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Geotechnical and Geologic Features of U.S. 189 in Provo Canyon, Utah

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ABSTRACT

Provo Canyon, located in north central Utah, is known to have landslide hazards for many years. Construction to widen and straighten a 2.5-mile-long section of U.S. 189 known as the "Narrows" commenced in December 1995. This project consists of twin 300-foot-long two-lane tunnels, 3/4 million cubic yards of soil and rock excavation, 60,000 square feet of cast-in-place concrete soil nailed walls, and 90,790 square feet of mechanically stabilized embankment. During excavation for some of the cuts, landslides occurred that required remediation. Cracks were noticed near the northern portal of the tunnels which necessitated immediate stabilization. Observations during construction are presented.

Immediately north of "The Narrows" section of U.S. 189 is an approximate six-mile-long segment called the Upper Provo Canyon project. The project includes a one-mile section of roadway that traverses over some landslides, known as the Hoover Slides, which have been active for at least 60 years. The Hoover Slides are within a thrust fault known as the Deer Creek thrust. From the exploration program, geotechnical and geologic features were identified which permitted the development of probable chronological events of the Hoover Slides and postulated sliding mechanisms responsible for the movements.

KEYWORDS

Slope Stability, Landslides, Tunnels, Hoover Slides, Site Exploration, Instrumentation.

INTRODUCTION

U.S. Highway 189 through Provo Canyon, Utah is being widened from 2 lanes to 4 lanes and realigned for a 50 mile per hour speed limit by the Utah Department of Transportation (UDOT). The multi-million dollar, 15-mile-long project is being designed and constructed in phases. The lower 7.5 miles have been constructed and are in use. The two mile-long middle section is called the "Narrows". The Narrows project includes two 300-foot-long tunnels, 0.75 million cubic yards of soil and rock excavation, and 151,000 square feet of retaining walls. Construction on this section was commenced in December 1995 and is expected to complete by Spring 1998. The upper 5 mile-long is called the "Upper Provo Canyon" project. The widening of the Upper Provo Canyon section of US-189 includes the crossing of two large active landslide zones; one in the Canyon Meadows and the other in the Horseshoe Bend of the Provo Canyon, both of which are collectively called the Hoover Slides area (Figure 1). The main challenge on the Upper Provo Canyon project is to develop methods for constructing the new road through the Hoover Slides area.

The Hoover Slides have been active for over 60 years. Five slides are currently active along Highway US-189. Of these five slides, at least three are significant slides. They are each measured to be 500 to 700 feet long and 100 to 300 feet wide. In addition, slumps of a minor nature occur in cuts above the existing highway and in the embankment downslope from the highway. In addition to landslides, the natural and cut slopes throughout the canyon experience rockfalls on to the roadway that increase in frequency in the spring when the ground thaws and runoff is at its peak. The new construction on U.S. 189 is meant to upgrade the capacity of the highway due to increased traffic volume as well as to mitigate, to the extent possible, the noted geologic hazards to the vehicles that travel through Provo Canyon.

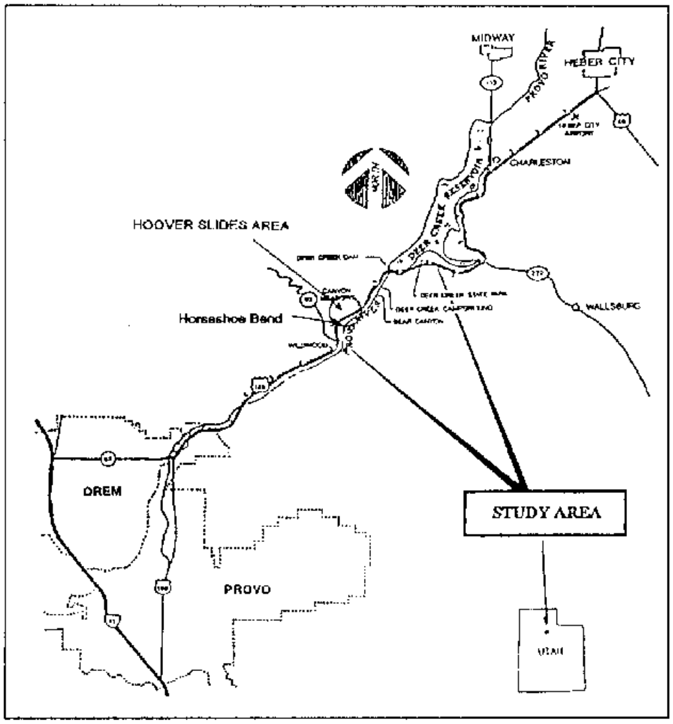

Figure 1 - Site Location Map

GEOTECHNICAL EXPLORATIONS

The Narrows

The geotechnical exploration consisted of fourteen (14) borings, geologic mapping, field permeability tests, installation of piezometers, and laboratory testing, all of which were performed in late 1990 and early 1991. Seismic refraction lines were also conducted in 1995 to determine soil/rock interfaces along the proposed alignment.

Due to strict environmental restrictions imposed for this portion of the canyon, many areas were either off limits to drilling or restrictions were placed on the time of year in which drilling was allowed. In some instances drills were mobilized by helicopter in order to minimize disturbance to the environment.

The Upper Provo Canyon Project

The geotechnical data for the Upper Provo Canyon project included approximately 50 exploration borings made along the alignment (20 of the borings were drilled at various times during the last 50 years), installation of inclinometers and piezometers, field mapping, seismic refraction, downhole geophysical logging, and laboratory testing (Abramson & Lee, 1995).

GEOLOGIC SETTING

Provo Canyon is located in the Wasatch Mountain Range, and is oriented generally northeast to southwest. The Provo River is situated at the bottom of the Canyon and flows to the southwest. The Wasatch Range is dominated by the Pennsylvanian-age Oquirrh Formation. More recent alluvial and colluvial deposits occur in the canyon bottoms and as a veneer covering the bedrock along the steep canyon slopes. The Oquirrh Formation consists predominantly of limestone and limy to quartzitic sandstone.

The Hoover Slides are a part of a large prehistoric landslide complex. The slide area underlain by the Manning Canyon Shale formation which consists of black to brown shale with interbedded slabby sandstone, thin beds of quartzite, and thin- to thick-bedded gray to black limestone. The shale weathers rapidly when exposed to the atmosphere and becomes highly plastic when wet.

The Hoover Slide section of Provo Canyon has been heavily altered by sub-horizontal thrust faulting, resulting in intense fracturing of the rock. The Provo River has eroded through the upper plate of the thrust fault, creating the Sulphur Springs. The Manning Canyon shale lies below the Oquirrh Formation limestone., The Manning Canyon shale and Oquirrh Formation limestone are in the thrust-fault contact.

SEISMICITY

In northern Utah, the Wasatch Fault Zone (WFZ) located at the base of the Wasatch Range, exhibits evidence of recurrence during Late Quaternary time. Studies of the Provo Segment indicate that there have been three to four surface faulting events in the last 8,000 years and the latest event occurred approximately 500 to 700 years ago. The project site is distant enough from the WFZ that surface rupture at the site is not expected. However, the site is in an area with a risk of experiencing strong ground shaking related to potential earthquake activities. It is located in the Uniform Building Code Seismic Zone 3. The source of the strong ground shaking is the Intermountain Seismic Belt (ISB), and peak ground acceleration on rock of 0.25g can be expected to have a 10 percent probability of exceedance in a 50 year period (Youngs et al., 1987).

OBSERVATIONS DURING CONSTRUCTION

The Narrows

The widening of U.S. 189 from two lanes to four lanes in this project requires construction of two short tunnels, several hillside excavations, and retaining walls along the Provo

River. Construction started in December 1995 and is expected to be completed in Spring 1998.

The potentials for landslides in Provo Canyon were known during planning and design of the Narrows project. Landslides generally occur as a result of periods of prolonged rainfall or spring snowmelt Localized geologic features and construction activities have caused several problems on the section of U.S. 189 just north of the new S.R. 92 intersection as well as on the north portal of the tunnels. These failure incidents are described in the following:

Failures Between Stations 602+00 to 608+00.

Between Stations 602+00 and 608+00, the new alignment required a soil/rock cut up to 75 feet in height. The planned cut intersected a prehistoric landslide area with very complicated geology. The geology in this area is dominated by rocks that form an interbedded sequence of limestone with calcite veins, weathered limestone, and sheared zones. The area is located near the Deer Creek thrust fault that was mapped by Baker (1964). The Deer Creek thrust fault is a regional feature and has a sub-horizontal orientation.

During excavation of the area between Stations 604+00 and 605+00 in July 1996, a rock slide occurred and the debris fell on to a backhoe. Due to the very steep terrain, a pioneer cut was made behind the top of the rock slide in attempt to stabilize the cut. To provide stability of the slope, the pioneer cut was recommended to be protected with soil nails/rock dowels and shotcrete. Portions of the pioneer cut were left unsupported due to difficult access.

In order to determine causes of the rock slide, a two-phase field exploration was performed in September 1996. The first phase consisted of twelve exploratory borings to depths of 20 to 80 feet using an air drill rig. The second phase comprised five horizontal boreholes to depths of 50 to 75 feet using a wire-line rotary drilling rig. The exploration program confirmed that the rock slope is composed of alternating layers of hard and weak limestones with clay seams, shear zones, and open fractures. Open fractures as wide as 2 feet were encountered during drilling. The presence of these geologic features led to the conclusion that the area is composed of landslide debris originated from the nearby Deer Creek Thrust fault.

In late October, 1996, another rock slide occurred at the top of the rock cut at Stations 602+50(±). This rock slide area had only a thin coating of shotcrete without any rock dowels as originally recommended.

Conditions along the pioneer cut continued to deteriorate with the onset of winter precipitation . Two rock slides occurred at the pioneer cut at Station 605+50 (approximately) on November 21, 1996 and January 4, 1997. These slides were adjacent to the initial slide that occurred in July 1996.

On March 12, 1997, boulders rolled down from the top of the cut at Station 606+00 (approximately) and hit a truck traveling on U.S. 189. This slide caused a temporary closure of US-189 for several days until a temporary rock fall zone was installed. The temporary rock fall zone consisted of a double rock fence system with aggregates placed from the toe of the cut to the rock fences (Figure 2).

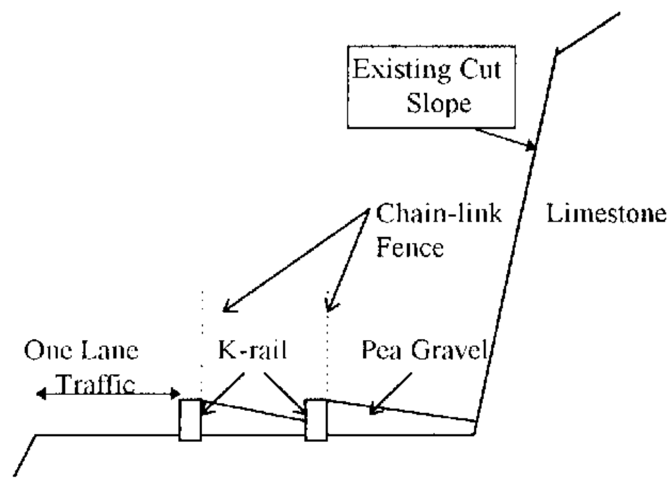

Figure 2. Double Rock Fence System (Schematic)

The initial (July 1996) failure is thought to have occurred by the undercutting of shear zones within the rockmass by the planned 0.1(H):1(V) cut. The subsequent failures have been the result of several factors including stress relief of adjacent ground toward the initial slide area, weather (precipitation and freeze-thaw), blast vibrations, timeliness of ground support installation, or a combination of the above. Exploratory holes drilled in the area after the first failure indicated that bedding attitudes are reasonably consistent with a north-northeast strike and dip to the east-southeast at about 60°. The rock is highly fractured likely due to two phenomena:

(1) shattering of the brittle rock units during past tectonic processes, in which case, the fracturing persists with depth.

(2) undercutting and downslope migration of blocks from upslope due to downcutting of the canyon by the Provo River after the Deer Creek thrust faulting, leaving voids (i.e., open fractures) between transported blocks.

Stabilization of this slide area consisted of soil nails on a 5 ft. x 5 ft. pattern, 30 to 40 feet long with 24 inch-wide strip drains, and 2-lifts of 3-inch-thick steel fiber reinforced shotcrete The excavation was redesigned with 30 foot-high, 0.5(H):1(V) cuts and five foot wide (typical) benches. At the highest point there are seven benches for a maximum cut height of 220 feet.

During implementation of the stabilization work, voids and open fractures as wide as 2 to 3 feet were encountered, and substantial amount of grout had to be pumped into holes to fill up the open fractures and voids of the rock mass. To minimize the amount of grout take, thicker grout mix (Cement:Water Ratio = 0.7:1) have been used. A total of about 650 bags of cement was reportedly used in a single 40 foot long drill hole (3.5 inch diameter) for a soil nail which would otherwise have required about 10 to 20 bags. Because of the presence of voids and open fractures, the stabilization work progressed very slowly.

Cracks at the North Portal Twin Tunnels.

Cracks were noticed in December of 1996 forming approximately 20 to 30 feet inside from the north portal face of the twin tunnels. The cracks extended from the crown to the springline of each tunnel. At the time the cracks formed, the northbound tunnel had been completely excavated to the invert subgrade. The southbound tunnel had the top heading, which extended to the springline of the tunnel, excavated for its full length. The lower bench of the southbound tunnel had approximately 60 to 70 feet of excavation remaining to its terminus at the north portal.

The tunnels are both 32 feet tall with a 21.25-foot radius at the springline (Figure 3) and approximately 300 feet long. Support for the tunnel consisted of 12-foot long rockbolts on a typical 4-ft. x 4-ft. pattern with 6-inches of shotcrete for primary support. The tunnels were excavated through shaly limestone of the Oquirrh Formation There were no notable problems in the driving of the tunnels. The ground was generally massive and presented good tunneling conditions until the time of the cracks forming. After the cracks were noted, all tunnel blasting and excavation were halted by UDOT until the cause of the problem was established.

Inspection of the northbound tunnel revealed a shear plane dipping approximately 30 degrees toward the north portal cut (Figure 4). This shear plane was assumed to be the base of a wedge that was projected as daylighting through the north portal cut. Cracks were also noted at ground surface above the tunnel and approximately 45 feet behind the portal cut. The postulated failure mechanism is that a stepped failure pattern exists along a series of discontinuities that are oriented parallel with the bedding and dip approximately 30 degrees toward the north portal excavation.

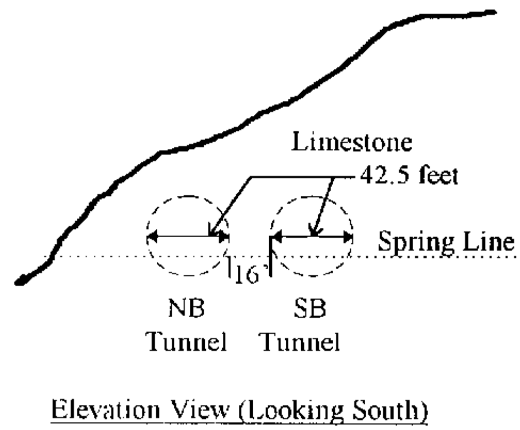

Figure 3 Twin Tunnels at the Narrows Project

The investigation into this problem consisted of convergence measuring points in both tunnels, drilling five NX-size cores from above the tunnels, and the installation of inclinometers in four of the five bore holes. Monitoring of the inclinometers started before excavation was allowed to resume in order to establish background baseline values. Convergence measurements were taken on number of chord locations across the tunnel openings on a daily basis. Throughout the period of monitoring, no movement was recorded in the inclinometers and only minor changes were noted in the convergence measurements. These were likely attributed to the thermal expansion and contraction in the shotcrete around the cracks.

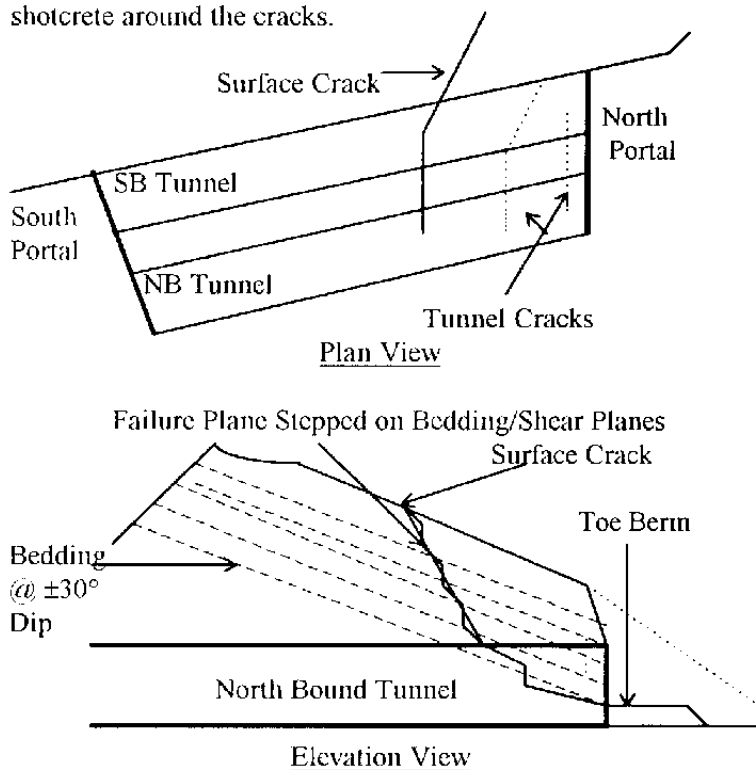

Figure 4. Assumed Failure Plane at the North Portal Cut

The stabilization of the portal cut was accomplished by the installation of 40-foot long untensioned rebars (1.375 inch diameter) installed on a 5-ft. x 5-ft. pattern across the cut face. Excavation of the southbound tunnel was allowed to continue once the support was in place. Monitoring of the convergence points and inclinometers continued until after all tunnel and portal excavation was completed and no further movements have been recorded.

Failure at Station 599+80.

A cut slope at Station 599+80 for a length of about 100 feet failed on April 17, 1997, two weeks after a toe berm was removed to the proposed final grade. The 90 foot-high cut has 10 to 25 feet of colluvial overburden overlying bedrock (Figure 5a). The overburden soil was supported by soil nails of lengths varying from 10 to 20-ft long on a 4-ft x 4-ft pattern. The bedrock was reinforced by 5-ft x 5-ft patterned 15-ft long rock dowels. The design cut angle for this portion of the project is a 0.1(H):1(V) (~84 degrees).

Inspection records indicated a block of rock (approximately 10 feet long x 5 feet deep x 4 feet in height) was dislodged five feet from the toe of the cut after the toe berm was removed (Figure 5b). No rock dowels and/or steel fiber reinforced shotcrete were in place at the toe of the cut before the failure.

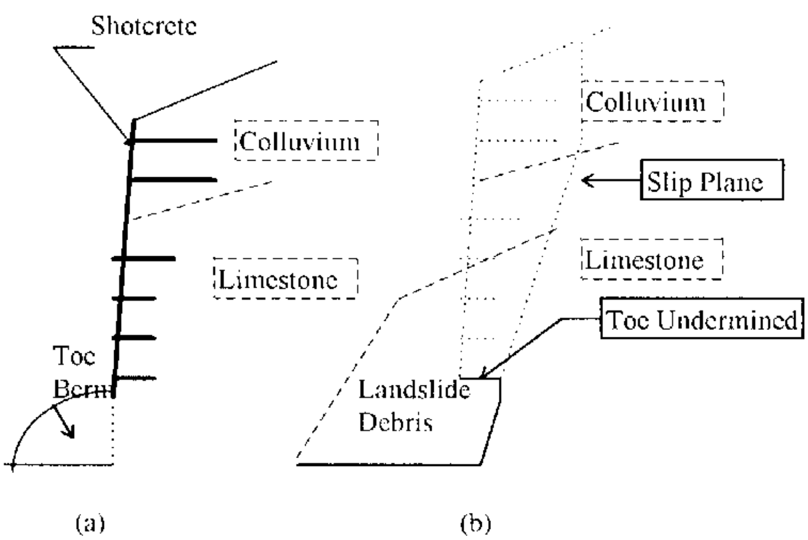

Figure 5. Cut Slope at Station 599+80 Before and After Failure (Schematic Diagrams

Post failure reconnaissance showed that the cut slope at Station 599+80 was triggered by progressive failure starting from the toe of the cut where the block of rock was dislodged, progressing upwards along subvertical and daylighting joints within the rock mass and then extending upwards to the unreinforced soil mass (i.e., beyond the soil nailed portion). At the time of failure, the following observations were made:

- The soil nailed wall came down as one whole mass, indicating the slip surface actually passed beyond the reinforced mass.
- Grout did not stick to the epoxy-coated reinforcing bars. Grout was only present on the centralizers of the rebar.
- No seepage of water was noticed at the failure scarp and the soil/rock debris were moist but not wet.
- Discontinuities dipped at approximately 65 to 75 degrees out of the cut face and were smooth and occasionally slickensided.

Slide stabilization work consisted of laying back the cut slope to 0.5(H):1(V) with soil nails and rock dowels. The final cut face was covered with steel fiber reinforced shotcrete and weeps to facilitate water seepage.

The Hoover Slides Section of Provo Canyon.

The Hoover Slides section of Provo Canyon include two large active landslide zones; one in the Canyon Meadows area and the other in the Horseshoe Bend area (Figure 1). The main challenge for this portion of the highway project was to develop methods for constructing the new road through the Hoover Slides area. Parsons Brinckerhoff was retained in 1993 by Centennial Engineering, Inc. (CEI) on behalf of UDOT to investigate the impact of the Hoover Slides on the new US-189 and to determine the probable causes and limits of the Hoover Slides and proposed remedial work.

Five slides are currently active within the Hoover Slides. Of these five slides, at least three are deep-seated slides and the other two are shallow (depth of less than 30 feet). The three deep-seated slides are each measured to be 500 to 700 feet long, 100 to 300 feet wide, and 80 to 120 feet deep. In addition to the five slides, slumps of a minor nature have occurred in cuts above the existing highway and in the embankment downslope from the highway.

Canyon Meadows: Three of the five landslides on existing US-189 are found near the Canyon Meadows housing development. Based on the inclinometer data, two sliding planes appear to exist in each of these three landslides. One slide plane is located at the interface between the fill and the landslide debris (herein called the upper slide), the other slide is in the weathered Manning Canyon Shale (which is called the lower slide) as shown in Figure 6. The upper slide occurs primarily where fills have been placed on top of ancient clayey landslide debris which is derived from the underlying shale. This upper slide is the most active and moves on the average of 0.5 to 1.5 inches per year. The deeper sliding zone is the base of the ancient landslide debris where it overlies highly weathered Manning Canyon Shale. The shale weathers rapidly when exposed to the atmosphere and becomes highly plastic when wet. The weathering process appears to have been accelerated by the presence of springs along the thrust fault zone. The shales have been weathered to a soil consistency to a depth of 16 to over 65 feet in this area.

The data from inclinometers in the Canyon Meadows slide area revealed that the upper slide is creeping at a rate of about 0.5 to 1.5 inches per year towards the river in a southeasterly direction, while the lower slide is moving very slowly at a rate (about 0.1 to 0.5 inches per year) generally to the southeast to south (toward the Provo River) as shown in Figure 7. The rate of ground movement on the downslope side of the highway increases as a result of the increased amount of road fill on the weak slide material as well as the close proximity to the river and high pore water pressures. Additional road fill is placed almost every year by UDOT as part of a maintenance program for the creeping highway. A boring drilled on the existing US 189 near Canyon Meadows encountered 15 ft of asphalt.

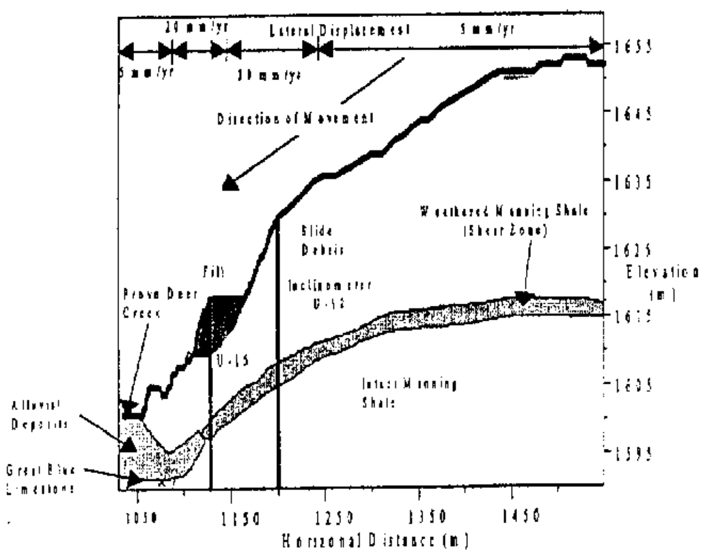

Figure 6. Inferred Geologic Cross Section at the Canyon Meadows (PBQ&D, 1995)

In the northern part of the slide inclinometers indicate that movement is deflected to the south-southeast as a result of the presence of a resistant limestone unit called the Great Blue Limestone, which acts as a buttress to movement of the slide material. In the southern portion of the slide area where Manning Canyon Shale is present at the bank of the river, there is no buttress, and thus the toe of the slide has continued to erode over time because there is little resistance to downslope movement within the alluvial soils in the river (Figure 7).

Horseshoe Bend: The geology inferred from the site investigation in this area is extremely complex because of faulting within the Horseshoe Bend area. It is postulated that the following geologic chronology related to the landslide movements could have occurred at Horseshoe Bend based on borehole data, shallow seismic refraction survey data, laboratory testing, downhole geophysical logging, and field mapping:

1. Movement along the sub-horizontal Deer Creek thrust (Late Cretaceous) fault sheared the rocks along both sides of the contact between the Manning Canyon shale and the overlying Oquirrh Formation (limestone and sandstone). The rocks of the Oquirrh Formation present at Horseshoe Bend are located close to the plane of shearing, and as a result, are highly sheared and fractured, resulting in a weak rock mass.

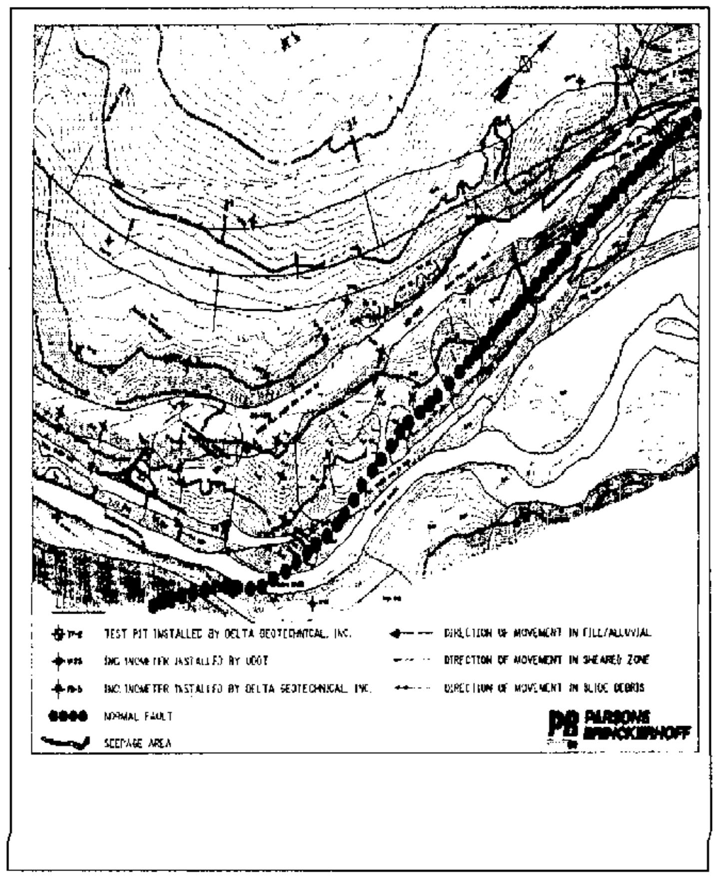

Figure 7 Movement Directions Recorded in the Canyon Meadows Area

2. In the northern portion of Horseshoe Bend (west side of the river in Figure 8), the weak Oquirrh Formation rock mass is resting on a plastic, sheared clay gouge that represents the top of the Manning Canyon shale. This weak Oquirrh Formation appears to be the result of landslide material that has slid

downslope toward the Provo River. The Oquirrh Formation has a high secondary permeability due to the fractured and weathered state of the rocks that allows water to percolate easily down through the unit. When the groundwater reaches the top of the Manning Canyon shale, which is nearly impervious, it saturates the shear zone as well as the top layers of the shale. Thus, the strength of this already weak zone is further reduced by the pore pressures created along the contact. Pore pressures may also be building in the clayey shales below the sheared contact zone. The saturated state of the shear plane probably also results in further chemical weathering of the shale, which gradually reduces its shear strength as discussed above.

Subsequent filling of a valley located in the northern portion of Horseshoe Bend in the 1930's has further accelerated movements in this local area as evidenced by inclinometer readings, resulting in roadway cracking. The cause of the movement appears to be due to subsurface groundwater flow at the interface between the fill and landslide debris as confirmed by the presence of localized springs at the toe of the fill slope below US-189 (Figure 8). Groundwater tends to exert pore pressure and weaken the shear resistance of the surrounding soils to slides. The movements are the greatest during the spring when snowmelt occurs.

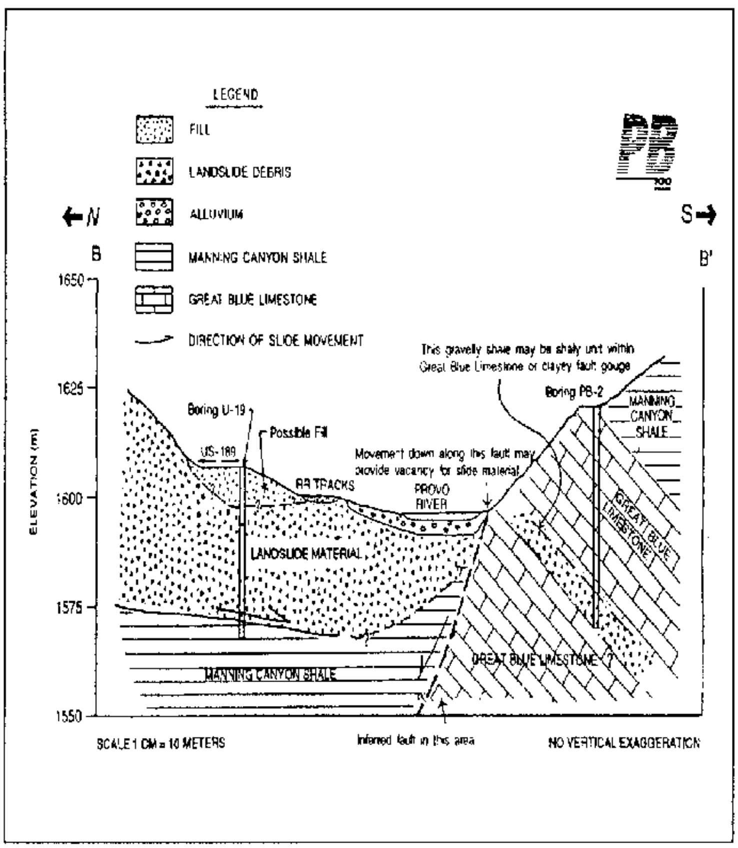

Figure 8. Inferred Geologic Cross Section at the North of Horseshoe Bend

3. The southern portion of the Horseshoe Bend area has distinctly different subsurface conditions as evidenced in borings PB-2, and PB-5 (Figure 9). After movement along the Deer Creek thrust, a normal fault trending east-west is postulated to have formed at Horseshoe Bend with the downthrown side on the north (upstream) side of the fault (Lee & Brandon, 1995). The upthrown block is composed of Great Blue Limestone, which crops out on both sides of the Provo River and the block dips to the south-southeast. A normal fault with the Great Blue limestone on the upthrown side would explain the cause for the Horseshoe Bend feature. The river deflects sharply to the west due to the hard resistant limestone at this location.

The geologic conditions in the southern portion of Horseshoe Bend are complex, as exemplified in the presence of overturned bedding in a southbound roadcut on US-189 at drill hole PB-5 (Figure 9). At this time, no reliable explanation of the geologic structure of the southern portion of Horseshoe Bend has been determined.

A shallow slide has occurred at the southern portion of Horseshoe Bend and is believed to have resulted from formation of local piping in the fill that connects to a 7-foot-deep sinkhole located about 5 feet south of drill hole PB-5. The formation of this sinkhole is attributed to groundwater flow within the loose fill that daylights in the slope downhill of the roadway.

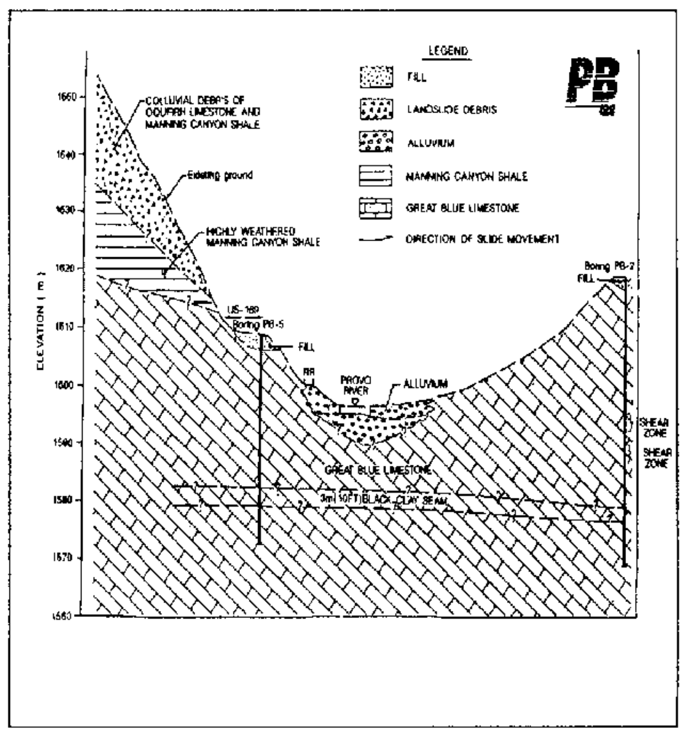

Figure 9. Inferred Geologic Cross Section at the South Horseshoe Bend

LESSONS LEARNED

The Narrows Project

Failure to apprehend geomorphic and hydrologic conditions of the site and vicinity due to:

- lack of geotechnical support in the field to oversee construction activities;
- lack of exploratory holes in the problem area before excavation started;
- underestimating the impact of adjacent ancient landslides on excavations;
- having a false sense of complacency in that fractured rock has no involvement in slope stability;
- not understanding the process of infiltration, throughflow, development of pore water pressure within the vadose zone.

Any slope failures should be addressed and requisite works carried out at the earliest possible time. Procrastination of stabilization work leads to increased slope deterioration, causing progressive failures. It is only through clear communication, mutual trust, co-operation, and partnering between management, designers, field staff, and the contractor that difficult field conditions can be tackled.

Upper Provo Canyon Project

Deep-seated failures such as the Hoover Slides are usually associated with very complex geology consisting pre-existing shear zones, fault breccia, and fractured zones as a result of prehistoric Deer Creek Thrust faulting. Albeit many technically feasible stabilization methods in hand, they are often very costly because of the deep-seated nature of the slides. The best approach to mitigate the problem would be to move the new highway to a more stable area to avoid expansive stabilization works. Stabilization works anticipated for the existing U.S.189 are deep drilled caissons (PBQD, 1995) and systems of horizontal drains. If implemented, the stabilization works would cost about 3 to 5 millions of dollars which appear to be unjustifiable for a rural highway like U.S. 189.

SUMMARY AND CONCLUSIONS

Many slope failures and ground deformations are attributed to unique geologic and hydrogeomorphic formations of the soil/rock mass that are sometimes underestimated by designers, field staff, and contractors. The need of having an engineering geologist or a geotechnical engineer on site in any major highway excavation projects, especially in a site with complex geology or a past history of landsliding, should not be overlooked.

This paper has identified possible causes that triggered slope failures and tunneling cracking in the Narrows project as well as those in the Upper Provo Canyon project. Although some of the causes were originated from the nature and could not be prevented, yet many of them were caused by human and might have been avoided. The list of "actions" that are considered probable causes of the failures in the Narrows project typically represents the fundamental causes of many slope failures. It often takes several of these actions occurring sequentially to set up a situation in which failures may occur. It is not just one or two "actions" listed above that could cause failures.

As for the prehistoric Hoover Slides, it is prudent not to fight with the mother nature that caused the slides. If we cannot fight it, we may as well live with it at an expense of putting up with it through routine maintenance.

ACKNOWLEDGMENT

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