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FIELD EVALUATION REPORT

Non-Destructive Evaluation of the Thickness of Linings and Pavements in Two Tunnels Using Ground Penetrating Radar

Morton Mountain and Chimney Tops Mountain Tunnels in the Great Smoky Mountains National Park

Jointly Prepared By:

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Executive Summary

The Morton Mountain and Chimney Tops Mountain tunnels are located on US Route 441 (Newfound Gap Road) in the Great Smoky Mountains National Park in Tennessee. This serves as the main access route for visitors to the park. The tunnels were constructed in the late 1930's and were originally unlined. The existing concrete linings were constructed circa 1960. Safety issues now exist as a result of substandard vertical clearances and roadway icing from water leakage through the tunnel linings.

The EFLHD has identified several rehabilitation alternatives to address the existing conditions in the tunnels. All of these involve rehabilitating the tunnel linings and all but one approach requires lowering the tunnel profile elevation by excavation to achieve the required vertical clearance. Thus, to facilitate selection of the most appropriate rehabilitation alternative, information regarding the thickness of the tunnel linings and the depth below pavement to rock is needed.

The objectives of this project involved determination of the following parameters using a combination of non-destructive and traditional test techniques, with additional limited coring for validation purposes:

1. Thickness of the concrete linings at the crown and spring line areas.
2. Depth of the base of the tunnel linings below the pavement.
3. Depth to bedrock in the driving lanes of the tunnels.
4. Depth to bedrock in the approach roadways of the tunnels.

Ground penetrating radar (GPR) technology was employed to obtain this information where possible and to obtain the most data in a timely and cost-effective manner. GPR surveys in the tunnels included the walls, crowns, and pavement (both inside the tunnels and at the approach roadways to the tunnels). Coring to determine the depth of the base of the tunnel linings below the pavement and to validate GPR survey results on the pavements was also required.

The objectives of this project were met using this combination of GPR technology and traditional investigation methods. The results obtained using GPR were generally consistent with direct measurements obtained on core samples.

The same investigation techniques can be used in similar future efforts, but consideration should be given to cost differences between non-destructive and traditional methods and to the level of destructive testing that is acceptable in a particular tunnel. When results are needed for large surface areas, or when other factors exist that restrain the ability to perform the required level of destructive testing, GPR appears to be a viable means of achieving concrete tunnel lining thickness and substrate material information under roadways paved with asphalt.

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I. Introduction

The Morton Mountain and Chimney Tops Mountain tunnels are located on US Route 441, Newfound Gap Road, in Sevier County, Tennessee. The tunnels are part of the Great Smoky Mountains National Park and US Route 441, Newfound Gap Road, traverses the park from north to south connecting Gatlinburg, Tennessee to Cherokee, North Carolina. This road has an ADT of 6,300 vehicles and is the main access route for visitors to the park.

The tunnels were constructed in the late 1930's and were originally unlined. The existing concrete linings were constructed circa 1960. Each tunnel consists of two lanes with two-way traffic and the length of the tunnels from portal to portal is 87 meters (Morton Mountain) and 77 meters (Chimney Tops Mountain). The horizontal width of both tunnels is 9.1 meters. In 1994 and again in 1996, the Bridge Inspection Team of the Eastern Federal Lands Highway Division (EFLHD) inspected the tunnels and reported the need for rehabilitation and/or reconstruction of both tunnels due to safety concerns and deteriorated tunnel linings.

Safety issues were raised as a result of substandard vertical clearances and roadway icing from water leakage through the tunnel linings. The vertical clearance when measured at 3.65 meters from the centerline in both tunnels was found to vary from only 3.4 to 3.6 meters. The maximum legal height for any vehicle is 4.1 meters and the vertical clearance recommended by the American Association of State Highway and Transportation Officials is 4.3 meters. Although the original vertical clearance in the tunnels is unknown, multiple re-paving efforts have been undertaken causing a continual reduction in the vertical clearances. As a result, the existing vertical clearance is creating a seriously dangerous situation as vehicles near the maximum legal height sometimes travel over the centerline of the tunnels to avoid colliding with the tunnel ceiling.

The linings in both tunnels were reportedly deteriorated with localized cracking, spalling, efflorescence, and water leakage causing unsafe conditions from ice buildup on the roadway surface and spalled concrete sections potentially falling onto passing vehicles.

The EFLHD has identified several rehabilitation alternatives to address the existing conditions in the tunnels. All of these involve rehabilitating the tunnel linings and all but one approach requires lowering the tunnel profile elevation by excavation to achieve the required vertical clearance. The primary difference amongst the various alternatives is related to the extent and duration of roadway closures during construction and this, in turn, directly impacts total construction time and cost.

No definitive information regarding the thickness of the tunnel linings and the depth below pavement to rock is available. Such information must be known In order to decide which rehabilitation alternative to choose since repair or removal of subsurface materials and repair of the concrete linings will directly impact construction time and cost estimates. Consequently, the EFLHD employed ground penetrating radar technology in an effort to obtain the required data in the most timely and cost-effective manner and the results are presented in this report.

II. Background Information on Ground Penetrating Radar

RADAR is an acronym, coined in 1934, for Radio Wave Detection and Ranging. There are two types of radar technology; air launched and ground coupled. The former involves transmission of radio frequency electromagnetic waves through the air. The reflected waves are analyzed to determine the location, size, and speed of distant objects. The application of air launched radar was refined during World War II in an effort to track enemy planes. The latter, ground coupled radar, uses electromagnetic wave propagation and scattering to image, locate and quantitatively identify changes in electrical and magnetic properties of materials at various depths in the ground. This technology was developed during the late 1950's and early 1960's to probe solids such as rocks and soil. The first commercial systems were marketed in 1972. Since that time, ground coupled radar has been extensively used to locate buried pipes and utilities in soil, to determine the thickness and structure of glaciers, examine the subsurface of the moon, profile the bottom of lakes, rivers, and oceans, locate subsurface voids and toxic materials, etc. More recent applications include determination of the thickness of asphalt layers on pavements and detection of sub-surface defects in concrete structures such as bridges and buildings.

A typical ground penetrating radar (GPR) system consists of one or more radar antennas, computer controlled instrumentation for generating, transmitting, and receiving the radio waves, and computer software for analyzing the reflected radio signals. Depending on the type of application, GPR antennas can be hand-held, mounted on a manually driven frame, or mounted on a vehicle. For bridge deck and pavement evaluations, the radar antennas are usually mounted on a vehicle. For evaluating a vertical component like a wall or a column, a hand-held unit is most appropriate. Either type may be used when locating buried utilities.

The radar antenna is composed of a transmitter and receiver and can be positioned directly on the surface to be surveyed or several inches above the surface. GPR antennas can operate over a wide range of frequencies (about 100 mega-hertz to 1500 mega-hertz or higher). The depth of penetration of the radio waves in a solid material is inversely related to the frequency; lower frequency antennas (for example, 100 MHz) being used for deep probing (extending to several hundred feet) and higher frequency antennas applicable at lesser depths. Also, data resolution improves as the distance between the radar antennas and test surface decreases. Thus, when surveying an asphalt layer of pavement or a typical reinforced concrete bridge deck, a 1500 MHz (or 1.5 giga-hertz) antenna would be most appropriate and, for best data resolution, the antenna should be positioned directly on the test surface. Also, baseline information should be obtained in order to correlate and verify the GPR results. This is most often accomplished by conducting standard sounding surveys in randomly selected areas or by extracting a limited number of cores in representative areas.

III. Project Objectives

The objectives of this project involved determination of the following parameters using a combination of non-destructive and traditional test techniques, with additional limited coring for validation purposes:

1. Thickness of the concrete lining in both tunnels at the crown and spring line areas.
2. Depth of the base of the tunnel linings below the pavement.
3. Depth to bedrock in the driving lanes of both tunnels.
4. Depth to bedrock in the approach roadways of both tunnels.

IV. Scope of Work

The tasks listed below comprise the scope of work required to meet the project objectives.

1. Obtain and review all available information on the tunnels from EFLHD.
2. Identify procedures, equipment needs and traffic control requirements.
3. Construct assemblies to mount the GPR equipment to the survey vehicle.
4. Develop a work plan to accomplish all surveying and testing at the sites.
5. Perform GPR surveys in the following areas in each tunnel:

   Walls (2 passes).
   Crown (1 pass).

Pavement Inside Tunnels (6 passes).
Approaches (6 passes each approach).

6. Process all GPR data at a horizontal increment of one meter.

7. Collect a total of eight cores to determine the depth of the base of the tunnel linings below the pavement.

8. Obtain one core through the pavement in the Morton Mountain Tunnel to verify results found by EFLHD. In 1999, EFLHD procured four cores inside of each tunnel. The cores were taken through pavement down to the bedrock depth. Core lengths were then directly measured to determine the depth to bedrock at each location drilled. The results were made available for comparison purposes with the planned radar survey findings. Therefore, with respect to pavement coring requirements, only one additional core was deemed necessary in the subject scope of work for verification purposes.

9. Prepare a comprehensive report detailing all aspects of the investigation and findings.

V. Equipment Used

The primary equipment required included a suitable radar system, coring equipment, and traffic control equipment. A detailed investigation of available radar systems was conducted to determine which system(s) were most appropriate for the scope of work involved. The UT GV4 system was chosen to determine the thickness of the concrete linings and the depth to bedrock below the pavement inside the tunnels and along the approach roadways. This ground coupled system operates at a frequency of 1 giga-hertz and is supplied with diversified depth interpretation software, a standard bistatic (i.e. transmitter and receiver are separate components) radar antenna (see Figure 1), a built in distance measuring instrument, and data acquisition software. Although many systems were researched, the UT GV4 system was chosen due to the software capabilities provided and the fact that the system employs high frequency (the target depths for the surveys in the tunnels were in the range of a few feet), ground coupled antennas (for better data resolution). In addition, this system was suitable for both hand held operation (used to survey the tunnel walls as shown in Figure 1) and vehicle mounted surveying (used for the crown and pavement surveys as shown in Figure 2). To perform the crown and pavement surveys, provisions were made to temporarily install the entire UT GV4 system onto a survey vehicle. The mounting system for the radar antennas and distance measuring device (see Figure 2) was designed and constructed as part of the subject project.

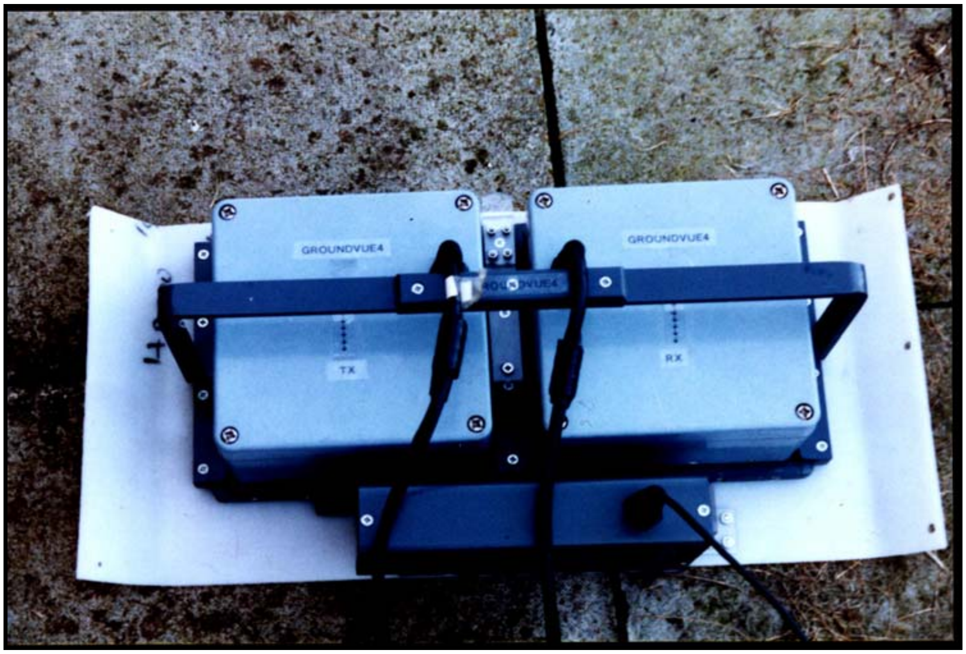


Figure 1. GPR antenna (top photograph) and survey in progress on the tunnel wall (bottom photograph).

Figure 2. GPR survey in progress on the crown of the tunnel (top photograph) and the tunnel pavement (bottom photograph).

Determination of the depth of the tunnel linings below the pavement posed the greatest challenge. Due to the geometry of the tunnel structures and the location of the underdrain pipes, no radar system with the required capability was identified. The underdrain pipes run the length of the tunnels and are positioned parallel to the tunnel walls. Therefore, efforts to determine the depth of the tunnel linings below pavement were limited to extracting cores for direct measurement. A specialized coring rig (see Figure 3), capable of drilling to depths of several feet at various angles, was rented for this purpose.

Traffic control was provided by the maintenance staff of the Great Smoky Mountains National Park.

VI. Investigation Findings

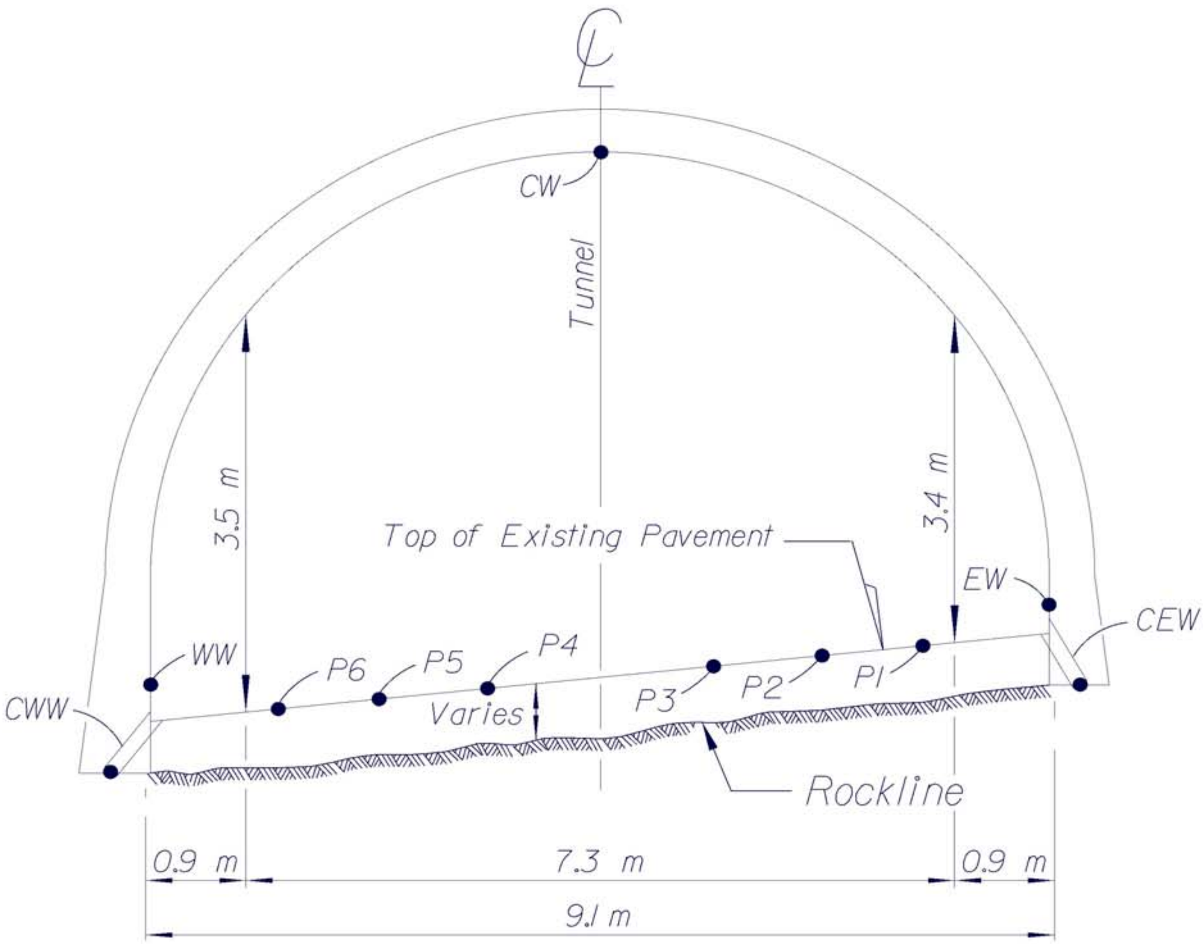
Figure 4 shows section views of the tunnels indicating where radar survey passes were made on the walls (two passes), crown (one pass), and pavement (six passes) inside each tunnel and where cores were taken through the tunnel linings (two cores on each wall of both tunnels). Figure 5 shows the location of the radar passes on the approaches of each tunnel (six passes per approach) and the locations where cores were taken through the pavement inside each tunnel. In addition, one core was taken through the pavement in the Morton Mountain Tunnel to verify the results found by EFLHD. This core was taken adjacent to location B-3 in Figure 5A. All radar survey data were processed at a longitudinal interval of one meter. Results of the radar surveys and measurements made on the cores are discussed below.

Thickness of the Concrete Lining in Both Tunnels

The thickness of the concrete lining was directly measured at one location, about 0.6 meters above the spring line, in the Chimney Tops Mountain Tunnel. The area where the measurement was made was spalled through the entire thickness of the lining. The results ranged from 0.36 to 0.43 meters. The lining thickness measured with GPR at the spring line directly below this area was 0.38 meters. No similarly damaged locations were found in the Morton Mountain Tunnel. GPR surveys were performed at three locations along the lining in each tunnel (see Figure 4). In each case, the survey initiated at the south end of the tunnel and continued along the entire length of the lining. Surveys on the east and west walls of each tunnel were conducted about 0.15 meters above grade. The crown surveys were located along the centerline of the linings. All GPR survey results are provided in the Appendix and a statistical summary is shown in Table 1.

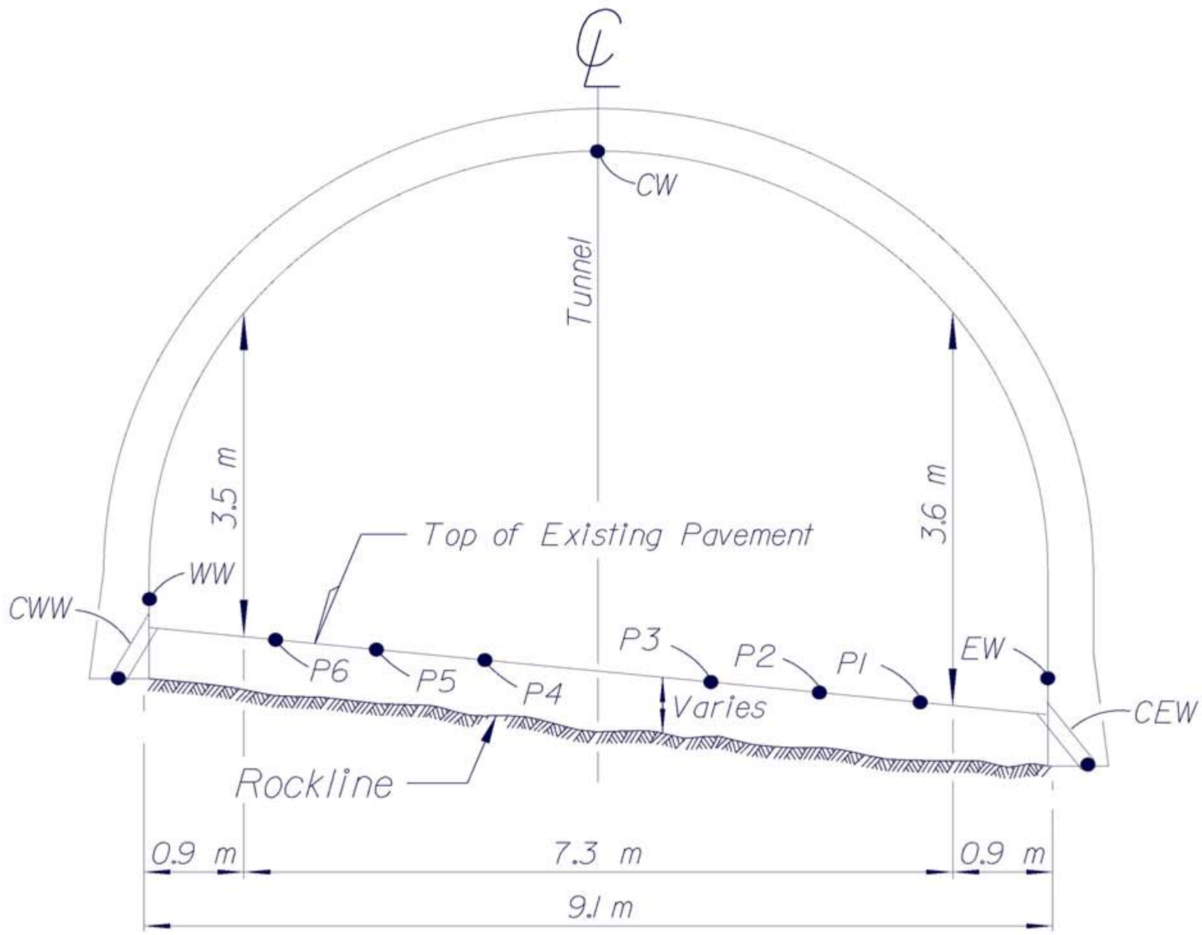
Based on the standard deviation for each pass, the results indicate that the thickness of the linings was relatively uniform lengthwise. The average thickness of individual passes was also similar with the exception of the crown pass in the Morton Mountain Tunnel. Also, with the same noted exception, GPR results along the spring line compare well with the direct thickness measurements made.

Figure 3. Coring equipment capable of drilling to more than two meters deep.



WW = Location of GPR pass on west wall.
EW = Location of GPR pass on east wall.
CW = Location of GPR pass on crown.
CWW = Location of cores in west wall.
CEW = Location of cores in east wall.
PI to P6 = Location of GPR passes on pavement inside tunnel.

Figure 4A. Existing typical section through Morton Mountain Tunnel looking northbound toward Gatlinburg.



WW = Location of GPR pass on west wall.
EW = Location of GPR pass on east wall.
CW = Location of GPR pass on the crown.
CWW = Location of cores in west wall.
CEW = Location of cores in east wall.
PI to P6 = Location of GPR passes on pavement inside tunnel.

Figure 4B. Existing typical section through Chimney Tops Mountain Tunnel looking northbound toward Gatlinburg.

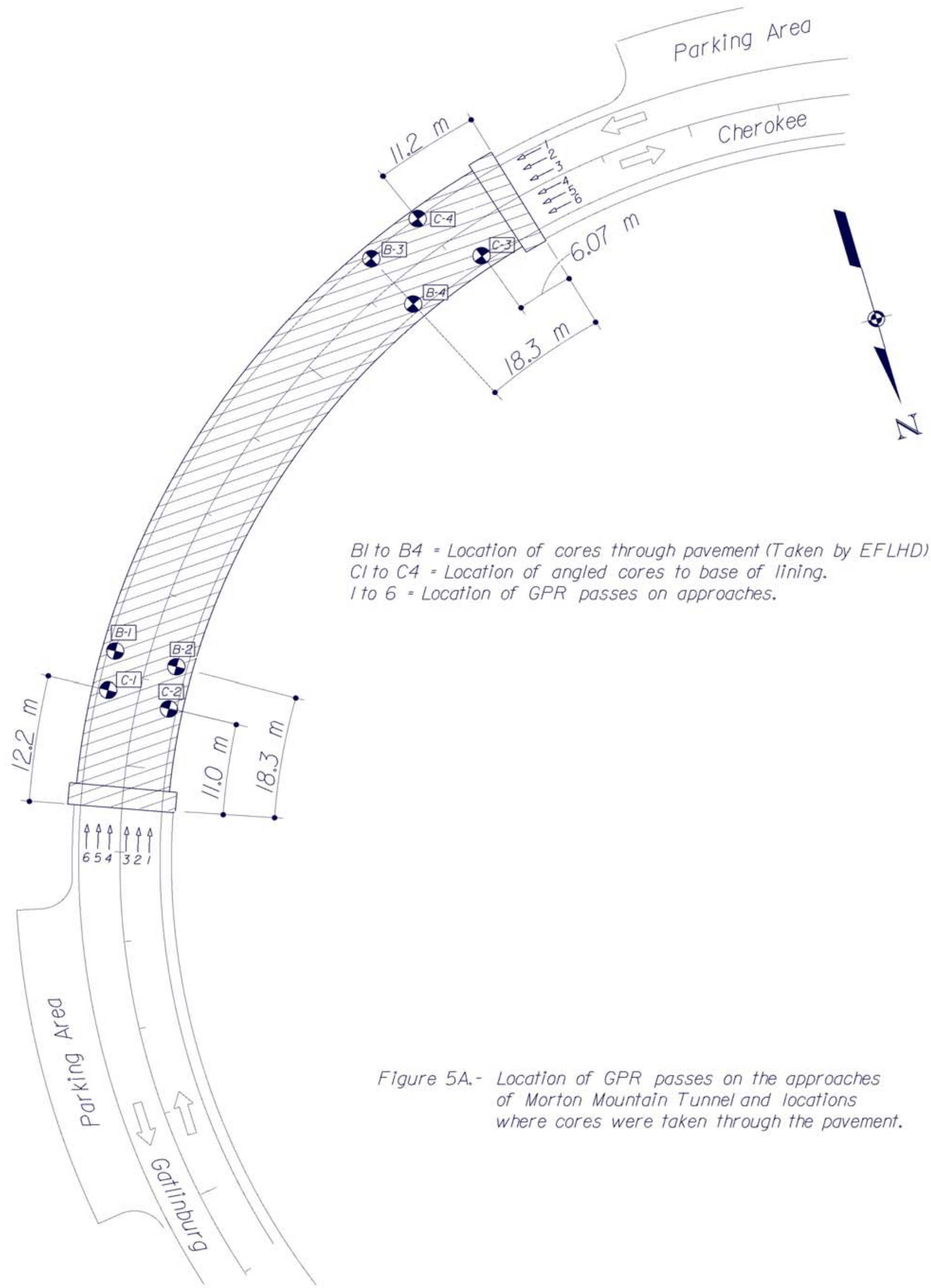


Figure 5A.- Location of GPR passes on the approaches of Morton Mountain Tunnel and locations where cores were taken through the pavement.

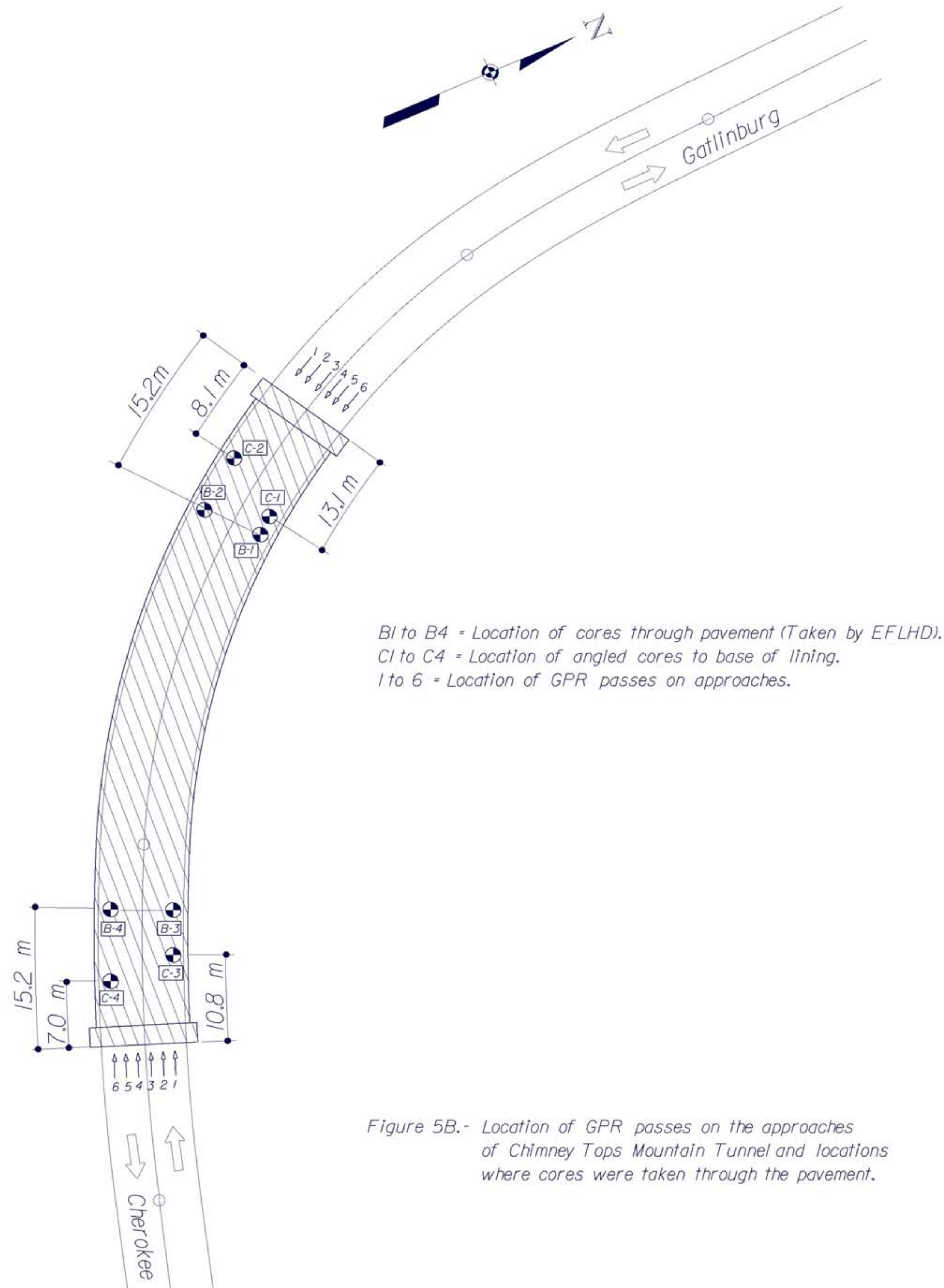


Figure 5B.- Location of GPR passes on the approaches of Chimney Tops Mountain Tunnel and locations where cores were taken through the pavement.

Table 1. GPR Survey Results on the Concrete Lining in Both Tunnels.

Result	Lining Thickness, meters		
	Crown	East Wall	West Wall
Morton Mountain Tunnel			
Average	0.20	0.44	0.44
Minimum	0.16	0.10	0.39
Maximum	0.32	0.47	0.50
Stnd. Dev.	0.04	0.04	0.02
Chimney Tops Mountain Tunnel			
Average	0.36	0.34	0.31
Minimum	0.35	0.30	0.28
Maximum	0.44	0.37	0.34
Stnd Dev	0.01	0.02	0.01

<u>Depth of the Base of the Tunnel Linings Below the Pavement</u>

The depth of the base of the tunnel linings below the pavement was determined by measuring the length of cores drilled to the depth of the bedrock. As shown in Figure 3 (also see Figure 4), cores were drilled at an angle to avoid the underdrain pipes that run parallel to the base of the lining. The cores were then measured and the vertical depth to bedrock was calculated using the core angle and measured core length. A total of two cores were obtained in each wall of each tunnel (total of eight cores) and the results are shown in Table 2. The distance along the wall where cores were taken was measured from the north end of the Morton Mountain Tunnel and south end of the Chimney Tops Mountain Tunnel.

Table 2. Depth of the Base of the Tunnel Linings Below the Pavement.

Core No.	Wall	Distance Along Wall, meters	Depth to Bedrock, meters
Morton Mountain Tunnel			
C1	East	12.2	0.35
C2	West	11.0	0.48
C3	West	81.4	0.50
C4	East	76.2	0.40
Chimney Tops Mountain Tunnel			
C1	East	64.0	0.75
C2	West	69.0	0.75
C3	East	10.8	0.65
C4	West	7.0	0.65

Depth to Bedrock in the Driving Lanes of Both Tunnels

EFLHD procured four cores through the pavement down to the bedrock depth inside of each tunnel. The locations of the cores are shown in Figure 5. Core lengths were then directly measured to determine the depth to bedrock at each location drilled and the results are shown in Table 3. The distance along the wall where cores were taken was measured from the north end of the Morton Mountain Tunnel and south end of the Chimney Tops Mountain Tunnel. The distance out from the wall ranged from about 1 to 2 meters for all cores. One additional core was taken in the Morton Mountain Tunnel for verification purposes and the measured depth to bedrock was 0.69 meters. This measurement compares well with the core results found by EFLHD. GPR results obtained in the vicinity of the respective core locations are also shown in Table 3.

Table 3. Depth to Bedrock Below Pavement in Both Tunnels.

Core No.	Distance Along Wall, meters	Depth to Bedrock, meters	
		Core	GPR
Morton Mountain Tunnel			
B1	18	0.70	0.73
B2	18	0.74	0.62
B3	69	0.68	0.69
B4	69	0.70	0.58
Chimney Tops Mountain Tunnel			
B1	62	0.68	0.57
B2	62	1.36	0.64
B3	15	0.57	0.60
B4	15	0.73	0.68

GPR surveys were performed along six longitudinal lines in the driving lanes of each tunnel (see Figure 4). In each case, the survey initiated at the south end of the tunnel and continued along the entire length of the tunnel. The specific location of each GPR pass, when looking north, was as follows:

- Pass 1 – Right-hand wheel path in the right lane.
- Pass 2 – Centerline between wheel paths in the right lane.
- Pass 3 – Left-hand wheel path in the right lane.
- Pass 4 – Right-hand wheel path in the left lane.
- Pass 5 – Centerline between wheel paths in the left lane.
- Pass 6 – Left-hand wheel path in the left lane.

All radar survey results are provided in the Appendix and a statistical summary is shown in Table 4 below. Erroneous shallow readings at the beginning and end of the survey area for each pass were not included in the statistical calculations, although they are shown in the tabulation in the Appendix.

Table 4. GPR Survey Results on the Pavement in Both Tunnels.

Result	Depth to Bedrock, meters						All
	Pass 1	Pass 2	Pass 3	Pass 4	Pass 5	Pass 6	Passes
Morton Mountain Tunnel							
Average	0.70	0.68	0.65	0.51	0.52	0.60	0.61
Minimum	0.57	0.51	0.59	0.46	0.46	0.50	0.46
Maximum	0.75	0.74	0.70	0.54	0.59	0.66	0.75
Stnd. Dev.	0.04	0.05	0.03	0.02	0.03	0.03	0.08
Chimney Tops Mountain Tunnel							
Average	0.58	0.59	0.58	0.64	0.65	0.64	0.61
Minimum	0.52	0.53	0.52	0.56	0.57	0.57	0.52
Maximum	0.63	0.63	0.63	0.76	0.75	0.74	0.76
Stnd Dev	0.03	0.02	0.03	0.05	0.05	0.04	0.05

Based on the standard deviation for each pass, the results indicate that the depth to bedrock was relatively uniform along the length of the pavement. The average depth to bedrock for all passes in both tunnels was 0.61 meters. The maximum variation between individual passes was 0.19 and 0.07 meters for the Morton Mountain and Chimney Tops Tunnels respectively. In general, the GPR results correlated well with the findings from cores. One notable exception is core B2 from the Chimney Tops Mountain Tunnel. The core result was 1.36 meters and the depth to bedrock indicated by GPR was 0.64 meters. Considering all findings from the cores and GPR surveys, it is probable that the core measurement is in error, but this could not be confirmed.

Depth to Bedrock in the Approach Roadways of Both Tunnels

GPR surveys were performed along six longitudinal lines on the approaches of each tunnel (see Figure 5). For each approach, the origin of the survey area was located 76 meters out from the right-hand side (looking north for the approach at the south end of the tunnel and looking south for the approach at the north end of the tunnel) of the tunnel and the radar passes were located as follows:

Pass 1 – Right-hand wheel path in the right lane.
Pass 2 – Centerline between wheel paths in the right lane.
Pass 3 – Left-hand wheel path in the right lane.
Pass 4 – Right-hand wheel path in the left lane.
Pass 5 – Centerline between wheel paths in the left lane.
Pass 6 – Left-hand wheel path in the left lane.

All radar survey results are provided in the Appendix and a statistical summary is shown in Table 5. Erroneous shallow readings at the beginning and end of the survey area for each pass were not included in the statistical calculations, although they are shown in the tabulation in the Appendix.

Based on the standard deviation for each pass, the results indicate that the depth to bedrock was relatively uniform along the length of the approaches. The average depth to bedrock for all passes on both approaches of the Morton Mountain Tunnel and the Chimney Tops Mountain Tunnel was 0.48 and 0.58 meters respectively. The maximum variation between individual passes for both tunnels was 0.14 meters.

VII. Problems Encountered

For reasons associated with unanticipated site conditions and the experimental nature of the work, a total of four site visits (one each in November 1999, December 1999, February 2000, and March 2000) were required to complete all project objectives. These included:

1. The first lining core was drilled to a depth where crushed bedrock was encountered. Subsequent lining cores were drilled down to solid bedrock. Consequently, FLH requested that an additional core be drilled adjacent to the location of the first core and that drilling be continued down to solid bedrock.

2. Wood and steel embedded in the concrete caused the core bits to seize and break off in the tunnel wall numerous times. Consequently, a total of 15 cores were extracted in order to obtain the required information.

3. The cores were extraordinarily long (ranging from 19 to 41 inches). A sample core is shown in Figure 6. Special coring rigs were rented and many problems were encountered with these. On several occasions, the rented equipment was found to be defective and had to be returned.

4. The leased GPR system was not designed to function in below freezing temperatures. On one site visit, the GPR system malfunctioned due to extremely low temperatures and this prevented any survey work from being performed at that time.

Table 5. GPR Survey Results on the Approaches of Both Tunnels.

Result	South End of Tunnel Depth to Bedrock, meters Pass 1	Pass 2	Pass 3	Pass 4	Pass 5	Pass 6
Morton Mountain Tunnel						
Average	0.44	0.44	0.49	0.51	0.48	0.56
Minimum	0.37	0.41	0.46	0.46	0.45	0.50
Maximum	0.51	0.47	0.52	0.55	0.51	0.64
Stnd. Dev.	0.04	0.02	0.01	0.03	0.02	0.03
Chimney Tops Mountain Tunnel						
Average	0.56	0.50	0.58	0.54	0.59	0.60
Minimum	0.46	0.38	0.52	0.47	0.54	0.54
Maximum	0.67	0.63	0.63	0.63	0.64	0.71
Stnd Dev	0.05	0.07	0.02	0.05	0.03	0.03

Result	North End of Tunnel Depth to Bedrock, meters Pass 1	Pass 2	Pass 3	Pass 4	Pass 5	Pass 6	All Passes
Morton Mountain Tunnel							
Average	0.42	0.47	0.46	0.56	0.48	0.44	0.48
Minimum	0.36	0.38	0.40	0.51	0.40	0.28	0.28
Maximum	0.47	0.55	0.54	0.68	0.59	0.60	0.68
Stnd. Dev.	0.02	0.05	0.03	0.04	0.05	0.09	0.06
Chimney Tops Mountain Tunnel							
Average	0.59	0.61	0.61	0.56	0.64	0.64	0.58
Minimum	0.50	0.53	0.15	0.50	0.51	0.49	0.15
Maximum	0.69	0.71	0.69	0.64	0.74	0.79	0.79
Stnd Dev	0.05	0.05	0.07	0.04	0.05	0.06	0.06

Figure 6. Typical core from the Chimney Tops Mountain tunnel.

VIII. Investigation Costs

The total cost for all work described in this report, including preparing the report and excluding traffic control which was provided by the park maintenance staff, was approximately $60,000. This cost could be reduced by at least 50% for future similar work based on the following:

1. The same radar system could be used, thus eliminating the need to research different systems and their capabilities. Also, the assembly used to mount the radar equipment to the survey vehicle was designed and constructed as part of this project and can be used again with the same radar system.

2. This was the first attempt in utilizing GPR technology for the purposes stated in this report and, thus, efficiency would be expected to improve in future efforts. For example, a similar investigation should now be able to be completed in one extended site visit. Also, in the future, the GPR data can be processed at a pre-determined interval. In the subject project, the data were first processed at a five meter interval. The results were not sufficiently detailed at this interval and all data were subsequently processed again at a one meter interval.

3. It is assumed that the problems encountered with the coring equipment could be minimized in future efforts based on the experience gained in this instance.

IX. Conclusions and Recommendations

The objectives of this project were achieved using a combination of ground penetrating radar technology and traditional investigation methods. The results obtained using ground penetrating radar were generally consistent with direct measurements obtained on core samples.

The same investigation techniques can be used in similar future efforts, but consideration should be given to cost differences between non-destructive and traditional methods and to the level of destructive testing that is acceptable in a particular tunnel. When results are needed for large surface areas, or when other factors exist that restrain the ability to perform the required level of destructive testing, ground penetrating radar appears to be a viable means of achieving concrete tunnel lining thickness and substrate material information under roadways paved with asphalt.

APPENDIX

Table A1. GPR Data on the Concrete Linings in Both Tunnels.

Horizontal Distance, meters	Morton Mountain Tunnel Lining Thickness, meters			Chimney Tops Mountain Tunnel Lining Thickness, meters		
	Crown	East Wall	West Wall	Crown	East Wall	West Wall
0	0.32	0.27	0.47	0.35	0.34	0.33
1	0.32	0.45	0.50	0.35	0.33	0.32
2	0.32	0.45	0.50	0.35	0.33	0.31
3	0.32	0.46	0.50	0.35	0.33	0.30
4	0.32	0.46	0.47	0.35	0.33	0.31
5	0.29	0.46	0.46	0.35	0.34	0.30
6	0.29	0.46	0.43	0.35	0.35	0.30
7	0.29	0.46	0.44	0.35	0.34	0.31
8	0.29	0.46	0.39	0.35	0.34	0.30
9	0.29	0.46	0.39	0.35	0.34	0.31
10	0.18	0.46	0.41	0.35	0.34	0.32
11	0.18	0.46	0.41	0.35	0.34	0.33
12	0.18	0.44	0.40	0.35	0.35	0.33
13	0.18	0.44	0.40	0.36	0.35	0.30
14	0.18	0.43	0.40	0.36	0.35	0.30
15	0.20	0.41	0.40	0.36	0.35	0.30
16	0.20	0.42	0.40	0.36	0.35	0.32
17	0.20	0.45	0.41	0.36	0.35	0.32
18	0.20	0.44	0.41	0.36	0.35	0.32
19	0.20	0.43	0.43	0.36	0.35	0.33
20	0.20	0.44	0.43	0.36	0.35	0.33
21	0.20	0.44	0.43	0.36	0.35	0.33
22	0.20	0.44	0.44	0.36	0.35	0.32
23	0.20	0.44	0.44	0.36	0.35	0.31
24	0.20	0.44	0.45	0.36	0.36	0.31
25	0.20	0.45	0.45	0.36	0.36	0.28
26	0.20	0.45	0.45	0.36	0.36	0.28
27	0.20	0.45	0.43	0.36	0.36	0.28
28	0.20	0.45	0.43	0.36	0.36	0.30
29	0.20	0.45	0.41	0.36	0.36	0.33
30	0.18	0.45	0.41	0.37	0.37	0.30
31	0.18	0.45	0.41	0.37	0.37	0.28
32	0.18	0.45	0.41	0.37	0.37	0.29
33	0.18	0.45	0.41	0.37	0.37	0.28
34	0.18	0.45	0.41	0.36	0.37	0.28
35	0.16	0.45	0.43	0.36	0.37	0.30
36	0.16	0.45	0.43	0.36	0.37	0.30
37	0.16	0.45	0.43	0.36	0.37	0.31
38	0.16	0.46	0.43	0.36	0.37	0.31

Table A1. GPR Data on the Concrete Linings in Both Tunnels.

Horizontal Distance, meters	Morton Mountain Tunnel Lining Thickness, meters			Chimney Tops Mountain Tunnel Lining Thickness, meters		
	Crown	East Wall	West Wall	Crown	East Wall	West Wall
39	0.16	0.47	0.43	0.36	0.37	0.31
40	0.16	0.47	0.46	0.36	0.37	0.31
41	0.16	0.47	0.49	0.36	0.37	0.31
42	0.16	0.47	0.49	0.36	0.36	0.30
43	0.16	0.46	0.48	0.36	0.36	0.30
44	0.16	0.46	0.46	0.36	0.35	0.30
45	0.16	0.46	0.46	0.36	0.35	0.33
46	0.16	0.46	0.45	0.36	0.34	0.31
47	0.16	0.46	0.45	0.36	0.34	0.31
48	0.16	0.46	0.45	0.36	0.34	0.31
49	0.16	0.45	0.45	0.36	0.34	0.30
50	0.18	0.45	0.45	0.36	0.34	0.32
51	0.18	0.45	0.44	0.44	0.34	0.33
52	0.18	0.45	0.44	0.35	0.34	0.32
53	0.18	0.45	0.44	0.35	0.34	0.32
54	0.18	0.45	0.44	0.36	0.34	0.32
55	0.18	0.46	0.44	0.36	0.33	0.30
56	0.18	0.47	0.44	0.36	0.33	0.32
57	0.18	0.45	0.44	0.36	0.33	0.34
58	0.18	0.45	0.44	0.36	0.33	0.33
59	0.18	0.45	0.43	0.36	0.33	0.33
60	0.18	0.46	0.42	0.36	0.33	0.33
61	0.18	0.47	0.46	0.36	0.33	0.32
62	0.18	0.46	0.46	0.36	0.33	0.30
63	0.18	0.46	0.46	0.36	0.33	0.29
64	0.18	0.46	0.46	0.36	0.33	0.30
65	0.20	0.46	0.46	0.36	0.33	0.30
66	0.20	0.46	0.46	0.36	0.33	0.31
67	0.20	0.46	0.46	0.36	0.33	0.31
68	0.20	0.46	0.46	0.36	0.32	0.31
69	0.20	0.46	0.46	0.36	0.32	0.30
70	0.20	0.46	0.45	0.36	0.32	0.30
71	0.20	0.46	0.43	0.36	0.31	0.31
72	0.20	0.46	0.43	0.36	0.31	0.31
73	0.20	0.46	0.41	0.35	0.31	0.30
74	0.20	0.46	0.44	0.35	0.30	0.29
75	0.20	0.45	0.44	0.35	0.30	0.29
76	0.20	0.45	0.44	0.35	0.30	0.30
77	0.20	0.45	0.44	0.35	0.30	0.30

Table A1. GPR Data on the Concrete Linings in Both Tunnels.

Horizontal Distance, meters	Morton Mountain Tunnel Lining Thickness, meters			Chimney Tops Mountain Tunnel Lining Thickness, meters		
	Crown	East Wall	West Wall	Crown	East Wall	West Wall
78	0.20	0.45	0.44			
79	0.20	0.45	0.44			
80	0.20	0.45	0.44			
81	0.20	0.45	0.44			
82	0.20	0.43	0.44			
83	0.20	0.42	0.44			
84	0.20	0.45	0.44			
85	0.20	0.45	0.44			
86	0.20	0.39	0.43			
87	0.20	0.10	0.43			

Table A2. GPR Data on the Pavement in Both Tunnels.

Horizontal Distance, meters	Morton Mountain Tunnel Depth to Bedrock, meters						Chimney Tops Mountain Tunnel Depth to Bedrock, meters					
	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6
0	0.60	0.74	0.61	0.50	0.00	0.00	0.00	0.61	0.62	0.15	0.64	0.65
1	0.61	0.73	0.60	0.50	0.59	0.58	0.61	0.63	0.62	0.15	0.66	0.64
2	0.60	0.71	0.60	0.50	0.57	0.61	0.63	0.63	0.63	0.67	0.66	0.61
3	0.60	0.72	0.61	0.50	0.57	0.60	0.63	0.62	0.63	0.65	0.66	0.61
4	0.60	0.73	0.59	0.49	0.57	0.59	0.62	0.62	0.63	0.66	0.65	0.61
5	0.61	0.73	0.59	0.49	0.57	0.59	0.62	0.63	0.62	0.69	0.65	0.71
6	0.63	0.72	0.60	0.49	0.57	0.58	0.63	0.63	0.62	0.71	0.65	0.67
7	0.64	0.72	0.61	0.49	0.57	0.58	0.63	0.63	0.61	0.74	0.67	0.68
8	0.65	0.71	0.61	0.51	0.57	0.58	0.63	0.62	0.61	0.71	0.68	0.66
9	0.66	0.71	0.61	0.51	0.57	0.59	0.62	0.62	0.61	0.67	0.71	0.69
10	0.66	0.71	0.61	0.53	0.57	0.59	0.62	0.62	0.60	0.68	0.71	0.71
11	0.67	0.70	0.62	0.53	0.57	0.61	0.62	0.61	0.60	0.63	0.71	0.72
12	0.67	0.70	0.63	0.53	0.57	0.59	0.61	0.61	0.60	0.65	0.73	0.67
13	0.67	0.70	0.63	0.52	0.57	0.59	0.61	0.60	0.60	0.70	0.75	0.68
14	0.68	0.70	0.63	0.52	0.57	0.59	0.61	0.60	0.60	0.71	0.71	0.70
15	0.68	0.70	0.64	0.52	0.57	0.59	0.60	0.60	0.60	0.73	0.69	0.68
16	0.68	0.70	0.64	0.52	0.56	0.58	0.60	0.60	0.60	0.74	0.75	0.59
17	0.69	0.70	0.64	0.52	0.56	0.58	0.60	0.60	0.60	0.72	0.70	0.69
18	0.69	0.70	0.64	0.52	0.56	0.58	0.60	0.60	0.60	0.67	0.72	0.61
19	0.69	0.71	0.64	0.52	0.55	0.58	0.60	0.60	0.60	0.71	0.72	0.68
20	0.69	0.72	0.64	0.52	0.55	0.58	0.60	0.60	0.60	0.75	0.71	0.73
21	0.69	0.72	0.65	0.52	0.55	0.58	0.60	0.60	0.57	0.70	0.73	0.71
22	0.69	0.71	0.65	0.53	0.55	0.59	0.60	0.60	0.57	0.72	0.74	0.71
23	0.69	0.71	0.65	0.51	0.54	0.59	0.60	0.60	0.57	0.72	0.66	0.71
24	0.69	0.70	0.65	0.51	0.54	0.59	0.60	0.58	0.57	0.72	0.67	0.71
25	0.69	0.70	0.65	0.51	0.54	0.59	0.60	0.58	0.57	0.60	0.69	0.71
26	0.69	0.69	0.65	0.52	0.54	0.59	0.60	0.58	0.57	0.59	0.62	0.57
27	0.69	0.69	0.65	0.53	0.54	0.58	0.60	0.58	0.59	0.61	0.65	0.61
28	0.70	0.69	0.65	0.53	0.54	0.57	0.60	0.58	0.59	0.61	0.60	0.59
29	0.70	0.69	0.65	0.52	0.54	0.56	0.60	0.58	0.59	0.57	0.66	0.61
30	0.70	0.68	0.64	0.52	0.53	0.58	0.60	0.58	0.59	0.61	0.63	0.61
31	0.71	0.68	0.64	0.51	0.53	0.59	0.60	0.58	0.59	0.59	0.67	0.61
32	0.71	0.68	0.63	0.51	0.53	0.59	0.60	0.58	0.59	0.61	0.61	0.57
33	0.72	0.69	0.63	0.51	0.53	0.61	0.60	0.58	0.59	0.62	0.61	0.63
34	0.72	0.69	0.63	0.51	0.53	0.62	0.60	0.57	0.59	0.61	0.57	0.70
35	0.73	0.69	0.63	0.53	0.53	0.61	0.60	0.59	0.59	0.64	0.61	0.72
36	0.73	0.68	0.63	0.53	0.53	0.61	0.59	0.59	0.59	0.66	0.61	0.74
37	0.73	0.68	0.64	0.51	0.53	0.59	0.59	0.59	0.59	0.63	0.57	0.64
38	0.73	0.68	0.65	0.51	0.53	0.61	0.59	0.59	0.59	0.70	0.63	0.67

Table A2. GPR Data on the Pavement in Both Tunnels.

Horizontal Distance, meters	Morton Mountain Tunnel Depth to Bedrock, meters						Chimney Tops Mountain Tunnel Depth to Bedrock, meters					
	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6
39	0.73	0.69	0.66	0.51	0.52	0.62	0.59	0.59	0.59	0.72	0.70	0.60
40	0.73	0.69	0.66	0.50	0.52	0.64	0.58	0.59	0.59	0.71	0.72	0.59
41	0.73	0.68	0.66	0.50	0.52	0.64	0.58	0.59	0.59	0.76	0.74	0.65
42	0.73	0.67	0.66	0.50	0.52	0.65	0.58	0.59	0.59	0.74	0.64	0.64
43	0.73	0.67	0.66	0.50	0.52	0.65	0.58	0.59	0.57	0.64	0.67	0.64
44	0.73	0.68	0.67	0.50	0.52	0.66	0.57	0.59	0.57	0.67	0.60	0.60
45	0.74	0.68	0.68	0.50	0.52	0.66	0.57	0.59	0.57	0.60	0.59	0.60
46	0.74	0.68	0.68	0.50	0.52	0.66	0.57	0.59	0.57	0.59	0.71	0.64
47	0.74	0.68	0.69	0.52	0.52	0.66	0.57	0.59	0.57	0.61	0.67	0.59
48	0.74	0.68	0.69	0.52	0.52	0.64	0.57	0.59	0.57	0.60	0.68	0.61
49	0.73	0.69	0.70	0.53	0.51	0.64	0.57	0.59	0.57	0.59	0.62	0.61
50	0.73	0.69	0.70	0.51	0.52	0.64	0.56	0.59	0.57	0.61	0.64	0.61
51	0.73	0.69	0.70	0.50	0.52	0.64	0.56	0.59	0.57	0.61	0.64	0.62
52	0.73	0.69	0.69	0.46	0.52	0.63	0.56	0.59	0.57	0.61	0.60	0.64
53	0.73	0.69	0.69	0.46	0.52	0.61	0.55	0.59	0.57	0.57	0.60	0.64
54	0.73	0.70	0.69	0.46	0.52	0.61	0.56	0.59	0.57	0.58	0.64	0.60
55	0.72	0.70	0.69	0.46	0.53	0.61	0.56	0.57	0.57	0.62	0.64	0.60
56	0.72	0.70	0.69	0.46	0.53	0.61	0.56	0.57	0.57	0.64	0.60	0.64
57	0.72	0.70	0.69	0.46	0.53	0.62	0.57	0.57	0.59	0.64	0.60	0.64
58	0.72	0.70	0.69	0.46	0.53	0.62	0.57	0.57	0.59	0.60	0.64	0.60
59	0.72	0.70	0.68	0.46	0.53	0.62	0.57	0.57	0.59	0.60	0.64	0.60
60	0.72	0.70	0.67	0.48	0.54	0.62	0.57	0.57	0.57	0.64	0.64	0.64
61	0.71	0.70	0.65	0.49	0.53	0.62	0.57	0.57	0.57	0.64	0.64	0.64
62	0.71	0.70	0.65	0.50	0.53	0.62	0.57	0.57	0.57	0.65	0.65	0.64
63	0.71	0.70	0.66	0.52	0.52	0.63	0.56	0.57	0.57	0.59	0.59	0.64
64	0.70	0.69	0.66	0.53	0.52	0.63	0.56	0.57	0.57	0.63	0.63	0.65
65	0.70	0.69	0.66	0.53	0.51	0.62	0.56	0.57	0.55	0.62	0.62	0.59
66	0.69	0.66	0.66	0.53	0.51	0.62	0.55	0.57	0.55	0.60	0.64	0.63
67	0.70	0.67	0.67	0.52	0.50	0.62	0.55	0.57	0.55	0.60	0.64	0.62
68	0.72	0.67	0.67	0.52	0.49	0.62	0.55	0.57	0.55	0.57	0.60	0.60
69	0.72	0.67	0.66	0.51	0.48	0.62	0.54	0.57	0.55	0.61	0.59	0.60
70	0.73	0.68	0.66	0.51	0.48	0.62	0.54	0.57	0.55	0.60	0.63	0.57
71	0.73	0.69	0.65	0.51	0.48	0.62	0.54	0.53	0.55	0.61	0.62	0.64
72	0.74	0.69	0.65	0.51	0.47	0.62	0.54	0.53	0.52	0.60	0.60	0.64
73	0.74	0.69	0.65	0.51	0.47	0.62	0.53	0.53	0.52	0.56	0.60	0.65
74	0.74	0.69	0.65	0.51	0.47	0.62	0.53	0.53	0.52	0.60	0.60	0.59
75	0.74	0.69	0.66	0.51	0.47	0.61	0.53	0.53	0.52	0.62	0.60	0.63
76	0.74	0.69	0.65	0.51	0.47	0.59	0.52	0.53	0.52	0.60	0.60	0.62
77	0.74	0.69	0.64	0.51	0.47	0.59	0.52	0.53	0.52	0.59	0.60	0.60

Table A2. GPR Data on the Pavement in Both Tunnels.

Horizontal Distance, meters	Morton Mountain Tunnel Depth to Bedrock, meters						Chimney Tops Mountain Tunnel Depth to Bedrock, meters					
	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6
78	0.75	0.68	0.63	0.51	0.46	0.59						
79	0.74	0.66	0.61	0.51	0.46	0.59						
80	0.74	0.63	0.63	0.51	0.46	0.58						
81	0.73	0.56	0.66	0.54	0.47	0.57						
82	0.73	0.54	0.68	0.54	0.49	0.56						
83	0.68	0.53	0.69	0.54	0.49	0.55						
84	0.59	0.51	0.70	0.52	0.50	0.52						
85	0.59	0.51	0.69	0.50	0.48	0.50						
86	0.57	0.51	0.68	0.49	0.47	0.50						
87	0.57	0.51	0.67	0.49	0.00	0.50						

Table A3. GPR Data on the Approaches of the Morton Mountain Tunnel.

Horizontal Distance, meters	South End of Tunnel Depth to Bedrock, meters						North End of Tunnel Depth to Bedrock, meters					
	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6
0	0.37	0.41	0.25	0.54	0.00	0.60	0.38	0.54	0.44	0.53	0.43	0.19
1	0.38	0.41	0.46	0.54	0.46	0.59	0.38	0.55	0.45	0.53	0.43	0.32
2	0.39	0.43	0.47	0.54	0.46	0.57	0.38	0.53	0.45	0.53	0.43	0.32
3	0.39	0.41	0.47	0.53	0.46	0.56	0.38	0.51	0.45	0.54	0.43	0.32
4	0.38	0.42	0.46	0.52	0.46	0.56	0.38	0.51	0.44	0.54	0.43	0.32
5	0.38	0.42	0.47	0.52	0.46	0.57	0.38	0.52	0.44	0.54	0.43	0.30
6	0.38	0.43	0.47	0.52	0.46	0.57	0.39	0.52	0.45	0.53	0.43	0.31
7	0.39	0.42	0.47	0.52	0.46	0.57	0.40	0.53	0.46	0.52	0.42	0.29
8	0.39	0.42	0.47	0.53	0.46	0.57	0.39	0.52	0.47	0.52	0.42	0.30
9	0.39	0.42	0.47	0.53	0.46	0.59	0.38	0.52	0.47	0.52	0.42	0.28
10	0.38	0.42	0.48	0.53	0.46	0.60	0.39	0.52	0.47	0.52	0.42	0.30
11	0.39	0.43	0.48	0.54	0.49	0.60	0.41	0.52	0.47	0.52	0.42	0.31
12	0.40	0.44	0.49	0.55	0.48	0.58	0.39	0.52	0.46	0.52	0.42	0.31
13	0.41	0.42	0.50	0.55	0.47	0.58	0.40	0.52	0.47	0.52	0.42	0.32
14	0.42	0.42	0.51	0.55	0.46	0.58	0.39	0.52	0.47	0.52	0.41	0.31
15	0.42	0.43	0.50	0.55	0.46	0.60	0.41	0.51	0.47	0.51	0.40	0.35
16	0.42	0.43	0.50	0.55	0.46	0.62	0.41	0.51	0.47	0.51	0.40	0.28
17	0.42	0.45	0.50	0.55	0.45	0.64	0.40	0.52	0.46	0.51	0.40	0.33
18	0.42	0.46	0.50	0.54	0.45	0.63	0.40	0.54	0.47	0.51	0.40	0.31
19	0.43	0.46	0.50	0.50	0.45	0.62	0.41	0.55	0.50	0.52	0.41	0.30
20	0.45	0.44	0.50	0.51	0.45	0.59	0.41	0.55	0.53	0.59	0.46	0.42
21	0.49	0.43	0.50	0.52	0.45	0.58	0.44	0.54	0.54	0.63	0.55	0.60
22	0.48	0.43	0.49	0.53	0.45	0.63	0.46	0.52	0.53	0.63	0.56	0.60
23	0.44	0.43	0.49	0.54	0.45	0.62	0.47	0.52	0.52	0.68	0.57	0.58
24	0.42	0.43	0.48	0.54	0.45	0.56	0.46	0.52	0.51	0.68	0.59	0.54
25	0.43	0.43	0.48	0.54	0.47	0.56	0.45	0.52	0.50	0.67	0.55	0.55
26	0.42	0.43	0.48	0.53	0.47	0.56	0.45	0.50	0.51	0.64	0.54	0.56
27	0.43	0.43	0.48	0.52	0.47	0.56	0.45	0.48	0.53	0.63	0.52	0.55
28	0.44	0.44	0.49	0.52	0.47	0.57	0.44	0.49	0.53	0.60	0.52	0.53
29	0.44	0.45	0.49	0.52	0.47	0.56	0.43	0.50	0.50	0.59	0.51	0.51
30	0.44	0.46	0.49	0.52	0.48	0.56	0.44	0.50	0.50	0.57	0.51	0.50
31	0.45	0.45	0.49	0.52	0.48	0.54	0.45	0.50	0.49	0.56	0.51	0.49
32	0.45	0.46	0.49	0.52	0.48	0.54	0.43	0.50	0.48	0.56	0.50	0.49
33	0.45	0.47	0.49	0.52	0.48	0.55	0.44	0.49	0.47	0.56	0.50	0.48
34	0.43	0.47	0.48	0.50	0.49	0.56	0.44	0.49	0.47	0.56	0.49	0.49
35	0.42	0.47	0.49	0.48	0.49	0.55	0.45	0.49	0.46	0.56	0.49	0.50
36	0.42	0.46	0.49	0.51	0.49	0.53	0.45	0.48	0.44	0.56	0.49	0.48
37	0.43	0.45	0.49	0.52	0.48	0.53	0.45	0.46	0.44	0.56	0.49	0.48
38	0.45	0.45	0.49	0.52	0.49	0.53	0.44	0.45	0.45	0.56	0.48	0.48

Table A3. GPR Data on the Approaches of the Morton Mountain Tunnel.

Horizontal Distance, meters	South End of Tunnel Depth to Bedrock, meters						North End of Tunnel Depth to Bedrock, meters					
	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6
39	0.47	0.47	0.49	0.52	0.51	0.51	0.43	0.42	0.46	0.56	0.48	0.48
40	0.49	0.47	0.49	0.52	0.51	0.50	0.43	0.42	0.47	0.56	0.48	0.48
41	0.50	0.45	0.50	0.51	0.50	0.52	0.44	0.43	0.47	0.55	0.48	0.47
42	0.49	0.44	0.51	0.49	0.49	0.53	0.41	0.43	0.41	0.55	0.48	0.47
43	0.49	0.44	0.51	0.48	0.49	0.54	0.43	0.42	0.42	0.53	0.48	0.47
44	0.48	0.43	0.50	0.47	0.49	0.55	0.39	0.41	0.42	0.52	0.48	0.46
45	0.46	0.44	0.50	0.47	0.49	0.55	0.39	0.41	0.42	0.52	0.47	0.45
46	0.45	0.46	0.49	0.46	0.49	0.55	0.40	0.41	0.44	0.52	0.45	0.45
47	0.45	0.47	0.49	0.46	0.48	0.55	0.39	0.42	0.44	0.53	0.45	0.45
48	0.44	0.46	0.48	0.46	0.48	0.55	0.38	0.42	0.44	0.54	0.45	0.44
49	0.48	0.45	0.47	0.46	0.48	0.55	0.36	0.42	0.43	0.53	0.45	0.43
50	0.47	0.44	0.46	0.46	0.48	0.55	0.39	0.42	0.42	0.53	0.45	0.43
51	0.47	0.43	0.46	0.46	0.48	0.55	0.39	0.42	0.41	0.52	0.45	0.43
52	0.47	0.43	0.46	0.46	0.48	0.54	0.39	0.42	0.41	0.55	0.45	0.43
53	0.48	0.44	0.47	0.47	0.49	0.53	0.40	0.42	0.42	0.57	0.45	0.43
54	0.48	0.44	0.47	0.48	0.49	0.53	0.42	0.44	0.43	0.57	0.46	0.44
55	0.49	0.44	0.47	0.49	0.49	0.52	0.41	0.46	0.44	0.57	0.47	0.46
56	0.49	0.44	0.48	0.49	0.49	0.50	0.40	0.47	0.45	0.57	0.48	0.46
57	0.47	0.44	0.51	0.50	0.49	0.52	0.41	0.46	0.47	0.59	0.49	0.46
58	0.46	0.43	0.50	0.50	0.49	0.53	0.45	0.42	0.47	0.59	0.49	0.48
59	0.46	0.44	0.49	0.50	0.49	0.53	0.39	0.39	0.42	0.59	0.48	0.50
60	0.46	0.44	0.49	0.49	0.49	0.53	0.39	0.39	0.40	0.59	0.50	0.50
61	0.44	0.45	0.49	0.49	0.49	0.53	0.41	0.39	0.41	0.59	0.49	0.49
62	0.44	0.47	0.49	0.49	0.49	0.53	0.41	0.38	0.41	0.58	0.46	0.50
63	0.46	0.47	0.49	0.49	0.49	0.53	0.41	0.38	0.42	0.57	0.45	0.50
64	0.49	0.47	0.49	0.49	0.49	0.53	0.42	0.39	0.43	0.58	0.45	0.49
65	0.50	0.45	0.49	0.50	0.49	0.54	0.41	0.41	0.44	0.58	0.47	0.51
66	0.50	0.45	0.50	0.50	0.49	0.55	0.43	0.43	0.45	0.60	0.49	0.52
67	0.51	0.45	0.51	0.50	0.49	0.56	0.43	0.45	0.47	0.64	0.51	0.52
68	0.45	0.45	0.52	0.49	0.49	0.56	0.42	0.46	0.48	0.61	0.51	0.52
69	0.40	0.45	0.50	0.49	0.49	0.57	0.43	0.44	0.48	0.60	0.53	0.52
70	0.40	0.45	0.49	0.49	0.49	0.58	0.42	0.40	0.46	0.60	0.53	0.52
71	0.42	0.45	0.49	0.48	0.49	0.56	0.43	0.41	0.47	0.56	0.53	0.51
72	0.45	0.45	0.48	0.48	0.49	0.55	0.43	0.42	0.47	0.53	0.53	0.51
73	0.45	0.45	0.48	0.48	0.49	0.55	0.43	0.43	0.48	0.53	0.54	0.50
74	0.44	0.44	0.47	0.48	0.49	0.57	0.45	0.44	0.51	0.53	0.54	0.40
75	0.44	0.44	0.46	0.48	0.48	0.56	0.45	0.45	0.51	0.53	0.54	0.15
76	0.15	0.44	0.46	0.48	0.47	0.55	0.45	0.46	0.49	0.53	0.54	

Table A4. GPR Data on the Approaches of the Chimney Tops Mountain Tunnel.

Horizontal Distance, meters	South End of Tunnel Depth to Bedrock, meters						North End of Tunnel Depth to Bedrock, meters					
	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6
0	0.18	0.13	0.52	0.62	0.63	0.15	0.62	0.60	0.16	0.50	0.56	0.54
1	0.18	0.13	0.52	0.62	0.63	0.15	0.63	0.60	0.16	0.50	0.56	0.54
2	0.18	0.13	0.55	0.63	0.64	0.69	0.65	0.60	0.17	0.50	0.57	0.54
3	0.18	0.52	0.55	0.63	0.63	0.71	0.66	0.64	0.65	0.50	0.59	0.54
4	0.53	0.52	0.55	0.63	0.61	0.70	0.68	0.63	0.64	0.50	0.55	0.54
5	0.53	0.50	0.55	0.63	0.60	0.67	0.63	0.64	0.62	0.50	0.55	0.54
6	0.53	0.47	0.56	0.60	0.57	0.68	0.63	0.64	0.63	0.51	0.55	0.54
7	0.53	0.43	0.56	0.60	0.55	0.68	0.64	0.61	0.61	0.51	0.56	0.53
8	0.53	0.43	0.56	0.60	0.55	0.65	0.66	0.64	0.62	0.51	0.53	0.51
9	0.53	0.43	0.56	0.58	0.57	0.62	0.63	0.61	0.67	0.53	0.51	0.50
10	0.53	0.43	0.56	0.54	0.59	0.59	0.67	0.64	0.69	0.53	0.57	0.49
11	0.53	0.43	0.56	0.57	0.61	0.58	0.68	0.67	0.64	0.51	0.55	0.54
12	0.53	0.47	0.58	0.60	0.60	0.59	0.61	0.67	0.61	0.51	0.58	0.57
13	0.53	0.50	0.61	0.60	0.62	0.59	0.61	0.67	0.63	0.51	0.60	0.60
14	0.52	0.52	0.61	0.59	0.59	0.59	0.63	0.65	0.64	0.51	0.61	0.61
15	0.52	0.57	0.61	0.58	0.59	0.60	0.66	0.71	0.69	0.51	0.62	0.62
16	0.52	0.60	0.61	0.58	0.59	0.60	0.66	0.67	0.67	0.53	0.63	0.60
17	0.51	0.60	0.60	0.58	0.61	0.60	0.63	0.67	0.68	0.53	0.63	0.63
18	0.51	0.63	0.60	0.58	0.61	0.59	0.65	0.68	0.66	0.54	0.64	0.64
19	0.51	0.63	0.59	0.58	0.58	0.60	0.62	0.68	0.68	0.54	0.59	0.63
20	0.51	0.63	0.59	0.60	0.59	0.63	0.62	0.68	0.64	0.52	0.59	0.65
21	0.51	0.63	0.59	0.60	0.62	0.62	0.62	0.68	0.64	0.51	0.59	0.69
22	0.51	0.63	0.60	0.60	0.61	0.63	0.61	0.67	0.65	0.50	0.59	0.66
23	0.51	0.59	0.60	0.60	0.62	0.60	0.62	0.67	0.67	0.51	0.59	0.65
24	0.51	0.50	0.61	0.59	0.61	0.58	0.62	0.67	0.66	0.54	0.62	0.69
25	0.51	0.50	0.61	0.59	0.57	0.59	0.63	0.66	0.65	0.55	0.69	0.67
26	0.51	0.50	0.62	0.56	0.58	0.59	0.67	0.65	0.65	0.57	0.70	0.65
27	0.51	0.50	0.63	0.51	0.55	0.56	0.69	0.65	0.65	0.57	0.71	0.66
28	0.58	0.52	0.60	0.51	0.58	0.58	0.68	0.66	0.65	0.57	0.70	0.69
29	0.59	0.55	0.60	0.51	0.59	0.61	0.67	0.66	0.67	0.58	0.70	0.70
30	0.59	0.57	0.60	0.51	0.62	0.62	0.60	0.66	0.67	0.58	0.73	0.70
31	0.58	0.57	0.59	0.51	0.62	0.56	0.59	0.66	0.69	0.60	0.73	0.70
32	0.58	0.57	0.58	0.50	0.62	0.58	0.59	0.65	0.69	0.61	0.72	0.70
33	0.58	0.57	0.59	0.49	0.64	0.56	0.57	0.65	0.68	0.59	0.71	0.70
34	0.58	0.55	0.61	0.49	0.61	0.56	0.57	0.65	0.62	0.58	0.71	0.70
35	0.58	0.51	0.58	0.49	0.61	0.54	0.57	0.65	0.62	0.58	0.70	0.69
36	0.58	0.50	0.58	0.51	0.58	0.55	0.58	0.62	0.60	0.57	0.66	0.71
37	0.62	0.48	0.58	0.50	0.58	0.58	0.60	0.60	0.59	0.55	0.71	0.68
38	0.63	0.43	0.60	0.50	0.59	0.58	0.61	0.59	0.60	0.55	0.74	0.66

Table A4. GPR Data on the Approaches of the Chimney Tops Mountain Tunnel.

Horizontal Distance, meters	South End of Tunnel						North End of Tunnel					
	Depth to Bedrock, meters						Depth to Bedrock, meters					
	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6
39	0.63	0.43	0.59	0.50	0.59	0.60	0.60	0.56	0.61	0.54	0.70	0.68
40	0.62	0.52	0.59	0.52	0.60	0.60	0.59	0.60	0.62	0.53	0.71	0.66
41	0.60	0.60	0.62	0.56	0.63	0.60	0.57	0.56	0.57	0.55	0.70	0.69
42	0.60	0.60	0.62	0.56	0.63	0.60	0.55	0.59	0.57	0.55	0.62	0.68
43	0.56	0.60	0.62	0.56	0.61	0.60	0.55	0.59	0.58	0.54	0.63	0.71
44	0.56	0.60	0.63	0.56	0.61	0.60	0.53	0.58	0.58	0.55	0.65	0.71
45	0.54	0.57	0.59	0.56	0.60	0.60	0.51	0.58	0.58	0.55	0.64	0.70
46	0.54	0.53	0.59	0.51	0.61	0.62	0.55	0.58	0.58	0.56	0.58	0.67
47	0.54	0.53	0.60	0.52	0.62	0.62	0.54	0.58	0.59	0.54	0.58	0.61
48	0.54	0.53	0.61	0.55	0.60	0.62	0.54	0.58	0.57	0.54	0.61	0.60
49	0.56	0.52	0.61	0.54	0.57	0.57	0.54	0.58	0.58	0.54	0.68	0.60
50	0.59	0.50	0.61	0.52	0.58	0.59	0.55	0.58	0.58	0.58	0.68	0.59
51	0.59	0.48	0.60	0.51	0.56	0.60	0.56	0.56	0.58	0.59	0.66	0.59
52	0.60	0.48	0.60	0.50	0.57	0.60	0.56	0.54	0.58	0.60	0.66	0.65
53	0.60	0.48	0.60	0.50	0.56	0.60	0.55	0.54	0.59	0.60	0.69	0.69
54	0.56	0.48	0.60	0.50	0.58	0.60	0.54	0.54	0.15	0.60	0.65	0.69
55	0.54	0.48	0.57	0.50	0.59	0.59	0.54	0.53	0.60	0.61	0.66	0.69
56	0.53	0.48	0.57	0.50	0.56	0.60	0.54	0.53	0.61	0.61	0.67	0.63
57	0.48	0.48	0.58	0.50	0.59	0.60	0.50	0.53	0.61	0.60	0.65	0.64
58	0.46	0.48	0.57	0.50	0.57	0.60	0.50	0.53	0.59	0.60	0.66	0.65
59	0.49	0.48	0.55	0.49	0.54	0.60	0.52	0.53	0.59	0.63	0.66	0.69
60	0.63	0.48	0.57	0.47	0.54	0.57	0.51	0.53	0.59	0.63	0.66	0.71
61	0.62	0.43	0.56	0.47	0.57	0.58	0.51	0.54	0.58	0.61	0.67	0.69
62	0.59	0.43	0.55	0.50	0.56	0.58	0.53	0.54	0.58	0.62	0.67	0.64
63	0.64	0.43	0.55	0.49	0.56	0.57	0.52	0.54	0.60	0.62	0.67	0.64
64	0.56	0.43	0.56	0.49	0.58	0.56	0.54	0.56	0.63	0.61	0.68	0.64
65	0.53	0.43	0.56	0.49	0.54	0.57	0.51	0.57	0.62	0.61	0.67	0.64
66	0.54	0.43	0.56	0.49	0.54	0.57	0.52	0.59	0.62	0.61	0.67	0.65
67	0.58	0.43	0.57	0.48	0.56	0.58	0.52	0.58	0.62	0.63	0.63	0.65
68	0.57	0.43	0.57	0.49	0.54	0.60	0.53	0.56	0.57	0.64	0.64	0.59
69	0.57	0.42	0.57	0.49	0.56	0.59	0.54	0.53	0.58	0.61	0.65	0.79
70	0.57	0.40	0.55	0.48	0.54	0.58	0.52	0.53	0.58	0.60	0.64	0.70
71	0.59	0.38	0.57	0.48	0.55	0.59	0.52	0.53	0.57	0.61	0.62	0.70
72	0.61	0.38	0.61	0.49	0.56	0.59	0.52	0.53	0.55	0.61	0.62	0.65
73	0.67	0.38	0.61	0.49	0.55	0.59	0.56	0.17	0.55	0.60	0.64	0.63
74	0.67	0.38	0.58	0.49	0.54	0.59	0.57	0.17	0.55	0.62	0.66	0.18
75	0.67	0.38	0.58	0.48	0.54	0.58	0.57	0.18	0.55	0.63	0.67	0.18
76	0.17	0.38	0.57	0.48	0.54	0.56	0.57	0.16	0.55	0.63	0.65	0.18