GEOTECHNICAL SERVICES
FINAL REPORT

INITIAL GEOTECHNICAL INVESTIGATION: BEARTOOTH HIGHWAY, U.S. 212, WYOMING

Prepared for
Department of Transportation
Federal Highway Administration
Central Federal Lands Highway Division
Lakewood, Colorado

October 29, 1999

URS Greiner Woodward Clyde Federal Services

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Stanford Place III, Suite 1000
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URSGWCFS Project No. 68FHAT002200

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This report presents the results of initial geotechnical investigations conducted by URS Greiner Woodward Clyde Federal Services (URSGWCFS) for planned improvements along a portion of the Beartooth Highway (U.S. 212), Wyoming Project FH 4-1(0), in cooperation with the Shoshone National Forest (SNF), the Wyoming Department of Transportation (WYDOT), and the National Park Service (NPS). Investigations including geologic mapping, rock fall hazard evaluation, and seismic refraction surveys were conducted along the existing highway alignment from approximately Station 41+450 to 42+150. This portion of the highway alignment (Figure 1) is located between the base of a high rock slope (north side of the highway) and the top of a high talus slope (south side of the highway). Proposed improvements along this interval of the highway include widening to provide a parking/viewing area for Beartooth Falls, which is located across the valley, south of the highway. Widening of the highway and additional roadway width for the parking/viewing area may be possible by making a rock cut along the north side of the highway, a fill wall along the south side of the highway, or a combination of rock cut and fill wall.

The objective of this investigation was to determine the most feasible alternative (cut, fill, or combination) to provide additional roadway width for the Beartooth Falls parking/viewing area. Recommendations for the location of cut and fill walls are included in Section 6.0 of this report to help determine the new highway alignment and location of the parking/viewing area. Recommendations for future investigations required for design of the highway improvements are also included in Section 6.0 of this report.

A previously prepared report (Woodward-Clyde Federal Services, 1998) includes a discussion of the geologic setting and geologic hazards along this and other intervals of the Beartooth Highway. The highway interval described at Site 2 in this previous report, Station 41+600 to 42+000, is the same as the highway interval included in this report.

The current concept for widening the Beartooth Highway and providing for a Beartooth Falls parking/viewing area (based on our discussions with FHWA project personnel) includes a bridge structure to span the ravine located at the west end of the project (west of approximately Station 41+480), a combination rock cut and fill wall to widen the highway (approximately Station 41+480 to 41+930), and a proposed rock cut on both sides of the highway (approximately Station 41+930 to 42+050). The highway stationing shown on Figure 1 is stationing used to describe the scope of work for this project and is approximately located based on stakes observed during mapping.

The proposed bridge structure at the west end of the highway interval would cross the ravine with 3 to 4 spans, supported by abutments at each end and 2 to 3 piers located within the ravine. The bridge would be about 30 meters above the deepest portion of the ravine.

In the area of the Beartooth Falls parking/viewing area the existing roadway width of 5.5 m (18 feet) would be widened to a subgrade width of up to 12.8 m (42 feet) and pavement width of about 9.8 m (32 feet). A combination cut and fill wall is the current concept for this widening. The cut wall, located along the north side of the existing highway, would provide about 2 m of additional width. A cantilevered fill wall, constructed with precast concrete elements on spread footings, would provide the remaining desired highway width, including about 2.5 m of fill between the existing highway pavement and the vertical portion of the fill wall element. Spread footings would be constructed at some depth within the talus deposits along the south side of the highway to form a foundation for the cantilevered fill wall. To help mitigate expected movements in the talus and spread footings before the concrete fill wall elements, back fill, highway subgrade, pavement, etc. are placed, grouting of the talus and post tensioning of the spread footings using ground anchors is envisioned. Ground anchors would be placed through the spread footings and underlying talus deposits and anchored in bedrock and/or talus.

Road widening at the east end of the project would require rock cut slopes constructed along both sides of the existing highway. Existing cut slopes are present on both sides of the highway, and would be cut back to provide additional highway width.

Geologic mapping was conducted using a topographic base map provided by the FHWA (Figure 1) to characterize rock mass conditions in bedrock where rock cuts might be made and conditions in talus where fill walls might be made. The area mapped extended about 100 meters on each side of the existing highway alignment. Results of the mapping are presented on Figure 1. A summary of the rock mass characterization for the bedrock is presented on Table 1. The topographic base map did not extend up station of Station 42+050; however, the relatively flat area between Stations 42+050 and 42+150 was investigated. This area contains a cover of glacial materials similar to those mapped on the adjacent topography near Station 42+000.

Bedrock cropping out at the project consists of granite and granite-gneiss of the Precambrian age Beartooth Block. The granite is medium to coarse grained, relatively strong and hard, and is typically slightly weathered to fresh. The granite-gneiss is also medium to coarse grained, strong and hard, and slightly weathered to fresh, but can be distinguished from the granite because of a typical banded texture formed of alternating light and dark minerals. The rock contains minor amounts of mica schist in banded areas and as xenoliths (fragments of schist incorporated into and surrounded by the granite and granite-gneiss. An estimate of intact rock compressive strength was made during mapping, and is based primarily on the degree of weathering observed in the outcrops (Table 1). An estimate of RQD (rock quality designation) was also made during mapping, and is based on fracture spacing and the number of joint sets present in the outcrops (Table 1).

Bedrock outcrops were divided into 8 areas (areas A to H on Table 1) for purposes of rock mass characterization. Joint sets and a description of these discontinuities are shown on Table 1. Bedrock exposed in areas A, B, F, G, and H can be described as blocky and bedrock in areas C, D, and E can be described as massive. Blocky bedrock often contains three to four joint sets (Figures 2 and 3) oriented roughly normal to each other, with the result that joints isolate and bound blocks of rock within the rock mass. Joint spacing is related to block size in these areas. The massive bedrock exposures typically contain widely spaced joints that are often healed and relatively strong. Most of the slightly weathered rock contains iron oxide stained joint surfaces that are usually planar and slightly rough to rough. All 8 areas of the bedrock contained a joint set interpreted to be the result of exfoliation or stress relief in the bedrock because the joints were oriented parallel to the outcrop surface. The presence of these joints results in "slabs" of rock that have become detached or partially detached from the underlying bedrock and tend to slide out of the bedrock slopes.

Large areas of the topographic base map (Figure 1) were mapped as talus and colluvial deposits. Talus consisted of gravel to large boulder sized fragments of the bedrock that have accumulated on slopes below bedrock outcrops. Portions of the talus deposits consist almost entirely of 1 to 5 m diameter blocks of rock with large voids between the blocks (Figure 4). The colluvial deposits consist of material similar to the talus, but with a sandy matrix between the gravel to large boulder sized rock fragments. Talus and colluvial deposits typically interfinger. In some areas the colluvium appears to cover underlying talus deposits and may have formed due to weathering and soil formation in the top of the talus. In addition, areas were mapped as manmade fill, and consist of material similar to colluvial deposits with a sandy matrix material. The fill is located below and along the existing highway alignment and appears to be relatively thin (less than 2 to 4 m thick), with the exception of an area across the road from and south of area C (Figure 1), where fill up to 15 or 20 m thick was probably placed along the base of the nearly vertical bedrock slope.

A rockfall hazard evaluation was conducted during field investigations using the FHWA Rockfall Hazard Rating System (FHWA, 1993). The bedrock slopes were divided into areas that correspond to the 8 rock mass classification areas (A to H) used for geologic mapping and rockfall hazard was evaluated for each of the 8 areas. Rockfall hazard data sheets for areas A to H are included in Appendix B.

Rockfall hazard scores for the 8 areas ranged from 406 to 620. The highest possible score at each area is1000 (includes 10 categories each with a score up to 100 points). High scores indicate a relatively higher rockfall hazard. Adversely oriented exfoliation or stress relief joints and high cut slopes contribute to these relatively high scores (see Tables B-1 and B-2 in Appendix B for a comparison of scores assigned for the mapped areas and maximum possible scores). It should be noted that areas C, D, and E consist of natural rock slopes, instead of rock cut slopes at the other areas. The natural rock slopes, in general, appear to be stable with little recent rock fall, compared to cut slopes recently made for the highway that contain loosened blocks of rock and raveling colluvial and talus slopes.

A large block of rock was observed above the highway at Station 41+425 that has moved outward and downward about 150-300 mm (6 to 12 inches) from the underlying bedrock. The block is about 15 m high, somewhat tabular in shape, about 15 to 20 m long, and about 5 m thick (Figures 5 and 6). Failure of this large loose block would possibly damage proposed piers for the bridge that will span the ravine located at the west end of the project. Based on our reconnaissance, it appears the movement occurred before the initial road was constructed through this area. We did not observe evidence of recent movement. During final design, consideration should be given to measures to stabilize this block or reduce risk of impact to the road or structures in the event of failure. These measures include creating a berm or ditch, anchoring, or excavation of the block.

Approximately 345 meters of seismic refraction data were collected as part of the initial geotechnical investigation. Five seismic spreads were completed parallel to the highway alignment just outside of the outboard lane and outside the guardrails. The seismic refraction was completed to obtain information on the thickness of overburden materials and the depth and configuration of bedrock. Details of the seismic refraction survey are provided in Appendix A. The locations of the seismic refraction spreads are shown on Figure 1. The geophysical data and interpretation of the subsurface conditions based on the seismic velocities observed are also included in Appendix A.

Seismic refraction data were collected using a 24-channel signal-enhancing seismograph and a geophone spacing of 3 meters (m), resulting in seismic spread lengths of 69 meters. The seismic source used was a sledgehammer impacting an aluminum plate. Although the sledge hammer source appeared to be sufficient for these data, the seismic refraction data collected were noisy and of moderate quality.

Results of the seismic refraction survey indicate a two-layer model of the subsurface. The near-surface seismic layer has a velocity of 340 meters/second (m/s) to 630 m/s and a thickness of 3 m to 6.5 m. The second seismic layer has a velocity of 3,040 m/s to 6,220 m/s. The seismic velocities observed of the lower seismic layer are consistent with slightly weathered to fresh bedrock materials.

6.1 HIGHWAY ALIGNMENT

We recommend that the alignment for the widened highway include a combination of rock cuts along the north side of the existing highway and fill walls built on talus slopes along the south side of the highway. Rock cuts could be used to widen the road by 2 m, with the exception of two intervals. The first interval, from Station 41+450 to 41+550, is located along the nose of a ridge where the highway could be widened approximately 4 m. The second interval, from Station 41+680 to 41+720, is located along the base of a steeply sloping rock outcrop where we recommend a rock cut is not made.

Criteria to be used to select a widened highway alignment would include up to 4 m (horizontal direction) of rock cut from Station 41+450 to 41+550, up to 2 m (horizontal direction) of rock cut from Station 41+550 to 41+680, no rock cut from Station 41+680 to 41+720, and up to 2 m (horizontal direction) of rock cut from Station 41+720 to 41+930. A tapered transition would be required between these rock cut station intervals. The most important interval from a slope stability concern is from Station 41+680 to 41+720 where a rock cut would undercut the toe of exfoliation or stress relief slabs on the 60 m high slope above.

Recommended rock cut slopes of 4:1 (vertical to horizontal) should be used between Stations 41+450 and 41+930. The rock cut slopes will be up to an estimated 8 to 10 m high in intervals where the road is widened up to 2 m, and approximately 15 to 25 m high where the road is widened up to 4 m. Portions of the rock cut slopes located in blocky rock masses, such as areas F, G, and H, are expected to require some spot and/or pattern rock bolting. In areas C and E spot bolting of isolated blocks of rock may be required, with most of the rock cut slope not needing rock bolts.

During mapping a number of joints were found in the general location of the rock cut slopes that could be used when excavating the rock to form a natural looking cut slope face. The joints are widely spaced and have relatively low continuity compared to the length of the rock cut along the highway alignment. The presence of these joints should therefore not be expected at the entire cut slope location to form a natural looking rock cut slope. We recommend that the highway alignment and desired highway widening determine the location of the rock cut slope. During excavation some joint faces may be present close to the rock cut and might be used to form a portion of the cut slope face. These joint surfaces may not have exactly the same strike and dip of the rock cut; however, they could still form a portion of the cut slope face, as long as the overall cut slope angle is maintained.

680 720

The natural rock slope between Stations 41+730 and 41+770, where we recommend no rock cut is made, contains exfoliation joints that dip about 50 to 60 degrees toward the highway and out of the slope (Figure 7). A rock cut slope excavated to widen the highway at this location would remove part of the toe of a slope with large slabs of rock extending higher up the slope. The height of the slope is about 60 m. The current slope appears to be stable; however, we recommend a rock cut not be made at this location because of the risk of destabilizing slabs of rock on the slope above the road.

Widening of the highway from Station 41+930 to 42+050 (Figure 1) includes moving existing rock cut slopes back approximately 3 m along both sides of the existing highway. Rock exposed in the existing cut slopes is blocky and loosened. We recommend 1:1 cut slopes be used in this area and that any loosened blocks encountered be cleaned from the cut slopes during excavation.

6.2 INVESTIGATIONS FOR DESIGN

The following recommendations are made for investigations conducted with the purpose of obtaining information needed for design:

1. Drill holes should be made by coring through talus and colluvial deposits to a minimum depth of 5 to 7 m (confirm bedrock location) into bedrock at each proposed abutment and pier location for the bridge structure located at the west end of the project. Bedrock portions of the drill holes should have oriented core to evaluate the potential for adversely dipping joints in the bedrock (stress relief and exfoliation joints with the foundation bedrock).
2. Detailed geologic mapping of discontinuities in the rock mass should be conducted in areas where relatively high (15 m high) proposed rock cut slopes are planned near the west end of the portion of the alignment, near areas F, G, and H. The mapping should be conducted on plan view and front view maps of the existing bedrock exposures and rock cuts. The information would be used for rock cut slope design and rock bolt stabilization design.
3. Drill holes should be made along the proposed foundation for the fill walls to confirm the depth of and characterize the material within the talus and colluvium. The drill holes should be extended into bedrock to provide information for design of ground anchors for post tensioning the spread footing foundation.
4. Additional seismic refraction surveys should be conducted at selected locations to tie information from drill holes together. The locations of the seismic refraction locations will be appropriate along the alignment of the fill wall, and at other selected locations where drilling will be difficult. Depending on the final layout of highway improvements, and the resulting locations for seismic refraction data collection, a more substantial seismic source than a sledgehammer may be required.
5. A laboratory testing program should be developed to measure properties of samples obtained from the above drill holes.

6.3 DESIGN

Recommendations for design include the following:

1. Stability analyses should be conducted as part of design of rock cut slopes in blocky rock mass areas to provide final cut slope angles and geometry, and if needed design rock cut slope stabilization alternatives such as rock bolting.
2. Stability analyses should be conducted as part of design for spread footings and fill wall structures. Based on observations of the talus during geologic mapping, we expect that relatively large movements (possibly up to about 1 m of movement) could occur during grouting and post tensioning of the spread footings. The movements are expected because of a possible mode of failure in the steep (near the angle of repose) talus slopes related to large blocks of rock with large void spaces between them. Movement in the talus may occur during grouting due to pressure developing along the blocks, wetting of fine grained matrix materials, and lubrication of point to point contacts between blocks of rock. Loading the talus slopes would in general be expected to produce a wide range in the magnitude of movement below and adjacent to the fill wall foundation. For example, in some areas the talus slope becomes locally very steep to almost vertical for heights of 5 to 7 m where large

blocks have prevented other talus from accumulating on the slope below. If the large blocks should topple or slide down the slope they would act as a "key stone" and start a progressive movement in the talus up slope of the block, and possibly result in relatively large movements in the talus below the spread footing. Stability analyses would be useful in estimating the design depth of the foundation in the talus, magnitude of expected movements for design of ground anchors, etc.

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Federal Highway Administration (FHWA), 1993. Rockfall Hazard Rating System, National Highway Institute (NHI) Course No. 130220. Prepared by the U.S. Department of Transportation, Federal Highway Administration Publication No. FHWA SA-93-057.

URS Greiner Woodward Clyde Federal Services, 1998. Initial Geohazards Evaluation and Geologic Study: Beartooth Highway, U.S. 212, Wyoming. Prepared for Department of Transportation, Federal Highway Administration, Central Federal Lands Highway Division, Lakewood, Colorado.

Table 1
ROCK MASS CHARACTERIZATION

Rockmass Area (Shown on Figure 1)	Rock Type	Rock Weathering	Estimated Intact Rock Compressive Strength (MPa)	Estimated RQD	Joint Set Orientation			Spacing (M)	Continuity (M)	Aperture	Infilling		Roughness	Surface Shape
					No.	Strike	Dip				Type	Amount		
A	Granite	SW	25-100	25-75	1	N70E	50NW	0.1-1	1-3	T-N	Fe	Su	SR	PL
					2	65SE	65SE	0.1-1	1-4	T-N	Fe	Su	SR-R	PL
					3	N30W	90	0.3-3	1-4	T-MW	Fe	Su	SR-R	PL
B	Granite	SW	25-100	25-75	1	N50E	50SE	0.3-1.5	5-10	N-W	Fe	Su	SR-R	PL
					2	N55E	60NW	0.1-1	5-7	T-N	Fe	Su	SR	PL
					3	N35W	80SW	0.2-2	2-7	N-W	Fe	Su	SR	PL
					4	N10E	70SE	0.5-1	2-4	T-MW	Fe	Su	SR	PL
C	Granite Gneiss	SW-F	100-200	75-100	1	N70E	90	0.5-8	3-20	T-N	H	Fi	R	PL-Wa
					2	N30W	80SE	1-2	2-7	T-N	H	Fi	R	PL-Wa
					3	N70E	10SE	2-5	3-20	T-N	H	Fi	R	PL-Wa
					4	Random		--	3-20	T-N	H	Fi	R	PL-Wa
D	Granite Gneiss	SW-F	100-200	75-100	1	N60E	50SE	2-10	4-30	T-W	H-Mn	Fi-Su	R	PL-Wa
					2	N35W	90	0.3-4	2-10	T-W	H-Fe	Fi-Sp	SR-R	PL-Wa
					3	N70E	80NW	0.3-4	4-10	T-N	H-Fe	Fi-Sp	R	PL-Wa
					4	Random		--	4-20	T-W	H-Mn	Fi-Sp	R	PL-Wa
E	Granite Gneiss	SW-F	100-200	75-100	1	E-W	65SW	0.5-4	2-25	T-W	Fe-Mn	Su-Sp	R	PL-Wa
					2	N30E	90	0.5-7	4-40	T-W	Fe-Mn	Fi-Su	R	PL
					3	N30W	75NE	4-10	2-8	T-W	Fe	Su	R	PL
					4	N40E	50NW	0.3-1	2-4	T-N	Fe	Su	SR-R	PL
					5	N70E	90	4-10	4-8	T-N	H-Mn	Fi-Sp	R	PL-Wa
					6	Random		--	4-20	T-N	H-Mn	Fi-Su	R	PL-Wa
F	Granite Gneiss	SW	25-100	50-75	1	N30E	20NW	0.2-1	2-15	N-MW	Fe	Su	SR-R	PL
					2	N60E	70SE	0.5-4	4-10	T-MW	Fe	Su	SR-R	PL
					3	N70E	45SE	1-4	2-7	T-MW	Fe	Su	SR-R	PL
					4	N30W	90	1-7	2-8	T-MW	Fe	Su	SR-R	PL
					5	Random		--	2-10	T-MW	Fe	Su	SR-R	PL-Wa
G	Granite Gneiss	SW-MW	10-100	25-50	1	N25E	60NW	0.1-1	2-15	N-W	Fe	Su	SR-R	PL
					2	N30W	90	1-7	2-10	N-W	Fe	Su	SR	PL
					3	N70E	40SE	1-7	1-8	N-W	Fe	Su	SR	PL
					4	Random		--	2-10	N-W	Fe	Su	SR-R	PL-Wa
H	Granite Gneiss	SW-MW	10-100	25-50	1	N20W	30SW	0.1-1	2-15	N-W	Fe	Su-Sp	SR-R	PL-Wa
					2	N60E	90	2-4	4-20	N-W	Fe	Su-Sp	SR	PL
					3	N70E	45NW	0.1-0.8	2-4	N-W	Fe	Su-Sp	SR-R	PL
					4	Random		--	2-15	N-W	Fe	Su-Sp	SR-R	PL-Wa

Table 1
ROCK MASS CHARACTERIZATION

LEGEND

ROCK WEATHERING

F	Fresh or unweathered, rock shows no discoloration, loss of strength, or other effect of weathering or alteration.
SW	Slightly weathered, rock is discolored, typically iron staining on joint surfaces, not noticeably lower in strength than fresh rock.
MW	Moderately weathered, rock is discolored into rock fabric and noticeably weakened, 2-inch-diameter sample cannot be broken by hand.

JOINT APERTURE (mm)

T	Tight (0)
N	Narrow (1-2)
MW	Moderately Wide (2-10)
W	Wide (>10)

JOINT INFILLING TYPE

Fe	Iron Oxide
H	Healed
Mn	Manganese Oxide

JOINT INFILLING AMOUNT

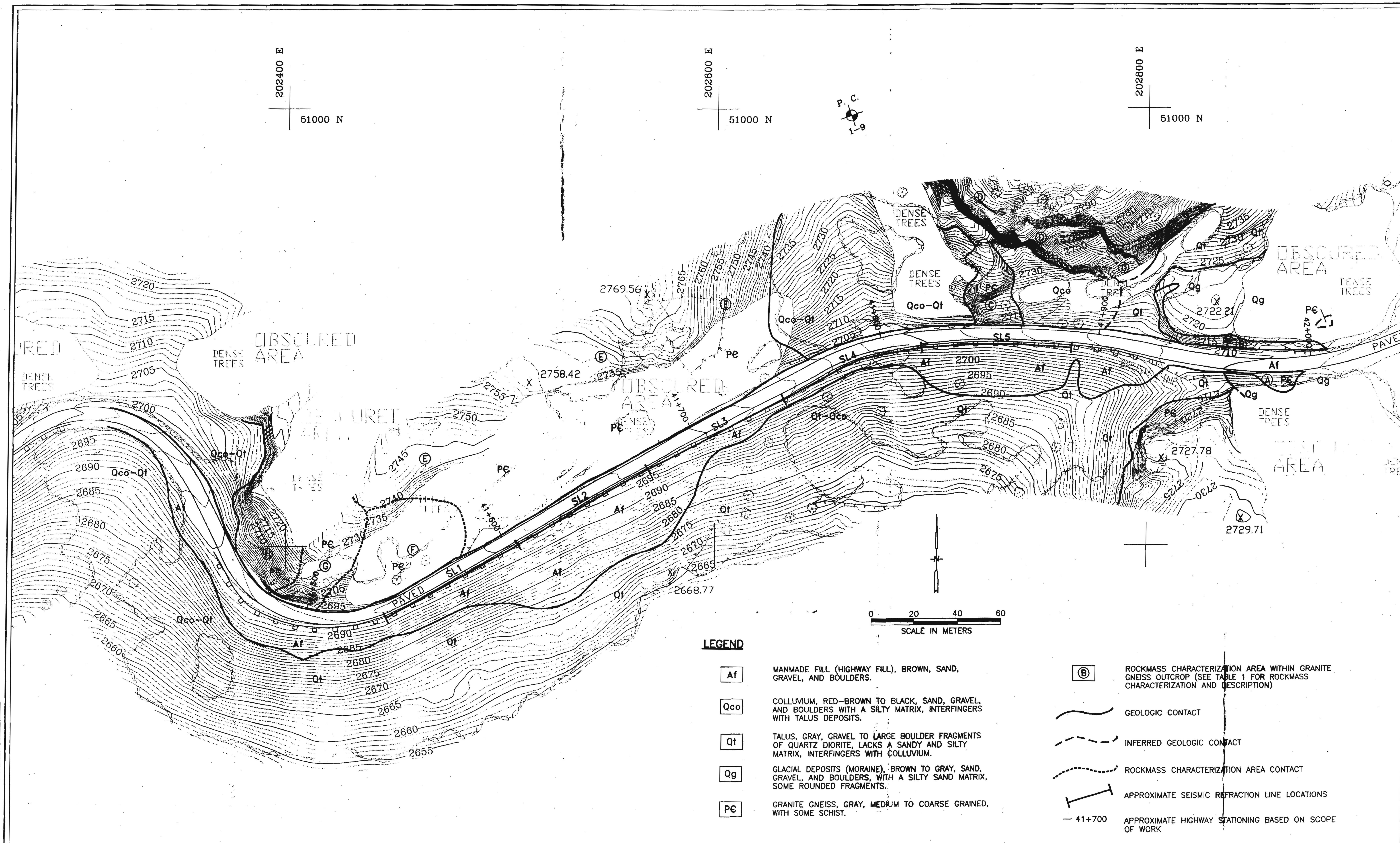
Su	Surface Stain
Sp	Spotty
Fi	Filled

JOINT SURFACE ROUGHNESS

SR	Slightly Rough - small asperities on surface feel like silt to fine sand.
R	Rough - asperities are visible and feel like sand.

JOINT SURFACE SHAPE

PL	Planar
Wa	Wavy



REV	DESCRIPTION OF REVISION	BY	DATE

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WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

DESIGNED: D.M.B.
DRAWN: R.A.M.
CHECKED:
PEER REVIEWED:
PROJECT MANAGER:
DATE: 10/1/99

BEARTOOTH HIGHWAY — PARK COUNTY, WY

BEARTOOTH HIGHWAY LOCATION AND GEOLOGIC MAP

REVISION 0
PROJECT 68FHAT0022
DRAWING 1
SHEET 1 OF 1

FILE # AT002207 — SCALE 1:1 — LOC. DENVER — DATE 10/1/99 — PROJ. # 68FHAT0022 — TASK #

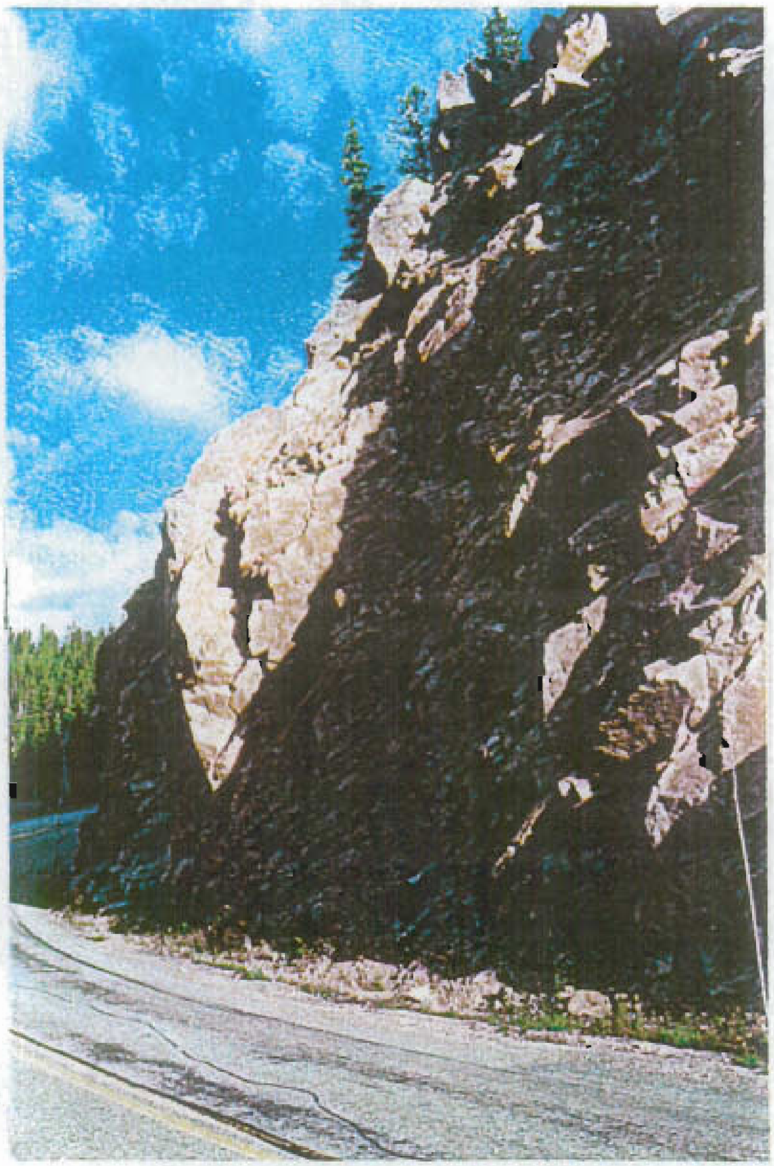


Figure 2. Blocky and Loosened Rock Mass at Station 41+520, Area F

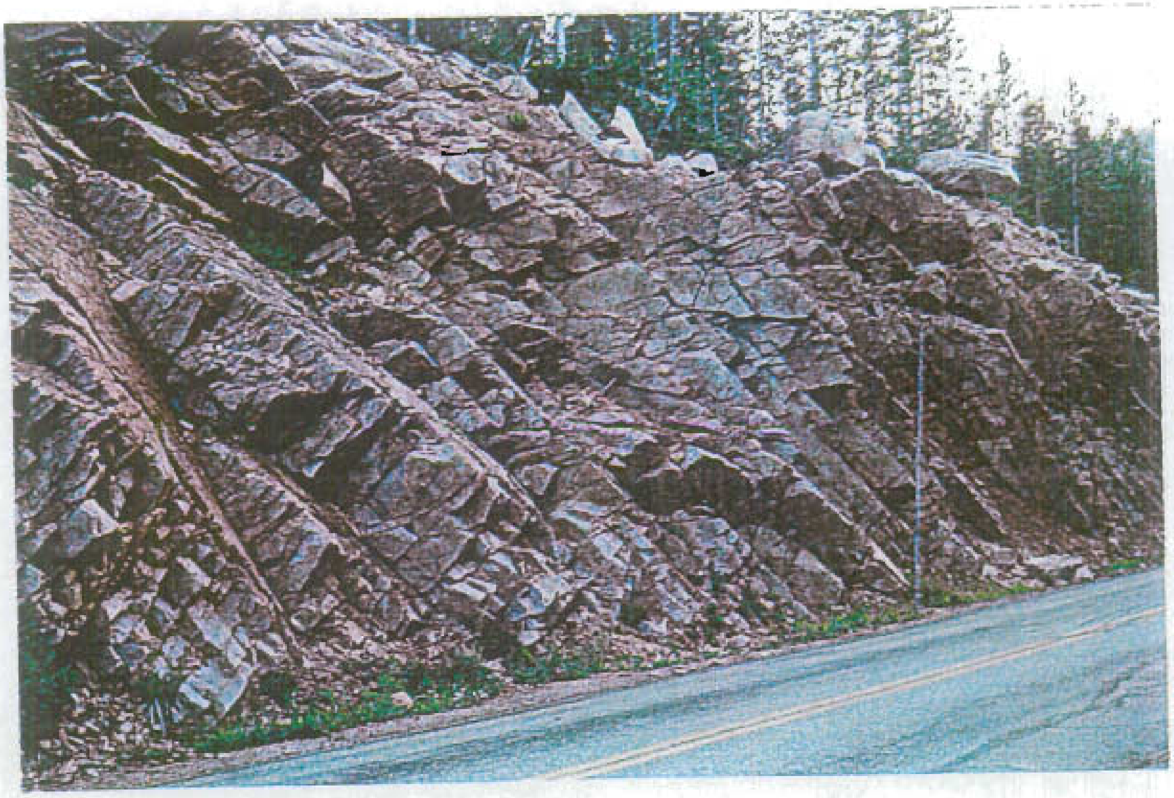


Figure 3. Blocky Rock Mass at Station 41+950, Area B

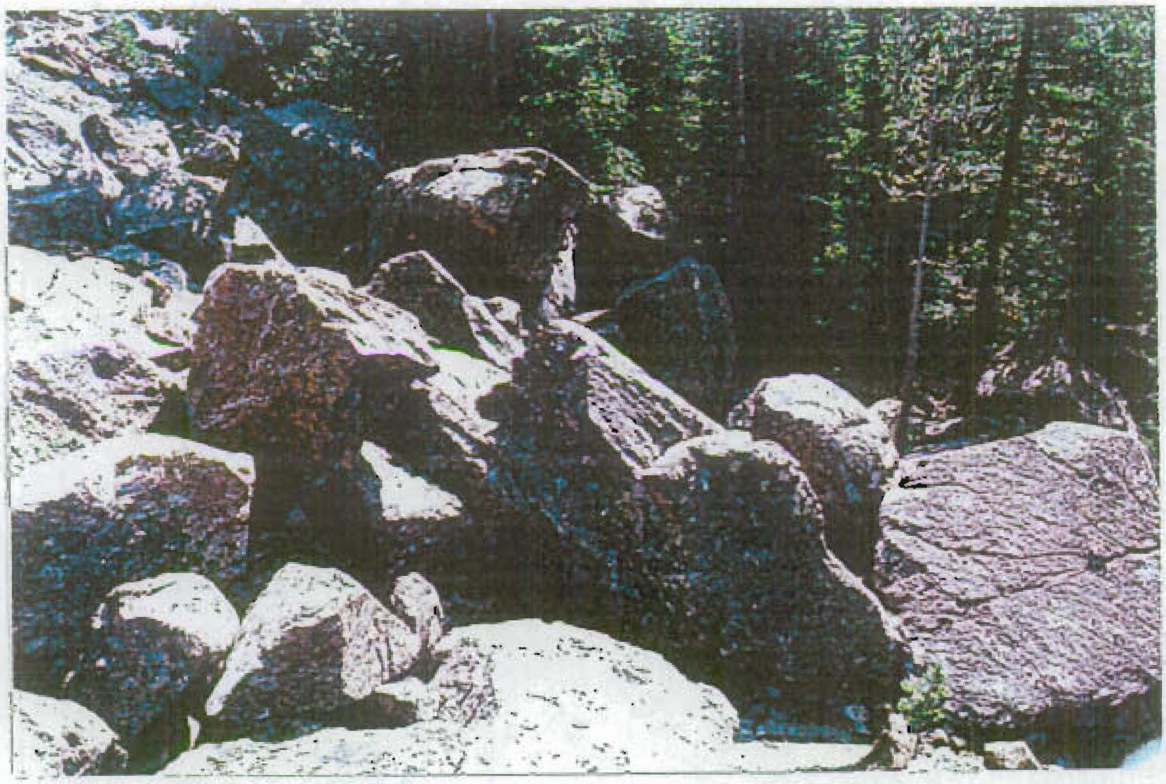


Figure 4. Large Talus Blocks Below Highway, Station 41+720

Figure 5. Large Loose Rock Block at Top of Slope at Station 41+425, Area H

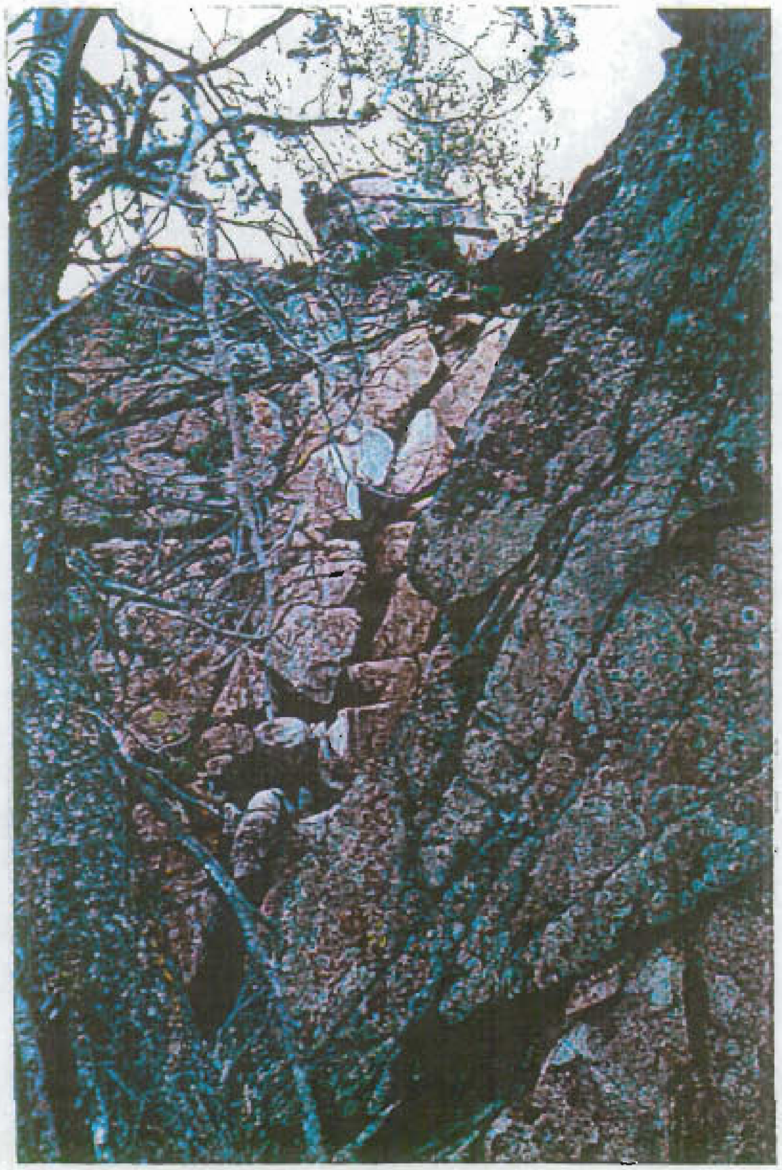


Figure 6. Open Joint and Movement of Large Rock Block at Station 41+425, Area H

Figure 7. Rock Slope at Stations 41+730 to 41+770, Area E

Appendix A
Seismic Refraction Surveys

Appendix A
Seismic Refraction Surveys

A.1 INTRODUCTION

Geophysical techniques were utilized as part of an initial geotechnical evaluation for proposed improvements along a section of the Beartooth Highway. The objectives of the geophysical survey were to:

- obtain seismic velocity information to facilitate estimation of the subsurface excavatability,
- estimate overburden thickness, and
- aid characterization of the bedrock surface.

This information was sought in selected areas along the length of a proposed retaining wall location as part of the highway improvements. The geophysical method used to accomplish the above was seismic refraction.

A.2 SEISMIC REFRACTION METHOD

Seismic refraction for engineering applications is most often used to infer geological boundaries as indicated by interfaces with seismic velocity contrasts. Seismic refraction data may be used to characterize:

- The thickness of alluvial or colluvial deposits, or weathered rock
- The depth to the water table and/or competent subsurface layers
- The configuration of the alluvial-bedrock contact
- Relative excavatability (inferred from seismic velocities)

The seismic refraction method consists of transmitting seismic energy into the ground and recording the arrival of direct or refracted sound waves at various distances along the earth's surface. The seismic energy travels within geologic units with a characteristic compressional seismic velocity that is dependent on the density, compressibility, porosity, and fluid content of the geologic layer. The seismic refraction method analyzes the first arrival times of the seismic compression wave (p-wave) versus distance from the source. This analysis is based on Snell's Law which predicts the behavior of a seismic raypath at a geologic interface. By measuring seismic velocities, as inferred from the recorded first-arrival travel times, and by determining seismic velocity contrasts, an interpretation can be made of the configuration and depths of subsurface seismic layers, which often infers or correlates to geologic units. A schematic of the method is shown in Figure A-1.

To record seismic refraction data, a seismic source, cables, geophones, and a seismograph are required. The seismic source may be a sledge hammer, buried explosives or an elastic wave generator, depending on the depth of investigation and attenuation properties of the near-surface material. Geophones implanted in the ground translate vibrations into an electrical signal displayed on the seismograph. The seismic record (seismogram) is a plot of the seismic data with response amplitude versus time recorded. Data can be output on hard copy records and/or saved on personal computer (PC)-compatible disks.

A minimum of three seismic sources are usually used for each seismic refraction setup or spread, one source on each end of the spread, and one in the middle. If the target layer is likely overlain by a relatively thick overburden, offset shots must be used to ensure that sufficient coverage of the target layer is made. However, the use of offset sources can be problematic if topographic or other physical constraints exist in the investigation area.

One limitation of the refraction method involves the primary assumption made in refraction interpretation that the seismic velocity of the subsurface increases with depth. If the velocity of a layer is less than that of the layer immediately overlying it, the observed travel time due to the deeper layer will be slower and not easily measured, yielding a first-arrival travel time of the faster layer. A decrease in velocity with depth can cause layers to be hidden or undetected and shadowed by shallower, faster layers, thus leading to depth estimates that may be in error.

Another limitation of the method is that a target layer must be sufficiently thick to be detected. The thickness required depends on the layer depth, the velocity contrast with overlying and underlying layers, and the field parameters utilized during data acquisition and recording. Additionally, the degree of subsurface weathering can make the interpretation of discrete seismic interfaces more difficult.

In some instances, the seismic refraction method is limited solely by physics. That is, the target geometry can be such that refracted raypaths to a target structure are either limited, or non-existent. For example, consider the scenario of a steep-walled narrow valley (on the order of 100 feet wide) and a deep incised channel resulting in a fluctuating, but very deep (on the order of 150 to 200 feet), bedrock surface. Considering the completion of a refraction line in light of this scenario, and also considering Figure A-1, one can imagine that the geometry of the canyon would limit the availability of seismic refraction raypaths to penetrate to the bedrock, resulting in failure to resolve or characterize such a target. Refractions could still occur but would be from shallower layers, and not from the desired bedrock interface.

Data collected can be processed and analyzed with one of several interactive seismic refraction interpretation packages. These packages, which operate on a PC, make all necessary topographic corrections, construct time-distance plots, allow calculation of apparent layer velocities, and calculate depths at each geophone location. From the seismogram, the arrival time of the compression wave for each geophone is selected and plotted versus the distance of each geophone from the seismic source, commonly denoted a time-distance plot. Analysis of the time-distance plot allows calculation of seismic compression wave velocity of the subsurface material(s), or several velocities for multiple layers if they are present. Application of Snell's Law governing the angle of refraction at an interface between layers with different seismic velocities permits calculation of upper layer thicknesses. From the analyses and results, a cross-section of the seismic layers is produced. Cross-sections from individual seismic spreads can be tied to available geologic or geophysical borehole information, as well as to other seismic spreads, to make a final geologic interpretation of the surveyed area.

A.3 FIELD PROGRAM

Five seismic refraction lines (denoted SL1 through SL5) were completed during the field program totaling approximately 345 linear meters. The final locations of the geophysical activities were chosen based on the project objectives and to maximize coverage along a proposed retaining wall. Final locations of the seismic refraction lines are shown in Plate 1.

Seismic refraction data were collected using a 24-channel, signal-enhancing, Geometrics Strataview Model R24 seismograph. A geophone spacing of 3 meters was used on all lines resulting in seismic spread lengths of 69 meters. Seismic sources were used at both ends of each spread for forward and reverse travel times and at locations within each spread to increase near-surface velocity control. On most of the seismic lines, offset seismic source locations were used to enhance coverage of the bedrock surface. For each seismic source, seismic energy was produced by a sledgehammer impacting an aluminum plate. Each seismic spread had four or five seismic sources.

Because the anticipated bedrock depths were less than 12 meters, the sledgehammer provided sufficient energy as a seismic source. Since the seismic lines were conducted adjacent to the highway, data were collected at times in which traffic was not present to minimize the seismic noise. However, because the overburden material was attenuative for the propagation of seismic waves, multiple sledgehammer blows were required and stacked together for each record. Overall, the seismic refraction data were of moderate to good quality using the sledgehammer.

A.4 DATA PROCESSING AND INTERPRETATION

Processing of the seismic refraction data involved the construction of a time-distance plot for each seismic spread. To construct the time-distance plots, the first compressional wave arrival at each geophone location was plotted versus the source-to-geophone distance. Velocities of the seismic layers were calculated based on the slope of the best-fit lines through the plotted compressional-wave time-distance data. The intercept of each velocity slope at time zero was used to calculate depths to particular seismic interfaces.

Interpretation of refraction survey data involved the computation of average velocities over surveyed volumes of subsurface material. For the upper seismic layer in which the direct seismic wave arrived at the geophone first, the velocity observed was the true average velocity between the energy source and the geophone. For deeper interfaces in which the refracted seismic wave arrived at the geophone first, the velocity observed is usually an apparent velocity. If the refractor surface is flat-lying, the apparent velocity will be equal to the true average velocity. If, however, the refractor surface is dipping or has a variable surface, the true average velocity can be estimated utilizing the apparent velocities obtained from the data collected form both the forward and reverse seismic energy sources.

Time-distance plots were constructed and interpreted using the software program GREMIX, an interactive seismic-refraction processing routine developed by Interpex Limited. GREMIX allowed interactive plotting of each travel time plot, selection of velocity slopes, and identifications of forward and reverse shot pairs. With elevation information from each geophone, the program calculated seismic layer thicknesses for each geophone travel time. Final interpretations are displayed for each seismic line in cross-section form in Figures A-2 through A-6.

Each of the seismic refraction plots display three panels. The top panel displays a plot of the arrival time data and is the p-wave arrival at each geophone versus distance along the seismic spread. The middle panel, which is the depth section, is the interpreted subsurface model based on the input arrival time data. The lower panel, which is the velocity section, displays the seismic velocities associated with the interpreted depth section. The depth and velocity sections are plotted in terms of seismic layers, which represent the interfaces at which a distinct velocity contrast is interpreted to exist. These seismic layer interfaces often relate to geologic boundaries as well, depending on the seismic velocity contrast observed in the geologic section. Note that distances portrayed in the plotted panels are slope distances. Table A-1 summarizes the seismic refraction results.

A.5 GEOPHYSICAL RESULTS

The travel time data, resulting cross sections and seismic velocities are plotted for the seismic profiles in Figures A-2 through A-6.

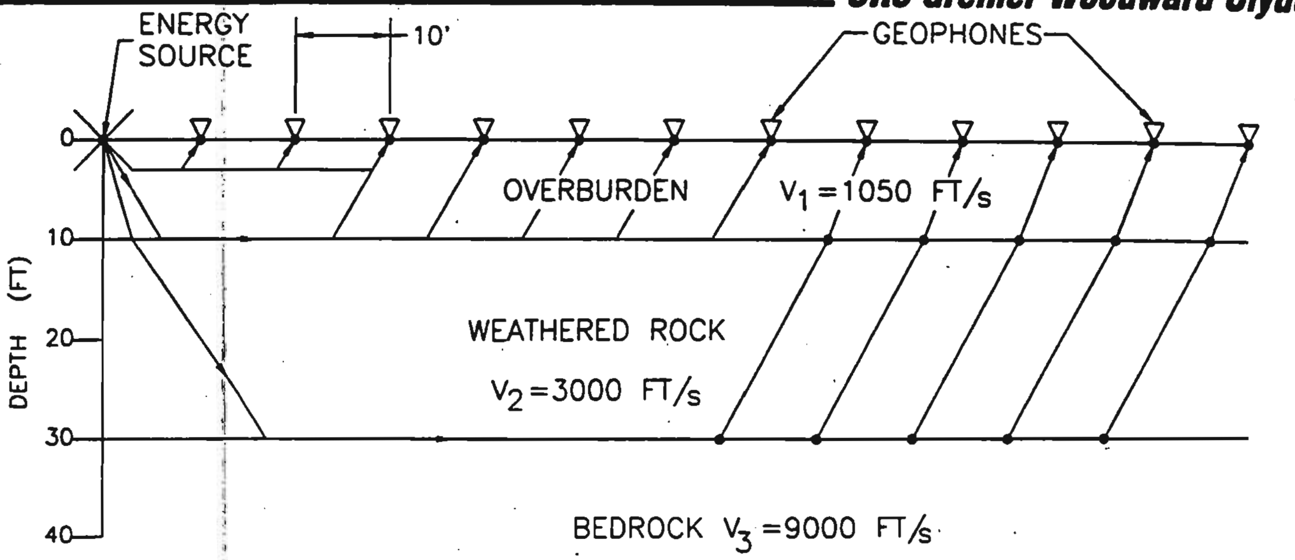
All of the seismic refraction lines indicate a two-layer model of the subsurface. The near-surface seismic layer has a seismic velocity ranging from 340 meters/second (m/s) to 630 m/s. The thickness of the near-surface seismic layer varies 3 meters to a maximum of about 6.5 meters.

The refractor layer has a seismic velocity ranging from 3,040 m/s to 6,220 m/s. Based on the relatively high seismic velocities observed, the refractor unit likely varies from slightly weathered to non-weathered high-strength bedrock materials.

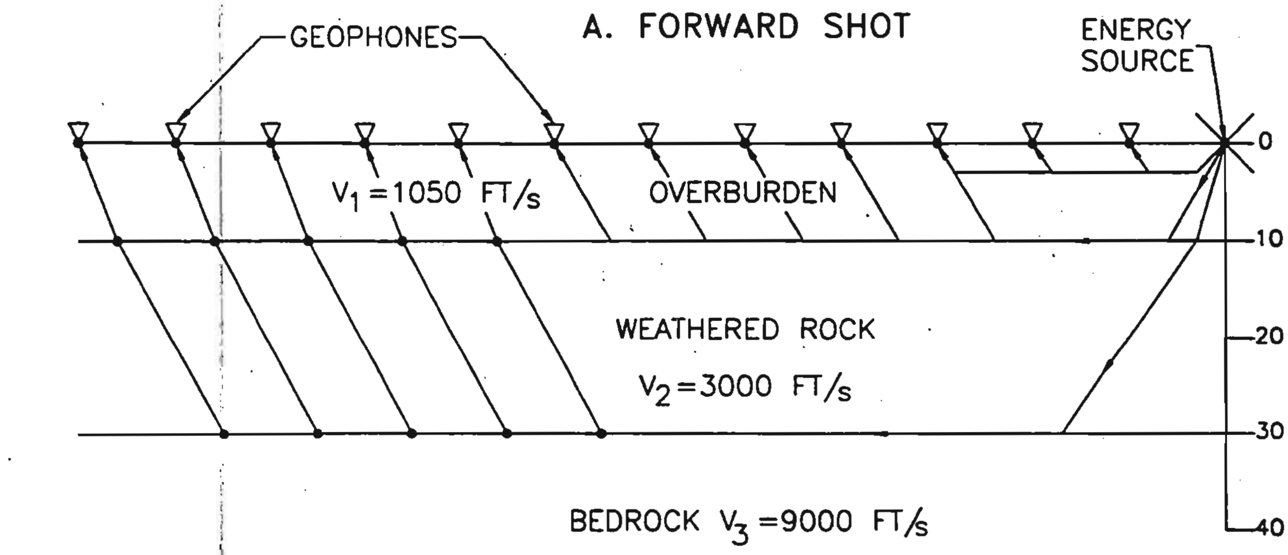
Table A-1

Seismic Refraction Results

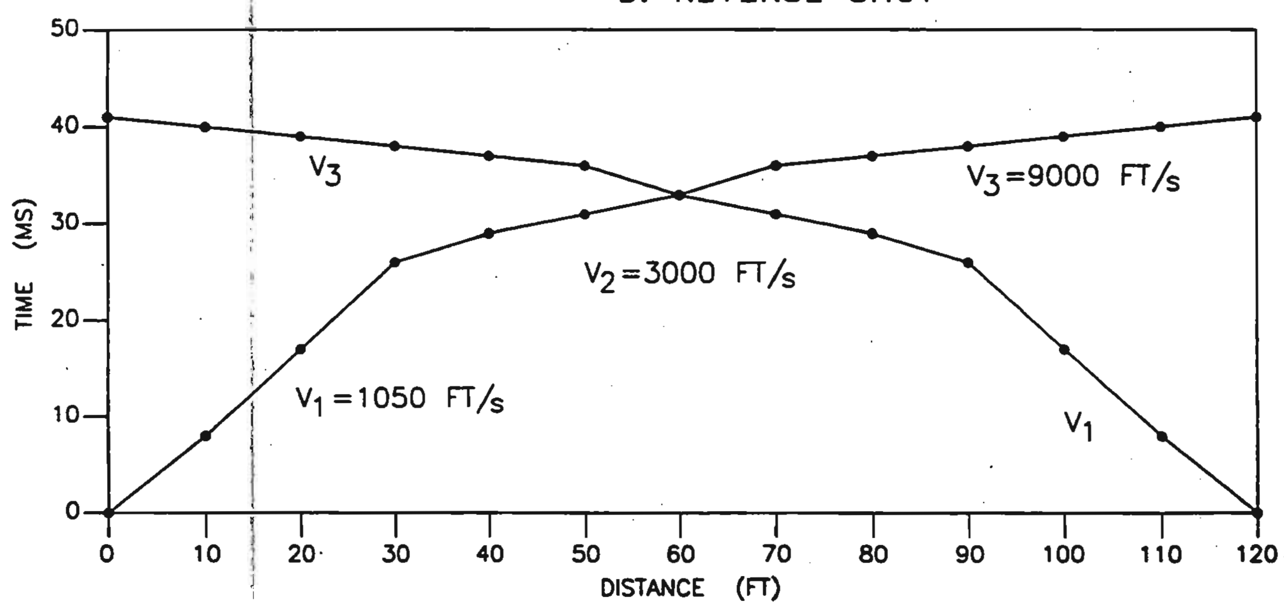
Seismic Line	Seismic Layer	Velocity Range (meters/second)	Thickness of Seismic Layer (meters)
SL1	1	340 – 360	3 – 5.5
	2	4930 – 5360	
SL2	1	350 – 400	5 – 8
	2	3770 – 4290	
SL3	1	360 – 450	6 – 8
	2	3040 – 4420	
SL4	1	350 – 630	5 – 9
	2	4910 – 5670	
SL5	1	340 – 380	4.5 – 6.5
	2	5200 – 6220	



A. FORWARD SHOT



B. REVERSE SHOT

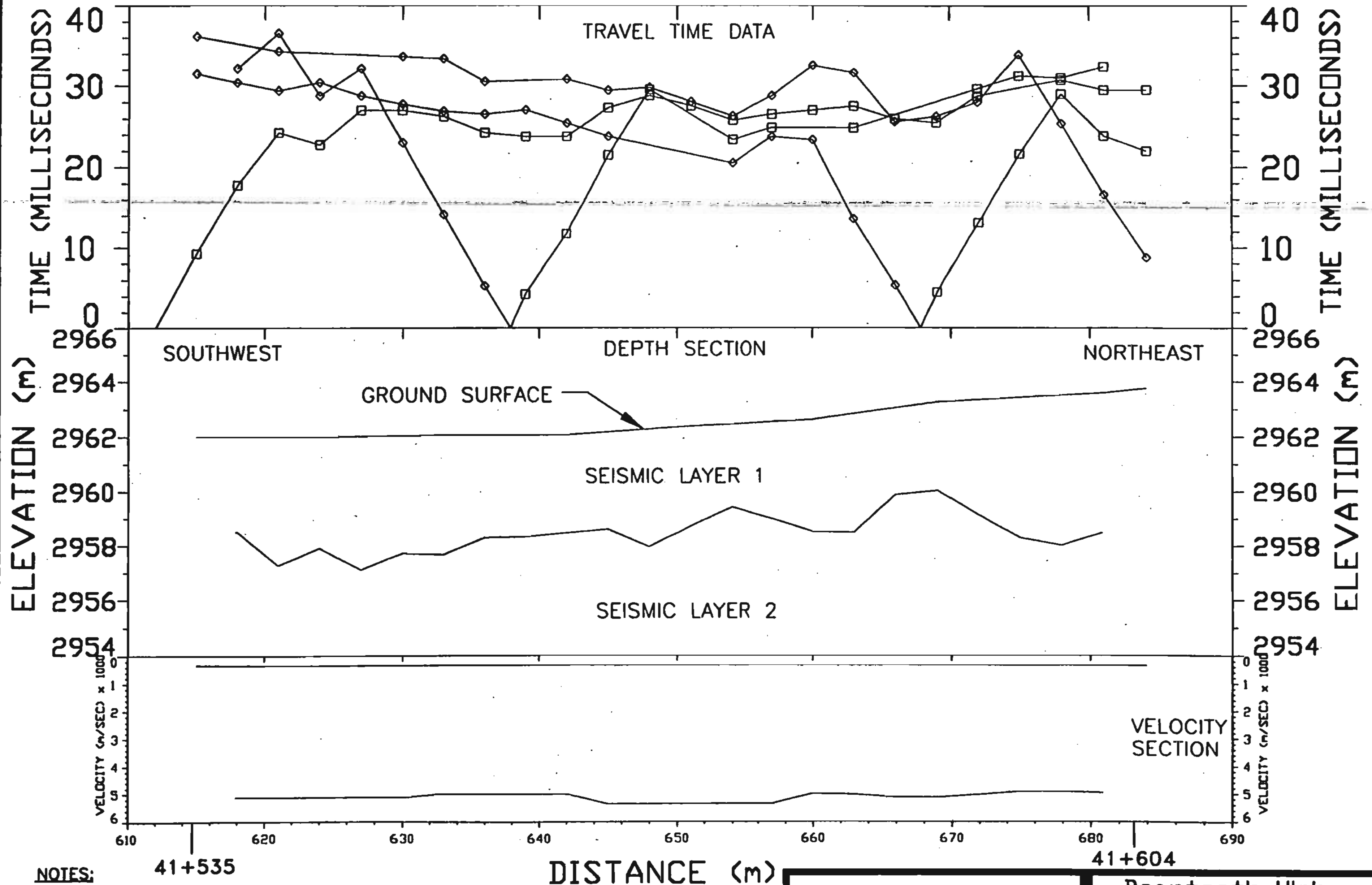


C. TIME–DISTANCE PLOT OF FORWARD AND REVERSE SHOTS

Job No. : 68FHAT0022	AN EXAMPLE OF THE SEISMIC REFRACTION METHOD
Prepared by : J.J.N.	
Date : 9/28/99	

FIG. A–1

at002201



NOTES:

1. ELEVATION ASSUMED AS 2692M AT STA. 41+615.
2. STATIONING USED CORRESPONDS TO THAT STAKED IN FIELD FOR MAINTENANCE.
3. STATIONING IDENTIFIED IN BOLD PER SCOPE OF WORK.

for: Project No. 68FHAT002200	
by: URS Greiner Woodward Clyde	
Data SetSL1	Date: Sept. '99
SCALE 1:400	Spread: SL1

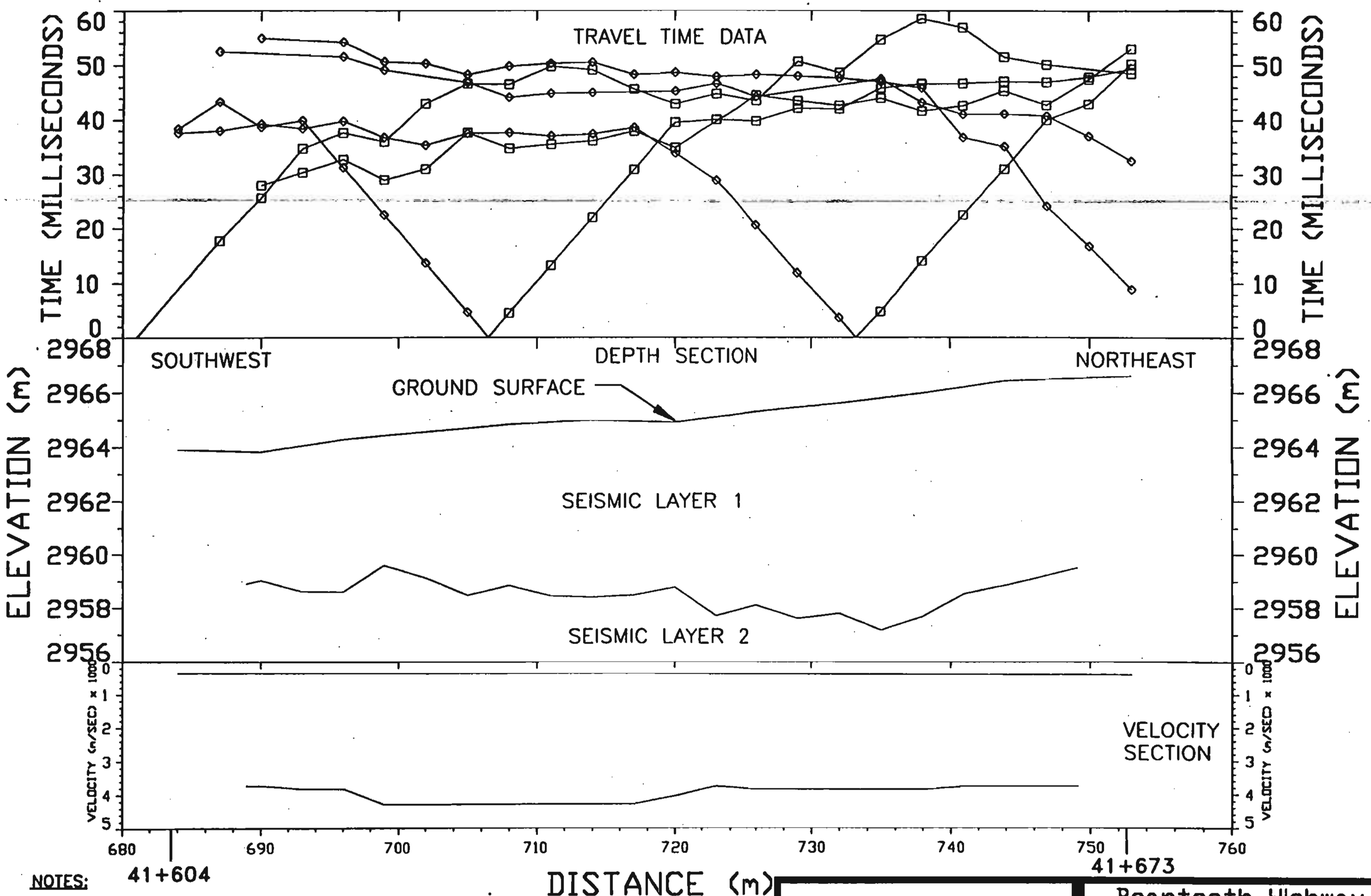
Beartooth Highway

Retaining Wall

Stationing 41+615 to 41+684

Figure A-2

AT022202

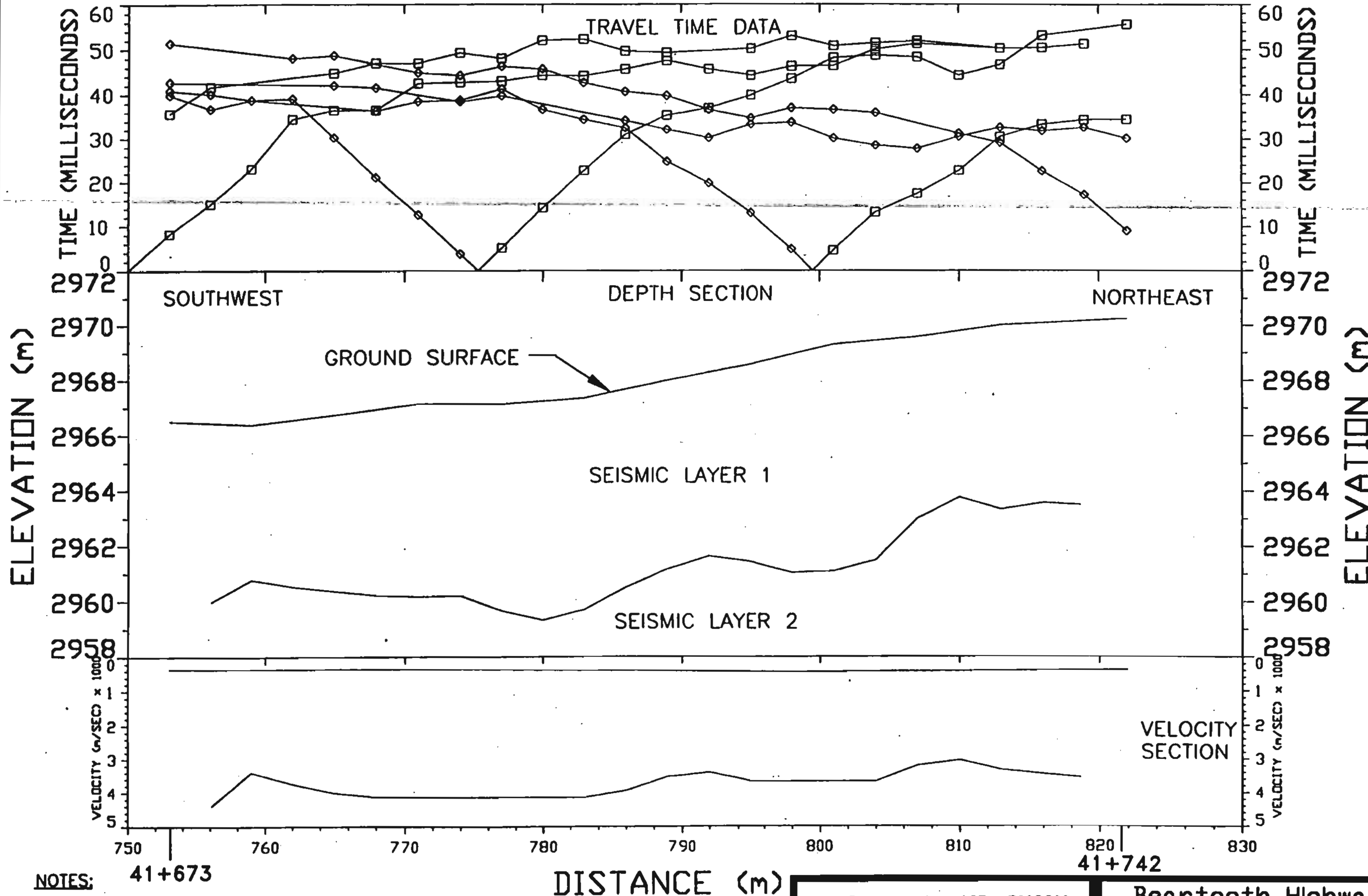


NOTES:

1. ELEVATION ASSUMED AS 2692M AT STA. 41+615.
2. STATIONING USED CORRESPONDS TO THAT STAKED IN FIELD FOR MAINTENANCE.
3. STATIONING IDENTIFIED IN BOLD PER SCOPE OF WORK.

for: Project No. 68FHAT002200		Beartooth Highway
by: URS Greiner Woodward Clyde		Retaining Wall Stationing 41+684 to 41+753
Data SetSL2	Date: Sept. '99	
SCALE 1:400	Spread: SL2	Figure A-3

AT002203



NOTES:

1. ELEVATION ASSUMED AS 2692M AT STA. 41+615.
2. STATIONING USED CORRESPONDS TO THAT STAKED IN FIELD FOR MAINTENANCE.
3. STATIONING IDENTIFIED IN BOLD PER SCOPE OF WORK.

for: Project No. 68FHAT002200	
by: URS Greiner Woodward Clyde	
Data SetSL3	Date: Sept. '99
SCALE 1:400	Spread: SL3

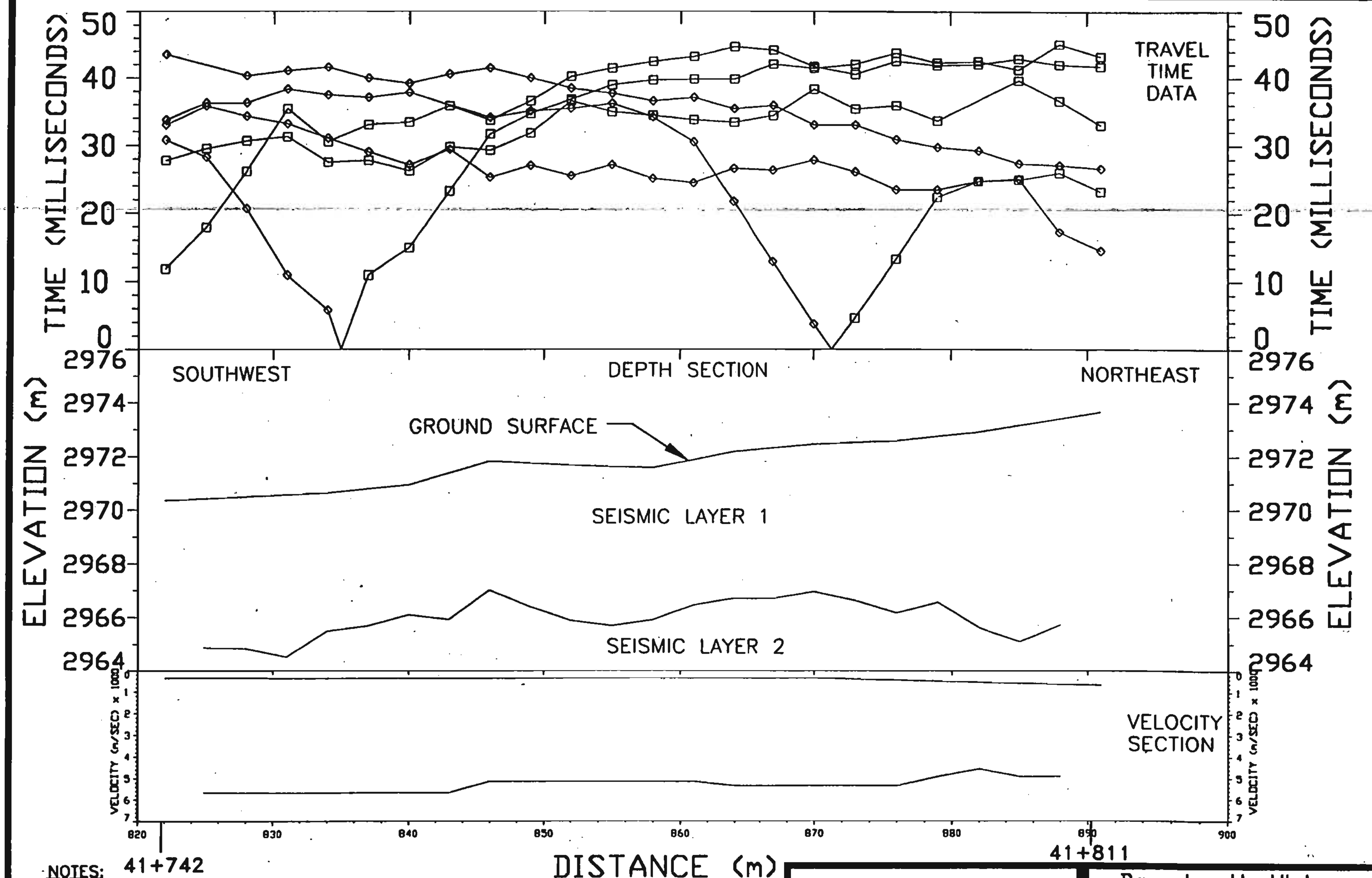
Beartooth Highway

Retaining Wall

Stationing 41+753 to 41+822

Figure A-4

AT002204

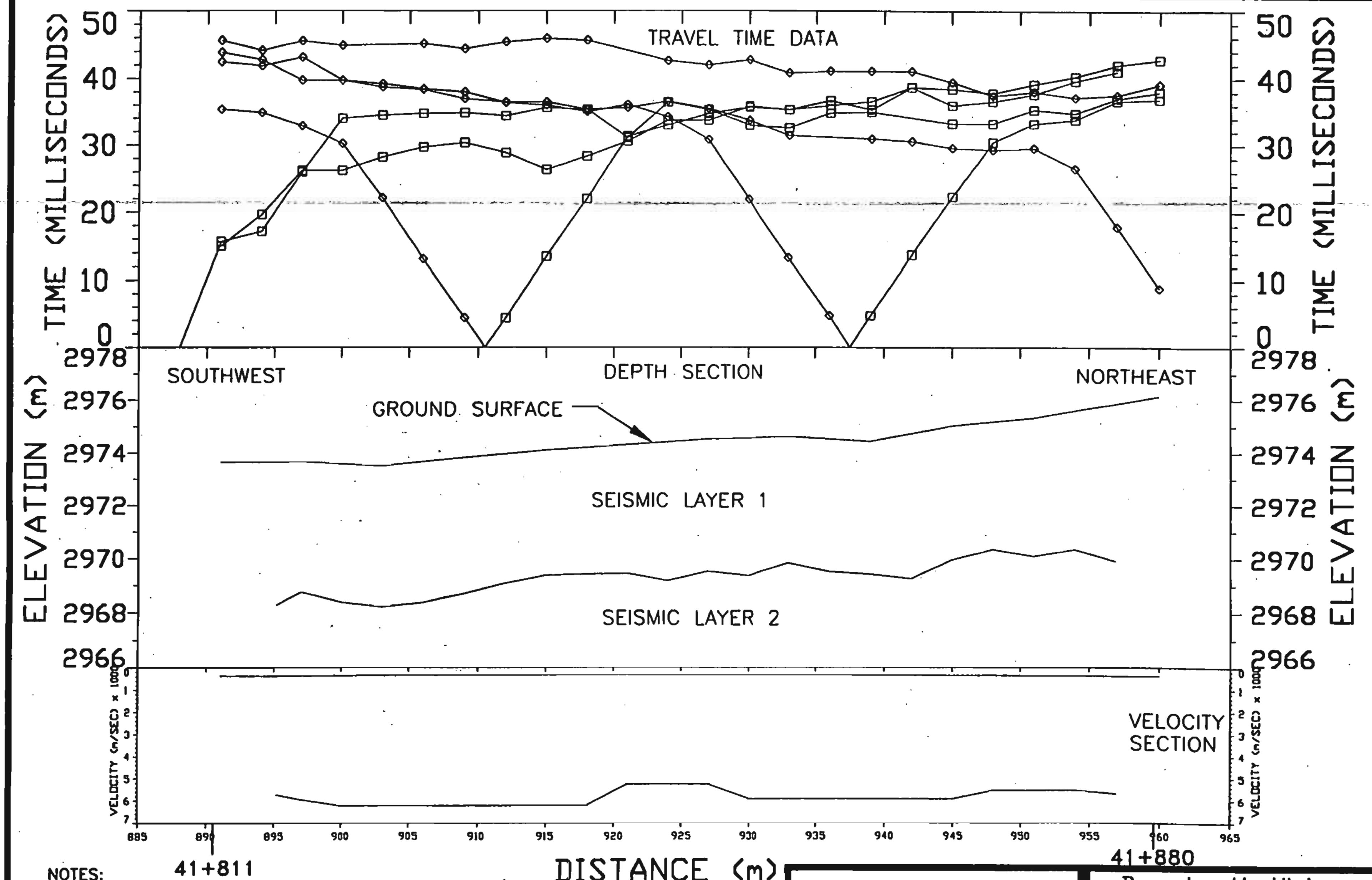


NOTES:

1. ELEVATION ASSUMED AS 2692M AT STA. 41+615.
2. STATIONING USED CORRESPONDS TO THAT STAKED IN FIELD FOR MAINTENANCE.
3. STATIONING IDENTIFIED IN BOLD PER SCOPE OF WORK.

for: Project No. 68FHAT002200		Beartooth Highway
by: URS Greiner Woodward Clyde		Retaining Wall Stationing 41+822 to 41+891
Data SetSL4	Date: Sept. '99	
SCALE 1:400	Spread: SL4	Figure A-5

AT002205



NOTES:

1. ELEVATION ASSUMED AS 2692M AT STA. 41+615.
2. STATIONING USED CORRESPONDS TO THAT STAKED IN FIELD FOR MAINTENANCE.
3. STATIONING IDENTIFIED IN BOLD PER SCOPE OF WORK.

for: Project No. 68FHAT002200	
by: URS Greiner Woodward Clyde	
Data SetSL5	Date: Sept. '99
SCALE 1:400	Spread: SL5

Beartooth Highway

Retaining Wall

Stationing 41+891 TO 41+960

Figure A-6

AT002206

Appendix B
Rockfall Hazard Data

Appendix B
Rockfall Hazard Data

RHRS FIELD DATA SHEET

HIGHWAY: Beartooth Highway REGION:

HIGHWAY # 212	Beginning M.P. (A)	L / (R)	Ending M.P.
COUNTY #	DATE 8/31/99	(NEW)	Rated By KSP / DMB
CLASS A B	ADT 600	UPDATE	Speed Limit 35 mph

CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height 15 ft		SLOPE HEIGHT	2
Ditch Effectiveness G M L (N)		DITCH EFFECT	81
Average Vehicle Risk / %		AVR	1
Sight Distance 150 ft Percent Decision Site Distance 29 %		SIGHT DISTANCE	100
Roadway Width 20 ft		ROADWAY WIDTH	81
GEOLOGIC CHARACTER		GEOLOGIC CHARACTER	
CASE 1	CUT SLOPE	CASE 1	
Structural Condition D (C) F R (A)		STRUCT COND	81
Rock Friction R I U (P) C - S		ROCK FRICTION	27
CASE 2		CASE 2	
Differential Erosion Features F O N M		DIF ER FEATURES	
Difference in Erosion Rates S M L E		DIF ER RATES	
Block Size/Volume 1 (ft)/yd³		BLOCK SIZE	3
Climate Precipitation (L) M H Freezing Period N S (L) Water on Slope (N) I C		CLIMATE	27
Rockfall History (F) O M C	NO EVIDENCE OF RECENT ROCKFALL	ROCKFALL HISTORY	3
COMMENTS:		TOTAL SCORE	406

RHRS FIELD DATA SHEET

HIGHWAY: Beartooth Highway REGION:

HIGHWAY # 212	Beginning M.P. (B)	(L) / R	Ending M.P.
COUNTY #	DATE 8/31/99	(NEW)	Rated By KSP/DMB
CLASS A B	ADT 600	UPDATE	Speed Limit 35 mph

CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height 25 ft		SLOPE HEIGHT	3
Ditch Effectiveness G M L (N)		DITCH EFFECT	81
Average Vehicle Risk 4 %		AVR	1
Sight Distance 100 ft; Percent Decision Site Distance 19 %		SIGHT DISTANCE	100
Roadway Width 20 ft		ROADWAY WIDTH	81
GEOLOGIC CHARACTER		**GEOLOGIC CHARACTER**	
CASE 1	CUT SLOPE	CASE 1	
Structural Condition D (C) F R (A)		STRUCT COND	81
Rock Friction R I U (P) C - S		ROCK FRICTION	27
CASE 2		CASE 2	
Differential Erosion Features F O N M		DIF ER FEATURES	
Difference in Erosion Rates S M L E		DIF ER RATES	
Block Size/Volume 3 (ft) yd³		BLOCK SIZE	27
Climate: Precipitation (L) M H; Freezing Period N S (L); Water on Slope (N) I C		CLIMATE	27
Rockfall History (F) O M C	NO EVIDENCE OF RECENT ROCKFALL	ROCKFALL HISTORY	3
		TOTAL SCORE	431

COMMENTS:

RHRS FIELD DATA SHEET

HIGHWAY: Beartooth Highway REGION:

HIGHWAY # 212	Beginning M.P. (C)	(L)/ R	Ending M.P.
COUNTY #	DATE 8/31/99	(NEW)	Rated By KSP/DMB
CLASS A B	ADT 600	UPDATE	Speed Limit 35 mph

CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height 140 ft		SLOPE HEIGHT	100
Ditch Effectiveness G M L (N)		DITCH EFFECT	81
Average Vehicle Risk 1 %		AVR	1
Sight Distance 300 ft Percent Decision Site Distance 57%		SIGHT DISTANCE	32
Roadway Width 20 ft		ROADWAY WIDTH	81
GEOLOGIC CHARACTER		GEOLOGIC CHARACTER	
CASE 1	NATURAL SLOPE	CASE 1	
Structural Condition (D) C/F R (A)		STRUCT COND	27
Rock Friction R I U (P) C - S		ROCK FRICTION	27
CASE 2		CASE 2	
Differential Erosion Features F O N M		DIF ER FEATURES	
Difference in Erosion Rates S M L E		DIF ER RATES	
Block Size/Volume 8 (ft) yd^3		BLOCK SIZE	100
Climate Precipitation (L) M H Freezing Period N S (L) Water on Slope (N) I C		CLIMATE	27
Rockfall History (F) O M C	NO EVIDENCE OF RECENT ROCKFALL	ROCKFALL HISTORY	3
COMMENTS:		TOTAL SCORE	479

RHRS FIELD DATA SHEET

HIGHWAY: BEARTOOTH HIGHWAY REGION:

HIGHWAY # 212	Beginning M.P. (D)	(L) / R	Ending M.P.
COUNTY #	DATE 8/31/99	(NEW)	Rated By KSP/DMB
CLASS A B	ADT 600	UPDATE	Speed Limit 35mph

CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height 200 ft		SLOPE HEIGHT	100
Ditch Effectiveness G M (L) N		DITCH EFFECT	27
Average Vehicle Risk 3 %		AVR	1
Sight Distance 170 ft Percent Decision Site Distance 32 %		SIGHT DISTANCE	100
Roadway Width 18 ft		ROADWAY WIDTH	100
GEOLOGIC CHARACTER		GEOLOGIC CHARACTER	
CASE 1	NATURAL SLOPE	CASE 1	
Structural Condition (D) C/F R (A)		STRUCT COND	27
Rock Friction R I U (P) C - S		ROCK FRICTION	27
CASE 2		CASE 2	
Differential Erosion Features F O N M		DIF ER FEATURES	
Difference in Erosion Rates S M L E		DIF ER RATES	
Block Size/Volume 10 (ft)/yd³		BLOCK SIZE	100
Climate Precipitation (L) M H Freezing Period N S (L) Water on Slope (N) I C		CLIMATE	27
Rockfall History (F) O M C	NO EVIDENCE OF RECENT ROCKFALL	ROCKFALL HISTORY	3
		TOTAL SCORE	512

COMMENTS:

RHRS FIELD DATA SHEET

HIGHWAY: Beartooth Highway REGION:

HIGHWAY # 212	Beginning M.P. (E)	(L) / R	Ending M.P.
COUNTY #	DATE 8/31/99	(NEW)	Rated By KSP/DME
CLASS A B	ADT 600	UPDATE	Speed Limit 35mph

CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height 200 ft		SLOPE HEIGHT	100
Ditch Effectiveness G M L (N)		DITCH EFFECT	81
Average Vehicle Risk 8 %		AVR	1
Sight Distance 175 ft Percent Decision Site Distance 33 %		SIGHT DISTANCE	100
Roadway Width 18 ft		ROADWAY WIDTH	100
GEOLOGIC CHARACTER		**GEOLOGIC CHARACTER**	
CASE 1	Natural Slope	CASE 1	
Structural Condition D (C) F R (A)		STRUCT COND	81
Rock Friction R I U (P) C - S		ROCK FRICTION	27
CASE 2		CASE 2	
Differential Erosion Features F O N M		DIF ER FEATURES	
Difference in Erosion Rates S M L E		DIF ER RATES	
Block Size/Volume 8 (ft)/yd^3		BLOCK SIZE	100
Climate Precipitation (L) M H Freezing Period N S (L) Water on Slope (N) I C		CLIMATE	27
Rockfall History (F) O M C	No evidence of recent rockfall	ROCKFALL HISTORY	3

COMMENTS:

TOTAL SCORE 620

RHRS FIELD DATA SHEET

HIGHWAY: Beartooth Highway | REGION:

HIGHWAY # 212	Beginning M.P. (F)	(L) / R	Ending M.P.
COUNTY #	DATE 8/31/99	(NEW)	Rated By KSP/DMB
CLASS A B	ADT 600	UPDATE	Speed Limit 35 mph

CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height 150 ft		SLOPE HEIGHT	100
Ditch Effectiveness G M L (N)		DITCH EFFECT	81
Average Vehicle Risk 3 %		AVR	1
Sight Distance 130 ft Percent Decision Site Distance 25 %		SIGHT DISTANCE	100
Roadway Width 20 ft		ROADWAY WIDTH	81
GEOLOGIC CHARACTER		**GEOLOGIC CHARACTER**	
CASE 1	NATURAL SLOPE	CASE 1	
Structural Condition D (C) F R (A)		STRUCT COND	81
Rock Friction R I U (P) C - S		ROCK FRICTION	27
CASE 2		CASE 2	
Differential Erosion Features F O M M		DIF ER FEATURES	
Difference in Erosion Rates S M L E		DIF ER RATES	
Block Size/Volume 6 (ft)/yd^3		BLOCK SIZE	100
Climate Precipitation (L) M H Freezing Period M S (L) Water on Slope (N) I C		CLIMATE	27
Rockfall History F (O) M C	SMALL ROCKS & DEBRIS AT TOE	ROCKFALL HISTORY	9
COMMENTS:		TOTAL SCORE	607

RHRS FIELD DATA SHEET

HIGHWAY: Beartooth Highway | REGION:

HIGHWAY # 212	Beginning M.P. (6)	(L) / R	Ending M.P.
COUNTY #	DATE 8/31/99	(NEW)	Rated By KSP/DMB
CLASS A B	ADT 600	UPDATE	Speed Limit 35mph

CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height 100 ft		SLOPE HEIGHT	81
Ditch Effectiveness G M L (N)		DITCH EFFECT	81
Average Vehicle Risk 1 %		AVR	1
Sight Distance 120 ft Percent Decision Site Distance 23 %		SIGHT DISTANCE	100
Roadway Width 20 ft		ROADWAY WIDTH	81
GEOLOGIC CHARACTER		GEOLOGIC CHARACTER	
CASE 1	CUT SLOPE	CASE 1	
Structural Condition D (C) F R (A)		STRUCT COND	81
Rock Friction R I U (P) C - S		ROCK FRICTION	27
CASE 2		CASE 2	
Differential Erosion Features F O N M		DIF ER FEATURES	
Difference in Erosion Rates S M L E		DIF ER RATES	
Block Size/Volume 6 (ft³)/yd³		BLOCK SIZE	100
Climate Precipitation (L) M H Freezing Period N S (L) Water on Slope (N) I C		CLIMATE	27
Rockfall History F (O) M C	SMALL ROCKS AND DEBRIS AT TOE	ROCKFALL HISTORY	9
COMMENTS:		TOTAL SCORE	588

RHRS FIELD DATA SHEET

HIGHWAY: BEARTOOTH HIGHWAY REGION:

HIGHWAY # 212	Beginning M.P. (H)	(L)/ R	Ending M.P.
COUNTY #	DATE 8/31/99	(NEW)	Rated By KSP/DMB
CLASS A B	ADT 600	UPDATE	Speed Limit 35mph

CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height 80 ft		SLOPE HEIGHT	34
Ditch Effectiveness G M L (N)		DITCH EFFECT	81
Average Vehicle Risk 3 %		AVR	1
Sight Distance 120 ft Percent Decision Site Distance 23 %		SIGHT DISTANCE	100
Roadway Width 20 ft		ROADWAY WIDTH	81
GEOLOGIC CHARACTER		GEOLOGIC CHARACTER	
CASE 1	CUT SLOPE	CASE 1	
Structural Condition D (C) F R (A)		STRUCT COND	81
Rock Friction R I U (P) C - S		ROCK FRICTION	27
CASE 2		CASE 2	
Differential Erosion Features F O N M		DIF ER FEATURES	
Difference in Erosion Rates S M L E		DIF ER RATES	
Block Size/Volume 6 (ft)/yd³		BLOCK SIZE	100
Climate Precipitation (L) M H Freezing Period N S (L) Water on Slope (N) I C		CLIMATE	27
Rockfall History F (O) M C	SMALL ROCKS AND DEBRIS AT TOE	ROCKFALL HISTORY	9
		TOTAL SCORE	541

COMMENTS:

TABLE B-1: SUMMARY SHEET OF THE ROCKFALL HAZARD RATING SYSTEM

CATEGORY			RATING CRITERIA AND SCORE			
			POINTS 3	POINTS 9	POINTS 27	POINTS 81
SLOPE HEIGHT			25 FEET	50 FEET	75 FEET	100 FEET
DITCH EFFECTIVENESS			Good catchment	Moderate catchment	Limited catchment	No catchment
AVERAGE VEHICLE RISK			25% of the time	50% of the time	75% of the time	100% of the time
PERCENT OF DECISION SIGHT DISTANCE			Adequate sight distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited sight distance, 60% of low design value	Very limited sight distance 40% of low design value
ROADWAY WIDTH INCLUDING PAVED SHOULDERS			44 feet	36 feet	28 feet	20 feet
GEOLOGIC CHARACTER	CASE 1	STRUCTURAL CONDITION	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
GEOLOGIC CHARACTER	CASE 1	ROCK FRICTION	Rough, Irregular	Undulating	Planar	Clay infilling, or slickensided
GEOLOGIC CHARACTER	CASE 2	STRUCTURAL CONDITION	Few differential erosion features	Occasional differential erosion features	Many differential erosion features	Major differential erosion features
GEOLOGIC CHARACTER	CASE 2	DIFFERENCE IN EROSION RATES	Small difference	Moderate difference	Large difference	Extreme difference
BLOCK SIZE / VOLUME OF ROCKFALL/EVENT			1 Foot / 3 cubic yards	2 Feet / 6 cubic yards	3 Feet / 9 cubic yards	4 Feet / 12 cubic yards
CLIMATE AND PRESENCE OF WATER ON SLOPE			Low to moderate precipitation; no freezing periods; no water on slope	Moderate precipitation or short freezing periods or intermittent water on slope	High precipitation or long freezing periods or continual water on slope	High precipitation and long freezing periods or continual water on slope and long freezing periods
ROCKFALL HISTORY			Few falls	Occasional falls	Many falls	Constant falls

Notes: From FHWA, 1993.

TABLE B-2

FEET	SLOPE HT. score	FEET	SLOPE HT. score
9	1	58	13
10	2	58	13
11	2	59	13
12	2	60	14
13	2	61	15
14	2	62	15
15	2	63	16
16	2	64	17
17	2	65	17
18	2	66	18
19	2	67	19
20	2	68	20
21	3	69	21
22	3	70	22
23	3	71	23
24	3	72	24
25	3	73	25
26	3	74	26
27	3	75	27
28	3	76	28
29	4	77	29
30	4	78	31
31	4	79	32
32	4	80	34
33	4	81	35
34	4	82	37
35	5	83	38
36	5	84	40
37	5	85	42
38	5	87	46
39	6	88	48
40	6	89	50
41	6	90	52
42	6	91	55
43	7	92	57
44	7	93	60
45	7	94	60
46	8	95	62
47	8	96	65
48	8	97	71
49	9	98	74
50	9	99	78
51	9	100	81
52	10	101	85
53	10	102	88
54	11	103	92
55	11	104	97
56	12	105	100
57	12		

%	AVR score	%	AVR score
9	1	58	13
10	2	59	13
11	2	60	14
12	2	61	15
13	2	62	15
14	2	63	16
15	2	64	17
16	2	65	17
17	2	66	18
18	2	67	19
19	2	68	20
20	2	69	21
21	3	70	22
22	3	71	23
23	3	72	24
24	3	73	25
25	3	74	26
26	3	75	27
27	3	76	28
28	3	77	29
29	4	78	31
30	4	79	32
31	4	80	34
32	4	81	35
33	4	82	37
34	4	83	38
35	5	84	40
36	5	85	42
37	5	86	44
38	5	87	46
39	6	88	48
40	6	89	50
41	6	90	52
42	6	91	55
43	7	92	57
44	7	93	60
45	7	94	60
46	8	95	62
47	8	96	65
48	8	97	71
49	9	98	74
50	9	99	78
51	9	100	81
52	10	101	85
53	10	102	88
54	11	103	92
55	11	104	97
56	12	105	100
57	12		

%	SIGHT DIST. score	%	SIGHT DIST. score
36	100	75	12
37	96	76	11
38	90	77	11
39	86	78	10
40	81	79	10
41	77	80	9
42	73	81	9
43	69	82	8
44	65	83	8
45	62	84	7
46	58	85	7
47	55	86	6
48	52	87	6
49	49	88	6
50	47	89	5
51	44	90	5
52	42	91	5
53	40	92	5
54	38	93	4
55	36	94	4
56	34	95	4
57	32	96	4
58	30	97	4
59	29	98	3
60	27	99	3
61	26	100	3
62	24	101	3
63	23	102	3
64	22	103	3
65	21	104	2
66	19	105	2
67	18	106	2
68	17	107	2
69	16	108	2
70	16	109	2
71	15	110	2
72	14	111	2
73	13	112	2
74	13	113	1

ROAD WIDTH IN FEET	ROAD WIDTH score
18	100
19	93
20	81
21	71
22	62
23	54
24	47
25	41
26	36
27	31
28	27
29	24
30	21
31	18
32	16
33	14
34	12
35	10
36	9
37	8
38	7
39	6
40	5
41	5
42	4
43	3
44	3
45	3
46	2
47	2
48	2
49	2
50	1

QUANTITY cu. yd.	score
1	1
1.5	2
2	2
2.5	2
3	3
3.5	4
4	4
4.5	5
5	6
5.5	7
6	9
6.5	11
7	13
7.5	16
8	19
8.5	22
9	27
9.5	32
10	39
10.5	47
11	56
11.5	67
12	81
12.5	97
13	100

Decision Sight Distance	MPH
300	20
375	25
450	30
525	35
600	40
675	45
750	50
875	55
1000	60
1015	65

BLOCK SIZE ft.	score
0.5	2
1	3
1.5	5
2	9
2.5	16
3	27
3.5	47
4	81
4.5	100

$$AVR\% = \frac{(ADT/24) \times \text{slope length (miles)} \times 100}{\text{speed limit}}$$

Where: ADT = Average Daily Traffic

Notes: 1. From FHWA, 1993.
2. See Table A for ditch effectiveness, geologic character, climate, and rockfall history scores.

TABLE B-3: LENGTH OF ROAD SUBJECT TO ROCKFALL HAZARD
(MEASURED ON GEOLOGIC MAP)

Segment	Approx. Length (m)	Approx. Length (mi)	AVR	Notes
A	21	0.01	1%	Cut Slope
B	80	0.05	4%	Cut Slope
C	21	0.01	1%	Natural Slope
D	60	0.04	3%	Natural Slope
E	185	0.11	8%	Natural Slope
F	73	0.04	3%	Natural Slope
G	22	0.01	1%	Cut Slope
H	73	0.04	3%	Cut Slope