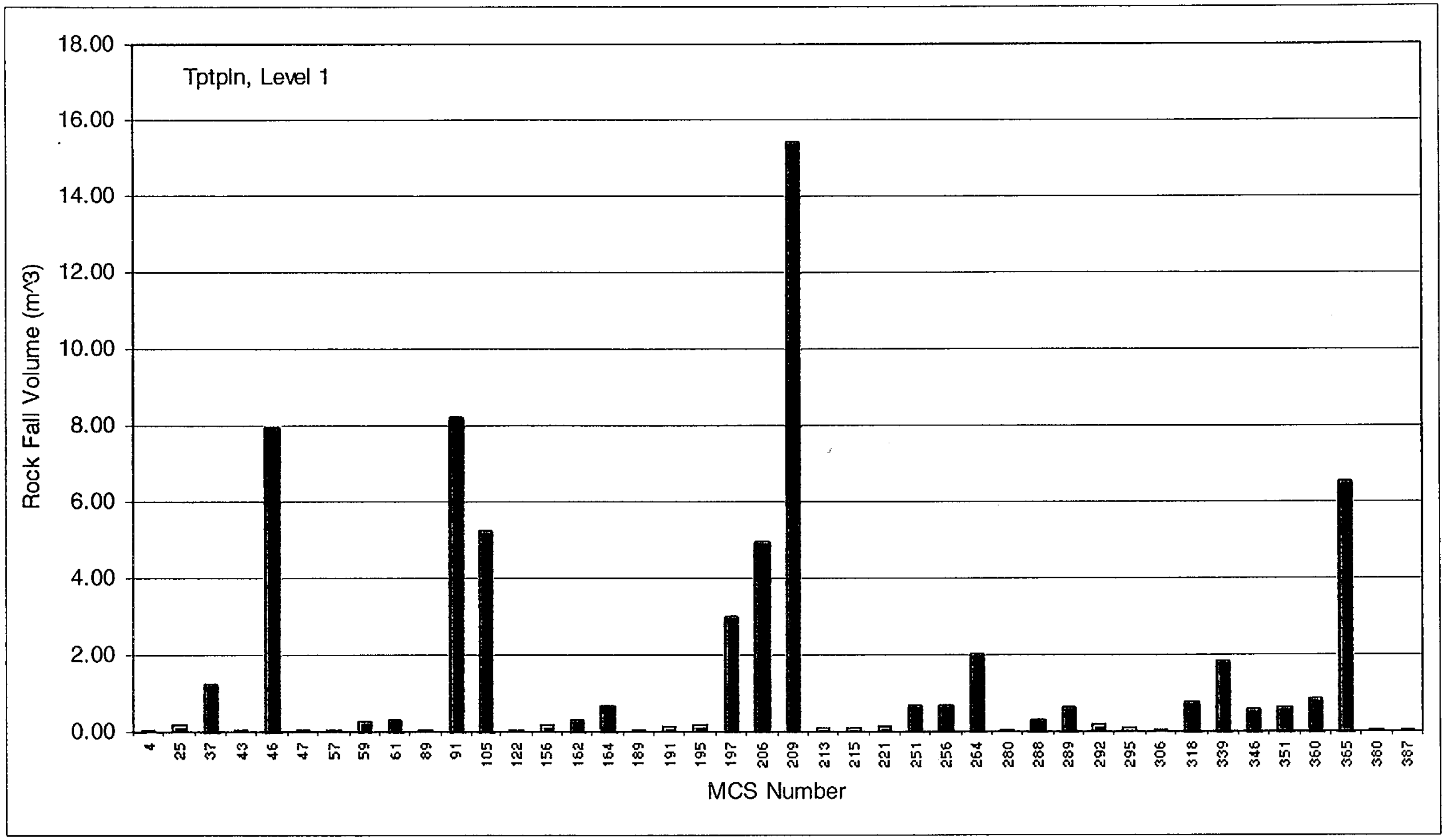


Figure XI-19. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpln, Seismic Level 1

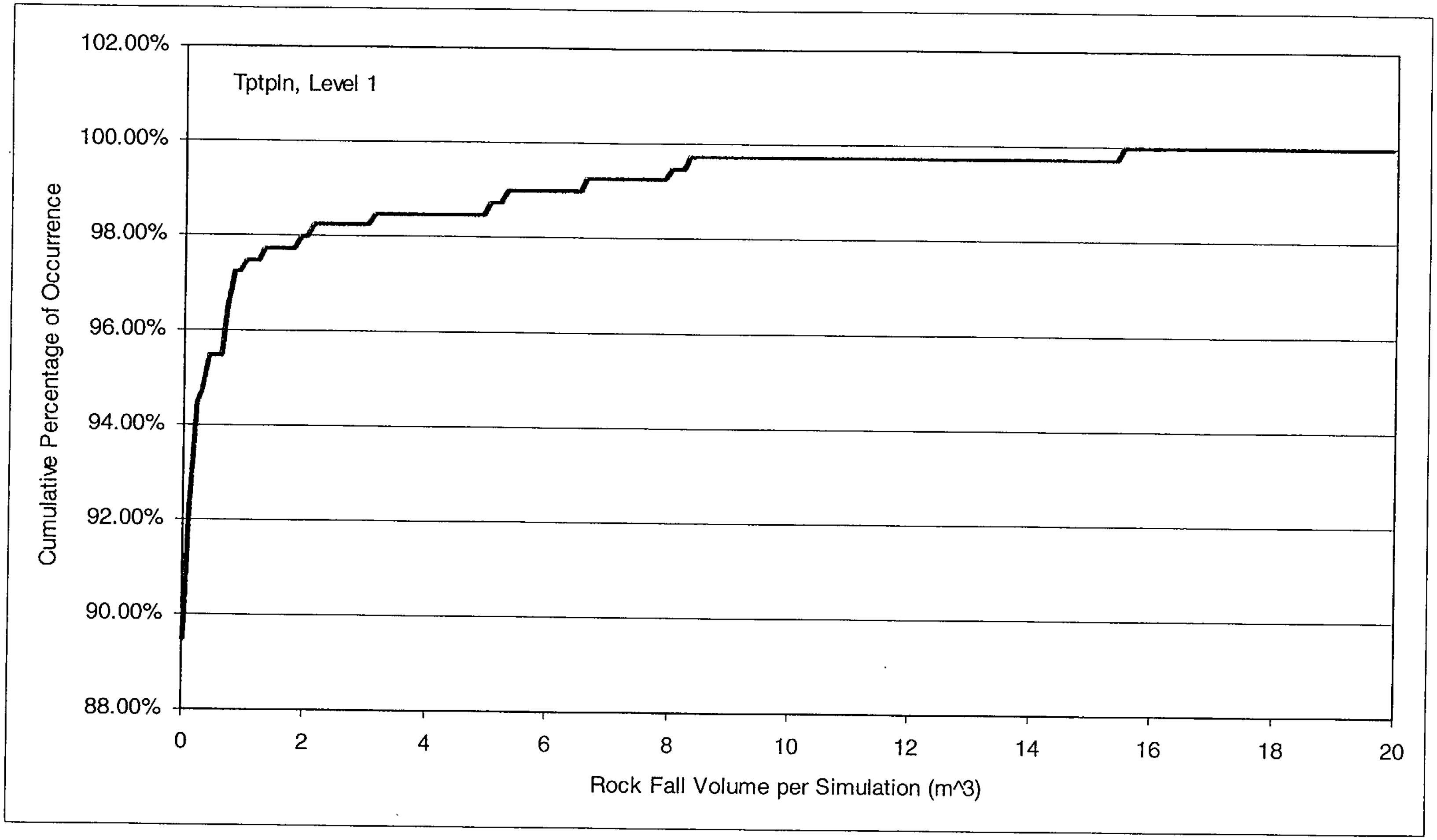


Figure XI-20. Cumulative Rock Fall Volume Distribution, Tptpln, Seismic Level 1

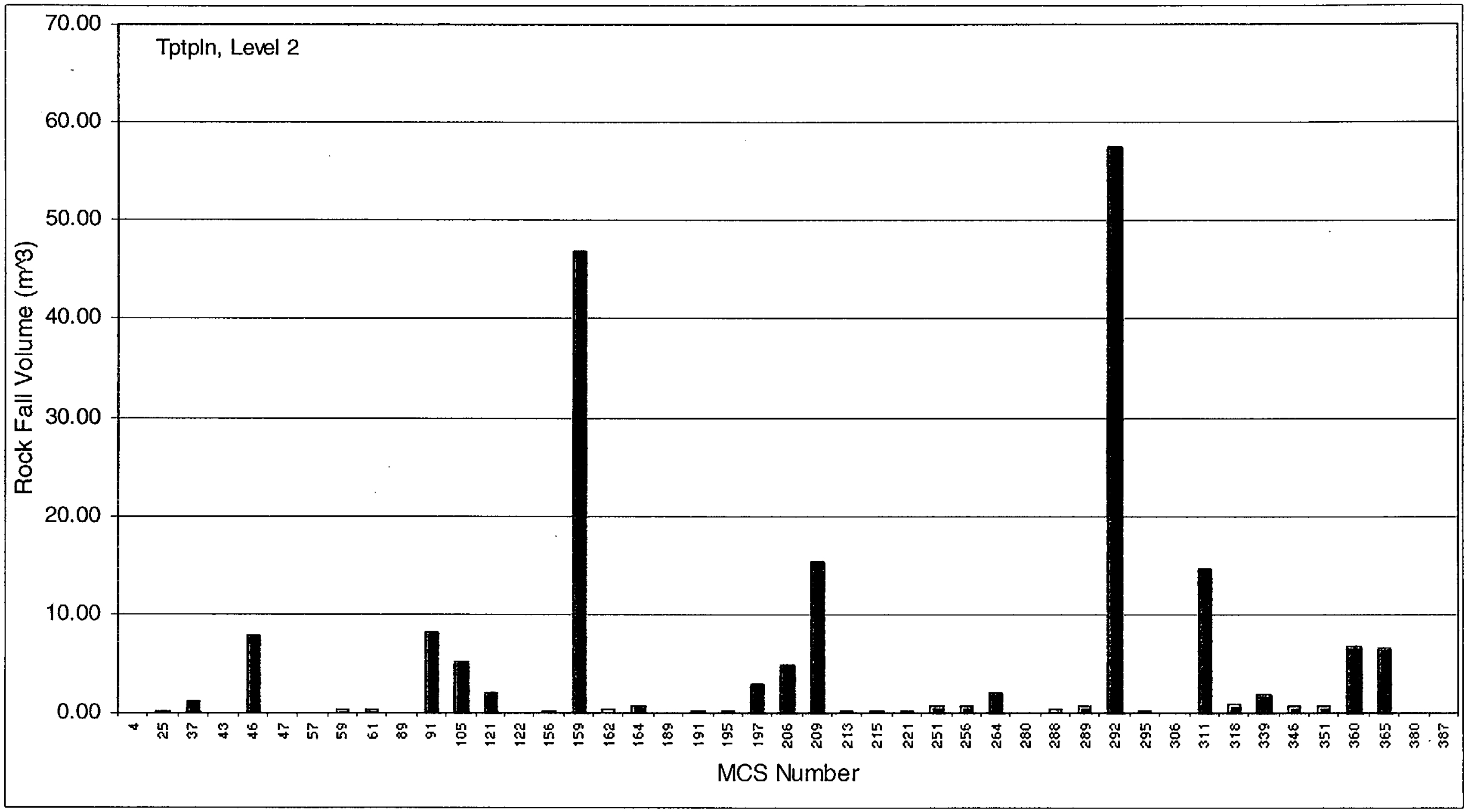


Figure XI-21. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpln, Seismic Level 2

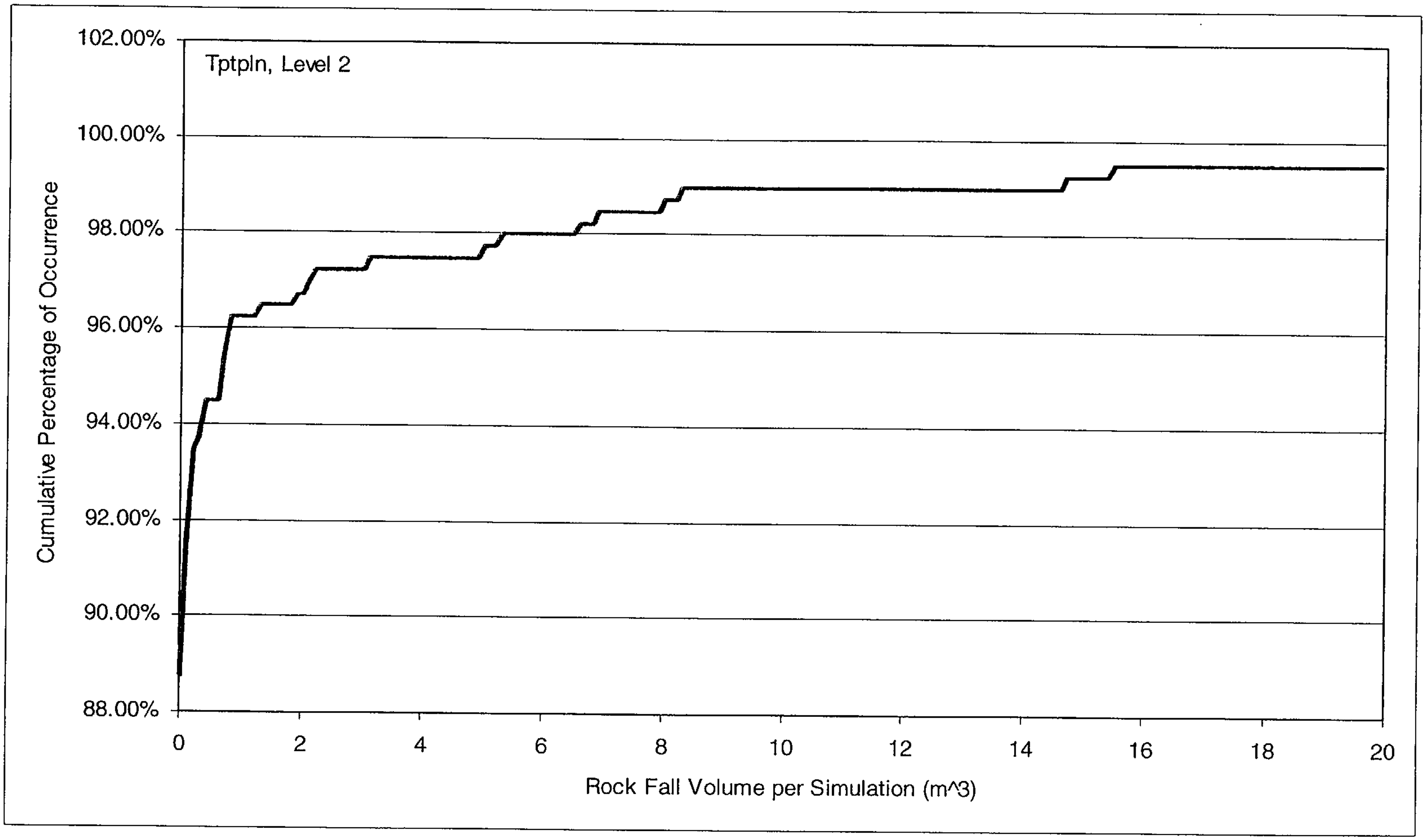


Figure XI-22. Cumulative Rock Fall Volume Distribution, Tptpln, Seismic Level 2

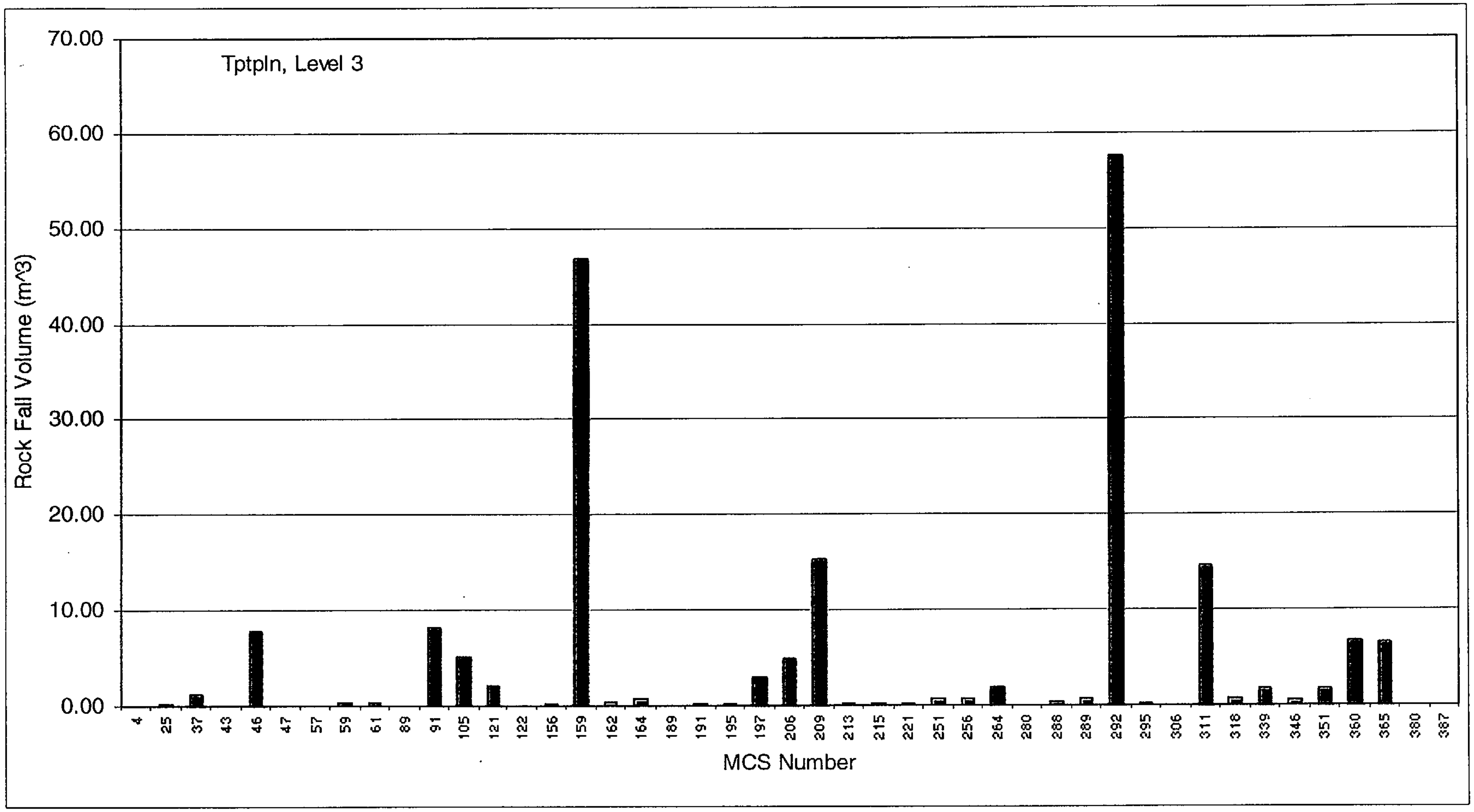


Figure XI-23. Histogram of Rock Fall Volume per One Monte Carlo Simulation, Tptpln, Seismic Level 3

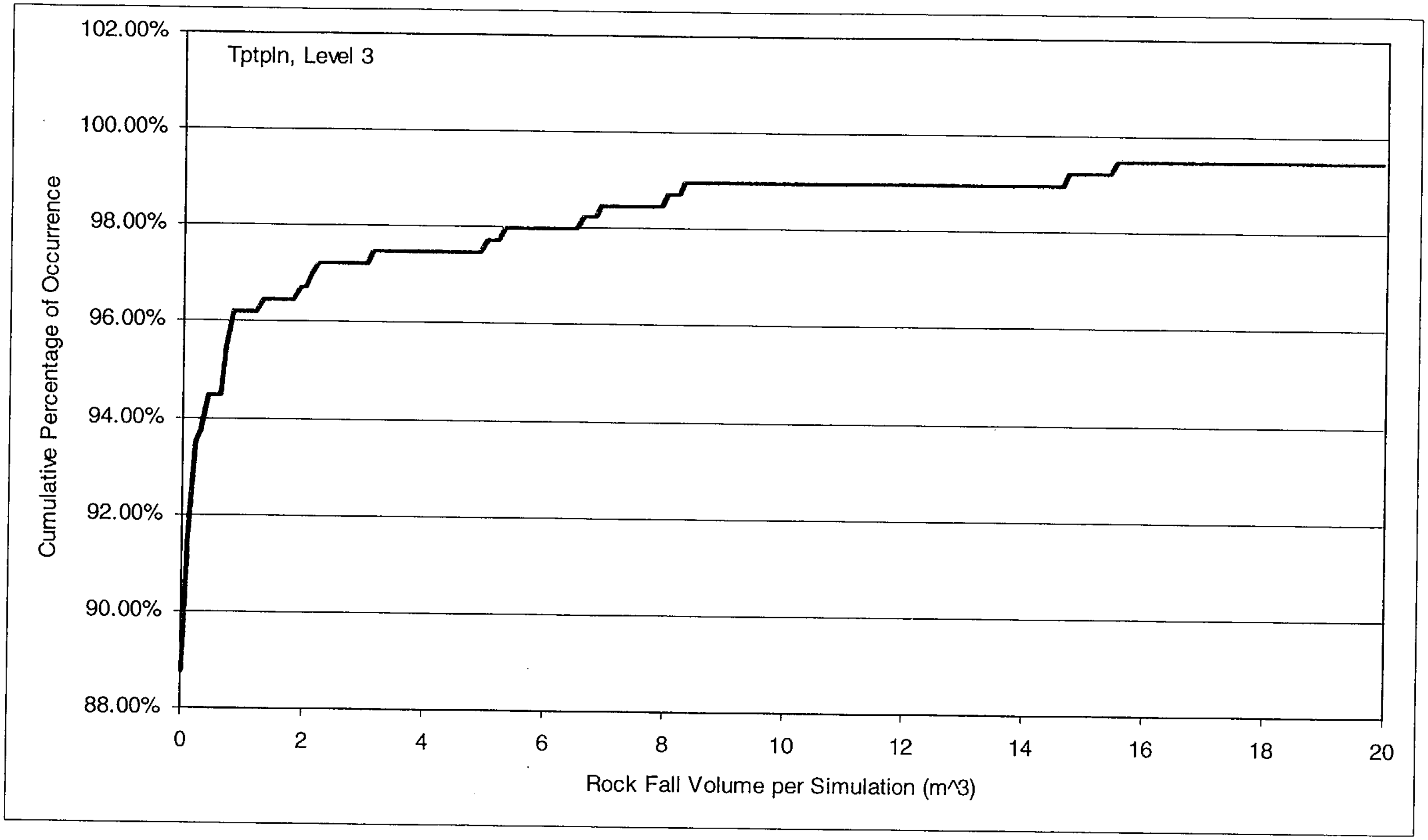


Figure XI-24. Cumulative Rock Fall Volume Distribution, Tptpln, Seismic Level 3

ATTACHMENT XII

DRIFT DEGRADATION PROFILES

DRIFT DEGRADATION PROFILES

Worst case drift degradation profiles for each of the stratigraphic units modeled, with various loading scenarios and configurations, are provided in this attachment. Additional information on the development of drift profiles is provided in Section 6.4.3.

105°-Azimuth Emplacement Drift Orientation, Seismic Loading, Without Backfill–As described in Section 6.4.1, the emplacement drifts with no backfill in place were simulated for four different cases. The first case considered static loading only. The next three cases considered static plus seismic loading, with each case representing a different level of seismic loading (see Section 6.4.1.2). For the length of drift simulated, a worst-case drift profile (i.e., the area with the greatest volume of failed rock) was selected. These profiles are shown in Figures XII-1 through XII-4 for each lithologic unit. With the selection of the worst-case profile for each individual case, the profile presented may not be located in the same area. For example: in Figure XII-1, the area of the rock fall for Static and Seismic Level 1 conditions is different from the area of the rock fall for Seismic Level 2 and Level 3. It is important to note that most of the emplacement drifts are not affected by rock fall. The percentages of the drifts affected by rock fall are shown in drift profile figure, along with the volume of the failed rock from the profile area and the DRKBA Monte Carlo simulation (MCS) in which the failure occurred.

105°-Azimuth Emplacement Drift Orientation, Thermal Loading and Time-Dependent Degradation, With Backfill–The drift profiles with backfill are shown at four different time intervals, with the progressive drift degradation a function of both thermal loading and the time dependent degradation of joint cohesion. As for the cases with no backfill, the drift profiles (Figures XII-5 through XII-8) represent the worst case, or greatest volume of rock fall within the simulated length of tunnel. The percentages of the drifts affected by rock fall considering time-dependent drift degradation are shown in each figure, along with the volume of the failed rock from the profile area and the DRKBA MCS in which the failure occurred..

105°-Azimuth Emplacement Drift Orientation, Thermal Loading and Time-Dependent Degradation, Without Backfill– The drift profiles without backfill are shown at four different time intervals, with the progressive drift degradation a function of both thermal loading and the time dependent degradation of joint cohesion. The drift profiles (Figures XII-9 through XII-12) represent the worst case, or greatest volume of rock fall within the simulated length of tunnel. The percentages of the drifts affected by rock fall considering time-dependent drift degradation are shown in each figure, along with the volume of the failed rock from the profile area and the DRKBA MCS in which the failure occurred.

75°-Azimuth Emplacement Drift Orientation, Seismic Loading, Without Backfill– The drift profiles for a 75°-azimuth emplacement drift without backfill are shown at four different loading cases. The first case considered static loading only. The next three cases considered static plus seismic loading, with each case representing a different level of seismic loading (see Section 6.4.1.2). The drift profiles (Figures XII-13 through XII-16) represent the worst case, or greatest volume of rock fall within the simulated length of tunnel. The percentages of the drifts affected by rock fall considering time-dependent drift degradation are shown in each figure, along with

the volume of the failed rock from the profile area and the DRKBA MCS in which the failure occurred.

75°-Azimuth Emplacement Drift Orientation, Thermal Loading and Time-Dependent Degradation, Without Backfill– The drift profiles for a 75°-azimuth emplacement drift without backfill are shown at four different time intervals, with the progressive drift degradation a function of both thermal loading and the time dependent degradation of joint cohesion. The drift profiles (Figures XII-17 through XII-20) represent the worst case, or greatest volume of rock fall within the simulated length of tunnel. The percentages of the drifts affected by rock fall considering time-dependent drift degradation are shown in each figure, along with the volume of the failed rock from the profile area and the DRKBA MCS in which the failure occurred.

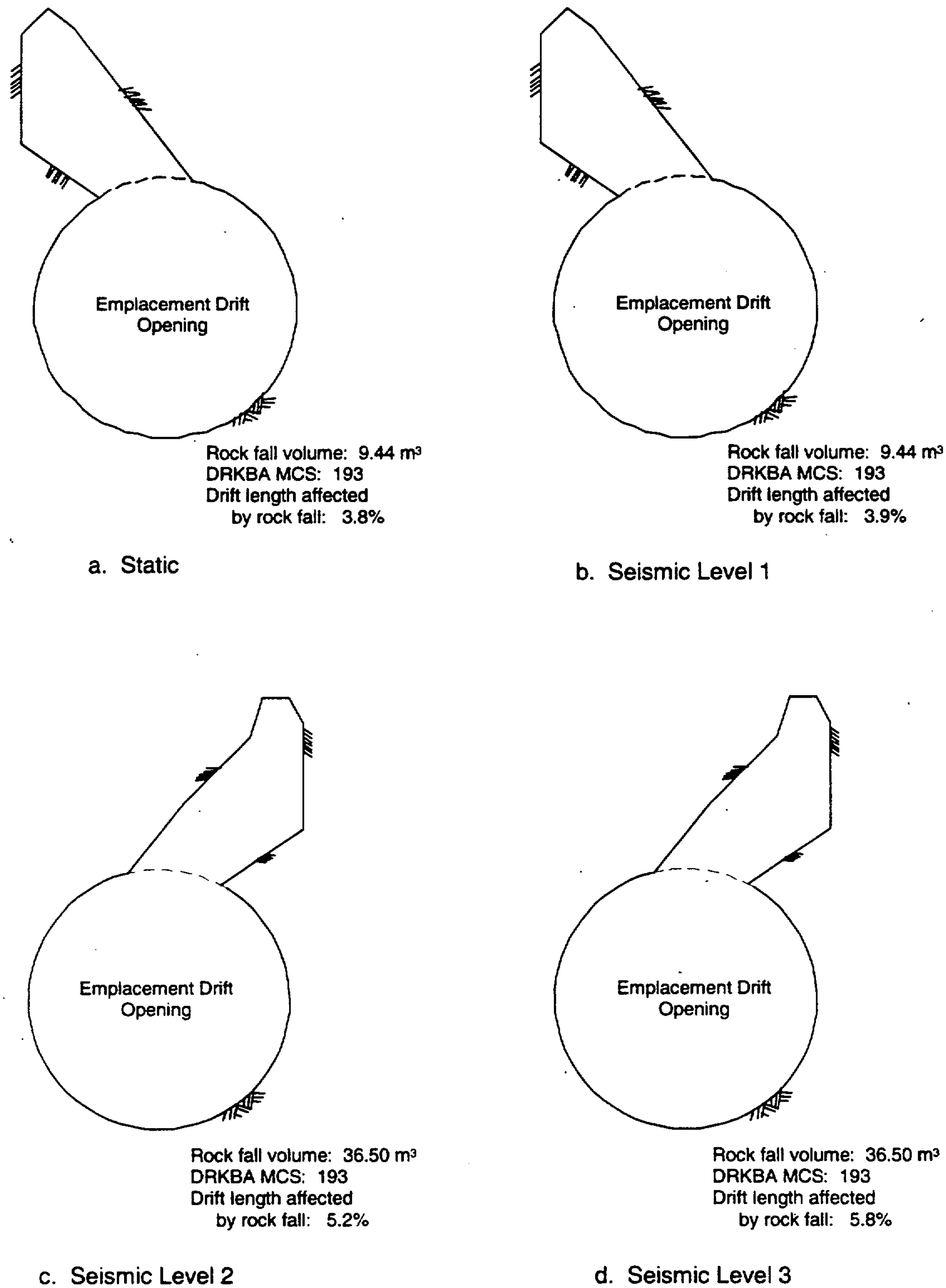


Figure XII-1. Emplacement Drift Profiles Considering Seismic Effects on Rock Fall for the Tptpul Unit, No Backfill, Drift Orientation: 105° Azimuth

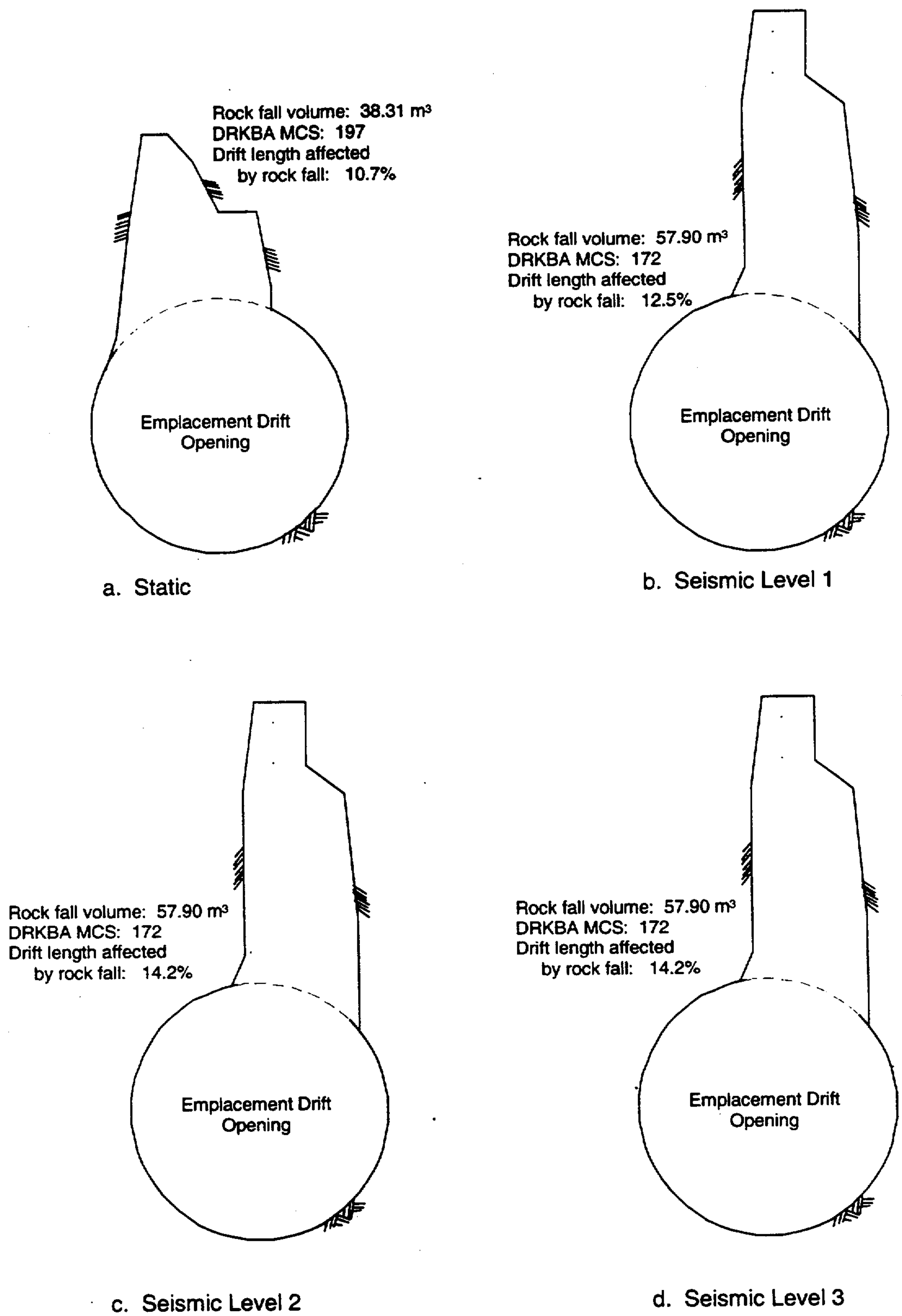


Figure XII-2. Emplacement Drift Profiles Considering Seismic Effects on Rock Fall for the Tptpmn Unit, No Backfill, Drift Orientation: 105° Azimuth

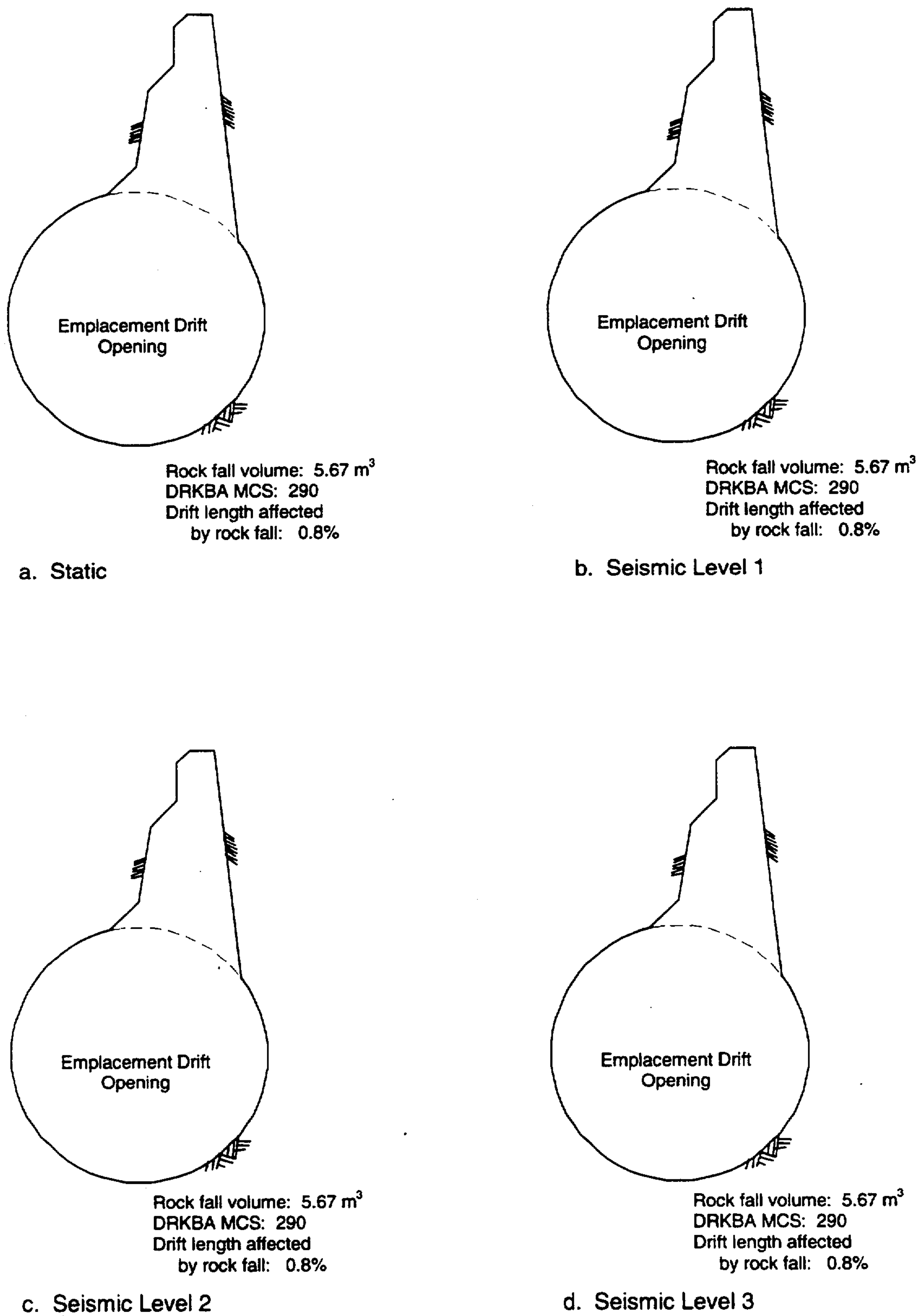


Figure XII-3. Emplacement Drift Profiles Considering Seismic Effects on Rock Fall for the Tptpll Unit, No Backfill, Drift Orientation: 105° Azimuth

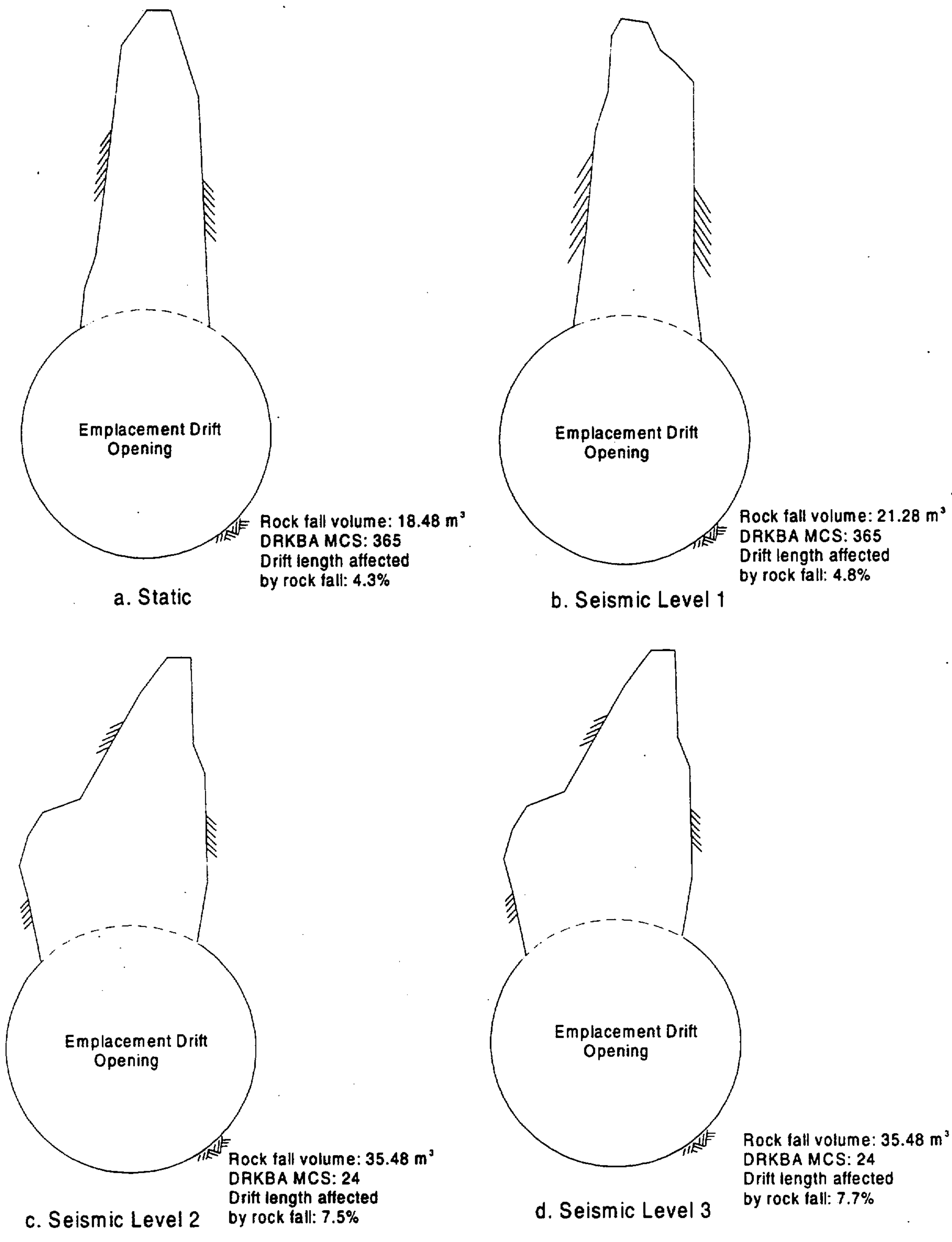


Figure XII-4. Emplacement Drift Profiles Considering Seismic Effects on Rock Fall for the Tptpln Unit, No Backfill, Drift Orientation: 105° Azimuth

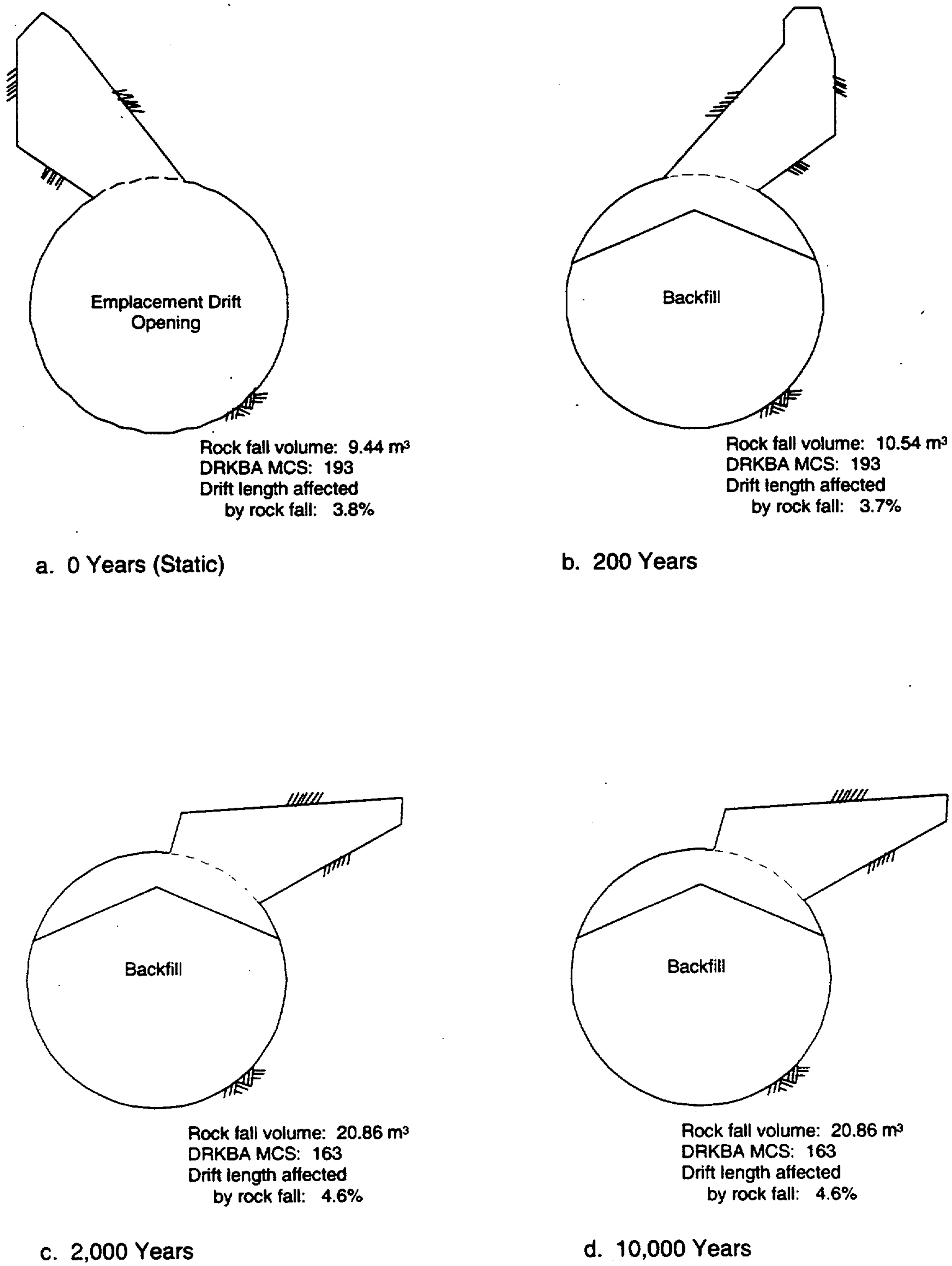


Figure XII-5. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpul Unit, With Backfill, Drift Orientation: 105° Azimuth

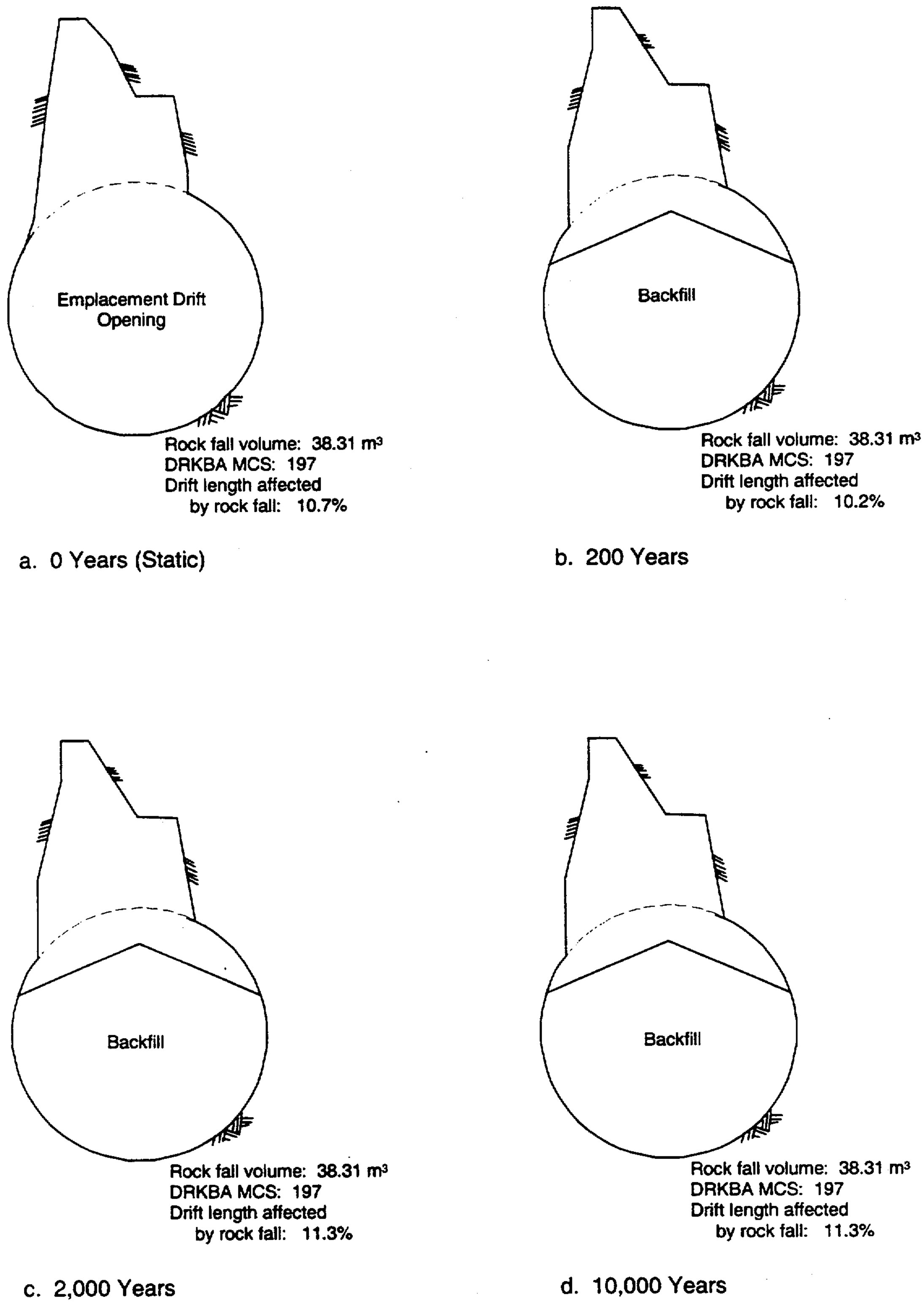


Figure XII-6. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpmn Unit, With Backfill, Drift Orientation: 105° Azimuth

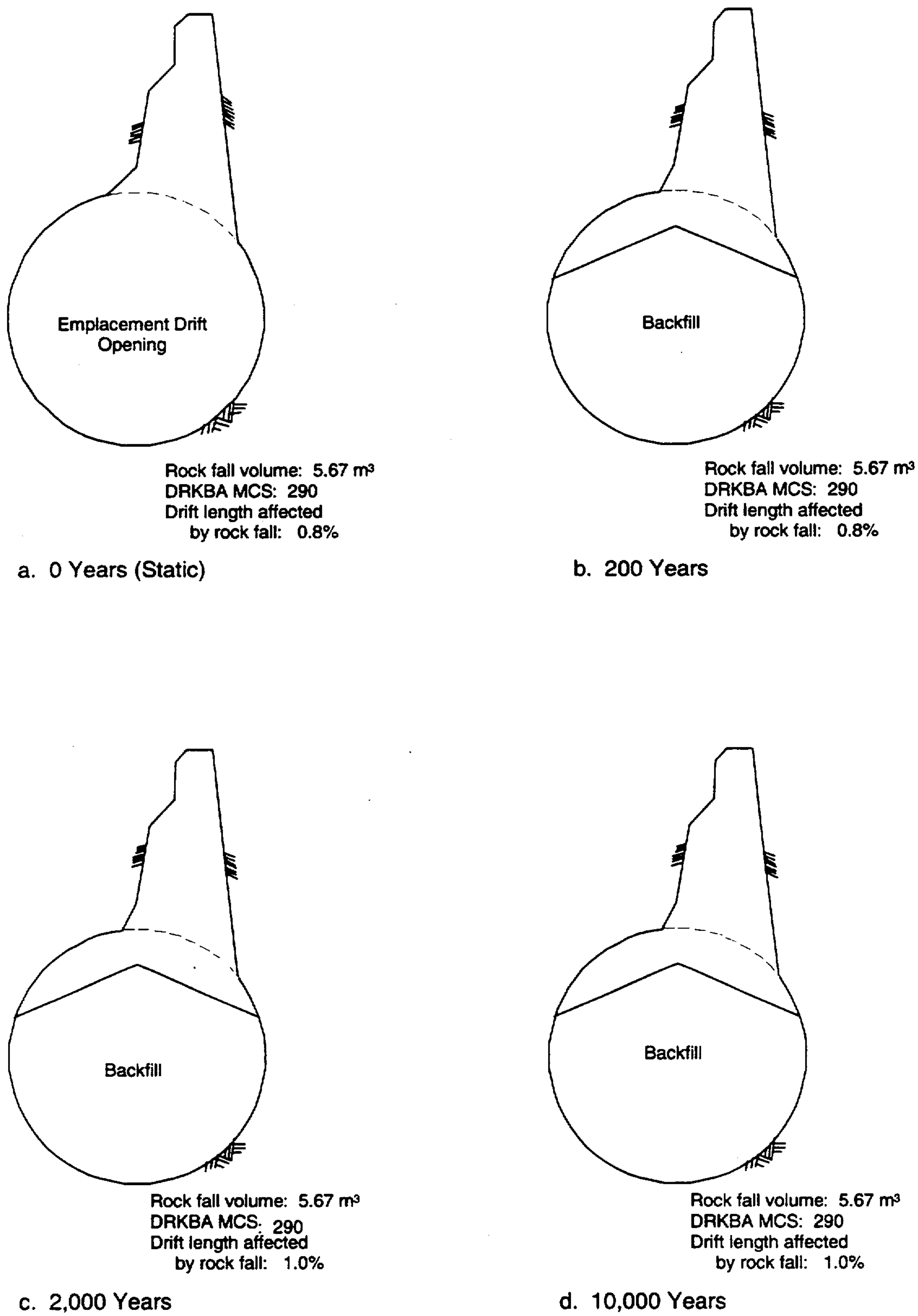


Figure XII-7. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpll Unit, With Backfill, Drift Orientation: 105° Azimuth

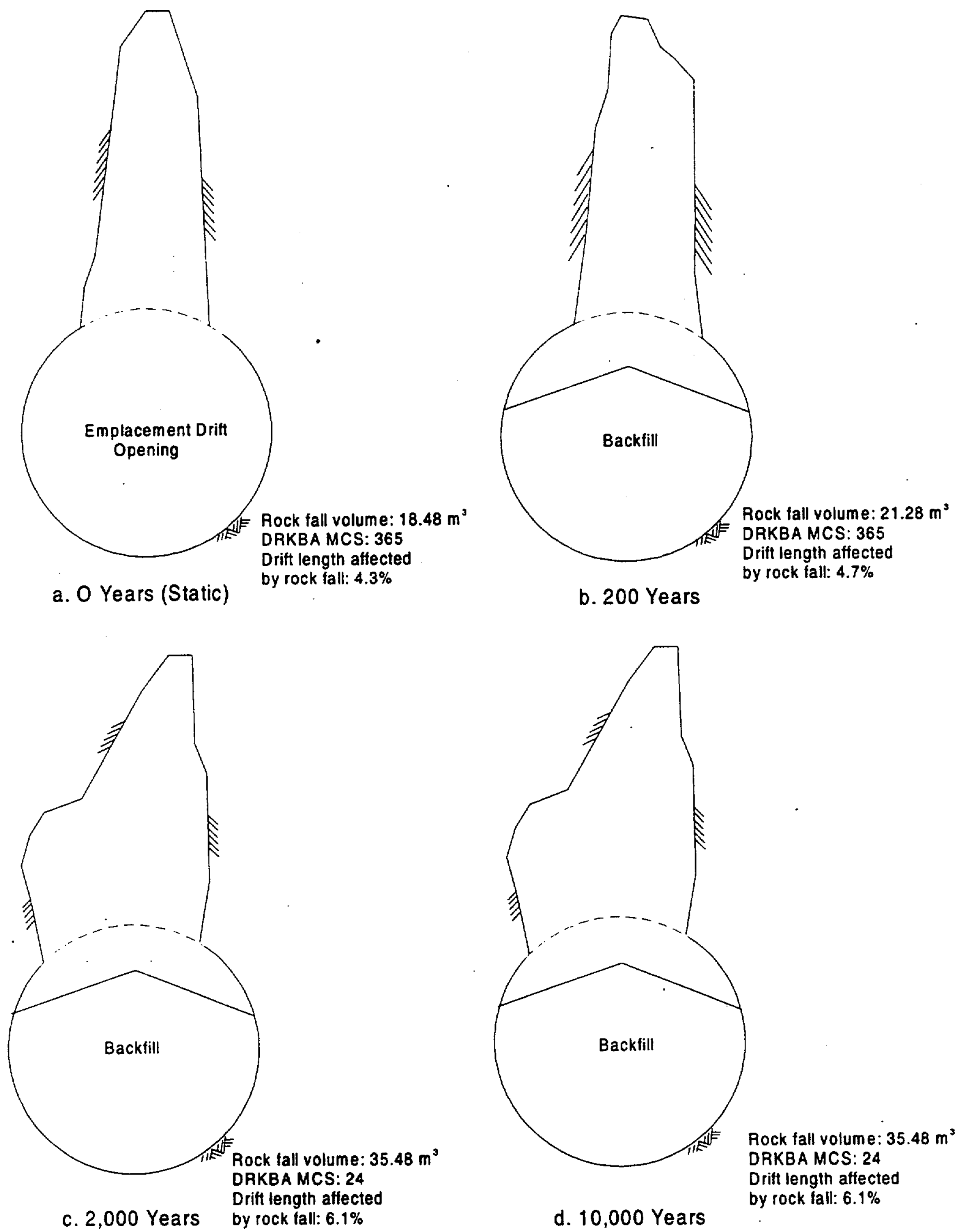


Figure XII-8. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpln Unit, With Backfill, Drift Orientation: 105° Azimuth

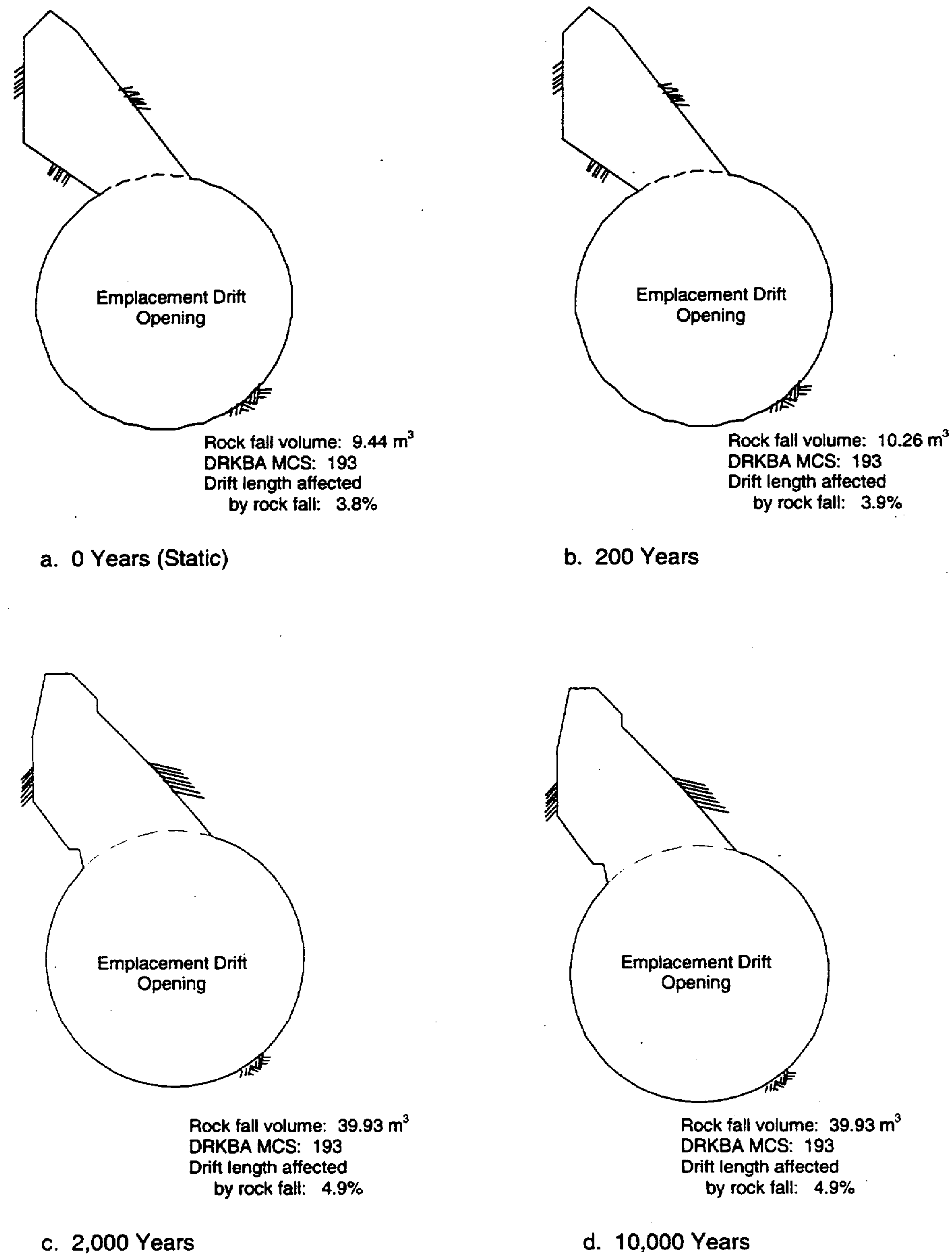


Figure XII-9. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpul Unit, No Backfill, Drift Orientation: 105° Azimuth

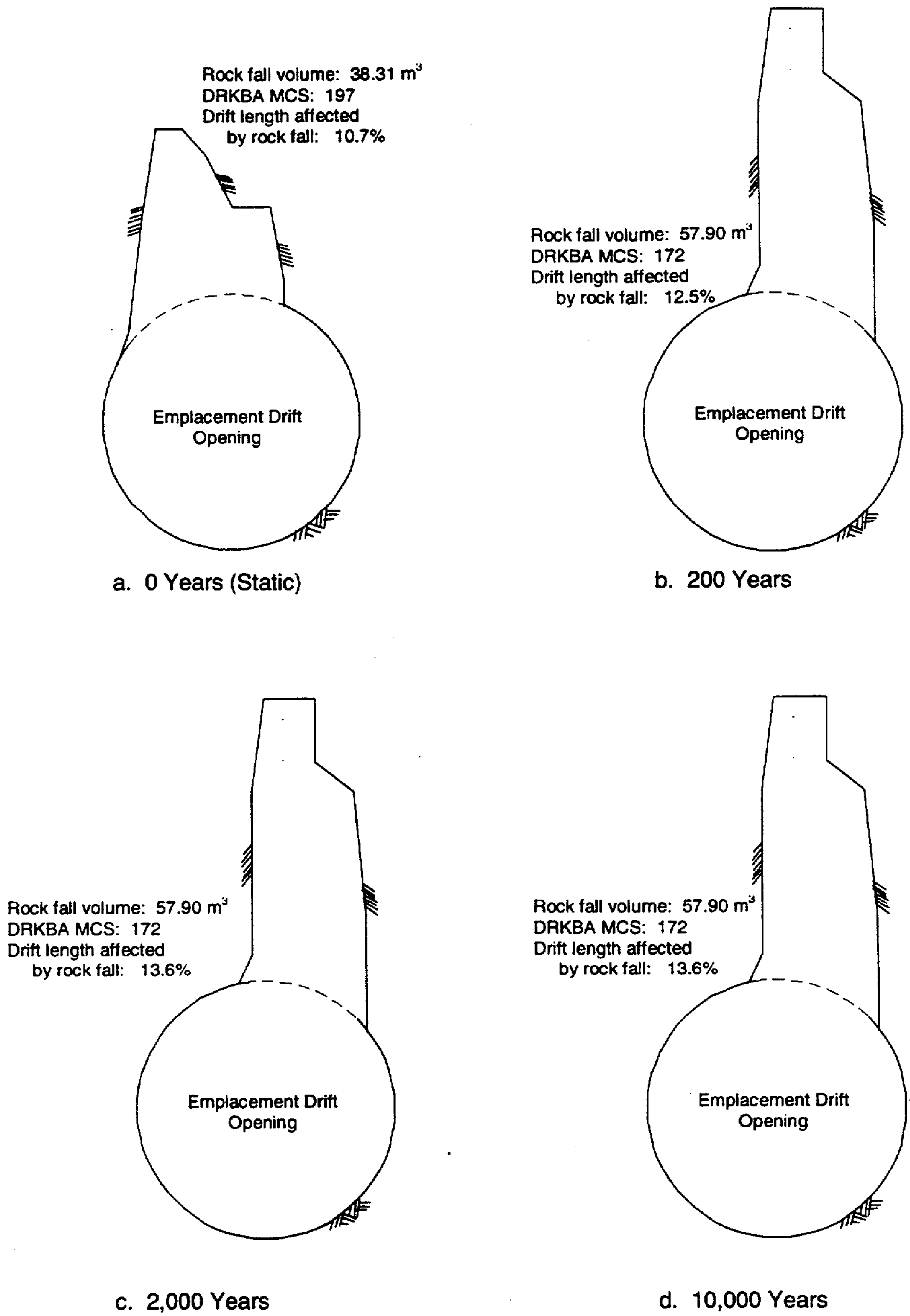


Figure XII-10. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpmn Unit, No Backfill, Drift Orientation: 105° Azimuth

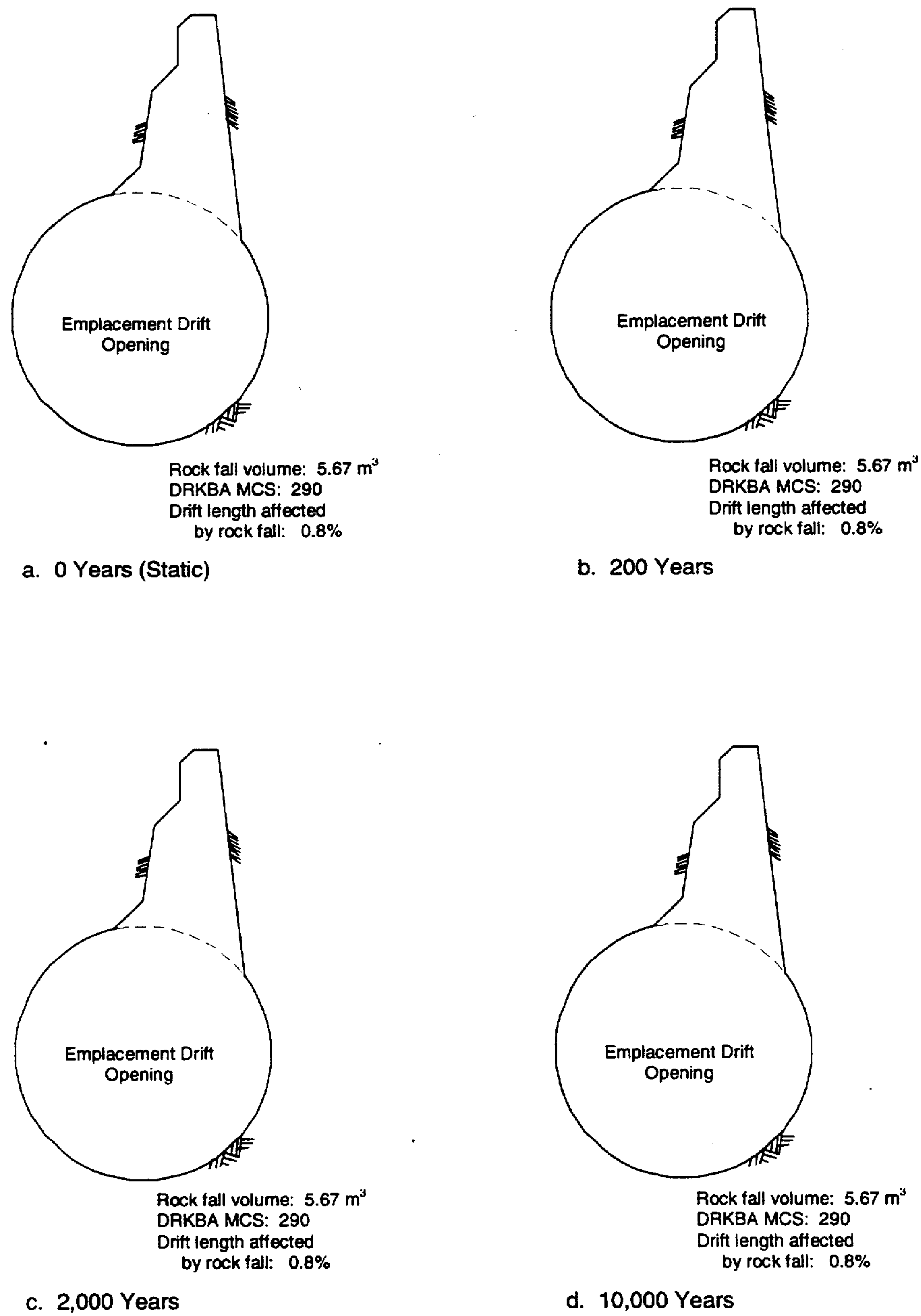


Figure XII-11. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpll Unit, No Backfill, Drift Orientation: 105° Azimuth

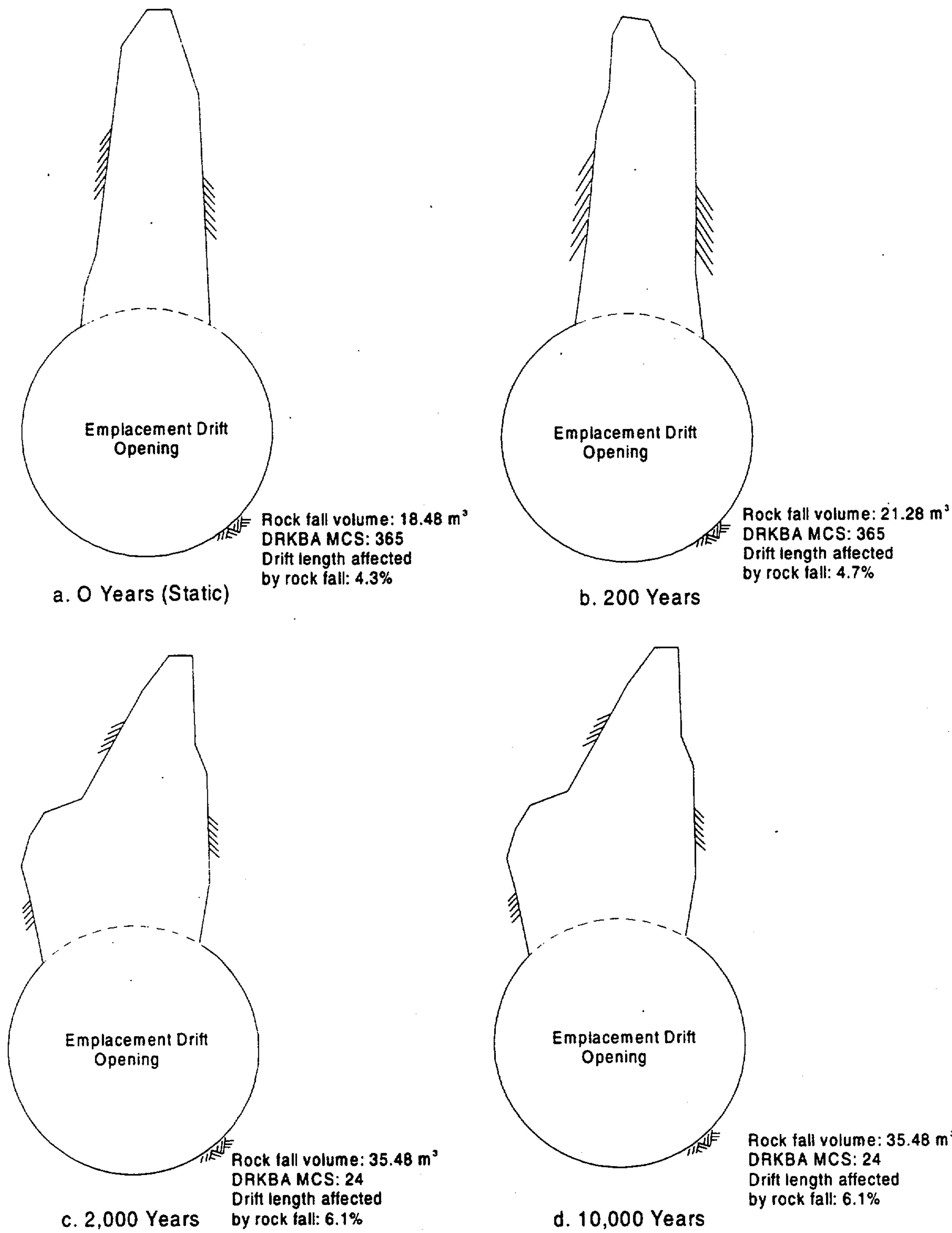


Figure XII-12. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpln Unit, No Backfill, Drift Orientation: 105° Azimuth

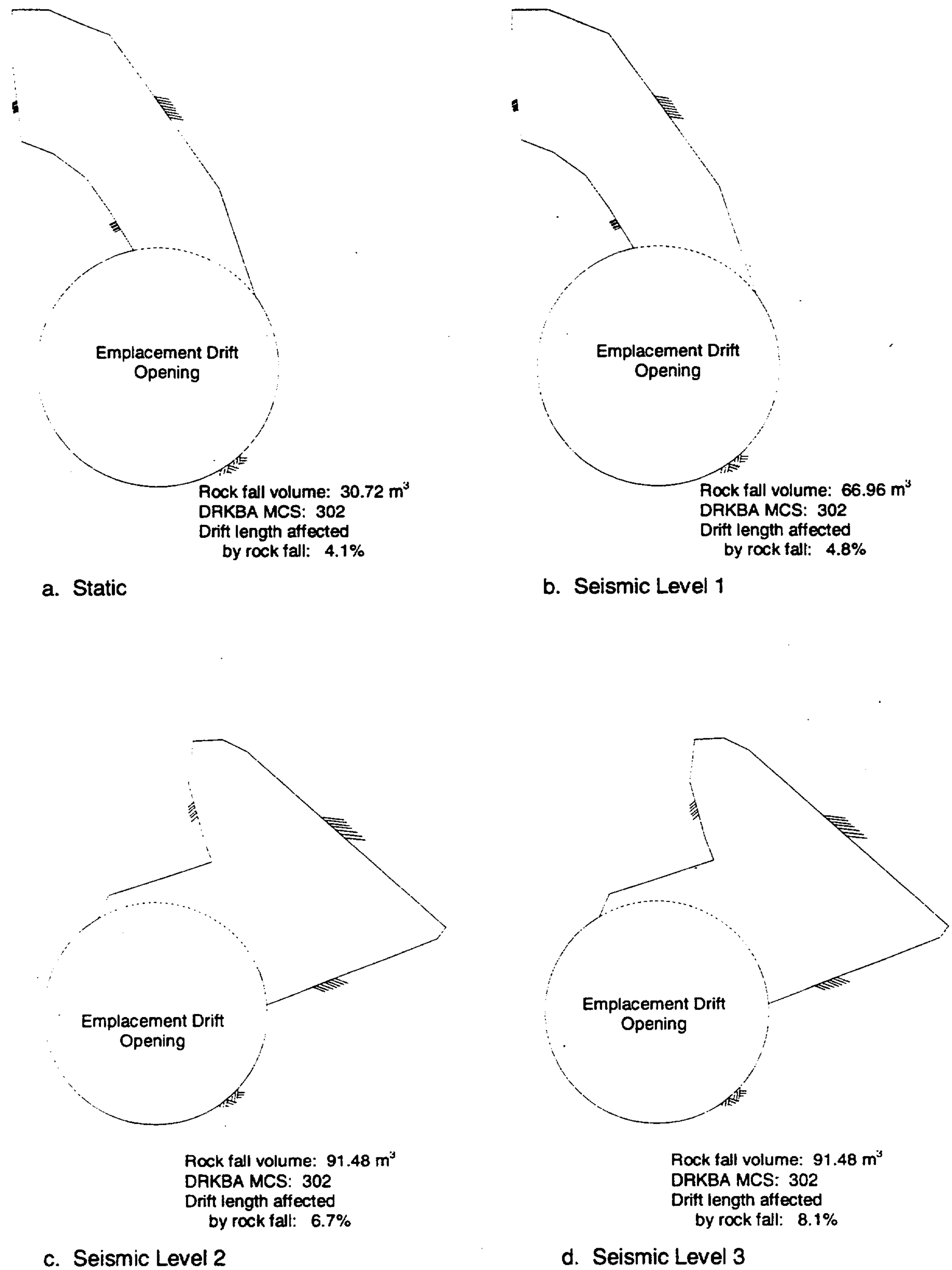


Figure XII-13. Emplacement Drift Profiles Considering Seismic Effects on Rock Fall for the Tptpul Unit, No Backfill, Drift Orientation: 75° Azimuth

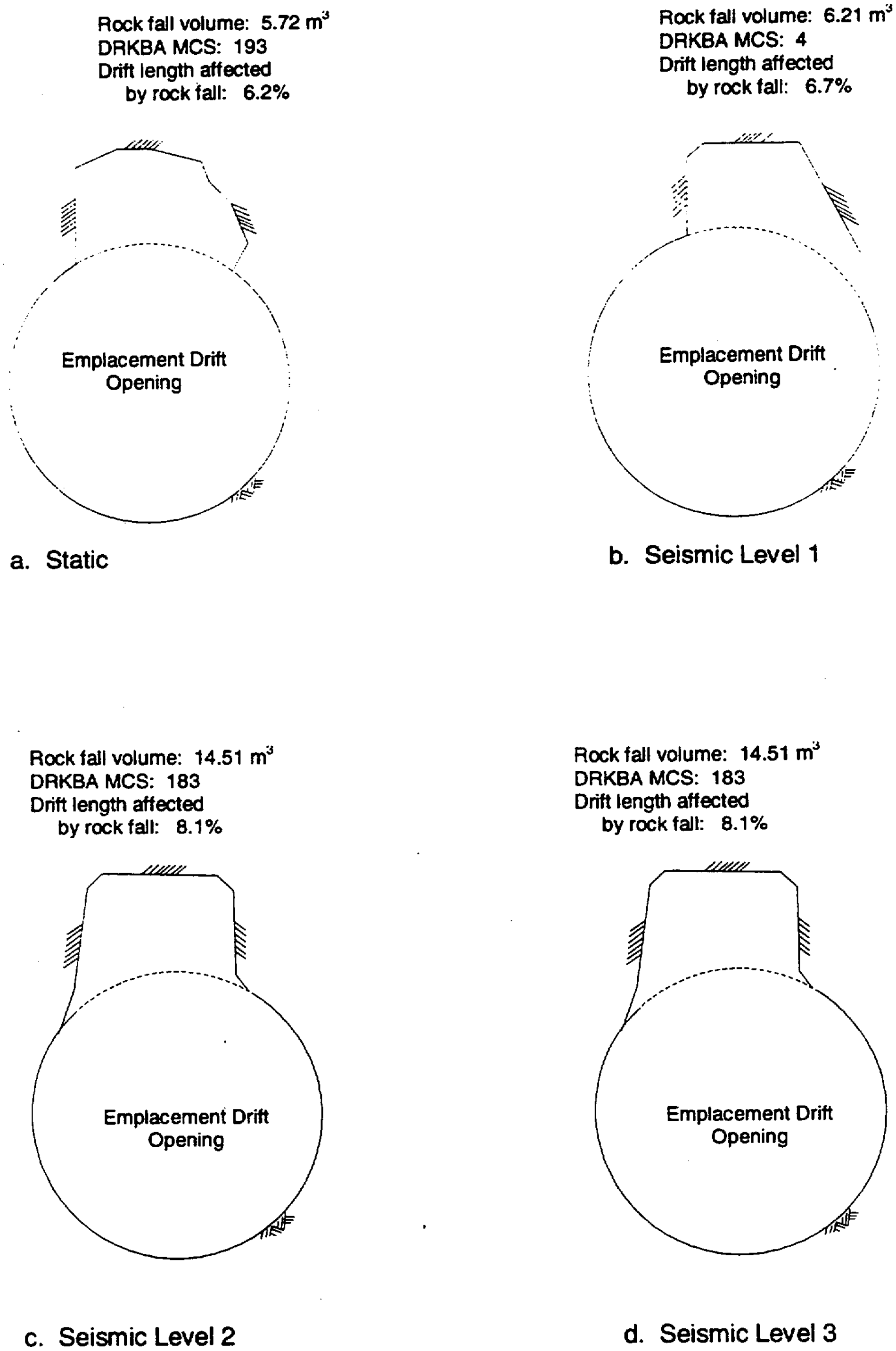


Figure XII-14. Emplacement Drift Profiles Considering Seismic Effects on Rock Fall for the Tptpmn Unit, No Backfill, Drift Orientation: 75° Azimuth

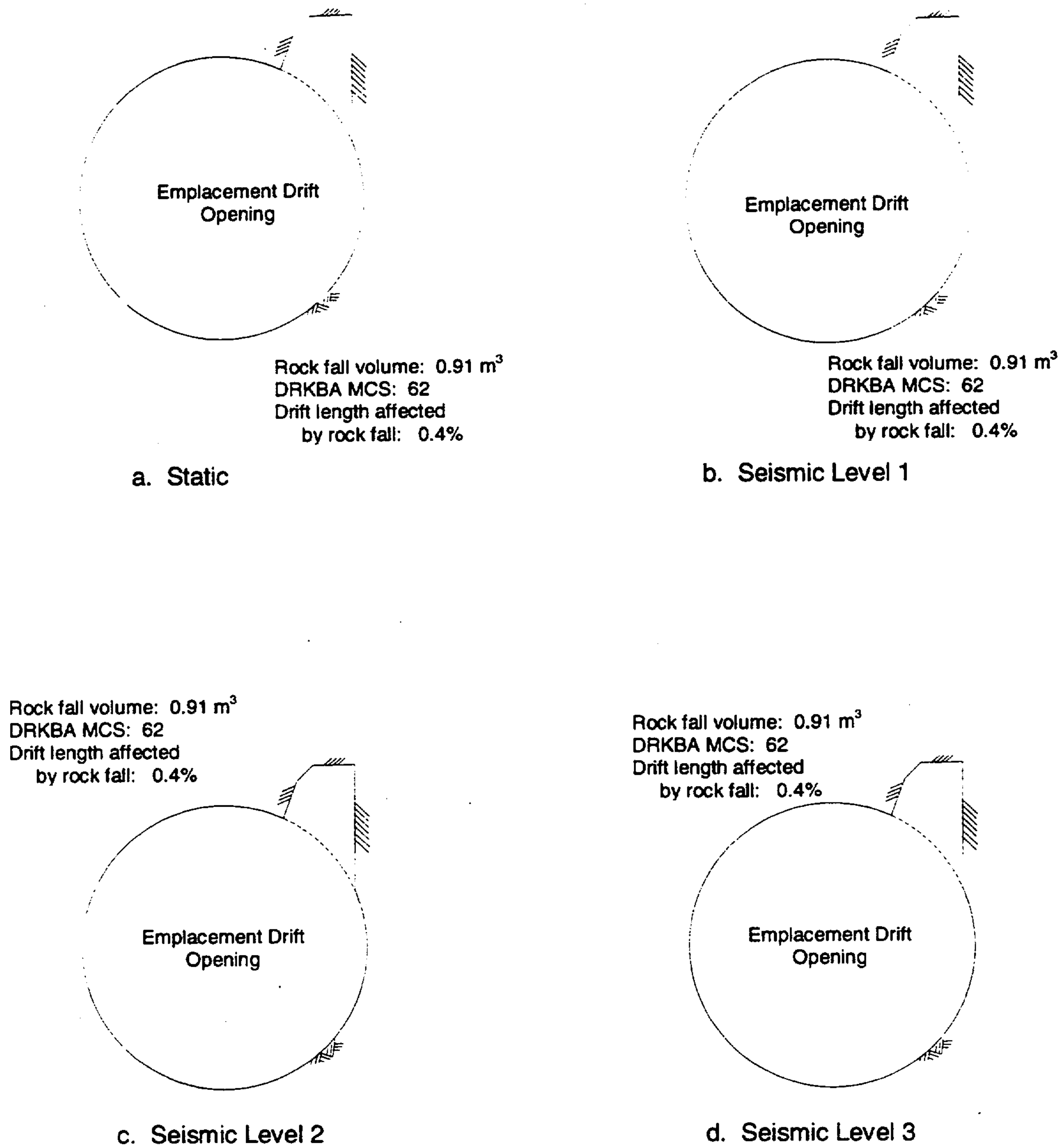


Figure XII-15. Emplacement Drift Profiles Considering Seismic Effects on Rock Fall for the Tptpll Unit, No Backfill, Drift Orientation: 75° Azimuth

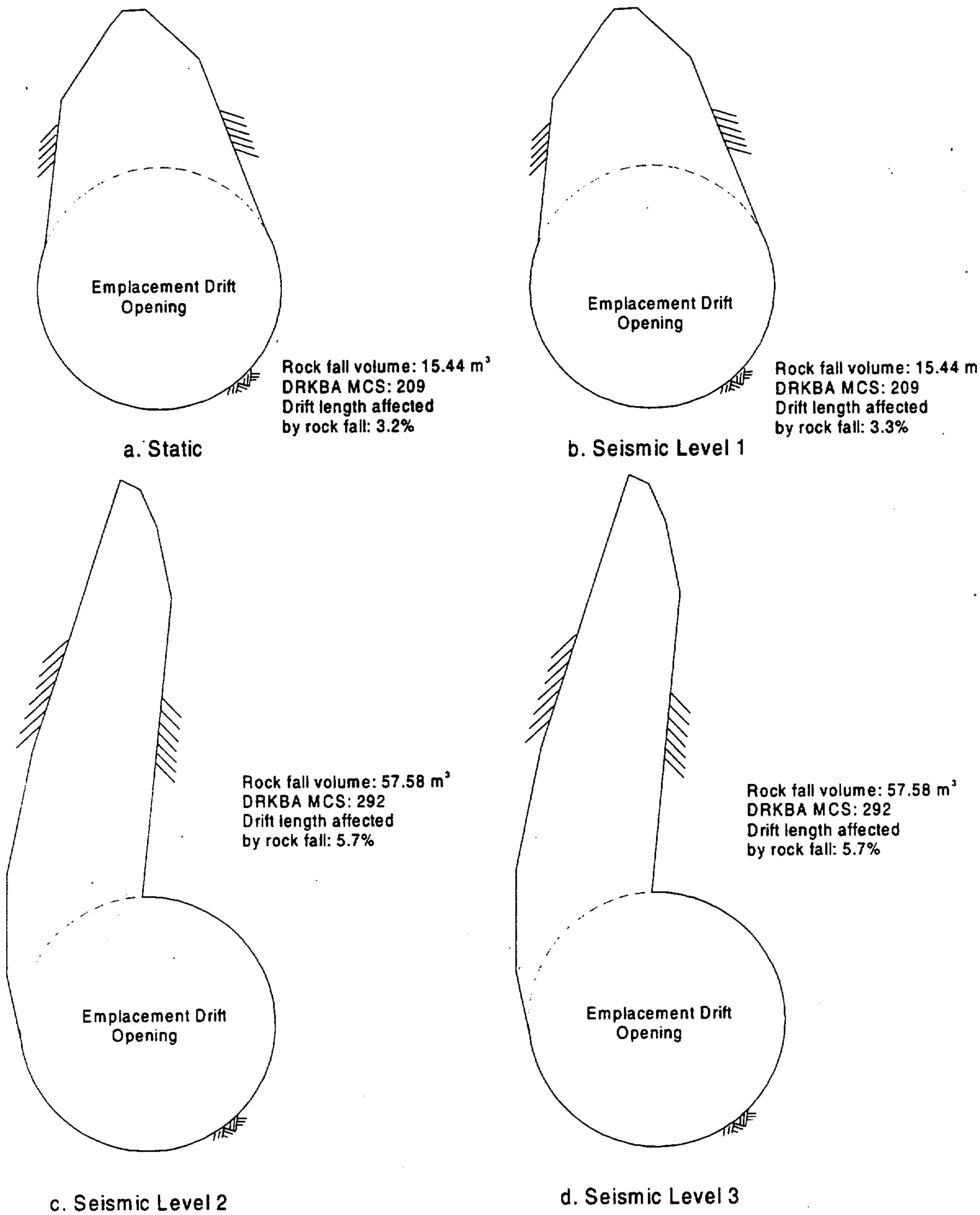


Figure XII-16. Emplacement Drift Profiles Considering Seismic Effects on Rock Fall for the Tptpln Unit, No Backfill, Drift Orientation: 75° Azimuth

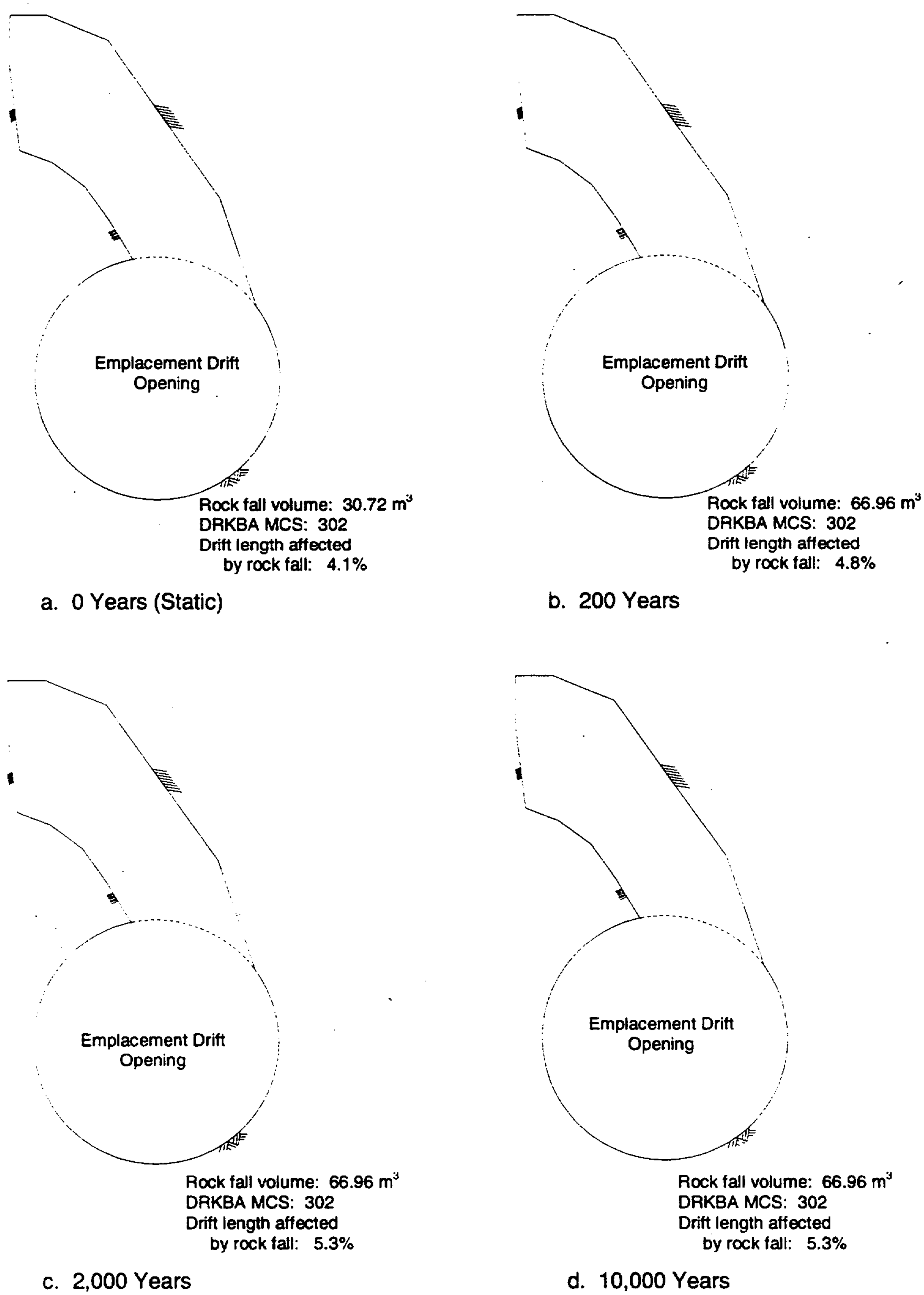


Figure XII-17. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpul Unit, No Backfill, Drift Orientation: 75° Azimuth

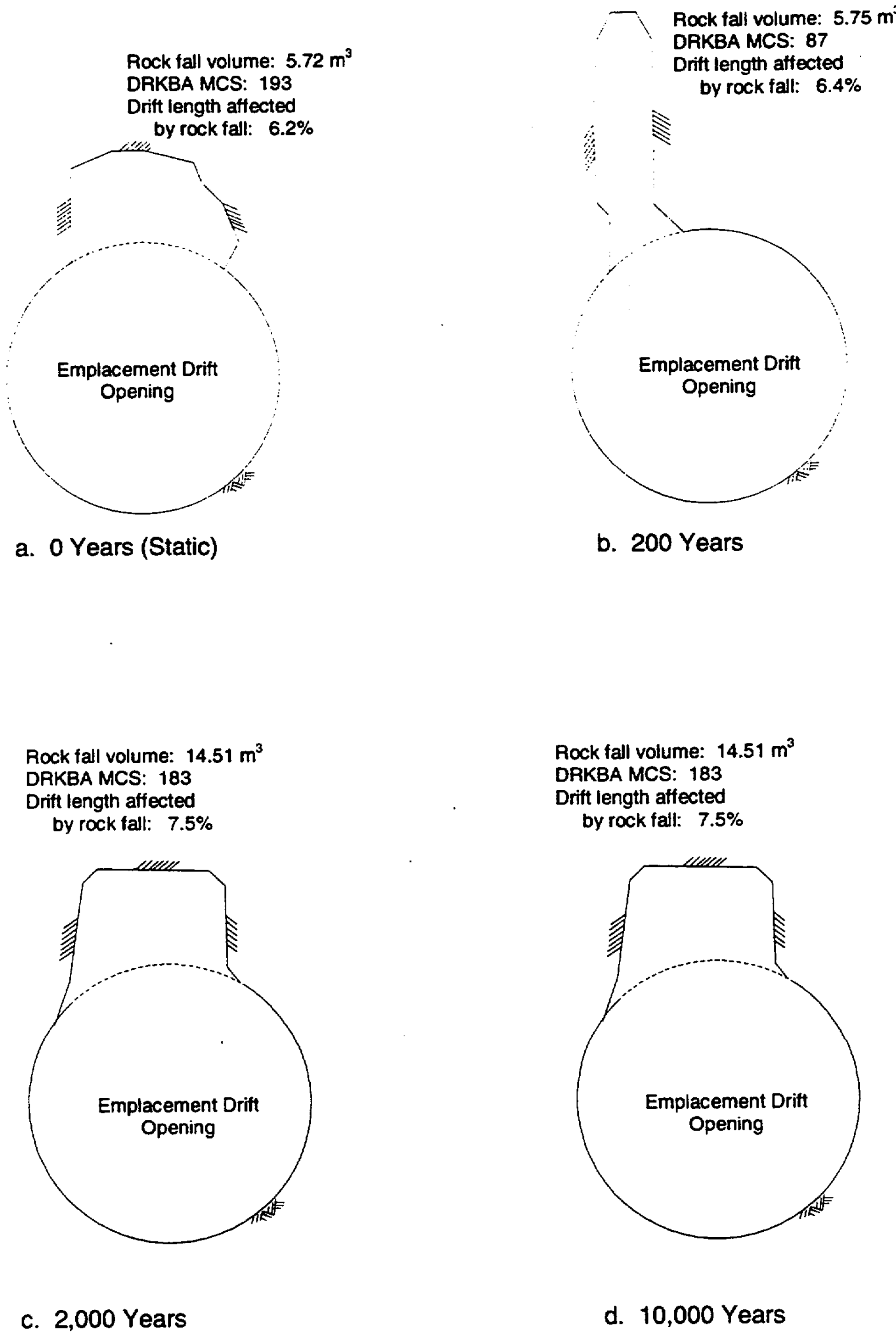


Figure XII-18. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpmn Unit, No Backfill, Drift Orientation: 75° Azimuth

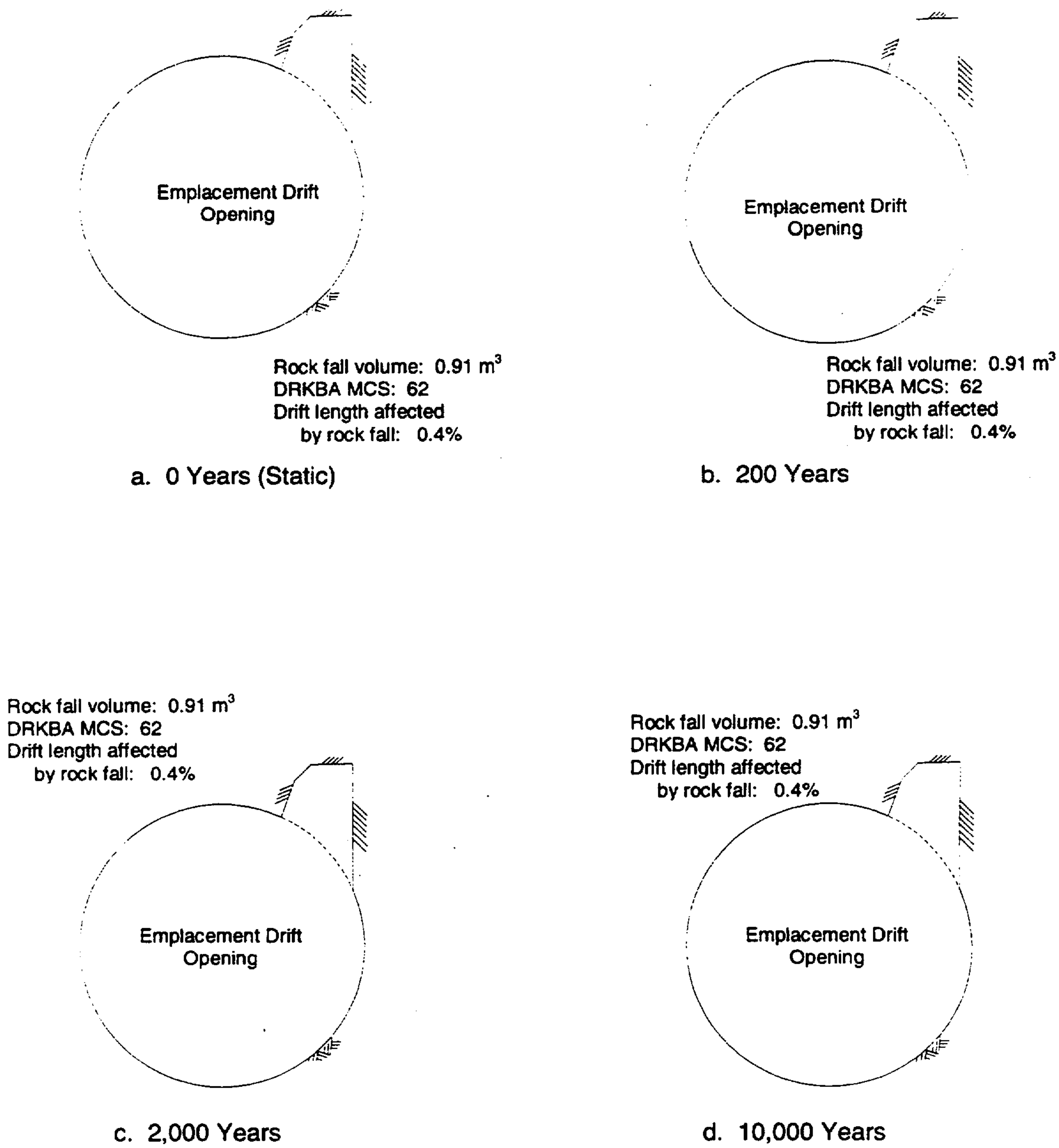


Figure XII-19. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpll Unit, No Backfill, Drift Orientation: 75° Azimuth

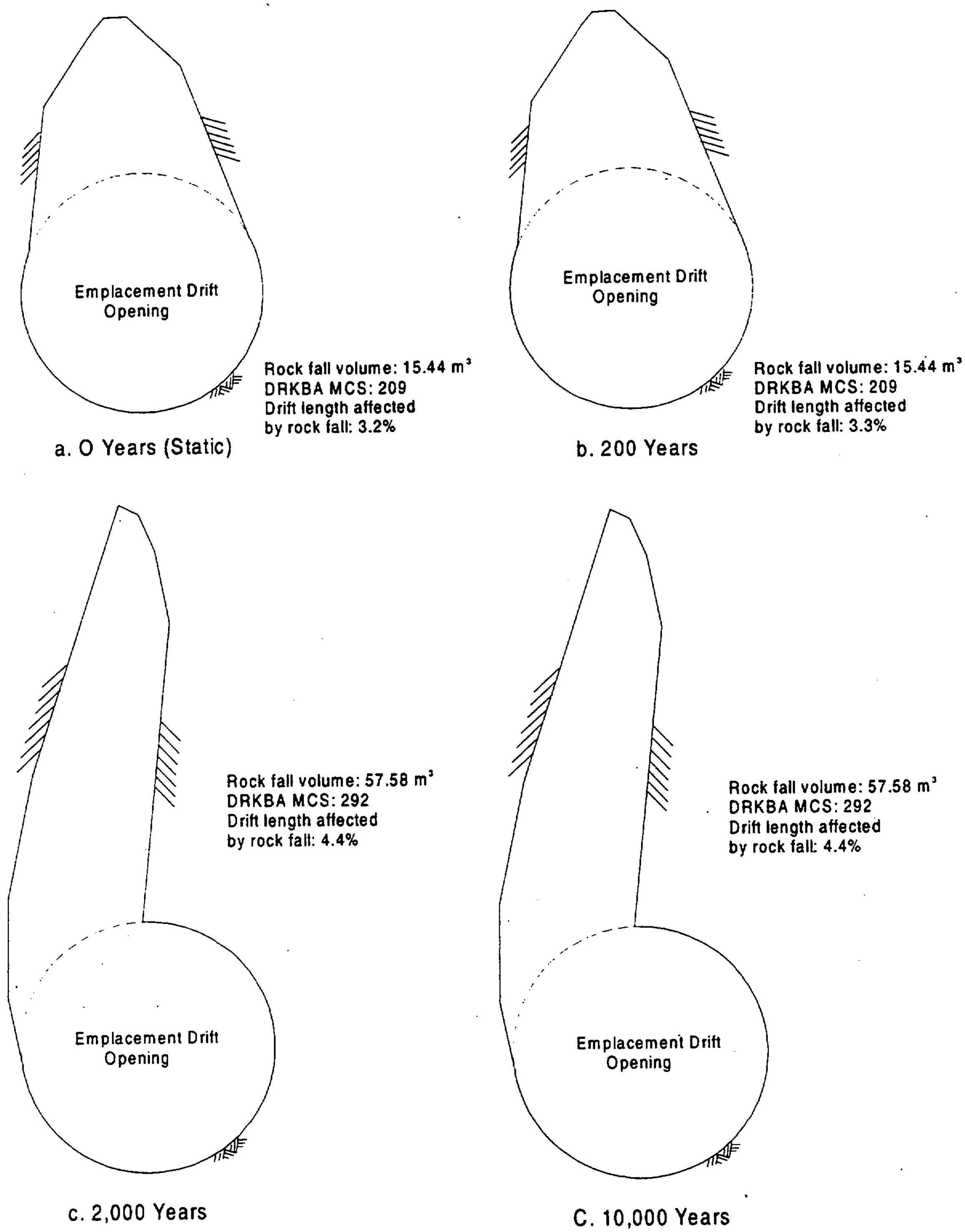


Figure XII-20. Emplacement Drift Profiles Considering Time-Dependent and Thermal Effects on Rock Fall for the Tptpln Unit, No Backfill, Drift Orientation: 75° Azimuth

ATTACHMENT XIII

CALCULATION OF MEAN ROCK PROPERTY VALUES

CALCULATION OF MEAN ROCK PROPERTY VALUES

This attachment documents the calculation of mean rock property values based on source data provided in the TDMS. The mean rock property values include joint cohesion, joint friction angle, density, elastic modulus, and Poisson's ratio. The use of these values in this analysis is described in Section 4.1.

XIII.1 MEAN JOINT STRENGTH

Data from shear stress experiments using core from the TSw2 thermal mechanical unit are provided in Table XIII-1. These data include pairs of normal stress (σ) and shear stress (τ_p) values determined from shear testing of various core specimens. The data pairs were plotted (Figure XIII-1) and a linear fit of the data was determined. The calculation of the linear fit is documented in *Excel* file, *joint strength.xls* (Attachment II). The equation for the linear fit is:

$$\tau_p = \tan\phi\ \sigma + C$$

where τ_p = peak shear stress (MPa)
$\tan \phi$ = coefficient of friction,
ϕ = friction angle,
σ = normal stress (MPa), and
C = cohesion.

Based on this linear fit, the following joint strength parameters were determined:

- Cohesion = 0.86 MPa
- Coefficient of friction = 0.87
- Friction angle = 41°.

Table XIII-1. Data from Shear Stress Experiments on Natural Fractures from the TSw2 Thermal Mechanical Unit

DTN	Borehole	Normal Stress, σ (MPa)	Peak Shear Stress, τ_p (MPa)
SNL02112293001.003	NRG-6	2.5	1.9
SNL02112293001.003	NRG-6	15.0	11.9
SNL02112293001.005	SD-9	2.5	2.4
SNL02112293001.005	SD-9	5.0	5.5
SNL02112293001.005	SD-9	5.0	5.5
SNL02112293001.005	SD-9	10.0	7.7
SNL02112293001.005	SD-9	10.0	9.0
SNL02112293001.005	SD-9	15.0	15.5
SNL02112293001.005	SD-9	15.0	14.0
SNL02112293001.007	SD-12	2.5	3.3
SNL02112293001.007	SD-12	5.0	6.6
SNL02112293001.007	SD-12	10.0	12.0

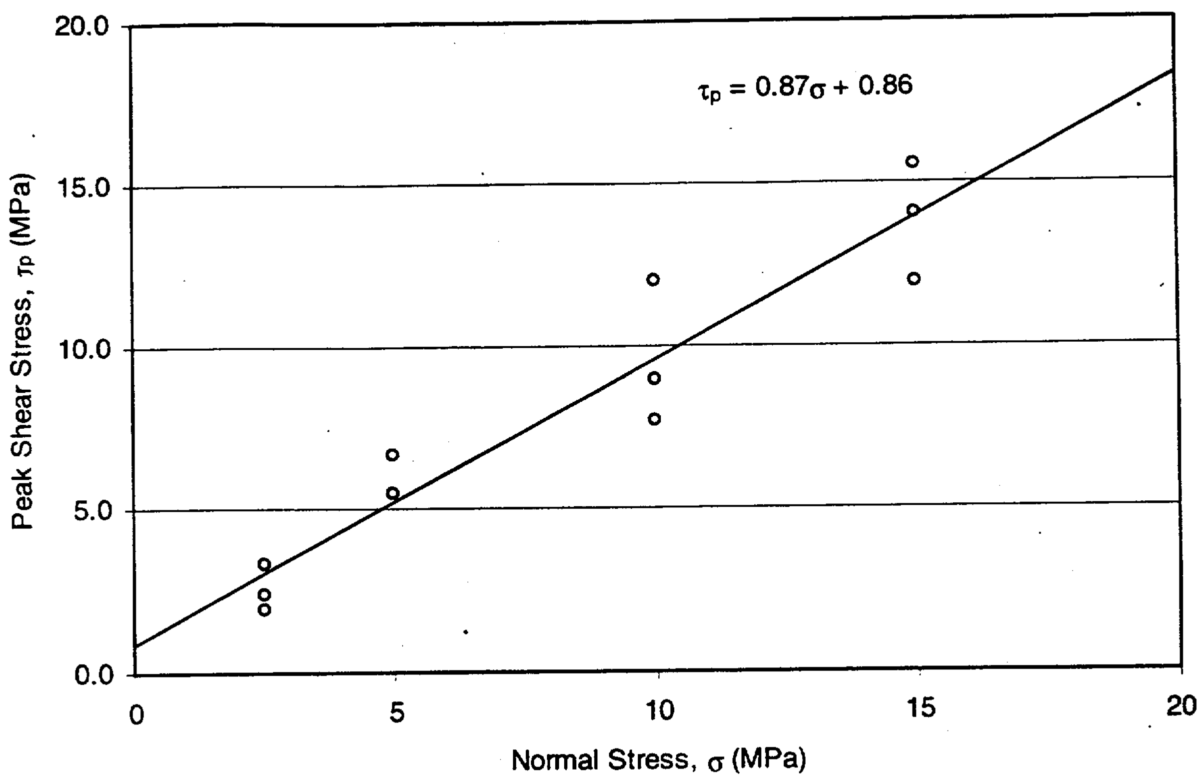


Figure XIII-1. Plot of Shear Strength Test Data from the TSw2 Thermal Mechanical Unit

To calculate the standard error of the joint strength parameters, a regression analysis was conducted as documented in *joint strength.xls* (Attachment II). The standard error for the cohesion value is ±0.81 MPa. The standard error for the coefficient of friction value is ±0.09. Applying the standard error for the coefficient of friction to the mean coefficient of friction yields:

$$\text{maximum } \tan\phi = 0.87 + 0.09 = 0.96\text{; therefore, maximum } \phi = 44^\circ$$
$$\text{minimum } \tan\phi = 0.87 - 0.09 = 0.78\text{; therefore, minimum } \phi = 38^\circ.$$

With a mean ϕ of 41°, the standard error for the friction angle is therefore ±3°.

XIII.2 MEAN DENSITY

Density data (DTN: SNL02030193001.027) from the Tptpln unit are provided in Table XIII-2. The mean density value for these data is 2.41 g/cc.

Table XIII-2. Density Data from the Tptpln Unit (Source DTN: SNL02030193001.027)

Borehole	Sample Number	Saturated Bulk Density (g/cc)
NRG-7a	NRG-7a-1230.2-SNL	2.395
NRG-7a	NRG-7a-1236.7-SNL	2.393
NRG-7a	NRG-7a-1252.3-SNL	2.369
NRG-7a	NRG-7a-1257.8-SNL	2.421
NRG-7a	NRG-7a-1259.1-SNL	2.420
NRG-7a	NRG-7a-1265.2-SNL	2.426
NRG-7a	NRG-7a-1314.8-SNL	2.418
NRG-7a	NRG-7a-1399.1-A-SNL	2.409
NRG-7a	NRG-7a-1400.5-B-SNL	2.428
NRG-7a	NRG-7a-1230.2-SNL	2.339
NRG-7a	NRG-7a-1263.7-SNL	2.416
NRG-7a	NRG-7a-1263.7-SNL	2.396
NRG-7a	NRG-7a-1263.7-SNL	2.421
NRG-7a	NRG-7a-1307.0-SNL	2.414
NRG-7a	NRG-7a-1307.0-SNL	2.411
NRG-7a	NRG-7a-1348.8-SNL	2.440
NRG-7a	NRG-7a-1348.8-SNL	2.424
NRG-7a	NRG-7a-1353.7-SNL	2.388
NRG-7a	NRG-7a-1363.5-SNL	2.442
NRG-7a	NRG-7a-1385.0-SNL	2.424
NRG-7a	NRG-7a-1385.0-SNL	2.419
NRG-7a	NRG-7a-1402.7-SNL	2.358
NRG-7a	NRG-7a-1409.0-SNL	2.450
SD-12	SD-12-1073.3-SNL	2.415
SD-12	SD-12-1077.1-SNL	2.426
SD-12	SD-12-1107.1-SNL	2.416
SD-12	SD-12-1112.1-SNL	2.400
SD-12	SD-12-1118.9-SNL	2.372
SD-12	SD-12-1209.0-SNL	2.423
SD-9	NRG-SD-9-1243-SNL	2.418
SD-9	NRG-SD-9-1298-SNL	2.439
SD-9	NRG-SD-9-1346.5-SNL	2.419
Mean Density Value		2.411

XIII.3 MEAN ELASTIC PROPERTIES

Elastic rock properties data, including elastic modulus and Poisson's ratio, from laboratory tests on core specimens from the TSw2 thermal mechanical unit are shown in Table XIII-3. The mean elastic modulus from this data is 32.9 GPa, and the mean Poisson's ratio is 0.21. It should be noted that the mean elastic modulus calculated in Table XIII-3 is slightly different than the mean value of 33.03 GPa reported by CRWMS M&O (1997b, p. 5-88). An elastic modulus

value of 33.03 GPa was used in this analysis as indicated in Section 4.1. This slight mean modulus value difference of 0.13 GPa does not impact the results of this analysis.

Table XIII-3. Elastic Properties Data from the TSw2 Thermal Mechanical Unit

Borehole	Sample Number	Elastic Modulus (GPa)	Poisson's Ratio	DTN
NRG-5	NRG-5-847.2-SNL-A	35.2	0.21	SNL02030193001.012
NRG-5	NRG-5-849.4-SNL-A	37.0	0.19	SNL02030193001.012
NRG-5	NRG-5-861.2-SNL-A	17.1	0.23	SNL02030193001.012
NRG-5	NRG-5-873.4-SNL-A	13.4	0.30	SNL02030193001.012
NRG-5	NRG-5-887.2-SNL-A	40.5	0.20	SNL02030193001.012
NRG-5	NRG-5-888.8-SNL-A	39.4	0.19	SNL02030193001.012
NRG-5	NRG-5-891.9-SNL-A	38.3	0.15	SNL02030193001.012
NRG-5	NRG-5-896.5-SNL-A	39.1	0.10	SNL02030193001.012
NRG-6	NRG-6-720.7-SNL-A	37.1	0.19	SNL02030193001.004
NRG-6	NRG-6-742.3-SNL-A	30.6	0.20	SNL02030193001.004
NRG-6	NRG-6-742.9-SNL-A	32.4	0.22	SNL02030193001.004
NRG-6	NRG-6-762.9-SNL-A	29.2	0.18	SNL02030193001.004
NRG-6	NRG-6-773.5-SNL-A	36.2	0.23	SNL02030193001.004
NRG-6	NRG-6-784.8-SNL-A	29.7	0.17	SNL02030193001.004
NRG-6	NRG-6-785.6-SNL-A	30.1	0.16	SNL02030193001.004
NRG-6	NRG-6-806.8-SNL-A	31.7	0.16	SNL02030193001.004
NRG-6	NRG-6-848.0-SNL-A	34.6	0.19	SNL02030193001.004
NRG-6	NRG-6-953.2-SNL-A	16.9	0.11	SNL02030193001.004
NRG-6	NRG-6-963.6-SNL-A	19.3	0.31	SNL02030193001.004
NRG-6	NRG-6-971.4-SNL-A	27.4	0.19	SNL02030193001.004
NRG-6	NRG-6-985.7-SNL-A	37.6	0.25	SNL02030193001.004
NRG-6	NRG-6-1017.8-SNL-A	27.4	0.23	SNL02030193001.004
NRG-7a	NRG-7/7A-777.0-SNL-A	32.9	0.22	SNL02030193001.019
NRG-7a	NRG-7/7A-806.3-SNL-A	36.7	0.19	SNL02030193001.019
NRG-7a	NRG-7/7A-818.5-SNL-A	33.1	0.20	SNL02030193001.019
NRG-7a	NRG-7/7A-859.2-SNL-A	38.8	0.20	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-A	32.3	0.19	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-B	34.0	0.21	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-D	32.0	0.25	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-E	34.1	0.22	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-C	35.0	0.20	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-F	34.5	0.21	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-G	34.0	0.18	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-H	36.8	0.21	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-I	34.3	0.20	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-J	33.5	0.19	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-K	34.9	0.22	SNL02030193001.019
NRG-7a	NRG-7/7A-865.4-SNL-L	35.7	0.21	SNL02030193001.019
NRG-7a	NRG-7/7A-1230.2-SNL-A	29.8	0.23	SNL02030193001.020

Table XIII-3. Elastic Properties Data from the TSw2 Thermal Mechanical Unit (Continued)

Borehole	Sample Number	Elastic Modulus (GPa)	Poisson's Ratio	DTN
NRG-7a	NRG-7/7A-1236.7-SNL-A	21.8	0.40	SNL02030193001.020
NRG-7a	NRG-7/7A-1252.3-SNL-A	30.4	0.14	SNL02030193001.020
NRG-7a	NRG-7/7A-1257.8-SNL-A	41.8	0.20	SNL02030193001.020
NRG-7a	NRG-7/7A-1259.1-SNL-A	40.6	0.21	SNL02030193001.020
NRG-7a	NRG-7/7A-1265.2-SNL-A	40.7	0.21	SNL02030193001.020
NRG-7a	NRG-7/7A-1314.8-SNL-A	37.7	0.21	SNL02030193001.020
NRG-7a	NRG-7/7A-805.6-SNL-A	21.4	0.27	SNL02030193001.021
NRG-7a	NRG-7/7A-827.4-SNL-A	23.4	0.33	SNL02030193001.021
NRG-7a	NRG-7/7A-861.7-SNL-A	33.9	0.21	SNL02030193001.021
NRG-7a	NRG-7/7A-977.8-SNL-A	29.6	0.20	SNL02030193001.021
NRG-7a	NRG-7/7A-1399.1-SNL-A	30.8	0.22	SNL02030193001.021
NRG-7a	NRG-7/7A-1400.5-SNL-B	39.6	0.26	SNL02030193001.021
SD-9	SD-9-761.5-SNL-A	33.9	0.21	SNL02030193001.026
SD-9	SD-9-768.7-SNL-A	36.9	0.20	SNL02030193001.026
SD-9	SD-9-771.7-SNL-A	34.8	0.19	SNL02030193001.026
SD-9	SD-9-774.6-SNL-B	16.8	0.19	SNL02030193001.026
SD-9	SD-9-826.7-SNL-A	31.9	0.21	SNL02030193001.026
SD-9	SD-9-832.8-SNL-A	29.8	0.19	SNL02030193001.026
SD-9	SD-9-842.1-SNL-E-1	36.3	0.20	SNL02030193001.026
SD-9	SD-9-1243.0-SNL-A	35.9	0.19	SNL02030193001.026
SD-9	SD-9-1298.0-SNL-A	39.9	0.25	SNL02030193001.026
SD-9	SD-9-1346.5-SNL-A	44.4	0.25	SNL02030193001.026
SD-12	SD-12-734.7-SNL-B	31.9	0.18	SNL02030193001.023
SD-12	SD-12-745.6-SNL-B	34.5	0.20	SNL02030193001.023
SD-12	SD-12-762.6-SNL-B	34.1	0.20	SNL02030193001.023
SD-12	SD-12-781.1-SNL-B	36.7	0.21	SNL02030193001.023
SD-12	SD-12-1073.3-SNL-B	35.9	0.28	SNL02030193001.023
SD-12	SD-12-1077.1-SNL-B	34.0	0.23	SNL02030193001.023
SD-12	SD-12-1107.1-SNL-B	34.5	0.23	SNL02030193001.023
SD-12	SD-12-1112.1-SNL-B	36.1	0.22	SNL02030193001.023
SD-12	SD-12-1118.9-SNL-B	32.9	0.21	SNL02030193001.023
SD-12	SD-12-1209.0-SNL-B	31.9	0.28	SNL02030193001.023
Mean property values		32.9	0.21	—

ATTACHMENT XIV

ASSESSMENT OF JOINT PLANE REPRESENTATION IN THE DRKBA ROCK FALL MODEL

ASSESSMENT OF JOINT PLANE REPRESENTATION IN THE DRKBA ROCK FALL MODEL

This attachment presents the results of a sensitivity calculation for the extent of the modeled joint plane based on the mapped joint trace length. It is recognized that the actual extent of a joint plane can not be fully known based on field mapping data. The mapped trace length of a joint represents some portion of the overall joint plane. Under-representing the extent of the joint plane would not be conservative in a key block analysis. Since the under-represented joint planes may not extent or connect to adjacent joint planes, under-representation would limit the number of blocks otherwise generated in the model. Conversely, overstating the extent of the joint plane would increase connectivity among joint planes, thus creating more blocks in the model and resulting in an increased, or conservative, estimate of block development. However, infinite joint planes would not be an accurate representation of the jointed rock mass. This attachment develops the basis to sufficiently model the extent of the joint plane based on the available field data.

As stated in Assumption 5.1, joint planes are represented as circular discs in the DRKBA rock fall model with the assumption that the radius of the joint plane is equal to twice the mapped trace length. Figure XIV-1 shows a top view of a circular fracture disc intersecting an opening. Figure XIV-1 depicts three parameters used for the sensitivity calculation, including joint trace length (TL), joint radius (R), and the shortest distance (C) from the center of the joint disc to the fracture trace.

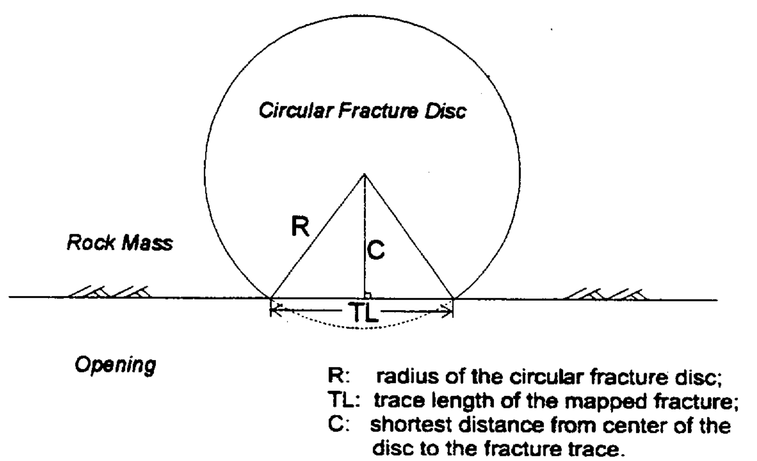


Figure XIV-1. Top View of a Circular Fracture Disc Intersecting an Opening

The multiplier, M, is used to obtain the radius of the circular fracture disc from the trace length as follows:

$$R = M * TL \qquad \text{(Eq. XIV-1)}$$

Based on standard trigonometric relationships for triangles, the shortest distance from the center of the disc to the fracture trace can be derived as follows:

$$C = (R^2 - (TL/2)^2)^{1/2} = (M^2 - 1/4)^{1/2} * TL \qquad \text{(Eq. XIV-2)}$$

It is reasoned that the location where the circular disc intersects the opening (i.e., the intersection point of line C and trace TL) is uniformly distributed at any point from the center of disc to the periphery of the disc. In other words, the opening can be located with equal probability to intersect any points of the disc. Therefore, the probability for the radius of the disc to be larger than the value derived from Equation XIV-1 can be simply expressed as a function of C/R, such that:

$$P = 100\% - C/R = 100\% - (M^2 - 1/4)^{1/2} / M \qquad \text{(Eq. XIV-3)}$$

where P is the probability that $R > M \times TL$.

The probabilities for various multipliers, M, are listed in Table XIV-1. For a circular joint plane described using a radius equal to twice the mapped trace length (i.e., M=2) as used in this analysis, there is an approximate 3% probability that the actual joint radius is greater than the modeled value. Assumption 5.1 is therefore considered as conservative.

Table XIV-1. Probability of R>MxTL for Various Multipliers

Multiplier (M)	0.5	0.6	0.7	0.8	1	1.5	2	3	5
Probability of R>MxTL	100.0%	44.7%	30.0%	21.9%	13.4%	5.7%	3.2%	1.4%	0.5%