FINAL
GEOTECHNICAL REPORT

Christiansted Bypass
St. Croix, Virgin Islands

Project:
VI NH-66(008)

Prepared for:

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL
LANDS HIGHWAY DIVISION

September, 2004

HDR

ONE COMPANY | *Many Solutions*

September 30, 2004

Ms. Melisa L. Ridenour, P.E., Division Engineer
Federal Highway Administration
Eastern Federal Lands Highway Division
21400 Ridgetop Circle
Sterling, VA 20166

Attention: Mr. Khalid T. Mohamed, P.E. Acting COTR

Re: DTFH71-02-00008
Project VI NH-66(008)
Christiansted Bypass
St. Croix, Virgin Islands
Final Geotechnical Report

Dear Mr. Mohamed:

This is our Final Report, which summarizes the results of the investigation conducted by HDR for the subject project in accordance with the Scope of Work and discussions with the FHWA-EFLHD. As indicated in your e-mail of September 23, 2004, there were no comments from the EFLHD on the draft report. As discussed, we have made several editorial corrections to arrive at this final report.

As required by your Statement of Work dated June 23, 2004, two bound copies and a compact disk containing the complete report in Microsoft .pdf format are being provided.

Please contact me at (412)-497-6039 if there are any questions.

Sincerely yours,

HDR ENGINEERING, INC.

James M. Sheahan

James M. Sheahan, P.E.
Chief Geotechnical Engineer for
Michael Dodson, Project Manager

JMS:cp

Enclosures:
2 copies of report
1 CD

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CHRISTIANSTED BYPASS
ST. CROIX, VIRGIN ISLANDS
PROJECT VI NH-66(008)

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TABLE OF CONTENTS

1.0 INTRODUCTION 1

1.1 Authorization, Purpose and Scope 1

1.2 Project Location and Description 1

1.3 General Geology 2

2.0 PROCEDURES 2

2.1 Test Borings 3

2.2 Laboratory Testing 4

2.3 Rock Exposures 4

3.0 RESULTS AND ANALYSIS 4

3.1 Subsurface Conditions Encountered 4

3.2 Laboratory Testing Results 6

3.3 Slope Design Analysis 6

3.3.1 Slope Mass Rating 7

3.3.2 DIPS Analysis 10

3.4 Alternates Slope Configurations 10

4.0 DISCUSSION 11

4.1 Evaluation of Existing and Alternate Slope Configurations 11

4.1.1 As-Planned Configuration 12

4.1.2 Alternate 1 12

4.1.3 Alternate 2 13

4.1.4 Alternate 3 14

4.1.5 Alternate 4 14

4.2 Construction Considerations 14

4.3 Treatment of Waste Material for Acid Producing Waste 15

5.0 RECOMMENDATIONS 15

6.0 LIMITATIONS 16

CHRISTIANSTED BYPASS
ST. CROIX, VIRGIN ISLANDS
PROJECT VI NH-66(008)

FINAL GEOTECHNICAL REPORT

1.0 INTRODUCTION

1.1 Authorization, Purpose and Scope

This report has been prepared for the U.S. Department of Transportation, Federal Highway Administration (FHWA), Eastern Federal Lands Highway Division (EFLHD), to summarize results from an investigation authorized as Delivery Order D008 under IDIQ Number DTFH71-02-D-00007 for the proposed Christiansted Bypass Project VI NH-66(008) on the island of St. Croix in the U.S. Virgin Islands. The purpose of the work under this Delivery Order (DO) was to perform a subsurface investigation and cut slope stability analysis in the area of the cut between Stations 88 and 96. The stability analysis was intended to verify that the proposed cut slope of 0.5H:1V is stable. If the 0.5H:1V slope is determined to be unstable, the DO indicates that a stable slope angle is to be determined or that corrective measures be developed to achieve stability at 0.5H:1V. Alternate corrective measures are to be developed on a conceptual basis and not taken to final design. Final design of corrective measures will be prepared under a separate DO for the selected alternative. The primary objective of this evaluation is to provide a slope design concept that will result in a finished cut slope within the current Right-of-Way (ROW) through this area.

The scope of the investigation included:

- Review of plans and sections developed previously by the EFLHD on the project,
- Field reconnaissance of the project area,
- Review of available geologic information obtained in St. Croix,
- A test boring program in the proposed cut area, and
- A laboratory testing program.

The work was performed in general conformance with Chapter 6 of the EFLHD Design Manual in English units of measurement.

1.2 Project Location and Description

The project is located in the City of Christiansted on the island of St. Croix in the U.S. Virgin Islands. A layout of the entire project was not provided, since the work performed under this delivery order is focused on an investigation of the cut between Stations 88 and 96. Figure 1 in Appendix A is a Project Location Map of the area, and Figure 2 is a Plan showing the segment of

the project containing the planned cut area. Figure 2 also shows the location of borings obtained during this investigation.

1.3 General Geology

St. Croix is part of the U.S. Virgin Islands and is also the largest of the Virgin Islands. The Virgin Islands are part of the West Indies Island chain also known as the Lesser Antilles. The West Indies are the summit of a submerged mountain chain, stretching from the tip of Venezuela to Puerto Rico. The Lesser Antilles are part of the island arc complex, marking the zone of western subduction of the Atlantic tectonic plate beneath the Caribbean Plate. The island chain is the result of volcanic activity triggered from the subduction zone.

The rock formations have been heavily folded and faulted as indicated by the Geologic Structure Map for St. Croix in Figure 3, which shows major faults to the east and west of the project area. The project area is located in the west end of the East End Range. Figure 3 shows that Cretaceous-Age rocks have been subdivided into 12 areas. Figures 4a and 4b show the geologic structure in the project area. These figures also show the measured strike and dip of bedding planes in the project area. The bearing and dip of eight of these planes have been measured and the data used in analyses for this report. A summary of these planes is shown in Appendix B. It shows a strike azimuth ranging from about 116° to 153° with a dip of 21 to 45 degrees to the southwest.

Based on information in a geologic publication obtained on the island (***Whitten***), St. Croix is comprised of Late Cretaceous and Tertiary (90-20 million years old) sedimentary rocks. The project area, which is just south of downtown Christiansted, includes rock that is part of the Judith Fancy Formation, a thick deposit of tuffaceous sedimentary rocks including limestones, volcanic pebble conglomerates and siltstones. The project lies in the Recovery Hill Member of the Judith Fancy Formation, which consists of blue-gray siltstones and fine-grained tuffaceous sandstones. The rock encountered during drilling was a hard blue-gray siltstone, which originated from the parent volcanic rock and subsequently weathered over time. Chlorite and pyrite are common, and carbonaceous material probably accounts for the occasional dark colored bedding. The siltstone grades between very fine-grained and slightly more coarse-grained, while the frequency and width of bedding planes differs throughout. Some zones of the siltstone are more calcareous than others and calcite is a common fracture infilling. Calcite growth was secondary after deposition and is probably the result of mineral replacement of quartz and feldspars. Vertical fractures appear quite common and probably contribute to the highly weathered zones in the upper portions of the test borings.

A review of seismic information in the AASHTO Bridge Design Specifications (***AASHTO, 2004***) indicates that the project is located in a Seismic Zone 4 with an Acceleration Coefficient, A, of 0.20g and a Soil Profile Type I.

2.0 PROCEDURES

A Field Investigation Plan was not prepared for this work. The plan of borings used for this investigation was developed by the EFLHD and provided to HDR as part of the DO. HDR entered into a subcontract with Caribbean Drilling Services, Inc. (CDS) for the drilling and

laboratory testing services performed under this contract. CDS was utilized since they had negotiated previously with the EFLHD for this work and time was of the essence in the schedule to complete the field investigation. CDS utilized the services of Amdrill from Orlando, Florida, to perform rock coring for the project.

2.1 Test Borings

A total of six borings were drilled for this investigation. Their locations and elevations were surveyed and staked by Best Winters Land Surveyors, Inc., working under a separate contract with the EFLHD. Boring coordinates received from Best Winters are included with the typed boring logs in Appendix F. Stations are shown on boring logs. As-drilled locations were within 3 feet of the surveyed locations. Standard Penetration Testing (SPT), consistent with AASHTO Method T-206, was performed at 2.5-foot intervals between 0 and 10 feet and 5-foot intervals below 10 feet until refusal--defined as greater than 100 blows/foot--or the planned depth of the boring was reached. When SPT or auger refusal was reached, coring was performed, using an HQ-wireline system with a double-tube barrel having a split inner barrel. When difficulties arose due to the spreading of the split inner tube, a solid inner tube was used. The maximum core run length was 5 feet, although shorter runs were made in broken rock to improve recovery. This was the case in particular for the first 40 to 50 feet in most of the borings. Drilling fluid was water hauled to the site and pumped to the drill rig except on a few occasions when a small amount of polymer fluid was added to the drill water.

On several occasions where core recovery was low despite a reduction of the core run length, supplemental SPT samples were taken to examine and verify that refusal conditions existed so that coring procedures could continue.

Groundwater levels were measured at the completion of drilling (0 hours) and again 24 hours later before grouting the boring closed. Engineer's Field Boring Logs for each boring are included in Appendix F.

All borings were generally to be taken to a depth of 10 feet below proposed grade.

All soil samples were placed in glass jars. Core samples were placed in wooden boxes along with soil jar samples.

All soil and rock samples were visually classified in the field by HDR's geologist and summarized on a field log. The amount of core recovery for each run was measured and reported in terms of percent recovery on the logs. In addition, the Rock Quality Designation (RQD) (***Deere, 1968*** and ***Deere, 1988***) was measured for each run and is reported as a percentage of the run length on the logs. Finally, the orientation, condition and spacing of discontinuities in the rock core were measured and reported on the logs for use in characterizing the rock mass. Conditions on discontinuities in the rock core were described in the field based on guidelines for Classification of Discontinuity Conditions developed by Bieniawski (***Bieniawski, 1989***) as part of his Rock Mass Rating (RMR) system. These conditions include: Discontinuity Length, Separation, Roughness, Infilling and Weathering. The orientation of discontinuities was described as the angle relative to horizontal; however, the spatial orientation of these discontinuities could not be determined. The relative dip of the discontinuities measured in the core ranged from 0° to 90°. Oriented core drilling, angled borings or down-hole

geophysical methods would be required to obtain that type of information, and these were not part of the program. In addition, it is not certain that these methods would be successful, since each has requirements or limitations that could make them unsuccessful. Therefore, a range of discontinuity angles and potential orientations was investigated in the evaluation of cut slope stability for this study.

A Typed Engineer's Field Log was prepared for each boring based on the field log and is included in Appendix F. Photos of the core boxes are also included in Appendix D..

Representative samples of rock core were selected for testing as described in the following section. At the completion of testing all remaining soil and rock samples were delivered to:

Virgin Islands Department of Public Works
Attention: Mr. Aloy W. Neilson
6002 Anna's Hope
Christiansted, St. Croix

2.2 Laboratory Testing

Selected representative samples of rock core were tested to determine their unconfined compressive strength, which was used to characterize the rock mass. Tests were performed by CDS in accordance with ASTM Method D2938 procedures. Results are summarized in Appendix B. Soil samples were not tested due their limited thickness and lack of impact on the project.

2.3 Rock Exposures

It was planned that the orientation and condition of discontinuities, e.g., bedding, fractures, joints, would be measured at rock exposures in the project area so that the information could be used in the subsequent evaluation. However, the number of rock exposures available and the extent of their depth was limited to less than about 20 feet from the ground surface. Five exposures were observed and notes were taken in the project area. That information is included on the Exposure Location Plan with exposure field notes after Typed Boring Logs in Appendix F. Where possible, a Brunton Compass was used to measure the strike and dip of apparent discontinuities.

3.0 RESULTS AND ANALYSIS

3.1 Subsurface Conditions Encountered

Very little soil was encountered in any of the six borings drilled in the cut. Refusal was obtained in the initial soil sample (<1 foot) in each boring. Therefore, rock coring was started in each boring at a depth less than 1 foot except in boring B-10A where an additional SPT sample taken at 2.5 feet also obtained refusal and coring began below that SPT sample. Geotechnical symbolic boring logs are shown on cross sections in Figures 5, 6 and 7 in Appendix A.

The rock encountered has been described as a siltstone based on field identification and geologic information. Pyrite was noted on the joint surfaces. Figures B-1 through B-6 in Appendix B

illustrate the estimated condition of the rock mass encountered in borings. Several points are made regarding these plots.

- Figure B-1 shows the Recovery and RQD for each core run in B-8 and 8A, which were 125 and 115 feet deep, respectively, and were located in the deepest area of the proposed cut (Station 91+50). Note that the recovery was 100% in almost all but a few core runs. Also, the RQDs were zero or close to zero percent in the top 50 feet of B-8 and 25 feet in B-8A. Below those depths the RQD increased to 50% or more except in a few runs. Figure B-4 shows only the RQDs for these borings to illustrate this data more clearly.

- Figure B-2 shows the Recovery and RQD for each core run in B-9 and 9A, which were 70 and 60 feet deep, respectively, and were located near Station 89+50 where the proposed cut is about 50 feet deep. Note again that the core recoveries were 100% in all but a few cases. Also, the RQDs were close to zero or less than 50% in approximately the top 30 feet of B-9A and the top 45 feet of B-9. The RQD is generally at least 50% below these intervals. Figure B-5 shows only the RQDs for these borings to illustrate this data more clearly.

- Figure B-3 shows the Recovery and RQD for each of the core runs in B-10 and 10A, which were 41 and 45 feet, respectively, and were located near Station 94+25, where the proposed cut is about 35 feet deep. The core recoveries were generally at least 60% and most were 100%. A few runs in B-10A had RQDs greater than 50% below 30 feet but over its entire length only one run in B-10 (33-35 feet) had an RQD greater than 50%. Otherwise, all RQDs were very low and close to zero. In B-10, drilling was especially difficult due to the broken nature of the rock, and supplemental SPTs were taken at depths of approximately 10, 14 and 23 feet to verify refusal conditions. In each case except one, refusal was obtained. Based on RQD values and supplemental information, it appears that the top 15 feet may be more accurately characterized as a mass of boulders. Figure B-6 shows only the RQDs for these borings to illustrate this point more clearly.

The high level of core recovery obtained during drilling has allowed viewing of almost all of the rock in the borings. Low RQD intervals show the rock is very broken in the top 30 to 50 feet depending on the boring. This may be due to stress relief jointing or tectonic activity in the region.

The inclination of discontinuities ranged from 0 to 90 degrees with many at high angles. The condition of the discontinuity surfaces also varied but, based on observation of the rock core, can be described with few exceptions as having:

- Separations along the discontinuities of less than 1mm (RMR Rating 4 to 6),
- Slightly to Very Rough surfaces (RMR Rating 4 to 6),
- Infilling less than 5mm (RMR Rating 4 to 6) although calcite was sometimes found,
- Moderate to unweathered surfaces (RMR Rating 3 to 6).

The length of the discontinuities could not be determined from core data alone but has been estimated at 10 to 30 feet (RMR Rating 2) based on observation of the rock exposures.

Groundwater conditions are difficult to define, since water was used during coring operations. No seepage was noted in the area but the surfaces of discontinuities were often stained, indicating groundwater flow. Groundwater levels at the completion of drilling were high and are believed to be due to "mudding" of the boring sidewalls by drilling water mixed with cuttings. Drill water loss was minimal, which is believed to be due to the same reason. In most cases the boring sidewalls caved for the 24-hour reading.

3.2 Laboratory Testing Results

Unconfined compression tests were performed on 13 core samples believed to be representative of rock encountered in the proposed cut area. Results, which are summarized in Appendix B, ranged widely from a low of 626 psi to a high of 18,587 psi. The average compressive strength was 6685 psi (46 MPa); but the standard deviation was over 4000 psi, which is indicative of the scattering of the data. Note that low tests are not necessarily located in the near surface, more broken intervals in the borings. Some samples with relatively low results were located at great depth in areas of greatest RQD, e.g., B-8 and B-8A. Test results may have been influenced by weak zones or pre-existing weak planes in the samples.

3.3 Slope Design Analysis

As part of this study, the stability of the proposed 0.5H:1V slope design was evaluated using two methods. The first is a quantitative method using the Slope Mass Rating (SMR) system (***Romana, 2003***); and the second is a qualitative method using the DIPS program. The DIPS program utilizes the stereographic projection of anticipated major discontinuities, e.g., joints, bedding, etc., in conjunction with the proposed slope configuration to graphically indicate the potential for planer, wedge and toppling failure.

While there is information available on the orientation of bedding in the area of the project as described previously in the Geology section of the report, there is a lack of good information on the orientation and frequency of other discontinuities, e.g., joints, fractures, etc. Therefore, some assumptions regarding the orientation of potential discontinuities have been made to evaluate stability.

Due to the limited information available for the evaluation in terms of the number of borings and rock exposures, the accuracy of the evaluation could be impacted. This must be considered in developing final design information for construction. This could include additional borings that provide orientation data or the inclusion of contract provisions that allow for modification in the field during construction. These considerations are discussed later in the report.

For these evaluations the orientation of the bedding plane has been given a strike azimuth of 131° and a dip of 45° to the southwest, based on measured orientations from the geologic literature as shown on Figures 4a and 4b in Appendix A. This represents the steepest bedding orientation measured. The azimuth of the centerline cut between its start at Station 88 and about Station 94 is 85°, although there is a slight curvature on the east end or ahead-station end of the cut, which ends at about Station 96. The maximum depth of cut is approximately 100 feet in this line segment while the depth of cut is less than 40 feet between Stations 94 and 96 where orientation is a less significant factor. For a 0.5H:1V slope, the dip of the north cut face (Left side of centerline) would be 64° to the southeast, while the south cut face (Right side of

centerline) would dip at 64° to the northwest. Table 1 summarizes the discontinuity planes used for the analyses as well as the cut slope orientations. Notice that each joint configuration was evaluated for three dip angles based on the range of results observed in the core. Also, Joint 1 represents the bedding plane in the analysis when a dip of 45°SW is used. The joint/ discontinuity planes used for the analyses are illustrated on lower hemisphere stereonet plots in Appendix B.

Table 1 Discontinuity planes and cut slope face orientations used for analyses

Planes for Analysis	Plane Orientation (Strike Azimuth:Dip)	Explanation
Cut Slope	North Cut Face - 85°: 64°SE South Cut Face - 85°: 64°NW	Measured on project Plan
Bedding	131°: 45°SW	Average from geologic literature
Joint 1	131°: 45°SW; 60°SW; 90°	Representative of bedding plane
Joint 2	41°: 45°SE; 60°SE; 90°	Perpendicular to bedding
Joint 3	70°: 45°SE; 60°SE; 90°	Approx. perpendicular to ground contours
Joint 4	160°: 45°NE; 60°NE; 90°	Approx. parallel to ground contours
Joint 5	160°: 45°SW; 60°SW; 90°	Approx. parallel to ground contours
Joint 6	70°: 45°NW; 60°NW; 90°	Approx. perpendicular to ground contours

3.3.1 Slope Mass Rating

The Rock Mass Rating (RMR) system was developed by Bieniawski (***Bieniawski, 1989***). While the system was originally developed for use in tunnels and mining, it has since been applied to foundations and cut slopes. In an attempt to improve its usefulness in these other applications the system continues to be modified by others. The "Slope Mass Rating" (SMR) system utilizes a modified version of the RMR system (***Romana, 1993, 2003***). A copy of the 2003 reference is included in Appendix E, and selected tables used in this analysis are included in Appendix B.

The SMR is obtained by determining the base RMR (RMR_B) of the rock according to Bieniawski's methods and applying adjustment factors F_1, F_2, F_3 and F_4. The base RMR adds rating values for five parameters: (1) the strength of the intact rock; (2) RQD; (3) the spacing of discontinuities; (4) the condition of the discontinuities; and (5) water inflow through discontinuities and/or pore pressure ratio. The "F" Factors reflect the relationship between joint and slope strike (F_1), joint dip angles in the planer mode (F_2), slope and joint dip (F_3), and methods of excavation used for the cut (F_4). The method has been verified against case studies of excavated slope performance by many authors so that probable failure modes can be defined; and it has been extended to correlations with support methods to maintain stability. Tables in the attached 2003 reference provide these correlation tables and are used in this evaluation.

In the analysis to determine SMR the dip direction of the joint (discontinuity) plane, defined as α_j, is measured in the direction of the dip, i.e., Strike + 90°; while the dip direction of the cut slope face, defined as α_s, is measured in the direction of the dip of the slope, i.e., Strike + 90°. The dips of the cut slope and joint in the analysis are defined as β_s and β_j respectively. Tables 2a and 2b summarize the discontinuity data use in the SMR analysis for the north and south cut

face, respectively. Models 1 and 2 represent potential joint sets perpendicular and parallel to bedding planes. Models 3 and 4 represent potential joint sets parallel and perpendicular to ground contours in the cut area. Model 3 would also represent joints near parallel to the north cut face, a likely worst-case condition. Models 5 through 8 were selected to represent the same or similar conditions for evaluation of the south cut face. It is believed that these models reflect a wide range of potential discontinuity planes to investigate the effects of possible discontinuities on the cut slope performance.

Table 2a SMR analyses for North Cut Face

Analysis Model	Plane Orientation (Strike Azimuth:Dip)	SMR Parameters			
		α_s	α_j	β_s	β_j
1	North Cut Face – 85°: 64°SE Joint 1 - 131°: 45°SW; 60°SW; 90°	175°	221°	64°	45°, 60°, 90°
2	North Cut Face – 85°: 64°SE Joint 2 – 41°: 45°SE; 60°SE; 90°	175°	131°	64°	45°, 60°, 90°
3	North Cut Face – 85°: 64°SE Joint 3 - 70°: 45°SE; 60°SE; 90°	175°	160°	64°	45°, 60°, 90°
4	North Cut Face – 85°: 64°SE Joint 4 - 160°: 45°NE; 60°NE; 90°	175°	70°	64°	45°, 60°, 90°

Table 2b SMR analyses for South Cut Face

Analysis Model	Plane Orientation (Strike Azimuth:Dip)	SMR Parameters			
		α_s	α_j	β_s	β_j
5	South Cut Face - 85°: 64°NW Joint 1 - 131°: 45°SW; 60°SW; 90°	355°	221°	64°	45°, 60°, 90°
6	South Cut Face - 85°: 64°NW Joint 2 – 41°: 45°SE; 60°SE; 90°	355°	131°	64°	45°, 60°, 90°
7	South Cut Face - 85°: 64°NW Joint 5 - 160°: 45°SW; 60°SW; 90°	355°	250°	64°	45°, 60°, 90°
8	South Cut Face - 85°: 64°NW Joint 6 - 70°: 45°NW; 60°NW; 90°	355°	340°	64°	45°, 60°, 90°

Boring B-8 was selected to make this preliminary evaluation on the assumption that the condition of the top 50 feet, referred to as the Upper Rock Zone in this boring, is reasonably representative of the low RQD--broken rock found in all of the other borings--while conditions below 50 feet in this boring, referred to as the Lower Rock Zone, would reasonably represent conditions in the higher quality rock in the other borings. An SMR was computed for rock described in boring B-8 for the joint configurations shown in Table 2 in conjunction with the proposed north and south cut slope faces. Results are summarized in Tables 3a and 3b. Supporting information for the analysis is included in Appendix B.

Table 3a
Summary of SMRs for Analysis Models of North Cut Face (Using boring B-8)

Model	Dip Directions (α_s, α_j, β_s)	Failure Mode	SMR					
			Upper Rock Zone			Lower Rock Zone		
			β_i=45°	β_i=60°	β_i=90°	β_i=45°	β_i=60°	β_i=90°
1	$\alpha_s = 175°$, $\alpha_j = 221°$, $\beta_s = 64°$	Planer	30	32	39	59	60	68
		Toppling	39	35	35	68	64	64
2	$\alpha_s = 175°$, $\alpha_j = 131°$, $\beta_s = 64°$	Planer	30	32	39	59	60	68
		Toppling	39	35	35	68	64	64
3	$\alpha_s = 175°$, $\alpha_j = 160°$, $\beta_s = 64°$	Planer	-3	4	39	26	33	68
		Toppling	39	35	35	68	64	64
4	$\alpha_s = 175°$, $\alpha_j = 70°$, $\beta_s = 64°$	Planer	30	32	39	59	60	68
		Toppling	39	35	35	68	64	64

Table 3b
Summary of SMRs for Analysis Models of South Cut Face (Using boring B-8)

Model	Dip Directions (α_s, α_j, β_s)	Failure Mode	SMR					
			Upper Rock Zone			Lower Rock Zone		
			β_i=45°	β_i=60°	β_i=90°	β_i=45°	β_i=60°	β_i=90°
5	$\alpha_s = 355°$, $\alpha_j = 221°$, $\beta_s = 64°$	Planer	30	32	39	59	60	68
		Toppling	39	35	35	68	64	64
6	$\alpha_s = 355°$, $\alpha_j = 131°$, $\beta_s = 64°$	Planer	30	32	39	59	60	68
		Toppling	39	35	35	68	64	64
7	$\alpha_s = 355°$, $\alpha_j = 250°$, $\beta_s = 64°$	Planer	30	32	39	59	60	68
		Toppling	39	35	35	68	64	64
8	$\alpha_s = 355°$, $\alpha_j = 340°$, $\beta_s = 64°$	Planer	-3	4	39	26	33	68
		Toppling	39	35	35	68	64	64

The results in the "Upper Rock Zone" range between 30 and 39 for all models except the planer mode in Models 3 and 8. SMRs for these models are much lower, since they represent potential

joint planes that are near parallel to the cut slope face, such that planer failure might occur. As shown in Appendix B tables after Romana, SMR ratings for the Upper Rock Zone between 21 and 40 fall into the Class IV category described as "Bad" with instability, the possibility of planer or big wedge failures, and the need for important corrective support measures. The low ratings associated with Models 3 and 8 indicate a Class V, "Very Bad," rock mass with completely unstable features, big-planer or soil-like failures, and the need for re-excavation for support. The rating assumes that blasting and/or mechanical means will be used for excavation of the slope ($F_4 = 0$).

The results in the "Lower Rock Zone" range between 59 and 68 for all models except the planer mode in Models 3 and 8 where the SMRs are again much lower. These two models represent potential joint planes that are near parallel to the cut slope face such that planer failure might occur. SMR ratings between 61 and 80 fall into the Class II category described as a "Good," stable rock mass, with the possibility of some block failures and the need for occasional support measures. Suggested support methods for a Class II rock mass include rock bolting or anchors, toe ditches, slope fences, or nets for catching of potential rock falls. The rating assumes that presplit blasting will be used for excavation of the slope ($F_4 = 10$).

3.3.2 DIPS Analysis

A stereographic analysis was performed using the DIPS program with the joint configurations in Models 1 through 6. DIPS analysis allows a more definitive look at the three separate failure modes: planer, toppling and wedges. Results are included in Appendix B. A friction angle of 45° was used to represent friction between plane surfaces based on experience with test results on similar rock on other projects (***HDR, 1995, 1996*** and ***1997***). For surfaces that are closed, i.e., in contact, and have not moved previously causing friction to be reduced to its "Base" value, 45° is likely to be conservative.

Joints in Models 7 and 8 represent more important potential failure planes in the south cut face. They were not included in this analysis, since it was believed those for the north cut face would illustrate "typical" results. While results must be considered preliminary, they show the potential for some planer failures or block failures depending on the friction along the discontinuities; but generally they were consistent with the SMR results. Also, many of the potential failures were for planes with borderline conditions. For example, the 33% to 50% planes with potential for planer sliding (4 to 6 of the 12 planes evaluated) in the north cut face includes three that are on the 45° friction circle and two that are just outside the "Daylight Envelope" that encapsulates the potential failure planes.

3.4 Alternates Slope Configurations

The slope configuration presented in the plans provided to HDR and used to develop the current right-of-way (ROW) through the cut area is based on the use of a 0.5H:1V slope for the full depth of the cut. Conceptual designs for three alternate configurations were also developed for consideration during this study, given a finding that the planned configuration may not be stable for its full height based on conditions in the more broken, "Upper Rock Zone," and analysis presented in Section 3.3. These alternates included:

- **Alternate 1** – A 0.5H:1V slope in the "Lower Rock Zone" and a flatter slope in the "Upper Rock Zone." Where the proposed flatter slope in the more broken "Upper Rock Zone" does not daylight to existing ground within the ROW, a wall would be used to accomplish this. The top of the cut slope or wall would be located a minimum of 10 feet from the ROW. The cut slope would begin at the same point off the pavement shoulder used in the initial design. Based on SMR and DIPS analyses, there would be some potential that rockfall from the slope could reach the roadway section; therefore, the slope should be stabilized using rock bolting and some form of facing to minimize or prevent the risk of rockfalls reaching the roadway.

- **Alternate 2** - A 0.5H:1V slope in the "Lower Rock Zone" and a flatter slope in the "Upper Rock Zone." Where the slope in the "Upper Rock Zone" does not daylight to existing ground within the ROW, a wall would be used to accomplish this. The top of the cut slope or wall would be located a minimum of 10 feet from the ROW. An area would be provided at the toe of the slope to retain rock falls and minimize the potential risk that falls would reach the roadway. The cut slope would begin at the back of this catchment area.

- **Alternate 3** – A cut-and-cover tunnel section where a temporary excavation would be made to construct the tunnel. Temporary slopes could be vertical with provision for stabilization using rock bolts or other methods. The excavated material would be retained for replacement over the cut-and-cover unit so that no permanent cut slope would be required. A 60-foot wide tunnel section was used for the conceptual study, although this may be greater if this alternate were considered favorably. For this conceptual study a cast-in-place concrete structural section was considered, although options using steel or other specialty designs could be considered.

- **Alternate 4** – A bored tunnel, which would require some transition cut slopes at each end of the tunnel.

4.0 DISCUSSION

4.1 Evaluation of As-Planned and Alternate Slope Configurations

Based on the available information the as-planned and alternate slope configurations were evaluated in Section 3 and are discussed in this section. Given the wide spacing of borings, the conditions in the borings, and the variability between borings, a range of assumptions was used for the study. For this evaluation, the simplifying assumption has been made, based on boring information, that the demarcation between the "Upper Rock Zone" and the "Lower Rock Zone" is at an average depth of about 40 feet below the ground surface. Clearly field conditions do vary to some unknown degree as shown by the six available borings. This variability must be considered in the evaluation and in subsequent design for construction.

While development of excavation quantities was not part of this study, some estimates of relative amounts were made. It is understood that the as-planned cut would develop approximately 150,000 cy of waste. The relative effect of each alternate on this quantity is provided in this discussion.

Also, detailed cost estimates of alternates are beyond the scope of this study; however, some information was developed and submitted in the interim period during preparation of this report to obtain a general magnitude of cost for significant items related to the cut excavation and slope stabilizations. This information, not included with this report, was submitted for information and for a general comparison. The information should not be relied on as representing total costs for the alternate treatments of the cut area nor for budgeting purposes.

4.1.1 As-Planned Configuration

Based on the results of the boring program, it does not appear that the planned cut configuration using a 0.5H:1V slope will provide a stable condition that can be maintained within the ROW. This is principally due to the broken rock interval referred to herein as the "Upper Rock Zone." Analyses indicate that flatter slope or extensive stabilization including a wall will be required in that interval to maintain stability. In addition, the characteristics of the rock mass in the "Lower Rock Zone," as depicted in the borings and analysis conducted thus far, indicate potential for rockfall that could present a safety hazard to the traveling public without stabilization on the slope or a catchment area at the base of the slope to retain falls and reduce that risk. Geotechnical work sections showing this scheme, the typical section, and boring information are included in Appendix C. Based on this information, one of the other alternates should be utilized.

4.1.2 Alternate 1

This configuration would use a 0.5H:1V slope in the "Lower Rock Zone" without a catchment area. Analyses to date indicate the slope should be stable with some falls along joints (planer mode) or on wedges (intersecting joints); therefore, provision would be needed for rock bolting or anchors. Since this configuration does not include a catchment area, extensive slope stabilization would be required to prevent falls onto the roadway area. For this conceptual study it is assumed this would include rock bolting or nailing with a reinforced permanent facing on the entire slope. The use of a vertical face was also considered. While it has only a small effect on the SMR and would save some excavation, it is believed this would increase the risk of falls; therefore, the 0.5H:1V slope is believed to be more reasonable for this alternate.

In the "Upper Rock Zone" it is assumed that a flatter slope of at least 1H:1V or preferably 1.5H:1V would be used. Neither of these slopes will allow the top of cut to be maintained within the ROW; therefore, a vertical wall with anchors or nails should be utilized in this interval. The wall should be maintained at least 10 feet from the ROW. While, based on our experience, it is believed to be reasonable that a 1.5V:1H slope will be stable in broken rock without stabilization, there is a possibility that falls could occur from a 1H:1V slope; therefore, a 1H:1V slope, if used, should be stabilized as described for the 0.5H:1V slope to prevent rock falls.

Schematic diagrams in Appendix C show the configuration of the alternate on selected geotechnical sections through the cut. It is anticipated that anchors used to support the wall faces could extend outside of the ROW, which typically requires an easement. It is understood that this issue can be accommodated and does not represent a "Fatal Flaw" for this or other similar alternate treatments.

The quantity of waste with this configuration should be slightly greater than the as-planned amount due to the flattening of the slope in the "Upper Rock Zone."

4.1.3 Alternate 2

This alternate would be similar to Alternate 1 but provides a catchment area at the base of the slope. It has been assumed that the ability to catch falls would eliminate the need for total stabilization in the "Lower Rock Zone" slope described in Alternate 1, although some provision for localized stabilization should be included if the alternate is considered for final design. Given the nature of the rock in borings, the wide spacing of the borings and the lack of good data on potential joint orientations, this localized stabilization could be used if significant blocks or broken intervals are encountered as the cut is excavated to grade (See Section 4.2).

Two methods are offered for the configuration of the catchment area. The first is based on the "Ritchie Ditch" developed in the 1960s (***Ritchie, 1963***) and modified since then by others. A schematic diagram showing the configuration of the Ritchie Ditch is shown as Figure 8 in Appendix A. The second method is based on one of the more significant modifications of the ditch presented by Pierson, et al (***Pierson, 2001***). This method utilizes a catchment area with various slopes and widths from the roadway shoulder. The configurations are designed based on an extensive research project where more than 11,000 rocks were rolled off a variety of slopes in conjunction with analyses of the rockfall information based on statistical and graphical methods.

Sections for the Ritchie Ditch and the rockfall catchment area were selected for this evaluation. The dimensions for the catchment area were selected based on retention of 90% of potential rockfalls. Based on a maximum 0.5H:1V slope of about 70 feet, the width of this catchment area using a 4H:1V slope in that area and for a 90% rockfall retention rate, would be 18 feet. The relevant table and diagrams from the reference that was used to determine these catchment area dimensions is shown in Figure 9 in Appendix A. These dimensions are used with this alternate in Appendix C schematics along with the Ritchie Ditch configuration. For information, Figure 10 shows a plot of catchment area width vs. cut slope height for percent rockfall retention using data in the reference. Based on discussion with the EFLHD, a safety barrier could be placed at the outside of the roadway shoulders to improve rockfall retention when the dimensions for the 90% retention are used.

Treatment in the "Upper Rock Zone" for this alternate would be the same as discussed in Alternate 1. A flatter slope of at least 1H:1V with stabilization, or preferably 1.5H:1V without stabilization, would be used in this rock zone. Neither of these slopes will allow the top of cut to be maintained within the ROW; therefore, a vertical wall with anchors or nails should be utilized in this interval. The wall should be maintained at least 10 feet from the ROW.

Schematic diagrams showing the configuration of the alternate on selected geotechnical sections through the cut are included in Appendix C. The quantity of excavation waste with this alternate is estimated to be greater by about 20% to 25% due principally to the incorporation of a catchment area.

4.1.4 Alternate 3

This alternate is a cut-and-cover tunnel that would allow backfilling of the cut area such that no long term cut slope would be required. This alternate could also significantly reduce the quantity of waste to be removed from the site.

Schematic diagrams showing the configuration of the alternate on selected geotechnical sections through the cut are included in Appendix C.

4.1.5 Alternate 4

This alternate is a full tunnel through the area. Based on general discussions, this alternate is not considered feasible or cost-effective by comparison with other alternates, given the length of the potential tunnel, the project location, and the need for special treatment at the end areas of the tunnel where significant broken rock is anticipated.

4.2 Construction Considerations

As indicated previously, the boring information indicates that variable conditions--particularly with respect to the impact of rock quality and the configuration for Alternates 1 and 2--will depend on the quality of rock in the cut area. The borings obtained are spaced approximately 250 to 300 feet apart, and conditions vary between borings; and the related conditions between borings cannot be clearly defined with the information thus far. For example, borings B-10 and B-10A were drilled near the west end of the cut. They encountered very broken rock, i.e.; RQD ~ 0%, over their entire depth of 40 to 45 feet. Borings B-8 and B-8A encountered very broken rock for a depth of about 50 feet and 20 feet, respectively. This zone is about 30 to 35 feet thick at the top of borings B-9 and B-9A. An average depth of 40 feet has been used to develop the schematic configuration for the alternates, but the conditions encountered during construction could vary.

In addition, the orientation of discontinuities cannot be well defined with the information available allowing for the possibility that local conditions of instability could be encountered as discussed previously. For these reasons and because of the limited ROW available to make field adjustments, provisions should be included in the final plans and specifications for the variability and potential conditions that could be encountered.

The types of provisions that should be considered include:

- A provision for an experienced geologist or geotechnical engineer to observe the cut conditions as the cut is brought down and to verify or modify the construction procedures in accordance with special provisions. This would include observation and cataloging discontinuity patterns to determine whether unfavorable conditions are being encountered.

- A pay item for modifying the quantity of walls based on field conditions encountered. This could include lengthening or increasing the amount of reinforcement.

- A pay item for stabilization of the cut slope where localized potential stability concerns--planer, wedge or toppling--are recognized by the on-site geologist or geotechnical engineer.

4.3 Treatment of Waste Material for Acid-Producing Waste

Field observation of core samples has indicated that pyrites are present in the rock. Previous experience with these types of materials have indicated that they can produce acidic drainage from waste piles if the quantity and concentration of the material is sufficient (***HDR, 1995, 1996*** and ***1997***). Identification tests and treatment procedures have been developed to recognize the issue and deal with it (***Byerly, 1990***). Dr. Byerly's studies have indicated that, "the material most prone to produce acidic drainage is rock containing pyritic sulfur in excess of 0.5 percent and containing little or no alkaline minerals." The acid-producing potential is measured using the Net Neutralization Potential (NNP), which is the net difference between the material's Neutralization Potential (NP) and its Acid Potential (AP) [i.e.; NNP = NP-AP]. NNP is measured in tons CaCO3 per 1000 tons of the material. An NNP of –5 tons CaCO3 or less is generally considered an indicator of acid-producing drainage production. While it is not clear that this is an issue at this site, rock samples should be tested to determine their concentration of these minerals and treatment methods, if necessary. Provisions for treatment can be included in the final documents if required.

5.0 RECOMMENDATIONS

Based on the available information and the evaluations made as part of this study, the following recommendations are made:

- Do not use the planned 0.5H:1V slope design, since the expectation of instability causing intrusion beyond the ROW in conjunction with rock falls that could reach the roadway, is high.

- Use one of the alternate designs presented herein or others that accomplish the objective of staying within the ROW while providing an acceptable level of protection against rock falls reaching the roadway. Additional analysis and details should be completed for development of final design plans, specifications, and estimates. The accepted alternate should be completed after a decision has been made regarding the level of protection that should be provided with the design.

- During final design provide provisions to deal with variable subsurface conditions including:

    - An experienced geologist or geotechnical engineer on-site to verify conditions and modify the procedures and quantities based on field conditions.

    - An "as needed" quantity of rock excavation, stabilization with walls, and reinforcement (nails, anchors, bolting) as well as mesh and shotcrete, for use where conditions dictate.

    - Make a thorough review of construction plans and specifications developed in the manner indicated. This should include discussion with contractors experienced in this work.

- Perform tests on rock samples from core borings to determine if they contain acid-producing materials and in what concentrations. If necessary, develop appropriate mitigation methods for the slopes and waste areas.

6.0 LIMITATIONS

This report has been prepared for the use of the Eastern Federal Lands Highway Division of the FHWA for specific application to project VI NH-66(008) in accordance with generally accepted geotechnical engineering practice. No warranty, expressed or implied, is made. The analyses and recommendations are based on the data available to HDR at the time of this study and on the data collected during the investigation. The report does not reflect soil, rock and groundwater variations that may occur between borings. Variations may become evident during construction, at which time re-evaluation of the conclusions may become necessary. In the event that changes occur in the project design or location after the final report is submitted, the recommendations should be reviewed and modified as necessary.

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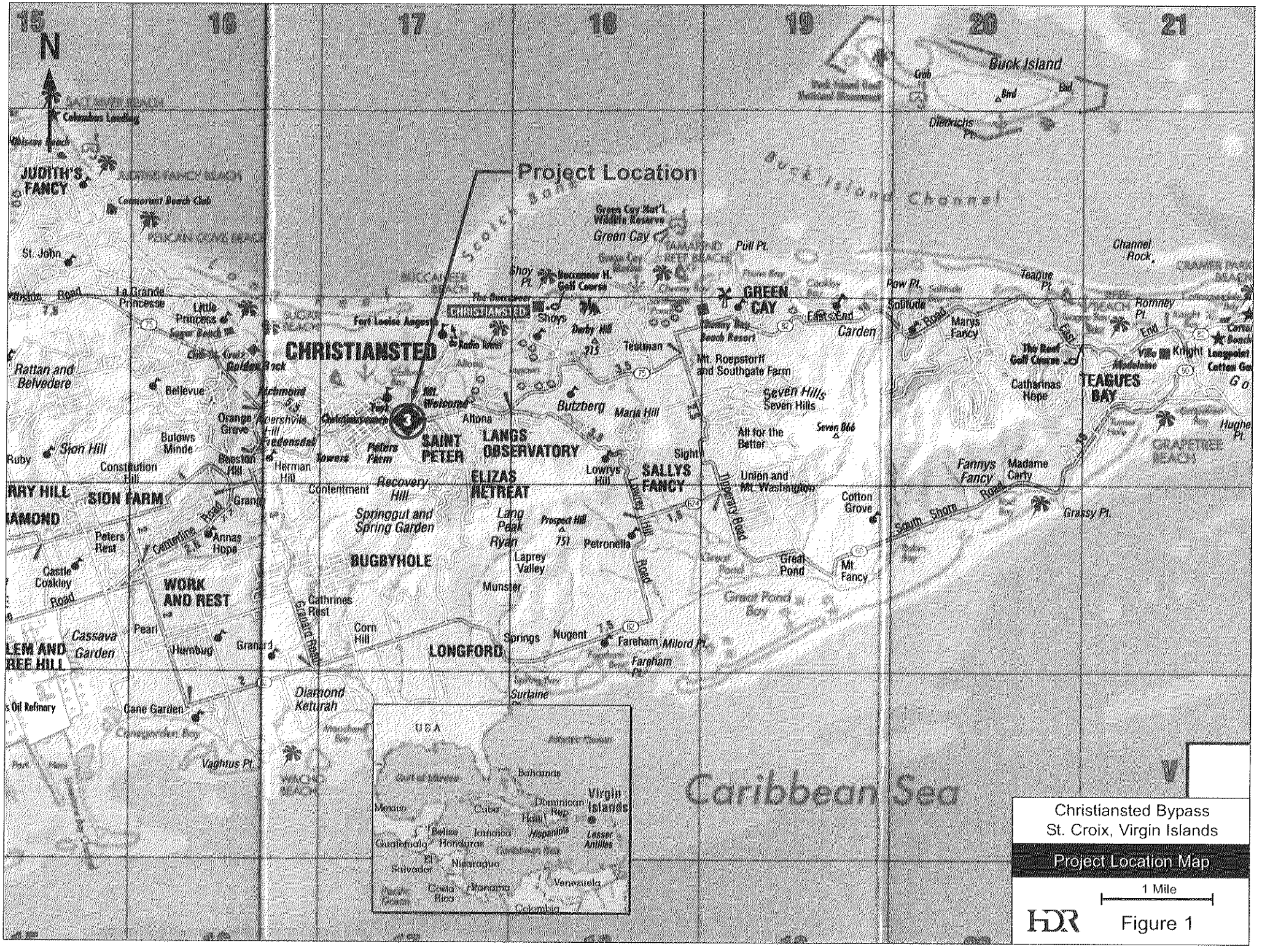
Appendix A

Figures



Christiansted Bypass
St. Croix, Virgin Islands

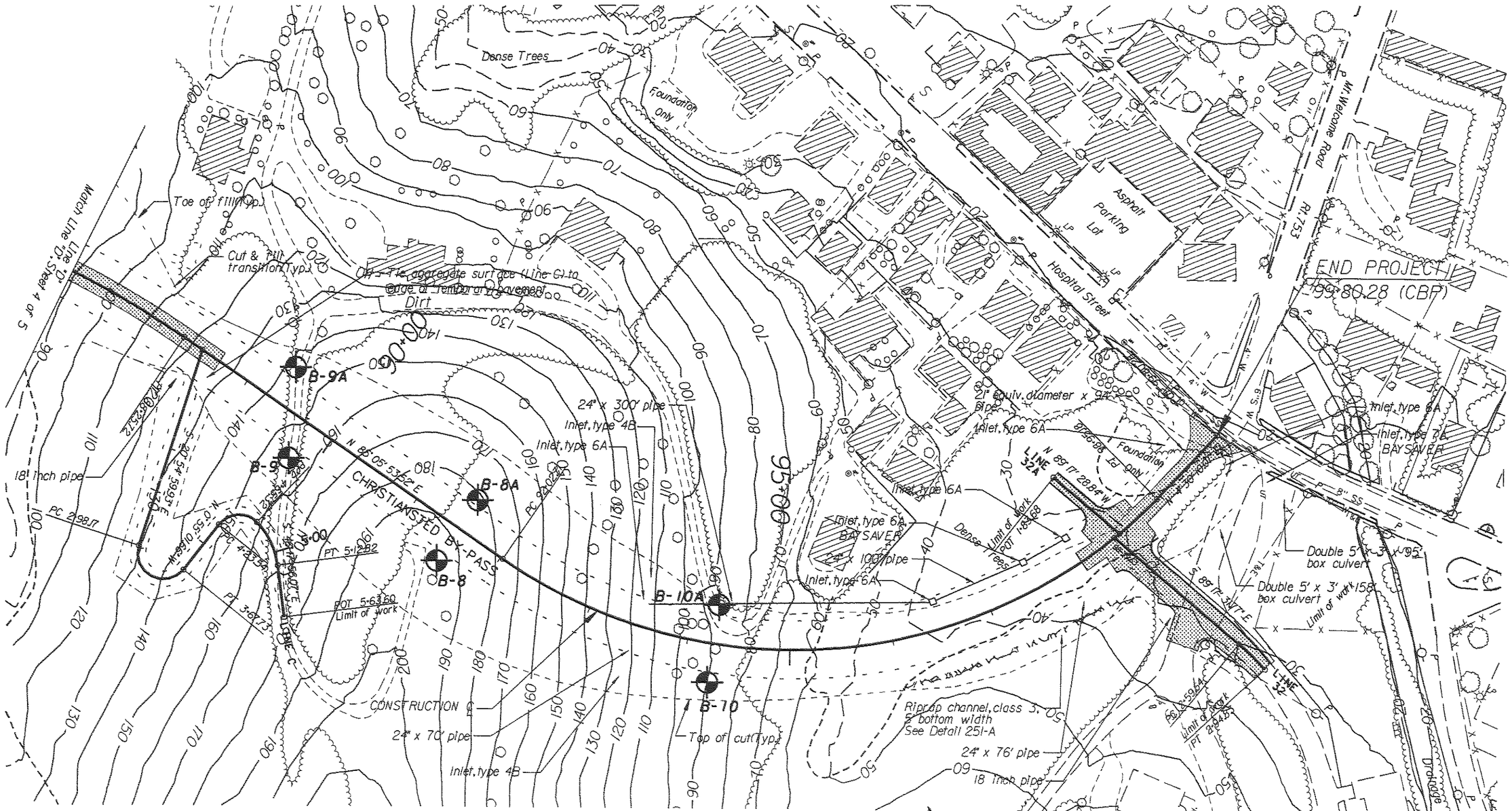
Project Location Map

HDR

Figure 1

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		

PAVED
(See Christiansted Bypass-Temporary Pavement Typical Section and Driveway/Sideroad Typical Section for detail)



CENTERLINE DATA

88+47.54 Bypass = 1+00 Line C
98+39.63 Bypass = 1+00 Line 32
98+45.73 Bypass = 1+00 Line 32A

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS
ST. CROIX, VI
TEST BORING LOCATION PLAN

0 50 100
SCALE IN FEET

FIGURE 2

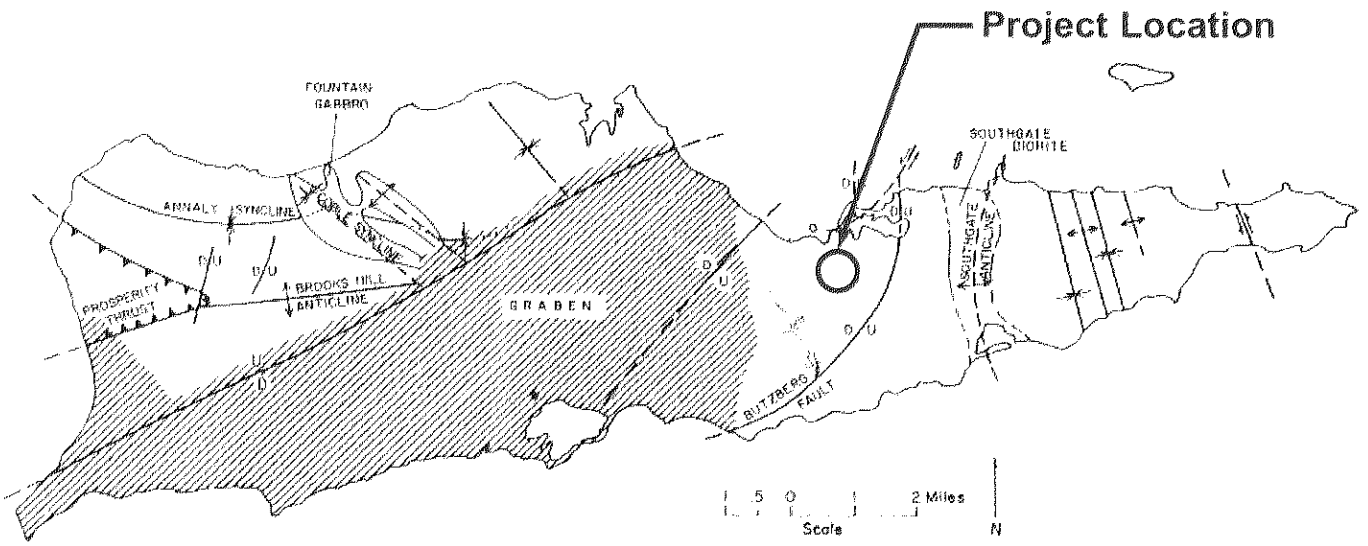


FIGURE 12. Structure map of St. Croix. Ruled area underlain by Tertiary rocks and alluvium. Traces of axial planes and faults, and major intrusions indicated.

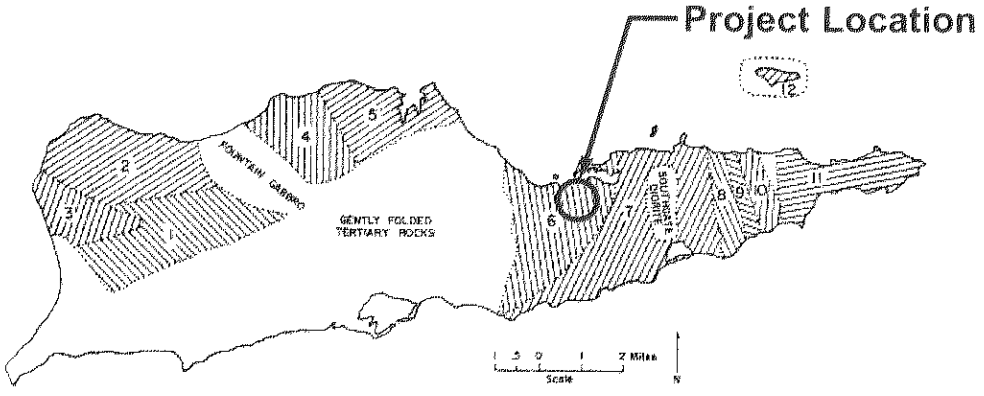


FIGURE 13. Index map to structure analysis. Strongly folded Cretaceous rocks (ruled pattern) are divided into 12 areas, each folded about a single axis. Fold axes in numbered areas are statistically determined in Figures 14, 15, and 16.

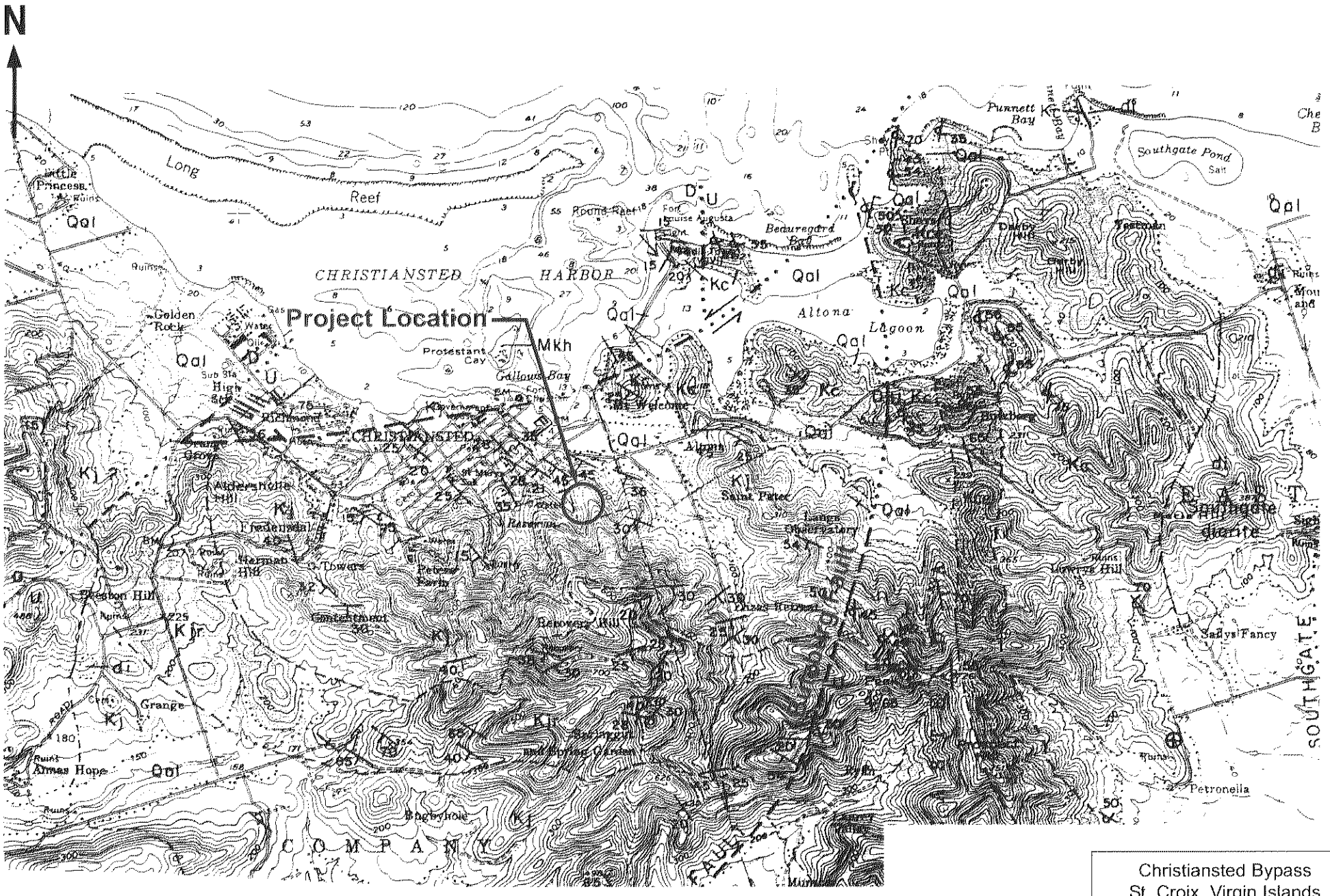
Ref: Caribbean Geological Investigations by J.T. Whetten (full title not available)

Christiansted Bypass
St. Croix, Virgin Islands

Geologic Structure Map of St. Croix

HDR

Figure 3



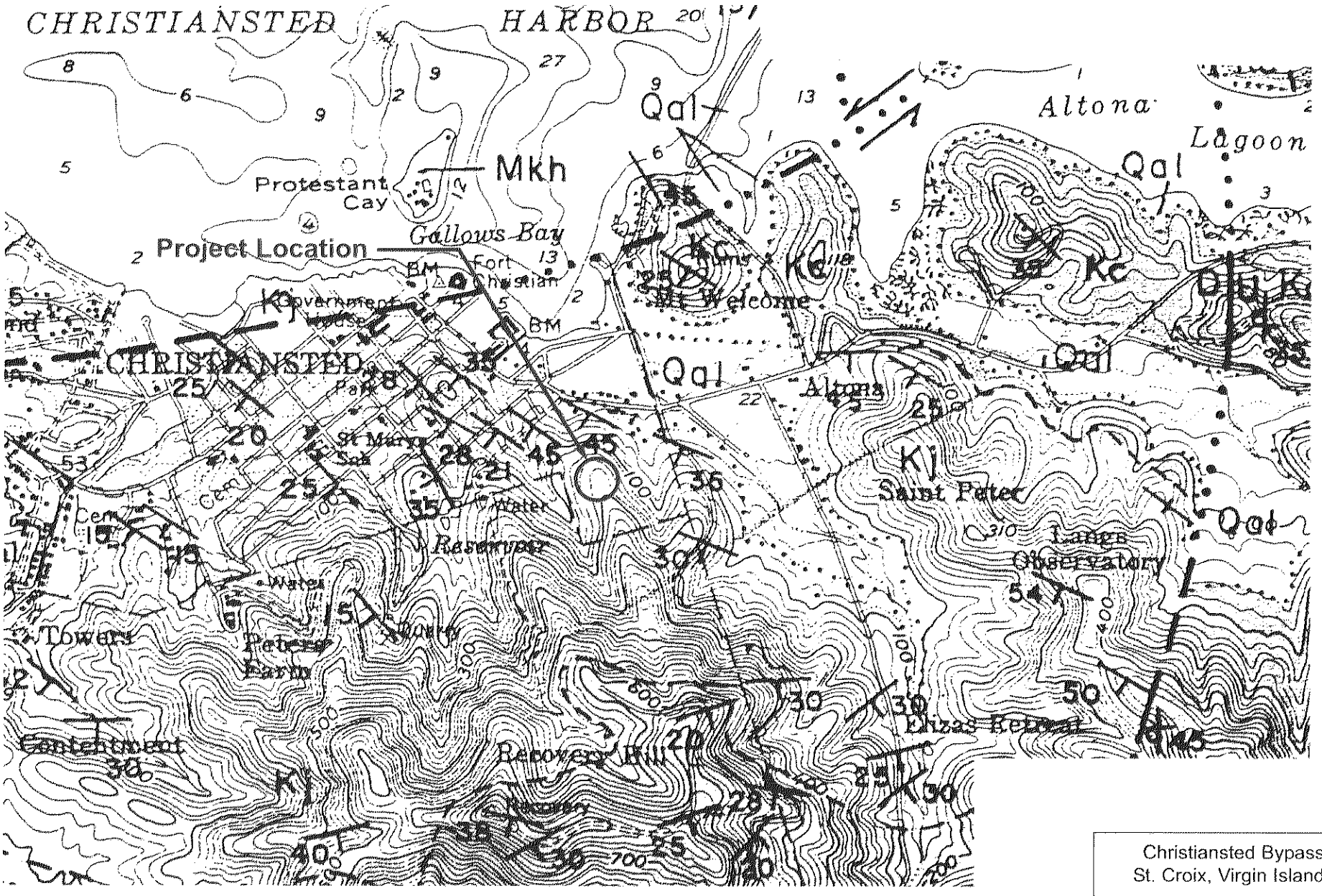
Ref: Caribbean Geological Investigations by J.T. Whetten (full title not available)

Christiansted Bypass
St. Croix, Virgin Islands

Geologic Structure Map of Project Area

HDR

Figure 4a



Ref: Caribbean Geological Investigations by J.T. Whetten (full title not available)

Christiansted Bypass
St. Croix, Virgin Islands

Geologic Structure Map of Project Area

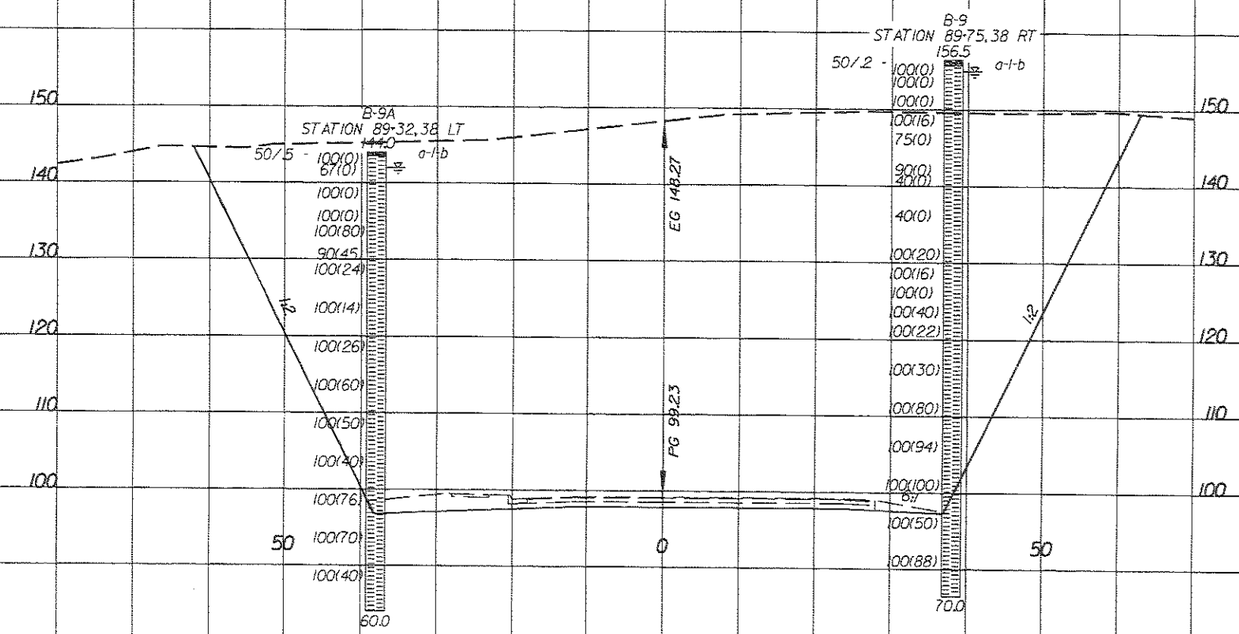
HDR

Figure 4b

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		



TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24

SPT<1 FOOT 50 BLOW/0.1 FOOT 50/.2

% CORE REC.(RQD%) 90(40)

WATER LEVEL (0 HRS)

WATER LEVEL (24 HRS)

BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH.

NOTE:

DETAILED BORING INFORMATION IS CONTAINED IN REPORT.

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

CROSS SECTION
STATION 89+50

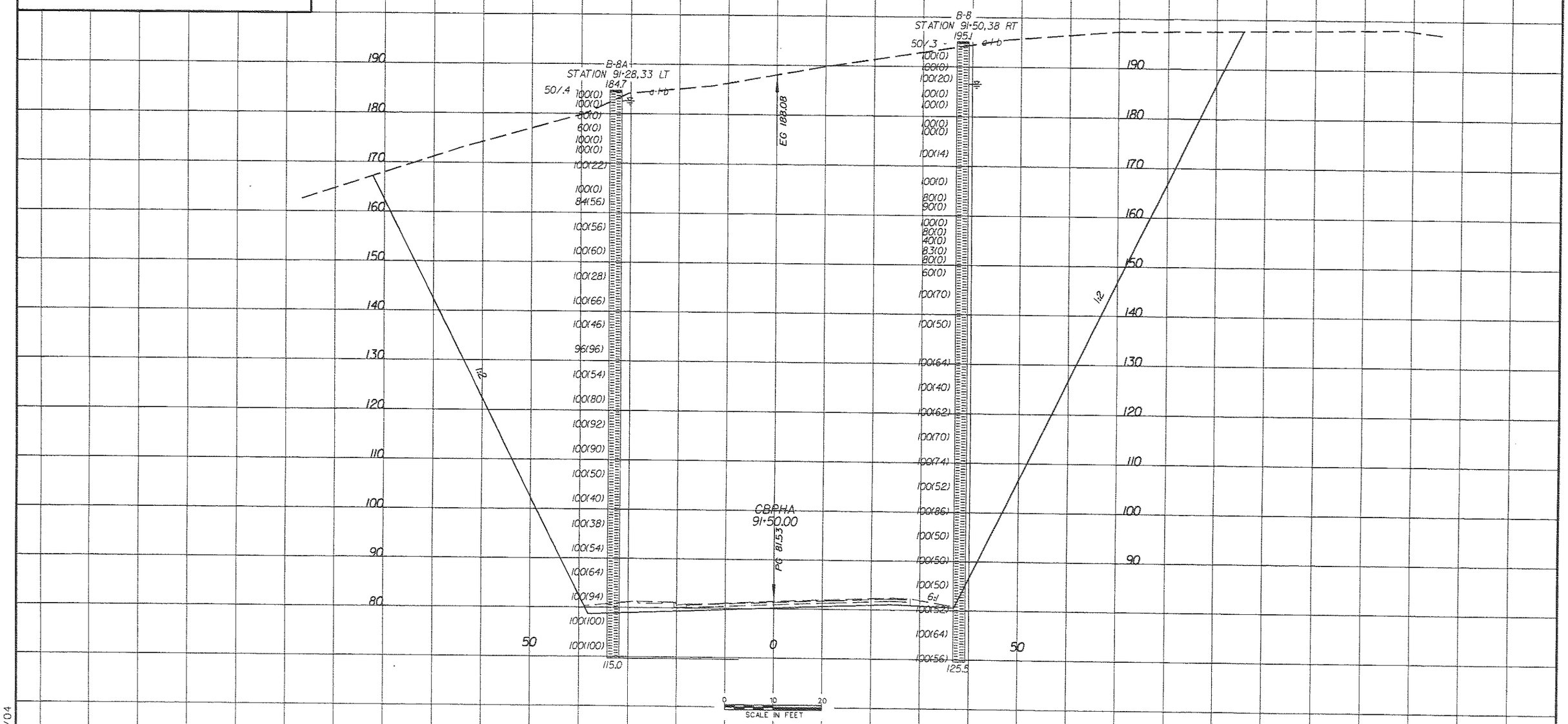
FIGURE 5

J:\ 15423\CADD\TBXSECTS.DGN 9/1/04

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		



TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24

SPT<1 FOOT
50 BLOW/0.1 FOOT 50/.2

% CORE REC.(RQD%) 90(40)

WATER LEVEL (0 HRS)

WATER LEVEL (24 HRS)

BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH.

NOTE:

DETAILED BORING INFORMATION IS CONTAINED IN REPORT.

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

CROSS SECTION
STATION 91+50

FIGURE 6

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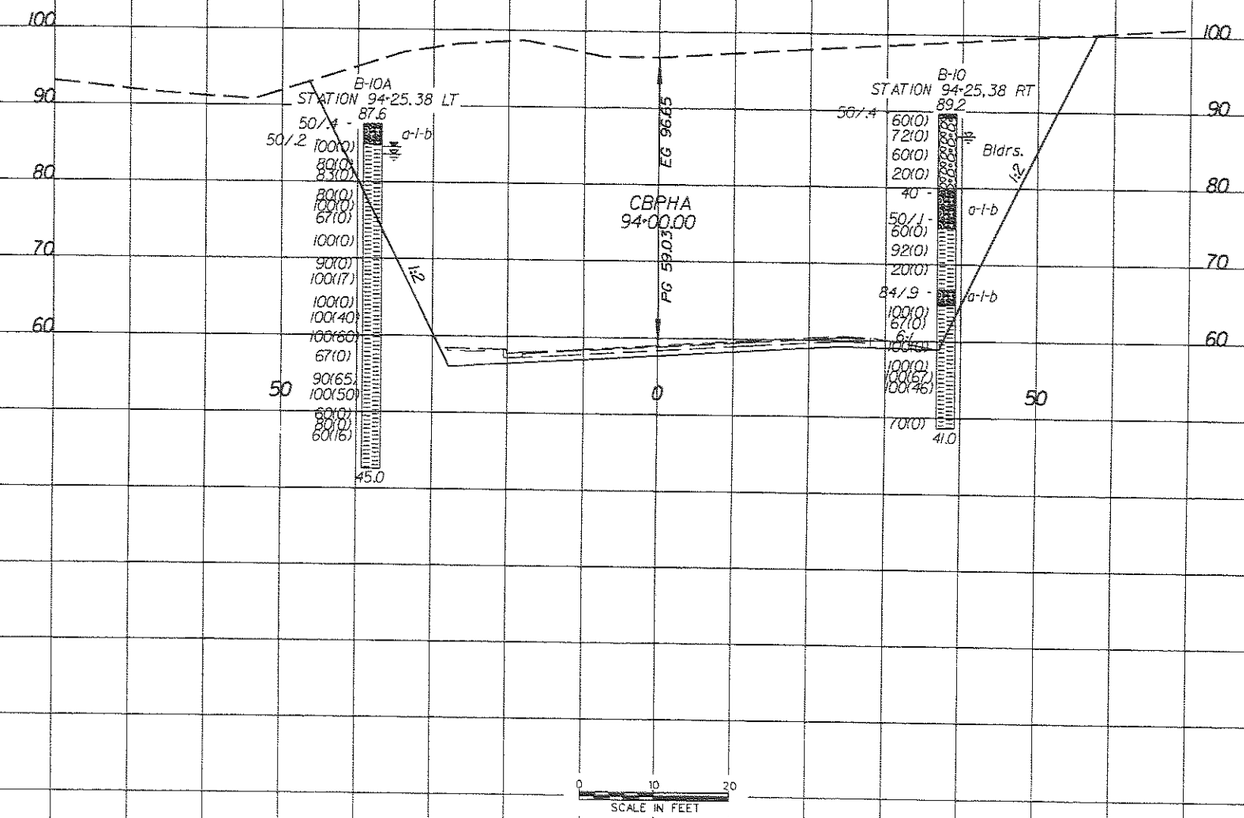
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		



TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24

SPT<1 FOOT
50 BLOW/0.1 FOOT 50/.2

% CORE REC.(RQD%) 90(40)

WATER LEVEL (0 HRS)

WATER LEVEL (24 HRS)

BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH.

NOTE:

DETAILED BORING INFORMATION IS CONTAINED IN REPORT.

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

CROSS SECTION
STATION 94+00

FIGURE 7

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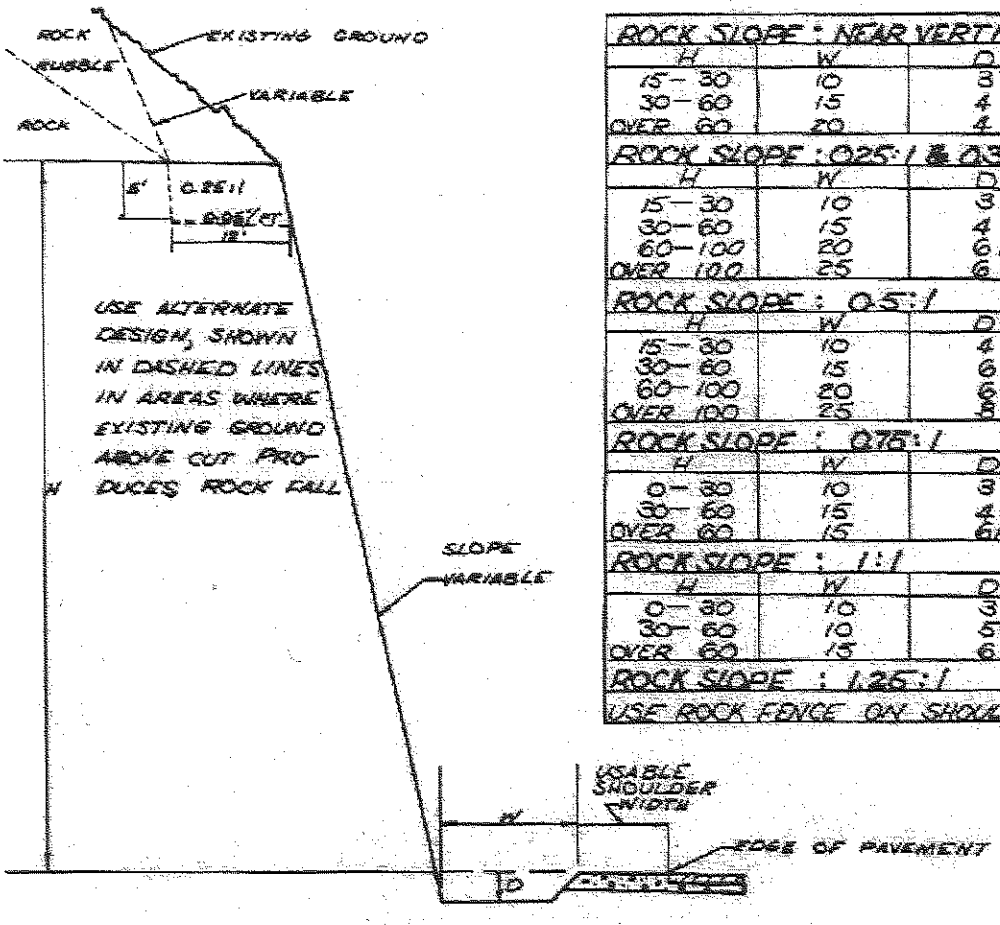
TABLE 1

RELATIONSHIP OF VARIABLES IN DITCH DESIGN FOR ROCKFALL AREAS



ROCK SLOPE : NEAR VERTICAL		
H	W	D
15 – 30	10	3
30 – 60	15	4
OVER 60	20	4
ROCK SLOPE : 0.25:1 & 0.3:1		
H	W	D
15 – 30	10	3
30 – 60	15	4
60 – 100	20	6 F
OVER 100	25	6 F
ROCK SLOPE : 0.5:1		
H	W	D
15 – 30	10	4
30 – 60	15	6
60 – 100	20	6 F
OVER 100	25	6 F
ROCK SLOPE : 0.75:1		
H	W	D
0 – 30	10	3
30 – 60	15	4
OVER 60	15	6 F
ROCK SLOPE : 1:1		
H	W	D
0 – 30	10	3
30 – 60	10	5 F
OVER 60	15	6 F
ROCK SLOPE : 1.25:1		
USE ROCK FENCE ON SHOULDER		

When required for slope stability the use of benches is satisfactory; however, they do not alter the design and values shown. Ordinarily their use will be a result of the soils study and be on the recommendation of the materials engineer.

Where the existing ground above the top of cut is on a slope approximating that of the cut slope, the height (H) shall include the existing slope or that portion of it that can logically be considered a part of the rock cut.

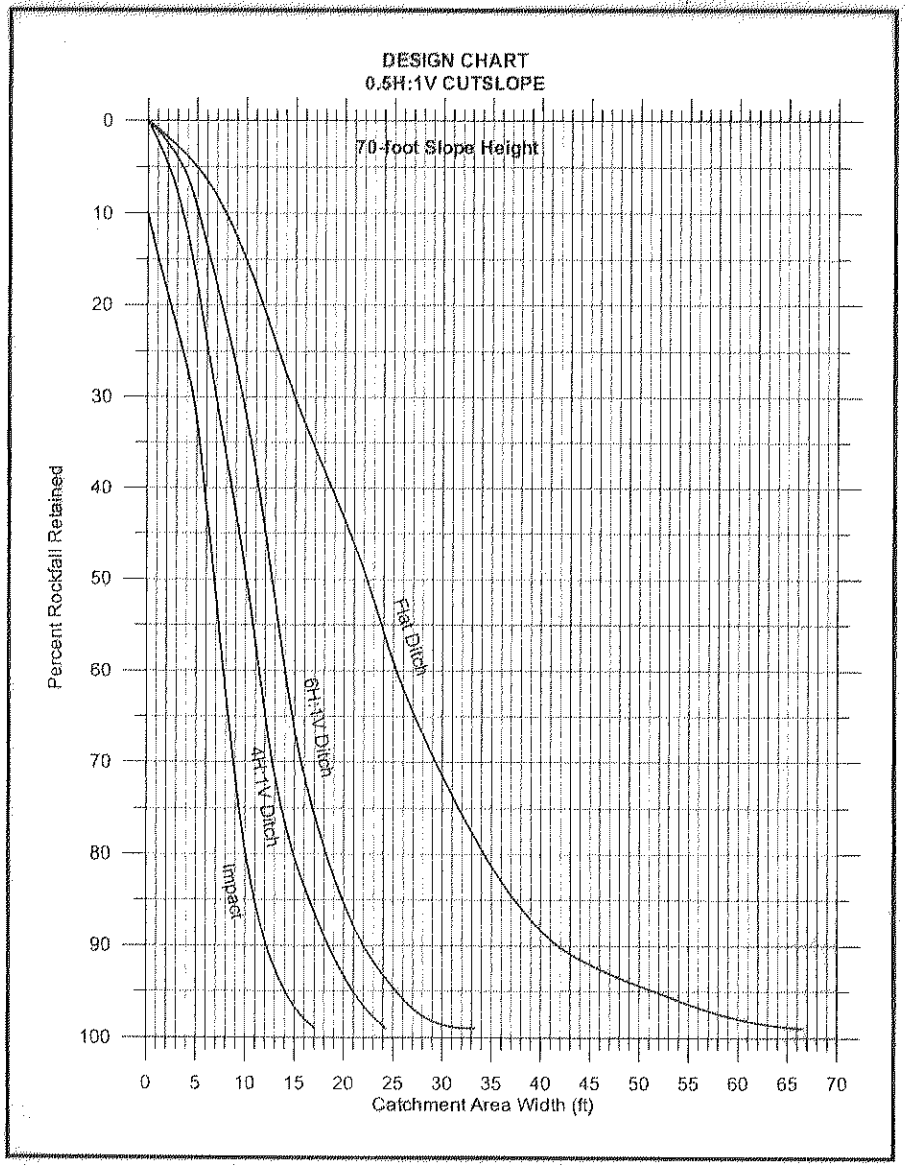
Ordinarily guardrail shall be provided where D is greater than 3. F permits diminishing D to 4 if fence is also used.

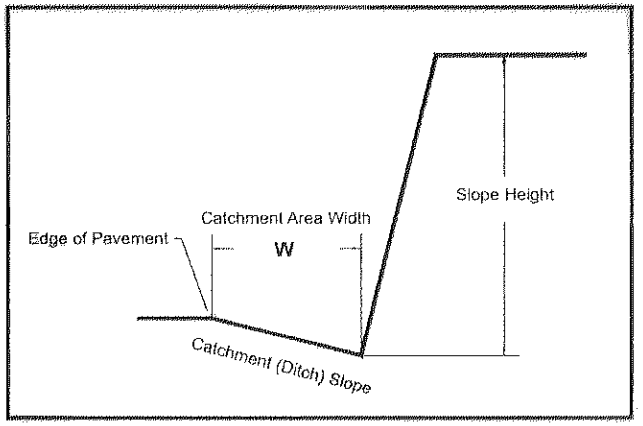
Ref: Ritchie, 1963

Christiansted Bypass
St Croix, Virgin Islands

Ritchie Ditch Typical Section

Figure 8





Quick Reference - 70-Ft Slope
Catchment Area Width - **W**

Percent Rockfall Retained	Impact	Catchment Area Slope		
		4H:1V	6H:1V	Flat
	W (ft)	W (ft)	W (ft)	W (ft)
50%	7	10	13	22
75%	9	14	17	32
80%	10	15	18	34
85%	11	16	20	37
90%	12	18	22	42
95%	14	21	25	52
99%	17	24	33	67

Ref: Figure 5.14 after Pierson, 2001

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St Croix, Virgin Islands

Catchment Area Design Chart
[For Slope Height of 70 feet]
Figure 9

Catchment Area Width vs Slope Height (for various % Rockfalls Retained)

[Ref: Pierson, 2001, for 0.5H:1V Cut Slope and 4H:1V Ditch Slope]

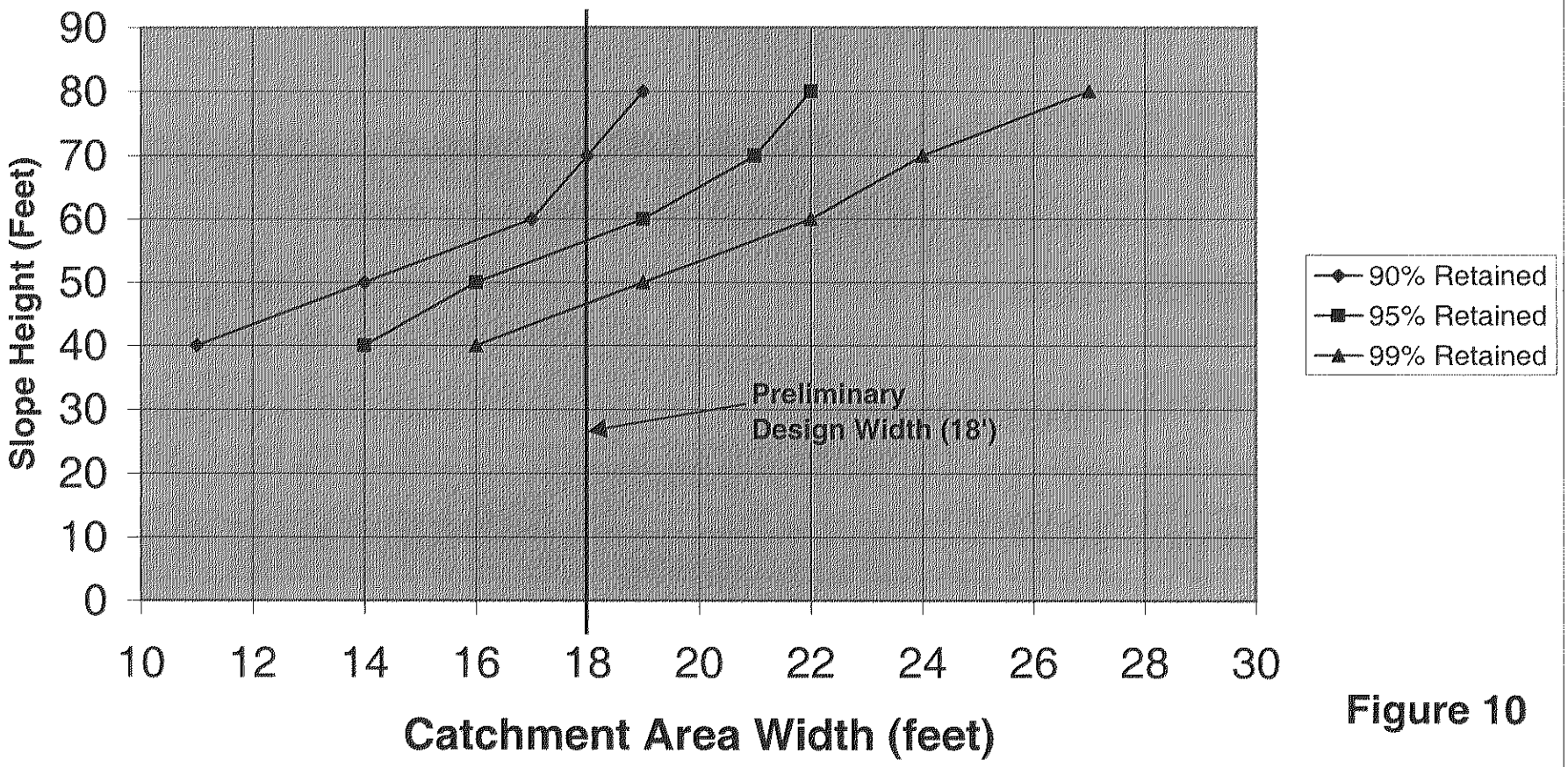


Figure 10

Appendix B

Summary of Laboratory Testing

(Figs B-1 to B-6) Core Recovery and RQD vs Boring Depth

Summary of Bedding Plane Orientations (per Whetten,___)

Hemisphere Plots of Bedding and Joint Planes for SMR and DIPS

SMR Computations and Ratings (per Romana,2003)

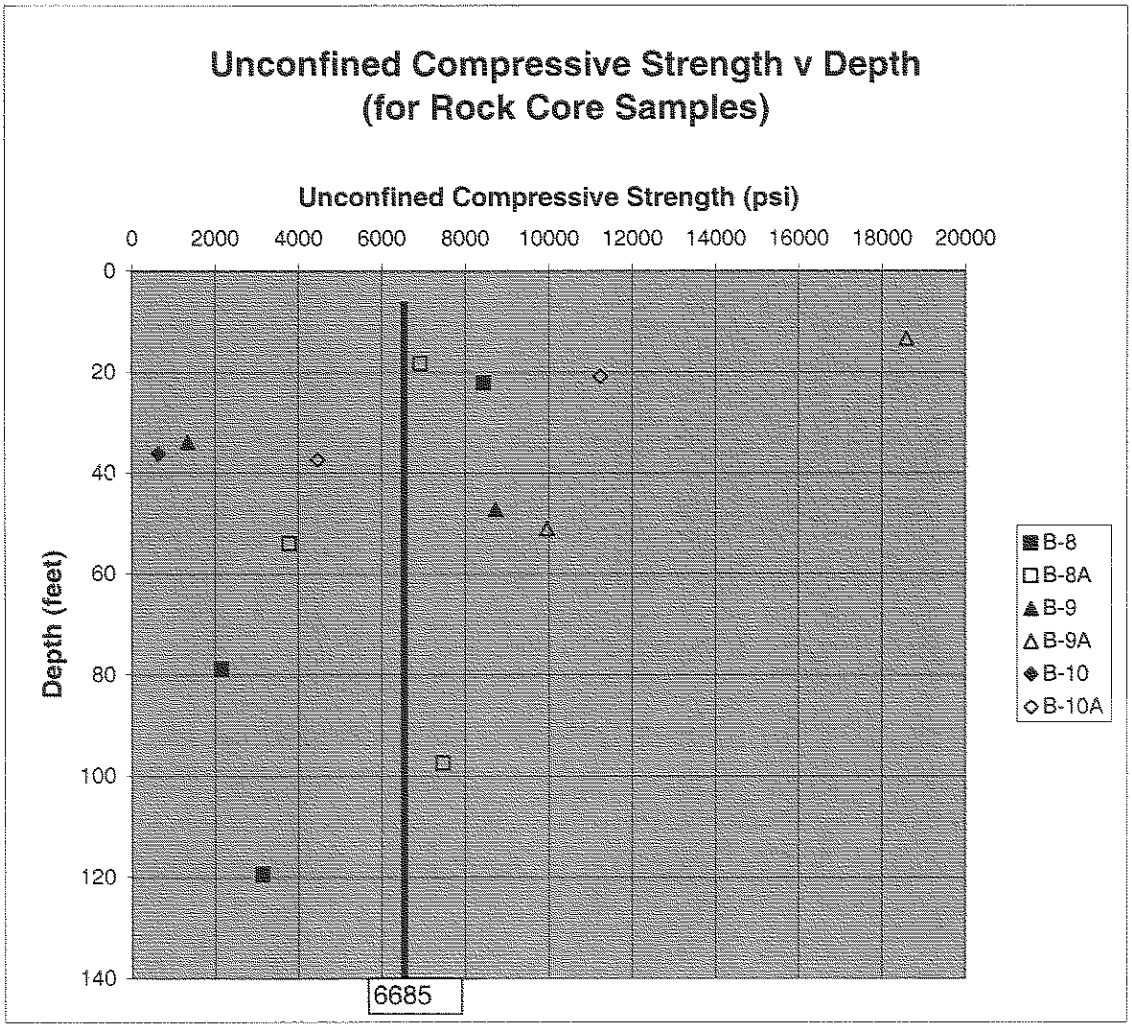
DIPS Analysis

Summary of Laboratory Testing

Christiansted Bypass
St Croix, Virgin Islands
Laboratory Test Results
Unconfined Compression Tests on Rock Core Samples

Boring	Depth (feet)	Depth[1] (feet)	Unc Comp Strength (psi)	Unc Comp Strength (MPa)
8	21.6-22.7	22.1	8449	58
8	78.5-79.0	78.8	2156	15
8	119.0-119.8	119.4	3143	22
8A	18.0-18.5	18.3	6930	48
8A	53.7-54.3	54.0	3787	26
8A	97.0-97.8	97.4	7476	52
9	33.5-34.0	33.8	1344	9
9	46.7-47.7	47.2	8737	60
9A	13.0-13.5	13.3	18587	128
9A	50.6-51.3	51.0	9957	69
10	35.7-36.4	36.1	626	4
10A	20.6-21.0	20.8	11243	78
10A	37.0-37.5	37.3	4467	31
		Average	6685	46
		STDEV	4939	34

Notes
1 Depth is to midpoint of sample



CARIBBEAN DRILLING SERVICES, INC.
P.O, Box 24319, Gallows Bay, St. Croix U.S. Virgin Islands

COMPRESSION TESTS OF RESULTS OF ROCK CORES

CLIENT: HDR ENGINEERING

Date of Report: August 27, 2004

Project: Road Cut – St. Croix

Required Strength (psi): N/A

Testing Specification: ASTM D 2938

Core Number	Length After Capping (inches)	Diameter (inches)	Area (sq.in.)	Breaking Load (lbs)	Unit Load (psi)	Location/Remarks
1	4.604	2.380	4.45	30,830	6,930	B-8A (18.0-18.5)
2	4.672	2.390	4.49	16,990	3,787	B-8A (53.7-54.3)
3	4.643	2.389	4.48	33,510	7,476	B-8A (97.0-97.8)
4	4.554	2.375	4.43	37,430	8,449	B-8 (21.6-22.7)
5	4.658	2.380	4.45	9,590	2,156	B-8 (78.5-79.0)
6	4.614	2.385	4.47	14,040	3,143	B-8 (119.0-119.8)
7	4.813	2.382	4.46	5,990	1,344	B-9 (33.5-34.0)
8	4.683	2.384	4.46	39,000	8,737	B-9 (46.7-47.7)
9	4.954	2.379	4.45	82,620	18,587	B-9A (13-13.5)
10	4.622	2.375	4.43	44,110	9,957	B-9A (50.6-51.3)
11	4.535	2.374	4.43	2,770	626	B-10 (35.7-36.4)
12	3.445	2.391	4.49	50,480	11,243	B-10A (20.6-21)
13	4.544	2.390	4.49	20,040	4,467	B-10A (37-37.5)

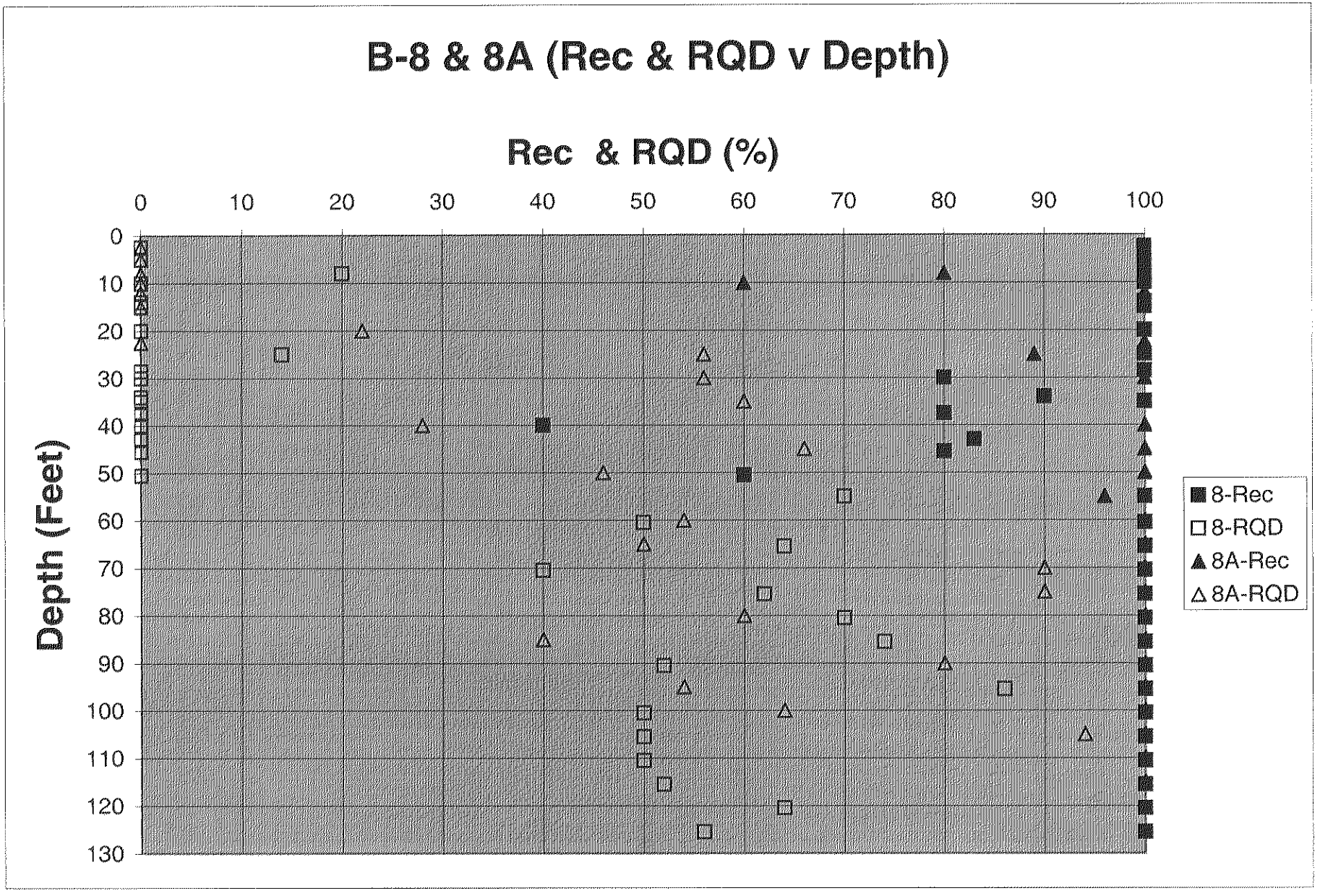
NOTES:
1. Rock cores secured and transported by CDS .
2. Date tested 08/27/04.

Checked by:
Carlos Sierra Del Llano , P.E.

Core Recovery and RQD Plots for Borings

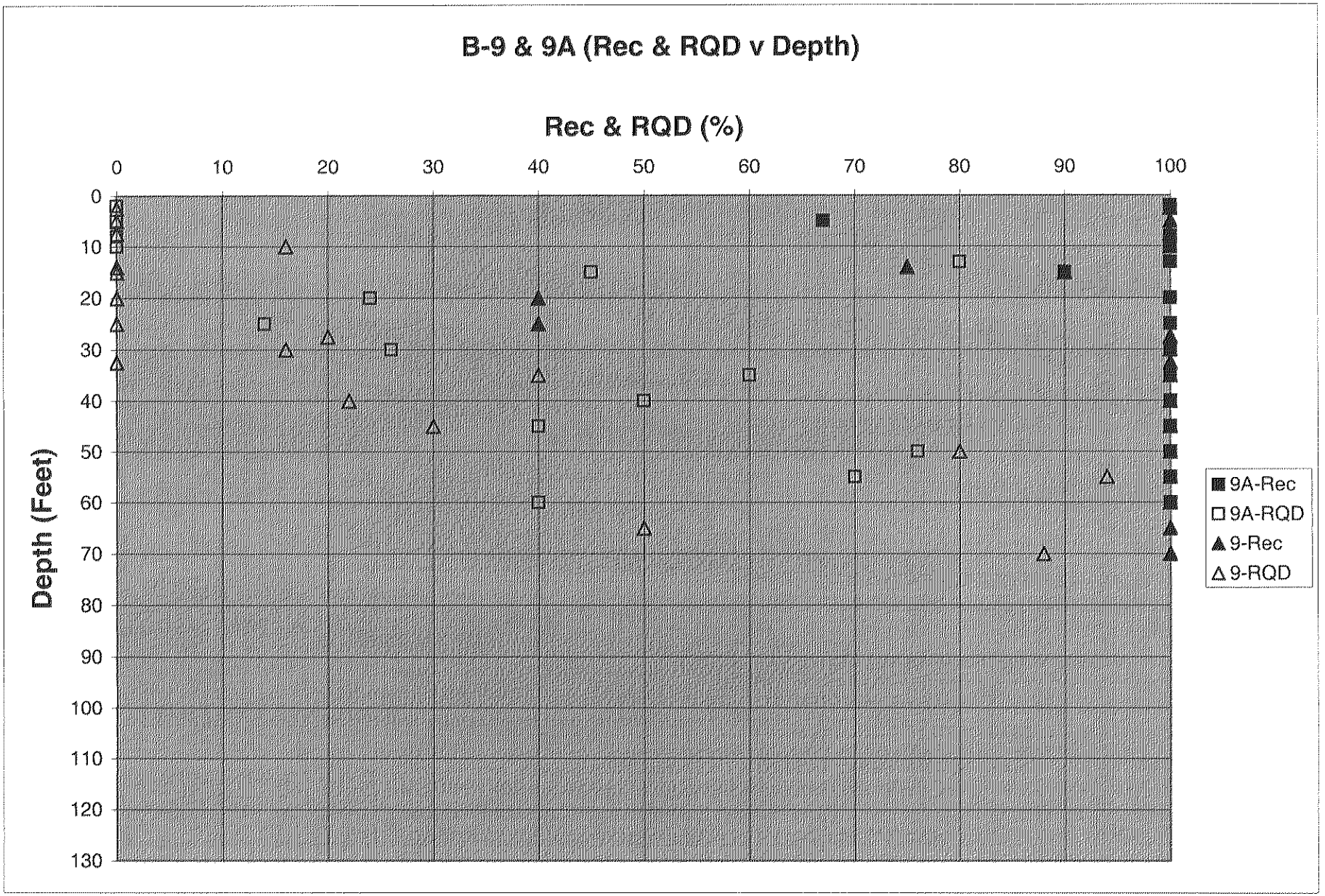
Christiansted Bypass
Core Recovery and RQD for B-8 and B-8A

Figure B-1



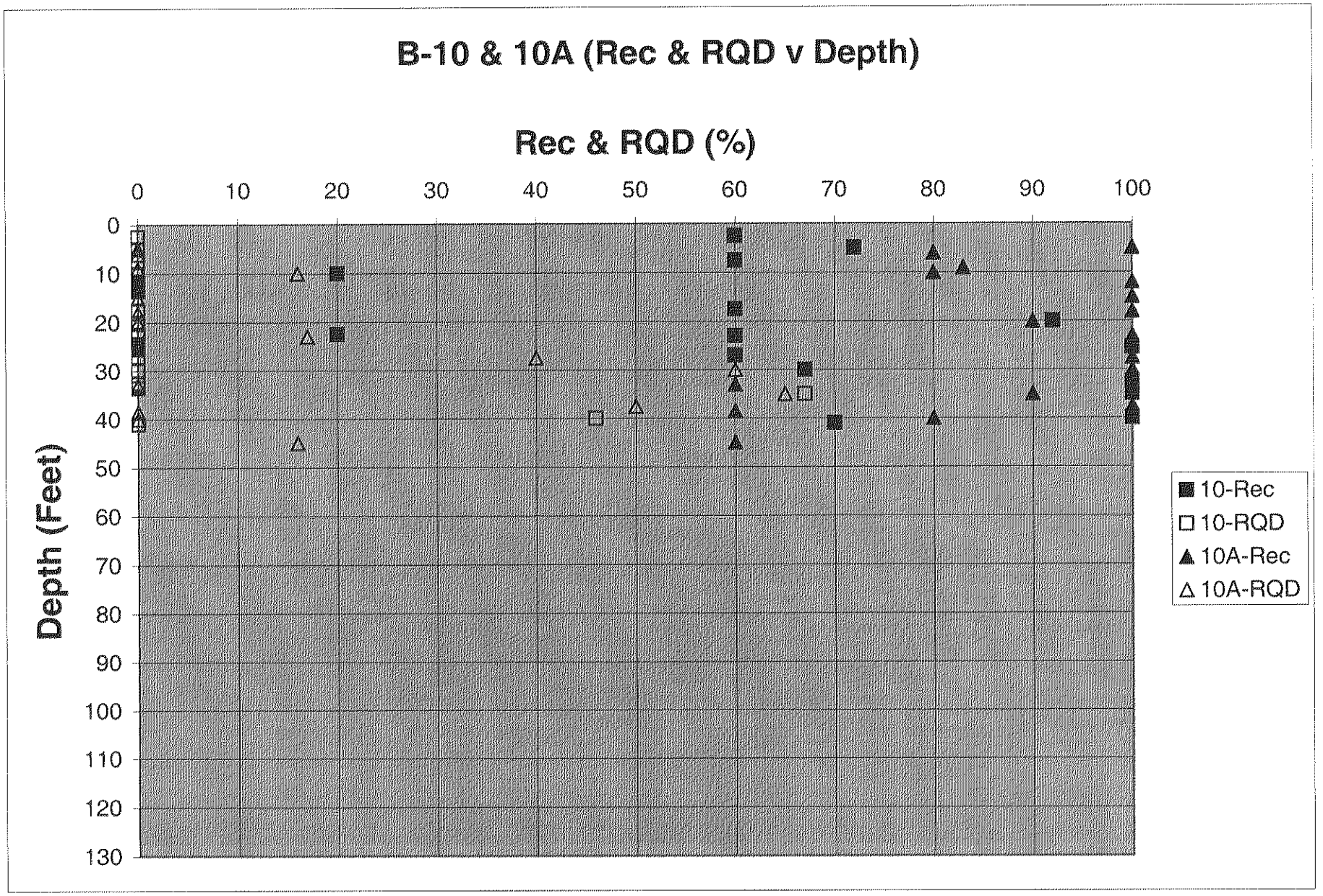
Christiansted Bypass
Core recovery and RQD for Borings B-9 and B-9A

Figure B-2



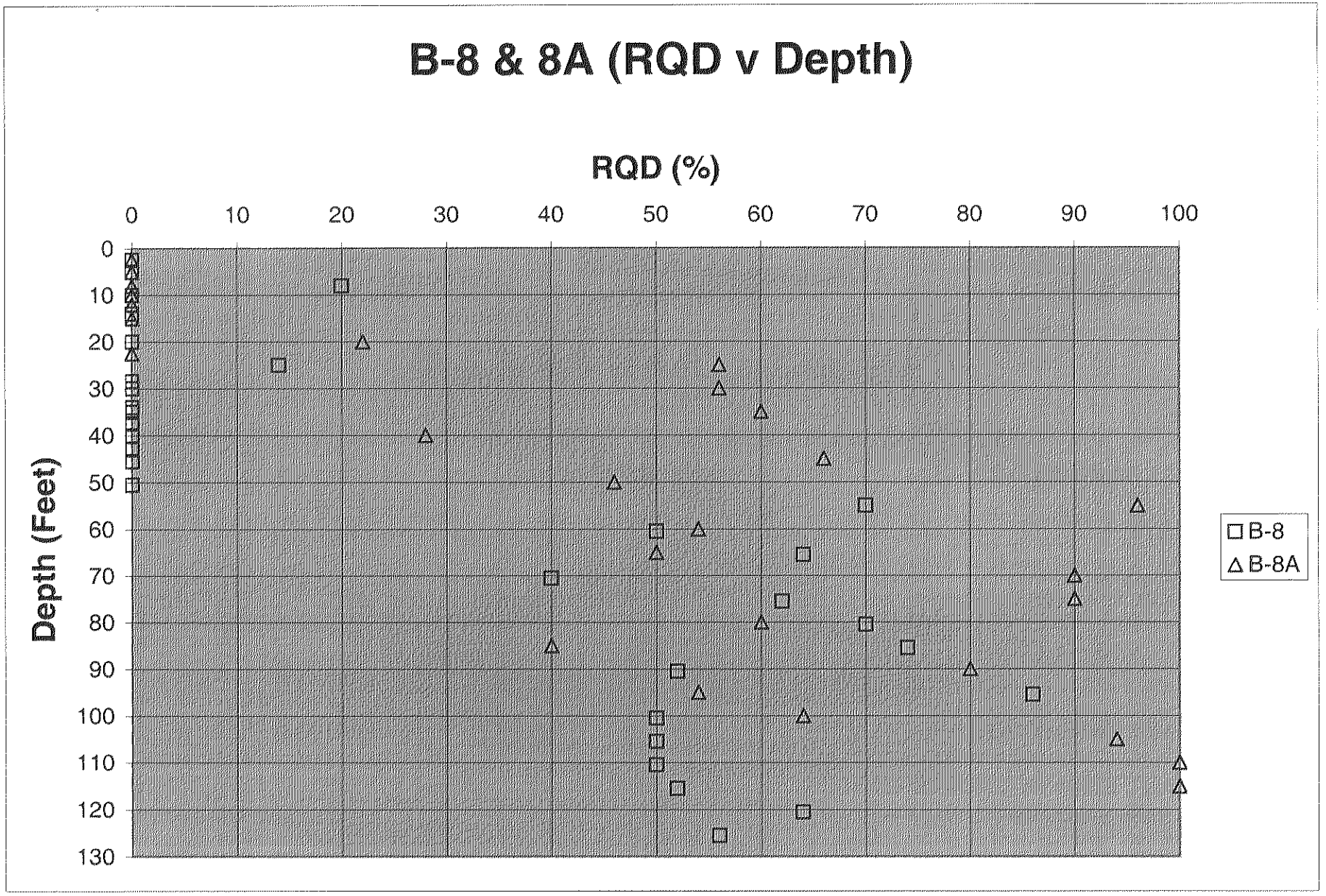
Christiansted Bypass
Core Recovery and RQD for B-10 and B-10A

Figure B-3



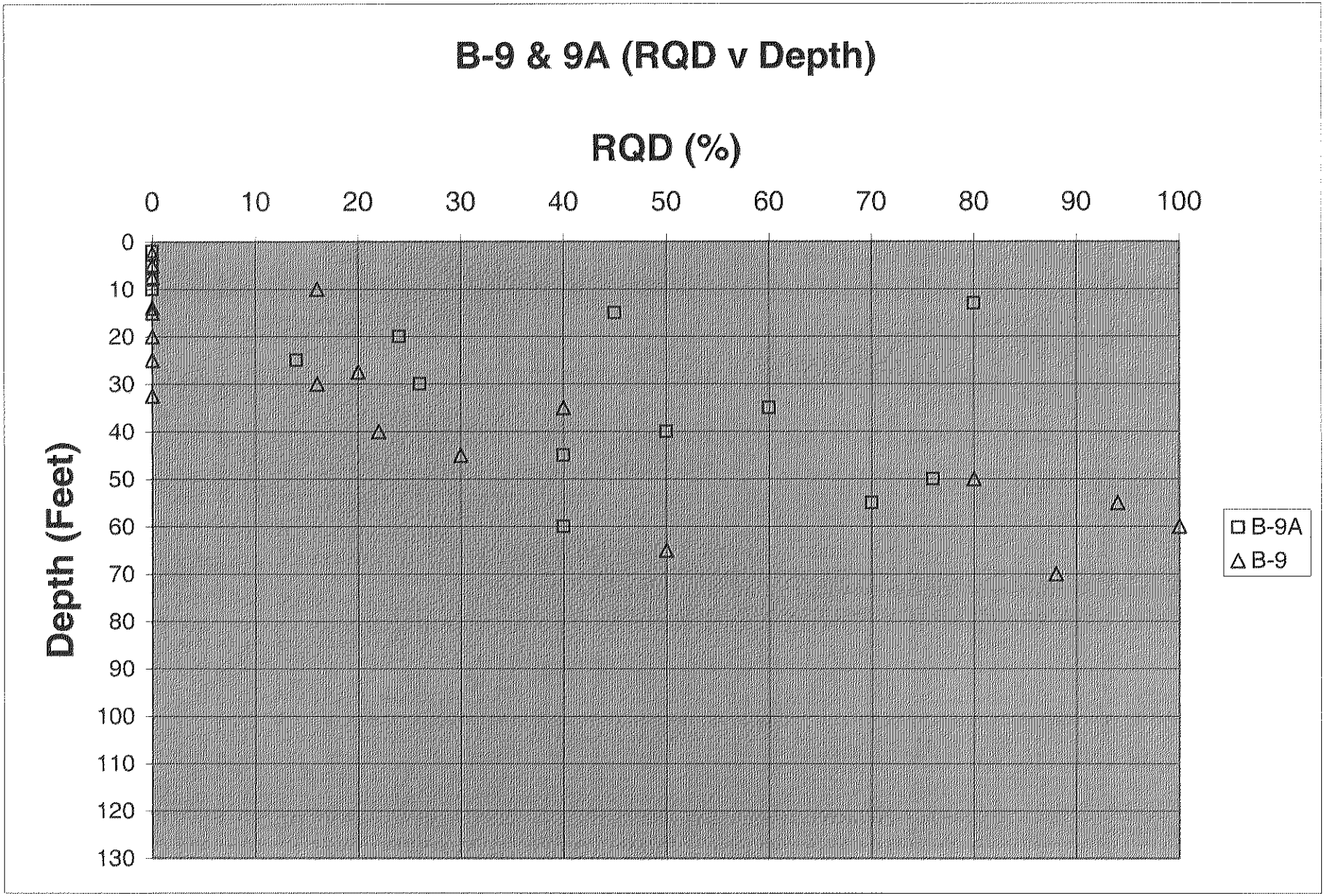
Christiansted Bypass
RQD for Core in B-8 and B-8A

Figure B-4



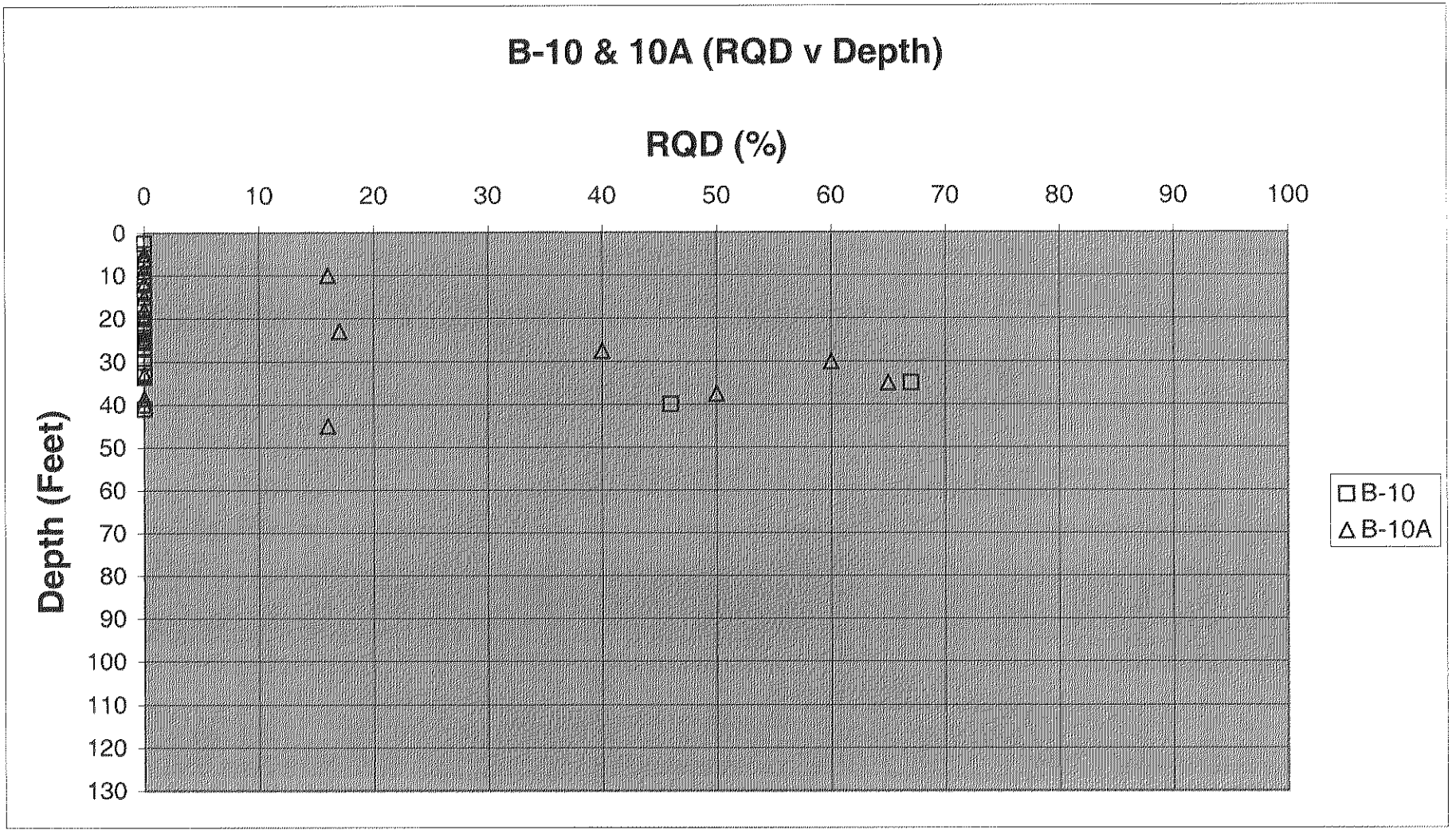
Christiansted Bypass
RQD for Core in B-9 and B-9A

Figure B-5



Christiansted Bypass
RQD for Core in B-10 and B-10A

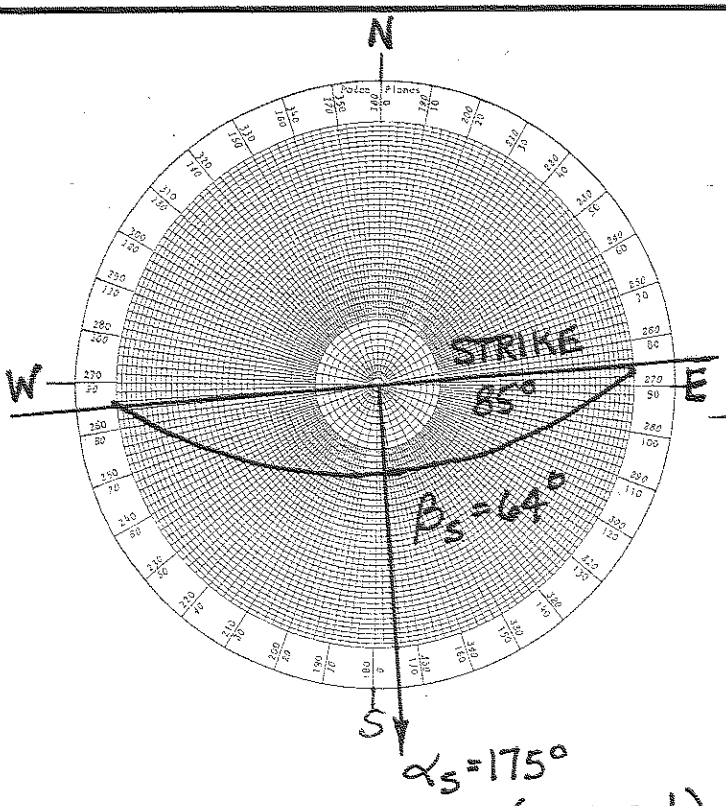
Figure B-6



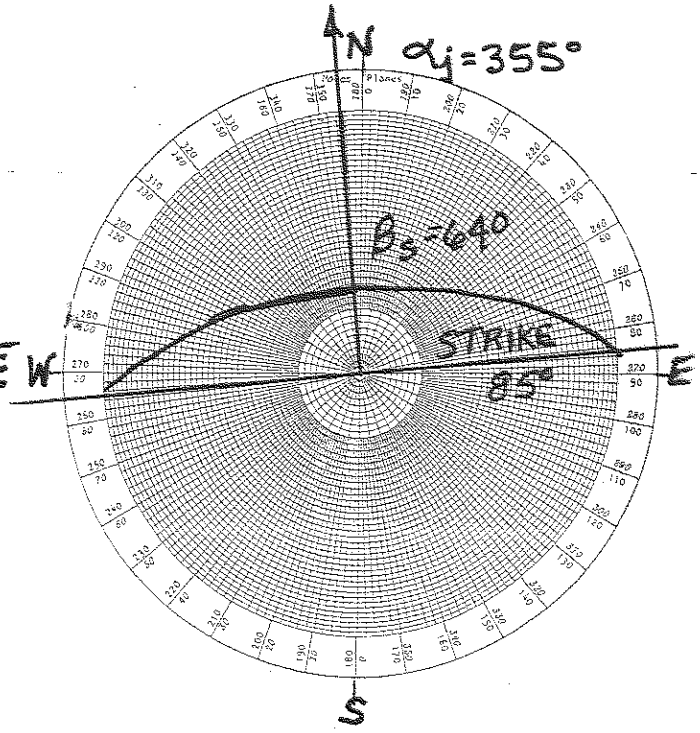
Summary of Bedding Plane Measurements in Vicinity of Project
(Reference: Measured on Figure 5b)

Measurement No	Strike (Azimuth)	Dip
1	112°	35°SW
2	123°	45°SW
3	123°	35°SW
4	117°	45°SW
5	123°	21°SW
6	135°	28°SW
7	116°	28°SW
8	153°	35°SW

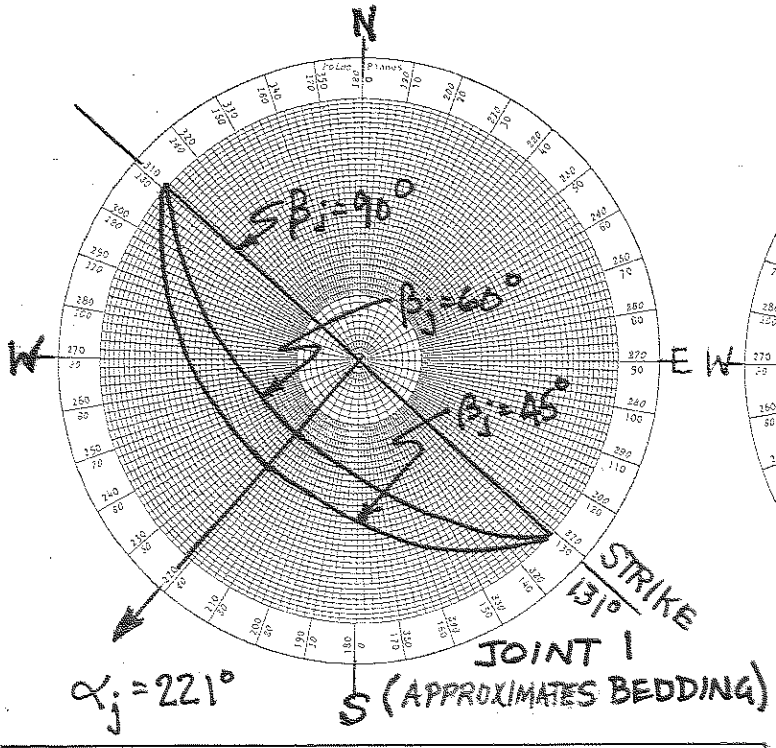
Joint (Discontinuity) Planes for SMR and DIPS Analyses



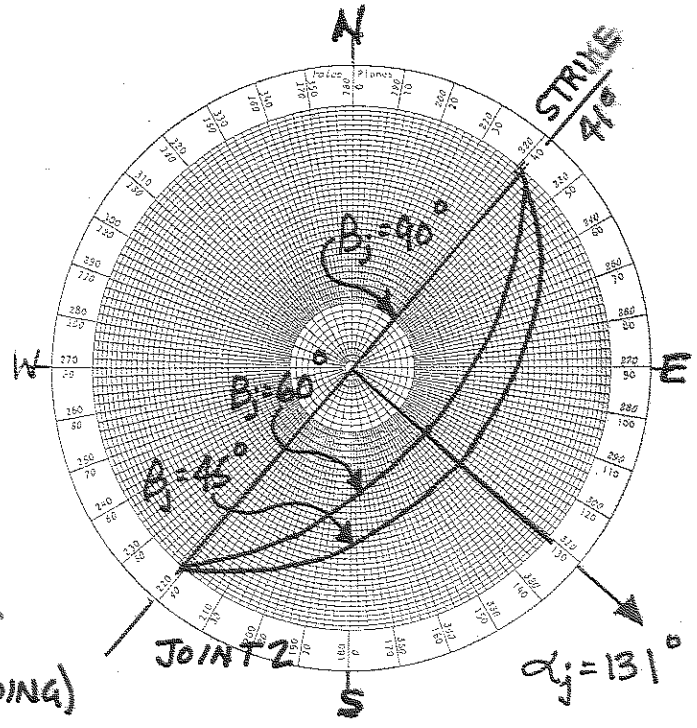
NORTH CUT FACE (LEFT OF ℄)



SOUTH CUT FACE (RIGHT OF ℄)



JOINT 1 (APPROXIMATES BEDDING)



JOINT 2

Notes:
For analyses spreadsheets:
$A_s = \alpha_s$ = Dip Direction of Cut Face
$A_j = \alpha_j$ = Dip Direction of Discontinuity (Joint)
$B_s = \beta_s$ = Dip of Cut Face
$B_i = \beta_i$ = Dip of Discontinuity (Joint)

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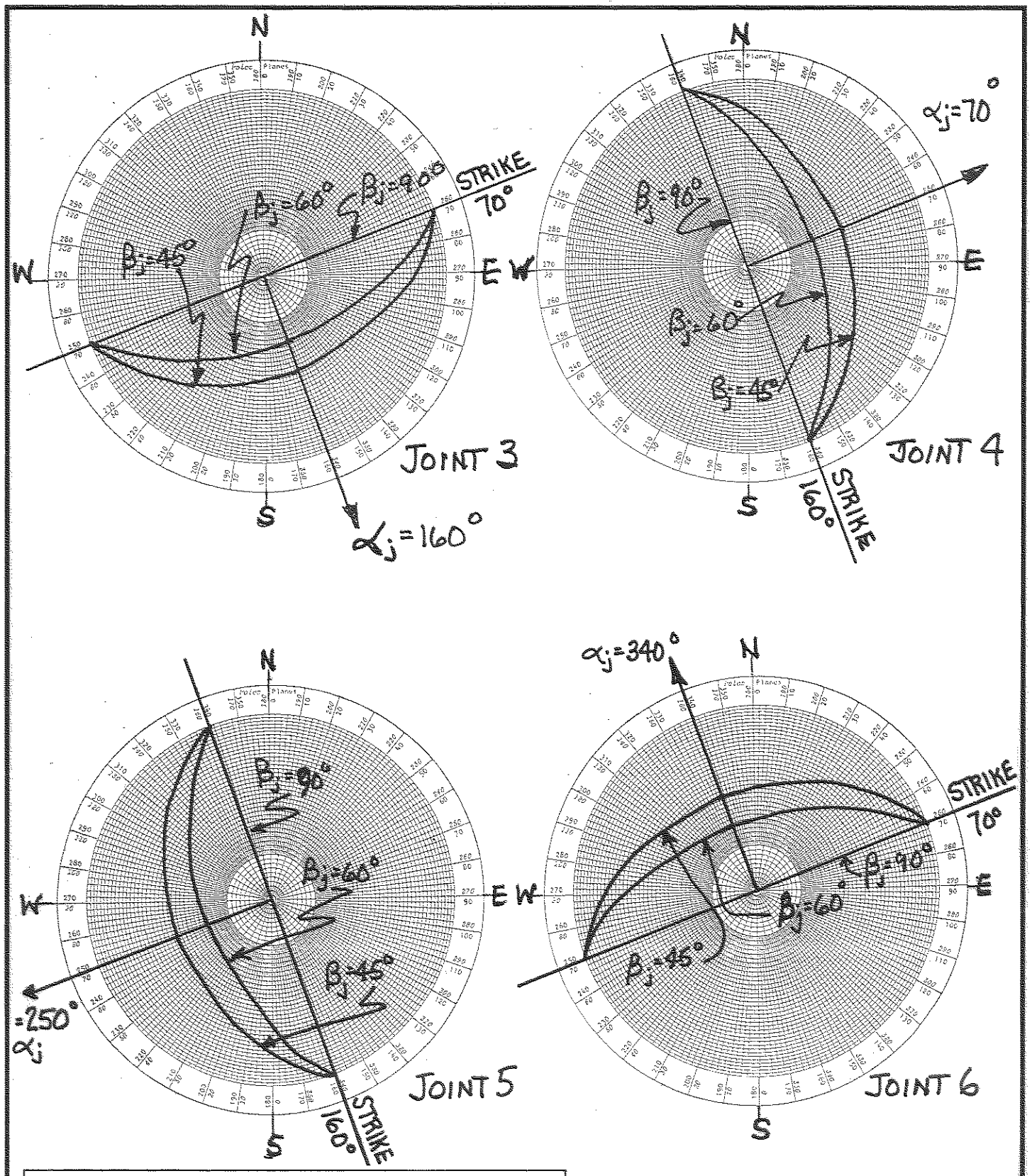
Lower Hemisphere Steronet Plots
Discontinuity Planes For
SMR and DIPS Analyses 1/2



Notes:
For analyses spreadsheets:
$A_s = \alpha_s$ = Dip Direction of Cut Face
$A_j = \alpha_j$ = Dip Direction of Discontinuity (Joint)
$B_s = \beta_s$ = Dip of Cut Face
$B_i = \beta_i$ = Dip of Discontinuity (Joint)

Christiansted Bypass
St Croix, Virgin Islands

Lower Hemisphere Steronet Plots
Discontinuity Planes For
SMR and DIPS Analyses

2/2

SMR Computations

Discontinuity Conditions
(From Boring Core Data)

Boring	Depth	Dip Angle	Discontinuity Length (L)	Separation (S)	Roughness (R)	Infilling (I)	Weathering (W)	
B-10	33.5-40.0	20°-90°	2	6 to 5	4	6 to 4	6 to 5	
B-10 A	2.7-10.0	0°-90°	2	1 to 0	4	0	2 to 1	
	10.0-15.0	0°-90°	2	1 to 0	4	0	4 to 3	
	14.0-16.5	90°	2	0	1	0	1	
	25.0-27.5	30°-70°	2	4	2	4 (calcite)	4	
	33.0-35.0	0°-70°	2	6 to 5	3	4 (calcite)	6 to 5	
	34.5	20°	2	5 to 4	0	6	5	
B-9	0.0-20.0	0°-90°	2	4 to 1	3	6, 2	3	
	40.0-42.0	0°-90°	2	4 to 1	3	6	5 to 3	
	43.5-50.0	0°-90°	2	5	5 to 3	6	5 to 3	
	63.5-65.0	0°-90°	2	4	5 to 4	6	6 to 5	
B-9A	0.5-10.0	0°-90°	2	5	5 to 3	6	4 to 3	
	15.0-21.0	0°-90°	2	5 to 4	3	6	5	
	21.0-30.0	0°-90°	2	5 to 4	5	6	5 to 3	
	30.0-40.0	0°-90°	2	5	4	6	5 to 4	
	44.0-45.0	0°-90°	2	6 to 5	3	6	5 to 4	
	45.0-50.0	45°-75°	2	5	4	6	5	
	55.0-60.0	40°-80°	2	6 to 5	3	6	5 to 4	
B-8	0.5-5.0	0°-90°	2	1	5 to 3	2	3	
	5.0-14.0	0°-90°	2	5 to 4	5	6	3 to 1	Upper Rock Zone
	25.0-34.0	0°-90°	2	0	5 to 3	6	5 to 3	
	35.0-37.5	0°-90°	2	1 to 0	4 to 3	6	5 to 4	
	37.5-50.5	0°-90°	2	0	4	6	5 to 1	
	55.5-60.5	0°-90°	2	6 to 5	5 to 4	6	5	
	65.5-70.5	0°-90°	2	6 to 5	4	6	5	
	70.5-72.0	60°-90°	2	5 to 1	3	6	5	
	75.0	60°	2	4	3	6	5	
	83.0	70°	2	6 to 5	5	4 (calcite)	6	Lower Rock Zone
	85.0	50°-70°	2	6 to 5	5	4 (calcite)	6	
	88.5	20°-40°	2	1 to 0	3	6	5 to 4	
	88.8-90.0	70°-90°	2	6 to 5	5	6	6	
	94	60°	2	5 to 4	3	4 (calcite)	5	
	95.5-100.5	0°-90°	2	5 to 4	3	6 to 4 (calcite)	6 to 5	
	104.5-105.5	0°-90°	2	6 to 5	4	6	6 to 5	
	108.0-110.0	0°-90°	2	6 to 5	4	6	6 to 5	
	110.5-115.5	0°-90°	2	6 to 5	4	6	6 to 5	
B-8A	0.5-10.0	0°-90°	2	2 to 1	4 to 3	6 to 4	2	
	15.0-20.0	0°-90°	2	5 to 4	3	6 to 4	5 to 3	
	20.0-22.5	0°-90°	2	5 to 4	4	6 to 4	5 to 4	
	22.5-30.0	0°-90°	2	6 to 5	3	6 to 4	5	
	30.0-35.0	30°-70°	2	6 to 5	3	6 to 4	5	
	35.0-38.0	20°-50°	2	6 to 5	3	6 to 5	5	
	38.0-40.0	40°-80°	2	4	5 to 4	6 to 4	5 to 4	
	40.0-43.0	20°-45°	2	6	3	6	5	
	45.0-47.5	80°-90°	2	5	3	6	5	
	56.5-60.0	0°-90°	2	6 to 5	3	6	5 to 4	
	63.5	65°	2	5	4	6	5 to 4	
	75.0-76.5	30°-75°	2	4	4	6	5	
	77.5-78.0	30°-75°	2	4	4	6	5	
	80.0-85.0	30°-70°	2	6 to 5	3	6	6 to 5	
	87.0-88.0	0°-90°	2	4	3 to 2	6, 2	4	
	90.0-95.0	40°-60°	2	6 to 4	3 to 2	6, 4	5	
	96.0-100.0	40°-60°	2	5	3	4 (calcite)	6 to 5	

FROM BIENIAWSKI, 1989

CHART E Guidelines for Classification of Discontinuity Conditions[a]

Parameter	Ratings				
Discontinuity length (persistence/continuity)	<1 m 6	1–3 m 4	3–10 m 2	10–20 m 1	>20 m 0
Separation (aperture)	None 6	<0.1 mm 5	0.1–1.0 mm 4	1–5 mm 1	>5 mm 0
Roughness	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge)	Hard filling			Soft filling	
	None 6	<5 mm 4	>5 mm 2	<5 mm 2	>5 mm 0
Weathering	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

[a] *Note:* Some conditions are mutually exclusive. For example, if infilling is present, it is irrelevant what the roughness may be, since its effect will be overshadowed by the influence of the gouge. In such cases, use Table 4.1 directly.

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

As = 175
Aj = 221
Bj = 45

Analysis 1a

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-60	-9	10	1	53	0.15	1.0	0	0	10	10	62
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-60	-9	10	1	59	0.15	1.0	0	0	10	10	68
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-60	-9	10	1	54	0.15	1.0	0	0	10	10	63
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-60	-9	10	1	63	0.15	1.0	0	0	10	10	72
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-60	-9	10	1	66	0.15	1.0	0	0	10	10	75
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-60	-9	10	1	52	0.15	1.0	0	0	10	10	61
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
															Avg Lower Zone		59					Avg Lower Zone		68
															Avg Upper Zone		30					Avg Upper Zone		39

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	221

[Aj-As]	46
[Aj-As-180]	134

Bs	Beta Slope 64
Bj	Beta Joint (Discontinuity) 45

Bj-Bs	-19
Bj+Bs	109

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-60	0

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 175
Aj = 221
Bj = 60

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

Analysis 1b

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-50	-7.5	10	2.5	55	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-50	-7.5	10	2.5	61	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-50	-7.5	10	2.5	56	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-50	-7.5	10	2.5	65	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-50	-7.5	10	2.5	68	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-50	-7.5	10	2.5	54	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		60					Avg Lower Zone		64
															Avg Upper Zone		32					Avg Upper Zone		35

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	221

[Aj-As]	46
[Aj-As-180]	134

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	60

Bj-Bs	-4
Bj+Bs	124

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-50	-25

Notes and Legend

SMR = RMR_B*(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 175
Aj = 221
Bj = 90

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Slope Face

Analysis 1c

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	0	0	10	10	62	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	0	0	10	10	68	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	0	0	10	10	63	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	0	0	10	10	72	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	0	0	10	10	75	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	0	0	10	10	61	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		68					Avg Lower Zone		64
															Avg Upper Zone		39					Avg Upper Zone		35

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	221

[Aj-As]	46
[Aj-As-180]	134

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	90

Bj-Bs	26
Bj+Bs	154

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	0	-25

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 175
Aj = 131
Bj = 45

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

Analysis 2a

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)$ $+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)$ $+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-60	-9	10	1	53	0.15	1.0	0	0	10	10	62
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-60	-9	10	1	59	0.15	1.0	0	0	10	10	68
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-60	-9	10	1	54	0.15	1.0	0	0	10	10	63
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-60	-9	10	1	63	0.15	1.0	0	0	10	10	72
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-60	-9	10	1	66	0.15	1.0	0	0	10	10	75
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-60	-9	10	1	52	0.15	1.0	0	0	10	10	61
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
															Avg Lower Zone		59					Avg Lower Zone		68
															Avg Upper Zone		30					Avg Upper Zone		39

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	131

[Aj-As]	44
[Aj-As-180]	224

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	45

Bj-Bs	-19
Bj+Bs	109

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-60	0

Notes and Legend

SMR = RMR_B*(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 175
Aj = 131
Bj = 60

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

Analysis 2b

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-50	-7.5	10	2.5	55	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-50	-7.5	10	2.5	61	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-50	-7.5	10	2.5	56	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-50	-7.5	10	2.5	65	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-50	-7.5	10	2.5	68	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-50	-7.5	10	2.5	54	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		60					Avg Lower Zone		64
															Avg Upper Zone		32					Avg Upper Zone		35

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	131

[Aj-As]	44
[Aj-As-180]	224

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	60

Bj-Bs	-4
Bj+Bs	124

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-50	-25

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 175
Aj = 131
Bj = 90

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

Analysis 2c

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	0	0	10	10	62	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	0	0	10	10	68	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	0	0	10	10	63	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	0	0	10	10	72	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	0	0	10	10	75	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	0	0	10	10	61	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		68					Avg Lower Zone		64
															Avg Upper Zone		39					Avg Upper Zone		35

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	131

[Aj-As]	44
[Aj-As-180]	224

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	90

Bj-Bs	26
Bj+Bs	154

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	0	-25

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 175
Aj = 70
Bj = 45

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

Analysis 3a

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-60	-9	10	1	53	0.15	1.0	0	0	10	10	62
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-60	-9	10	1	59	0.15	1.0	0	0	10	10	68
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-60	-9	10	1	54	0.15	1.0	0	0	10	10	63
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-60	-9	10	1	63	0.15	1.0	0	0	10	10	72
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-60	-9	10	1	66	0.15	1.0	0	0	10	10	75
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-60	-9	10	1	52	0.15	1.0	0	0	10	10	61
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
															Avg Lower Zone		59					Avg Lower Zone		68
															Avg Upper Zone		30					Avg Upper Zone		39

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	70

[Aj-As]	105
[Aj-As-180]	285

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	45

Bj-Bs	-19
Bj+Bs	109

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-60.0	0.0

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

As = 175
Aj = 70
Bj = 60

Analysis 3b

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-50	-7.5	10	2.5	55	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-50	-7.5	10	2.5	61	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-50	-7.5	10	2.5	56	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-50	-7.5	10	2.5	65	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-50	-7.5	10	2.5	68	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-50	-7.5	10	2.5	54	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		60					Avg Lower Zone		64
															Avg Upper Zone		32					Avg Upper Zone		35

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	70

[Aj-As]	105
[Aj-As-180]	285

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	60

Bj-Bs	-4
Bj+Bs	124

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-50	-25

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

Notes and Legend

SMR = RMR_B*(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

As = 175
Aj = 70
Bj = 90

Analysis 3c

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
5.0		5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	0	0	10	10	62	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	0	0	10	10	68	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	0	0	10	10	63	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	0	0	10	10	72	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	0	0	10	10	75	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	0	0	10	10	61	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		68					Avg Lower Zone		64
															Avg Upper Zone		39					Avg Upper Zone		35

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	70

(Aj-As)	105
(Aj-As-180)	285

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	90

Bj-Bs	26
Bj+Bs	154

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	0	-25

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

Notes and Legend

SMR = RMR_B*(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 175
Aj = 160
Bj = 45

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

Analysis 4a

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.7	1.0	-60	-42	0	-42	-7	0.15	1.0	0	0	0	0	35
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.7	1.0	-60	-42	0	-42	-7	0.15	1.0	0	0	0	0	35
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.7	1.0	-60	-42	0	-42	0	0.15	1.0	0	0	0	0	42
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-60	-42	0	-42	0	0.15	1.0	0	0	0	0	42
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-60	-42	0	-42	0	0.15	1.0	0	0	0	0	42
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-60	-42	0	-42	0	0.15	1.0	0	0	0	0	42
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-60	-42	0	-42	0	0.15	1.0	0	0	0	0	42
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.7	1.0	-60	-42	0	-42	-3	0.15	1.0	0	0	0	0	39
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-60	-42	0	-42	-3	0.15	1.0	0	0	0	0	39
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-60	-42	0	-42	-3	0.15	1.0	0	0	0	0	39
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-60	-42	0	-42	-3	0.15	1.0	0	0	0	0	39
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	-60	-42	10	-32	23	0.15	1.0	0	0	10	10	65
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.7	1.0	-60	-42	10	-32	20	0.15	1.0	0	0	10	10	62
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.7	1.0	-60	-42	10	-32	26	0.15	1.0	0	0	10	10	68
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.7	1.0	-60	-42	10	-32	21	0.15	1.0	0	0	10	10	63
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.7	1.0	-60	-42	10	-32	30	0.15	1.0	0	0	10	10	72
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.7	1.0	-60	-42	10	-32	33	0.15	1.0	0	0	10	10	75
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.7	1.0	-60	-42	10	-32	19	0.15	1.0	0	0	10	10	61
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.7	1.0	-60	-42	10	-32	23	0.15	1.0	0	0	10	10	65
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	-60	-42	10	-32	23	0.15	1.0	0	0	10	10	65
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
															Avg Lower Zone		26					Avg Lower Zone		68
															Avg Upper Zone		-3					Avg Upper Zone		39

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	160

[Aj-As]	15
[Aj-As-180]	195

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	45

Bj-Bs	-19
Bj+Bs	109

	Planer	Toppling
F1	0.7	0.15
F2	1.0	1.0
F3	-60	0

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

Notes and Legend

SMR = RMR_B*(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

As = 175
Aj = 160
Bj = 60

Analysis 4b

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.7	1.0	-50	-35	0	-35	0	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.7	1.0	-50	-35	0	-35	0	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.7	1.0	-50	-35	0	-35	7	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-50	-35	0	-35	7	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-50	-35	0	-35	7	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-50	-35	0	-35	7	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-50	-35	0	-35	7	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.7	1.0	-50	-35	0	-35	4	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-50	-35	0	-35	4	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-50	-35	0	-35	4	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-50	-35	0	-35	4	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	-50	-35	10	-25	30	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.7	1.0	-50	-35	10	-25	27	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.7	1.0	-50	-35	10	-25	33	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.7	1.0	-50	-35	10	-25	28	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.7	1.0	-50	-35	10	-25	37	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.7	1.0	-50	-35	10	-25	40	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.7	1.0	-50	-35	10	-25	26	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.7	1.0	-50	-35	10	-25	30	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	-50	-35	10	-25	30	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		33					Avg Lower Zone		64
															Avg Upper Zone		4					Avg Upper Zone		35

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	160

[Aj-As]	15
[Aj-As-180]	195

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	60

Bj-Bs	-4
Bj+Bs	124

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.7	0.15
F2	1.0	1.0
F3	-50	-25

Notes and Legend

SMR = RMR_{Bf}(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
North Cut Face

As = 175
Aj = 160
Bs = 90

Analysis 4c

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.7	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.7	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.7	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.7	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.7	1.0	0	0	10	10	62	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.7	1.0	0	0	10	10	68	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.7	1.0	0	0	10	10	63	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.7	1.0	0	0	10	10	72	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.7	1.0	0	0	10	10	75	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.7	1.0	0	0	10	10	61	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.7	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		68					Avg Lower Zone		64
															Avg Upper Zone		39					Avg Upper Zone		35

		Degrees
As	Alpha Slope	175
Aj	Alpha Joint (Discontinuity)	160

[Aj-As]	15
[Aj-As-180]	195

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	90

Bj-Bs	26
Bj+Bs	154

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.7	0.15
F2	1.0	1.0
F3	0	-25

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 355
Aj = 221
Bj = 45

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

Analysis 5a

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-60	-9	10	1	53	0.15	1.0	0	0	10	10	62
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-60	-9	10	1	59	0.15	1.0	0	0	10	10	68
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-60	-9	10	1	54	0.15	1.0	0	0	10	10	63
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-60	-9	10	1	63	0.15	1.0	0	0	10	10	72
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-60	-9	10	1	66	0.15	1.0	0	0	10	10	75
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-60	-9	10	1	52	0.15	1.0	0	0	10	10	61
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
															Avg Lower Zone		59					Avg Lower Zone		68
															Avg Upper Zone		30					Avg Upper Zone		39

		Degrees		
As	Alpha Slope	355	[Aj-As]	134
Aj	Alpha Joint (Discontinuity)	221	[Aj-As-180]	314

Bs	Beta Slope	64	Bj-Bs	-19
Bj	Beta Joint (Discontinuity)	45	Bj+Bs	109

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-60	0

Notes and Legend

SMR = RMR_B*(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 355
Aj = 221
Bj = 60

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

Analysis 5b

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-50	-7.5	10	2.5	55	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-50	-7.5	10	2.5	61	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-50	-7.5	10	2.5	56	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-50	-7.5	10	2.5	65	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-50	-7.5	10	2.5	68	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-50	-7.5	10	2.5	54	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		60					Avg Lower Zone		64
															Avg Upper Zone		32					Avg Upper Zone		35

		Degrees		
As	Alpha Slope	355	[Aj-As]	134
Aj	Alpha Joint (Discontinuity)	221	{Aj-As-180}	314

Bs	Beta Slope	64	Bj-Bs	-4
Bj	Beta Joint (Discontinuity)	60	Bj+Bs	124

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-50	-25

Notes and Legend

SMR = RMR_B*(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (infilling) + W (Weathering) per Bieniawski, 1989

As = 355
Aj = 221
Bj = 90

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Slope Face

Analysis 5c

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)$ $+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)$ $+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	0	0	10	10	62	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	0	0	10	10	68	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	0	0	10	10	63	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	0	0	10	10	72	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	0	0	10	10	75	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	0	0	10	10	61	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		68					Avg Lower Zone		64
															Avg Upper Zone		39					Avg Upper Zone		35

		Degrees		
As	Alpha Slope	355	[Aj-As]	134
Aj	Alpha Joint (Discontinuity)	221	[Aj-As-180]	314

Bs	Beta Slope	64	Bj-Bs	26
Bj	Beta Joint (Discontinuity)	90	Bj+Bs	154

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	0	-25

Notes and Legend

SMR = RMR_B/(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 355
Aj = 131
Bj = 45

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

Analysis 6a

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)$ $+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)$ $+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-60	-9	10	1	53	0.15	1.0	0	0	10	10	62
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-60	-9	10	1	59	0.15	1.0	0	0	10	10	68
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-60	-9	10	1	54	0.15	1.0	0	0	10	10	63
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-60	-9	10	1	63	0.15	1.0	0	0	10	10	72
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-60	-9	10	1	66	0.15	1.0	0	0	10	10	75
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-60	-9	10	1	52	0.15	1.0	0	0	10	10	61
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
															Avg Lower Zone		59					Avg Lower Zone		68
															Avg Upper Zone		30					Avg Upper Zone		39

		Degrees
As	Alpha Slope	355
Aj	Alpha Joint (Discontinuity)	131

[Aj-As]	224
[Aj-As-180]	404

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	45

Bj-Bs	-19
Bj+Bs	109

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-60	0

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 355
Aj = 131
Bj = 60

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

Analysis 6b

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-50	-7.5	10	2.5	55	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-50	-7.5	10	2.5	61	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-50	-7.5	10	2.5	56	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-50	-7.5	10	2.5	65	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-50	-7.5	10	2.5	68	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-50	-7.5	10	2.5	54	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		60					Avg Lower Zone		64
															Avg Upper Zone		32					Avg Upper Zone		35

			Degrees
As	Alpha Slope		355
Aj	Alpha Joint (Discontinuity)		131

[Aj-As]	224
[Aj-As-180]	404

Bs	Beta Slope		64
Bj	Beta Joint (Discontinuity)		60

Bj-Bs	-4
Bj+Bs	124

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-50	-25

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 355
Aj = 131
Bj = 90

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

Analysis 6c

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	0	0	10	10	62	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	0	0	10	10	68	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	0	0	10	10	63	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	0	0	10	10	72	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	0	0	10	10	75	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	0	0	10	10	61	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		68					Avg Lower Zone		64
															Avg Upper Zone		39					Avg Upper Zone		35

		Degrees
As	Alpha Slope	355
Aj	Alpha Joint (Discontinuity)	131

[Aj-As]	224
[Aj-As-180]	404

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	90

Bj-Bs	26
Bj+Bs	154

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	0	-25

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

As = 355
Aj = 250
Bj = 45

Analysis 7a

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-60	-9	0	-9	26	0.15	1.0	0	0	0	0	35
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-60	-9	0	-9	33	0.15	1.0	0	0	0	0	42
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-60	-9	0	-9	30	0.15	1.0	0	0	0	0	39
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-60	-9	0	-9	29	0.15	1.0	0	0	0	0	38
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-60	-9	10	1	53	0.15	1.0	0	0	10	10	62
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-60	-9	10	1	59	0.15	1.0	0	0	10	10	68
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-60	-9	10	1	54	0.15	1.0	0	0	10	10	63
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-60	-9	10	1	63	0.15	1.0	0	0	10	10	72
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-60	-9	10	1	66	0.15	1.0	0	0	10	10	75
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-60	-9	10	1	52	0.15	1.0	0	0	10	10	61
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-60	-9	10	1	56	0.15	1.0	0	0	10	10	65
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-60	-9	10	1	61	0.15	1.0	0	0	10	10	70
															Avg Lower Zone		59					Avg Lower Zone		68
															Avg Upper Zone		30					Avg Upper Zone		39

		Degrees
As	Alpha Slope	355
Aj	Alpha Joint (Discontinuity)	250

[Aj-As]	105
[Aj-As-180]	285

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	45

Bj-Bs	-19
Bj+Bs	109

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-60	0

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

As = 355
Aj = 250
Bj = 60

Analysis 7b

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	-50	-7.5	0	-7.5	28	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	-50	-7.5	0	-7.5	35	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	-50	-7.5	0	-7.5	32	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	-50	-7.5	0	-7.5	31	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	-50	-7.5	10	2.5	55	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	-50	-7.5	10	2.5	61	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	-50	-7.5	10	2.5	56	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	-50	-7.5	10	2.5	65	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	-50	-7.5	10	2.5	68	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	-50	-7.5	10	2.5	54	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	-50	-7.5	10	2.5	58	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	-50	-7.5	10	2.5	63	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		60					Avg Lower Zone		64
															Avg Upper Zone		32					Avg Upper Zone		35

		Degrees
As	Alpha Slope	355
Aj	Alpha Joint (Discontinuity)	250

[Aj-As]	105
[Aj-As-180]	285

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	60

Bj-Bs	-4
Bj+Bs	124

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	-50	-25

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

As = 355
Aj = 250
Bj = 90

Analysis 7c

											PLANER FAILURE							TOPPLING FAILURE						
Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.15	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.15	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.15	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.15	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.15	1.0	0	0	10	10	62	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.15	1.0	0	0	10	10	68	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.15	1.0	0	0	10	10	63	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.15	1.0	0	0	10	10	72	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.15	1.0	0	0	10	10	75	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.15	1.0	0	0	10	10	61	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.15	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.15	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		68					Avg Lower Zone		64
															Avg Upper Zone		39					Avg Upper Zone		35

		Degrees
As	Alpha Slope	355
Aj	Alpha Joint (Discontinuity)	250

[Aj-As]	105
[Aj-As-180]	285

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	90

Bj-Bs	26
Bj+Bs	154

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.15	0.15
F2	1.0	1.0
F3	0	-25

Notes and Legend

SMR = RMR_B*(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

As = 355
Aj = 340
Bj = 45

Analysis 8a

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.7	1.0	-60	-42	0	-42	-7	0.15	1.0	0	0	0	0	35
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.7	1.0	-60	-42	0	-42	-7	0.15	1.0	0	0	0	0	35
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.7	1.0	-60	-42	0	-42	0	0.15	1.0	0	0	0	0	42
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-60	-42	0	-42	0	0.15	1.0	0	0	0	0	42
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-60	-42	0	-42	0	0.15	1.0	0	0	0	0	42
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-60	-42	0	-42	0	0.15	1.0	0	0	0	0	42
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-60	-42	0	-42	0	0.15	1.0	0	0	0	0	42
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.7	1.0	-60	-42	0	-42	-3	0.15	1.0	0	0	0	0	39
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-60	-42	0	-42	-3	0.15	1.0	0	0	0	0	39
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-60	-42	0	-42	-3	0.15	1.0	0	0	0	0	39
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-60	-42	0	-42	-3	0.15	1.0	0	0	0	0	39
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-60	-42	0	-42	-4	0.15	1.0	0	0	0	0	38
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	-60	-42	10	-32	23	0.15	1.0	0	0	10	10	65
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.7	1.0	-60	-42	10	-32	20	0.15	1.0	0	0	10	10	62
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.7	1.0	-60	-42	10	-32	26	0.15	1.0	0	0	10	10	68
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.7	1.0	-60	-42	10	-32	21	0.15	1.0	0	0	10	10	63
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.7	1.0	-60	-42	10	-32	30	0.15	1.0	0	0	10	10	72
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.7	1.0	-60	-42	10	-32	33	0.15	1.0	0	0	10	10	75
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.7	1.0	-60	-42	10	-32	19	0.15	1.0	0	0	10	10	61
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.7	1.0	-60	-42	10	-32	23	0.15	1.0	0	0	10	10	65
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	-60	-42	10	-32	23	0.15	1.0	0	0	10	10	65
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-60	-42	10	-32	28	0.15	1.0	0	0	10	10	70
															Avg Lower Zone		26					Avg Lower Zone		68
															Avg Upper Zone		-3					Avg Upper Zone		39

		Degrees
As	Alpha Slope	355
Aj	Alpha Joint (Discontinuity)	340

[Aj-As]	15
[Aj-As-180]	195

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	45

Bj-Bs	-19
Bj+Bs	109

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.7	0.15
F2	1.0	1.0
F3	-60	0

Notes and Legend

SMR = RMR_B*(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 355
Aj = 340
Bj = 60

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

Analysis 8b

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.7	1.0	-50	-35	0	-35	0	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.7	1.0	-50	-35	0	-35	0	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.7	1.0	-50	-35	0	-35	7	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-50	-35	0	-35	7	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-50	-35	0	-35	7	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-50	-35	0	-35	7	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	-50	-35	0	-35	7	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.7	1.0	-50	-35	0	-35	4	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-50	-35	0	-35	4	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-50	-35	0	-35	4	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	-50	-35	0	-35	4	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	-50	-35	0	-35	3	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	-50	-35	10	-25	30	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.7	1.0	-50	-35	10	-25	27	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.7	1.0	-50	-35	10	-25	33	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.7	1.0	-50	-35	10	-25	28	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.7	1.0	-50	-35	10	-25	37	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.7	1.0	-50	-35	10	-25	40	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.7	1.0	-50	-35	10	-25	26	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.7	1.0	-50	-35	10	-25	30	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	-50	-35	10	-25	30	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	-50	-35	10	-25	35	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		33					Avg Lower Zone		64
															Avg Upper Zone		4					Avg Upper Zone		35

		Degrees
As	Alpha Slope	355
Aj	Alpha Joint (Discontinuity)	340

Bs	Beta Slope	64
Bj	Beta Joint (Discontinuity)	60

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

[Aj-As]	15
[Aj-As-180]	195

Bj-Bs	-4
Bj+Bs	124

	Planer	Toppling
F1	0.7	0.15
F2	1.0	1.0
F3	-50	-25

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

As = 355
Aj = 340
Bs = 90

SMR Computations
Boring B-8
Cut Slope 0.5H:1V (Bs = 64)
South Cut Face

Analysis 8c

Depth	Strength (MPa)	Rating	RQD (%)	Rating	Disc'ty Spacing (m)	Rating	Disc'ty Condition (See Note)	Rating	GW Rating (Damp)	RMR_B	PLANER FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR	TOPPLING FAILURE F_1	F_2	F_3	$F_1xF_2xF_3$	F_4	$(F_1xF_2xF_3)+F_4$	SMR
2.5	46	5	0	3	<.06m	5	2+1+4+2+3	12	10	35	0.7	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
5.0	46	5	0	3	<.06m	5	ditto	12	10	35	0.7	1.0	0	0	0	0	35	0.15	1.0	-25	-3.75	0	-3.75	31
8.0	46	5	20	3	<.06m	5	2+4+5+6+2	19	10	42	0.7	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
10.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
14.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
15.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
20.0	46	5	0	3	<.06m	5	ditto	19	10	42	0.7	1.0	0	0	0	0	42	0.15	1.0	-25	-3.75	0	-3.75	38
25.0	46	5	14	3	<.06m	5	2+0+4+6+4	16	10	39	0.7	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
28.5	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
30.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
34.0	46	5	0	3	<.06m	5	ditto	16	10	39	0.7	1.0	0	0	0	0	39	0.15	1.0	-25	-3.75	0	-3.75	35
35.0	46	5	0	3	<.06m	5	2+0+3+6+4	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
37.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
40.0	46	5	0	3	<.06m	5	2+0+4+6+3	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
43.0	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
45.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
50.5	46	5	0	3	<.06m	5	ditto	15	10	38	0.7	1.0	0	0	0	0	38	0.15	1.0	-25	-3.75	0	-3.75	34
55.0	46	5	70	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
60.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
65.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
70.5	46	5	40	8	.2-.6m	10	2+3+3+6+5	19	10	52	0.7	1.0	0	0	10	10	62	0.15	1.0	-25	-3.75	10	6.25	58
75.5	46	5	62	13	.2-.6m	10	2+4+3+6+5	20	10	58	0.7	1.0	0	0	10	10	68	0.15	1.0	-25	-3.75	10	6.25	64
80.5	46	5	70	13	.2-.6m	10	2+5+5+4+6	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
85.5	46	5	74	13	.2-.6m	10	2+0+3+6+4	15	10	53	0.7	1.0	0	0	10	10	63	0.15	1.0	-25	-3.75	10	6.25	59
90.5	46	5	52	13	.2-.6m	10	2+5+5+6+6	24	10	62	0.7	1.0	0	0	10	10	72	0.15	1.0	-25	-3.75	10	6.25	68
95.5	46	5	86	17	.6-2m	15	2+4+3+4+5	18	10	65	0.7	1.0	0	0	10	10	75	0.15	1.0	-25	-3.75	10	6.25	71
100.5	46	5	50	8	.2-.6m	10	2+4+3+4+5	18	10	51	0.7	1.0	0	0	10	10	61	0.15	1.0	-25	-3.75	10	6.25	57
105.5	46	5	50	8	.2-.6m	10	2+5+4+6+5	22	10	55	0.7	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
110.5	46	5	50	8	.2-.6m	10	ditto	22	10	55	0.7	1.0	0	0	10	10	65	0.15	1.0	-25	-3.75	10	6.25	61
115.5	46	5	52	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
120.5	46	5	64	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
125.5	46	5	56	13	.2-.6m	10	ditto	22	10	60	0.7	1.0	0	0	10	10	70	0.15	1.0	-25	-3.75	10	6.25	66
															Avg Lower Zone		68					Avg Lower Zone		64
															Avg Upper Zone		39					Avg Upper Zone		35

			Degrees
As	Alpha Slope		355
Aj	Alpha Joint (Discontinuity)		340

[Aj-As]	15
[Aj-As-180]	195

Bs	Beta Slope		64
Bj	Beta Joint (Discontinuity)		90

Bj-Bs	26
Bj+Bs	154

Alpha Slope - Dip Direction of Cut (Azimuth)
Alpha Joint - Dip Direction of Joint (Azimuth)
Beta Slope - Dip of Cut Slope
Beta Joint - Dip of Joint

	Planer	Toppling
F1	0.7	0.15
F2	1.0	1.0
F3	0	-25

Notes and Legend

SMR = RMR_B+(F1xF2XF3)+F4

RMR_B = RMR Basic (after Romana et al)

$RMR_B = RMR_{UCS}+RMR_{RQD}+RMR_{Spacing}+RMR_{Condition}+RMR_{GW}$

F4=10 (Presplitting)
F4=0 (Blasting or Mechanical)
Discontinuity Condition = Length (L)+S (Separation)+ R (Roughness + I (Infilling) + W (Weathering) per Bieniawski, 1989

Table 1 . RMR_B= BASIC RMR = Σ RATINGS (BIENIAWSKI, 1979)							
PARAMETER	*INTERVALS*						
UCS (MPa) UNCONFINED COMPRESSIVE STRENGTH OF INTACT ROCK MATERIAL	*<250*	*250-100*	*100-50*	*50-25*	*25-5*	*<25 5-1*	*<1*
	15	*12*	*7*	*4*	*2*	*1*	*0*
RQD (%) ROCK QUALITY DESIGNATION	*100-90*	*90-75*	*75-50*	*50-25*	*<25*		
	20	*17*	*13*	*8*	*3*		
SPACING (mm) BETWEEN DISCONTINUITIES	*>2000*	*2000-600*	*600-200*	*200-60*	*<60*		
	20	*15*	*10*	*8*	*5*		
CONDITION OF DISCONTINUITIES ROUGHNESS, PERSISTENCE, SEPARATION, WEATHERING OF WALLS AND GOUGE	*VERY ROUGH SURFACES NO SEPARATION UNWEATHERED WALL ROCK NOT CONTINUOUS*	*SLIGHTLY ROUGH SEPARATION < 1 mm SLIGHTLY WEATH. WALLS NOT CONTINUOUS*	*SLIGHTLY ROUGH SEPARATION < 1 mm HIGHLY WEATH. WALLS*	*SLICKENSIDED WALLS Or GOUGE < 5 mm Or SEPARATION1-5 mm*	*SOFT GOUGE >5 mm or SEPARATION >5 mm CONTINUOUS*		
	30	*25*	*20*	*10*	*0*		
GROUNDWATER IN JOINTS (PORE PRESSURE RATIO)	*COMPLETELY DRY (0)*	*DAMP (0-0.1)*	*WET (0.1-0.2)*	*DRIPPING (0.2-0.5)*	*FLOWING (0.5)*		
	15	*10*	*7*	*4*	*0*		

Table 2 SMR = RMR_B + (F_1 x F_2 x F_3)+ F_4 (ROMANA, 1985)					
ADJUSTING FACTORS FOR JOINTS (F_1, F_2, F_3)	*αj = DIP DIRECTION OF JOINT* *αs =DIP DIRECTION OF SLOPE*		*βj = DIP OF JOINT* *βs = DIP OF SLOPE*		
	VERY FAVOURABLE	*FAVOURABLE*	*FAIR*	*UNFAVOURABLE*	*VERY UNFAVOURABLE*
PLANE FAILURE $\lvert \alpha j-\alpha s \rvert$ = *TOPPLING* $\lvert \alpha j-\alpha s-180° \rvert$ =	*> 30°*	*30° - 20°*	*20° - 10°*	*10° - 5°*	*< 5°*
F_1 VALUE	*0.15*	*0.40*	*0.70*	*0.85*	*1.00*
RELATIONSHIP	$F_1 = (1- \sin \lvert \alpha_j-\alpha_s \rvert)^2$				
$\lvert \beta j \rvert$ =	*< 20 °*	*20°-30°*	*30°-35°*	*35°-45°*	*>45°*
F_2 VALUE *PLANE FAILURE*	*0.15*	*0.40*	*0.70*	*0.85*	*1.00*
TOPPLING	*1.00*				
RELATIONSHIP	$F_2 = tg^2 \beta j$				
PLANE FAILURE $\beta j-\beta s$ =	*>10°*	*10°-0°*	*0°*	*0°-(-10°)*	*<(-10°)*
TOPPLING $\beta j+\beta s$ =	*< 110°*	*110°-120°*	*>120°*	-	-
F_3 VALUE	*0*	*-6*	*-25*	*-50*	*-60*
RELATIONSHIP	F_3 (BIENIAWSKI ADJUSTMENT RATINGS FOR JOINTS ORIENTATION, 1976)				
F_4 ADJUSTING FACTOR FOR EXCAVATION METHOD	F_4 = EMPIRICAL VALUES FOR METHOD OF EXCAVATION				
	NATURAL SLOPE	*PRESPLITTING*	*SMOOTH BLASTING*	*BLASTING or MECHANICAL*	*DEFICIENT BLASTING*
F_4 VALUE	*+15*	*+10*	*+8*	*0*	*-8*

Ref (Tables 1 through 5):
"SMR Geomechanics classification: Application, experience and validation",
by Romana, M.; Seron J.; and Montalar, E.
ISRM 2003-Technology roadmap for rock mechanics,
South African Institute of Mining and Metallurgy, 2003

Note:

- RMR Basic parameters for SMR analyses are per Bieniawski, 1989
- "F" factors are per Romana, 2003

Table 3 DESCRIPTION OF SMR CLASSES

CLASS N°	Vb	Va	IVb	IVa	IIIb	IIIa	IIb	IIa	Ib	Ia
DESCRIPTION	VERY BAD		BAD		FAIR		GOOD		VERY GOOD	
STABILITY	COMPLETELY UNSTABLE		UNSTABLE		PARTIALLY STABLE		STABLE		COMPLETELY UNSTABLE	
FAILURES	BIG PLANAR or SOIL-LIKE		PLANAR or BIG WEDGES		SOME JOINTS or MANY WEDGES		SOME BLOCKS		NONE	
SUPPORT	REEXCAVATION		IMPORTANT / CORRECTIVE		SYSTEMATIC		OCCASIONAL		NONE	

Table 4 PROBABLE FAILURES ACCORDING SMR VALUES

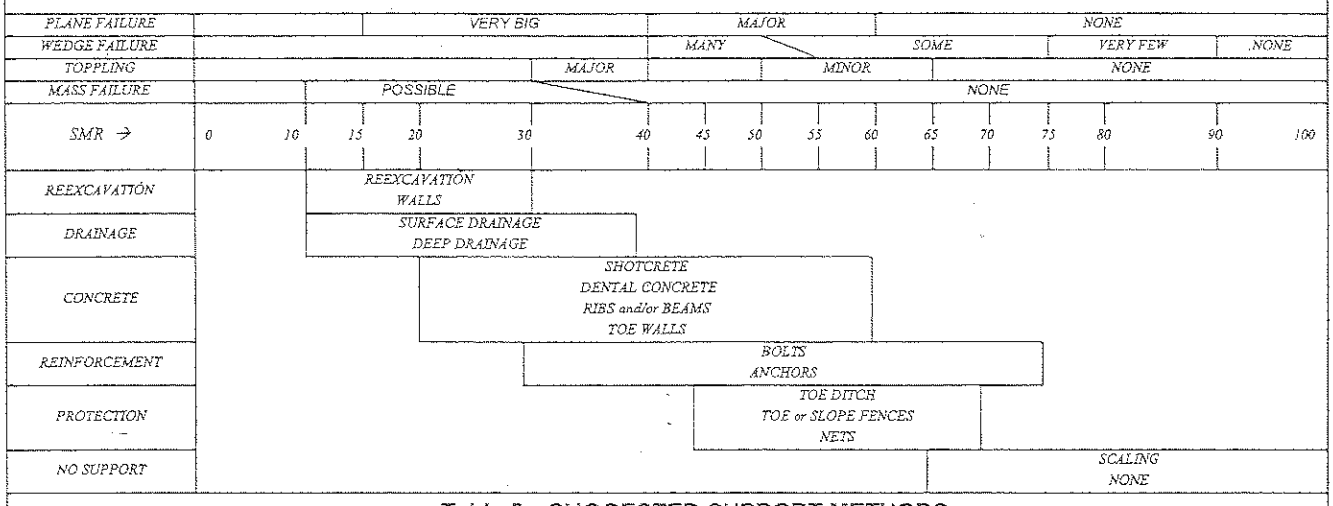


Table 5 SUGGESTED SUPPORT METHODS

DIPS Analysis

Christiansted Bypass,
St Croix, Virgin Islands

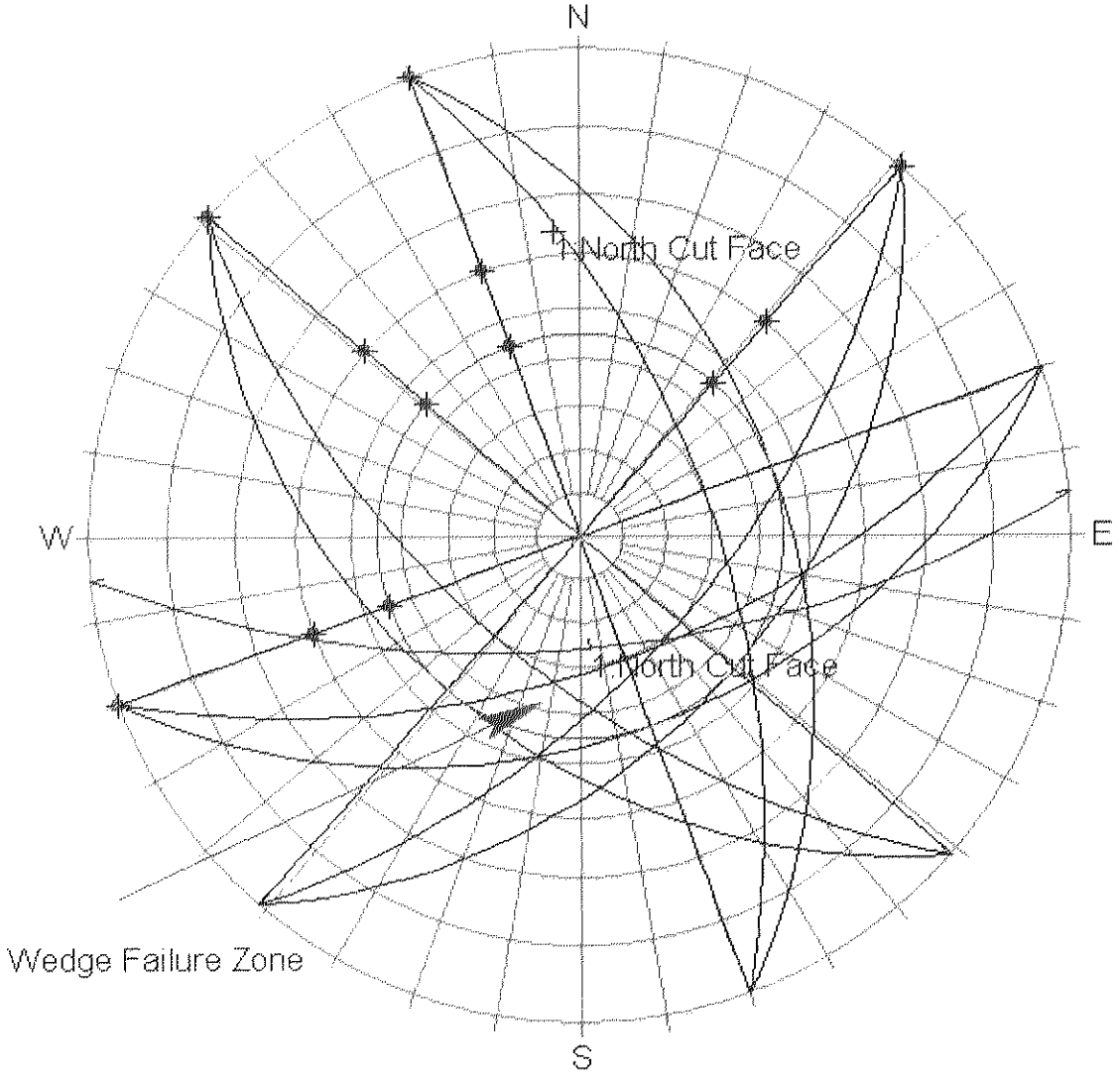
Summary of Discontinuity Dip and Dip Directions for Dips Program

Discontinuity (Joint) No	Dip Direction (°)	Dip (°)
4	70	45
2	131	45
3	160	45
1	221	45
4	70	60
2	131	60
3	160	60
1	221	60
4	70	90
2	131	90
3	160	90
1	221	90

Note: Cut Slope Face and Joints coincide with those used in SMR analyses

Cut Slope Face Dip and Dip Direction for Dips Program

Cut Slope Face	Dip (°)	Dip Direction (°)
North Side	64	175
South Side	64	355



Poles

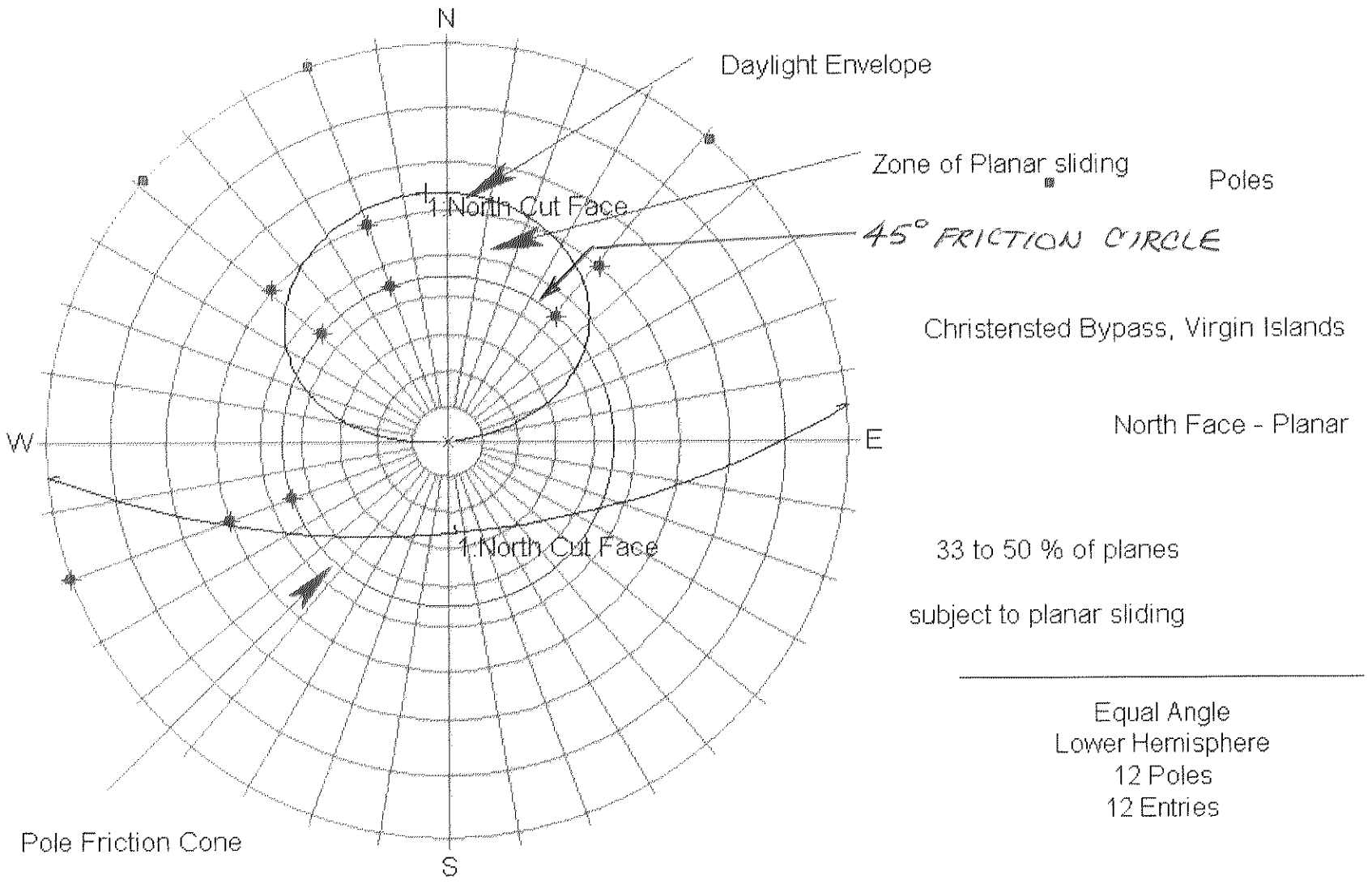
Christensted Bypass, Virgin Islands

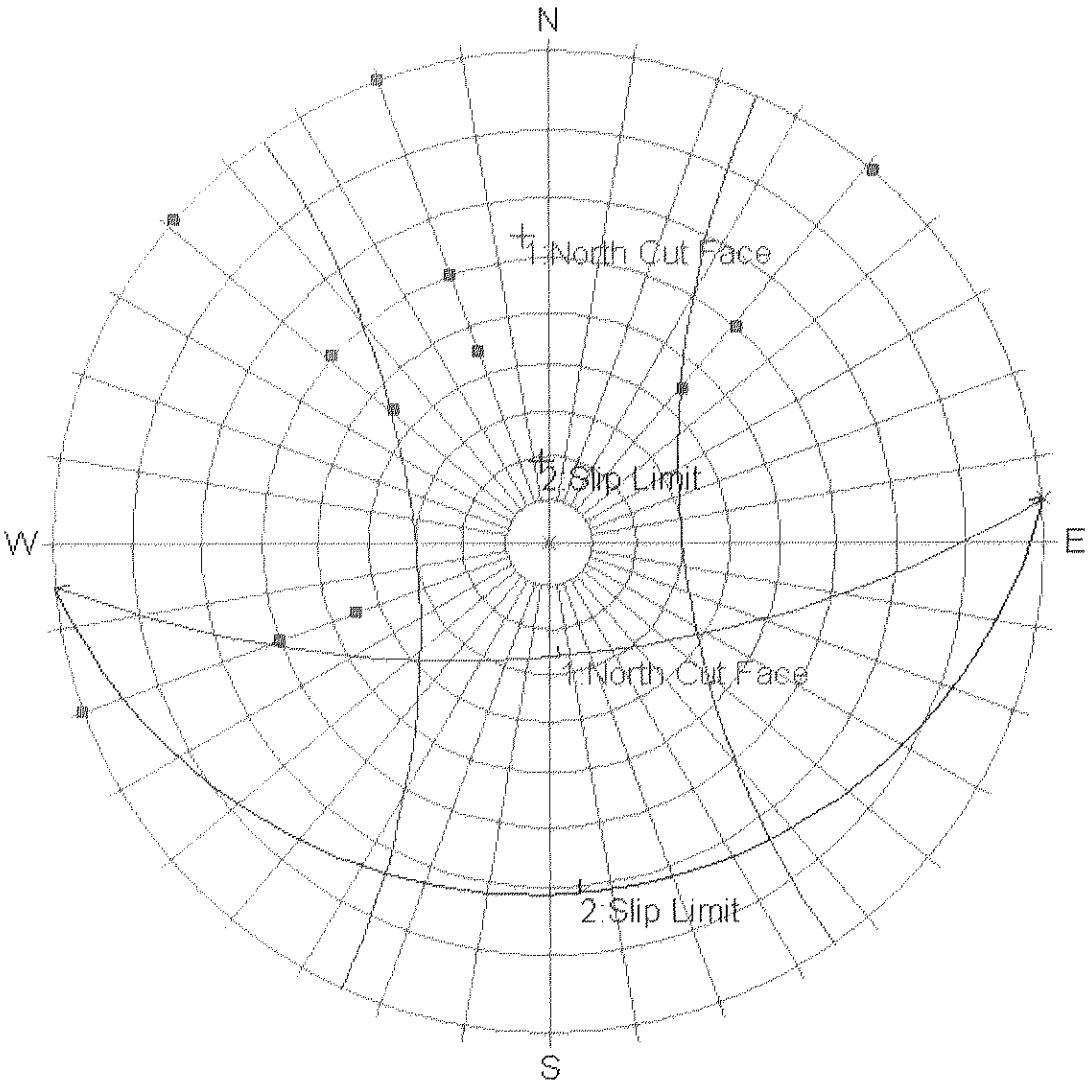
North Face - Wedge

32% of Joint Planes intersect

to form wedge failures

Equal Angle
Lower Hemisphere
12 Poles
12 Entries


N
Daylight Envelope
Zone of Planar sliding
Poles
1.North Cut Face
45° FRICTION CIRCLE
Christensted Bypass, Virgin Islands
North Face - Planar
W
E
1.North Cut Face
33 to 50 % of planes
subject to planar sliding
Equal Angle
Lower Hemisphere
12 Poles
12 Entries
Pole Friction Cone
S



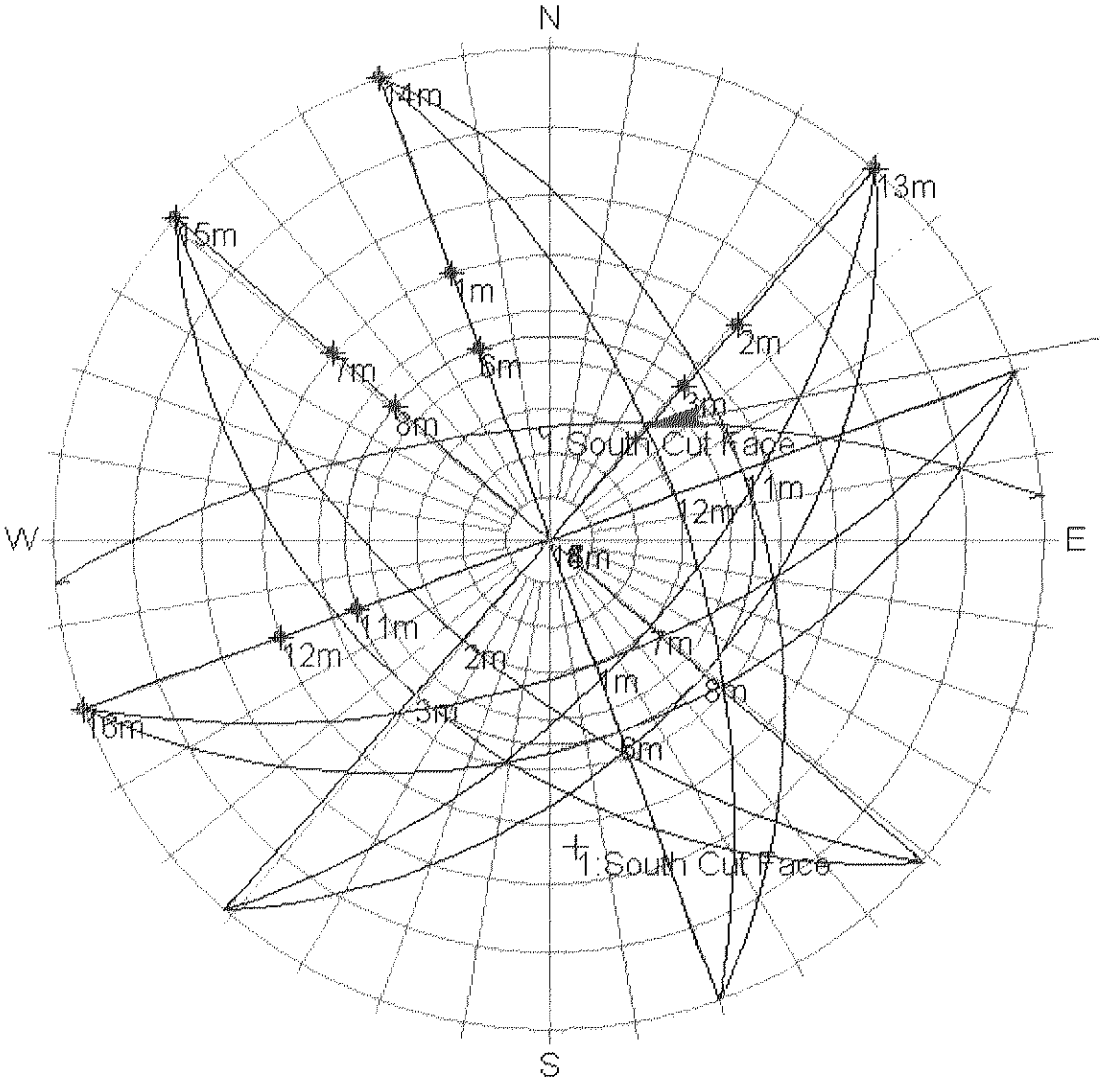
Poles

Christensted Bypass, Virgin Islands

North Face - Toppling

No Toppling

Equal Angle
Lower Hemisphere
12 Poles
12 Entries



Poles

Wedge Intersection

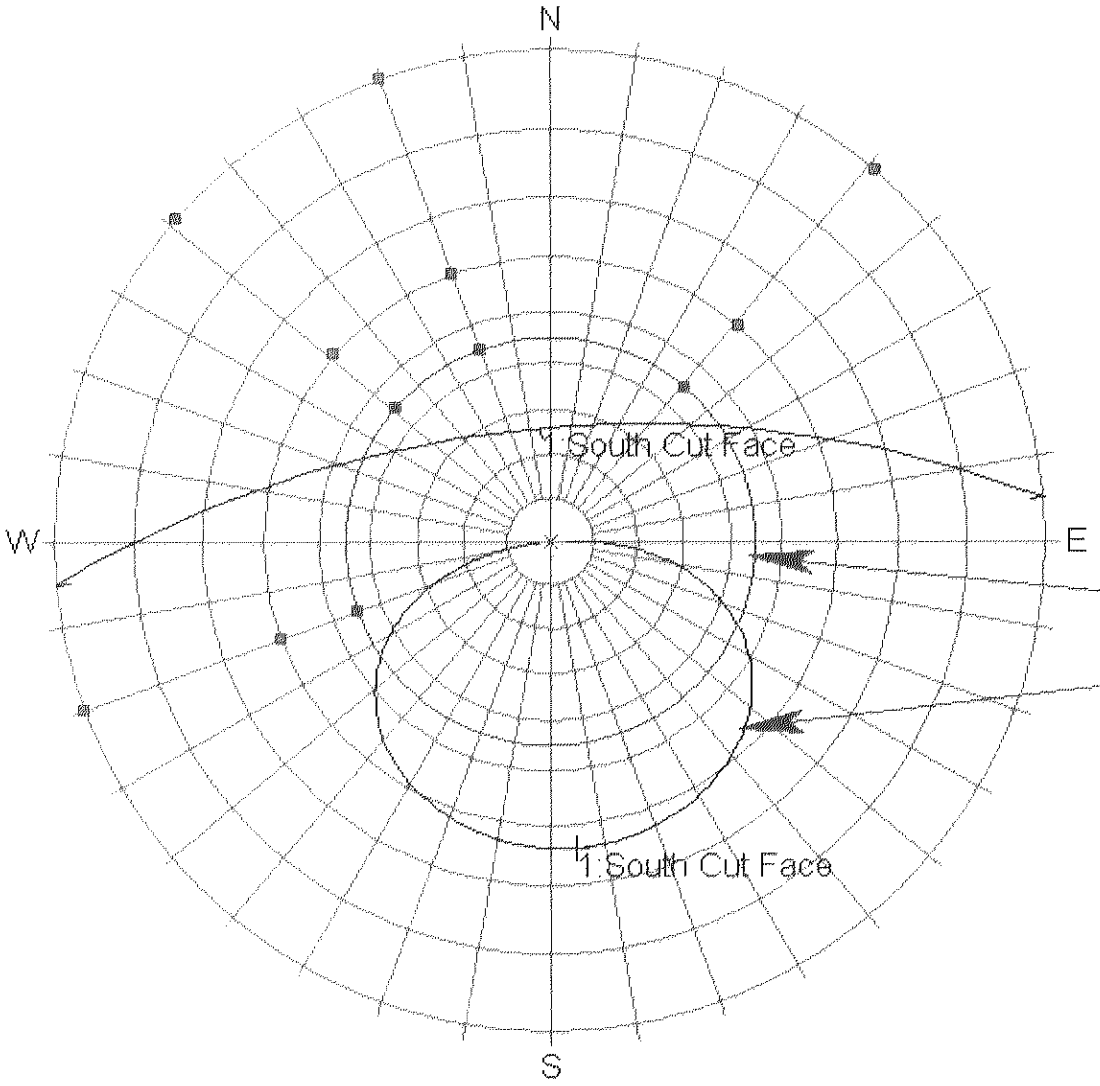
Christensted Bypass, Virgin Islands

South Face - Wedge

2% of joint planes intersect

to form wedge failures

Equal Angle
Lower Hemisphere
12 Poles
12 Entries



Poles

Christensted Bypass, Virgin Islands

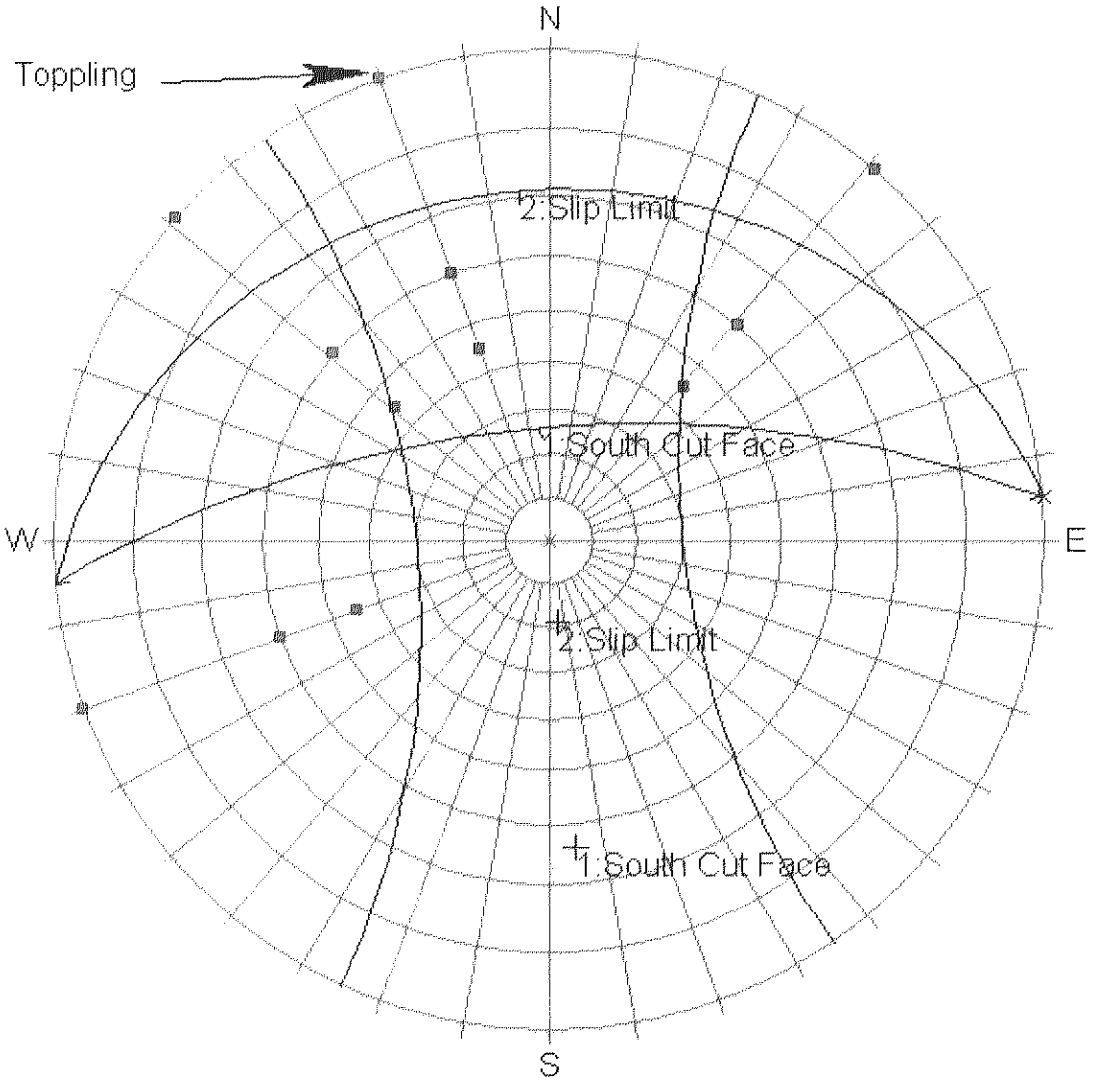
South Face - Planar

Pole Friction Cone

Daylight Envelope

No Joint Plane Failures

Equal Angle
Lower Hemisphere
12 Poles
12 Entries



Poles

Christensted Bypass, Virgin Islands

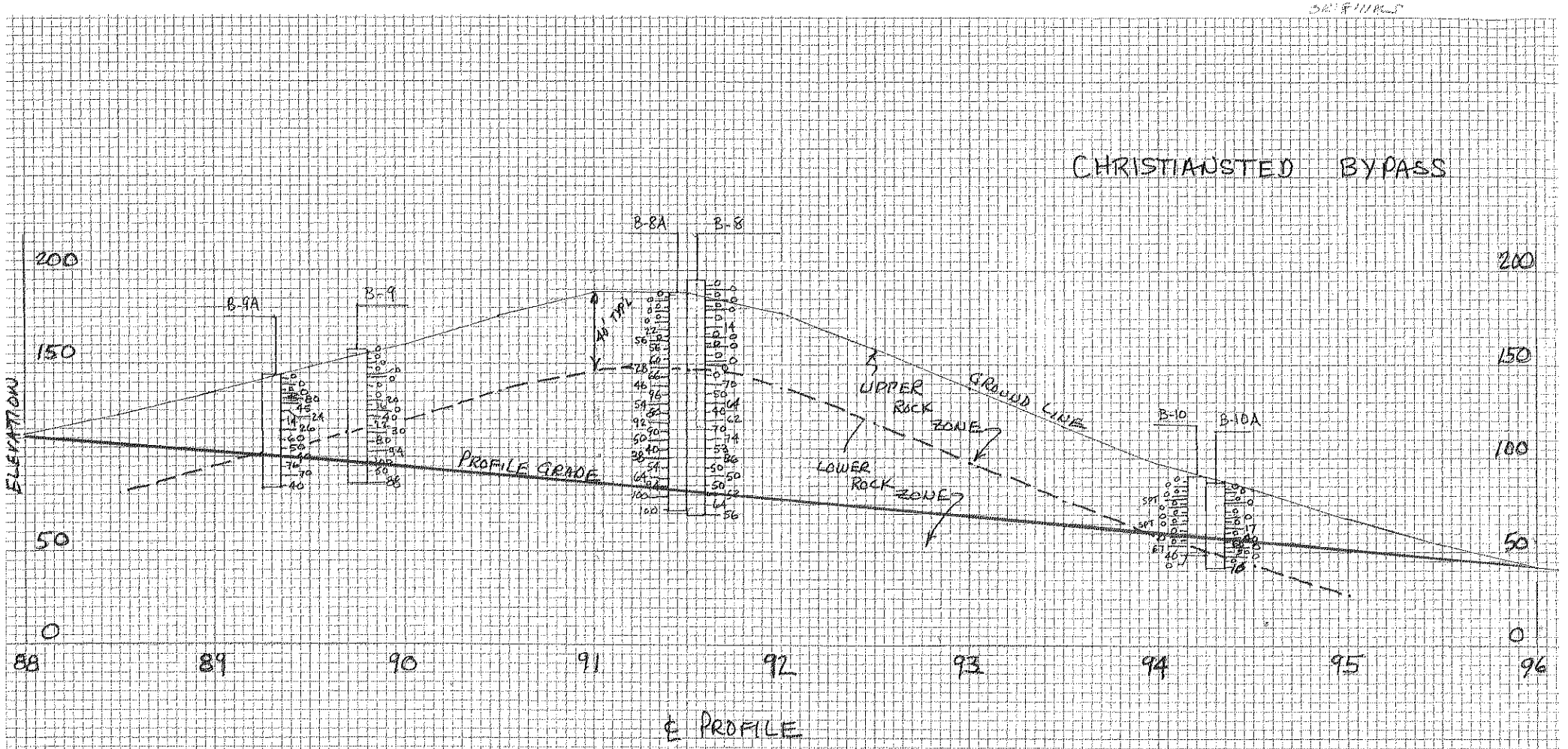
South Face - Toppling

1 of 12 joints can topple

Equal Angle
Lower Hemisphere
12 Poles
12 Entries

Appendix C

Selected Cross Sections
With Alternate Concepts

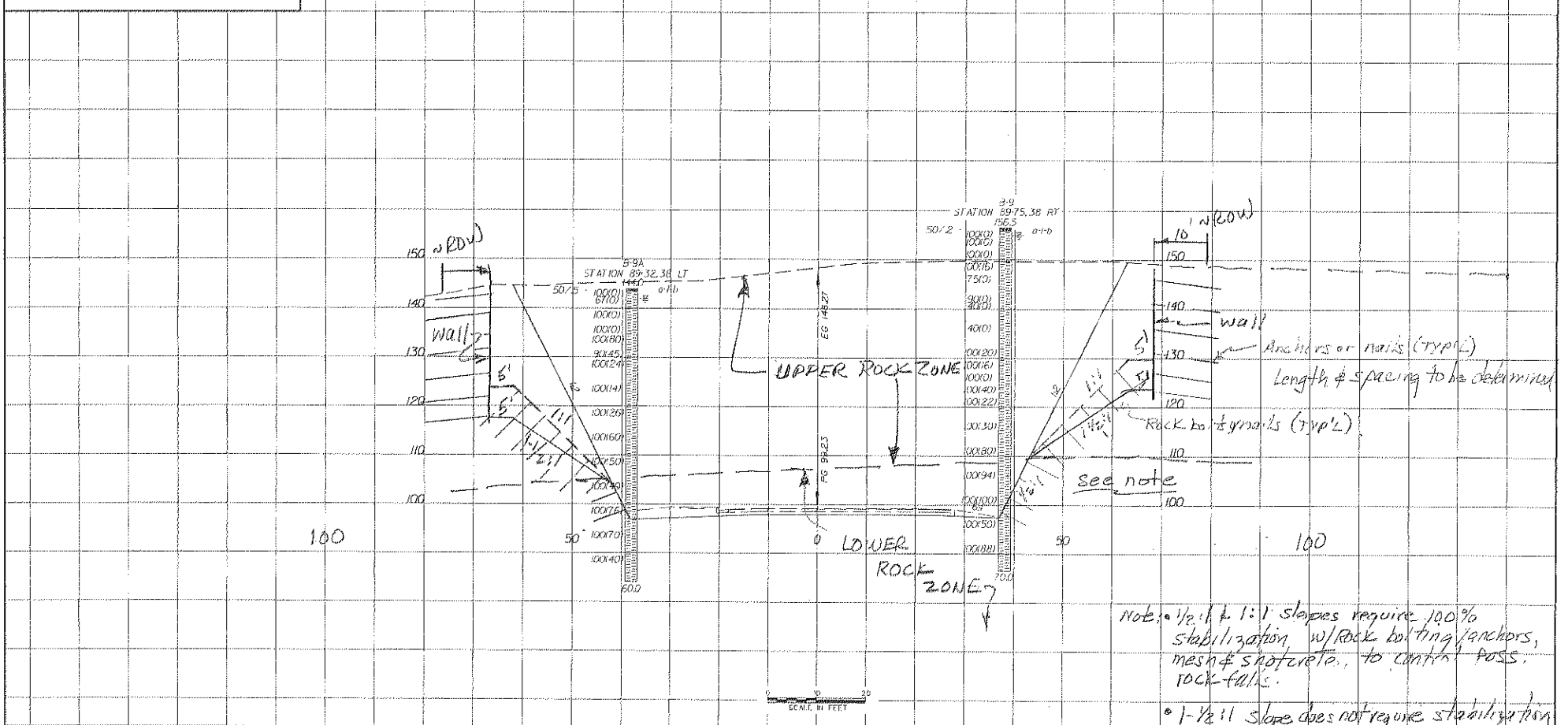


NOTE: VALUES SHOWN ADJACENT TO BORINGS ARE RQDs IN % SHOWN AT BOTTOM OF CORE RUN. SEE LOGS FOR RECOVERY %.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		



Note: • 1/2:1 & 1:1 slopes require 100% stabilization w/Rock bolting/anchors, mesh & shotcrete, to control poss. rock falls.

• 1-1/2:1 slope does not require stabilization

TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24

SPT(1) FOOT 50 BLOWS/FOOT FEET 50/.2

% CORE REC.(RQD%) 90(40)

WATER LEVEL (0 HRS)

WATER LEVEL (24 HRS)

BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH.

NOTE:

DETAILED BORING INFORMATION IS CONTAINED IN REPORT.

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

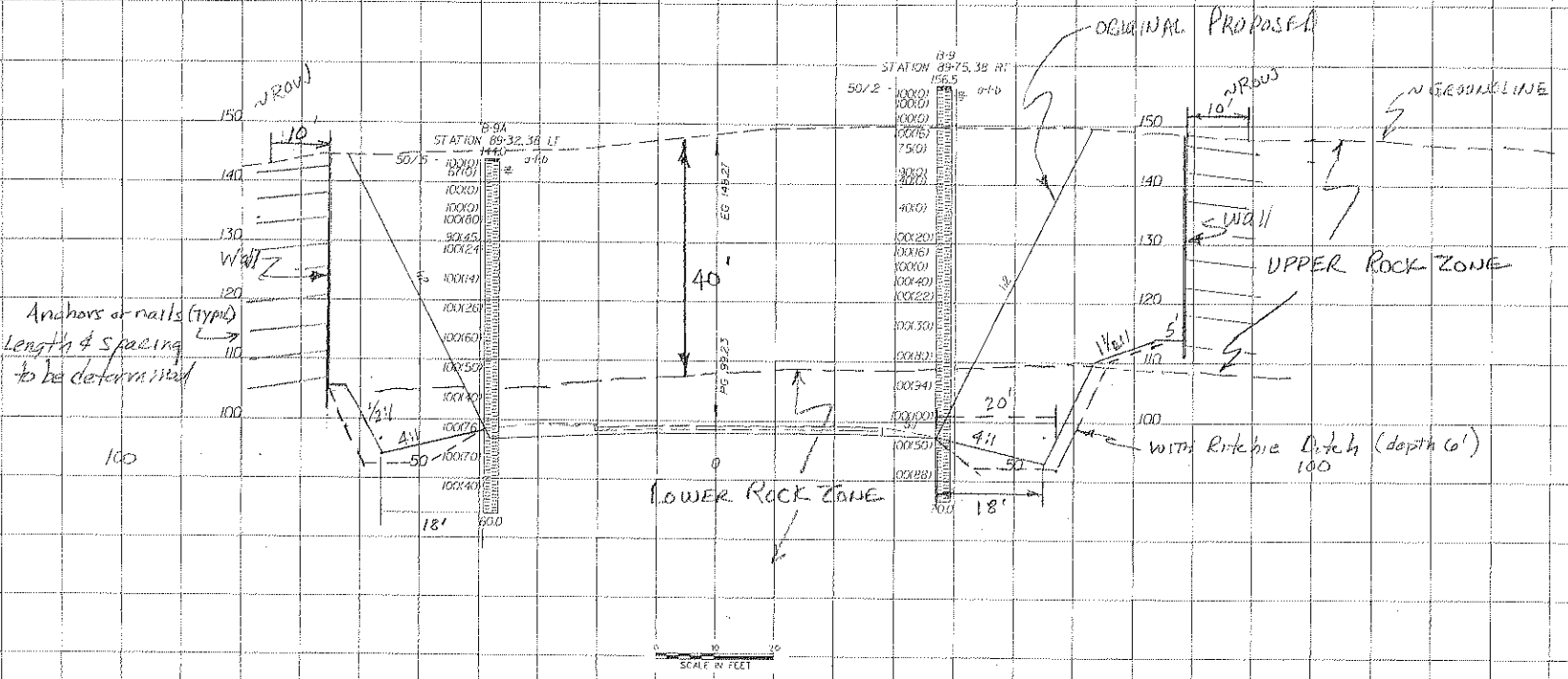
CROSS SECTION
STATION 89+50

CONCEPTUAL SECTION
cut slope stabilization & wall

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		



TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24
WATER LEVEL (0 HRS)
SPT (1 FOOT 50 BLOWS OR FEET) 50/2
WATER LEVEL (24 HRS)
% CORE REC. (RQD%) 90(40)

BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH

NOTE:
DETAILED BORING INFORMATION IS CONTAINED IN ESSER

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

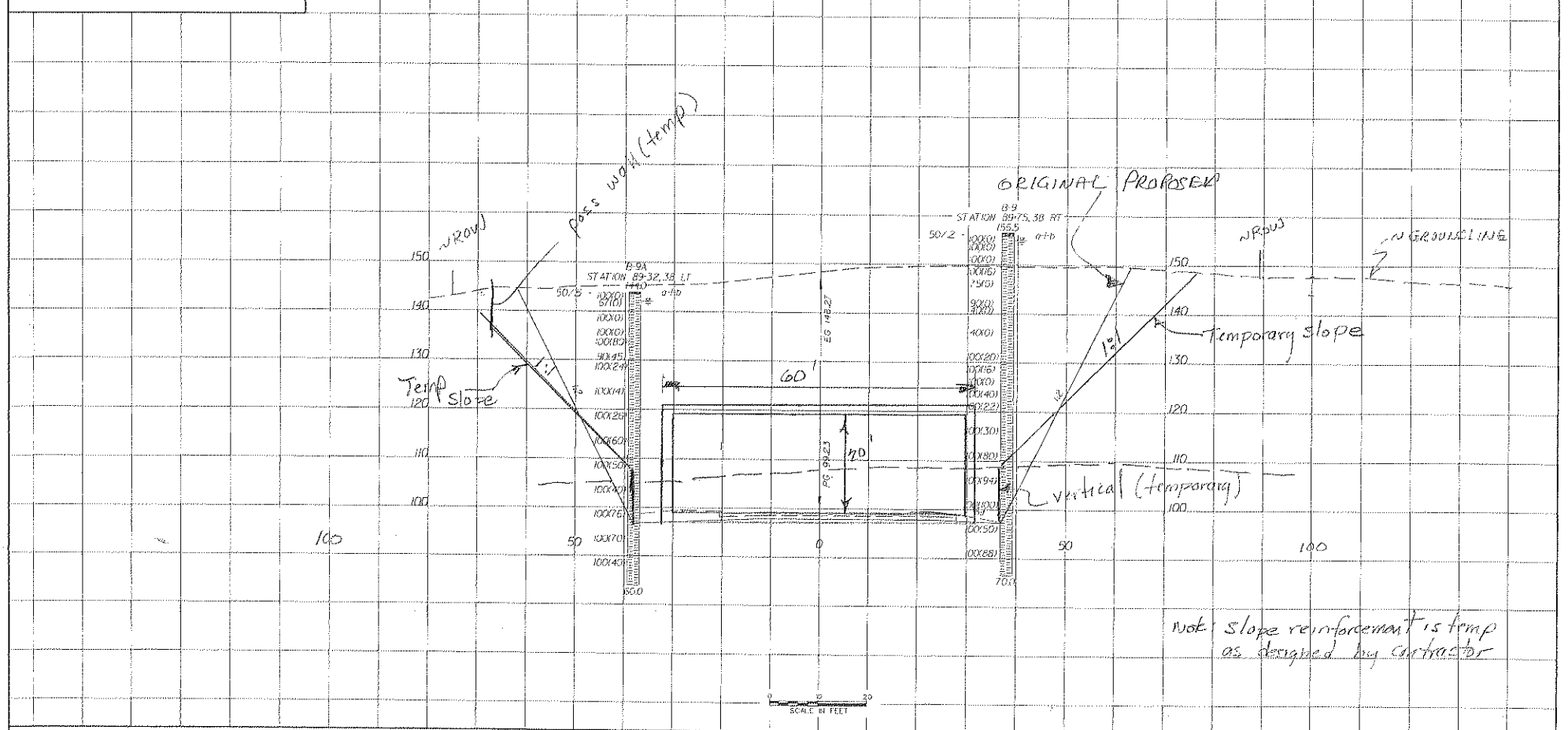
CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

CROSS SECTION
STATION 89+50
CONCEPTUAL SECTION
CUT w/Ditch Area + Wall

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		



Note: slope reinforcement is temp as designed by contractor

TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24
SPT-1 FOOT 50 BLOWS/FEET 50/.2
% CORE REC.(RQD) 90(40)

WATER LEVEL (0 HRS)
WATER LEVEL (24 HRS)

BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH.

NOTE:
DETAILED BORING INFORMATION IS CONTAINED IN REPORT

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

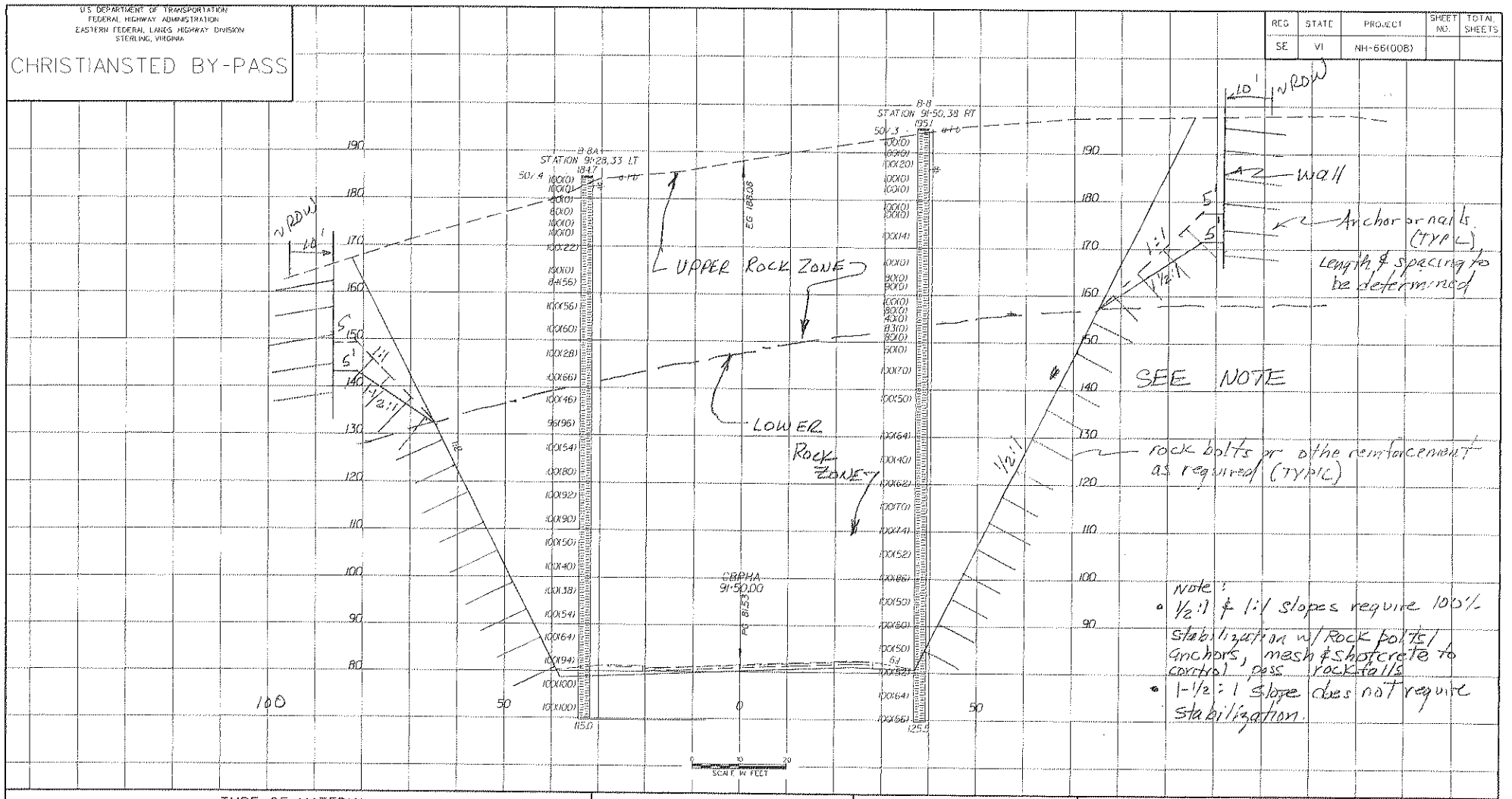
CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

CROSS SECTION
STATION 89+50
CONCEPTUAL SECTION
C & C TUNNEL

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		



TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24
SPT(1) FOOT 50 BLOW 10.1 FEET 50/.2
0.1
% CORE REC.(RQD%) 90(40)
WATER LEVEL (0 HRS)
WATER LEVEL (24 HRS)
BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. ROD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH.

NOTE:
DETAILED BORING INFORMATION IS CONTAINED IN REPORT.

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

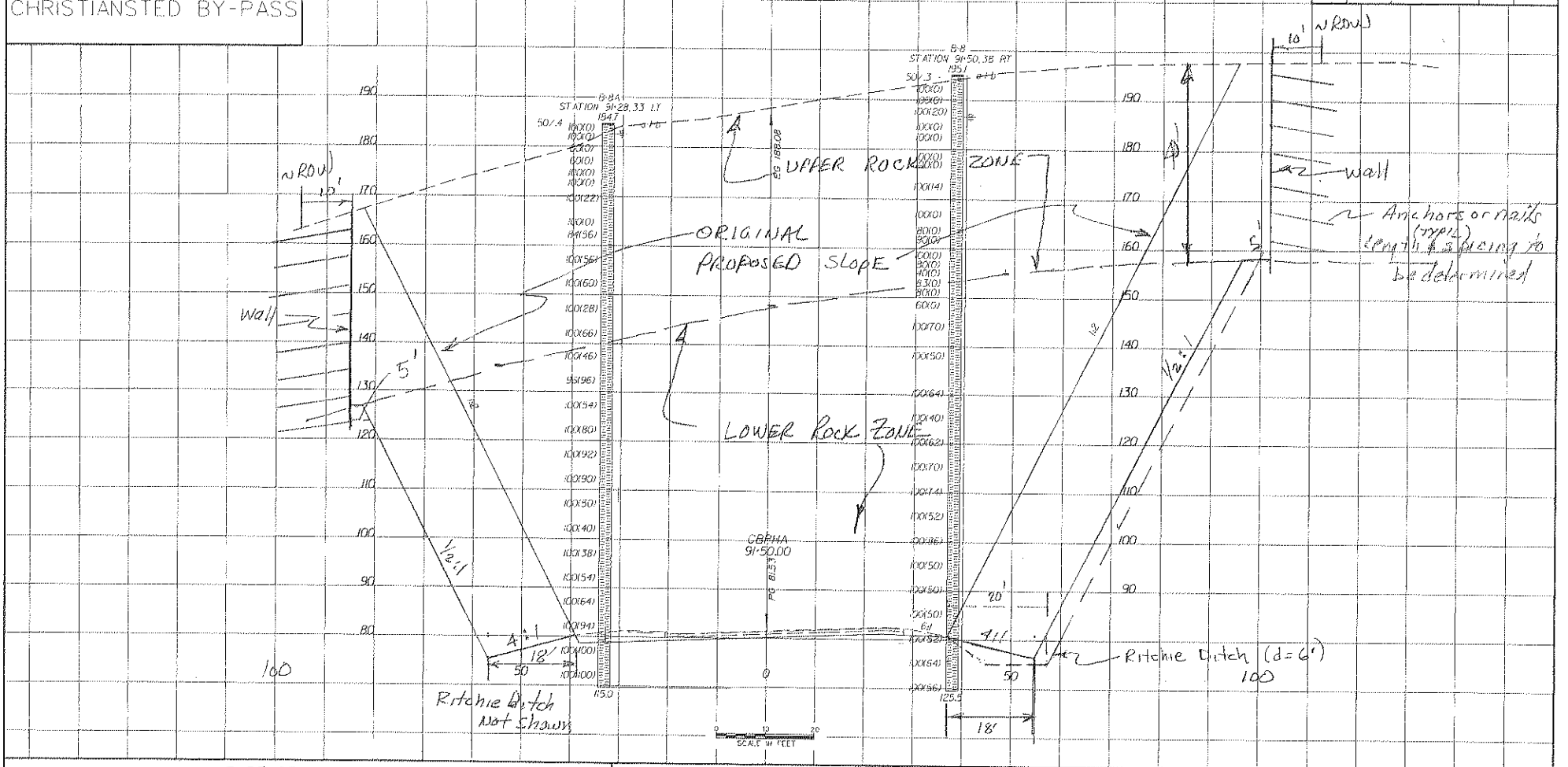
CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

CROSS SECTION
STATION 91+50
CONCEPTUAL SECTION
CUT W/ STABILIZATION & WALL

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO	TOTAL SHEETS
SE	VI	NH-68(008)		



TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24 — WATER LEVEL (0 HRS)

SPT(1 FOOT 50 BLOW NO. FEET) 50/.2 — WATER LEVEL (24 HRS)

% CORE REC.(RQD%) 90(40)

BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH.

NOTE:
DETAILED BORING INFORMATION IS CONTAINED IN REPORT.

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

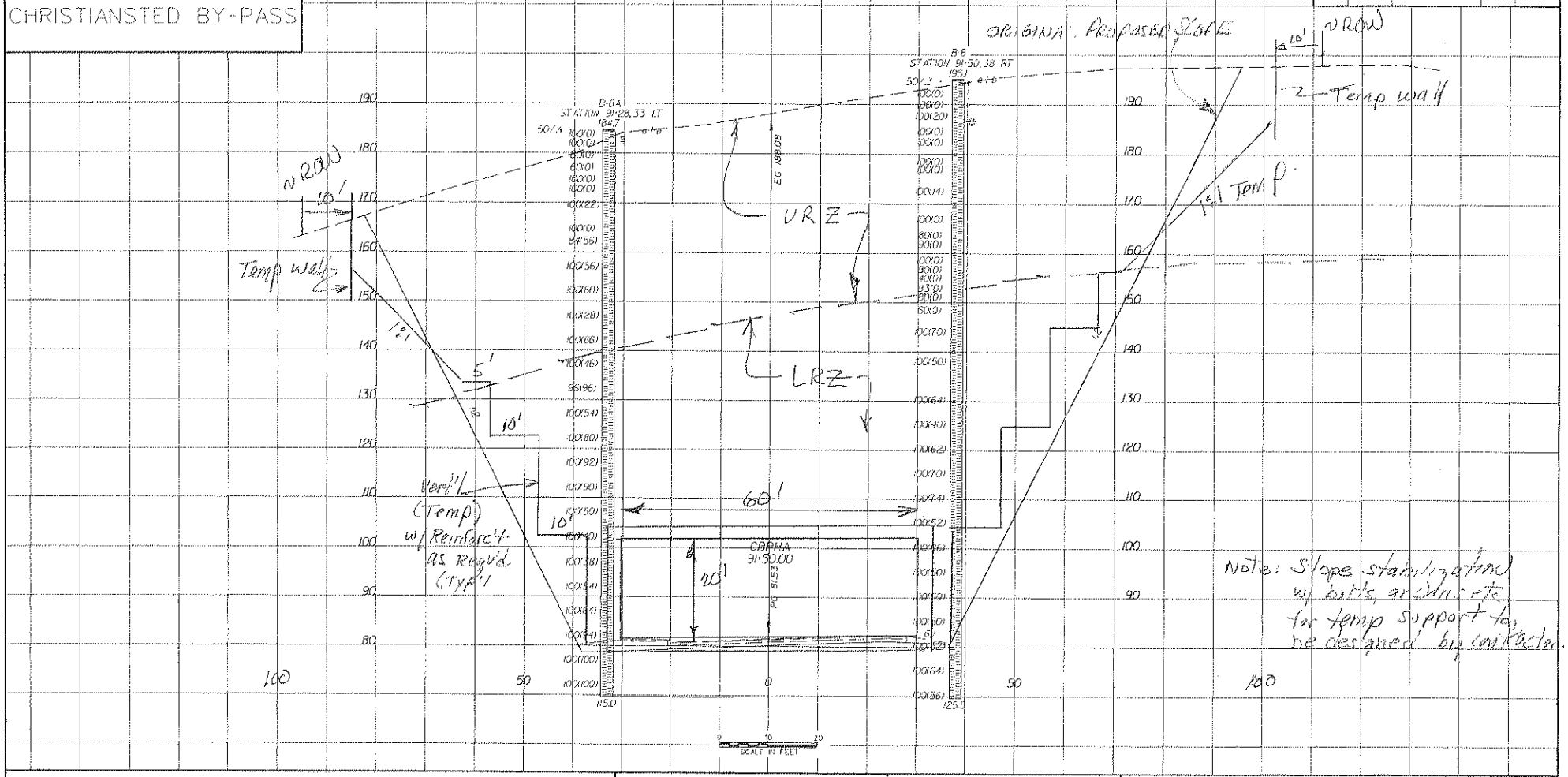
CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

CROSS SECTION
STATION 91+50
CONCEPTUAL SECTION
CUT w/CATCH AREA + WALL

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO	TOTAL SHEETS
SE	VI	NH-66(008)		



TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24
SPT<1 FOOT 50 BLOW/10 FEET 50/.2
% CORE REC.(RQD%) 90(40)
WATER LEVEL (0 HRS)
WATER LEVEL (24 HRS)
BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH.

NOTE:

DETAILED BORING INFORMATION IS CONTAINED IN REPORT

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

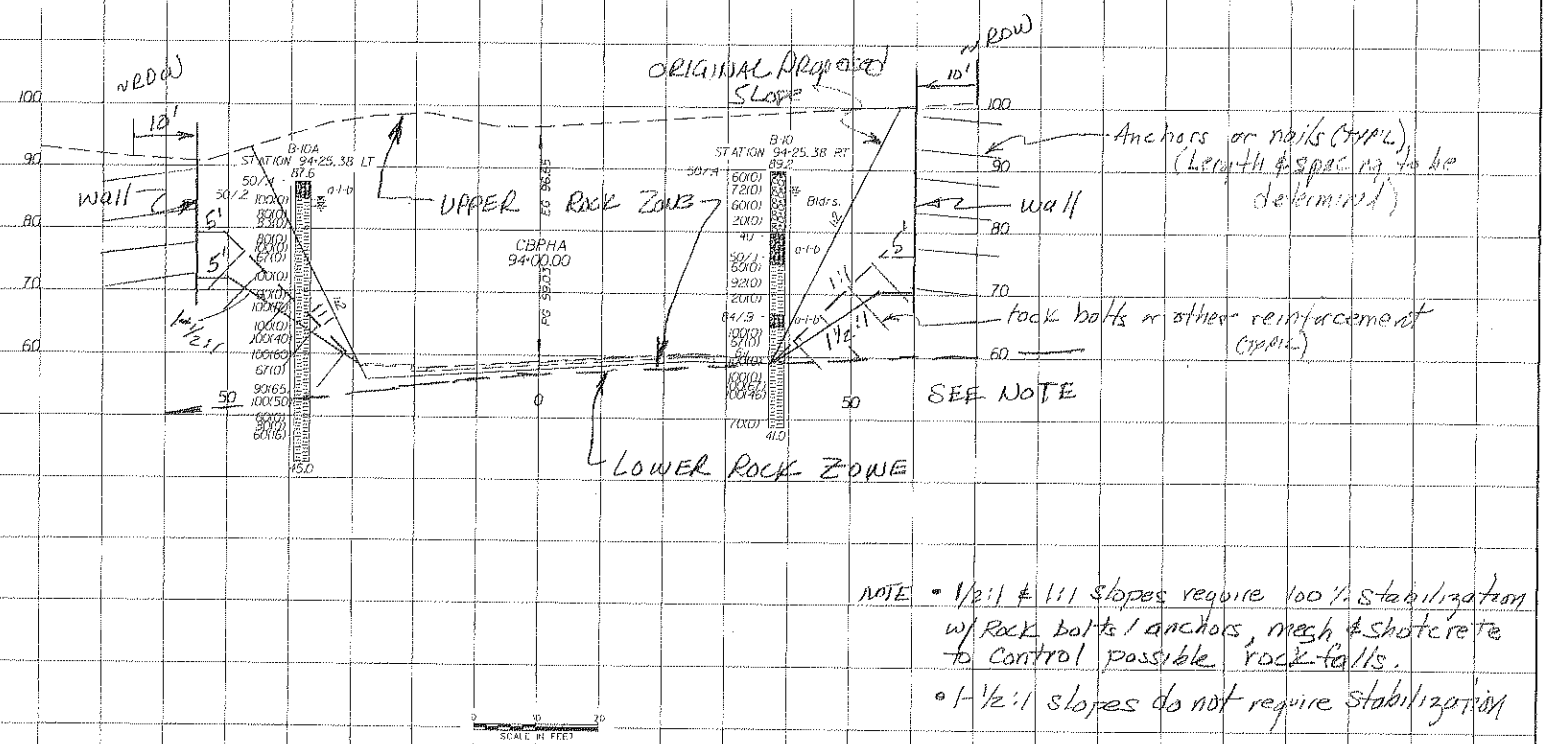
CROSS SECTION
STATION 91+50

CONCEPTUAL SECTION
C & C TUNNEL

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		



NOTE • 1/2:1 & 1:1 slopes require 100% stabilization w/ Rock bolts/anchors, mesh & shotcrete to control possible rock falls.

• 1-1/2:1 slopes do not require stabilization

TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24
SPT(-) FOOT 50 BLOW/10.1 FEET 50/.2
Coil
% CORE REC.(RQD%) 90(40)

WATER LEVEL (0 HRS)
WATER LEVEL (24 HRS)

BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH.

NOTE:
DETAILED BORING INFORMATION IS CONTAINED IN REPORT.

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

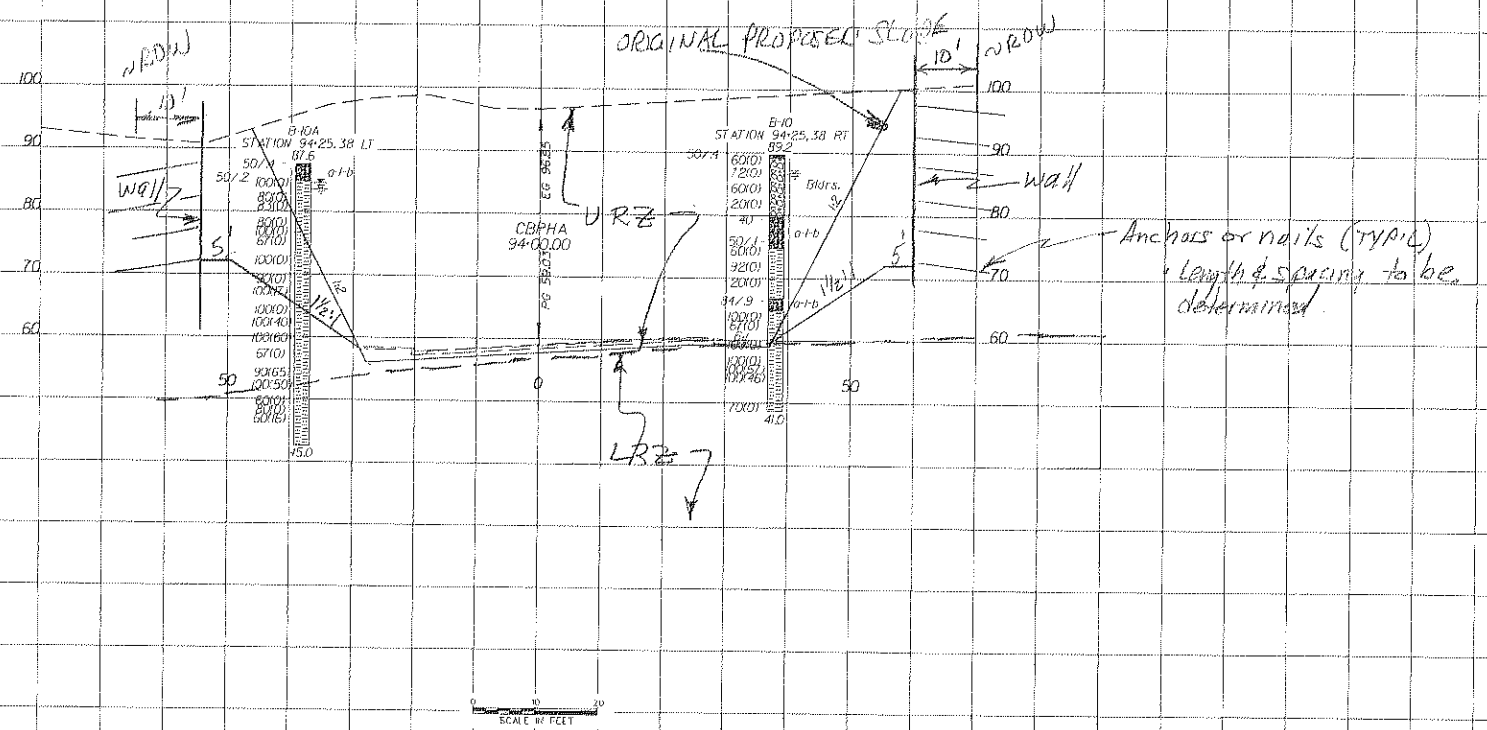
CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

CROSS SECTION
STATION 94+00
CONCEPTUAL SECTION
CUT w/stabilization & wall

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		



TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING

BORING NO.
STATION & OFFSET
TOP ELEV.

N-BLOWS/FOOT (SPT) 24
SPT<1 FOOT 50 BLOW/0.1 FEET 50/.2
% CORE REC.(RQD%) 90(40)

WATER LEVEL (0 HRS)
WATER LEVEL (24 HRS)

BORING DEPTH

MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO T206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH.

NOTE:
DETAILED BORING INFORMATION IS CONTAINED IN REPORT.

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

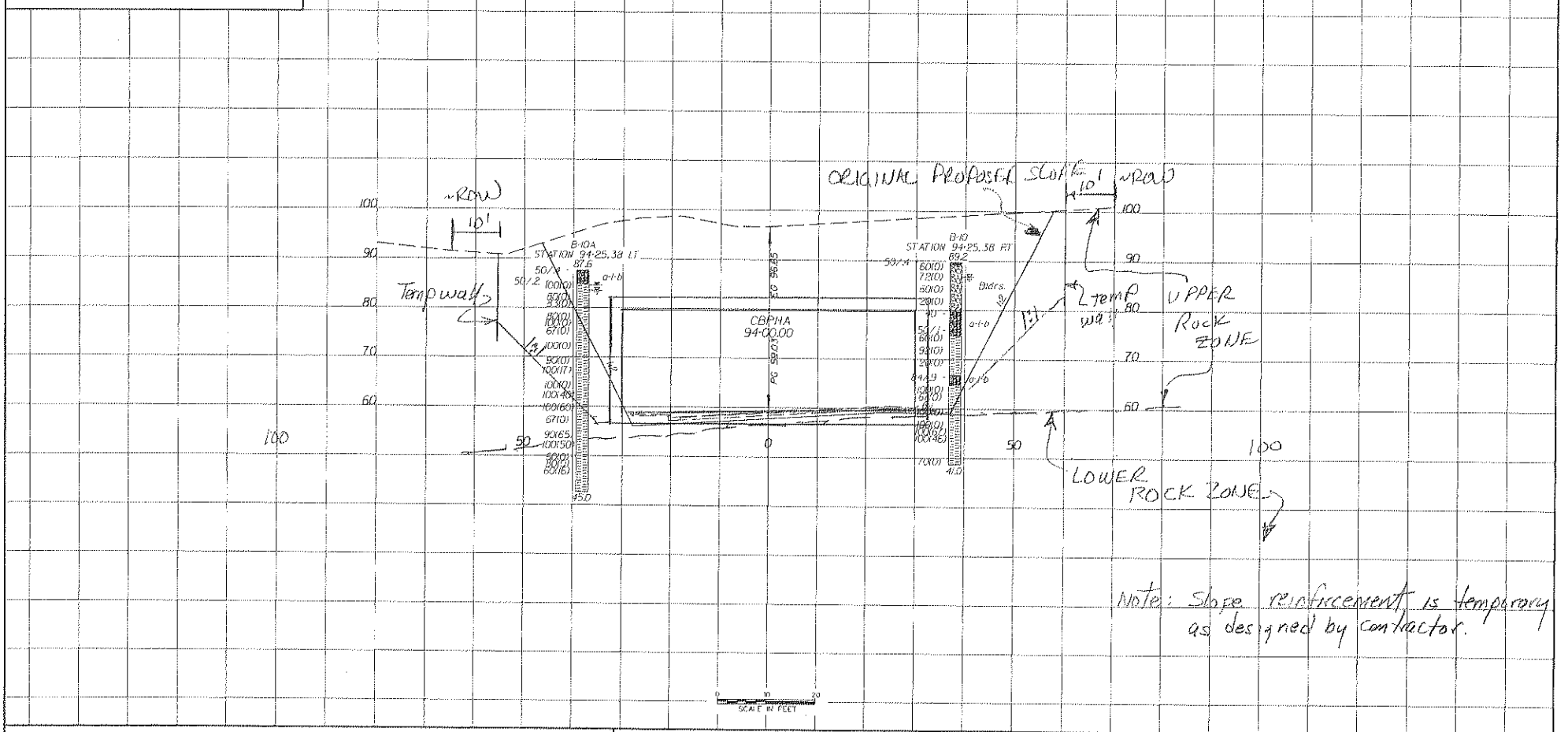
CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

CROSS SECTION
STATION 94+00
CONCEPTUAL SECTION
CUT W/CATCH AREA + WALL

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		



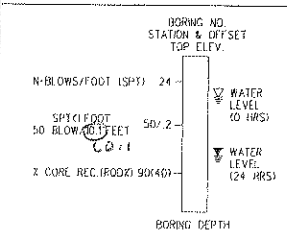
Note: Slope reinforcement is temporary as designed by contractor.

TYPE OF MATERIAL

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	OVERBURDEN (SAND WITH GRAVEL, CLAY, SILT)		SILTY SAND
	SANDSTONE, INCLUDES METAMORPHOSED ROCK		SLATE AND SCHIST
	CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SAND AND GRAVEL
	SANDSTONE & CONGLOMERATE, INCLUDES METAMORPHOSED ROCK		SILT AND GRAVEL
	CLAYEY SAND		PHYLLITE
	SILT		CLAYEY GRAVEL
	WASHOUT		SILTSTONE, INCLUDES METAMORPHOSED ROCK
	SLATE		CLAYSHALE

NOTE: LINE WEIGHT DENOTES PREDOMINANCE OF SOIL TYPE

TEST BORING



MISCELLANEOUS

1. SPT-STANDARD PENETRATION TEST - AASHTO 1206-74
2. RQD-ROCK QUALITY DESIGNATION
3. BORINGS ARE PLOTTED TO ACTUAL ELEVATIONS
4. VISUAL SOIL CLASSES PER AASHTO SHOWN TO RIGHT OF SYMBOLIC LOG
5. SAMPLE DATA IS SHOWN AT TOP OF SAMPLE DEPTH

NOTE:

DETAILED BORING INFORMATION IS CONTAINED IN REPORT.

FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION

CHRISTIANSTED BY-PASS
ST. CROIX, VIRGIN ISLANDS

CROSS SECTION
STATION 94+00
CONCEPTUAL SECTION
C&C TUNNEL

Appendix D

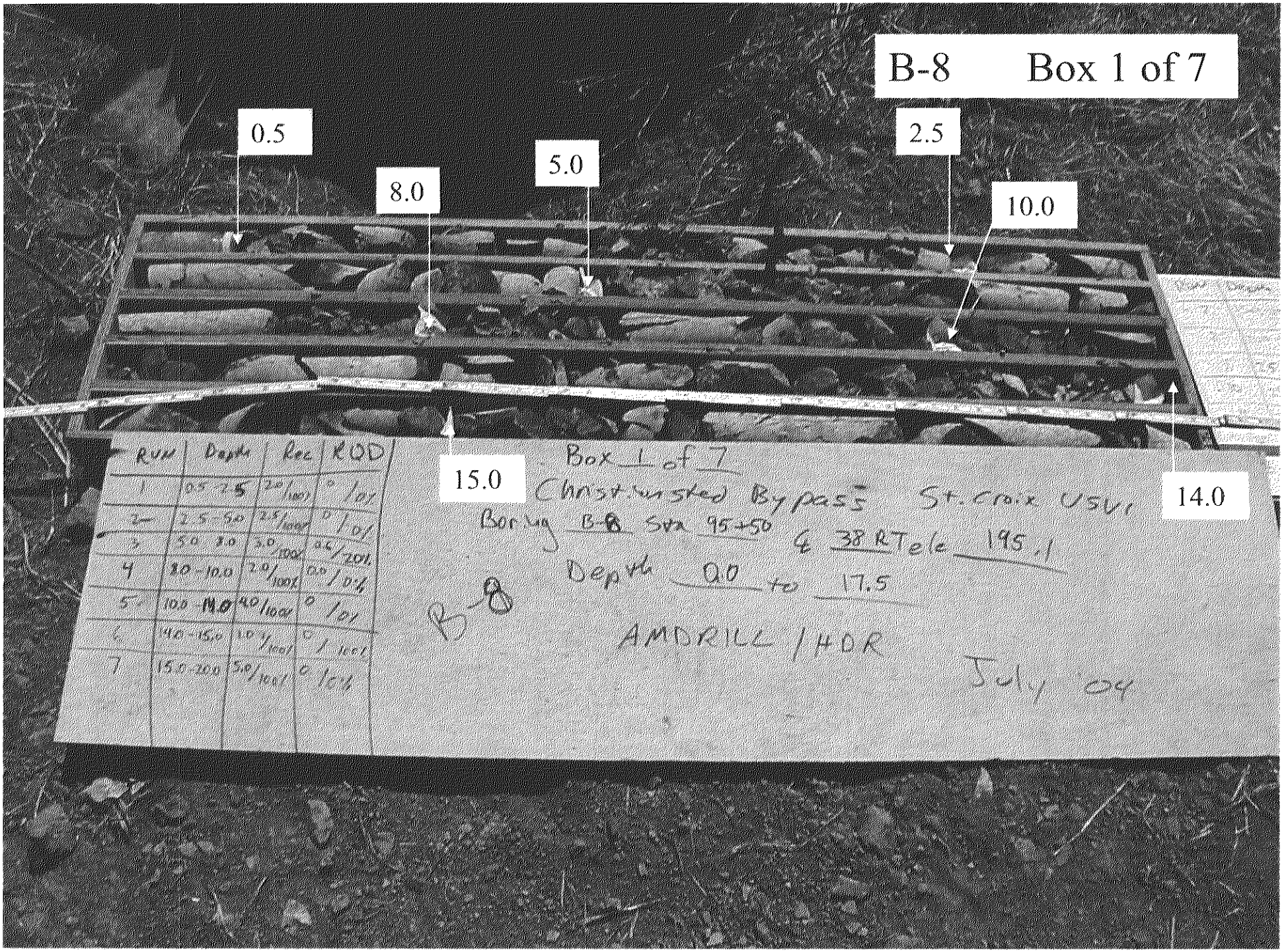
Photos of Core Samples

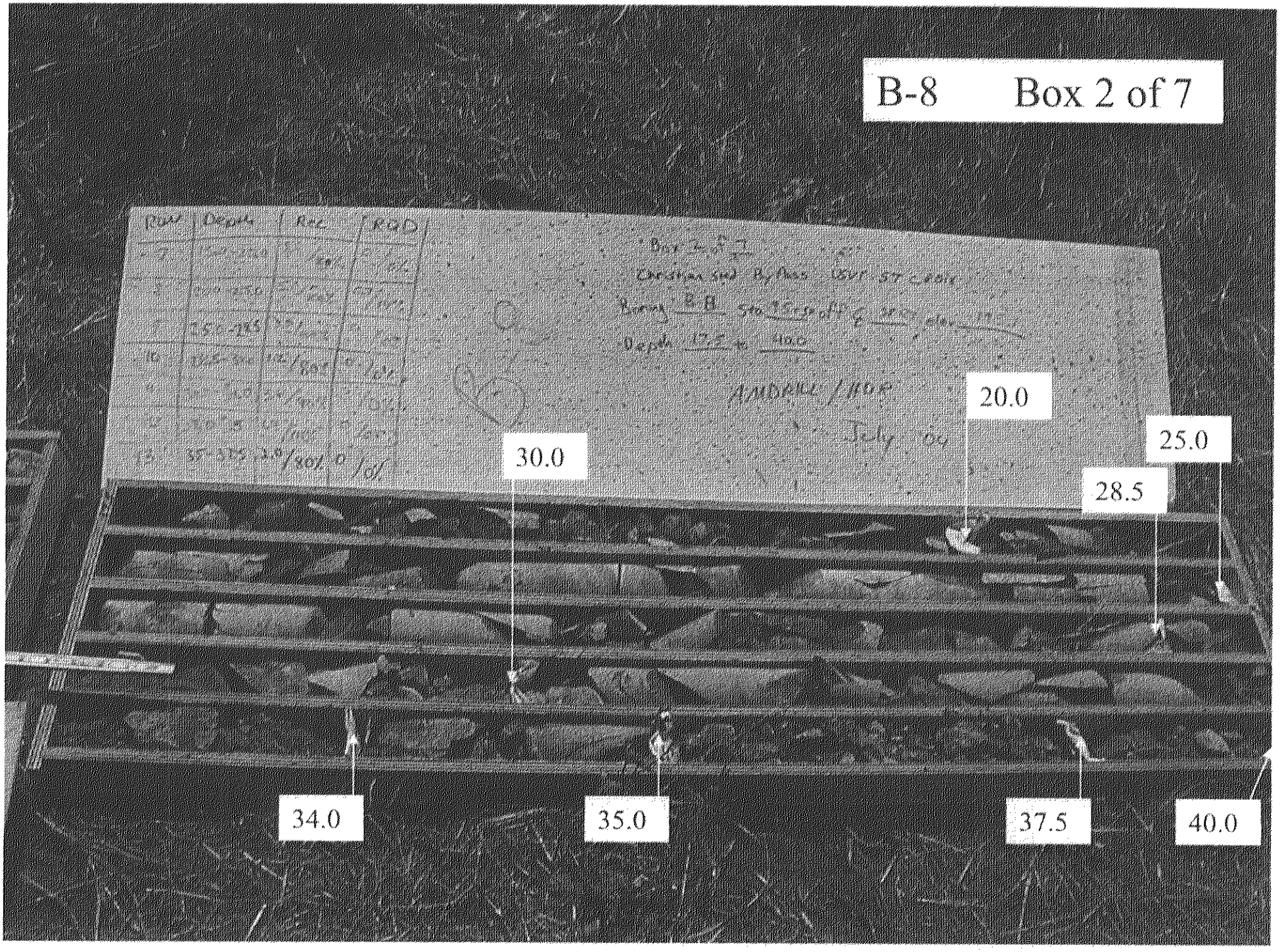
Christiansted By Pass

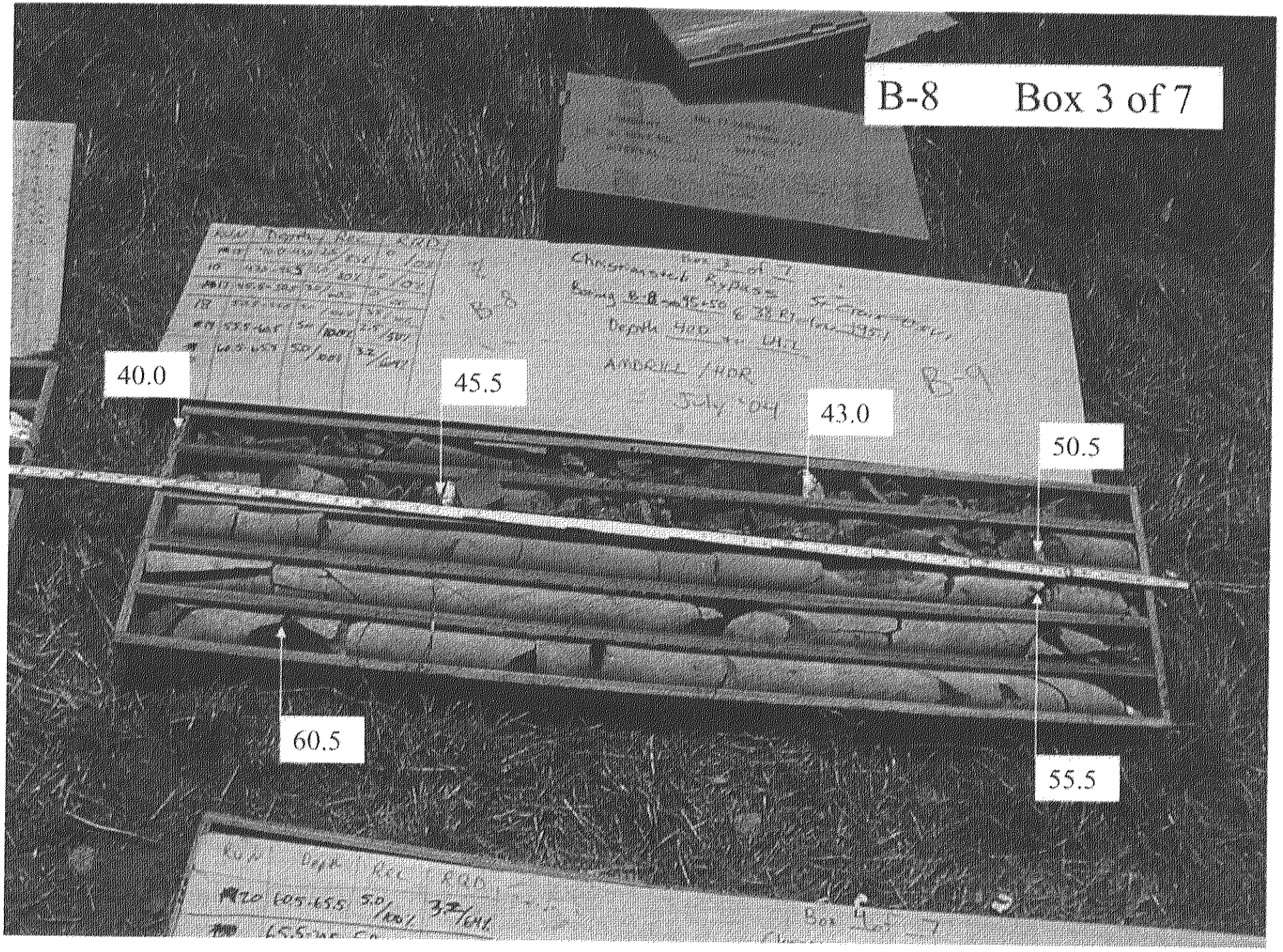
Photos of Cores from Borings

HDR (7-30-04)

Boring B-8


B-8 Box 1 of 7
0.5
8.0
5.0
2.5
10.0
15.0
14.0
Box 1 of 7
Construction Bypass St. Croix USVI
Boring B-8 Sta 95+50 @ 38 RT ele 195.1
Depth 0.0 to 17.5
AMDRILL 140R
July 04


B-8 Box 2 of 7
20.0
25.0
28.5
30.0
34.0
35.0
37.5
40.0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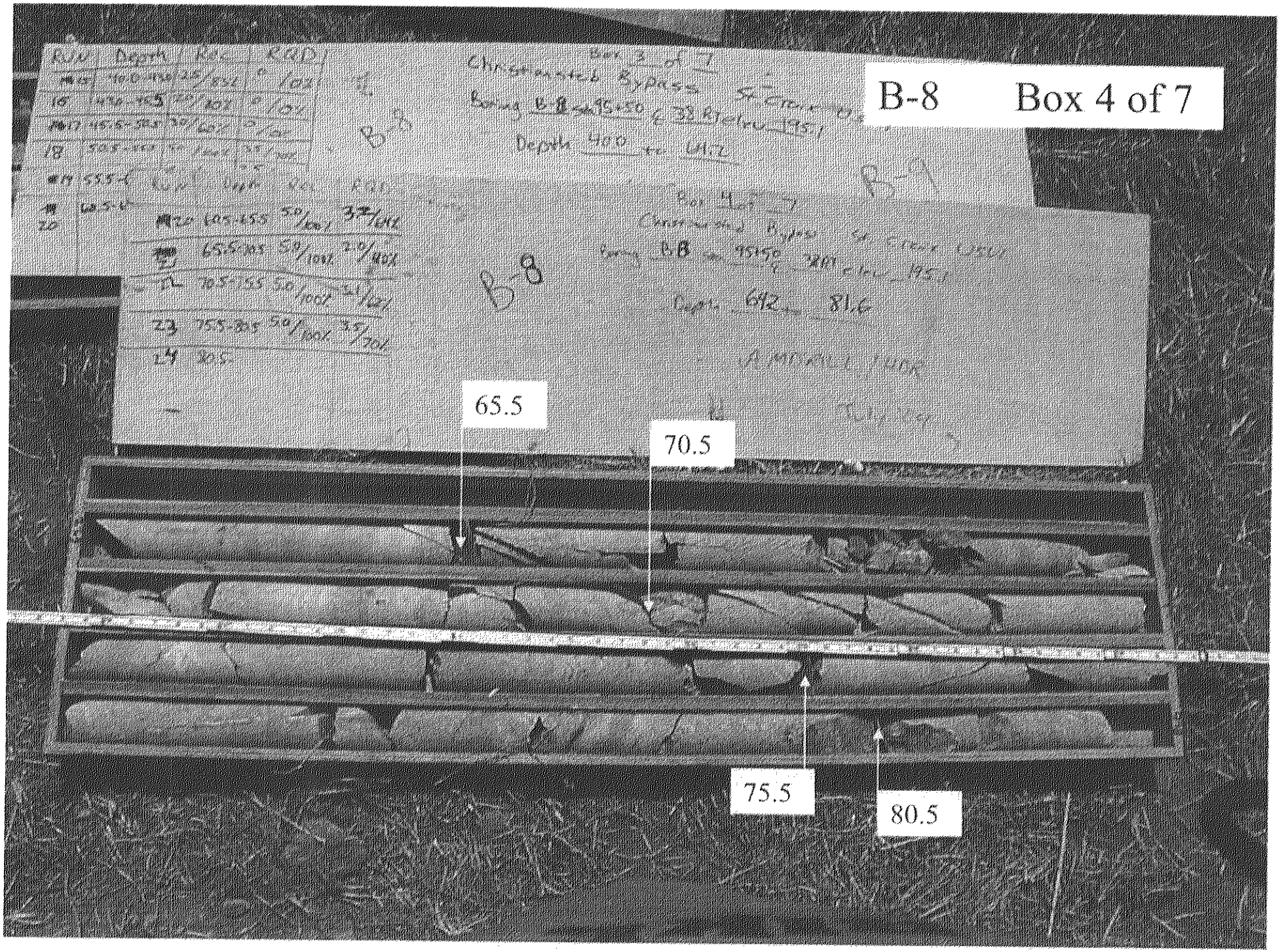
40.0
45.5
43.0
50.5
60.5
55.5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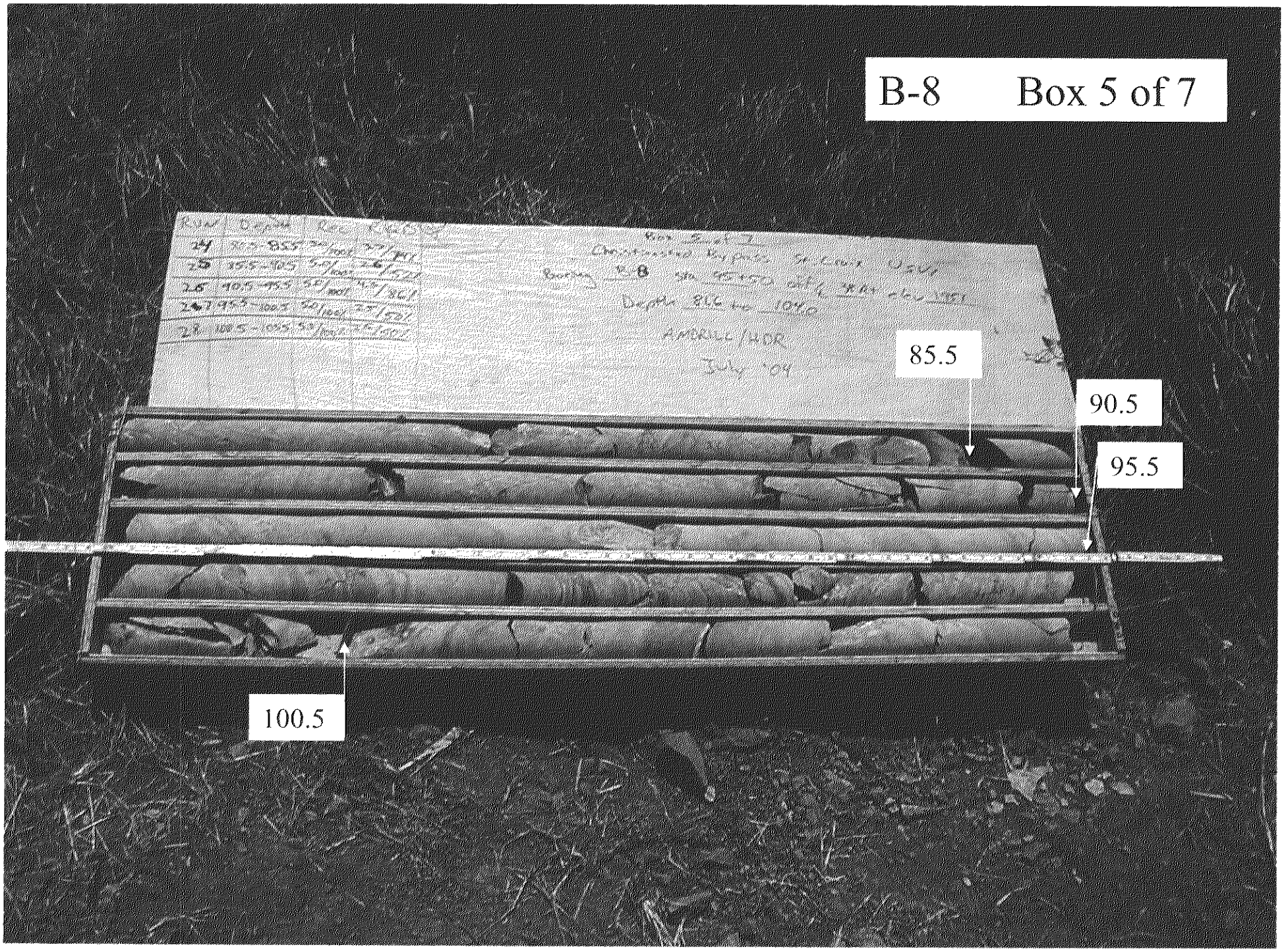
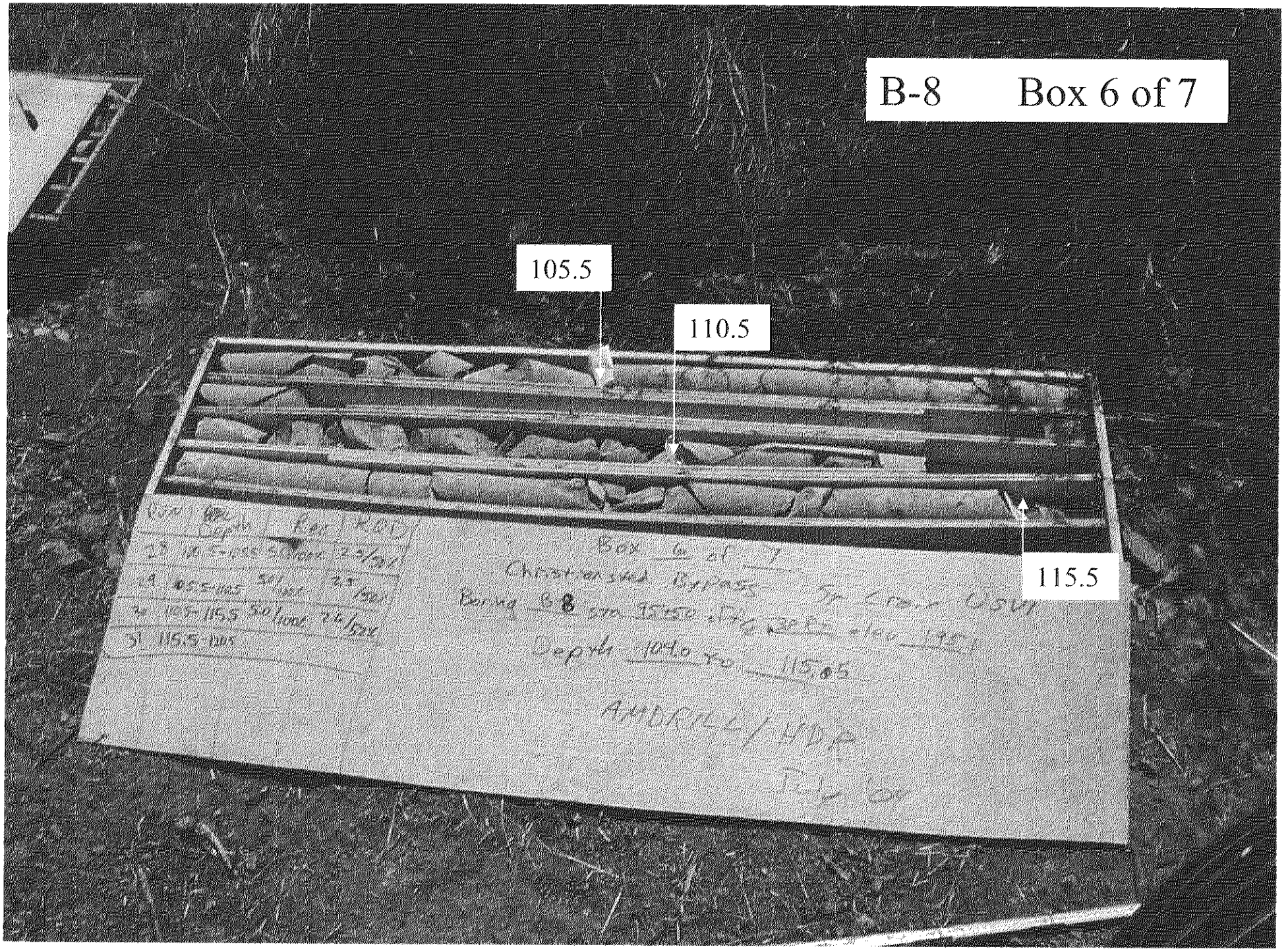
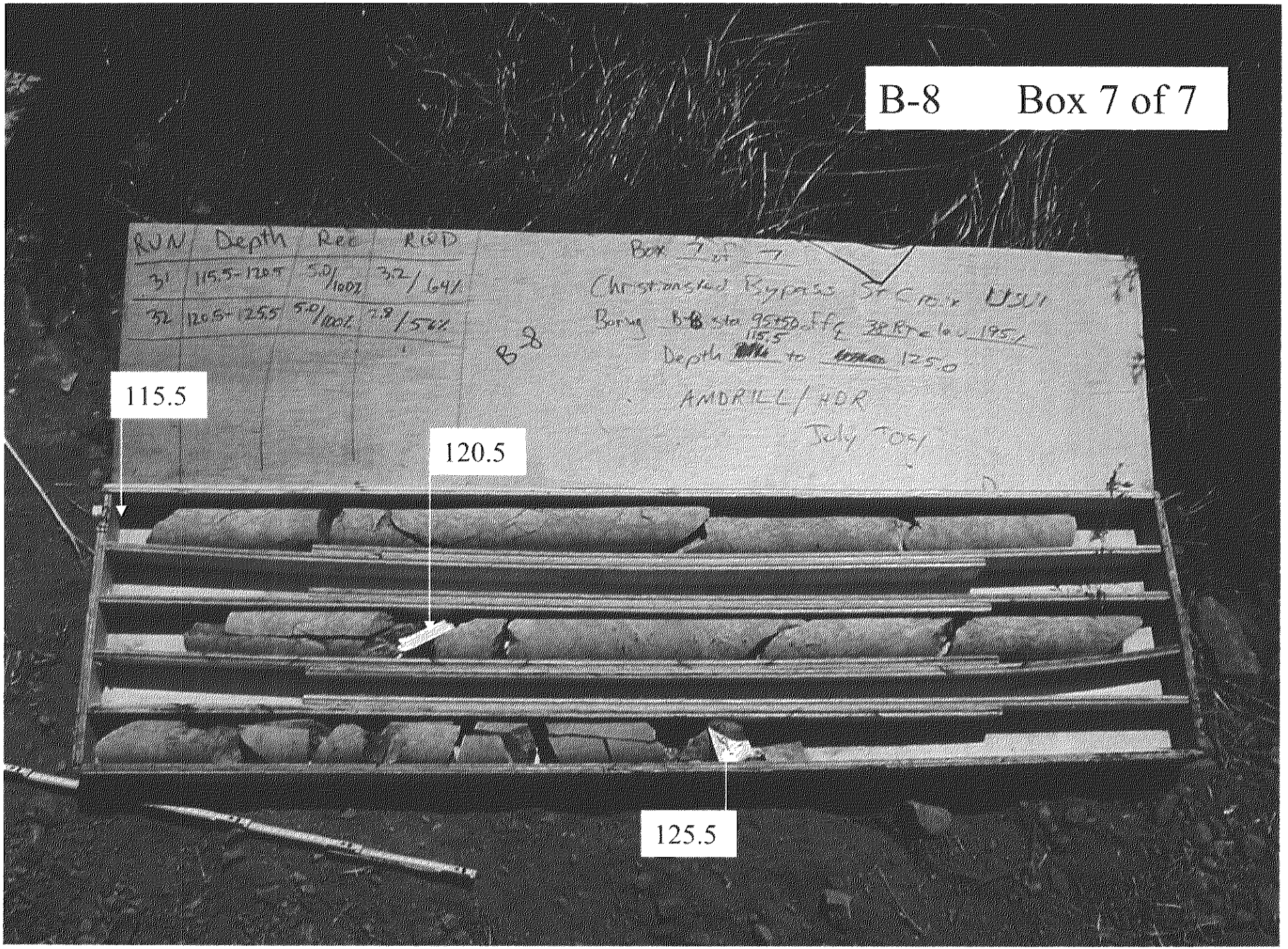
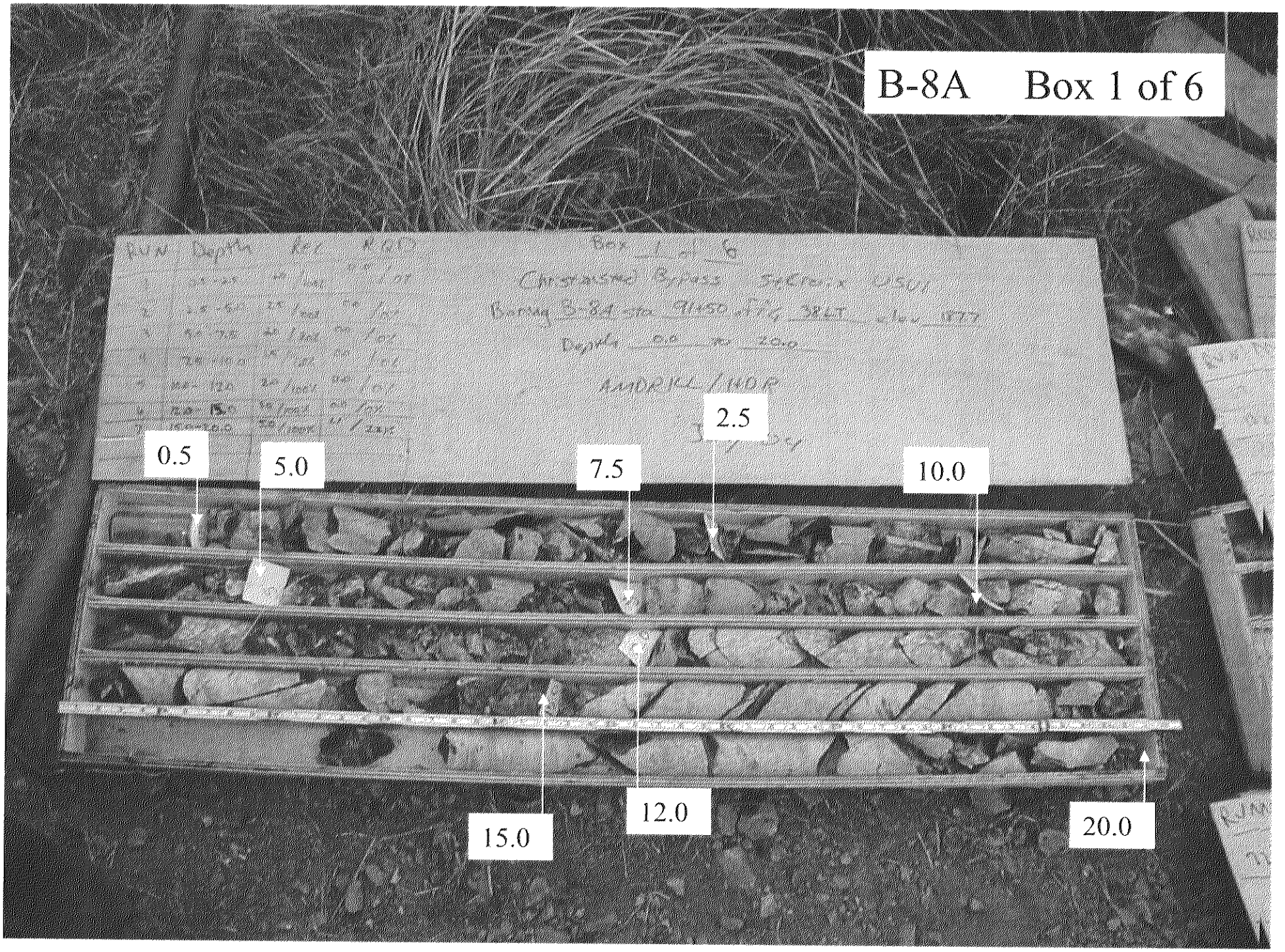
65.5
70.5
75.5
80.5


B-8 Box 5 of 7
85.5
90.5
95.5
100.5


B-8 Box 6 of 7
105.5
110.5
115.5
Box 6 of 7
Depth 105.0 to 115.5


B-8 Box 7 of 7
115.5
120.5
125.5

Boring B-8A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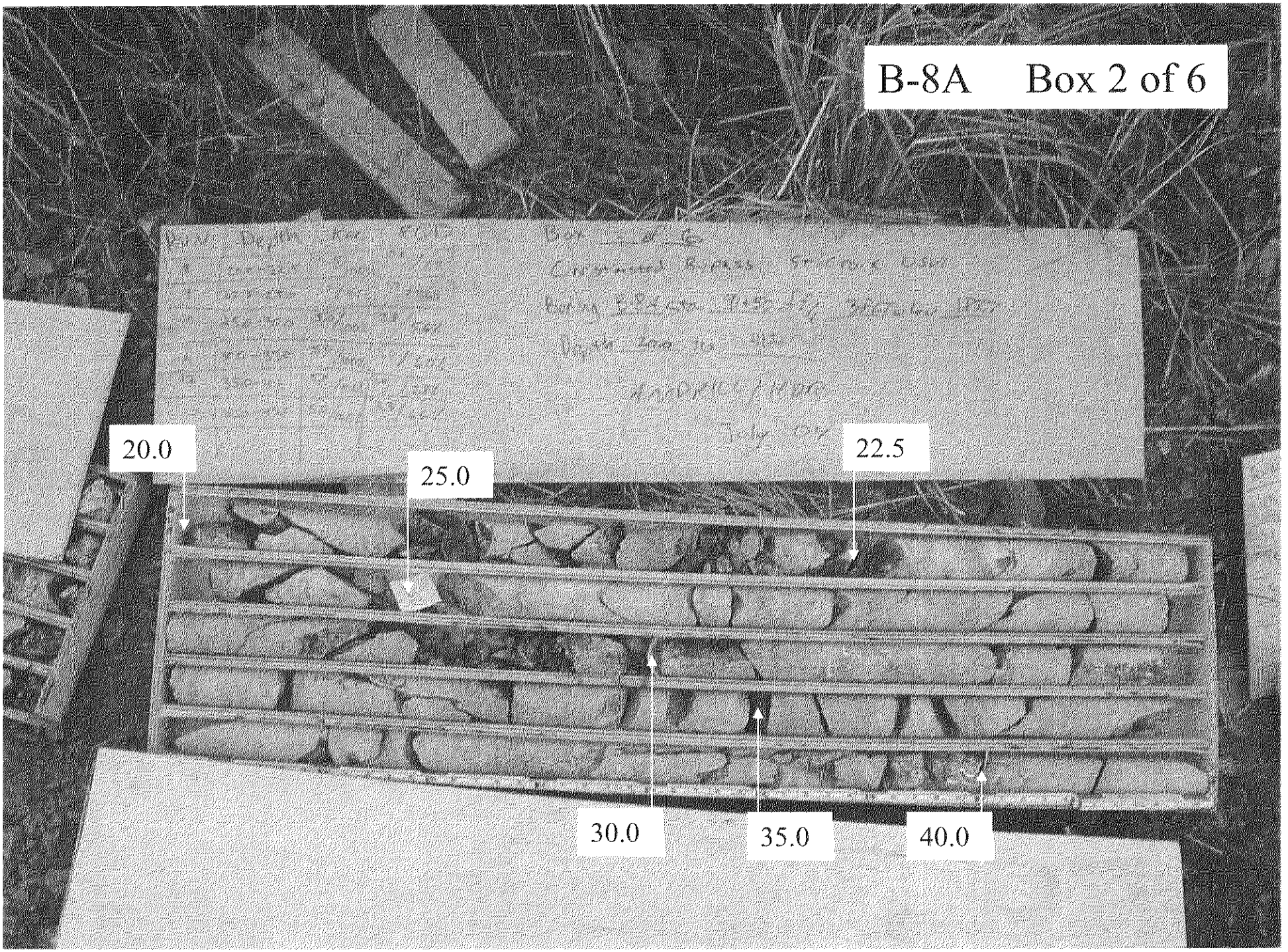
0.5
5.0
7.5
2.5
10.0
15.0
12.0
20.0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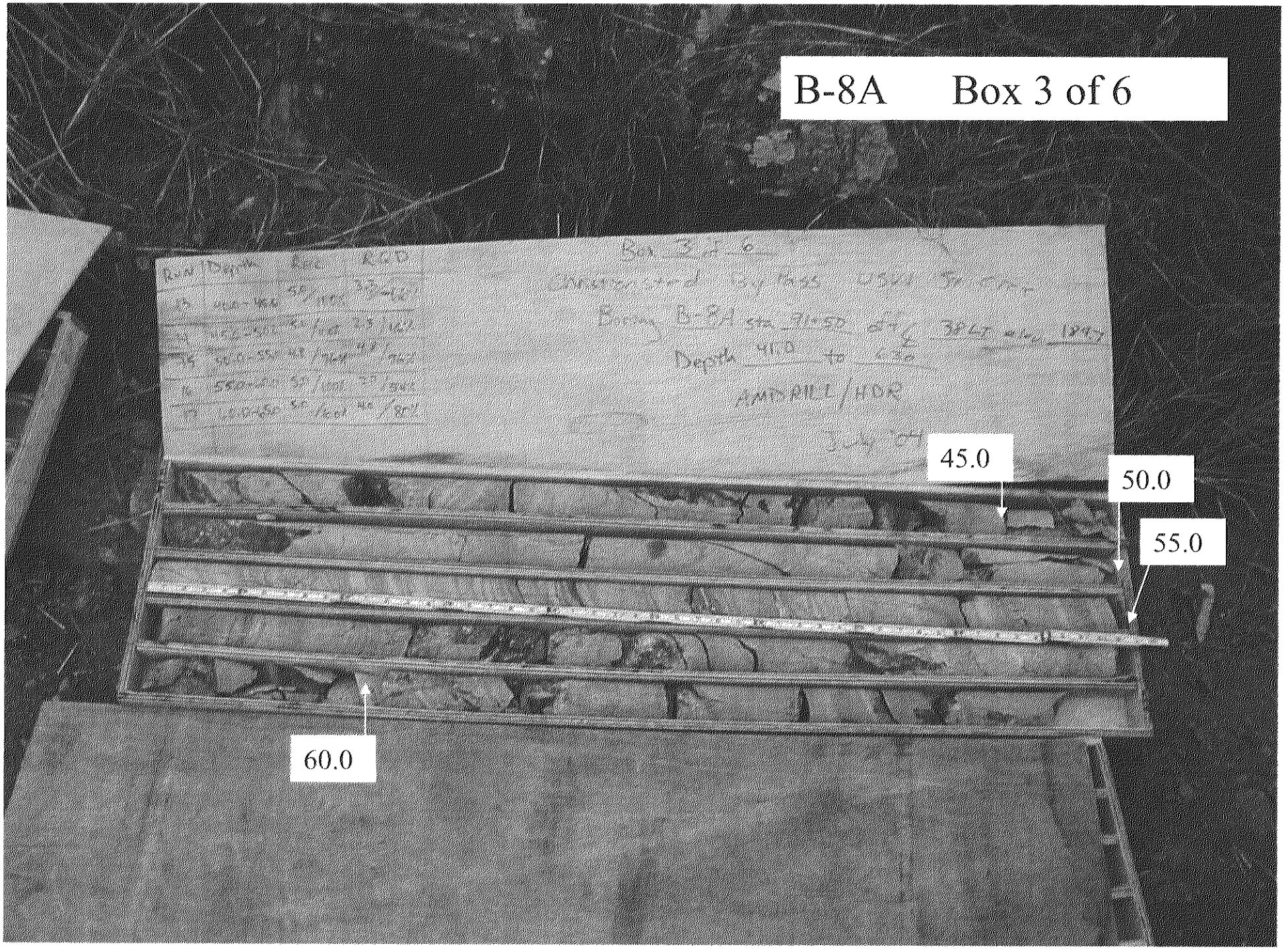
20.0
25.0
22.5
30.0
35.0
40.0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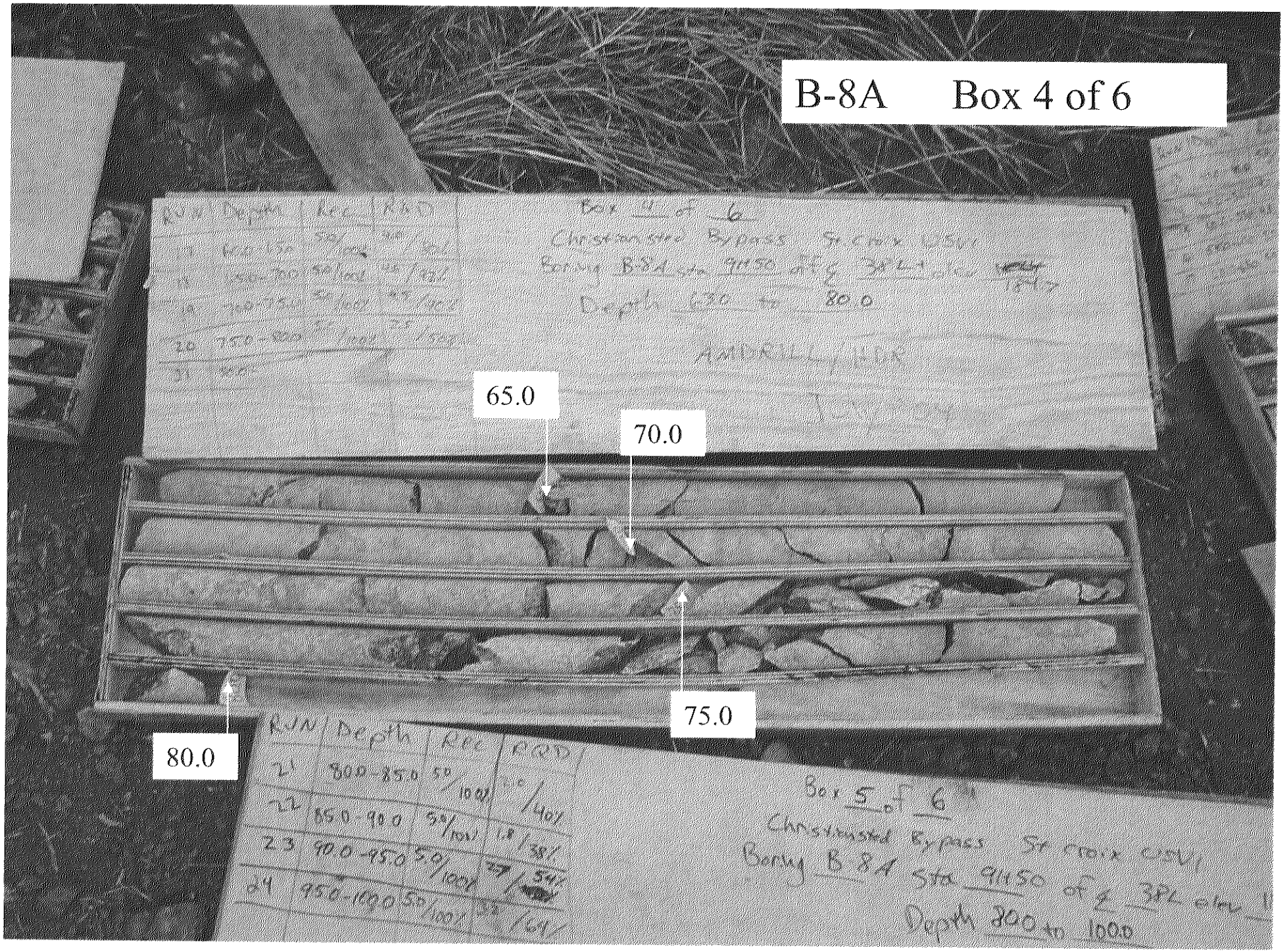
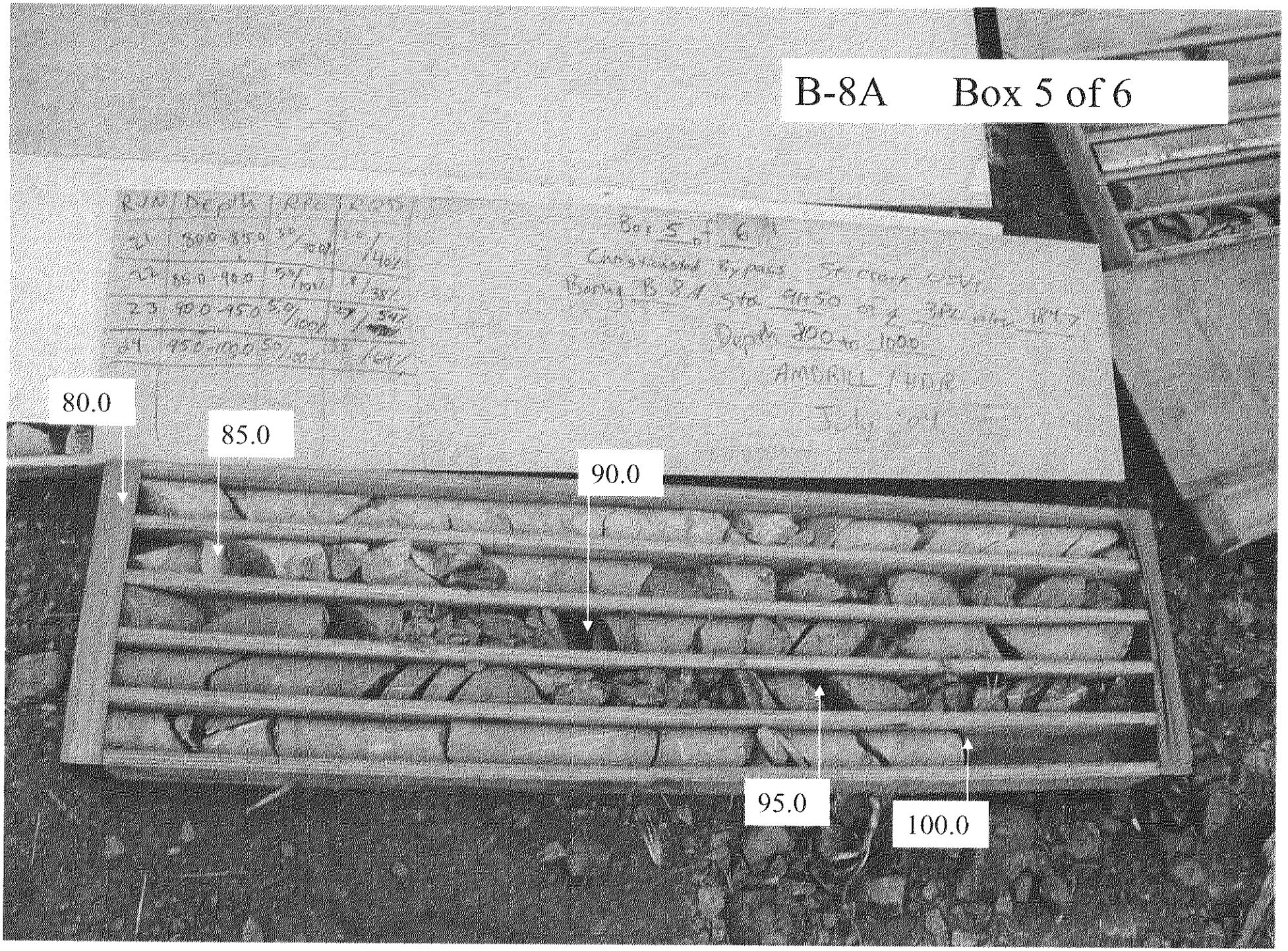
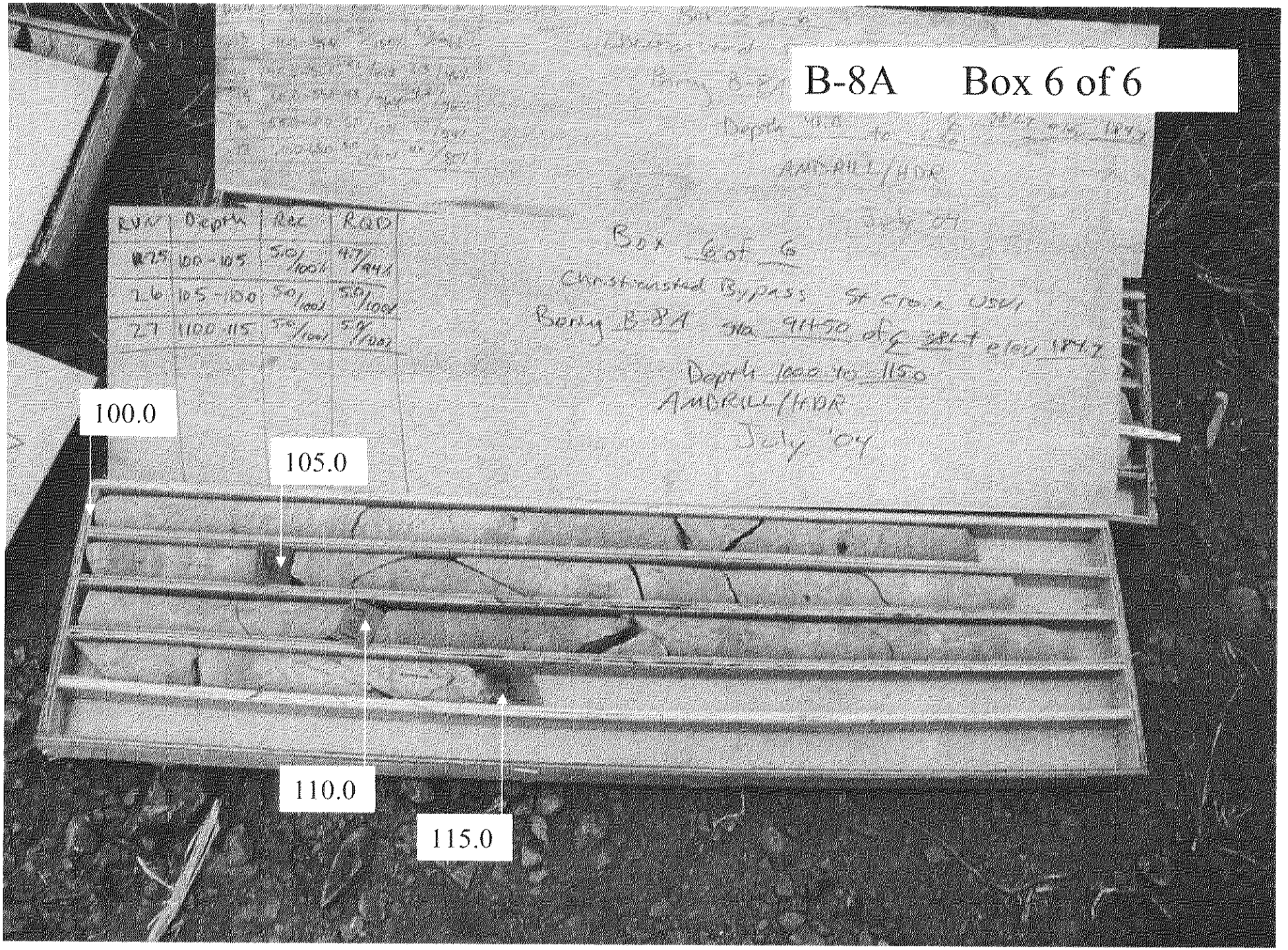
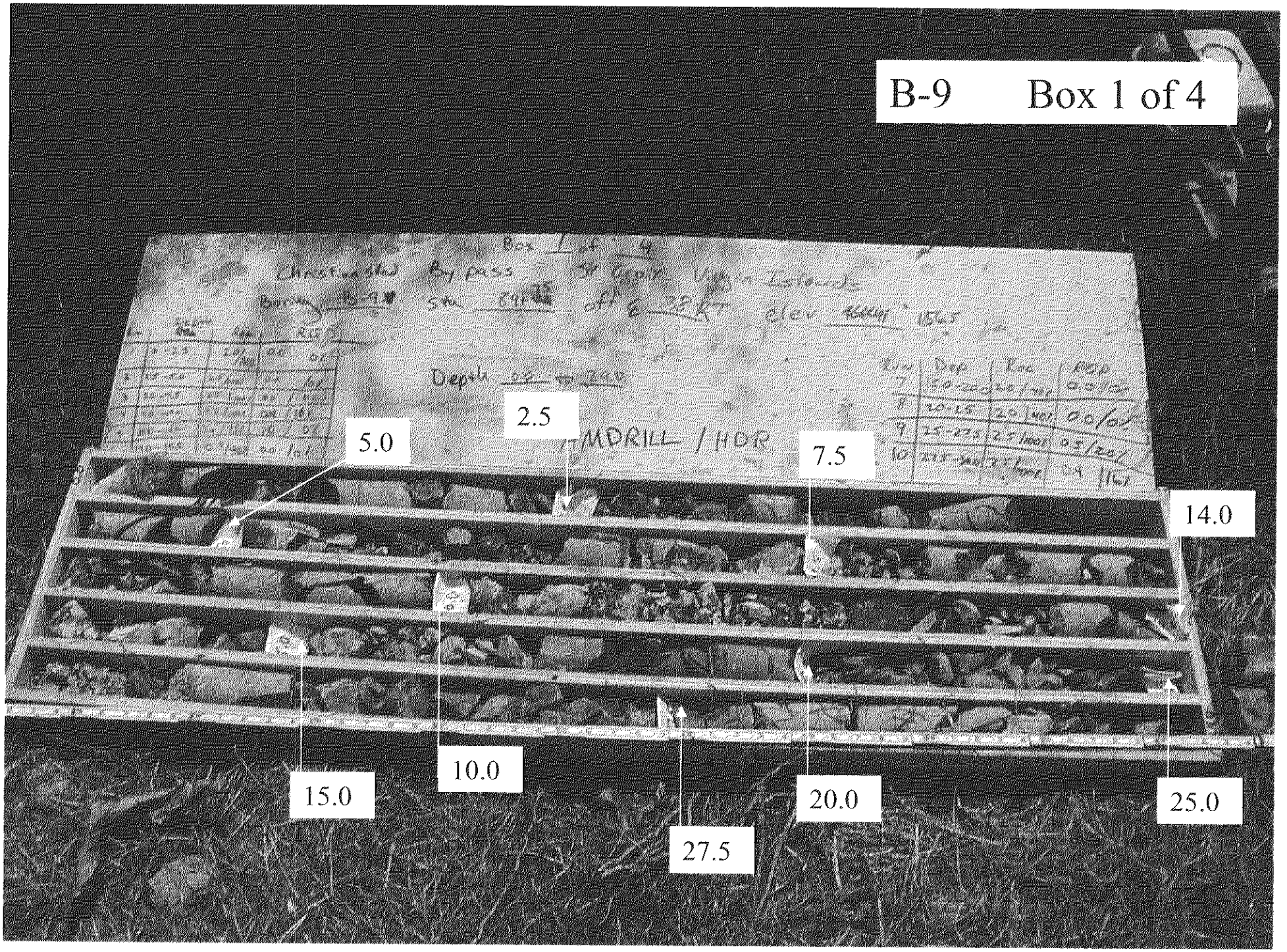
50.0
55.0
60.0

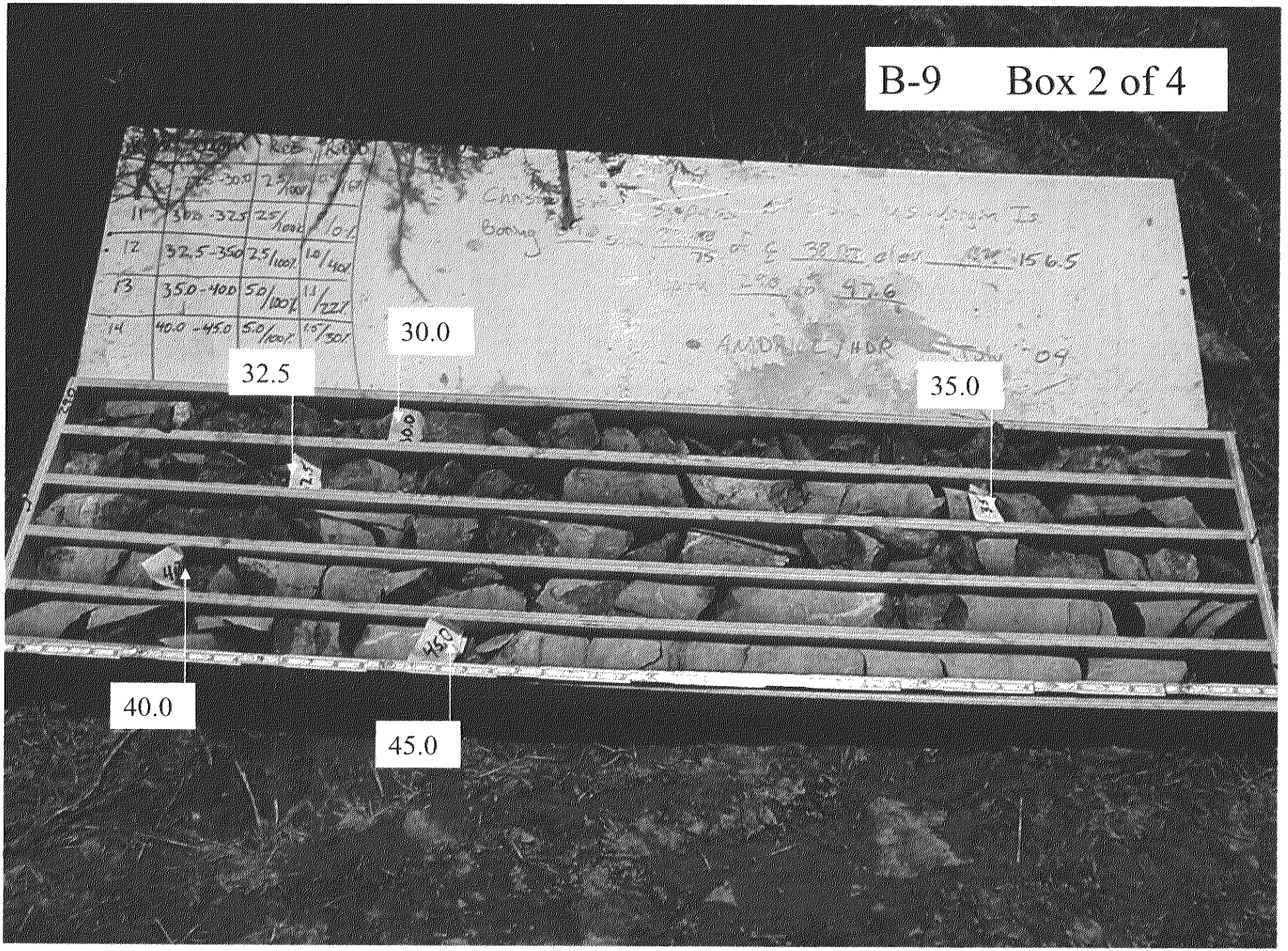

B-8A Box 4 of 6
65.0
70.0
75.0
80.0

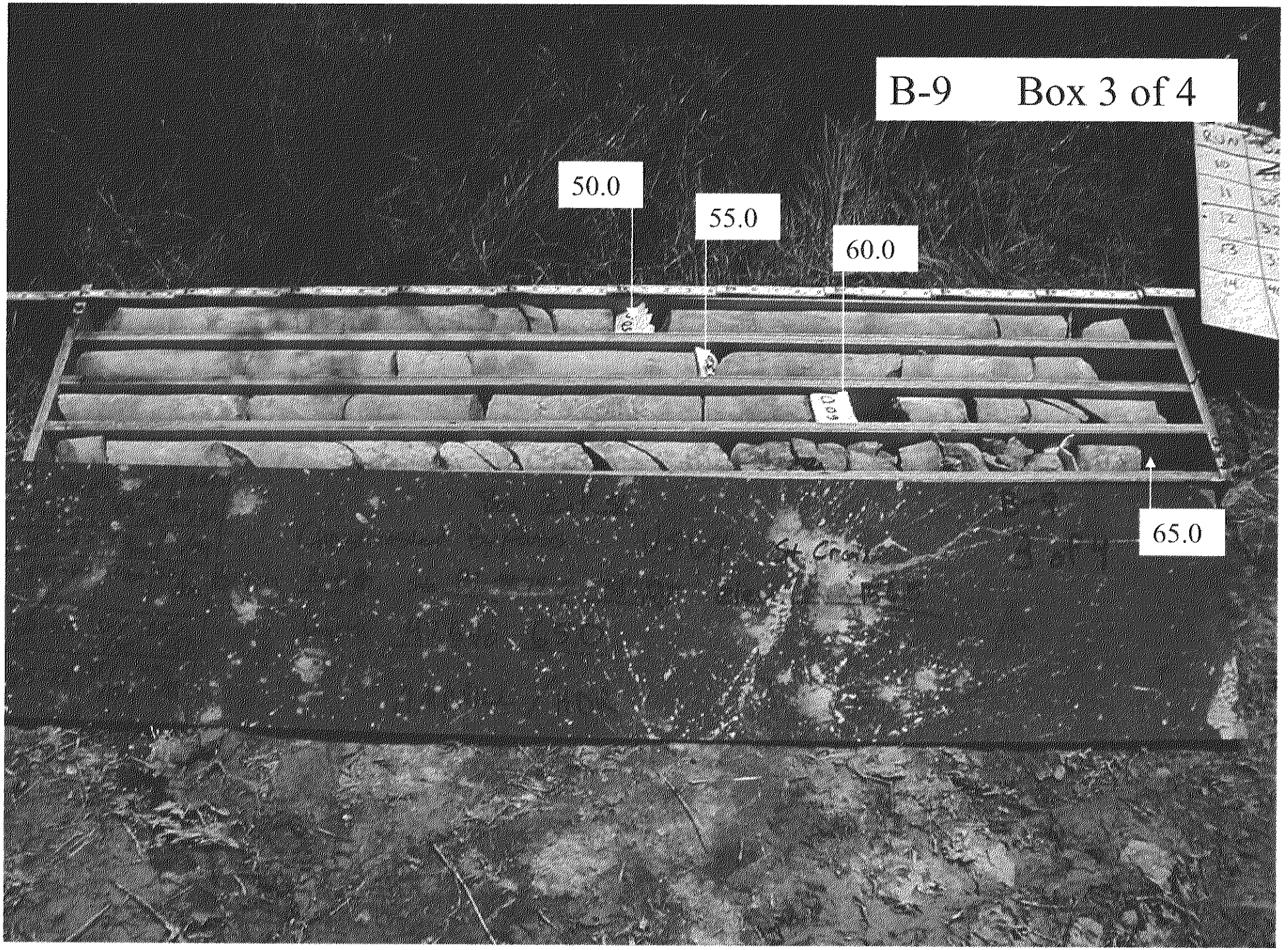

B-8A Box 5 of 6
80.0
85.0
90.0
95.0
100.0

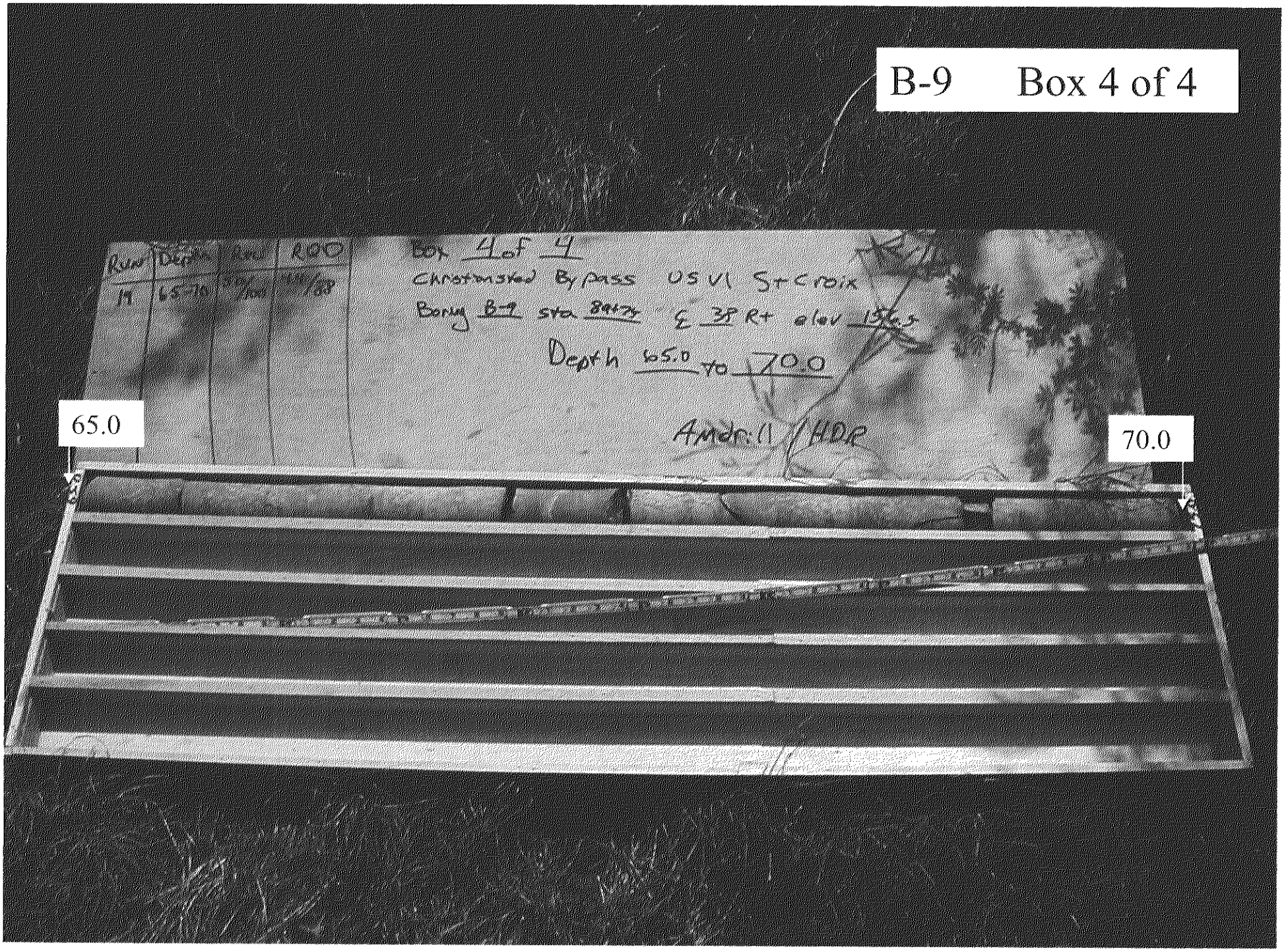

B-8A Box 6 of 6
Box 6 of 6
Christiansted Bypass St Croix USVI
Boring B-8A Sta 91+50 of ℄ 38Lt elev 184.7
Depth 100.0 to 115.0
AMDRILL/HDR
July '04
RUN Depth Rec RQD
25 100-105 5.0/100% 4.7/94%
26 105-110.0 5.0/100% 5.0/100%
27 110.0-115 5.0/100% 5.0/100%
100.0
105.0
110.0
115.0

Boring B-9

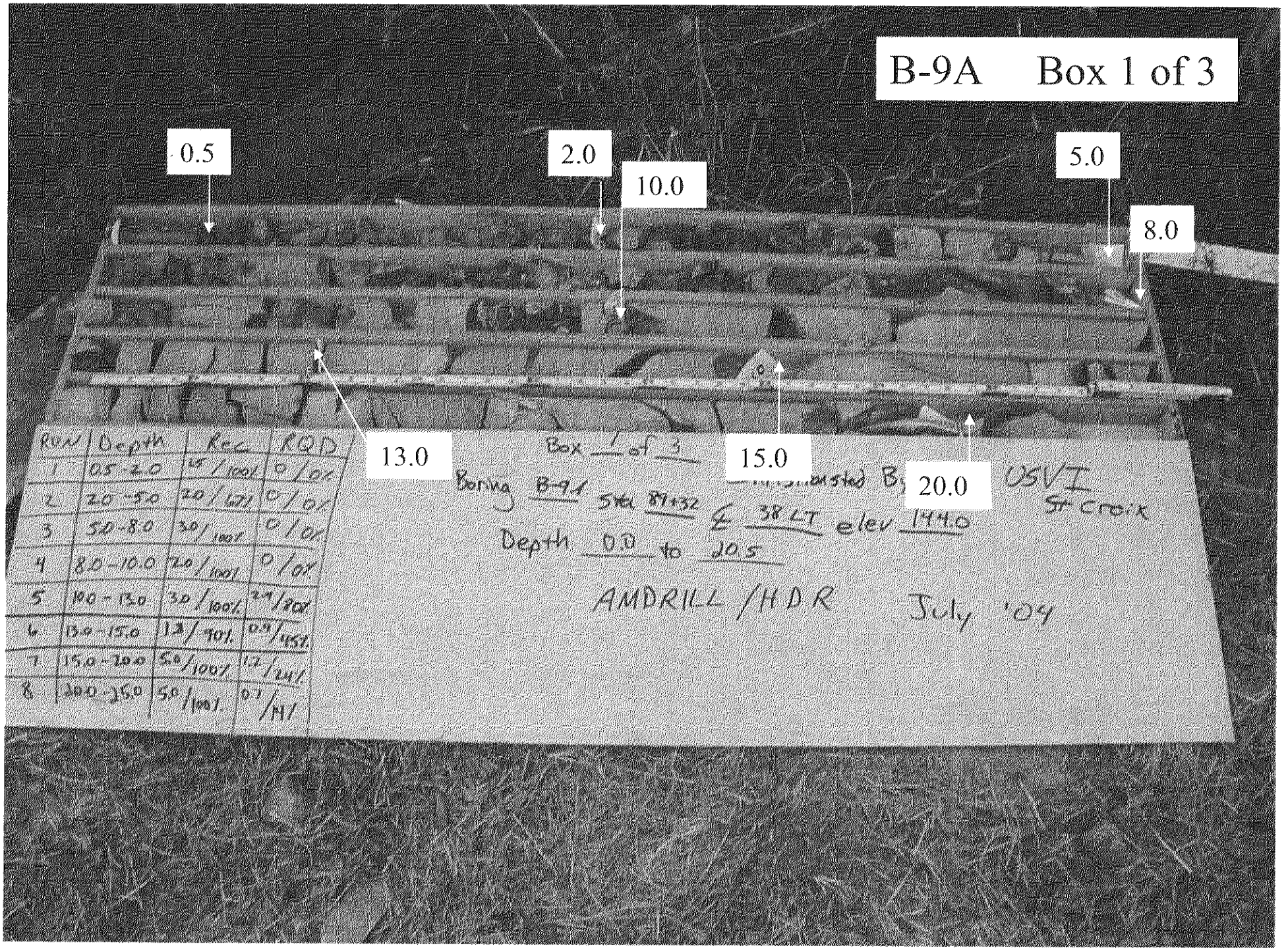

B-9 Box 1 of 4
5.0
2.5
7.5
14.0
15.0
10.0
20.0
25.0
27.5


B-9 Box 2 of 4
30.0
32.5
35.0
40.0
45.0

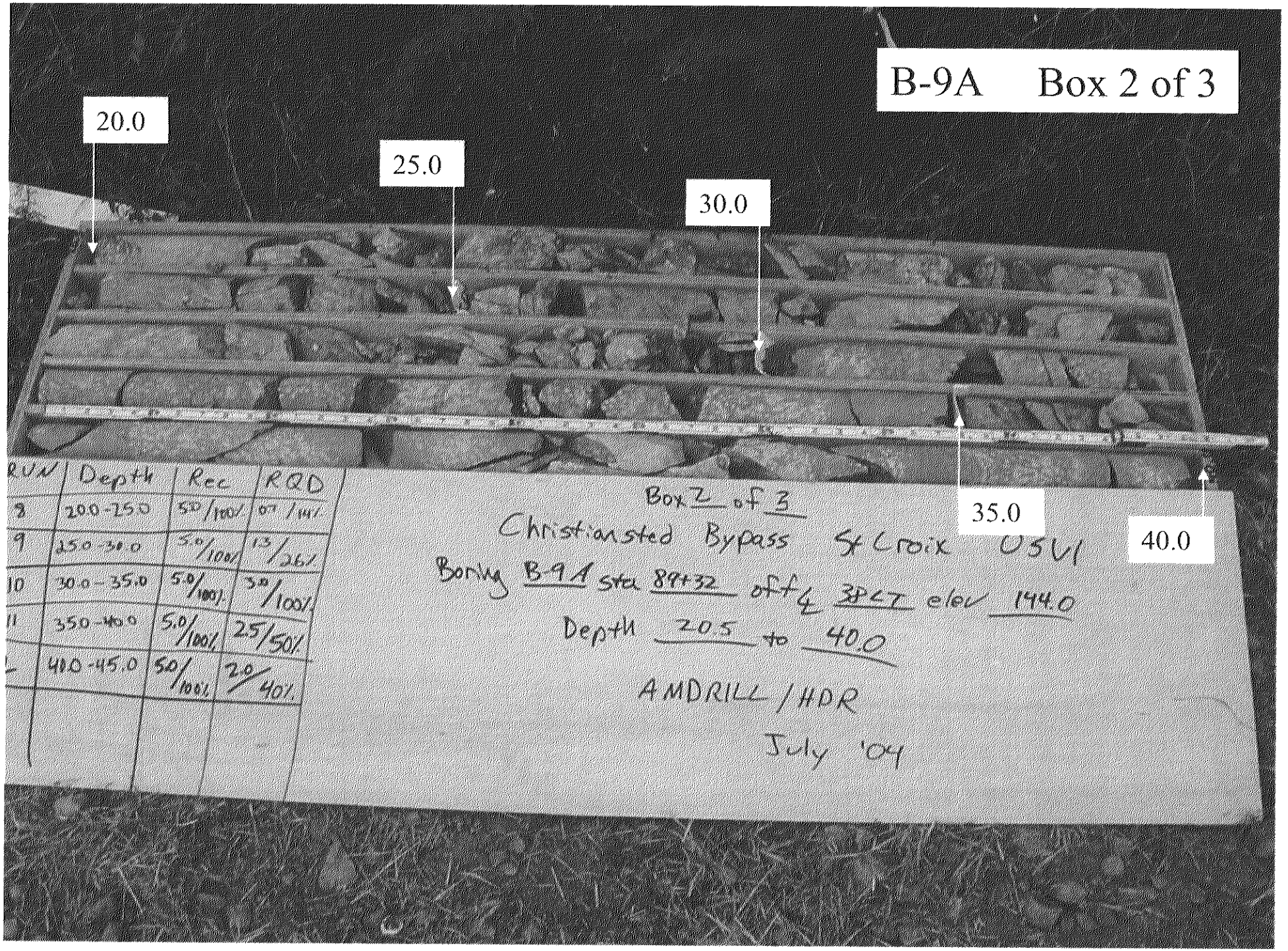

B-9 Box 3 of 4
50.0
55.0
60.0
65.0

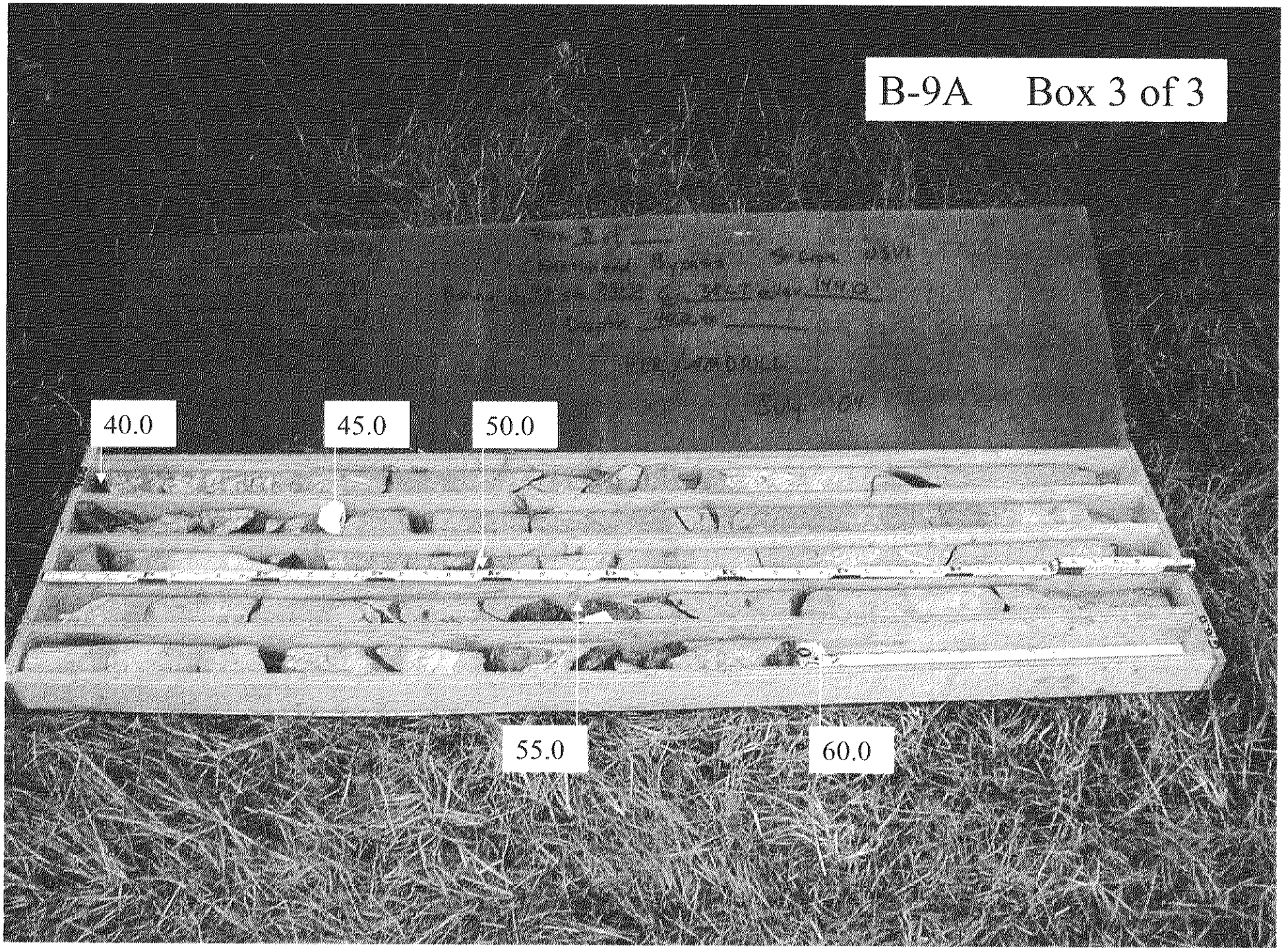

B-9 Box 4 of 4
Box 4 of 4
Christmasted By pass US VI St Croix
Boring B-9 sta 89+74 ℄ 38 Rt elev 156.5
Depth 65.0 to 70.0
Amdrill / HDR
65.0
70.0

Boring B-9A

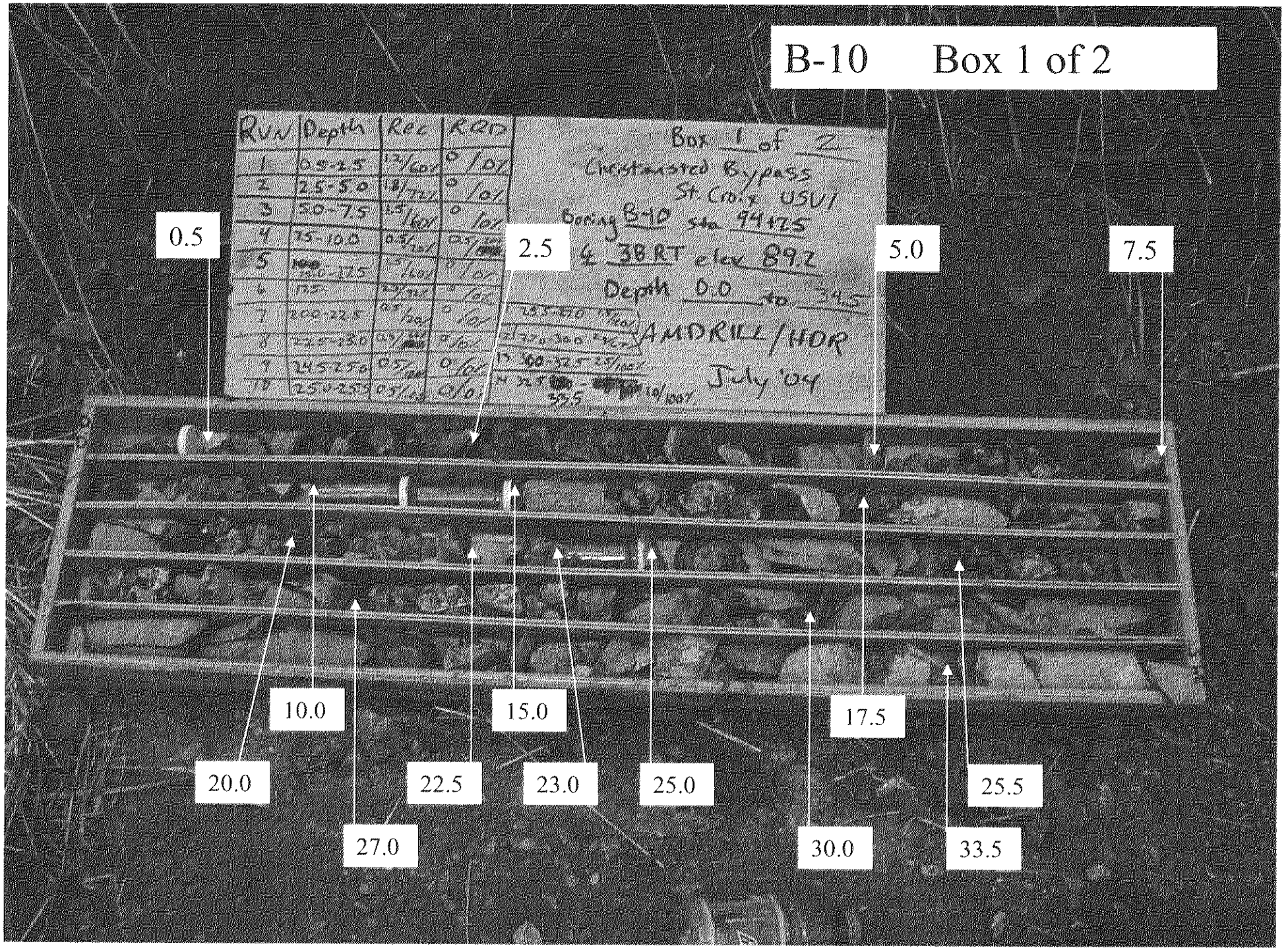


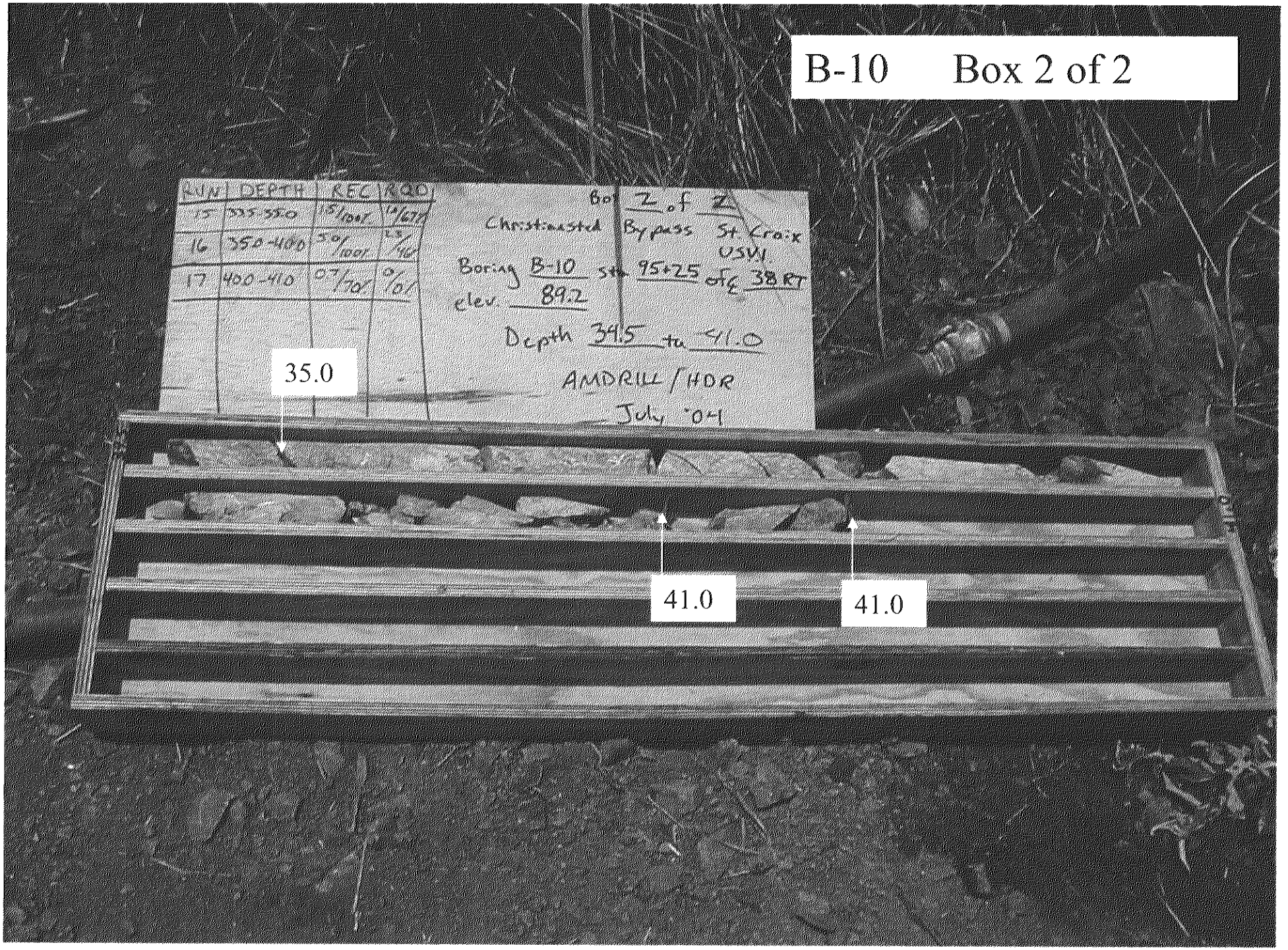
Run	Depth	Rec	RQD
1	0.5-2.0	1.5 / 100%	0 / 0%
2	2.0-5.0	2.0 / 67%	0 / 0%
3	5.0-8.0	3.0 / 100%	0 / 0%
4	8.0-10.0	2.0 / 100%	0 / 0%
5	10.0-13.0	3.0 / 100%	2.4 / 80%
6	13.0-15.0	1.3 / 90%	0.9 / 45%
7	15.0-20.0	5.0 / 100%	1.2 / 24%
8	20.0-25.0	5.0 / 100%	0.7 / 14%


B-9A Box 2 of 3
20.0
25.0
30.0
35.0
40.0
RUN | Depth | Rec | RQD
8 | 20.0-25.0 | 5.0/100% | 0.7/14%
9 | 25.0-30.0 | 5.0/100% | 1.3/26%
10 | 30.0-35.0 | 5.0/100% | 3.0/100%
11 | 35.0-40.0 | 5.0/100% | 2.5/50%
40.0-45.0 | 5.0/100% | 2.0/40%
Box 2 of 3
Christiansted Bypass St Croix USVI
Boring B-9A sta 89+32 off ℄ 38LT elev 144.0
Depth 20.5 to 40.0
AMDRILL / HDR
July '04

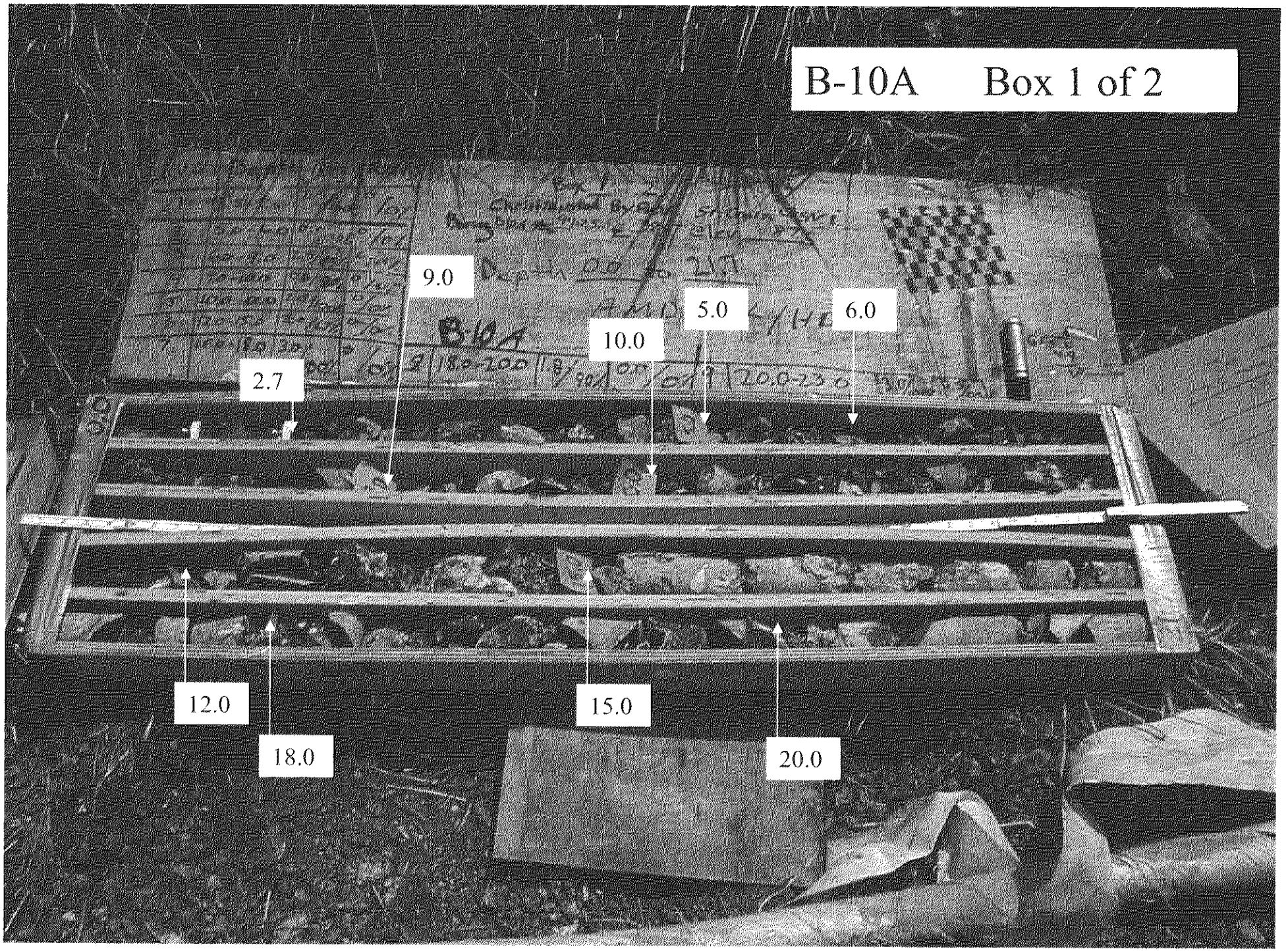

B-9A Box 3 of 3
40.0
45.0
50.0
55.0
60.0

Boring B-10


B-10 Box 1 of 2
Box 1 of 2
Christiansted Bypass
St. Croix USVI
Boring B-10 sta 94+25
℄ 38 RT elev 89.2
Depth 0.0 to 34.5
AMDRILL/HDR
July '04
0.5
2.5
5.0
7.5
10.0
15.0
17.5
20.0
22.5
23.0
25.0
25.5
27.0
30.0
33.5


B-10 Box 2 of 2
RUN DEPTH REC RQD
15 335-350 15/100% 12/67%
16 350-400 50/100% 23/46%
17 400-410 07/70% 0/0%
Box 2 of 2
Christiansted Bypass St. Croix USVI
Boring B-10 sta 95+25 of ℄ 38 RT
elev. 89.2
Depth 34.5 to 41.0
AMDRILL / HDR
July '04
35.0
41.0
41.0

Boring B-10A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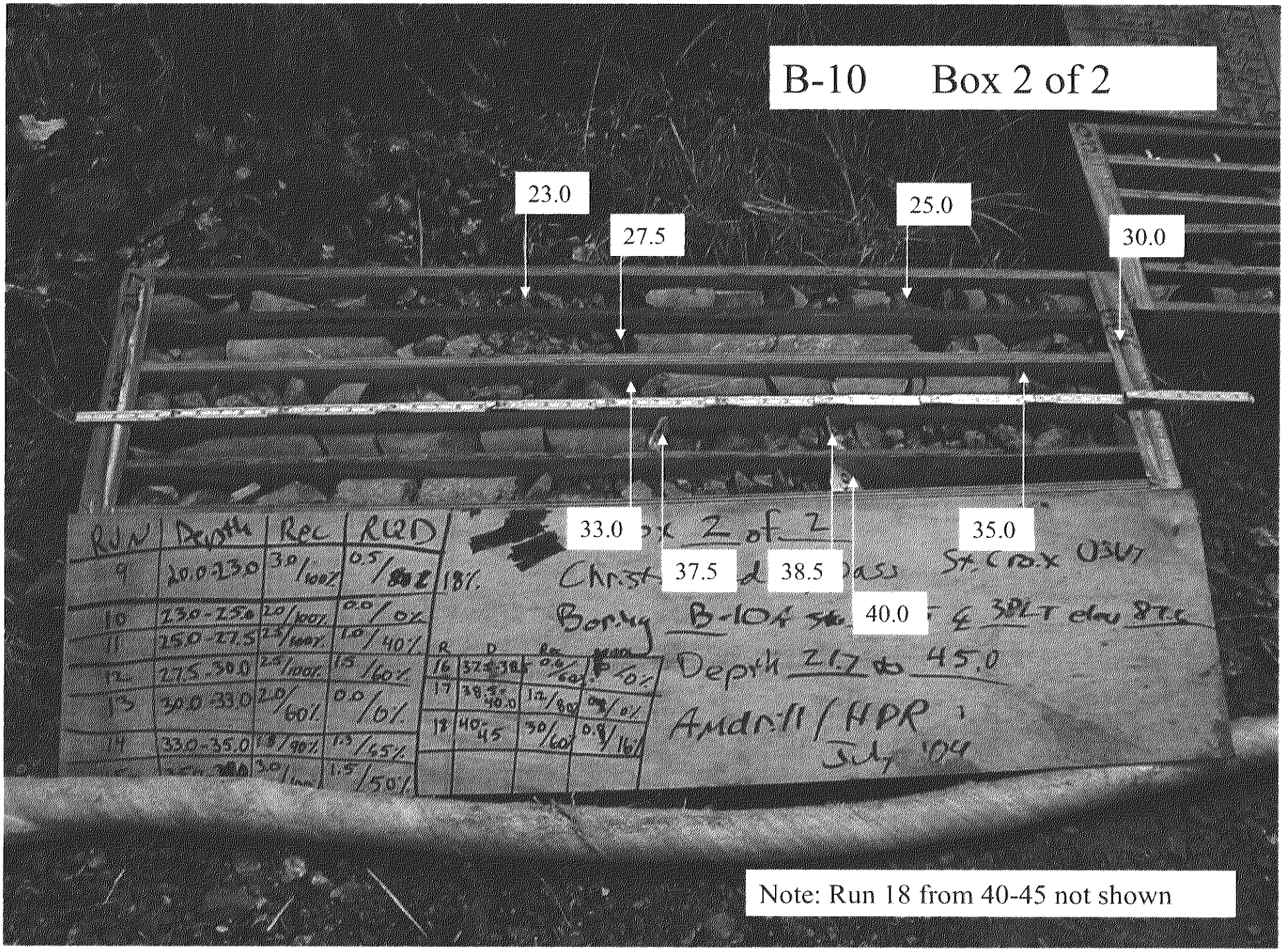
9.0
5.0
6.0
10.0
2.7
12.0
18.0
15.0
20.0


B-10 Box 2 of 2
23.0
27.5
25.0
30.0
33.0
37.5
38.5
40.0
35.0
Note: Run 18 from 40-45 not shown

Appendix E

Excerp s from References

(See Report References for Details)

- *Engineering Rock Mass Classifications* – by Bieniawski, Z.T., 1989

- *SMR Geomechanics Classification: Application, Experience and Validation* – by Romana, M., Seron, J.B., and Montalar,E., 2003

- *A Geomechanical Classification System for Slopes: Slope Mass Rating* – Pergamon Press, 1993

- *Rockfall Catchment Area Design Guide* (Final Report) - by Pierson, L.A.; Gullixson, C. F.; Chassie, R.G., 2001

Engineering Rock Mass Classifications

A Complete Manual for Engineers and Geologists in Mining, Civil, and Petroleum Engineering

Z. T. Bieniawski
Professor and Director
Mining and Mineral Resources Research Institute
The Pennsylvania State University

WILEY

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John Wiley & Sons

New York / Chichester / Brisbane / Toronto / Singapore

TABLE 4.1 The Rock Mass Rating System (Geomechanics Classification of Rock Masses)[a]

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

Parameter			Ranges of Values						
1	Strength of intact rock material	Point-load strength index (MPa)	>10	4–10	2–4	1–2	For this low range, uniaxial compressive test is preferred		
		Uniaxial compressive strength (MPa)	>250	100–250	50–100	25–50	5–25	1–5	<1
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD (%)		90–100	75–90	50–75	25–50	<25		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		>2 m	0.6–2 m	200–600 mm	60–200 mm	<60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered wall	Slickensided surfaces or Gouge < 5 mm thick or Separation 1–5 mm Continuous	Soft gouge > 5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Groundwater	Inflow per 10 m tunnel length (L/min)	None	<10	10–25	25–125	>125		
		or		or	or	or	or		
		Ratio $\frac{\text{Joint water pressure}}{\text{Major principal stress}}$	0	<0.1	0.1–0.2	0.2–0.5	>0.5		
		or		or	or	or	or		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

	stress	or	or	or		
	General conditions	Completely dry	Damp	Wet	Dripping	Flowing
Rating		15	10	7	4	0

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS

Strike and Dip Orientations of Discontinuities		Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
Ratings	Tunnels and mines	0	−2	−5	−10	−12
	Foundations	0	−2	−7	−15	−25
	Slopes	0	−5	−25	−50	−60

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	<20
Class no.	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK MASS CLASSES

Class no.	I	II	III	IV	V
Average stand-up time	20 yr for 15-m span	1 yr for 10-m span	1 wk for 5-m span	10 h for 2.5-m span	30 min for 1-m span
Cohesion of the rock mass (kPa)	>400	300–400	200–300	100–200	<100
Friction angle of the rock mass (deg)	>45	35–45	25–35	15–25	<15

[a] After Bieniawski (1979).

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CHART A Ratings for Strength of Intact Rock

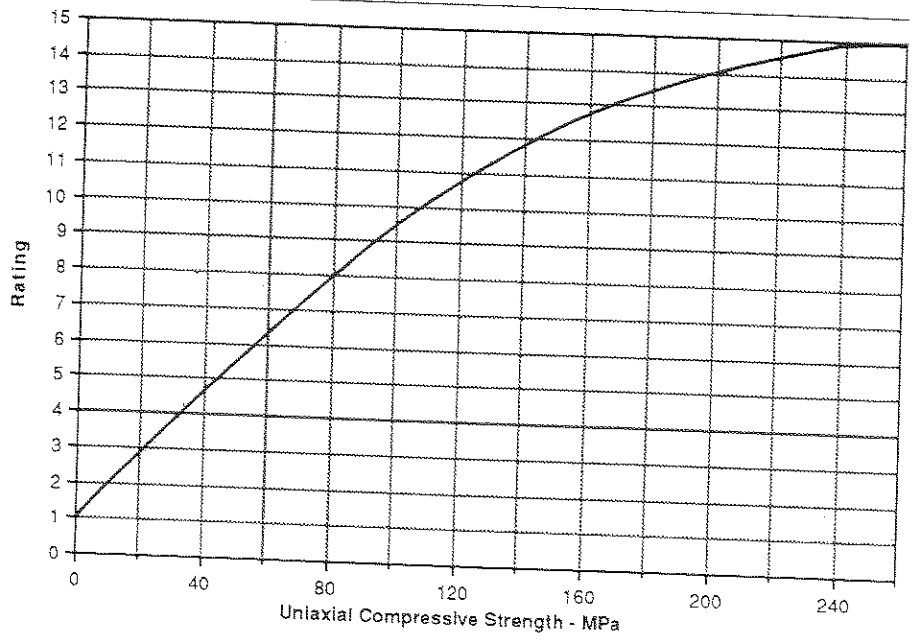
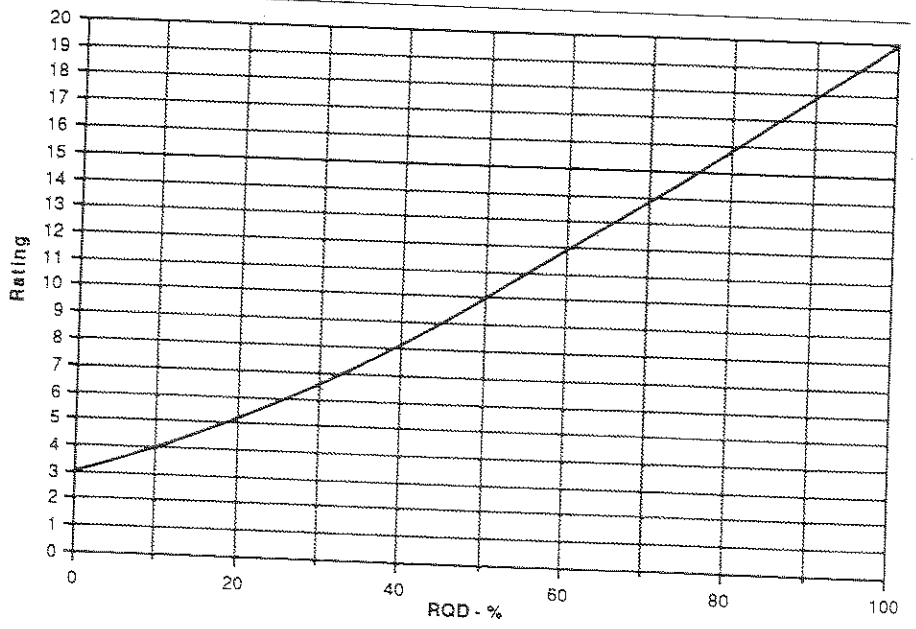


CHART B Ratings for RQD



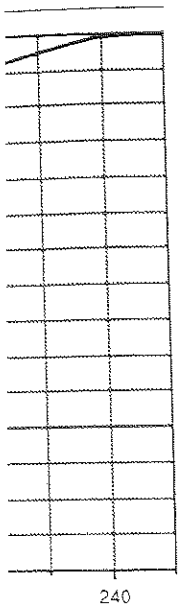
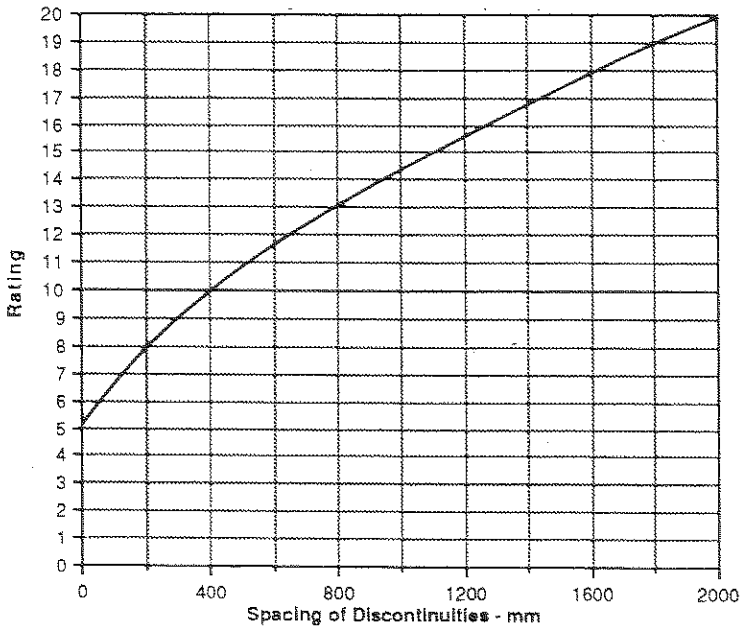


CHART C Ratings for Discontinuity Spacing



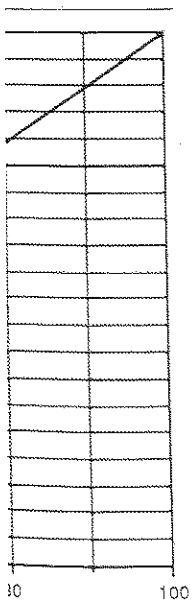


CHART D Chart for Correlation between RQD and Discontinuity Spacing

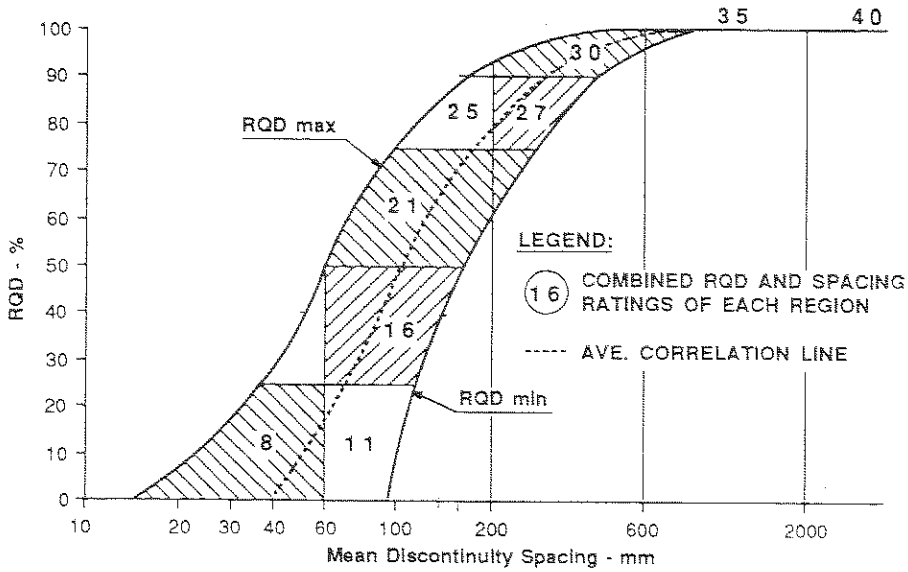


CHART E Guidelines for Classification of Discontinuity Conditions[a]

Parameter	Ratings				
Discontinuity length (persistence/continuity)	<1 m 6	1–3 m 4	3–10 m 2	10–20 m 1	>20 m 0
Separation (aperture)	None 6	<0.1 mm 5	0.1–1.0 mm 4	1–5 mm 1	>5 mm 0
Roughness	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge)	Hard filling			Soft filling	
	None 6	<5 mm 4	>5 mm 2	<5 mm 2	>5 mm 0
Weathering	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

[a] *Note:* Some conditions are mutually exclusive. For example, if infilling is present, it is irrelevant what the roughness may be, since its effect will be overshadowed by the influence of the gouge. In such cases, use Table 4.1 directly.

TABLE 4.2 Effect of Discontinuity Strike and Dip Orientations in Tunneling[a]

Strike Perpendicular to Tunnel Axis			
Drive with Dip		Drive against Dip	
Dip 45–90	Dip 20–45	Dip 45–90	Dip 20–45
Very favorable	Favorable	Fair	Unfavorable

Strike Parallel to Tunnel Axis		Irrespective of Strike
Dip 20–45	Dip 45–90	Dip 0–20
Fair	Very unfavorable	Fair

[a] Modified after Wickham et al. (1972).

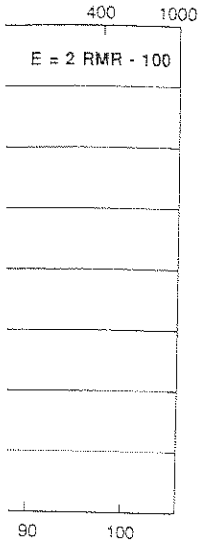
summed-up ratings of the classification parameters for this discontinuity set will constitute the overall RMR. On the other hand, in situations where no one discontinuity set is dominant and of critical importance, or when estimating rock mass strength and deformability, the ratings from each discontinuity set are averaged for the appropriate individual classification parameter.

In the case of civil engineering projects, an adjustment for discontinuity orientations will generally suffice. For mining applications, other adjustments may be called for, such as the stress at depth or a change in stress; these have been discussed by Laubscher (1977) and by Kendorski et al. (1983). The procedure for these adjustments is depicted in Table 4.3.

After the adjustment for discontinuity orientations, the rock mass is classified according to Section C of Table 4.1, which groups the final (adjusted) RMR into five rock mass classes, the full range of the possible RMR values varying from zero to 100. Note that the rock mass classes are in groups of 20 ratings each. This concept of rating a rock mass out of a maximum value of 100 has a distinct advantage over an open-ended system in that it allows the engineer or geologist to get the sense of a relative quality, or the lack of it, of a given rock mass in terms of its maximum potential.

Next, Section D of Table 4.1 gives the practical meaning of each rock mass class by relating it to specific engineering problems. In the case of tunnels, chambers, and mines, the output from the Geomechanics Classification is the stand-up time and the maximum stable rock span for a given RMR, as shown in Figure 4.1.

When mixed-quality rock conditions are encountered at the excavated rock face, such as good-quality and poor-quality rock being present in one exposed area, it is essential to identify the "most critical condition" for the assessment of the rock strata. This means that the geological features most significant for stability purposes will have an overriding influence. For example, a fault or shear in high-quality rock face will play a dominant role irrespective of the high rock material strength in the surrounding strata.



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RMR cases. (After Barton,

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k slopes. He developed
liscontinuity orientation
. Recognizing that rock
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The new adjustment rating for joints in rock slopes is a product of three factors:

F_1 reflects parallelism between the slope and the discontinuity strike.
F_2 refers to the discontinuity dip in the plane mode of failure.
F_3 relates to the relationship between the slope angle and the discontinuity dip.

The adjustment factor for the method of excavation F_4 depends on whether one deals with a natural slope or one excavated by presplitting, smooth blasting, mechanical excavation, or poor blasting.

The appropriate ratings are given in Table 9.5. The final calculation is of the form

$$\text{Adjusted RMR slope} = \text{RMR}_{\text{basic}} + (F_1 \times F_2 \times F_3) + F_4 \quad (9.13)$$

Romana (1985) applied this procedure to 28 slopes with varying degrees of instability, including six completely failed ones, and found good agreement with stability assessment (rock mass quality) predicted by the RMR system. He listed all these case histories and stated that further work is under way on several other slopes.

9.4 SPECIAL USES

9.4.1 Rippability

This was the first excavation index to be evaluated by a rock mass classification approach. Based on the Geomechanics Classification, Weaver (1975) proposed a rippability rating chart as a guide for the case of excavation by tractor-mounted rippers of the Caterpillar type. In this approach, seismic velocity was a parameter selected to replace two standard parameters in the RMR system: the intact rock strength and the RQD.

Over a decade later, Smith (1986) modified the chart by Weaver (1975) by omitting seismic velocity, while Singh et al. (1986) discussed ground rippability in open cast mining operations and pointed out that the use of a single value of the seismic velocity can be a misleading parameter in the assessment of the rock rippability. The chart by Weaver (1975), and hence by Smith (1986), while based on many pertinent parameters, was considered of limited value because some parameters might not be easily quantified at the initial stage of design. Accordingly, an alternative rippability rating chart was suggested by Singh et al. (1986) and tested in a number of case histories

TABLE 9.5 Modification of the Geomechanics Classification for Rock Slopes[a]

	Parameter		Bieniawski (1979) Ratings for RMR — Ranges of Values						
1	Strength of intact rock material	Point-load strength index (MPa)	>10	4–10	2–4	1–2	For this low range, uniaxial compressive strength test is preferred		
		Uniaxial compressive strength (MPa)	psi > 36,000 >250	14500-36,000 100–250	7250-14500 50–100	3625-7250 25–50	5–25	1–5	<1
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD (%)		90–100	75–90	50–75	25–50		<25	
	Rating		20	17	13	8		3	
3	Spacing of discontinuities		>2 m	0.6–2 m	200–600 mm	60–200 mm		<60 mm	
	Rating		20	15	10	8		5	
	Condition of discontinuities		Very rough surfaces. Not continuous. No separation. Unweathered wall rock	Slightly rough surfaces. Separation < 1 mm. Slightly weathered walls	Slightly rough surfaces. Separation < 1mm. Highly weathered walls	Slickensided surfaces. Or Gouge < 5 mm thick. Or Separation 1–5 mm Continuous		Soft gouge > 5 mm or Separation > 5 mm Continuous	

extracted from all known case histories for the Rock Mass Rating system. Each chapter ends with extensive references and there is an

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2	Drill core quality RQD (%)	90–100	75–90	50–75	25–50		<25	
	Rating	20	17	13	8		3	
3	Spacing of discontinuities	>2 m	0.6–2 m	200–600 mm	60–200 mm		<60 mm	
	Rating	20	15	10	8		5	
4	Condition of discontinuities	Very rough surfaces. Not continuous. No separation. Unweathered wall rock	Slightly rough surfaces. Separation < 1 mm. Slightly weathered walls	Slightly rough surfaces. Separation < 1mm. Highly weathered walls	Slickensided surfaces. Or Gouge < 5 mm thick. Or Separation 1–5 mm Continuous		Soft gouge > 5 mm or Separation > 5 mm Continuous	
	Rating	30	25	20	10		0	
5	Groundwater in joint	Completely dry	Damp	Wet	Dripping		Flowing	
	Rating	15	10	7	4		0	

Joint Adjustment Rating for Joints[b]

Case		Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
P	$\lvert\alpha_j - \alpha_s\rvert$	>30°	30–20°	20–10°	10–5°	<5°
T	$\lvert\alpha_j - \alpha_s - 180°\rvert$					
P/T	F_1	0.15	0.40	0.70	0.85	1.00
P	$\lvert\beta_j\rvert$	<20°	20–30°	30–35°	35–45°	>45°
P	F_2	0.15	0.40	0.70	0.85	1.00
T	F_2	1	1	1	1	1
P	$\beta_j - \beta_s$	>10°	10–0°	0°	0°–(−10°)	<−10°
T	$\beta_j + \beta_s$	<110°	110–120°	>120°		
P/T	F_3	0	−6	−25	−50	−60

P = plane failure. α_s = slope dip direction. α_j = joint dip direction.
T = toppling failure. β_s = slope dip. β_j = joint dip.

(Table continues on p. 190.)

TABLE 9.5 *(Continued)*

Adjustment Rating for Methods of Excavation of Slopes

Method	Natural Slope	Presplitting	Smooth Blasting	Regular Blasting	Deficient Blasting
F_4	+15	+10	+8	0	−8

$SMR = RMR - (F_1 \times F_2 \times F_3) + F_4$

Tentative Description of SMR Classes

Class No.	V	IV	III	II	I
SMR	0–20	21–40	41–60	61–80	81–100
Description	Very poor	Poor	Fair	Good	Very good
Stability	Very unstable	Unstable	Partially stable	Stable	Fully Stable
Failures	Large planar or soil-like	Planar or large wedges	Some joints or many wedges	Some blocks	None
Support	Reexcavation	Extensive corrective	Systematic	Occasional	None

[a] By Romana (1985).

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Romana, M., Serón, J.B., Montalar, E., SMR Geomechanics classification: Application, experience and validation
ISRM 2003–Technology roadmap for rock mechanics, South African Institute of Mining and Metallurgy, 2003.

SMR Geomechanics classification: Application, experience and validation

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The SMR geomechanics classification system (adaptation of RMR for slopes) is reviewed with data from 87 actual slopes in Valencia. In a research project, SMR has been applied by a GIS system, as a method to forecast stability problems in future road construction. As a result of this work a methodology for GIS application has been developed.

On revient sur la classification geomechanique SMR (une adaptation du RMR pour talus et pentes) avec les dates de 87 talus existant autour de Valencia. Dans le cadre d'un projet de recherche SMR a été appliquée, avec un système GIS, comme méthode de prévision de stabilité problèmes dans la construction de futures routes. Une méthodologie pour l'application du GIS a été développe.

Das Geomechanische Einteilungssystem SMR (eine Anpassung des RMR an Böschungen) wird an Hand der Daten von 87 Böschungen im Gebiet von Valencia überdacht. In einem Forschungsprojekt wurde das SMR in einem Geographischen Informationssystem (GIS) als Methode zur Vorhersage von Stabilitätsproblemen bei zukünftigen Straßenbauprojekten eingesetzt. Das Ergebnis dieser Arbeit ist die Entwicklung einer Methodologie für die GIS-Anwendung

Introduction

RMR "Rock Mass Rating" geomechanics classification (also called CSIR) was introduced and developed by BIENIAWSKI (1973, 1984, 1989) deal extensively with RMR (and other geomechanics classification systems). A good recent reference to RMR application to tunnels in BIENIAWSKI (1993). RMR has become a standard for use in tunnels and many professionals apply it to describe any rock mass. ORR (1996) has given a good overview of the RMR use in slopes. LAUBSCHER (1976), HALL (1985) and ORR (1992) proposed different relationships between RMR value and limit angle for slopes. STEFFEN (1978) classified 35 slopes and concluded that "results had a statistical trend". ROBERTSON (1988) established that when RMR > 40 the slope stability is governed both by orientation and shear strength of discontinuities whereas for RMR < 30 the failure develops across the rock mass.

In the 1976 version, the "rating adjustments for discontinuity orientation" for slopes were: very favourable 0, favourable – 5, fair –25, unfavourable –50, very unfavourable –50, very unfavourable –60. No guidelines have been published for the definition of each class. A mistake in this value can supersede by far any careful evaluation of the rock mass, and classification work becomes both difficult and arbitrary. ROMANA (1985, 1993, 1995) proposed a new addenda to RMR concept, specially suited to slopes. BIENIAWSKI (1989) has endorsed the method.

SMR Classification system

The "Slope Mass Rating" (SMR) is obtained from RMR by adding a factorial adjustment factor depending on the relative orientation of joints and slope and another adjustment factor depending on the method of excavation.

$$SMR = RMR_B + (F_1 \times F_2 \times F_3) + F_4$$

The RMR_B (see Table 1) is computed according Bieniawski's1979 proposal, adding rating values for five parameters: (i) strength of intact rock; (ii) RQD; (iii) spacing of discontinuities; (iv) condition of discontinuities; and (v) water inflow through discontinuities and/or pore pressure ratio.

The adjustment rating for joints (see Table 2) is the product of three factors as follows:

(i) F_1 depends on parallelism between joints and slope face strike. Its range is from 1.00 to 0.15. These values match the relationship: $F_1 = (1 - \sin A)^2$ where A denotes the angle between the strikes of slope face and joints.

(ii) F_2 refers to joint dip angle in the planar mode of failure. Its value varies from 1.00 to 0.15, and match the relationship: $F_2 = tg^2B_j$ denotes the joint dip angle. For the toppling mode of failure F_2 remains 1.00.

(iii) F_3 reflects the relationship between slope and joints dips. Bieniawski's 1976 figures have been kept (all are negative).

(iv) F_4 (adjustment factor for the method of excavation has been fixed empirically.

Table 3 shows the different stability classes. The empirically found limit values of SMR for the different failure modes are listed in Table 4. All slopes with SMR values below 20 fail very quickly. No slopes have been registered with SMR value below 10. Many different remedial measures can be taken to support a unstable slope. The study of a potentially unstable rock slope is a difficult task requiring careful field work, detailed analysis and good engineering sense in order to understand the relative importance of the several instability factors acting on the slope. No classification system can replace all that work. However, they may be of some utility indicating the normal limits of use for each class of support measures (see Table 5). The choice between them is out of the scope of the classification system. The support measures can be grouped in six different classes:

(i) No support	None. Scaling
(ii) Protection	Toe ditches. Fences. Nets
(iii) Reinforcement	Bolts. Anchors
(iv) Concreting	Shotcrete. Concrete. Ribs. Walls
(v) Drainage	Surface. Deep. Adits.
(v) Reexcavation	

Normally no support measures are needed for slopes with SMR values of 75-100. There are some stable slopes with SMR values of 65. No totally reexcavated slope has been found with SMR over 30.

Validation

Many authors have published case records and checking of SMR classification applied to actual slopes in different countries: Brazil, Greece, India, Italy, Korea, Mexico, Spain (see Table 6 for references)

ZUYU (1995) has adapted SMR to the Chinese local conditions with two additional factors for height of slope (if higher than 80 m) and for conditions of joints. The system, called CSMR (Chinese Slope Mass Rating) has become "a national standard for slopes" to be used in design and construction of dams and hydroelectric power stations.

Most of the authors deal with cases, covering one or several actual slopes. SMR concepts has been used in three different ways: a) as a geomechanics classification, b) taking F_1, F_2, F_3 as a risk parameter (generally in natural slopes) and c) as a complementary method of work. Most of the authors agree that: 1) SMR geomechanics classification is slightly conservative, 2) the extreme values of F_3 proposed by Bieniawski (-50, -60) are something difficult to cope with, 3) failure modes proposed by SMR do occur, in practice, 4) excavation method is important (and inclusion of factor F_4 is justified). 5) classification of slopes with berms is difficult and 6) SMR classification system does not take account of slope height. The last two conclusions are a drawback of the classification. In soil-like materials (and in some soft rocks) the SMR classification can give misleading results (when the failure is almost circular and classification uses joints properties as parameter). Probably some correction should be added for the block size (relative to slope height).

A systematic validation process has been done by the Geotechnic Engineering Department of the Polytechnic University of Valencia. Jorda & Romana (1997) (with reference in Jorda et al, 1999), studied 57 big road and railway slopes near Valencia, with heights between 10 and 65 m and aged between several months and more than 100 years. As these slopes are placed in operating roads and railways, all are fully or partially stable (class II and/or III). For each slope: SMR value and actual state were compared. In more than 80% of the cases both values were almost coincident. Maximum difference in 55 cases was 5 points (in the limit of the field estimation normal error). There is a tendency to the calculated values being slightly minor than the observed ones, a conservative trend that is perhaps partially due to the existence in the sample of "young" slopes which can develop instabilities with time. When comparing the SMR proposed support methods with the observed ones there is a general coincidence with some differences: shotcrete appears in more cases than proposed and some slopes have no support with SMR values of 50, well below the SMR value of 65 proposed as a limit by the SMR classification.

In the GISLYT research project other 30 slopes (in roads and railways) were evaluated. The range of heights was 30-40 m and age was from several months to more than 150 years old (railway slopes). 24 from 30 slopes are in the same stability class and 15 from 30 are in the same stability subclass. Again observed behaviour is slightly better than predicted one.

Application of SMR by a GIS system

A joint Spanish research project (5 Universities and 2 Technologic Institutes) have dealt with application of Geographic Information System (GIS) to the forecast of stability problems in natural and excavated slopes, in soils and rocks. For rocks the SMR was chosen as instability predictor. The aim was to establish thematic maps of the geomechanics properties of the rock masses in order to be able to estimate the stability conditions in future slopes, to be excavated along new communication lines, or in isolated cases (pits, housing developments...).

Work was done in a 1:10.000/1:5.000 scale, covering two major and several local roads and two railways. The terrain was composed of (from Cretacic to Quaternary) limestone, sandstones, conglomerates, alluvial, beach deposits and miscellaneous fills. Topographic data were obtained from a "terrain digital model" and field data were gathered in 69 field stations. The more than 20.000 geomechanics parameters obtained were "regionalised" (neither interpolation nor extrapolation was convenient) in three groups of properties: rock's, joints and water. Criteria for designs of "regions" were lithology, tectonic style, morphology, topography, climate and biotope. Values for each parameter were assigned statistically in each area (means – or mode – in the centre and extrapolation in the limit, buffer zones) obtaining 5 "thematic" maps.

The basic RMR was obtained from the "thematic" maps and checked with the field observations. Buffer correction has been done for special zones, like faults, rifts and scarps. The SMR index can be generated in three different ways: for the natural slopes, along one orientation or for a slope

Table 1 RMR_B = BASIC RMR = Σ RATINGS (BIENIAWSKI, 1979)

PARAMETER	INTERVALS						
UCS (MPa) UNCONFINED COMPRESSIVE STRENGTH OF INTACT ROCK MATERIAL	<250	250-100	100-50	50-25	<25 25-5	5-1	<1
	15	12	7	4	2	1	0
RQD (%) ROCK QUALITY DESIGNATION	100-90	90-75	75-50	50-25	<25		
	20	17	13	8	3		
SPACING (mm) BETWEEN DISCONTINUITIES	>2000	2000-600	600-200	200-60	<60		
	20	15	10	8	5		
CONDITION OF DISCONTINUITIES ROUGHNESS, PERSISTENCE, SEPARATION, WEATHERING OF WALLS AND GOUGE	VERY ROUGH SURFACES NO SEPARATION UNWEATHERED WALL ROCK NOT CONTINUOUS	SLIGHTLY ROUGH SEPARATION < 1 mm SLIGHTLY WEATH. WALLS NOT CONTINUOUS	SLIGHTLY ROUGH SEPARATION < 1 mm HIGHLY WEATH. WALLS	SLICKENSIDED WALLS Or GOUGE < 5 mm Or SEPARATION1-5 mm	SOFT GOUGE >5 mm or SEPARATION >5 mm CONTINUOUS		
	30	25	20	10	0		
GROUNDWATER IN JOINTS (PORE PRESSURE RATIO)	COMPLETELY DRY (0)	DAMP (0-0.1)	WET (0.1-0.2)	DRIPPING (0.2-0.5)	FLOWING (0.5)		
	15	10	7	4	0		

Table 2 SMR = $RMR_B + (F_1 \times F_2 \times F_3) + F_4$ (ROMANA, 1985)

ADJUSTING FACTORS FOR JOINTS (F_1, F_2, F_3)	αj = DIP DIRECTION OF JOINT αs = DIP DIRECTION OF SLOPE	βj = DIP OF JOINT βs = DIP OF SLOPE			
	VERY FAVOURABLE	FAVOURABLE	FAIR	UNFAVOURABLE	VERY UNFAVOURABLE
PLANE FAILURE $\lvert \alpha j - \alpha s \rvert =$	> 30°	30° - 20°	20° - 10°	10° - 5°	< 5°
TOPPLING $\lvert \alpha j - \alpha s - 180° \rvert =$					
F_1 VALUE	0.15	0.40	0.70	0.85	1.00
RELATIONSHIP	$F_1 = (1 - \sin \lvert \alpha_j - \alpha_s \rvert)^2$				
$\lvert \beta j \rvert =$	< 20°	20°-30°	30°-35°	35°-45°	>45°
F_2 VALUE PLANE FAILURE	0.15	0.40	0.70	0.85	1.00
F_2 VALUE TOPPLING	1.00				
RELATIONSHIP	$F_2 = tg^2 \beta j$				
PLANE FAILURE $\beta j - \beta s =$	>10°	10°-0°	0°	0°-(-10°)	<(-10°)
TOPPLING $\beta j + \beta s =$	< 110°	110°-120°	>120°	-	-
F_3 VALUE	0	-6	-25	-50	-60
RELATIONSHIP	F_3 (BIENIAWSKI ADJUSTMENT RATINGS FOR JOINTS ORIENTATION, 1976)				
F_4 ADJUSTING FACTOR FOR EXCAVATION METHOD	F_4 = EMPIRICAL VALUES FOR METHOD OF EXCAVATION				
	NATURAL SLOPE	PRESPLITTING	SMOOTH BLASTING	BLASTING or MECHANICAL	DEFICIENT BLASTING
F_4 VALUE	+15	+10	+8	0	-8

Table 3 DESCRIPTION OF SMR CLASSES

CLASS N°	Vb	Va	IVb	IVa	IIIb	IIIa	IIb	IIa	Ib	Ia
DESCRIPTION	VERY BAD		BAD		FAIR		GOOD		VERY GOOD	
STABILITY	COMPLETELY UNSTABLE		UNSTABLE		PARTIALLY STABLE		STABLE		COMPLETELY UNSTABLE	
FAILURES	BIG PLANAR or SOIL-LIKE		PLANAR or BIG WEDGES		SOME JOINTS or MANY WEDGES		SOME BLOCKS		NONE	
SUPPORT	REEXCAVATION		IMPORTANT / CORRECTIVE		SYSTEMATIC		OCCASIONAL		NONE	

Table 4 PROBABLE FAILURES ACCORDING SMR VALUES

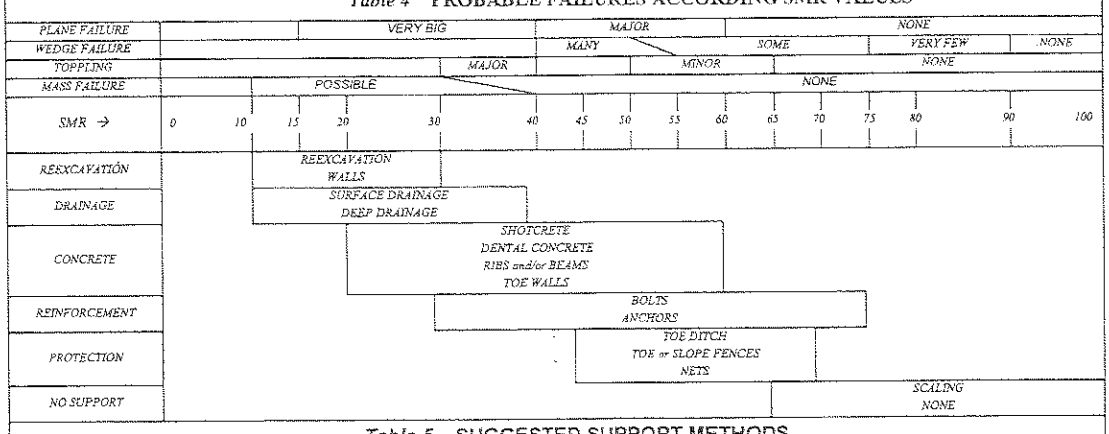

Table 5 SUGGESTED SUPPORT METHODS

Table 6. Some selected references on SMR

Country	Reference	Year
Spain	Collado & Gili	1988
Spain	Romana & Izquierdo	1988
India	Anbalagan	1991
Greece	Tsimbaos & Telli	1991
Greece	Angelidis et al	1992
Spain	Chacon et al	1992
Spain	Salueña & Corominas	1992
Mexico	Ayala & Aguirre	1994
Italy	Budetta et al	1994
Brazil	Nonato & Gripp	1994
México	Padilla	1994
Korea	Hyun-Koe et al	1995
USA	Mehrotra et al	1995
China	Zuyu Chen	1995
Italy	Eusebio et al	1996
India	Sharma et al	1996
Spain	Calderón & Gonzalez	1997
Spain	Jordá & Romana	1997
Italy	Calcaterra et al	1998
Spain	Jordá et al	1999
France	El Sáyeb & Verdel	1999
Italy	Ronzani et al	1999
Spain	Irigaray et al	2000
Spain	Romana et al	2001
Spain	Seron et al	2001

References can be provided by mromana@stmr.com

with prefixed orientation. The adjusting factor F_1, F_2, F_3 can be obtained from the "terrain digital model" and mapped. Also the product $F_1 \times F_2 \times F_3$ can be mapped (Irigaray et al, 2000; Ronzari et al, 1999). Model validation was done comparing the actual results in a field station with the results generated by a model, in which this station was not included. Table 7 shows validation results suppressing one station each time.

Table 7. Validation of RMR results suppressing one station

Station	Field value	Model value	RMR
A 16	66	69.56	+3.56
A 20	64	70.27	+6.27
A 21	67	67.81	+0.81
T 20	72	70.30	-1.70
T 21	72	71.10	-0.90

In the area one highway slope was unstable (class IV) during construction requiring massive support. The model detected the problem from neighbours field stations. Therefore it is possible to use GIS systems to get regional values for RMR and SMR, but an important field work is necessary. The product of correction factor $F_1 \times F_2 \times F_3$ can be regionalised with less fieldwork and gives an excellent indication of slopes stability risk.

Final remark

The authors wish to express their gratitude to the CICYT Agency, which sponsored the research project on the GIS application to slopes, and to Prof Corominas (who coordinated it), and Prof. Chacón. Both gave support and very valuable advice during the research work.

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4. SLOPE MASS RATING (SMR)

The proposed 'Slope Mass Rating' (SMR) is obtained from RMR by subtracting a factorial adjustment factor depending on the joint—slope relationship and adding a factor depending on the method of excavation

$$SMR = RMR + (F_1 . F_2 . F_3) + F_4$$

The RMR (see Table 1) is computed according to Bieniawski's 1979 proposal, adding rating values for five parameters: (i) strength of intact rock; (ii) RQD (measured or estimated); (iii) spacing of discontinuities; (iv) condition of discontinuities; and (v) water inflow through discontinuities (estimated in the worst possible conditions). RMR has a total range of 0 - 100.

The adjustment rating for joints (see Table 2) is the product of three factors as follows:

(i) F_1 depends on parallelism between joints and slope face strikes. Its range is from 1.00 (when both are near parallel) to 0.15 (when the angle between them is more than 300 and the failure probability is very 10°). These values were established empirically, but afterwards were found to approximately match the relationship

$$F_1 = (1 - \sin A)^2$$

where A denotes the angle between the strikes of the slope face and the joint.

(ii) F_2 refers to joint dip angle in the planar mode of failure. In a sense it is a measure of the probability of joint shear strength. Its value vanes from 1.00 (for joints dipping more than 45°) to 0.15 (for joints dipping less than 200). Also established empirically, it was found afterwards to match approximately the relationship

$$F_2 - tg^2 \beta_j$$

where β_j denotes the joint dip angle. For the toppling mode of failure F_2 remains 1.00.

(iii) F_3 reflects the relationship between the slope face and joint dip. Bieniawski's 1976 figures have been kept. In the planar mode of failure E_3 refers to the probability that joints 'daylight' in the slope face. Conditions are fair when slope face and joints are parallel. When the slope dips 100 more than joints, very unfavourable conditions occur.

(iv) Soil-type failure along a surface which only partially develops along joints, but mainly crosses them. These failures can only happen in heavily jointed rock masses with a very small block-type size and/or very weak or heavily weathered rock. In both cases, the RMR value is very low, and the material is borderline with a soil.

Any classification system has to take account of the following 'parameters'.

(i) Rock mass global characterization (including joints frequency, state and water inflow).

(ii) Differences in strike between slope face and prevalent joints.

(iii) Differences between joint dip angle and slope dip angle, as they control the 'daylighting' of a joint in the slope face, a necessary condition for plane and/or wedge failure.

(iv) Relationship of joint dip angle with normal values of joint friction (for plane and/or wedge failure).

(v) Relationships of tangential stresses, developed along a joint, with friction (for toppling failure).

For the toppling mode of failure, unfavourable or very unfavourable conditions cannot happen in view of the nature of toppling, as there are very few sudden failures and many toppled slopes remain standing. The Goodman-Bray [10] condition has been used to evaluate toppling probability, with the hypothesis that this failure is more frequent in weathered slopes and there is a small reduction (around 50) of shear strength due to rotational friction, as proposed by Goodman [11].

The adjustment factor for the method of excavation (see Table 3) has been fixed empirically as follows:

(i) Natural slopes are more stable, because of long time erosion and built-in protection mechanisms (vegetation, crust desiccation, etc.): $F_4 = +15$.

(ii) Presplitting increases slope stability for half a class: $F_4 = \pm 10$.

(iii) Smooth blasting, when well done, also increases slope stability: $F_4 = \pm 8$.

(iv) Normal blasting, applied with sound methods, does not change slope stability: $F_4 = 0$.

Table 2. Adjustment Rating for Joints

Case		Very favorable	Favorable	Fair	Unfavorable	Very unfavorable
P	$\lvert\alpha_j - \alpha_s\rvert$	> 30°	30-20°	20-10°	10-5°	5°
T	$\lvert(\alpha_j - \alpha_s) - 180°\rvert$					
P/T	F_1	0.15	0.40	0.70	0.85	1.00
P	$\lvert\beta_j\rvert$	< 20°	20-30°	30-35°	35-45°	45°
P	F_2	0.15	0.40	0.70	0.85	1.00
T	F_2	1	1	1	1	1
P	$\beta_j - \beta_s$	> 10°	10-0°	0°	0° to 10°	< -10°
T	$\beta_j - \beta_s$	< 110°	110-120°	> 120°	-	-
P/T	F_3	0	-6	- 25	-50	- 60

P, plane failure; T, toppling failure; α_j, joint dip direction; α_s slope dip direction; β_j, joint dip; β_s, slope dip

Table 3. Adjustment Rating for Methods of Excavation of Slopes

Method	Natural Slope	Presplitting	Smooth blasting	Blasting or mechanical	Deficient blasting
F_4	+ 15	+ 10	+ 8	0	- 8

(v) Deficient blasting, often with too much explosive, no detonation timing and/or nonparallel boles, damages stability: $F_4 = -8$.

(vi) Mechanical excavation of slopes, usually by ripping, can be done only in soft and/or very fractured rock, and is often combined with some preliminary blasting. The plane of slope is difficult to finish. The method neither increases nor decreases slope stability: $F_4 = 0$.

A tentative description of the SMR classes is given in Table 4.

Swindells [12] presented the results of an investigation on 16 different cuts, in five locations in Scotland (natural slopes, railways, highways, quarries), to assess the influence of blasting methods on slope stability. All the cuts were in igneous or metamorphic rocks. The cuts were investigated with different techniques (visual inspection, field seismic refraction profiling, borehole TV camera, and laboratory testing). Swindells concluded that 'the degree of measurable disturbance is related to excavation technique. Faces excavated by uncontrolled or bulk blasting, or quarry blasting, exhibit greater thicknesses of measurable disturbances'. The numerical data presented by Swindells have been reworked and compared with the SMR corrective factor F_4 in Table 5.

Figure 2 reproduces Swindells data and Figure 3 compares the depth of the disturbed zone with the value of F_4. There is a general similarity between the thickness of disturbed zone and SMR F_4 correction factor. The most important difference occurs with smooth blasting techniques. The two cases investigated were registered by Swindells as 'unsuccessful presplit' and 'bulk-smooth blasting'. Therefore it is possible that these data do not correspond to real, successful excavations by smooth blasting methods.

Kendorski *et al.* [7] evaluated blasting damage in underground mines, by caving, with a factor AB which multiplies RMR. Table 6 compares AB with the SMR corrective factor F_4.

The final Slope Mass Rating is

$$SMR = RMR + (F_1 . F_2 . F_3) + F_4$$

No special factors taken for the wedge mode of failure are different from those applied for the plane mode of failure. The practice of classification seems to prove that wedge failures are no more dependent on RMR value than plane failures. Therefore, the classification must be applied for each joints system. The minor value of SMR is retained for the slope.

Weathering cannot be assessed with rock mass classification as it is a temporal process which depends mostly on the mineralogical conditions of rock and the climate. In certain evolutive rocks (like some marls and clay-shales) the slopes are stable when open, and fail some time afterwards (usually one to two years later). The classification must be applied twice: for actual fresh and future weathered conditions.

Table 4. Tentative Description of SMR Classes

Class	SMR	Description	Stability	Failures	Support
I	81-100	Very good	Completely stable	None	None
II	61-80	Good	Stable	Some blocks	Occasional
III	41-60	Normal	Partially stable	Some joints or many wedges	Systematic
IV	21-40	Bad	Unstable	Planar or big wedges	Important/corrective
V	0-20	Very bad	Completely unstable	Big planar or soil-like	Reexcavation

Table 5. Comparison between Disturbance effects of blasting methods and F_4 [12]

Excavation method	N	Thickness of disturbance		SMR
		Range (m)	Mean (m)	F_4
Natural slope	4	0	0	+15
Presplitting	3	0-0.6	0.5	+10
Smooth blasting	2	2-4	3	+8
Bulk blasting	3	3-6	4	0

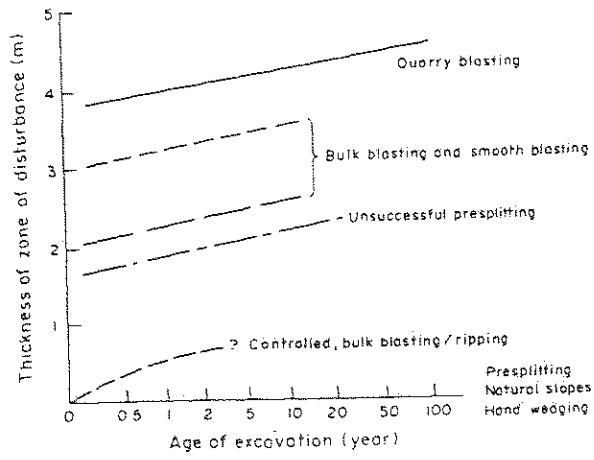

Figure 2. Generalized relationship between excavation technique, age of excavation and seismically detectable disturbance (Swindells [12])

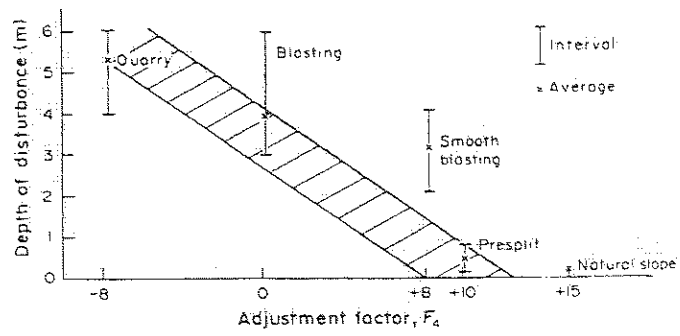

Figure 3. Relationship between depth of disturbed zone, according to Swindells [12], and SMR correction factor F_4

Table 6. Comparison between Kendorski [7] Blasting Coefficient and F_4

Excavation method	A_B	(%)	SMR F_4
Controlled blasting	0.97-0.94	108-104	+8
Good blasting	0.94-0.90	104-100	0
Poor blasting	0.90-0.80 (worst)	100-89	- 8

Water conditions govern the stability of many slopes which are stable in summer and fail in winter because of heavy ram or freezing. The worst possible water conditions must be assumed. The stability of a dry slope is evaluated by an increase of 15 in the RMR.

6. CASE RECORDS

To establish the SMR classification, 28 slopes with several degrees of instabilities have been registered and classified. Six of these failed completely and have been reexcavated. In several cases the failure was due to weathering and happened a long time after construction (at least one year). Results are shown in Tables 12, 13 and 14, and seem to offer a good concordance with stability classes as predicted by the proposed classification. That gave us enough encouragement to publish the classification in *1985* [19 - 21].

Collado and Gili [22] applied the SMR classification to 44 slopes during the geotechnical studies for a new highway in highway 420 (Coll de la Teixeta—Coll Negre) in Tarragona (Spain). The slopes had been recently excavated (one to two years old). Many of them were small in height. All the cases are listed in Table 15.

Figure 4 shows the correlation between the observed behaviour and that estimated from SMR classification. Collado and Gili concluded that 'there is a good correlation ... with more stable behaviour in slopes with bigger SMR values. However, actual behaviour is slightly better than predicted'. They explain the difference from the fact that 'SMR tries to evaluate long term behaviour and (we have observed) slopes one to two years old'.

Romana and Izquierdo [23] applied SMR classification to the study of final slopes of a quarry for dolomitic materials at Cartagena harbor. Slopes had different orientations, a maximum height of 35 m and a total length of 260 m. In this area ENAGAS installed a big tank for liquified natural gas (LNG). Previously, a total correction of slopes was done in order lo avoid any instability risk, after a very detailed study. In Table 16 a comparison is shown between actual and SMR predicted stability chasses and correction methods.

Table 12. Case Records / Standing slopes / Plane failure

Case number	Rock	Excavation method	SMR	Class	Failures	Support	Ref. (only 1 st author)
1	Limestone	P	85	I	None	None	Romana (1985)
5	Sandy marl	N	82	I	None	None	Romana (1985)
2	Limestone	P	77	II	Three small blocks W	Toe ditch	Romana (1985)
18	Gneiss	P	74	II	Small wedges d.c.W	None, instrumented	González (1982)
10	Limestone	B	72	II	None	None	Romana (1985)
22	Dolostone	B	64-76	II	Small planes d.c.P	None	Romana (1985)
19	Limestone	SB	61-73	II	None	None, instrumented	Roman Buj (1982)
11 a	Marl	SB	71	II	None. Failure a.w. P	None, see case 11 b	Cedrun (1976)
25 a	Limestone	B	70	II	Small blocks W	Spot bolting	Intecsa (1984)
13	Sandstone/siltstone	N	64	II	Some blocks W	None. Scaling	Uriel (1976)
4	Limestone	DB	63	III	Many blocks W	Insufficient toe ditch	Romana (1985)
14	Marls/limestone	M	59	III	Local problems	None	R. Miranda (1972)
21	Gypsum rock	N	53	III	Some blocks (1 m^3) W	Toe ditch. Fence	Intecsa (1983)
26 a	Claystone/sandstone	B	52	III	Big Wedge (15 m^3) W	Systematic bolts. Net.	Intecsa (1984)
3	Claystone	M	47	III	Surface erosion	Toe ditch	Romana (1985)
8	Sandstone/marl	B	43	III	Many blocks W	Systematic bolting	López (1981)
28	Limestone	DB	40	IV	Many failures P	Concrete wall	Correcher (1985)
20	Gypsum rock	N	31-43	IV	Big failure (100 m^3) W	None	Intecsa (1983)
6	Sandy marl	M	32	IV	Blocks. Mud flows S	None	Romana (1985)
7	Sandstone/marl	B	30	IV	Big plane failures d.c.P.	Systematic bolting. Reexcavation	López (1981)
9	Limestone	B	29	IV	Several blocks (50 m^3) W	None	Romana (1985)

Table 13. Case Records / Toppling

Case number	Rock	Excavation method	SMR	Class	Failures	Support	Ref. (only 1 st author)
16 b	Volcanic tuff/diabase	P	74	II	None	Systematic bolting	R. Oyanguren
25 b	Limestone	B	56	III	Some blocks	Syst. bolting/net	Intecsa (1984)
26 b	Sandstone/claystone	B	56	III	No data	Syst. bolting/2 net	Intecsa (1984)
15 a	Claystone/marls/limestone	M	21-37	IV	Total failure (T)	Reexcavated (to 15b)	R. Miranda (1972)
15 b	Claystone/marls/limestone	M	60	III	Some cracks	None	R. Miranda (1972)
27 b	Slates/grauwacks	M	23	IV	Some failures	Shotcrete/nets/bolting	Intecsa (1984)

Table 14 Case Records / Failed and Rebuilt Slopes /Plane Failure

Case number	Rock	Excavation method	SMR	Class	Failures	Support	Ref. (only 1 st author)
11 b	Marl	SB	36	IV	Almost total a.w. P	Reexcavated to joints	Cedrun (1976)
16 a	Volcanic tuff / diabase	B	30	IV	Big plane failure P	Reexcavated (to 16 b)	R. Oyanguren (1972)
23 a	Marls	B	16	V	Total failure a.w.P	Reexcavated (to 23 b)	Intecsa (1984)
23 b	Marls	B	42	III	Small blocks W	Toe wall/anchors/fence	Intecsa (1984)
24 a	Marls	B	17	V	Total failure a.w.P	Reexcavated (to 24 b)	Intecsa (1984)
24 b	Marls	B	43	III	Small blocks W	Toe wall/anchors/fence	Intecsa (1984)
27 a	Slates/grauwacks	M	17	V	Soil-like failure S	Reexcavated (to 27b)	Intecsa (1984)

Excavation methods: P, presplitting; DB , deficient blasting; SB, smooth blasting; M, mechanical excavation; B, blasting; N, natural slope. Failure: d.c., during construction; W, wedge; a.w , after weathering; T, toppling; P, plane; S, soil-like

Table 15. Slopes studied by Collado and Gili [22]

Heigh (m)	Number	Lithology
42	1	Sandstone and porphyry
33.5	1	Sandstone and quartzite
25	1	Slate and porphyry
16-20	3	Slate and sandstone
12-16	5	Sandstone and slate
8-12	18	Varied
< 8	15	Varied
	TOTAL 44	

The behaviour of the slopes was slightly better than predicted by SMR, with an average difference of 5 to 10 points. In one case the slope was in a worse state than predicted. The correction work was very careful with a daily definition of operations. Corrective measures actually used were those predicted by SMR classification but with less intensity. Overall the predictions were slightly conservative.

7. STABILITY CLASSES

Table 4 shows the different stability classes, and these are summarized below.

Class I	Completely stable. No failures
Class II	Stable. Some block failures
Class III	Partially stable. Planar failures in some joints and many wedge failures
Class IV	Unstable. Planar failures in many joints or big wedge failures
Class V	Completely unstable. Big planar failures or soil-hike failures

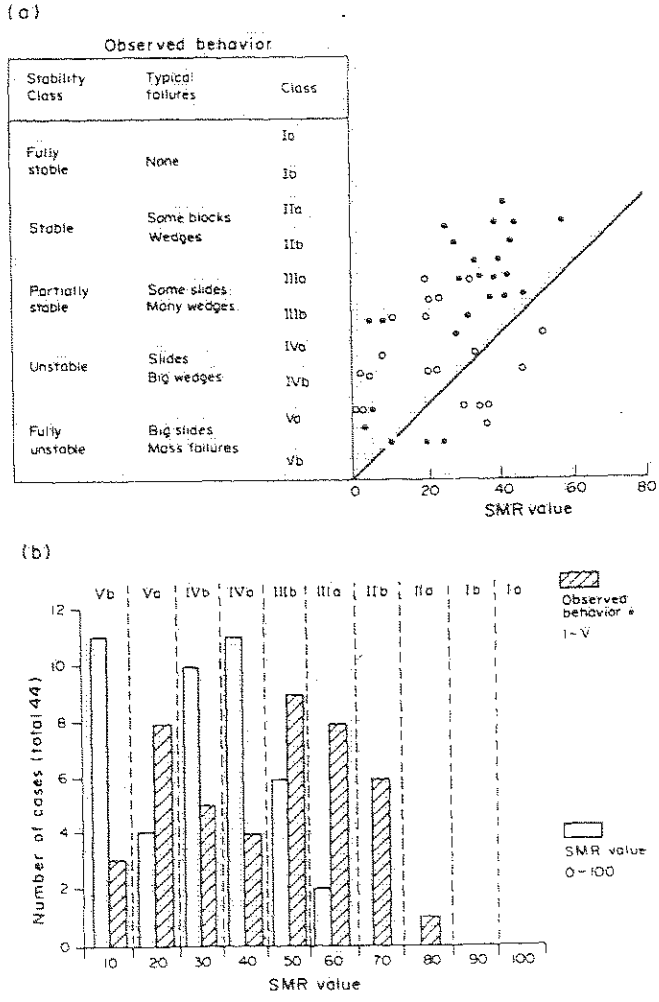

Figure 4. **SMR in 44 slopes (1 to 2 years old) in Tarragona (Collado and Gili [22]; (a) observed behaviour against SMR value; (b) histogram of cases for each class**

Table 16. Predicted and Actual Behavior of Cap Negre Slopes (Romana and Izquierdo [23])

RMR	Stability class		Correction[a]	
	SMR	Actual	SMR	Actual
54-61	III a	II b	sB sS	pS
20-40	IV	III	W	W
55-65	III a – II b	III a	sB pS	pB pS
42-54	III b	III b	sB sG (M)	pB R

The empirically found limit values of SMR for the different failure modes are listed in Table 17. All slopes with SMR values below 20 fail very quickly. No slope has been registered with SMR value below 10. These slopes would not be physically feasible.

8. SUPPORT MEASURES

8.1 GENERAL

Many different remedial measures can be taken to support an unstable slope, or to prevent a believed potential instability. There is not enough technical literature about the real effects of support measures in rock slopes, especially when different measures are adopted simultaneously. On the other hand many case histories document analytically the correction of landslides in soil using deep drainage and/or resistant inclusions in the slopes.

SMR	Plane/failures	Wedge	
> 75	None	None	
60-75	None	Some	
40-55	Big	Many	
15-40	Major	No	
SMR	**Toppling failures**	**SMR**	**Soil-like failures**
> 65	None	30	None
50-65	Minor	10-30	Possible
30-35	Major		

The study of potentially unstable rock slopes is a difficult task requiring careful field work, detailed analysis and good engineering sense in order to understand the relative importance of the several instability factors acting on the slope. No classification system can replace all that work. However, they may be of son utility in indicating the normal limits of use for each class of support measures. The choice between them is out of the scope of the classification system.

The support measures can be grouped in six different classes.

(i) No support	None
	Scaling
(ii) Protection	Toe ditches
	Fences (at toe or in the slope)
	Nets (over the slope face)
(iii) Reinforcement	Bolts
	Anchors

(iv) Concreting	Shotcrete
	Dental concrete
	Ribs and/or beams
	Toe walls
(v) Drainage	Surface
	Deep
(vi) Reexcavation	

From the collected case histories Table 18 presents the more common support measures for each class interval (see also Figure 5).

Normally no support measures are needed for slopes with SMR values of 75-100. There are some stable slopes with SMR values of 65.

Total reexcavation of a slope is a drastic measure, normal in soil slopes, but less practical in rock ones, except in the instability mode is planar through a big continuous joint. It may be adopted in order to reduce its grade, to take away weight in its upper part and/or to add a stabilizing weight at the toe. No totally reexcavated slope has been found with SMR value over 30. No slope has been found with a SMR value below 10. Probably such a low value would imply total and instant instability, the excavation of the slope (even during a very short time) would not be physically feasible.

In a broad sense, the ranges of SMR for each class of support measures are listed in Table 19. Selection of the adequate measures must be made taking into account the prevalent failure mechanism and also the frequency of joints. Two parameters can be useful to quantify frecuency of joints.

(i) Joint spacing, S. The modal value of joint spacing distribution in a family. Frequently the governing joint spacing value corresponds to the joints family which originates the instability.

(ii) Joint volumetric count, J_v. The number of joints per cubic meter, J_v, can evaluated with the formula.

$$J_v = \sum 1/\overline{S_i}$$

where $\overline{S_i}$ is the mean (not the modal) spacings for each joints family. The ISRM 'Suggested Method for the Quantitative Description of Discontinuities in Rock Masses' [13] gives the following:

Table 18. Recommended Support Measures for Each Stability Class

Class	SMR	Support
Ia	91-100	None
Ib	81-90	None. Scaling
II a	71-80	(None. Toe ditch or fence)
		Spot bolting
II b	61-70	Toe ditch or fence. Nets
		Spot or systematic bolting
III a	51-60	Toe ditch and/or nets
		Spot or systematic bolting
		Spot shotcrete
III b	41-50	(Toe ditch and/or nets)
		Systematic bolting. Anchors
		Systematic shotcrete
		Toe wall and/or dental concrete
IV a	31-40	Anchors
		Systematic shotcrete
		Toe wall and/or concrete
		(Reexcavation) Drainage
IV b	21-30	Systematic reinforced shotcrete
		Toe wall and/or concrete
		Reexcavation. Deep drainage
V a	11-20	Gravity or anchored wall
		Reexcavation

(i) Very often several different support methods are used in the same slope.

(ii) Less usual support measures are in brackets

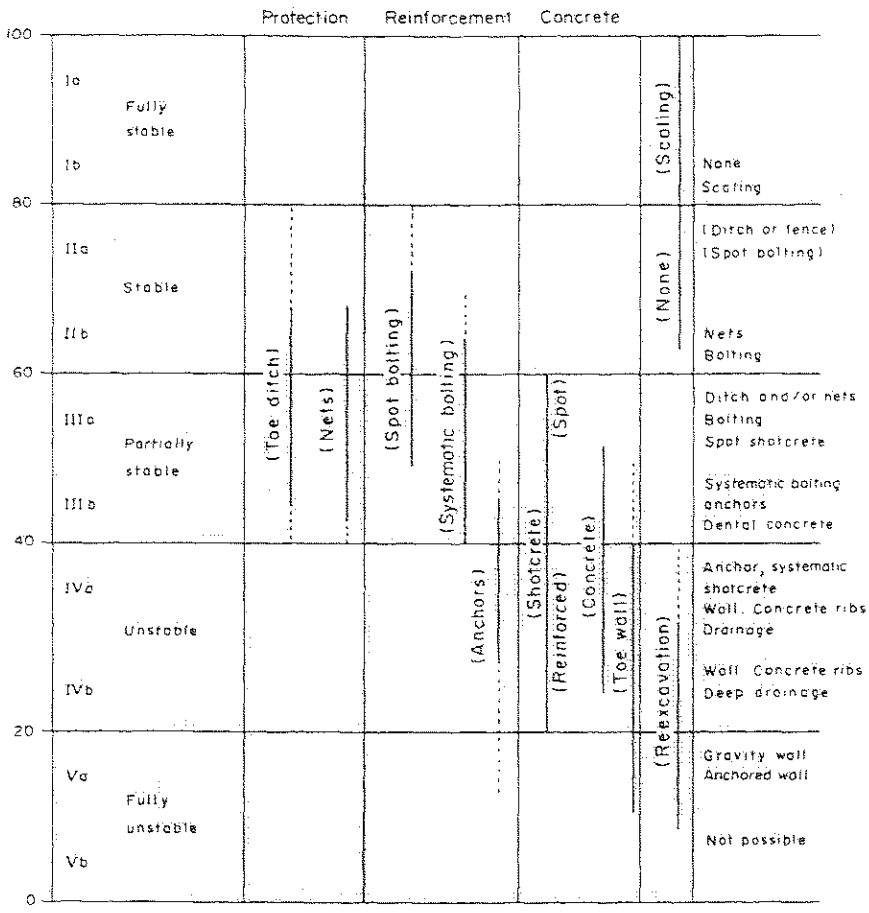

Figure 5. Correction methods according to SMR range

Table 19. Range of SMR for Support Measure Classes

SMR	Support measures
65-100	None. Scaling
45-70	Protection
30-75	Reinforcing
20-60	Concreting
10-40	Drainage
10-30	Toe walls. Reexcavation

Description of block sizes according to J_v.

Description of blocks	J_v (joints m^{-3})
Very large	< 1
Large	1-3
Medium	3-10
Small	10-30
Very small	30-60
Crushed rock	> 60

J_v and RQD can be approximately correlated through the Palmstrom [17] formula

$$RQD = 115 - 3.3\ J_v \quad RQD \leq 100$$

8.2 PROTECTION MEASURES

8.2.1. Toe ditch

Toe ditches are useful to keep fallen rocks out of the road when failures are wedges, planes and/or minor topples.

Ritchie [24] filmed rockfalls in several slopes, identifying three fall modes: (i) direct fall, for slopes 1H:4V and steeper; (ii) rebound, for slopes around 1H:2V; and (iii) roll, for slopes 1H:1V and flatter.

Ritchie also proposed empirical criteria for dimensioning ditches and fences (Table 20). These values have been widely reproduced and quoted. Nevertheless many engineers believe that Ritchie´s values are too big and lead to designs that are too expensive. Whiteside [25] (based on Fookes and Sweeney [26]) has published an abacus reducing Ritchie´s proposed dimensions.

On the other hand Ritchie seems to have worked with slopes in hard rocks, therefore having high rebound coefficients. In softer rocks part of the rebound energy is lost in breakout, and the distances to the slope toe are smaller.

«-- Return to Menu

ROCKFALL CATCHMENT AREA DESIGN GUIDE

FINAL REPORT
SPR-3(032)

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15. Supplementary Notes

16. Abstract

The data gathered from an extensive research project consisting of rolling approximately 11,250 rocks off vertical; 0.25H:1V; 0.5H:1V; 0.75H:1V; and 1.0H:1.0V slopes of three different heights (40, 60 and 80 feet) into three differently inclined catchment areas (flat, 6H:1V and 4H:1V) has been used to develop design charts for dimensioning rockfall catchment areas adjacent to highways. A standard suite of 250 rocks was rolled for each slope and catchment area configuration tested. The standard suite included 100 rocks averaging 1 foot in diameter, 75 rocks averaging 2 feet in diameter and 75 rocks averaging 3 feet in diameter. The data was evaluated using statistical and graphical methods. The design charts are presented in a "practitioner-friendly" form that can be used to rapidly dimension rockfall catchment areas that satisfy specific rock catching/retention requirements. Based on cut slope angle and height and catchment area slope, the design charts estimate the catchment area widths required to retain percentages of rockfall ranging up to 99 percent.

Design guidelines and step-by-step design procedures are presented and illustrated with three worked example design problems. Seven actual highway project case study examples are also presented. They illustrate the practical application of the design procedure and design charts and/or use of site-specific rock rolling to aid in the rockfall mitigation design.

This report documents the test methods, the fieldwork performed, the data gathered, the means of analysis, the research results and sample application of the design charts. The data results in both tabular and graphical form are included in the Appendices. The Appendices also include the detailed project case study application examples.

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ROCKFALL CATCHMENT AREA DESIGN GUIDE

TABLE OF CONTENTS

ACKNOWLEDGMENTS iii

DEDICATION iv

GLOSSARY OF TERMS ix

EXECUTIVE SUMMARY xi

1.0 INTRODUCTION 1

1.1 SIGNIFICANCE OF THE ROCKFALL PROBLEM 1
1.2 ROCKFALL CATCHMENT AREA DESIGN PRACTICE 2
1.3 RESEARCH PROJECT GOALS 2
1.4 REPORT CONTENT SUMMARY 3
1.5 PROJECT BENEFITS 4
1.6 REPORT TERMINOLOGY 4

2.0 BACKGROUND 5

2.1 1963 RITCHIE STUDY 5
2.2 LIMITATIONS OF RITCHIE RESEARCH 7
2.3 ODOT'S 1994 PILOT STUDY FOR 0.25H:1V SLOPES 8
2.3.1 1994 Survey of Rockfall Catchment Area Design Practice 9
2.3.2 Comparison to a Ritchie Test Catchment Area (Pilot Study) 10
2.3.3 Comparison with Computer Rockfall Simulation (Pilot Study) 13

3.0 FULL SCALE TESTING OF ADDITIONAL SLOPES 15

3.1 RESEARCH SITE TEST COMPONENTS 15
3.2 SLOPE EFFECTS AND IMPACT DISTANCE 19
3.3 CATCHMENT AREA SLOPE AND ROLL OUT DISTANCE 22
3.4 IMPACT DISTANCE VERSUS ROLL OUT DISTANCE 26
3.5 ROCKFALL ENERGY DATA 28

4.0 DESIGN GUIDELINES AND APPLICATION EXAMPLES 31

4.1 DESIGN GUIDELINES 31
4.2 CATCHMENT AREA PERCENT RETENTION GRAPHS 32
4.3 CUMULATIVE PERCENT RETAINED DESIGN CHARTS 34
4.4 STEP-BY-STEP DESIGN PROCEDURE 36
4.4.1 Worked Example 1 - Designing a New Catchment Area 36
4.4.2 Worked Example 2 - Evaluating an Existing Catchment Area 38
4.4.3 Worked Example 3 - Benefit/Cost Comparison 40
4.4.4 Project Case Study Application Examples 42

5.0 COMPLETE SUITE OF DESIGN CHARTS **45**

5.1 USE OF DESIGN CHARTS 45
5.2 DESIGN CHART LIMITATIONS 46

6.0 CONCLUSIONS **73**

6.1 SUMMARY OBSERVATIONS AND CONCLUSIONS 73
6.2 FURTHER RESEARCH NEEDS 74

7.0 REFERENCES **77**

APPENDICES

APPENDIX A: RITCHIE TEST CATCHMENT AREA COMPARISON
APPENDIX B: ROCK ROLLING FIELD DATA
APPENDIX C: ROCKFALL IMPACT DISTANCE HISTOGRAMS
APPENDIX D: ROCKFALL ROLL OUT DISTANCE HISTOGRAMS
APPENDIX E: ROCKFALL ENERGY DATA
APPENDIX F: CATCHMENT AREA PERCENT RETENTION GRAPHS
APPENDIX G: PROJECT CASE STUDY APPLICATION EXAMPLES

LIST OF FIGURES AND PHOTOS

Figure 1.1: Rockfall travel modes (*Ritchie 1963*) 1
Figure 2.1: Rockfall travel modes (*Ritchie 1963*) 5
Figure 2.2: Ritchie's rockfall catch ditch design chart (*FHWA 1989*) 6
Figure 2.3: Tested slope heights and catchment area configurations (Pilot Study) 8
Figure 2.4: Tested Ritchie catchment area shape and dimensions 11
Figure 2.5: Comparison of tested Ritchie to 4H:1V and 6H:1V sloped catchment areas 12
Figure 2.6: Cumulative percentage rockfall retained for tested Ritchie catchment area 12
Figure 2.7: Field data and computer simulation comparison (0.25H:1V slope) 14
Figure 3.1: Tested slope height and catchment area configurations 16
Figure 3.2: 80-foot high, 0.25H:1V presplit slope (Oregon test site) 17
Figure 3.3: Rockfall testing; 40-foot high vertical presplit slope, 2-foot diameter rocks, 4H:1V catchment area foreslope 18
Figure 3.4: Rockfall testing; 40-foot high vertical presplit slope 18
Figure 3.5: Preferred rockfall paths 20
Figure 3.6: 40-foot impact histogram (0.25H:1V slope) 21
Figure 3.7: 60-foot impact histogram (0.25H:1V slope) 22
Figure 3.8: 80-foot impact histogram (0.25H:1V slope) 22
Figure 3.9: Definition of roll out distance 23
Figure 3.10: Average roll out distance vs. slope height (0.25H:1V slope) 24
Figure 3.11: Average roll out distance vs. slope height (1H:1V slope) 24
Figure 3.12: Roll out histogram, 80-foot slope – flat catchment area 25
Figure 3.13: Roll out histogram, 80-foot slope – 6H:1V catchment area 25
Figure 3.14: Roll out histogram, 80-foot slope – 4H:1V catchment area 26
Figure 3.15: Standard deviation of impact distance (0.25H:1V slope) 27
Figure 3.16: Standard deviation of roll out distance (0.25H:1V slope) 28
Figure 3.17: Energy data for 1-foot rocks (80-foot high, 0.5H:1V slope) 29
Figure 4.1: 50% Retention graph (0.75H:1V slope) 33
Figure 4.2: 90% Retention graph (0.75H:1V slope) 34

Figure 4.3: Cumulative percent retained for the 80-foot, 0.25H:1V slope....35
Figure 4.4: Design chart for 80-foot high, 0.25H:1V slope (Example 1)....38
Figure 4.5: Design chart for 80-foot high, 0.25H:1V slope (Example 2)....39
Figure 4.6: Slope cross-sections; benefit/cost comparison (Example 3)....41
Figure 4.7: Example benefit/cost comparison (Example 3)....42
Figure 5.1: Design chart for 40-foot high vertical cutslopes....47
Figure 5.2: Design chart for 50-foot high vertical cutslopes....48
Figure 5.3: Design chart for 60-foot high vertical cutslopes....49
Figure 5.4: Design chart for 70-foot high vertical cutslopes....50
Figure 5.5: Design chart for 80-foot high vertical cutslopes....51
Figure 5.6: Design chart for 40-foot high 0.25H:1V cutslopes....52
Figure 5.7: Design chart for 50-foot high 0.25H:1V cutslopes....53
Figure 5.8: Design chart for 60-foot high 0.25H:1V cutslopes....54
Figure 5.9: Design chart for 70-foot high 0.25H:1V cutslopes....55
Figure 5.10: Design chart for 80-foot high 0.25H:1V cutslopes....56
Figure 5.11: Design chart for 40-foot high 0.5H:1V cutslopes....57
Figure 5.12: Design chart for 50-foot high 0.5H:1V cutslopes....58
Figure 5.13: Design chart for 60-foot high 0.5H:1V cutslopes....59
Figure 5.14: Design chart for 70-foot high 0.5H:1V cutslopes....60
Figure 5.15: Design chart for 80-foot high 0.5H:1V cutslopes....61
Figure 5.16: Design chart for 40-foot high 0.75H:1V cutslopes....62
Figure 5.17: Design chart for 50-foot high 0.75H:1V cutslopes....63
Figure 5.18: Design chart for 60-foot high 0.75H:1V cutslopes....64
Figure 5.19: Design chart for 70-foot high 0.75H:1V cutslopes....65
Figure 5.20: Design chart for 80-foot high 0.75H:1V cutslopes....66
Figure 5.21: Design chart for 40-foot high 1H:1V cutslopes....67
Figure 5.22: Design chart for 50-foot high 1H:1V cutslopes....68
Figure 5.23: Design chart for 60-foot high 1H:1V cutslopes....69
Figure 5.24: Design chart for 70-foot high 1H:1V cutslopes....70
Figure 5.25: Design chart for 80-foot high 1H:1V cutslopes....71

TABLES

Table 5.1: Slope ratio/slope angle equivalents....46

4.4 STEP-BY-STEP DESIGN PROCEDURE

The following summarizes the step-by-step design procedure for dimensioning new rockfall catchment areas or evaluating existing catchment areas, using the developed design charts (Figures 5.1 - 5.25). Qualified, experienced rock slope engineering personnel should perform the overall rock slope design and catchment area dimensioning.

Step 1 - Establish overall design rock cut slope ratio based on overall rock slope stability.

Step 2 - Select critical rock cut slope design cross-section(s).

Step 3 - Select appropriate catchment area design chart, based on slope ratio and slope height.

Step 4 - When dimensioning new catchment areas, enter the appropriate slope design chart for a specified or desired percent rockfall retention and read off the required catchment area width, W, for the selected catchment area configuration(s), i.e., flat-bottom, 6H:1V or 4H:1V. This may need to be an iterative process, since wider catchment areas commonly result in higher rock cuts. It is also appropriate to perform a constructibility check to evaluate if the required catchment area width, W, will result in an overall rock excavation width sufficiently wide for excavation equipment to work the proposed cut slope to grade. Refer to Worked Example 1.

When evaluating the effectiveness of an existing catchment area, enter appropriate existing rock cut slope/catchment area slope design chart at existing catchment area width, W, and read off estimated percent rockfall retention. Refer to Worked Example 2.

Step 5 - When appropriate, perform benefit/cost comparison of alternate designs to select recommended final design. Refer to Worked Example 3.

The following worked examples illustrate the step-by-step design procedure and application of the design charts. See the Appendix G case study examples for more in-depth actual project application examples.

4.4.1 Worked Example 1 - Designing a New Catchment Area

Project Description: An existing section of highway in mountainous terrain is to be reconstructed as part of a safety improvement project. The project includes an approximate 1000-foot long rock slope consisting of basalt rock. The existing cut is 65-foot maximum height with slope ratio varying from near vertical to 0.3H:1V through the length of the cut. Natural ground slope behind the top of cut is approximately 2H:1V. The original construction was done in the 1950's when uncontrolled blasting was used, resulting in significant blast damage several feet into the slope, causing significant rockfall. Only a narrow 5-foot ditch width exists between the edge of pavement (EP) and base of rock slope. Two rockfall-caused accidents have occurred along the cut section during the past 5 years.

The design project manager has decided that construction of a rockfall catchment area is warranted. Agency policy on primary highways is to design catchment areas to provide 90% rockfall retention, whenever economically feasible.

Determine: Required catchment area width, W, to provide 90% rockfall retention.

Step 1 - Establish overall design rock cut slope ratio based on overall rock slope stability.

Agency geotechnical personnel recommend a design slope ratio of 0.25H:1V for overall slope stability. Agency policy is to use controlled blasting to improve overall stability and to minimize long-term rockfall.

Step 2 - Select critical rock cut slope design cross-section(s).

Plotting the 0.25H:1V slope on the roadway design cross-section, and assuming a cut widening in the 20-30 foot range to provide rockfall catchment, gives a maximum new cut slope height of approximately 80 feet.

Step 3 - Select the appropriate catchment area design chart based on slope ratio and slope height.

The Design Chart for 0.25H:1V Cut Slope, 80-foot Slope Height is selected. See Figure 4.4.

Step 4 - When dimensioning new catchment areas, enter appropriate slope design chart for a specified or desired percent rockfall retention and read off the required catchment area width, W, for desired catchment area slope(s), i.e., flat-bottom, 6H:1V or 4H:1V.

Entering the Figure 4.4 design chart at 90% rockfall retained and reading across to the various catchment area slope curves gives the following required catchment area widths, W:

Catchment Area Slope	Required Width W
Flat	51 feet
6H:1V	31 feet
4H:1V	22 feet

Agency policy is to use a 6H:1V sloped clear zone slope whenever possible. This gives a required catchment area width of 31 feet.

Perform the constructibility check. The Agency's controlled blasting specifications limit drilling lift heights to 40 feet. The 80-foot high cut excavation will require two excavation lifts. Examination of all cross-sections through the length of proposed cut shows that the 31-foot excavation width is wide enough to accommodate construction drilling and excavation equipment working the cut. Constructibility OK.

Design Recommendation: A rockfall catchment area width of 31 feet with 6H:1V bottom slope is recommended for final design.

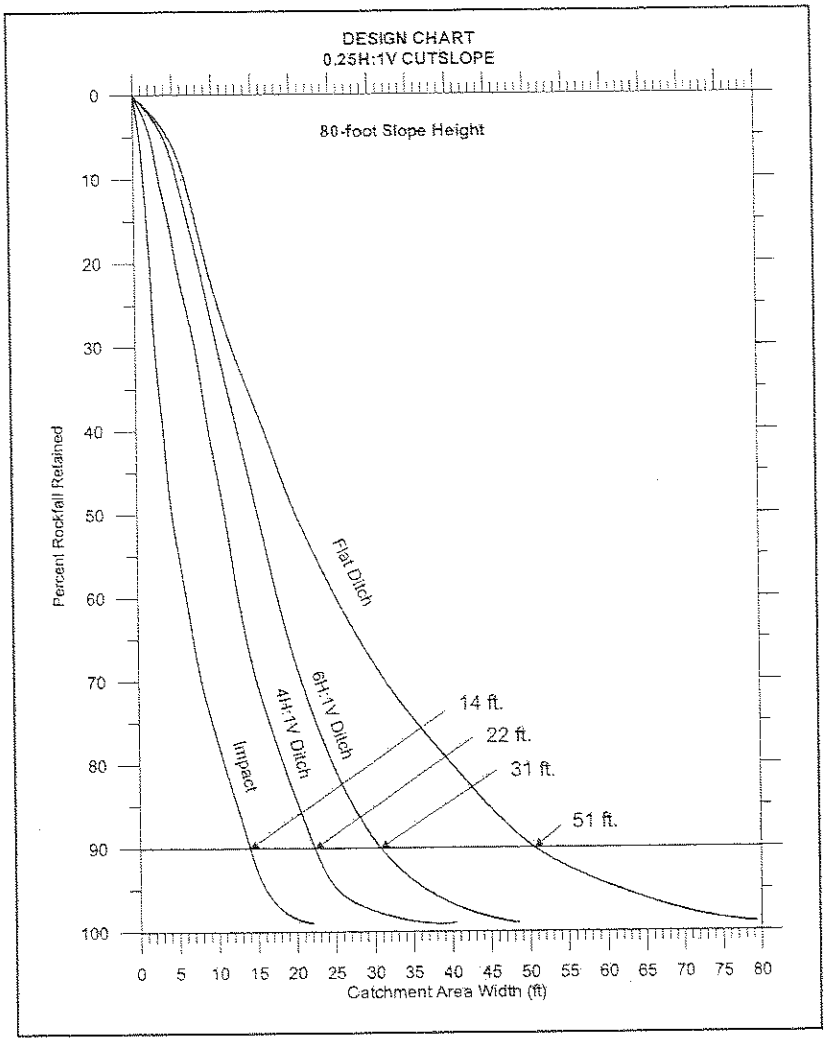


Figure 4.4: Design chart for 80-foot high, 0.25H:1V slope (Example 1)

4.4.2 Worked Example 2 - Evaluating an Existing Catchment Area

Using the cumulative percent retained design charts, the practitioner can also quickly evaluate the effectiveness of existing catchment areas adjacent to rock slopes. This is demonstrated in the following example.

Project Description: An 80-foot high, 500-foot long highway cut has a rockfall problem. The slope ratio is 0.25H:1V. A site visit reveals that a small portion of the cut length possesses the greatest hazard. Rockfalls appear to be generated primarily from the upper half of the cut. The existing catchment area width is constant at 25 feet, and most catchment area sections slope toward the toe of slope at approximately 4H:1V. However, the catchment area slope changes to 6H:1V or flatter in the problem area.

Determine: Estimate the percent rockfall retention provided by the existing catchment area and the most cost-effective way to increase the catchment area effectiveness.

Finding a catchment area width of 25 feet in the Figure 4.5 design chart. Following it up to the 6H:1V curve indicates that only 80% of the rocks falling into this section of the catchment area can be expected to be retained. Approximately 20% of rocks are allowed to reach the roadway. Alternately, 95% of rockfalls are retained in a catchment area of the same width with a 4H:1V catchment area slope, an increase in catchment of 15%.

Design Recommendation: Recommending a simple re-grading of the catchment area slope from the existing 6H:1V to 4H:1V significantly increases catchment area effectiveness and enhances public safety for a relatively small investment.

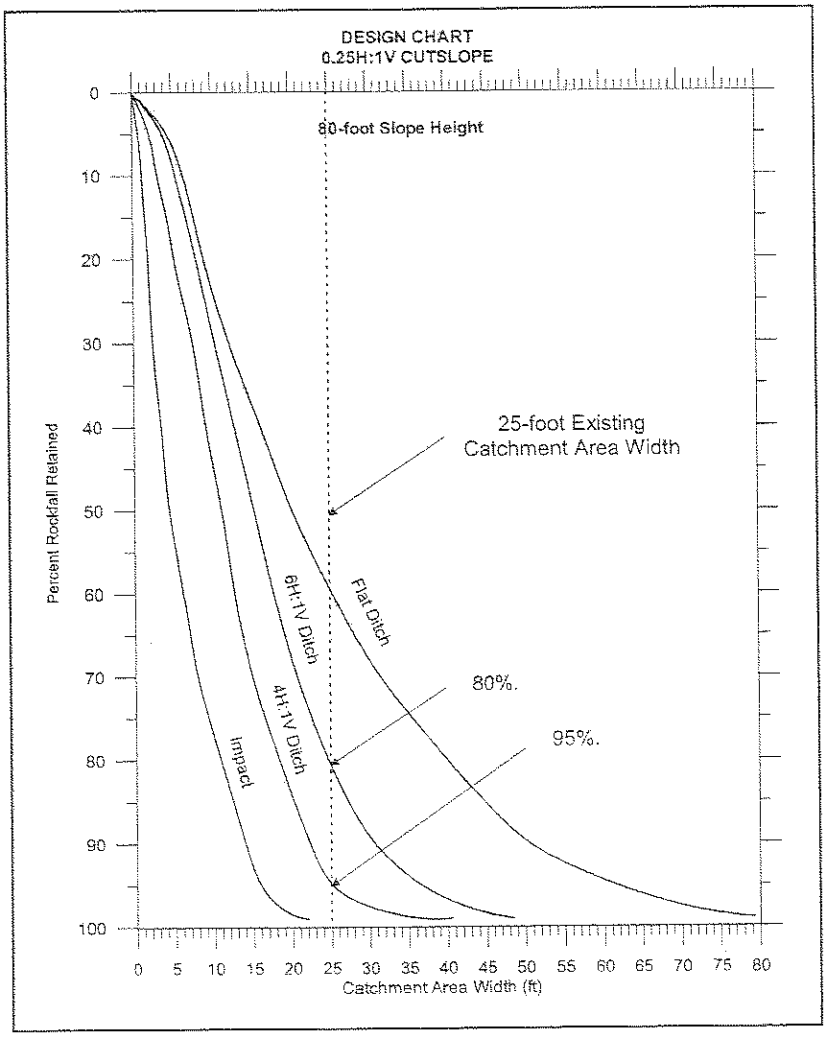


Figure 4.5: Design chart for 80-foot high, 0.25H:1V slope (Example 2)

Using the research data in this manner demonstrates a method for evaluating existing slopes. In a real highway cut, rocks could begin their fall from anywhere on the slope. Rockfalls may only initiate from one or two zones or from random locations scattered throughout the slope. In addition, catchment area geometry may vary appreciably throughout a cut section. Because of this, a higher or lower percentage of rocks may be retained than the design charts estimate. Obviously, an application of this sort requires the user to make a qualitative assessment of the slope. Site-specific characteristics must be considered if a realistic evaluation of catchment area effectiveness is to be obtained. Experienced rock slope engineering personnel should make these assessments.

4.4.3 Worked Example 3 - Benefit/Cost Comparison

On a national and international level, the problem of rockfall is significant, particularly in mountainous states/countries. Rockfall problems are typically dealt with using either a strategy of elimination or reduction. The goal of 100 % (zero tolerance) rockfall hazard elimination, while desirable, is difficult to attain. A limited budget, as well as a desire to limit the effects of highway construction on adjacent properties and the environment, usually precludes directing sufficient resources toward the total 100% elimination of a rockfall problem.

A more practical approach is to reduce the potential for rock on the road along as many miles of roadway as possible using the budget available. Hazard reduction along many miles of roadway provides a more consistent benefit than if only a short section of a given roadway had its entire rockfall problem eliminated for the same cost.

An informed decision must be made regarding hazard reduction relative to cost. The following generic example illustrates such a benefit/cost approach.

Project Description: Rockfall on the highway has been a serious problem along the high side of a 400-foot long through cut for many years. A design cross section of the site is shown in Figure 4.6. No catchment area was provided during the original construction. The agency would like to reduce the rockfall hazard but is unsure what level of improvement can be obtained for a reasonable investment.

Determine: Perform a benefit/cost comparison of alternate catchment area widths.

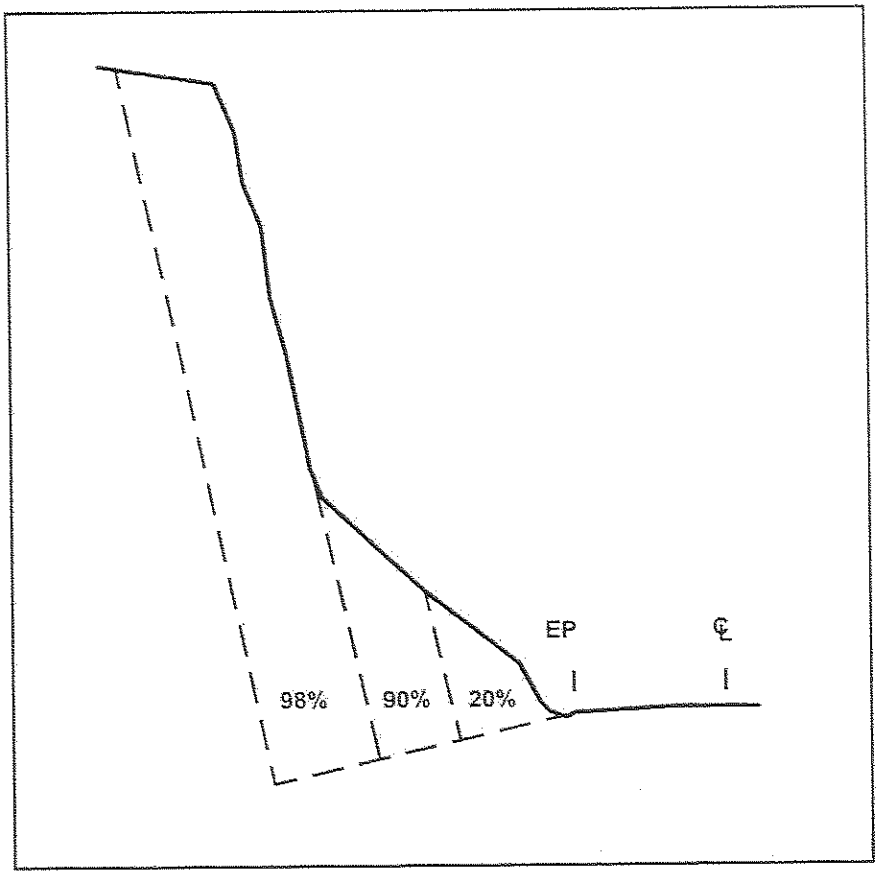
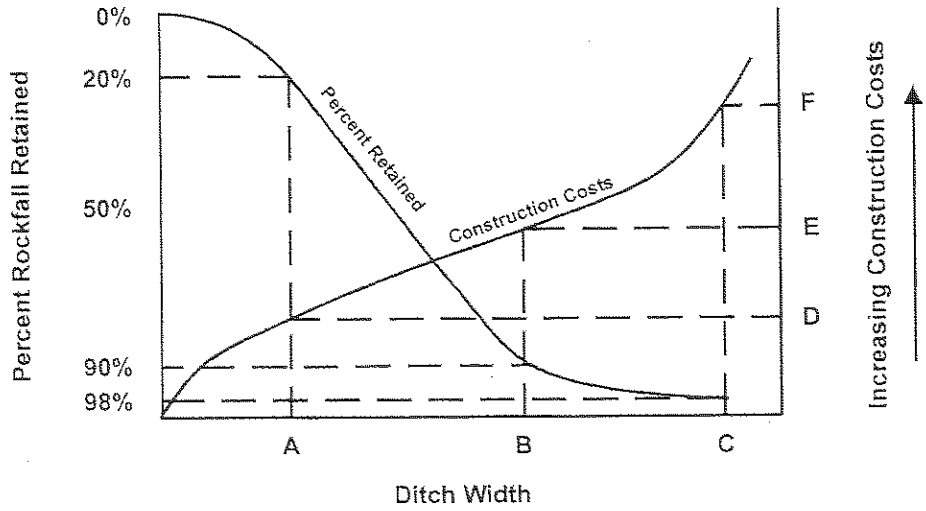


Figure 4.6: Slope cross-sections; benefit/cost comparison (Example 3)

Rockfall is possible from anywhere on the slope. Because of the shape of the slope (see Figure 4.6), excavation quantities will increase in a non-linear fashion as the catchment area width is increased. Therefore, the cost of a small amount of increased width is low initially, since the cut height would be low. As excavation of the entire slope is approached, the cost of each increment of catchment area width becomes higher due to the increasing cut height. For this example, the catchment area widths associated with providing 20%, 90% and 98 % rockfall retention are shown on Figure 4.6.

The results of this benefit/cost analysis can also be illustrated graphically as shown on Figure 4.7. Different excavation costs based on catchment area width are plotted against the percentage of rock that will be retained for a specific slope height and catchment area width. Using this method enables different options to be discussed in the decision making process. Both the benefits and costs can be clearly shown, and a prudent decision on the allocation of funds can be made. In this example, the cost of improvement between 20% and 90% rockfall retention is about the same as it is between 90% and 98%, i.e., increasing the percent retention the additional 8% from 90% to 98% nearly doubles the construction cost. Further, the additional catchment area width required to provide the additional 8% retention from 90% to 98% approximately triples the cut height, causing a far more severe impact to adjacent properties and the environment.



Construction Cost = f (Excavation Costs, R.O.W. Costs / Ft. of Width)

Increased Width from A to B increases Percent Rockfall Retained by 70% and increases cost from D to E.

For the same increase in Cost from E to F, Percent Rockfall Retained is increased by only 8%.

Figure 4.7: Example benefit/cost comparison (Example 3)

Design Recommendation: Based on this benefit/cost comparison, a catchment area width that provides 90% rockfall containment is selected.

4.4.4 Project Case Study Application Examples

Seven actual project case study examples are provided to further illustrate the practical application and ease of use of the rockfall catchment area design charts to dimension rockfall catchment areas. Several of the participating state and FHWA Technical Advisory Committee members provided case studies of actual projects where the new design criteria and design charts have been used, or where site specific rockfall testing was conducted to aid in the rockfall mitigation design. The case studies also illustrate the type of benefit/cost comparisons and experienced geotechnical judgment applied to arrive at final design recommendations.

Arizona, California, Federal Highway Administration - Central Federal Lands Highway

Division (FHWA-CFLHD), New York, Oregon, Washington, and Wyoming submitted project case study examples. These are included in Appendix G in their entirety.

The **Arizona** project involves highway widening of a portion of US 191 near the town of Morenci, AZ. Existing cutslopes generate substantial rockfall onto the road during rainstorms. Interesting features of this project include the use of actual rock rolling from one of the cutslopes during construction, combined with computer simulation using CRSP, to determine the extent of draped slope mesh required. This was necessitated by a roadway design decision to reduce the rockfall catchment area width and depth below that called for by the Ritchie criteria. ADOT also provides a comparison to the new design charts presented in this design guide.

The **California** project involves a curve correction along State Route 101 near the Monterey and San Benito county line by Caltrans District 5. The California project illustrates benefits of the new design charts to estimate percent rockfall retention and use of a flatter slope catchment versus a very deep Ritchie ditch.

The **New York** (Corning Bypass) project involves highway widening on State Route 17. This project utilized site specific rock rolling, combined with computer simulation, to determine the required height of a rockfall catchment fence, when roadway design changes reduced the available rockfall catchment area width.

The **Oregon** project is a cut widening being done as part of a roadway alignment improvement project on US 26 in the Mt. Hood National Forest.

The **FHWA-CFLHD** project includes a cut widening for a realignment of New Mexico Forest Highway, Route 45 near Sunspot, New Mexico.

The Oregon and FHWA-CFLHD examples are projects where the rockfall catchment areas had already been designed prior to the new design charts becoming available. These case studies illustrate "after the fact" catchment area width and cost comparisons of the as-designed catchment area widths, based on the Ritchie criteria, to the widths given by the new design charts.

The **Washington** project involves highway widening on a project on SR-243 in eastern Washington. The Washington case study compares use of the new design charts to current WSDOT rockfall ditch criteria (modified after Ritchie) for dimensioning new rockfall catchment areas and illustrates benefits of the new design charts. The Washington case study also illustrates the importance and benefit of paying attention to constructibility considerations as part of design.

The **Wyoming** project illustrates use of the new design charts to dimension a new rockfall catchment area constructed as part of a highway-widening project on US 26-89 in the Snake River Canyon.

Special thanks to Bill Hurguy and John Lawson (Arizona DOT), John Duffy (Caltrans), Barry Siel and Sam Holder (FHWA-CFLHD), Alex Yatsevitch (New York DOT) and Mike Vierling (New York Thruway Authority), Don Turner (Oregon DOT), Steve Lowell (Washington State DOT), and Mark Falk (Wyoming DOT) for their extra time and effort preparing these case study submittals.

5.0 COMPLETE SUITE OF DESIGN CHARTS

The Rockfall Catchment Area Design Guide is a current state of the practice reference for sizing rockfall catchment areas for 40- to 80-foot high rock cut slopes.

With the newly developed design charts, practitioners can more quickly and easily dimension new rockfall catchment areas or evaluate the effectiveness of existing catchment areas for rock cut slopes in the 40- to 80-foot height range. Practitioners will also be able to design and construct catchment areas that will have a predictable rockfall retention capacity.

5.1 USE OF DESIGN CHARTS

The Cumulative Percent Rockfall Retained Design Charts are included here for the vertical, 0.25H:1V, 0.5H:1V, 0.75H:1V, and 1.0H:1V cut slopes (Figures 5.1 - 5.25). These charts are derived from the data in the percent retention graphs for a specific slope height. The design charts are presented in a handy format that allows rapid evaluation of catchment area widths as a comparison between the three catchment area slopes tested.

To facilitate practical design usage, the field measured catchment area impact and roll out <u>slope</u> distances have been converted to <u>horizontal</u> catchment area width on the design charts.

The design charts are presented in a form that can be used to rapidly size rockfall catchment areas that satisfy specific rock catching/retention requirements. Based on slope angle, slope height and catchment area slope, the design charts estimate the required catchment area widths that will retain percentages of rockfall, ranging from 0 to 99 percent.

As a further design aid, the design charts include a handy "Quick Reference" table, listing the rockfall catchment width, W, required to provide 50%, 75%, 80%, 85%, 90%, 95% and 99% rockfall retention.

While the design charts have been developed for standard slope ratios (i.e., vertical, 0.25H:1V, 0.5H:1V, 0.75H:1V, 1H:1V) for practical design use, non-geotechnical users are cautioned that this should not be taken to imply that rock slopes are always designed to these standard slope ratios. Proper rock slope design requires designing the slope ratio (or angle) based upon the orientation of the predominant structural discontinuities that will control the slope's overall stability. In many instances, this will be a slope ratio (or angle) different from those represented on the design charts. When this occurs, interpolation between charts can be used to determine the required catchment width. To facilitate this, the following table of slope ratio/slope angle equivalents is provided for easy reference:

Table 5.1: Slope ratio/slope angle equivalents

Decimal Slope Ratio	Fraction Slope Ratio	Slope Angle (Degrees)
Vertical	Vertical	90
0.25H:1V	¼ to 1	76
0.5H:1V	½ to 1	63
0.75H:1V	¾ to 1	53
1H:1V	1 to 1	45

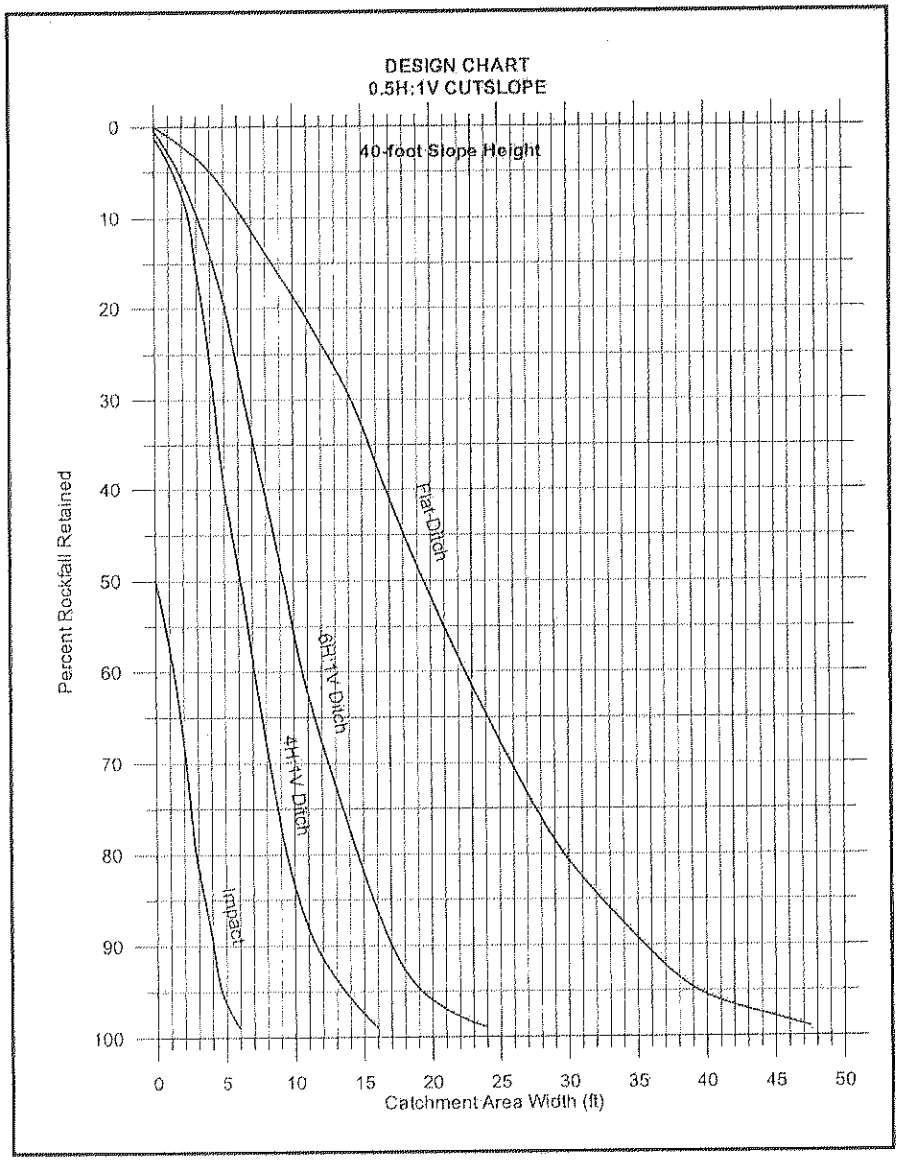
5.2 DESIGN CHART LIMITATIONS

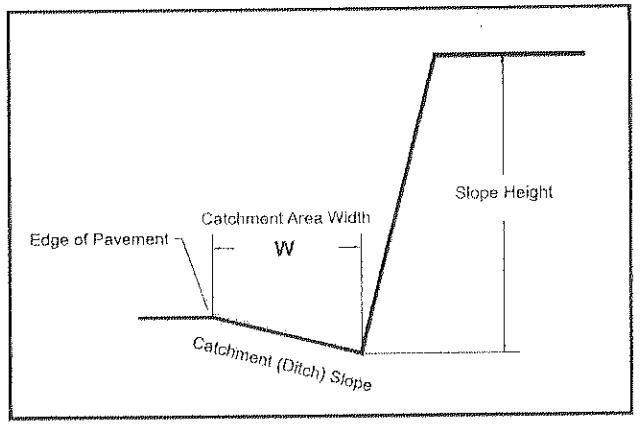
It is important to note that the design charts developed by this research effort are considered to be conservative. In general, the rock type at the Krueger Quarry test site is hard durable basalt that rebounds well after impact and rolls well. Slopes comprised of softer rocks would tend to have lesser impact and roll out distances. In addition, all the rocks started at the top of the slope for each slope height tested. In reality, rocks can and do fall from all portions of a slope. The result is that rocks that initiate from heights less than the maximum possible may not require the entire catchment area width to achieve the specified containment.

Although this was an extensive research effort, it should be kept in mind that different weather, slope and catchment area conditions, rock qualities and rockfall generation sources that vary significantly from those present at the research site may result in different behavior. **It is important to have experienced rock slope engineering personnel (engineering geologists/ geotechnical engineers) involved in designing rock slope catchment areas. They should evaluate and decide when it is appropriate to directly use the figures in the enclosed design charts or to modify the catchment area dimensions shown.**

Because there are many different combinations of slopes, catchment areas, rock types and maintenance practices, it is possible for rockfall to occur where the result exceeds the maximum-recorded value documented in this report. With any data set, outliers are possible. For that reason, the highest retention design chart represents 99% retention, not 100%.

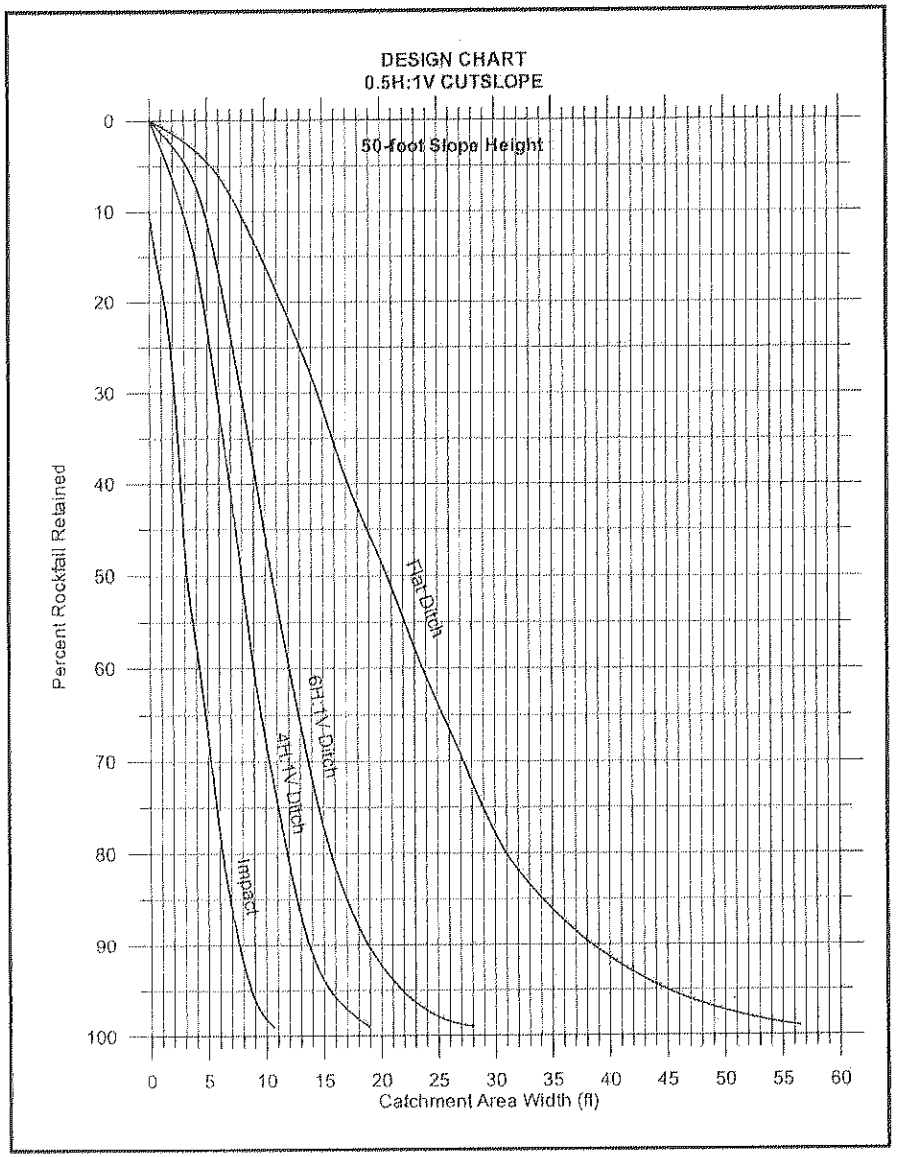
In a real highway cut, rocks could begin their fall from anywhere on the slope. Rockfalls may initiate from one or two zones or from random locations scattered throughout the slope. In addition, catchment area geometry may vary appreciably throughout a cut section. Because of these factors, a higher or lower percentage of rocks may be retained than the design charts estimate. Obviously, an application of this sort requires the user to make a qualitative assessment of the slope. Site-specific characteristics must be considered if a realistic evaluation of catchment area effectiveness is to be obtained. **Experienced rock slope engineering personnel should make these assessments.**

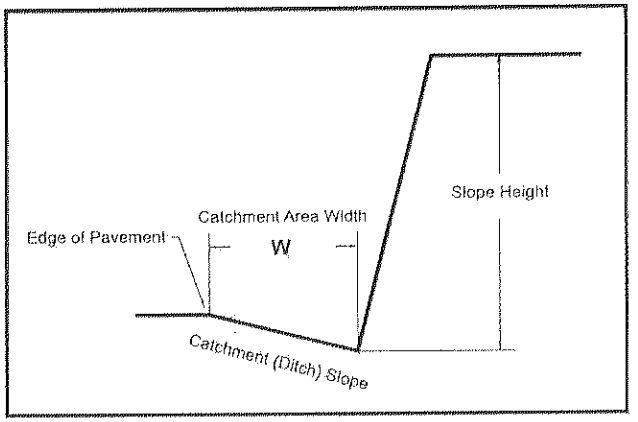




Quick Reference - 40-Ft Slope Catchment Area Width - **W**				
Percent Rockfall Retained	Impact	Catchment Area Slope		
		4H:1V	6H:1V	Flat
	W (ft)	W (ft)	W (ft)	W (ft)
50%	0	6	9	19
75%	2	9	14	28
80%	3	9	15	30
85%	3	10	16	32
90%	4	11	17	35
95%	5	14	19	39
99%	6	16	24	48

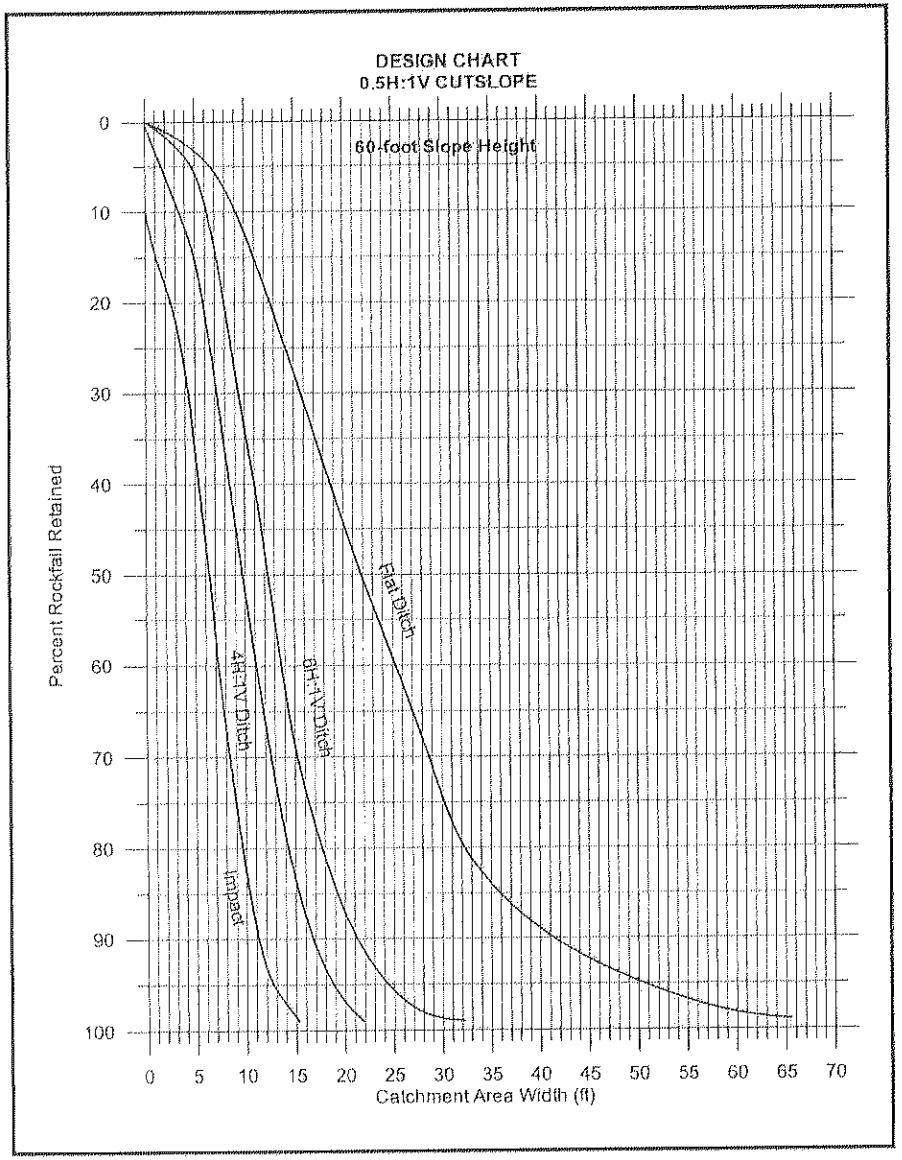
Figure 5.11: Design chart for 40-foot high 0.5H:1V cutslopes

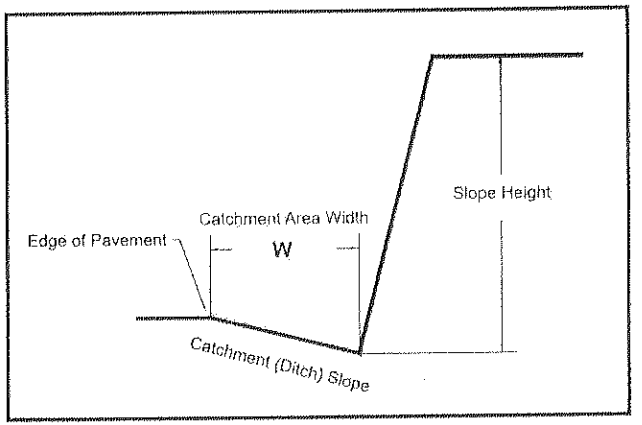




Quick Reference - 50-Ft Slope Catchment Area Width - **W**				
Percent Rockfall Retained	Impact	Catchment Area Slope		
		4H:1V	6H:1V	Flat
	W (ft)	W (ft)	W (ft)	W (ft)
50%	3	8	11	21
75%	6	11	15	29
80%	6	12	16	31
85%	7	13	17	34
90%	8	14	19	38
95%	9	16	22	45
99%	11	19	28	57

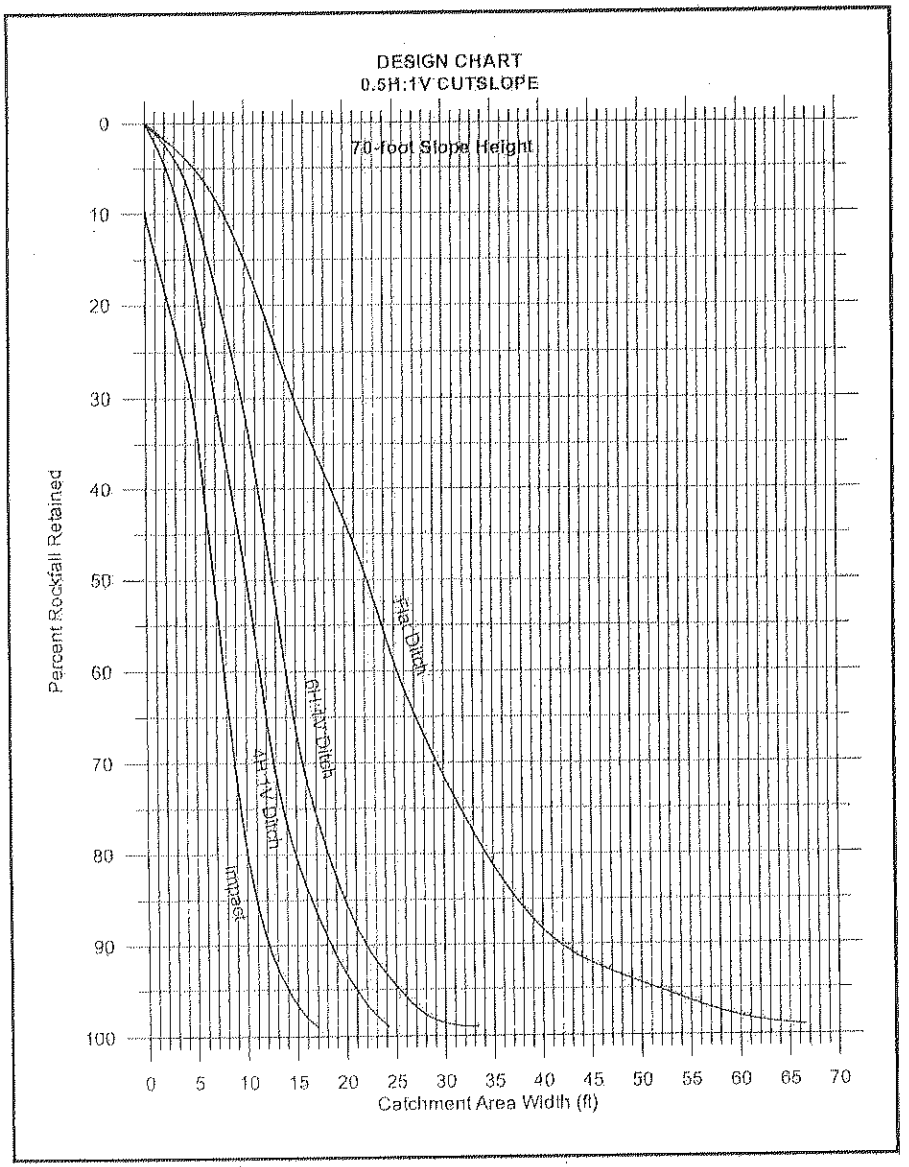
Figure 5.12: Design chart for 50-foot high 0.5H:1V cutslopes

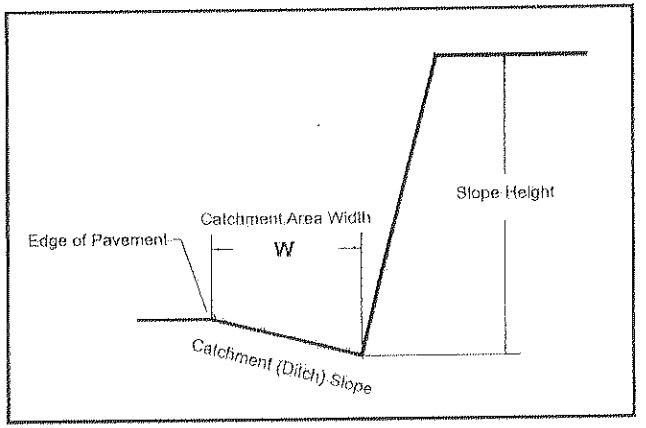




Quick Reference - 60-Ft Slope Catchment Area Width - **W**				
Percent Rockfall Retained	Impact	Catchment Area Slope		
		4H:1V	6H:1V	Flat
	W (ft)	**W** (ft)	**W** (ft)	**W** (ft)
50%	6	10	12	22
75%	9	13	16	30
80%	10	14	18	32
85%	10	15	19	36
90%	11	17	21	41
95%	13	19	24	51
99%	15	22	32	66

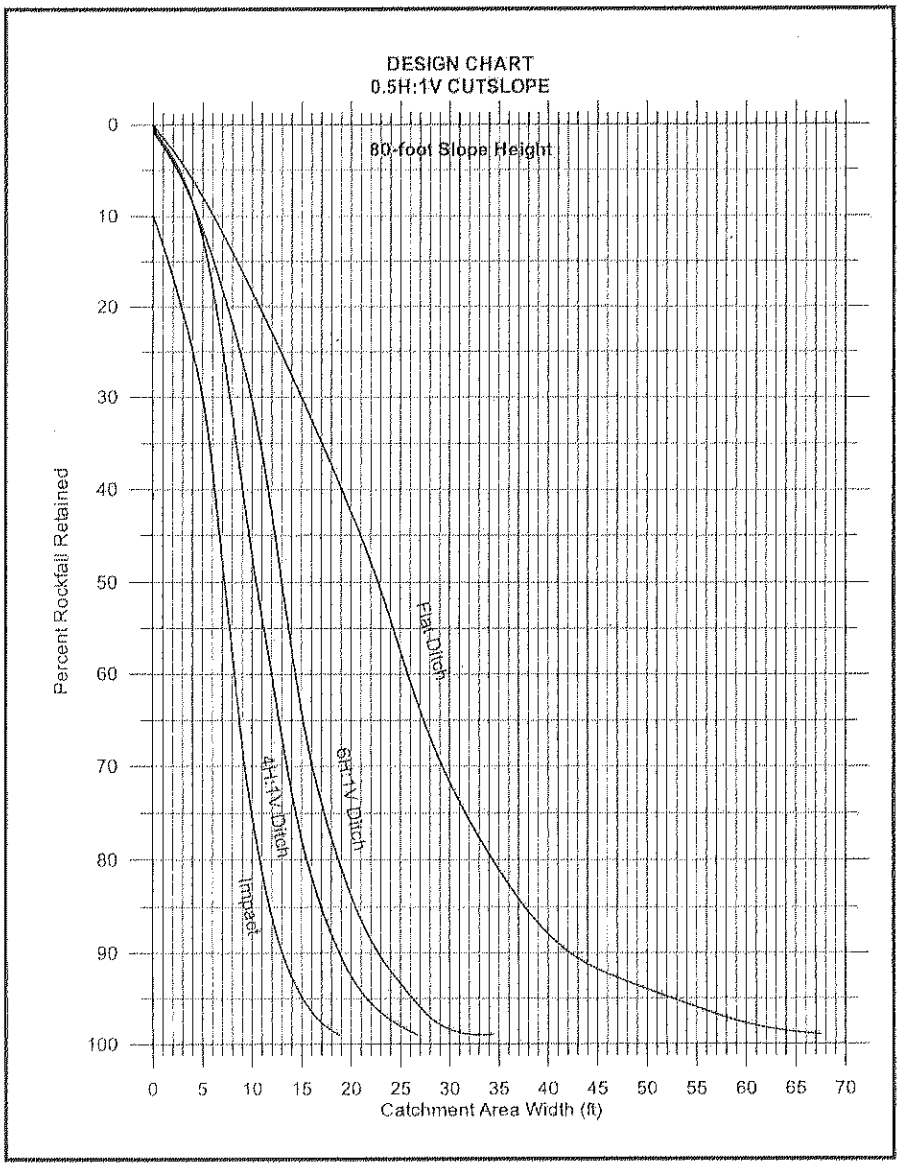
Figure 5.13: Design chart for 60-foot high 0.5H:1V cutslopes

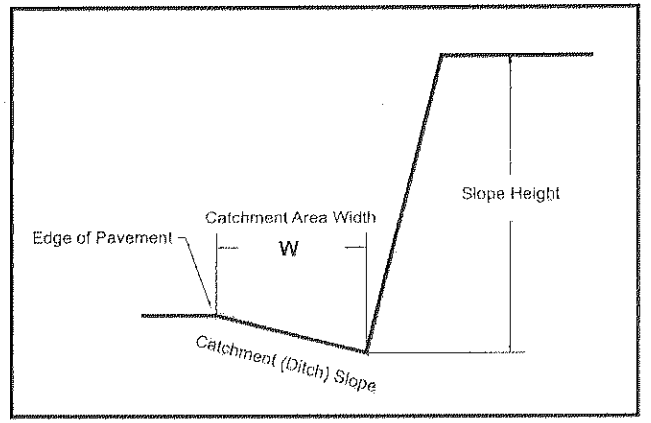




Quick Reference - 70-Ft Slope Catchment Area Width - **W**				
Percent Rockfall Retained	Impact	Catchment Area Slope		
		4H:1V	6H:1V	Flat
	W (ft)	W (ft)	W (ft)	W (ft)
50%	7	10	13	22
75%	9	14	17	32
80%	10	15	18	34
85%	11	16	20	37
90%	12	18	22	42
95%	14	21	25	52
99%	17	24	33	67

Figure 5.14: Design chart for 70-foot high 0.5H:1V cutslopes





Quick Reference - 80-Ft Slope Catchment Area Width - **W**				
Percent Rockfall Retained	Impact	Catchment Area Slope		
		4H:1V	6H:1V	Flat
	W (ft)	**W** (ft)	**W** (ft)	**W** (ft)
50%	7	10	13	23
75%	10	14	17	32
80%	11	16	19	34
85%	12	17	20	38
90%	13	19	23	42
95%	15	22	26	53
99%	19	27	34	68

Figure 5.15: Design chart for 80-foot high 0.5H:1V cutslopes

6.0 CONCLUSIONS

6.1 SUMMARY OBSERVATIONS AND CONCLUSIONS

The following general observations and conclusions may be drawn from the research. Some items may seem intuitively obvious but are worth summarizing here, especially for those who have had limited experience with rockfall behavior. The extensive number of rockfalls observed in this study provides a comprehensive basis for these observations.

- A catchment area's slope, whether flat-bottom or inclined, has insignificant influence on where a falling rock will first impact the catchment area.
- Steeper catchment area slopes dramatically reduce roll out distances.
- Cut slope irregularities, commonly referred to as "launch features," strongly influence a rockfall's point of impact when struck by the falling rock.
- Factors such as the presence of launch features and increasing slope height are key to the development of preferred rockfall paths.
- "Launched" rocks tend to have greater impact distances, increasing the spread or dispersion of recorded impacts, compared to rocks that do not strike launch features.
- Launch features change a rock's vertical drop to horizontal displacement. Typically, the higher the rock velocity when it strikes a launch feature, the greater the horizontal displacement.
- Higher slopes and flatter catchment areas produce rockfall roll out distances that are more widely scattered or variable.
- Higher slopes typically produce larger average roll out and impact distances.
- Higher slopes produce impact distances that are more variable.
- Large roll out distances are possible when a falling rock's translational momentum is changed into rotational momentum by impacting the slope, especially if the rock strikes near the base of the cut slope.
- On vertical slopes, falling rocks rarely strike the slope in trajectory. They typically drop undisturbed into the catchment area. Angular momentum is not imparted to the falling rocks, which results in smaller roll out values.

- On flatter slopes (0.75H:1V and flatter) where rocks are rolling down the cut slope, the impact distances are lower, with most rocks entering the catchment area very near the base of the slope.

- On flatter slopes, movement out into the catchment area is due primarily to roll out.

- Rockfall velocities are a function of cut slope angle and height and the amount of time the rocks are in contact with the slope.

- When in contact with the slope, friction decelerates a rockfall, which lowers the resulting energies.

- Because rocks are less often in contact with steeper slopes (free falling or bouncing not rolling), the resulting velocities and energies are higher than for flatter slopes (0.75H:1V or flatter).

- Field testing of a Ritchie catchment area sized to meet the modified FHWA chart for an 80-foot high, 0.25H:1V slope provided a rockfall retention value of 85 percent.

- Compared to field testing results, the computer simulations for 0.25H:1V slopes tended to under-predict the rockfall roll out distances for 80-foot high slopes and over-predict the roll out distances for the 40-foot high slopes, but the simulations still gave reasonable results. Computer simulations produced distributions similar to field testing, and the effects of rock size and catchment area slope were also similar.

- **It is important to have experienced rock slope engineering personnel (engineering geologists/ geotechnical engineers) involved in designing rock slope catchment areas. They should evaluate and decide when it is appropriate to directly use the figures in this report's design charts or to modify the catchment area dimensions shown.**

6.2 FURTHER RESEARCH NEEDS

The research project Technical Advisory Committee members jointly developed the following list of future research needs to further improve rockfall catchment area designs. TAC members are listed in the Acknowledgments section at the beginning of this report.

- Test other rock slope heights (less than 40 feet and greater than 80 feet).

- Compile case studies of in-service existing rock cut slopes to document the performance history of rockfall catchment area design and/or other rockfall mitigation elements.

- Perform some abbreviated testing on existing highway rock cut slopes to check the sensitivity of different catchment area (ditch) shapes and/or different bedding materials.

- Determine the effect on rockfall roll out distance if a portion of catchment area width is pavement.

- Compile and digitize the available rock rolling video footage from ODOT testing and other available sources for use in future rockfall energy research.

- Document more rock rolling energy data – similar to that presented in Appendix E – for use in structural design of different rockfall mitigation elements (barriers, fences, slope mesh, etc.).

- Test to the point of failure commonly used rockfall mitigation measures, such as conventional concrete guardrail, timber-backed conventional concrete guardrail, metal guardrail, and rockfall catch fences, to determine their ultimate structural/rockfall energy absorbing capacity.

- Use ODOT-generated rockfall energy data to help refine computer simulations provided by Colorado Rockfall Simulation Program (CRSP) or other rockfall computer programs.

Appendix F

From: Larry Best [mailto:bestwinters@viaccess.net]
Sent: Monday, August 02, 2004 4:17 PM
To: Pulice, Daniel
Subject: Bore Hole Coordinates, St. Sroix

Dan Pulice,

These are the coordinates as staked out.

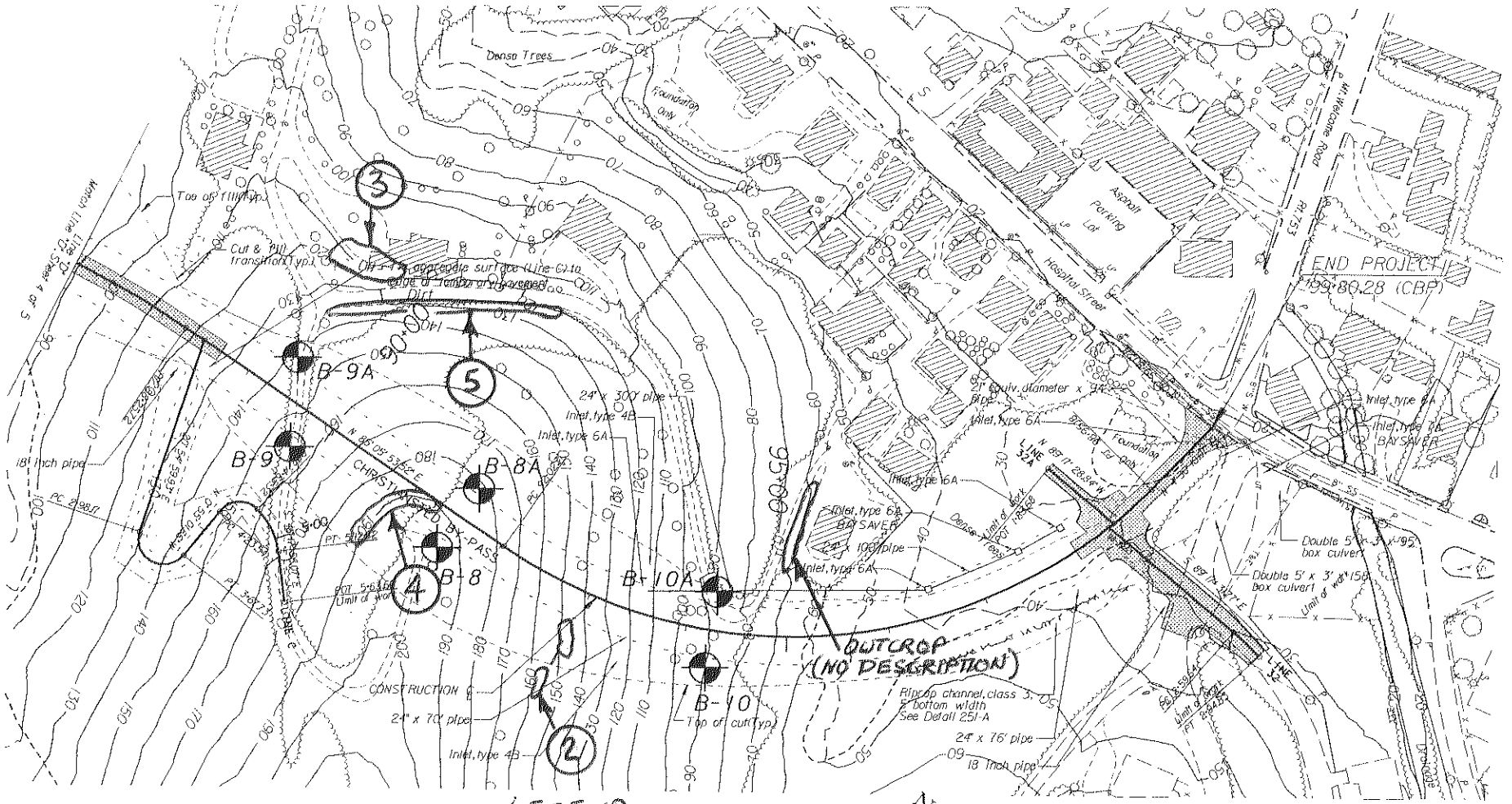
Note that B-8A was staked out about 22 feet from the design location due to our mistake. The staked station for this point is 91+28, 33 Lt.

Point, Northing, Easting, Elevation, Description.
100,70720.072,1103860.191,87.63,CS B-10A
101,70654.828,1103898.975,89.15,CS B-10 3
102,70646.221,1103592.441,184.66,CS B-8A
103,70577.822,1103620.197,195.08,CS B-8 2
105,70562.216,1103446.267,156.49,CS B-9 6
106,70634.868,1103404.061,144.68,CS B-9A
Larry Best
Best Winters Land Surveyors Inc.
340-693-9339 voice + fax

Rock Exposure Locations

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		

PAVED
(See Christiansted Bypass-Temporary Pavement Typical Section and Driveway/Sideroad Typical Section for detail)



CENTERLINE DATA

88+47.54 Bypass = 1+00 Line C
98+39.63 Bypass = 1+00 Line 32
98+45.73 Bypass = 1+00 Line 32A

LEGEND

ROCK EXPOSURE LOCATION
(SEE DESCRIPTIONS)
LOGGED DURING FIELD WORK

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

CHRISTIANSTED BY-PASS
ST. CROIX, VI

ROCK EXPOSURE LOCATIONS

0 50 100

Refer to Exposure Location Plan

Outcrop Exposure #1

Location: about ½ mile from project area behind the City of Christiansted water supply tank.
(Limited data based on most observations being made from car)

- Approx. 20 to 45' high
- Approx 100 to 200' wide
- Probable very fine grained sandstone
- Exposure is the possible result of previous excavation for undetermined reason.
- Grayish Brown to Brown
- Slightly to Highly Weathered
- Very Thinly to Medium Bedded.
- Vertical fracturing very visible w/ colluvium pile at base of cut.
- Some calcite apparent on portions of exposure

Outcrop Exposure #2

Location: In between borings B-8/B-8A and B-10/B-10A on hillside. The bulldozer operator made a semi-path between the boring when the outcrop was noticed. The outcrop sits in waist high grass and weeds

- Light brown to brownish gray to grayish brown
- Approx. 3 to 6' high and Approx. 7 to 10' wide
- Siltstone
- Very thinly to thinly bedded
- Vertical fractures visible, with some to trace calcite
- Slightly to Moderately weathered

Outcrop Exposure #3
Location: Behind 1st house (pink) on left coming up dirt road

-Approx. 6-14' high, approx 50-80' wide
- Siltstone with some possible inter-bedded very fine grained sandstone.
-Light gray to Black (d. gray)
-Slopes @ 60 to 80 degrees
-8" thick vertical highly weathered zone, noted in picture w/ pencil (tan / orangish brown, somewhat sandy) – picture 5
-Vertical to near vertical fractures throughout, some calcite filled
-Various bedding patterns, very thin to Indistinct

-Surface is slightly to Highly Weath. . (differential weathering)
-Outcrop was exposed by track-hoe and bulldozer upon initial construction of house. This information was obtained by personal discussion with the same equipment operator on our job for the test boring location access road.
- Joint orientations: N10°W, N50°W, N0°E
- Strike and dips: N40°W dip 40° SW, N5°W dip 60-70° W, N55°W dip 40° S (srikes and dips vary due to uncertainty of some bedding planes due to weathering)

Outcrop Exposure #4

-Location: 20' SW of B-8A, curves contours around top of hill side @ approx. same elev., outcrop sits near the crest of hill.

-Approx. 2' to 4' high (varies) and about 150-200' wide (not continuous)
- Weathered Siltstone
-Some of outcroppings were covered with colluvium or vegetation.
-Light Brown to Brownish Gray
-Slightly to Mod. To Highly Weath. (differential weathering)
- Tree roots were observed growing in a vertical fracture.

Outcrop Exposure #5

-Location: top of dirt road, driveway to last house on road lined with conch shells.

-Approx. 250' to 300' long, some portions covered with colluvium
-Varies in height from 2 to 10'
- Siltstone to Very fine grained sandstone
-Light brown to grayish brown
- Slope varies from 60 to 30 degrees
-Vertical to near vertical fractures visible through out. Trace calcite veins visible in some joints and fractures
- Slightly to Highly weathered. Differential Weathering through out exposure
-Outcrop was exposed when Bulldozer cut road initially for access to the last house.
- the owner of the house at the end of driveway provided information about heavy rains sometimes causes some small boulders (moveable by himself) to fall and block his driveway (access road).
- Joint Orientations: Numerous Vertical Joints and Fracs., N5°E, N15°W, N10°E
- Strike and Dip: N35°E dips 70° S, N15°W dips 50° S, N75°W dip 40° S

Typed Boring Logs

ENGINEERS FIELD BORING LOG

BORING NO.	B-8
SHEET	1 OF 6
DATE: START:	7/17/04
END:	7/18/04
G.S. ELEV.	195.1

PROJECT NAME: Christiansted Bypass, U.S. Virgin Islands COUNTY:
STATE RTE. NO.: - SECT.: - SEGMENT: - OFFSET: -
STATION: 91+50 OFFSET FROM CENTERLINE: 38 RT
INSPECTOR (SIGNED): Dan Pulice DRILLERS NAME/COMPANY: Jeff Page / Amdrill
EQUIPMENT USED: BK 51 HDT Track Mount
DRILLING METHODS: SPT / HQ wireline
CASING: SIZE: 94mm ID DEPTH: 125.5 WATER: DEPTH: 12.0 TIME: 0 HR DATE: 7/18/04
CHECKED BY: JMB DATE: 8.30.04 DEPTH: Caved TIME: 24 HR DATE: 7/19/04

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
0.3	S-1	50/.3	0.3	100	N/A	gm		194.6 SILTY GRAVEL (a-1-b) - Brown; Dry; Very Dense 0.5	
0.5	R-1		2.0	100 / 0		a-1-b		SILTSTONE - Gray/ Brownish Gray to Blueish Gray; Hard to Very Hard; Highly to Freshly Weathered; Very Thinly to Medium to Indistinct Bedding, RD=20-60°; Very Closely to Medium Spaced Fracs, FRD=0-90° (Stratum RQD=34%)	- 0.5-5.0, mod. weath. 0-90° fracs L=2,S=1,R=5-3,I=2 W=3
2.5	R-2		2.5	100 / 0					
5.0	R-3		3.0	100 / 20					- 5.0-14.0, Very Broken, mod. to highly weath 0-90° L=2,S=5-4,R=5,I=6 W=3-1
8.0	R-4		2.0	100 / 0					
10.0	R-5		4.0	100 / 0				Pyrite present throughout the siltstone, with higher concentrations in some zones.	- 10.0, 14.0, 15.0 - core blocked off prob. due to frac. zones
14.0	R-6		1.0	100 / 0				Stratum RQD does not accurately represent the total length of the Siltstone, the indivual RQD runs increase @ 50.5'.	- 14.0-20.0, very broken
15.0	R-7		5.0	100 / 0				- 80.0-125.0 very thin to laminated cross-bedding	
20.0	R-8		5.0	100 / 14					
25									

NOTE: N/A - Not applicable due to the presence of granular material
Northing=70577.822, Easting=1103620.197
High water levels may result from drilling process

ENGINEERS FIELD BORING LOG

BORING NO.	B-8
SHEET	2 OF 6
DATE: START:	7/17/04
END:	7/18/04
G.S. ELEV.	195.1

PROJECT NAME: Christiansted Bypass, U.S. Virgin Islands COUNTY:
STATE RTE. NO.: - SECT.: - SEGMENT: - OFFSET: -
STATION: 91+50 OFFSET FROM CENTERLINE: 38 RT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
25 / 25.0	R-9		3.5	100 / 0				SILTSTONE - (cont.)	
28.5	R-10		1.2	80 / 0					- 25.0-34.0, very broken 0-90° fracs Sl. to Highly Weathered L=2,S=0,R=5-3 I=6,W=5-3
30 / 30.0	R-11		3.6	90 / 0					
34.0	R-12		1.0	100 / 0					
35 / 35.0	R-13		2.0	80 / 0				- 35.0-37.5, extremely broken (small pieces)	
37.5	R-14		1.0	40 / 0					- 35.0-37.5, extremely broken 0-90° fracs Sl. to Highly Weath. L=2,S=1-0,R=4-3 I=6,W=5-4
40 / 40.0	R-15		2.5	83 / 0					
43.0	R-16		2.0	80 / 0				- occasional calcite veins through out	- 37.5-50.0 extremely broken 0-90° fracs Sl. to Highly Weath L=2,S=0,R=4 I=6,W=5-1
45 / 45.5	R-17		3.0	60 / 0					
50									

ENGINEERS FIELD BORING LOG

BORING NO.	B-8
SHEET	3 OF 6
DATE: START:	7/17/04
END:	7/18/04
G.S. ELEV.	195.1

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 91+50 OFFSET FROM CENTERLINE 38 RT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
50								SILTSTONE - (cont.)	
50.5	R-18		5.0	100 / 70					- 50.5, core becomes Sl. to Fr. Weath
55									
55.5	R-19		5.0	100 / 50					R-19, occasional 0-90° fracs L=2, S=6-5,R=5-4,I=6 W=5
60									
60.5	R-20		5.0	100 / 64					
65									
65.5	R-21		5.0	100 / 40				- Unweathered fracture surface, mechanical breaks, are Greenish Gray	- R-21, occasional 0-90° fracs L=2, S=6-5,R=4,I=6 W=5
70									
70.5	R-22		5.0	100 / 62					- 70.5-72.0, 60-90° fracs L=2,S=5-1 R=3,I=6,W=5
75									

ENGINEERS FIELD BORING LOG

BORING NO.	B-8
SHEET	4 OF 6
DATE: START:	7/17/04
END:	7/18/04
G.S. ELEV.	195.1

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 91+50 OFFSET FROM CENTERLINE 38 RT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
75									
75.5	R-23		5.0	100 / 70				SILTSTONE - (cont.)	- 75.0, 60° frac. L=2,S=4,R=3,I=6, W=5
80									
80.5	R-24		5.0	100 / 74				- 80.0-125.0 very thin to laminated cross-bedding	- 83.0, 70° and 85.0, 50-70° fracs L=2,S=6-5,R=5, I=4 (Calcite) W=6
85									
85.5	R-25		5.0	100 / 52					- 88.5, 20-40° fracs L=2,S=1-0 R=3,I=6,W=5-4 - 88.8-90.0, 70-90° fracs L=2,S=6-5 R=5,I=6,W=6
90									
90.5	R-26		5.0	100 / 86				- @ 90.5 core becomes laminated to very thinly bedded, cross-bedded w/ calcite veins	- 94.0, 60° frac. L=2,S=5-4,R=3 I=4 (calcite) W=5
95									
95.5	R-27		5.0	100 / 50					- 95.5-100.5, occasional 0-90° fracs L=2,S=5-4, R=3 I=6-4 (Calcite), W=6-5
100									

ENGINEERS FIELD BORING LOG

BORING NO.	B-8
SHEET	5 OF 6
DATE: START:	7/17/04
END:	7/18/04
G.S. ELEV.	195.1

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 91+50 OFFSET FROM CENTERLINE 38 RT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
100								SILTSTONE - (cont.)	
100.5	R-28		5.0	100 / 50					
105									
105.5	R-29		5.0	100 / 50					- 104.5-105.5, 0-90° fracs L=2 S=6-5,R=4,I=6, W=6-5 - 108.0-110.0, 0-90° fracs L=2 S=6-5,R=4,I=6, W=6-5
110									
110.5	R-30		5.0	100 / 52					- R-30 occasional 0-90°, fracs L=2 S=6-5,R=3,I=6 W=6
115									
115.5	R-31		5.0	100 / 64					
120									
120.5	R-32		5.0	100 / 56					
125									

ENGINEERS FIELD BORING LOG

BORING NO.	B-8
SHEET	6 OF 6
DATE: START:	7/17/04
END:	7/18/04
G.S. ELEV.	195.1

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY

STATE RTE. NO. - SECT. - SEGMENT - OFFSET -

STATION 91+50 OFFSET FROM CENTERLINE 38 RT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
125									
125.5								69.6 SILTSTONE - (cont.) 125.5	
								BOH @ 125.5	
130									
135									
140									
145									
150									

ENGINEERS FIELD BORING LOG

BORING NO.	B-8A
SHEET	1 OF 5
DATE: START:	7/18/04
END:	7/20/04
G.S. ELEV.	184.7

PROJECT NAME: Christiansted Bypass, U.S. Virgin Islands COUNTY:
STATE RTE. NO.: - SECT.: - SEGMENT: - OFFSET: -
STATION: 91+28 OFFSET FROM CENTERLINE: 33 LT
INSPECTOR (SIGNED): Dan Pulice DRILLERS NAME/COMPANY: Jeff Page / Amdrill
EQUIPMENT USED: BK 51 HDT Track Mount
DRILLING METHODS: SPT / HQ wireline
CASING: SIZE: 94mm ID DEPTH: 115.0 WATER: DEPTH: 3.0 TIME: 0 HR DATE: 7/20/04
CHECKED BY: JML DATE: 8.30.04 DEPTH: Caved TIME: 24 HR DATE: 7/21/04

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
0.4	S-1	50/.4	0.4	100	N/A	gm		184.2 SILTY GRAVEL (a-1-b) - Brown; Dry; Very Dense 0.5	
0.5	R-1		2.0	100 / 0		a-1-b		SILTSTONE - Brownish Gray to Blueish Gray; Hard to Very Hard; Highly to Freshly Weathered; Indistinct to Very Thinly Bedded, RD=0-45°; Very Closely to Widely Spaced fracs, FRD=0-90° (Stratum RQD=55%)	- 0.5-10.0, very broken - 0-90° fracs, Highly to Slightly Weathered L=2, S=2-1 R=4-3,I=6-4,W=2
2.5	R-2		2.5	100 / 0					
5.0	R-3		2.0	80 / 0					
7.5	R-4		1.5	60 / 0				Pyrite present throughout the siltstone, with higher concentrations in some zones.	
10.0	R-5		2.0	100 / 0					
12.0	R-6		3.0	100 / 0				Stratum RQD does not accurately represent the total length of the Siltstone, the indivual RQD runs increase @ 40.0'.	
15.0	R-7		5.0	100 / 22					- 15.0-20.0, 0-90° fracs. L=2,S=5-4 R=3,I=6-4,W=5-3
20.0	R-8		2.5	100 / 0					- 20.0-22.5, 0-90° fracs L=2,S=5-4 R=4,I=6-4,W=5-4
22.5	R-9		2.1	84 / 56					- 22.5-30.0, 0-90° fracs L=2,S=6-5 R=3,I=6-4,W=5
25									

NOTE: N/A - Not applicable due to the presence of granular material
Northing=70646.221, Easting=1103592.441
High water levels may result from drilling process

ENGINEERS FIELD BORING LOG

BORING NO.	B-8A		
SHEET	2	OF	5
DATE:	START:	7/18/04	
	END:	7/20/04	
G.S. ELEV.	184.7		

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 91+28 OFFSET FROM CENTERLINE 33 LT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
25 / 25.0	R-10		5.0	100 / 56				SILTSTONE - (cont.)	
30 / 30.0	R-11		5.0	100 / 60					- 30.0-35.0, 30-70° fracs. L=2,S=6-5 R=3,I=6,W=6-5
35 / 35.0	R-12		5.0	100 / 28					- 35.0-38.0, 20-50° fracs L=2,S=6-5 R=3,I=6-5,W=5 - 38.0-40.0, 40-80° fracs L=2,S=4 R=5-4,I=6-4,W=5-4
40 / 40.0	R-13		5.0	100 / 66					- 40.0-43.0, 20-45° fracs L=2,S=6, R=3 I=6,W=5 -43.0-45.0, moderately weathered
45 / 45.0	R-14		5.0	100 / 46				- 45.0-55.0, Laminated to Thinly Bedded w/ cross-bedding and calcite veins	- 45.0-47.5, 80-90° fracs L=2,S=5, R=3 I=6,W=5
50									

ENGINEERS FIELD BORING LOG

BORING NO.	B-8A
SHEET	3 OF 5
DATE: START:	7/18/04
END:	7/20/04
G.S. ELEV.	184.7

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 91+28 OFFSET FROM CENTERLINE 33 LT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
50 50.0	R-15		4.8	96 / 96				SILTSTONE - (cont.)	
55 55.0	R-16		5.0	100 / 54					- 56.5-60.0, 0-90° fracs L=2,S=6-5 R=3,I=6,W=5-4
60 60.0	R-17		5.0	100 / 80					- 63.5, 65° frac. L=2,S=5,R=4,I=6 W=5-4
65 65.0	R-18		5.0	100 / 92					
70 70.0	R-19		5.0	100 / 90					
75									

ENGINEERS FIELD BORING LOG

BORING NO.	B-8A
SHEET	4 OF 5
DATE: START:	7/18/04
END:	7/20/04
G.S. ELEV.	184.7

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 91+28 OFFSET FROM CENTERLINE 33 LT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
75 / 75.0	R-20		5.0	100 / 50				SILTSTONE - (cont.)	- 75.0-76.5, 77.5-78.0, 40-90° fracs L=2,S=4,R=4 I=6, W=5
80 / 80.0	R-21		5.0	100 / 40				- 80.0-100.0 traces of pyrite visible on frac surfaces	- 80.0-85.0, 30-70° fracs L=2,S=6-5,R=3, I=6,W=6-5
85 / 85.0	R-22		5.0	100 / 38					- 87.0-88.0, 0-90° fracs L=2,S=4,R=3-2 I=6,2, W=4
90 / 90.0	R-23		5.0	100 / 54					- 90.0-95.0 occasional 40-60° fracs L=2,S=6-4 R=3-2,I=6,4 W=5
95 / 95.0	R-24		5.0	100 / 64				- 95.0-96.0, very broken Slightly to Moderately Weathered	- 96.0-100.0, 40-60° fracs L=2,S=5,R=3 I=4 (Calcite),W=6-5
100									

ENGINEERS FIELD BORING LOG

BORING NO.	B-8A
SHEET	5 OF 5
DATE: START:	7/18/04
END:	7/20/04
G.S. ELEV.	184.7

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 91+28 OFFSET FROM CENTERLINE 33 LT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
100.0								SILTSTONE - (cont.)	
	R-26		5.0	100 / 94					
105.0									
	R-27		5.0	100 / 100					
110.0									
	R-28		5.0	100 / 100					
115.0								69.7 115.0	
								BOH @ 115.0	

100 105 110 115 120 125

ENGINEERS FIELD BORING LOG

BORING NO.	B-9
SHEET	1 OF 3
DATE: START:	7/14/04
END:	7/15/04
G.S. ELEV.	156.5

PROJECT NAME: Christiansted Bypass, U.S. Virgin Islands COUNTY:
STATE RTE. NO.: - SECT.: - SEGMENT: - OFFSET: -
STATION: 89+75 OFFSET FROM CENTERLINE: 38 RT
INSPECTOR (SIGNED): Dan Pulice DRILLERS NAME/COMPANY: Jeff Page / Amdrill
EQUIPMENT USED: BK 51 HDT Track Mount
DRILLING METHODS: SPT / HQ wireline
CASING: SIZE: 94mm ID DEPTH: 70.0 WATER: DEPTH: 1.5 TIME: 0 HR DATE: 7/15/04
CHECKED BY: JML DATE: 8.30.04 DEPTH: Caved TIME: 24 HR DATE: 7/16/04

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
0	S-1	40 50/.2	0.4	57	N/A	gm / a-1-b		155.8 SILTY GRAVEL (a-1-b) - Brown; Dry; Very Dense 0.7	
0.7	R-1		1.8	100 / 0				SILTSTONE - Brownish Blueish Gray; Hard; Moderately to Freshly Weathered; Very Thinly to Indistinct Bedding, RD=45-90°; Very Closely to Closely Spaced Fracs, FRD=0-90° (Stratum RQD=36%) Pyrite present throughout the siltstone, with higher concentrations in some zones. Stratum RQD does not accurately represent the total length of the Siltstone, the indivual RQD runs increase @ 45.0'.	- 0.0-7.5, multiple 0-90° fracs, trace to some clay infilling, orangish brown staining of frac. surfaces - short runs are due to highly fractured zones blocking off core runs
2.5	R-2		2.5	100 / 0					
5 / 5.0	R-3		2.5	100 / 0					
7.5	R-4		2.5	100 / 16					
10 / 10.0	R-5		3.0	75 / 0					- 0.0-20.0, 0-90° fracs L=2, S=4-1 R=3,I=6,2 W=3
14.0	R-6		0.9	90 / 0					
15 / 15.0	R-7		2.0	40 / 0					
20 / 20.0	R-8		2.0	40 / 0					- some sand in water return @ 20.0- 25.0
25									

NOTE: N/A - Not applicable due to the presence of granular material
Northing=70562.216, Easting=1103446.267
High water levels may result from drilling process.

ENGINEERS FIELD BORING LOG

BORING NO.	B-9
SHEET	2 OF 3
DATE: START:	7/14/04
END:	7/15/04
G.S. ELEV.	156.5

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 89+75 OFFSET FROM CENTERLINE 38 RT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
25 25.0	R-9		2.5	100 / 20				SILTSTONE - (cont.)	
27.5	R-10		2.5	100 / 16					
30 30.0	R-11		2.5	100 / 0					
32.5	R-12		2.5	100 / 40					- 32.5, becoming less weathered, larger core pieces
35 35.0	R-13		5.0	100 / 22					- slightly calcareous
40 40.0	R-14		5.0	100 / 30					- 40.0-42.0, 0-90° fracs, L=2,S=4-1 R=3,I=6,W=5-3 - 43.5-50.0, 0-90° fracs, L=2,S=5, R=5-3,I=6, W=5-3
45 45.0	R-15		5.0	100 / 80					
50									

ENGINEERS FIELD BORING LOG

BORING NO.	B-9
SHEET	3 OF 3
DATE: START:	7/14/04
END:	7/15/04
G.S. ELEV.	156.5

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 89+75 OFFSET FROM CENTERLINE 38 RT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
50 50.0	R-16		5.0	100 / 94				SILTSTONE - (cont.)	
55 55.0	R-17		5.0	100 / 100					
60 60.0	R-18		5.0	100 / 50					
65 65.0	R-19		5.0	100 / 88					- 63.5-65.0, highly fractured 0-90° fracs L=2,S=4 R=5-4, I=6, W=6-5
70 70.0								86.5 70.0 BOH @ 70.0	
75									

ENGINEERS FIELD BORING LOG

BORING NO.	B-9A
SHEET	1 OF 3
DATE: START:	7/15/04
END:	7/16/04
G.S. ELEV.	144.0

PROJECT NAME: Christiansted Bypass, U.S. Virgin Islands COUNTY:
STATE RTE. NO.: - SECT.: - SEGMENT: - OFFSET: -
STATION: 89+32 OFFSET FROM CENTERLINE: 38 LT
INSPECTOR (SIGNED): Dan Pulice DRILLERS NAME/COMPANY: Jeff Page / Amdrill
EQUIPMENT USED: BK 51 HDT Track Mount
DRILLING METHODS: SPT / HQ wireline
CASING: SIZE: 94mm ID DEPTH: 60.0 WATER: DEPTH: 2.0 TIME: 0 HR DATE: 7/16/04
CHECKED BY: JMA DATE: 8.30.04 DEPTH: Caved TIME: 24 HR DATE: 7/17/04

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
0								143.5	
0.5	S-1	50/.5	0.4	80	N/A	gm		SILTY GRAVEL (a-1-b) - Brown; Dry; Very Dense 0.5	
	R-1		1.5	100 / 0		a-1-b		SILTSTONE - Brownish Gray to Blueish Gray; Hard to Very Hard; Highly to Freshly Weathered; Very Thinly to Medium to Indistinct Bedding, RD=0-70°; Very Closely to Widely Spaced Fracs, FRD=0-90° (Stratum RQD=39%)	- 0.5-10.0, Very broken 0-90°
2.0	R-2		2.0	67 / 0					
5 5.0	R-3		3.0	100 / 0					
8.0	R-4		2.0	100 / 0				Pyrite present throughout the siltstone, with higher concentrations in some zones.	- 8.0 slightly less weathered
10 10.0	R-5		3.0	100 / 80				Stratum RQD does not accurately represent the total length of the Siltstone, the indivual RQD runs increase @ 30.0'.	
13.0	R-6		1.8	90 / 45					
15 15.0	R-7		5.0	100 / 24					- 15.0-21.0, 0-90° fracs L=2,S=5-4 R=3,I=6,W=5
20 20.0	R-8		5.0	100 / 14					- 21.0-30.0, 0-90° fracs L=2,S=5-4, R=5,I=6,W=5-3
25									

NOTE: N/A - Not applicable due to the presence of granular material
Northing=70634.868, Easting1103404.061
High water levels may result from drilling process

ENGINEERS FIELD BORING LOG

BORING NO.	B-9A
SHEET	2 OF 3
DATE: START:	7/15/04
END:	7/16/04
G.S. ELEV.	144.0

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 89+32 OFFSET FROM CENTERLINE 38 LT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
25 25.0	R-9		5.0	100 / 26				SILTSTONE - (cont)	- 23.0-25.0, 90° frac
30 30.0	R-10		5.0	100 / 60					- Freshly Weathered core is Very Hard - Sl. to Mod. Weath. core is Med. Hard to Hard
35 35.0	R-11		5.0	100 / 50					- 30.0-40.0 occasional 0-90° fracs L=2,S=5,R=4, I=6,W=5-4
40 40.0	R-12		5.0	100 / 40					
45 45.0	R-13		5.0	100 / 76					- 44.0-45.0, very broken 0-90° fracs. L=2,S=6-5,R=3 I=6,W=5-4
50									

ENGINEERS FIELD BORING LOG

BORING NO.	B-9A
SHEET	3 OF 3
DATE: START:	7/15/04
END:	7/16/04
G.S. ELEV.	144.0

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 89+32 OFFSET FROM CENTERLINE 38 LT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
50 50.0	R-14		5.0	100 / 70				SILTSTONE - (cont.)	- 45.0-50.0, occasional 45-75° fracs L=2,S=5,R=4 I=6,W=5
55 55.0	R-15		5.0	100 / 40					- 55.0-60.0, occasional 40-80° fracs. L=2,S=6-5 R=3,I=6,W=5-4
60 60.0								84 60.0 BOH @ 60.0	
65									
70									
75									

ENGINEERS FIELD BORING LOG

BORING NO.	B-10
SHEET	1 OF 2
DATE: START:	7/22/04
END:	7/23/04
G.S. ELEV.	89.2

PROJECT NAME: Christiansted Bypass, U.S. Virgin Islands COUNTY:
STATE RTE. NO.: - SECT.: - SEGMENT: - OFFSET: -
STATION: 94+25 OFFSET FROM CENTERLINE: 38 RT
INSPECTOR (SIGNED): Dan Pulice DRILLERS NAME/COMPANY: Jeff Page / Amdrill
EQUIPMENT USED: BK 51 HDT Track Mount
DRILLING METHODS: SPT / HQ wireline through 4 1/4" ID HSAs
CASING: SIZE: 4 1/4" ID DEPTH: 25.0 WATER: DEPTH: 3.0 TIME: 0 HR DATE: 7/23/04
CHECKED BY: JMR DATE: 8.30.04 DEPTH: Caved TIME: 24 HR DATE: 7/24/04

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
0									
0.4	S-1	50/.4	0.4	100	N/A	gm / a-1-b		88.7 SILTY GRAVEL (a-1-b) - Brown; Dry; Very Dense 0.5	
0.5	R-1		1.2	60 / 0				SILTSTONE and LIMESTONE BOULDERS	- probable boulder and colluvium zone 0.0-15.0
2.5	R-2		1.8	72 / 0					
5 5.0	R-3		1.5	60 / 0					
7.5	R-4		0.5	20 / 0					- silt and sand mixed w/ core 7.5-10.0
10 10.0	S-2	6 10 30	1.0	67	N/A	gm / a-1-b		79.2 SILTY GRAVEL (a-1-b) - Grayish Brown; Dry; Dense to Very Dense 10.0	- 10.0 pulled out casing and ran augers
11.5									
13.5	S-3	50 50/.1	0.6	100	N/A				
14.1									
15 15.0	R-5		1.5	60 / 0				74.2 SILTSTONE - Brownish Gray to Blueish Gray; Highly to Sl. Weathered; Med. to Thinly Bedded, RD=20-60°; V. Closely to Med. Spaced Fracs., FRD=0-90° (Stratum RQD=0%) 15.0	- auger refusal @ 15.0 - calcareous siltstone, occasional calcite veins and calcite filled fracs
17.5	R-6		2.3	92 / 0					
20 20.0	R-7		0.5	20 / 0				- Possible Boulder	R-8, 22.5-23.0, Rec= 60%, RQD= 0%
22.5	R-8							ran auger to 23, auger ref. @ 25	
22.5								66.2 23.0	
23.0	S-4	5 34 50/.4	1.4	100	N/A	gm / a-1-b		SILTY GRAVEL (a-1-b) - Brown; Dry to Moist; Very Dense; little clay	R-9, 24.5-25,Rec= 80%, RQD=0%
24.4	R-9							64.2 25.0	
25									

NOTE: N/A - Not applicable due to the presence of granular material
Drilling polymer used at various times during drilling of the hole
Northing=70654.828, Easting=1103898.975
High water levels may result from drilling process

ENGINEERS FIELD BORING LOG

BORING NO.	B-10
SHEET	2 OF 2
DATE: START:	7/22/04
END:	7/23/04
G.S. ELEV.	89.2

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 94+25 OFFSET FROM CENTERLINE 38 RT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
25 24.5	R-10								
25.0				100				SILTSTONE - Brownish Gray to Blueish Gray; Hard; Moderately to Freshly Weathered; Thinly to Indistinct Bedding, RD=0-60°; Very Closely to Medium Spaced Fracs, FRD=0-90° (Stratum RQD=21%)	R-10, 25.0-25.5, Rec=100%, RQD= 0%
25.5	R-11		1.5	-----					
27.0				0					
	R-12		2.0	67 ----- 0					- 25.0-30.0, very broken
30 30.0									
	R-13		2.5	100 ----- 0				Pyrite present throughout the siltstone, with higher concentrations in some zones.	
32.5	R-14		1.0	100					- 33.5-40.0, 20-90° fracs. L=2,S= 6-5, R=4,I=6-4,W= 6-5
33.5	R-15		1.5	----- 0				- calcareous siltstone w/ calcite veins	
35 35.0				100 ----- 67				- some zones are more calcareous than others	Note: Hole was proposed for to 45.0', debris in hole resulted in termination of hole @ 41.0'
	R-16		5.0	100 ----- 46					
40 40.0	R-17		0.7	70					
41.0				0				48.2 41.0 BOH @ 41.0	
45									
50									

ENGINEERS FIELD BORING LOG

BORING NO.	B-10A
SHEET	1 OF 2
DATE: START:	7/20/04
END:	7/22/04
G.S. ELEV.	87.6

PROJECT NAME: Christiansted Bypass, U.S. Virgin Islands COUNTY:
STATE RTE. NO.: - SECT.: - SEGMENT: - OFFSET: -
STATION: 94+25 OFFSET FROM CENTERLINE: 38 LT
INSPECTOR (SIGNED): Dan Pulice DRILLERS NAME/COMPANY: Jeff Page / Amdrill
EQUIPMENT USED: BK 51 HDT Track Mount
DRILLING METHODS: SPT @ 2.5 intervals / HQ wireline through 4 1/4" ID HSAs
CASING: SIZE: 4 1/4 ID DEPTH: 2.7 WATER: DEPTH: 4.0 TIME: 0 HR DATE: 7/22/04
CHECKED BY: JMB DATE: 8.30.04 DEPTH: 3.0 TIME: 24 HR DATE: 7/23/04

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
0	S-1	5 50/.4	0.6	67	N/A	gm / a-1-b		SILTY GRAVEL (a-1-b) - Brown; Dry; Very Dense; trace clay	- rock outcropping where road was cut, hole was drilled in road
0.9									
2.5	S-2	50/.2	0.2	100	N/A			84.9 2.7	
2.7	R-1		2.3	100 / 0				SILTSTONE - Grayish Brown to Gray to Blueish Gray; Hard to Very Hard; Highly to Slightly Weathered; Very Thinly to Medium to Indistinct Bedded, RD=0-60°; Very Closely to Widely Spaced Fracs FRD=0-90° (Stratum RQD=16%)	- 2.7-6.0, extremely broken - calcareous siltstone, some zones are more calcareous than others
5.0	R-2		0.8	80 / 0					
6.0	R-3		2.5	83 / 0					- 2.7-10.0, 0-90° fracs L=2,S=1-0, R=4, I=0,W=2-1
9.0	R-4		0.8	80 / 0					
10.0	R-5		2.0	100 / 0				Pyrite present throughout the siltstone, with higher concentrations in some zones. - siltstone grading between very fine grained and finer grained	- 10.0-15.0, 0-90° fracs L=2,S=1-0, R=4 I=0,W=4-3
12.0	R-6		2.0	67 / 0					
15.0	R-7		3.0	100 / 0					- 14.0-16.5, 90° frac L=2,S=0,R=1, I=0,W=1
18.0	R-8		1.8	90 / 0				- 2.7-20.0, orangish dark brown and black staining on fracs. surfaces	
20.0	R-9		3.0	100 / 17					
23.0	R-10		2.0	100 / 0					
25									

NOTE: N/A - Not applicable due to the presence of granular material
Drilling polymer used at various times during drilling of the hole
Northing=70720.072, Easting=1103860.191
High water levels may result from drilling process

ENGINEERS FIELD BORING LOG

BORING NO.	B-10A
SHEET	2 OF 2
DATE: START:	7/20/04
END:	7/22/04
G.S. ELEV.	87.6

PROJECT NAME Christiansted Bypass, U.S. Virgin Islands COUNTY
STATE RTE. NO. - SECT. - SEGMENT - OFFSET -
STATION 94+25 OFFSET FROM CENTERLINE 38 LT

DEPTH (FT.)	SAMPLE NO. AND TYPE/CORE RUN	BLOWS/0.5 FT. ON SAMPLER	RECOVERY (feet)	Recovery (%) / RQD (%)	POCKET PENET or TORVANE (TSF)	USCS / AASHTO	H_2O CONTENT	DESCRIPTION	REMARKS
25 25.0	R-11		2.5	100 / 40				SILTSTONE - (cont.)	- 25.0-27.5, 30-70° fracs L=2,S=4, R=2 I=4(calcite) W=4
27.5	R-12		2.5	100 / 60					
30 30.0	R-13		2.0	67 / 0					- 31.0-32.0, highly weath. zone, core loss here
33.0	R-14		1.8	90 / 65				- 33.0-35.0= 0-70° fracs L=2, S=6-5, R=3, I=4 (calcite) W=6-5	- 34.5, 20° slickenside L=2 S=5-4,R=0,I=6, W=5
35 35.0	R-15		2.5	100 / 50					- 35.0, becoming slightly more coarse grained
37.5	R-16		0.6	60 / 0					
38.5	R-17		1.2	80 / 0					
40 40.0	R-18		3.0	60 / 16				42.6 45.0	- R-18, Low recovery due to worn out bit and damaged landing ring
45 45.0								BOH @ 45.0	
50									

U.S. Department of Transportation
Federal Highway Administration

Memorandum

Date: April 14, 2005

To: Khalid Mohamed, EFLHD, Sterling, VA

From: Khamis Haramy, Geotechnical Engineer, CFLHD, Lakewood, CO

Through: Scott Anderson, FDL Geotechnical Engineer, CFLHD, Lakewood, CO

Subject: Seismic Refraction Survey Results
Christiansted By-Pass Project at St. Croix, VI.

This report presents the findings of a seismic refraction survey (SR) performed by CFLHD in coordination with EFLHD at the subject location. Scott Anderson (FDL), Khalid Mohamed (EFLHD) and Khamis Haramy (CFLHD) performed the field survey during the period March 29 through April 2, 2005. Khamis Haramy processed the data with assistance from Blackhawk, a geophysical company in Golden CO.

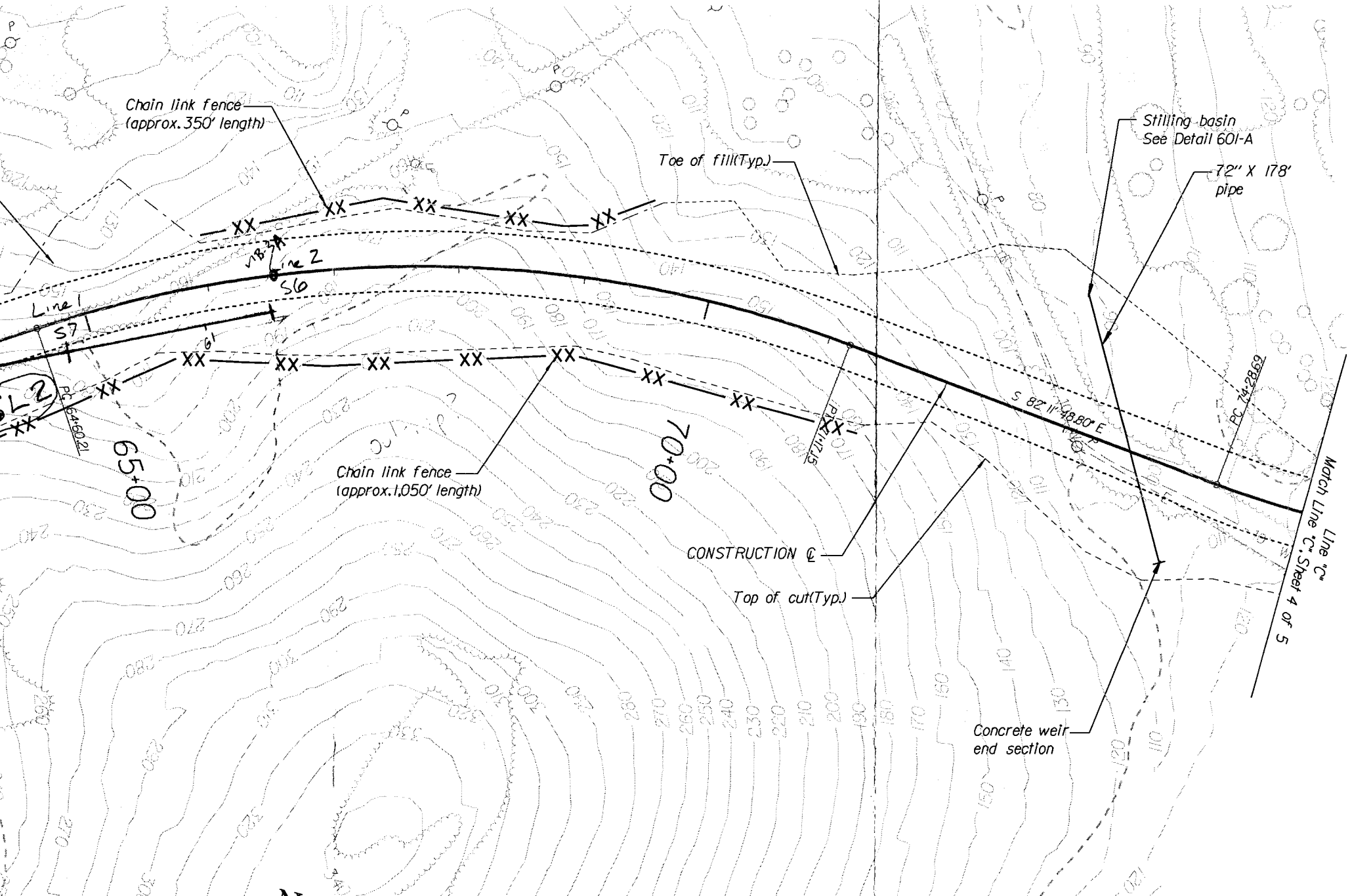
The project is located near the town of Christiansted on the Island of St. Croix, U.S. Virgin Islands. The Virgin Islands are part of the West Indies Island chain. The project is for rerouting highway 70 outside the town limits into the outskirt hills. The seismic surveys were conducted along the hillside east of the town were the new alignment is proposed. The main purpose of the seismic refraction survey is to measure the seismic velocity of the underlying rock layers at several locations. The seismic line locations are mainly selected over proposed deep through cuts. Borings were also advanced in these areas and the boring logs are available in the geotechnical report. The information intended to be used by EFLHD engineers in conjunction with borings in these areas to evaluate the relative quality and depth to rock and to determine the maximum safe cut slope ratios. The intent of this memorandum is to mainly to document the seismic data and analysis.

Field observations

During the seismic survey work, the following observations were made in areas near the surveyed lines:

1. Quality of bedrock exposed near surface is generally better than envisioned based on information provided in the geotechnical report. The geotechnical report was apparently prepared for Site B and observations suggest the rock quality near the surface is better at Sites A and C than at Site B. Bedrock outcrops were more prevalent at Sites A and C than at Site B.
2. The bedrock is generally closely jointed, with fracture frequency often on the order of 2-inches or less. Rock strength, even at the surface is moderate, often requiring several blows to break with a hammer.
3. Bedrock is mapped regionally as Cretaceous siltstone but bedding is not easily identified in most outcrops and bedrock may have undergone low-grade

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		

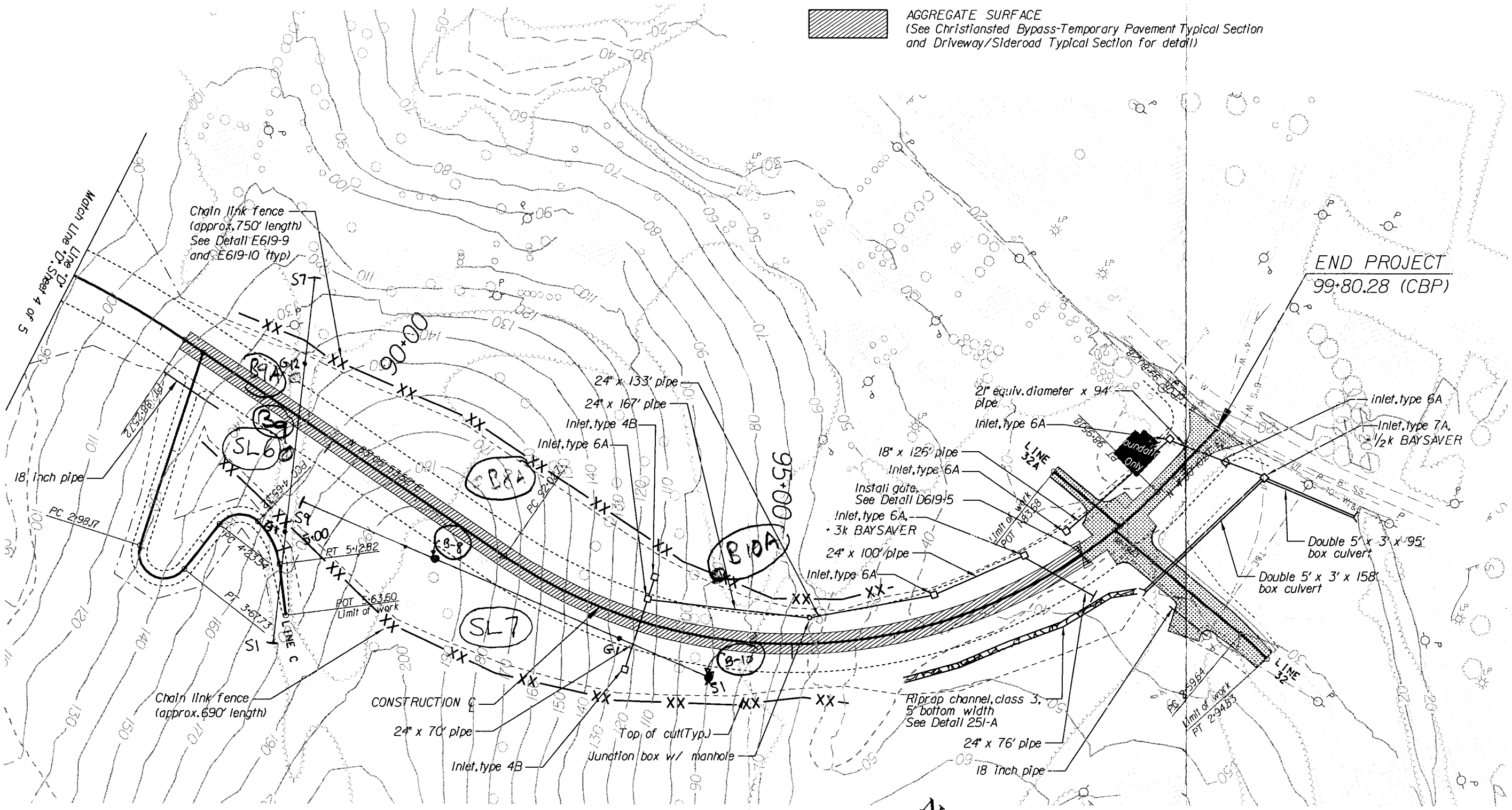


REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		

SITE B

PAVED
(See Christiansted Bypass-Temporary Pavement Typical Section and Driveway/Sideroad Typical Section for detail)

AGGREGATE SURFACE
(See Christiansted Bypass-Temporary Pavement Typical Section and Driveway/Sideroad Typical Section for detail)



Note :

Remove miscellaneous items (shown as ▬). includes a concrete foundation.

CENTERLINE DATA

88+47.54 Bypass = 1+00 Line C
98+39.63 Bypass = 1+00 Line 32
98+45.73 Bypass = 1+00 Line 32A

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

PLAN
CHRISTIANSTED BY-PASS
87+00 TO 99+80
AND SIDE ROADS
LINES: 32,32A

0 50 100
SCALE IN FEET

SHEET 5 OF 5

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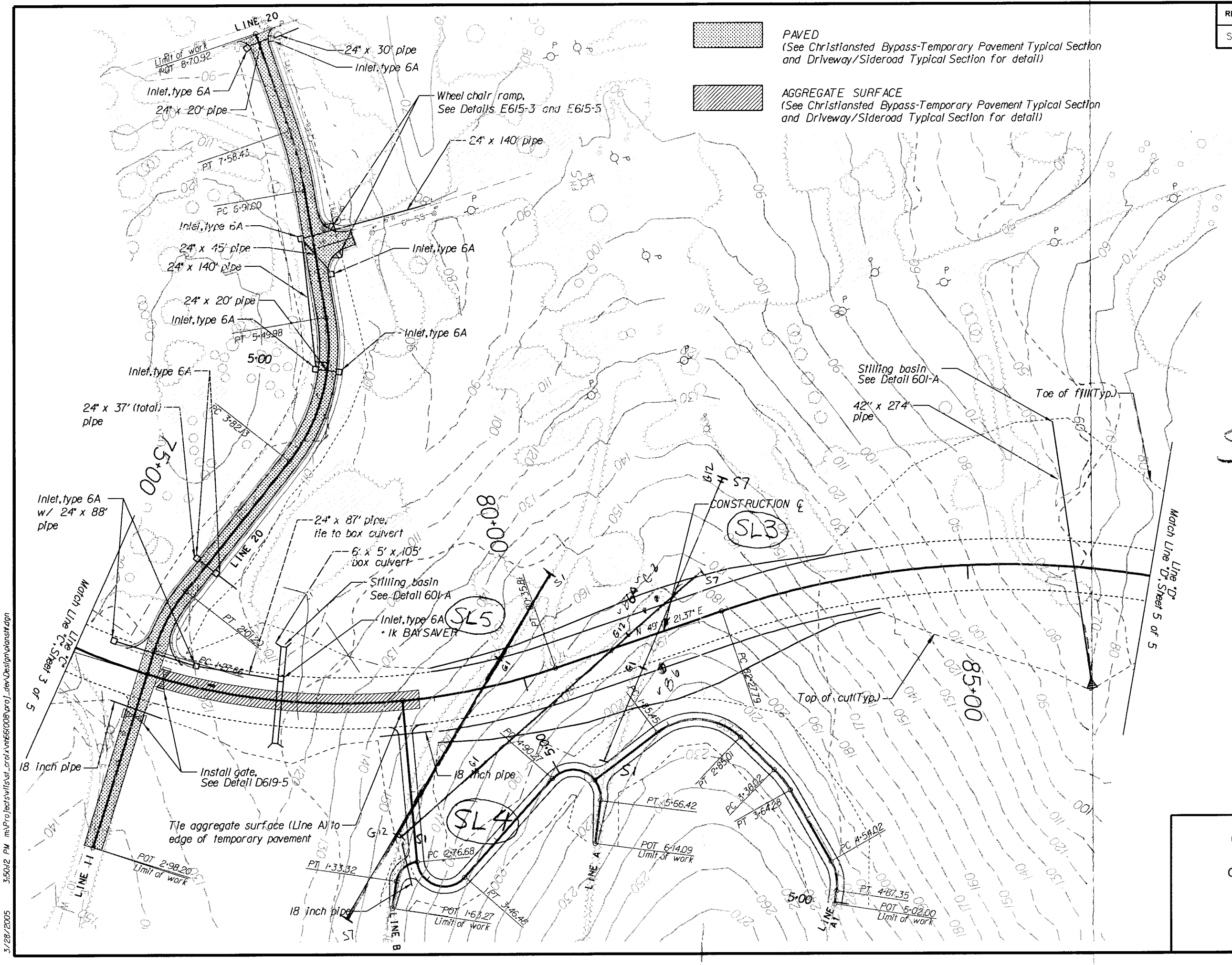
REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
SE	VI	NH-66(008)		

PAVED
(See Christiansted Bypass-Temporary Pavement Typical Section and Driveway/Sideroad Typical Section for detail)

AGGREGATE SURFACE
(See Christiansted Bypass-Temporary Pavement Typical Section and Driveway/Sideroad Typical Section for detail)



CENTERLINE DATA

75+83.69 Bypass = 1+00 Line II
75+83.69 Bypass = 1+00 Line 20
78+65 Bypass = 1+00 Line A
2+76.68 Line A = 1+00 Line B
5+43.18 Line A = 1+00 Line A1

SITE C

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN FEDERAL LANDS HIGHWAY DIVISION
STERLING, VIRGINIA

PLAN
CHRISTIANSTED BY-PASS
75+00 TO 87+00
AND SIDE ROADS
LINES: II, A, B, 20

0 50 100
SCALE IN FEET

SHEET 4 OF 5

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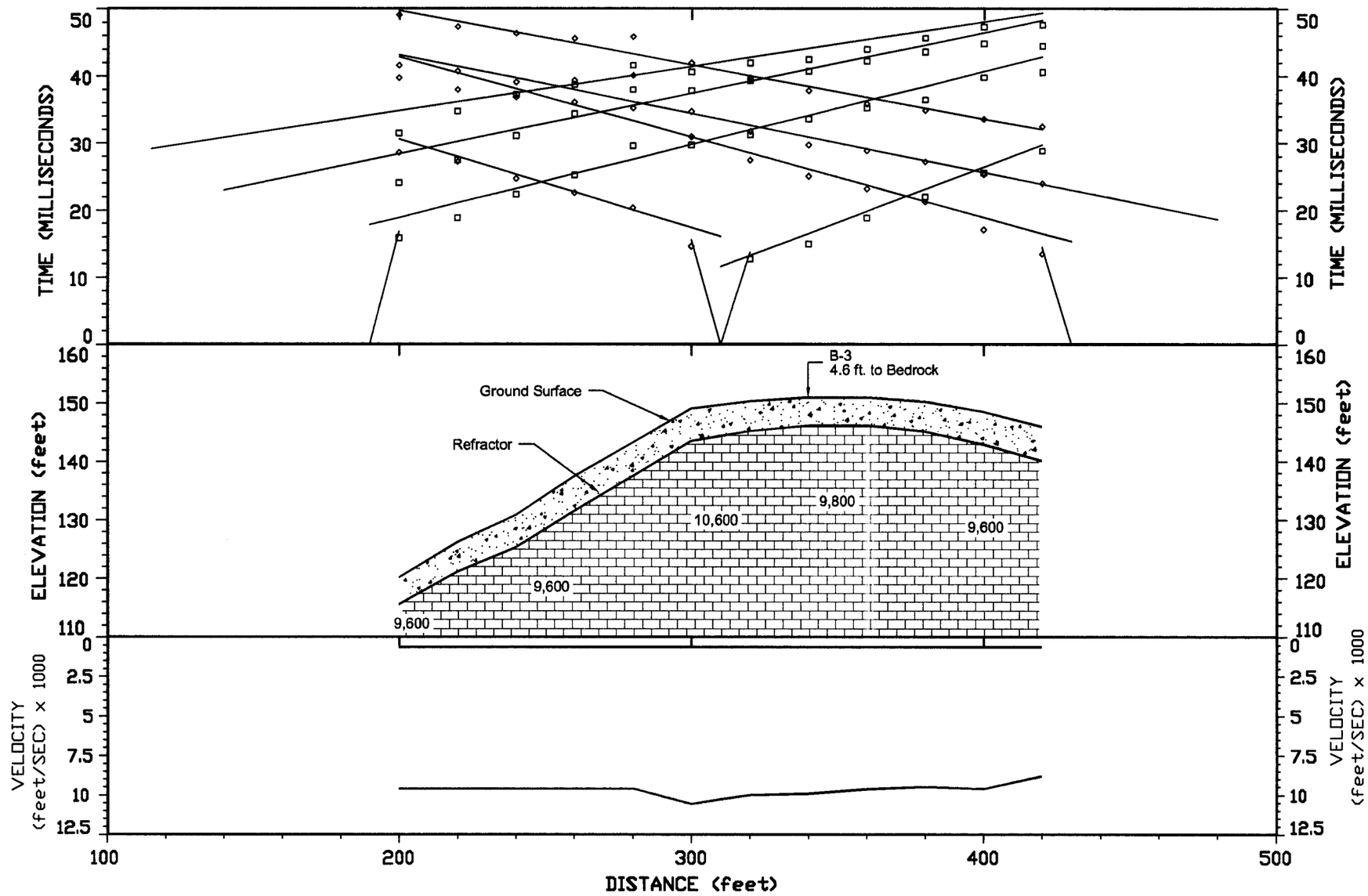

Plate: 1

for: EFLHD-FHWA		GRM
by: CFLHD-FHWA		St.Croix Virgin Islands
Data SetVI NH-66	Date: 4-11-05	
Equipment: Smartseis	Spread: 1	Azimuth:

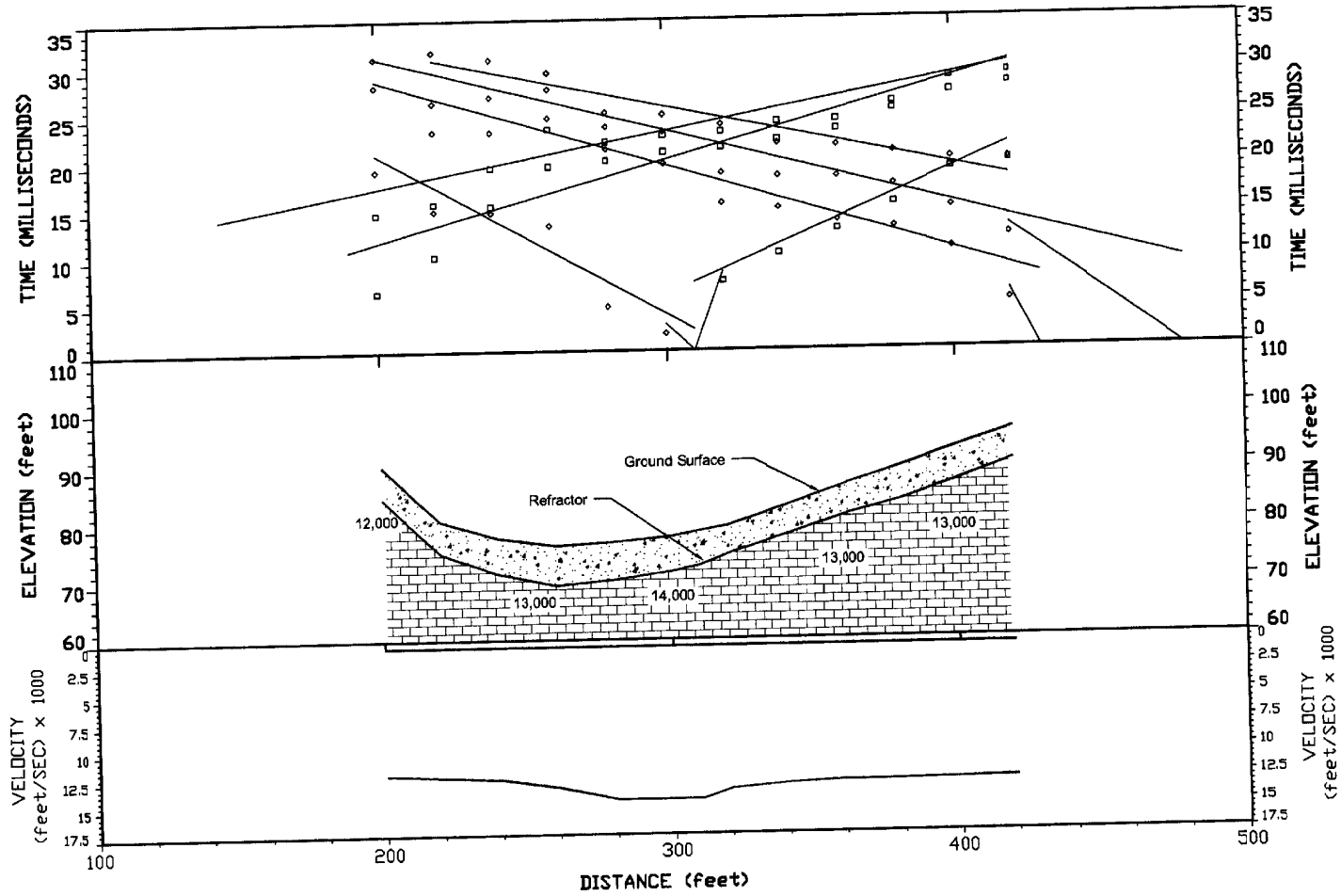

Plate: 2

for: EFLHD-FHWA	GRM
by: CFLHD-FHWA	St.Croix Virgin Islands
Data Set LINE2	Date: 4-11-05
Equipment: Smartsels	Spread: 2
	Azimuth:

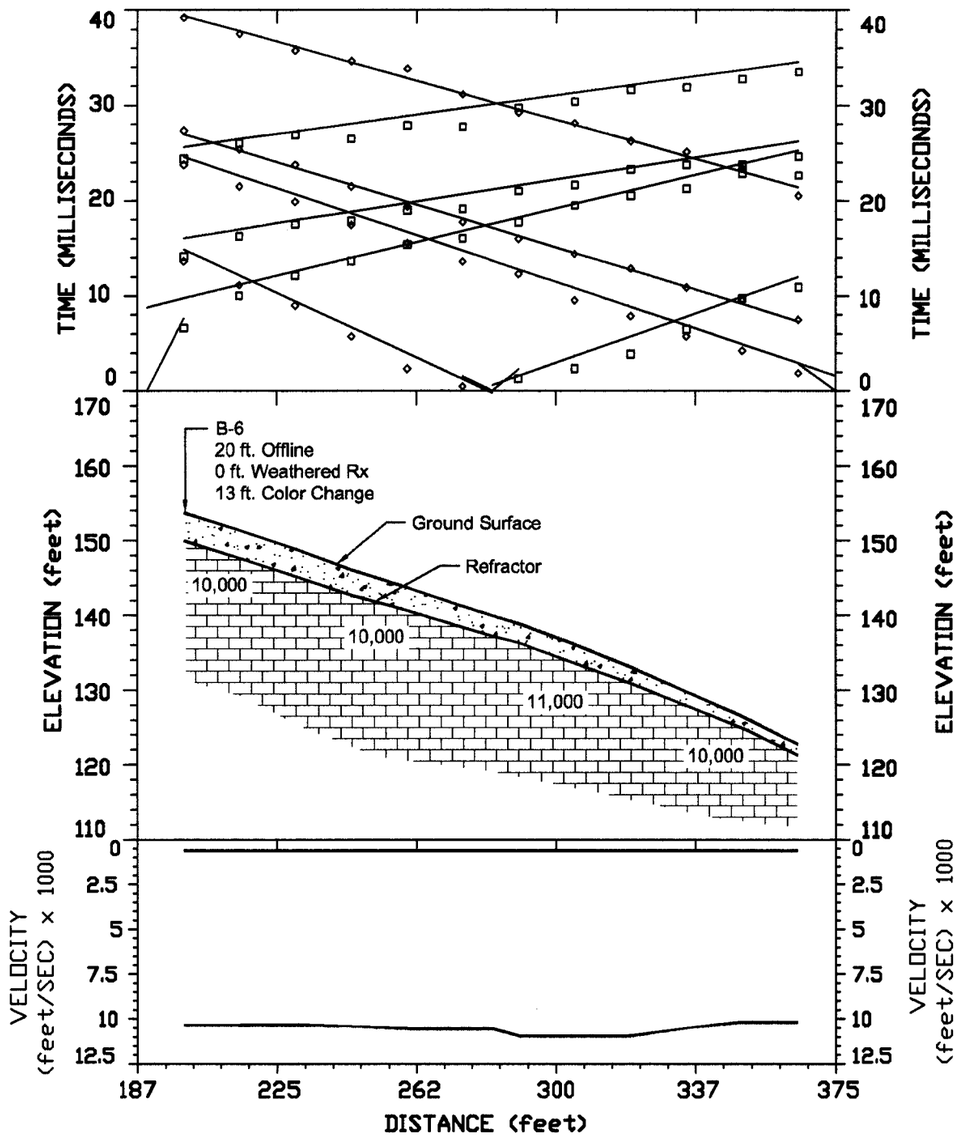

Plate: 3

for: EFLHD-FHWA	GRM
by: CFLHD-FHWA	St.Croix Virgin Islands
Data SetLINE3 / Date: 4-11-05	
Equipment: SmartSeis / Spread: 3	Azimuth:

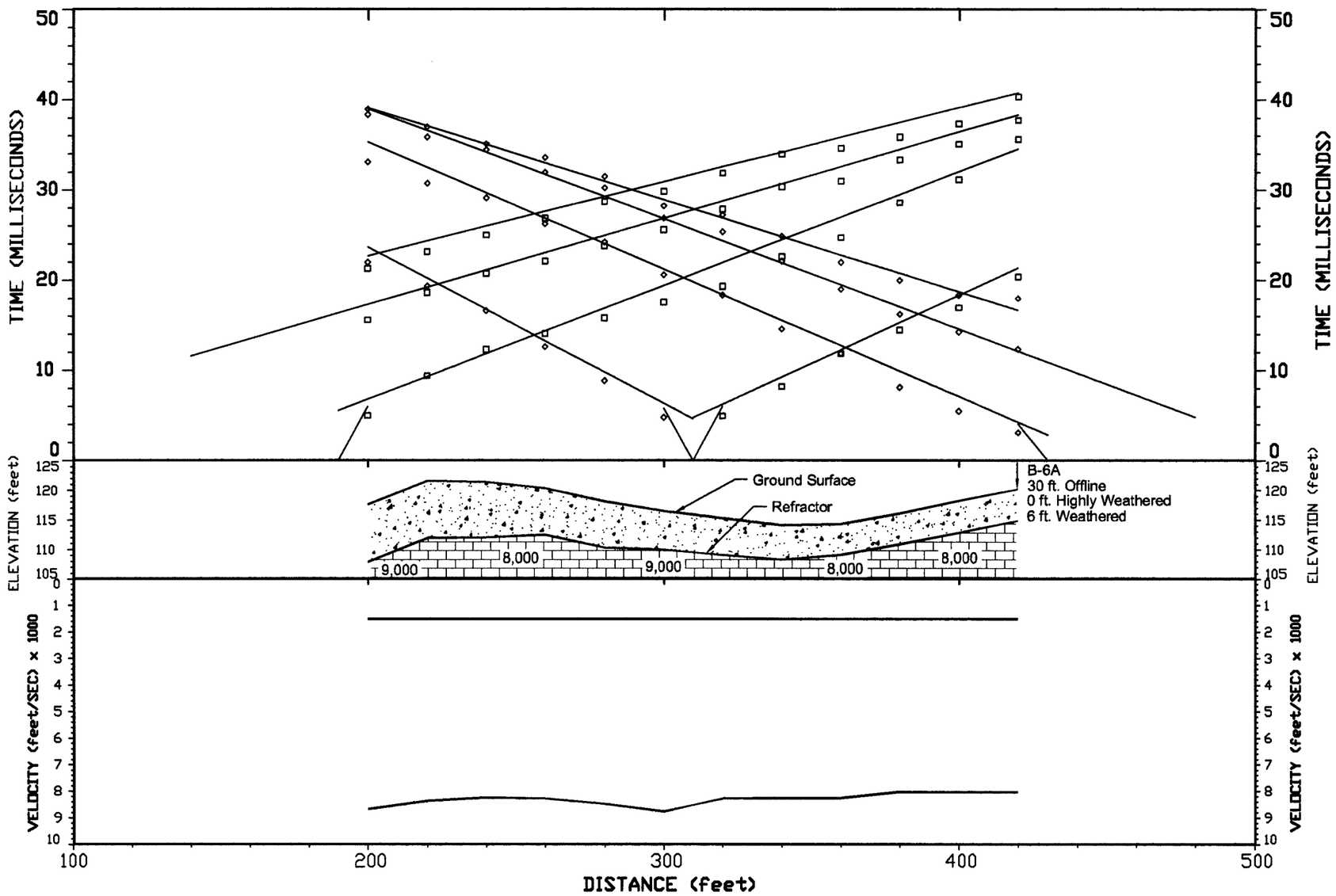

Plate: 4

for: EFLHD-FHWA	GRM
by: CFLHD-FHWA	St.Croix Virgin Islands
Data SetLINE4 / Date: 4-11-05	
Equipment: Smartseis / Spread: 4	Azimuth:

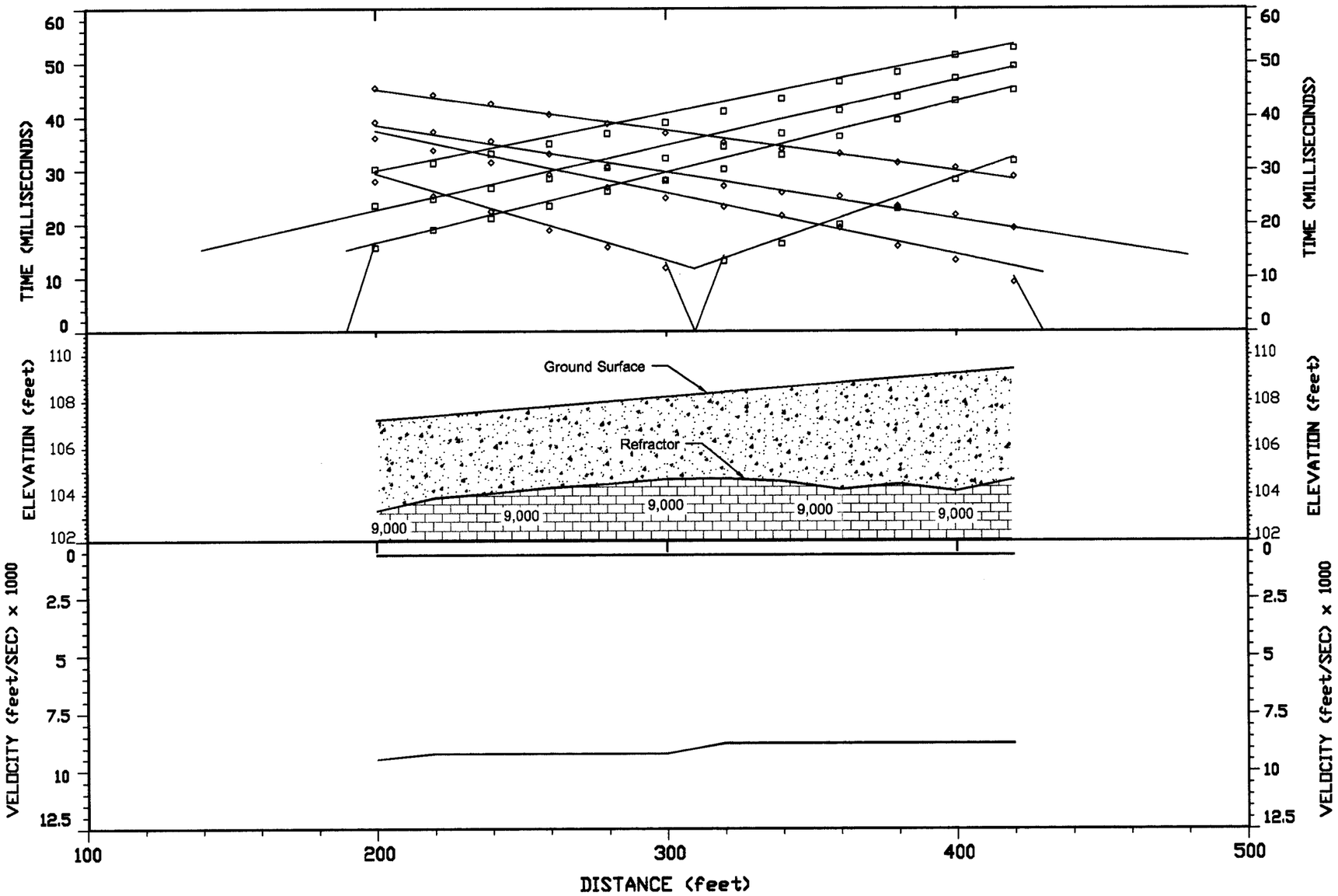

Plate: 5

for: EFLHD-FHWA	GRM
by: CFLHD-FHWA	St.Croix Virgin Islands
Data SetLINE5	Date: 4-11-05
Equipment: Smartseis	Spread: 5
	Azimuth:

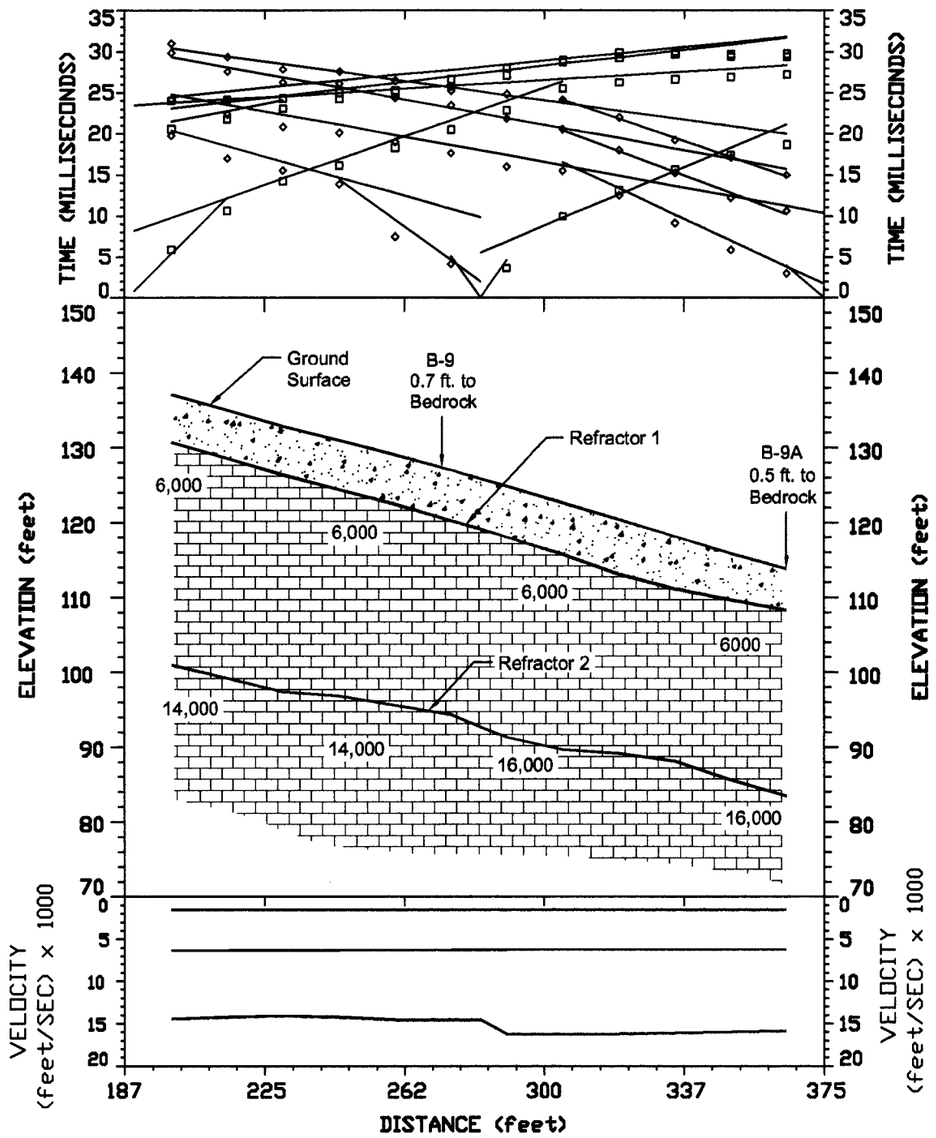

Plate: 6

for: EFLHD-FHWA	GRM
by: CFLHD-FHWA	St.Croix Virgin Islands
Data SetLINE6 / Date: 4-11-05	
Equipment: Smartseis / Spread: 6	Azimuth:

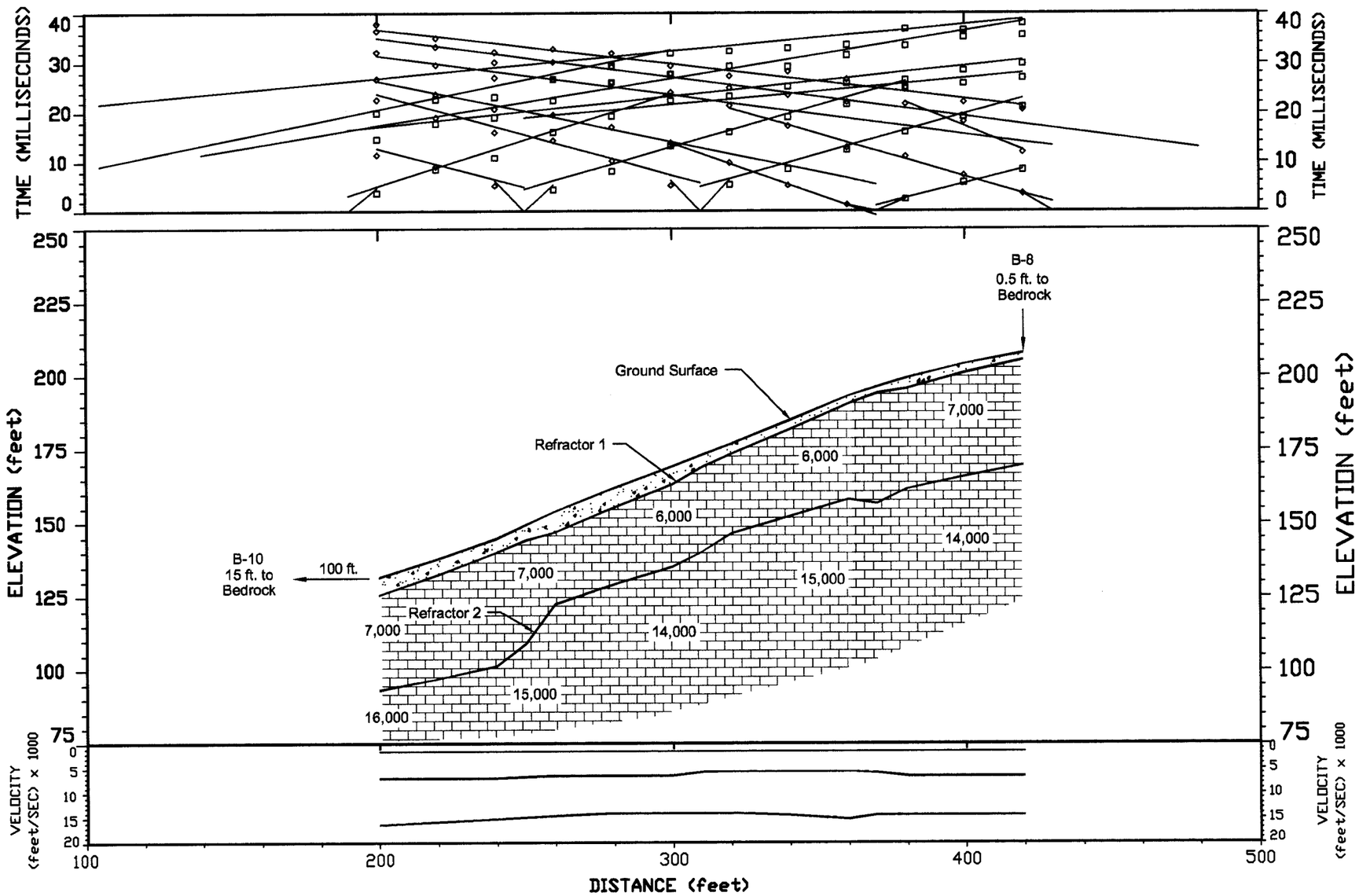

Plate: 7a

for: EFLHD-FHWA	GRM
by: CFLHD-FHWA	St.Croix Virgin Islands
Data Set: LINE7A — Date: 4-11-05	
Equipment: Smartsels — Spread: 7	Azimuth: