STATE OF UTAH

DEPARTMENT OF TRANSPORTATION

REGION THREE

Independent Geotechnical Peer Review
Hoover Slide Section
Provo Canyon

US-189: Wildwood to Deer Creek State Park

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REPORT

LANDSLIDE TECHNOLOGY

Report

State of Utah
Department of Transportation
Region Three Headquarters
825 North 900 West
Orem, Utah 84057

INDEPENDENT GEOTECHNICAL PEER REVIEW
SR-189 HOOVER SLIDE SECTION, PROVO CANYON
WILDWOOD TO DEER CREEK STATE PARK

July 2001

By

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INTRODUCTION

Landslide Technology was asked to perform an office and field peer review of the preliminary geotechnical engineering design along the Preferred Alignment for the US-189 Widening Project across the Hoover Slide Section and to identify any significant geotechnical issues or concerns with the recommendations described in the December 1995 Geotechnical Engineering Study (see reference). This report summarizes our independent geotechnical peer review. The Hoover Slide Section is located within the project limits 'Wildwood to Deer Creek State Park' in Provo Canyon, Utah.

This project is situated in a complex geologic environment referred to as the Hoover landslide and interpreted as a very large ancient slide that affects about a half mile of highway. While the toe area of the interpreted ancient slide, including US 189, has experienced several active smaller slides, the actual stability of the overall slide area is not known. The stability of the ground under the Preferred Alignment, which is upslope of US 189, is not certain; especially above the active smaller toe slide areas. A concern for project development is to develop a roadway design that will maintain the level of stability that currently exists where the Canyon Meadows subdivision is located.

The project alignment and widening will necessitate new slope cuts and embankments that could require special construction considerations given the geologic complexity and hazards. Previous experience from the highway improvements made to the west of Wildwood, as well as slide repairs and maintenance in the Hoover Slide area, can provide valuable insights for development of the current highway section. This report includes recommendations for conceptual mitigation measures and immediate SEIS-level and Final Design investigations. The first phase of the review included:

1. Review project background – available reports, geologic publications, aerial photographs, maps, and subsurface data.
2. Perform site reconnaissances – on the ground and by fixed wing airplane, including oblique airphotos.
3. Perform office analyses – airphoto and geologic interpretations, subsurface data and instrumentation evaluations, conceptual stability analyses, and evaluation of the earthwork and potential mitigations for the Preferred Alignment.

EXECUTIVE SUMMARY

Based on our geotechnical peer review of the Preferred Alignment, the general alignment appears reasonable and feasible. Some small adjustments to the vertical and horizontal alignments are recommended to achieve the balanced cut/fill weights to maintain ground and slope stability. Also, mitigations to maintain stability are feasible. Changes to the vertical and horizontal alignment near Horseshoe Bend should be evaluated to address construction staging, landslide, and cut slope issues.

BACKGROUND INFORMATION

The project corridor has been studied for over 15 years. During the planning stages, Shannon and Wilson prepared an engineering geology report (Ref 41), which describes background information for the Hoover Slides area, referring primarily to the series of small slides affecting US 189, in a succinct manner, excerpted as follows:

"The Hoover Slides area has been active for at least the past 50 years. At least 3 significant slides, each 100 to 300 feet wide, are currently active along the highway in this area. Several additional slumps occur in cuts above this portion of the road and in the embankment downslope from the road. These slides appear to occur within an ancient slide mass approximately ¾ mile long and ½ mile wide that forms the flat area on which most of the Canyon Meadows residential development has occurred. This large ancient slide mass is vaguely outlined on the air photos. Based on an absence of any cracks or deformations in the numerous asphalt roads which crisscross Canyon Meadows, it appears that this ancient large slide is not currently moving."

"In the Hoover Slides section, slopes of about 10 degrees appear generally stable." "However, a significant number of natural slopes are in a state of semi-active failure resulting in numerous shallow slumps. Unstable subsoils have resulted in periodic offsets of the roadway by up to several inches, requiring quarterly patching and drainage reconstruction. Reportedly the greatest movements normally occur in the springtime with the highest rainfall. The reported total asphalt thickness at one of the slides is about 14 feet. The existing drainage culverts have been repaired and replaced a number of times. Nevertheless many of the drainage ditches contain several inches of flowing water derived from nearby springs. In 1986 tension cracks and sunken sections of pavement produced hazardous driving conditions within 2 months of the previous maintenance. Lateral offset of the Heber Creeper railroad tracks, up to several feet, has required recent realignment. These same landslides have formed a large swampy-soil fan about 500 feet long and 50 to 100 feet wide, extending into the river and forming a local set of rapids. Low rapids were observed along this stretch of the river, confirming that the river bed is heaving at the toe of the slide."

"The Manning Canyon Shale formation 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 Slides section of Provo Canyon is heavily thrust faulted, resulting in intense fracturing of the rock. The presence of sulphur springs accelerates the weathering process along the fault zone. Consequently, the shales have been weathered to a soil consistency to a depth of 20 to over 50 feet in this area."

"These active slides (along the existing highway) occur primarily where fills have been placed on top of very clayey soil derived from weathering of the underlying shale. It is likely that the existing highway and particularly the added weight of the fill and asphalt patch material have aggravated the slides over the years. Furthermore, the toes of the slides extend into Provo River and are likely being eroded in a conveyor belt effect, involving the input of asphalt and weight at the top and the output of soil eroded by the river at the bottom of the slides. Seeps and springs tend to buoy the slide material up, increase pore pressure, and produce swelling of the clays and subsequent loss of cohesion, all of which aggravate the slope instability."

Reports by Delta Consultants and Parsons-Brinckerhoff also have detailed descriptions of interpreted geology, and existing ground and landslide conditions for this Hoover Slide area (see Ref's 21 and 39).

SITE VISIT SUMMARY

Landslide Technology met with Bureau of Reclamation staff and performed an aerial reconnaissance of the Canyon Meadows/Deer Creek Reservoir area on April 30, 2001. The Bureau of Reclamation meeting provided insights into the Deer Creek Dam construction history. In particular, useful information on the thickness of Provo river sediments was obtained. During the aerial reconnaissance, features related to river alignment, springs, topography (local Canyon Meadow's ground features), overall erosion and geomorphology of both sides of Provo River and along Provo Deer Creek, and the arcuate-shaped area referred to as the Hoover Landslide were observed. Those on the flight were Dan Nelson of Mountainland Assoc. of Governments, Brent Schvaneveldt of Utah Department of Transportation, and George Machan and Larry Pierson of Landslide Technology.

On May 1, Landslide Technology personnel performed a ground reconnaissance. The morning and early afternoon were spent observing the geology and ground features related to the Canyon Meadows/Hoover Landslide. They were joined in the late afternoon by Tom Twedt of Bio-West, Inc. and observed other geotechnical aspects along the haul road and areas northeast of Horseshoe Bend.

Figures 1 through 4 present oblique air photos of the highway section across the Hoover Slide area. Approximate stationing is shown for the Preferred Alignment. Topographic features, facilities, and active slide areas are indicated on the air photos. For reference, Appendix A contains project site plans, showing topography, existing highway, Preferred Alignment (stationing), and preliminary design features.

Observations

Flight Reconnaissance

From the air, the Hoover Slide area, which includes the Canyon Meadows development, is roughly triangular in shape covering at least 2 square kilometers. It is flanked by topographic highs on two sides roughly to the west and northeast and by the Provo River to the east. Along the Provo River, the area extends from Horseshoe Bend on the south to Weeks Bench on the northeast. The highway closely follows along the west side of the river.

The Canyon Meadows area slopes easterly towards the Provo River. Springs were observed that drain to the east and south before they are captured by man-made ditches. Small drainages have been disrupted by local roads and fill for the current highway alignment. Roadway patching for highway slides were observed. In many cases, the locations of the slides coincided with the disrupted drainages.

The ridges that delineate the Canyon Meadows area are relatively steep sided. The central area is hummocky. The western ridge continues on to the north-northwest where it merges with the side slope of the Provo Deer Creek drainage. The Northeast-flanking ridge extends to the Provo River and appears to continue on to the east side of the river. Northeast of this ridge near the confluence of the Provo River and Provo Deer Creek, a deposit of primarily alluvial materials known as Weeks Bench has accumulated.

The Provo Deer Creek drainage flows towards Canyon Meadows but makes an abrupt direction change to the east just north of the Hoover Slide area. Effected by the Weeks Bench deposit, the channel continues to curve towards the southeast resulting in a slightly up-canyon flow direction before it enters the Provo River.

Ground Reconnaissance

The ridges and the central area were observed for any evidence of recent movement such as scarps or cracks. Other than a gentle, hummocky topography in the central area, no evidence of recent movement was found. Older slope failure features likely related to rotated or displaced blocks of the Oquirrh formation can be inferred but these features have been masked and subdued over time by erosion.

Some of the older homes in Canyon Meadows and the road system, which has been in place since the early 1980's, were observed. No cracks or distresses caused by landsliding were observed within Canyon Meadows. This includes the clubhouse that contains an in-ground swimming pool, which has not experienced any structural damage.

Mr. Victor Orvis, who is a representative for the Canyon Meadows Homeowners Association, was interviewed. Mr. Orvis described the lack of apparent slide-related cracking or effects in the internal road system, the buried water pipeline that reportedly has not leaked, or local homes. He knew of no Canyon Meadows homes that suffered from any slide-related distress, such as cracks in walls/foundations, or binding of doors and windows. Mr. Orvis checked on the condition of Helen Hall's home, reportedly built sometime between 1978 and 1982, and learned that there are no cracks evident in the foundation or walls or apparent distress affecting any of the windows or doors. Mr. Orvis also cited satisfactory foundation and wall conditions in two old condo buildings (built mid 1980's) and stated that no adverse ground movements occurred during the 1982/83 and 1993/94 wet years, which triggered many slides elsewhere in Utah. Residential sewage is disposed by individual septic systems. Some near-surface seepage has been observed. The results of percolation tests have been varied, with some not meeting infiltration requirements.

One other homeowner, Dee Olsen, was interviewed regarding the condition of his home. He was asked if there were any problems with his home that could be construed as related to active landsliding. He stated his home, located near the northeast ridge that bounds the Canyon Meadows area, has been there for 14 years and shows no signs of slide-related distress.

There are several masonry-block houses known as Hoover Cabins, located near Station 20+900 to 21+100, which have not experienced structural distress. These houses have been in place at least 50 years.

Springs in the development are found in the low spots. Trenching has been done to collect and redirect seeps. The Manning Canyon Shale weathers to low permeable clay that acts as an aquitard. Precipitation/runoff/snowmelt flowing in the surface soils daylights to form much of the spring activity. Flow is typically restricted to the surface soils by the Manning Canyon Shale residual soils; however, one larger spring observed flowing in excess of 20 to 50 gallons per minute is evidence that some springs may be fault related.

Substantial pre-historic movement is interpreted to have occurred near the contact between the Oquirrh and the Manning Canyon Formations along the low angle Deer Creek thrust fault. This displacement has brecciated (broken) and sheared the rock for some distance on either side of the fault (plastic and brittle deformation) and has reduced the rock's strength and integrity and has increased both formations' susceptibility to erosion. Locally, the damage has increase permeability and allowed greater movement and concentration of groundwater.

It has been interpreted in previous reports that blocks of the Oquirrh formation have become detached and have rafted toward the Provo River on the Manning Canyon Shale. It is possible that these blocks may be in-place remnants from faulting and erosion. Along with smaller remnant blocks these would include the topographic high forming the west flank of Canyon Meadows and the rounded hill located northeast of Horseshoe Bend along the highway. No evidence of current movement of these large blocks was observed.

We observed the various slides along the existing highway at the toe of the Hoover Slide area. The localized pavement slides were identified across from approximately Station 20+130 to 20+200, 21+140 to 21+340, 21+380 to 21+550, and 21+770 to 21+820. These slide areas were also identified by the authors in September 2000 following a recent asphalt chip seal overlay. We also observed two other slide areas south of Horseshoe Bend, at Stations 18+800 and 19+270. The first is a high talus slope slide. The second is a cut slope failure, locally known as the 'Blue Mud Slide.' Slide debris flows from the Blue Mud Slide above a rock contact in the existing cut slope, which requires frequent maintenance to remove debris from the ditch and roadway.

Haul Road

The Haul Road was observed from Horseshoe Bend to Weeks Bench. The Haul Road closely follows the proposed new alignment. Existing ground features were compared to the proposed construction using cross sections provided by BioWest and Washington Infrastructure Services. There are sections particularly where the alignment crosses Canyon Meadows or is in close proximity to the existing road and the Provo River where vertical or horizontal alignment adjustments may be beneficial.

The Haul Road begins at Horseshoe Bend. Between Stations 19+800 and 20+300, the area is geologically complex. Two normal faults and the Deer Creek thrust fault have been mapped here. Horseshoe Bend represents the approximate southern terminus of the ancient Hoover Slide Complex. Two small active landslides can be seen in the existing roadway. The subsurface materials have been disturbed and weakened by fault and slide movements.

Between Stations 20+300 and 20+700, the Haul Road passes through a topographic low (saddle) located west of a semi-intact block of Oquirrh Formation limestone. The block has been displaced and broken (brecciated) by plastic and brittle deformation caused by movement along the Deer Creek thrust fault and likely by subsequent block creep (slide movement) towards the Provo River. Upslope of the saddle to the west, the materials may be slide debris that has accumulated behind the displaced limestone block.

The Haul Road continues through the Central Hoover Slide area between Stations 20+700 and 21+850. The ground surface exhibits less relief with small drainage channels crossing the alignment. The surficial soils (clay) are mapped as Manning Canyon Shale slide debris. The average slope of the Canyon Meadows area of Hoover Slide is about 10 degrees.

Spring flow was observed discharging from a collector pipe located about 80 m south of the Haul Road, near Station 21+250. A slight sulfur odor was noticed.

From Station 21+850 (northeast side of Canyon Meadows) to Station 22+200 (Weeks Bench), the Haul Road passes through a cut slope in a side-hill (the Northeast Ridge) mapped as the Manning Canyon Shale Formation. It is gray to black limestone and shale. The cut slope has experienced some small rockfalls but otherwise is performing well.

Office Studies

The office studies included a review of published geologic maps and reports and previous consultant reports, and an evaluation of aerial and oblique photographs. The information reviewed is listed in the Reference section at the end of this report. The gleaned information was combined with the field reconnaissance data to develop interpreted geologic cross-sections used for preliminary stability analyses.

Aerial Photograph Interpretation

The airphotos spanned a period of 45 years and showed changes to U.S. 189 and on-going residential development. Geologic units were distinguished and compared to published geologic maps. Bedrock units and slide features were identified such as the central part of the Canyon Meadows development, which displayed hummocky topography characteristic of the Manning Canyon Shale and past slide activity. Small slides were observed but no active large-scale slide block movements could be seen upslope of the existing highway.

The various ridges and other topographic features were studied for possible trends and similarities. The ridge separating SR-92 (Sundance) and the Hoover Slide area appears resistant, while its northeasterly flanks have the appearance of separated slump blocks. The ridge to the northeast of Hoover slide is nested among other similar smaller ridges that align NE – SW and appear deeply eroded, but no signs of landsliding are apparent in that location.

The pond near Station 20+930 appears to have been constructed between 1959 and 1962. Downslope of this pond are the Hoover Cabins, located in a topographic low. The drainage path across the Hoover Slide area appears to be generally directed towards the Hoover Cabins area (about Station 20+800 to 21+100). There are other localized drainage exits, such as near Stations 21+250, 21+470, 21+630, 21+820, etc. Higher elevations in the north perimeter of Canyon Meadows appear drier in several of the aerial photographs studied.

Subsurface Conditions

The boring logs in the Canyon Meadows area indicate that the remnant of apparent ancient slide/thrust fault debris averages roughly 20 meters deep. The slide debris consists of unstratified sand, silt, and clay from weathering of the Manning Canyon Shale and the Oquirrh Formation. Groundwater levels have been relatively shallow. At least one recent boring encountered artesian water at depth, which might have an influence on the slide shear zone. The Hoover Slide area contains numerous surface seepage zones and springs. Reference 48 (1960) recounts exploration information where: "holes 4 and 6 the water level was noted to rise rapidly upon penetration of granular layers indicating the presence of isolated aquifers under hydrostatic pressure."

Deer Creek Dam is sited over alluvial deposits about 25 to 30 meters thick at the downstream end (Ref 15). This indicates that sediment thicknesses may be deep in the Provo River at the toe of the Hoover Slide area (unless displaced by slide debris).

Geologic Interpretations

Most interpretations of the Canyon Meadows/Hoover Slide area are based on early work by Baker and Bryant (ref. 15). Previous UDOT consultants have interpreted a large deep-seated landslide below Canyon Meadows that is exiting in or beneath the current Provo River bed.

Baker described the Sulphur Springs Window through the Oquirrh formation exposing the Manning Canyon Shale as an erosional feature. Previous efforts have not described the means of erosion, but the presence of the Hoover Slide could be a cause. Blocks of the Oquirrh formation may have rafted into the Provo River over geologic time creating the window. The blocks would eventually be broken down and carried away by river action. The isolated blocks of the Oquirrh formation still present within the

Sulphur Springs Window may be displaced slide blocks that did not reach the river and have since come to a halt.

Some of the isolated outcrops of the Oquirrh formation may simply be erosional remnants. Erosion by an older, displaced channel of Provo Deer Creek or a downstream blockage resulting in a channel change of the Provo River may have been a recurring geologic process. From the air, the upper part of the Provo Deer Creek aligns to intersect with Canyon Meadows. Determining if Provo Deer Creek ever flowed through the Meadows area in the past could not be accomplished during this short reconnaissance.

Whether a block of Oquirrh Formation is in-place or has been displaced can be estimated by comparing the elevation at the base of the block, where it rests on the Manning Canyon Shale, to the in-place contact elevation exposed in the Sulphur Springs Window. Obvious lower contact elevations could indicate that down-slope slide movement (rafting) has occurred. Overall, it is likely that a combination of ground movements and erosion have led to the formation of the Sulphur Springs Window, which is much larger than the Canyon Meadows area.

To the northeast of Horseshoe Bend, a block of Oquirrh Formation is separated from the main canyon walls. The block appears to have a contact elevation well below that of the exposures in the Sulphur Springs Window. Although it is bounded by previously mapped normal faults, the elevation difference suggests that it may be a displaced, rafted block. Upslope of this block is a saddle area of filled-in sediments, which could be slide debris. These materials exhibit gentle natural slope angles.

To the south of this block is a mapped slump, with a significant tension crack in a depressed area above the highway cutslope (Ref 28, Lund, 1980). Seepage zones were identified at the highway ditch and downslope towards the railroad. Above the highway cut is an old drainage swale, which has been dammed by a small section of fill.

Regardless of how the Sulphur Springs Window was formed, the Manning Canyon Shale has been disturbed and weakened at depth by the Deer Creek thrust fault and associated tectonic activity. Borings within the Canyon Meadows development disclosed disturbed materials present to roughly 20 meters deep with weathered clay zones below that. Residual shear strength of the "near-surface" materials should be used as the effects of the proposed highway construction across Canyon Meadows are evaluated. Because no movement can be observed at the surface or in any of the deep inclinometers upslope of the existing highway, an assumed failure surface will need to be analyzed.

REVIEW OF INCLINOMETER DATA

Overview

Landslide Technology has performed a review of inclinometer data collected in the vicinity of the Hoover Slide Area. Erik Mikkelsen reviewed key inclinometer graphs to confirm our interpretations. Inclinometer casings have been installed by three groups: 1) UDOT, 2) Delta Geotechnical for Parsons-Brinckerhoff, and 3) Terracon. UDOT supplied a separate digital file of inclinometer readings for each group listed. The following paragraphs provide summary comments about the inclinometer data and the UDOT summary report "Provo Canyon Inclinometers," June 22, 1999 (Ref 46). Refer to Table 1, "Hoover Slide Inclinometer Review Summary," which includes a summary of the instruments and our evaluation comments.

UDOT Inclinometer Casings

Inclinometers installed within active slide areas (at the existing highway) have generally identified the depth of slide movement. However, some of the inclinometers in active slide areas have not shown shear movement. Inclinometer HC001 was previously interpreted as showing movement at a depth of 40 feet; however, we conclude that the inclinometer data does not show slide movement. Inclinometer HC001, as well as HC005 and HC007, near Station 21+360, were installed in or near the active slide in the existing highway, but the limited instrumentation readings do not showing slide movement. It is interpreted that the slide zone at HC001 is somewhere in the 23 to 28m depth range. HC007 was prematurely damaged in 1995 (run over by a vehicle) and HC005 was terminated in 1994, therefore there was not sufficient time to record movements in those inclinometer casings.

Inclinometers installed upslope of the existing highway and into Canyon Meadows do not indicate movement, in our opinion. Inclinometer HC012 was previously interpreted as showing movement at a depth of 56 feet; however, we conclude that it does not show slide movement. Inclinometers HC012, HC013, HC016, HC018A, and HC020 show variable inaccuracies within the range of the instrument, and do not indicate shear movement. These deviations are likely caused by bias-shift and sensor alignment shift (rotation error).

Parsons-Brinckerhoff Inclinometer Casings

Inclinometers were installed along or near the proposed highway alignment. No apparent slide movement is observed in these borings (HPB-01 through HPB-15). Inclinometer HPB05 shows a wave-like distortion from 25 to 52-foot depth. A similar casing distortion is observed in several other casings in this group. This type of distortion is likely caused by consolidation of backfill material around the casing during installation and for a certain amount of time following installation. This can occur where unconsolidated cuttings become lodged in voids outside the borehole diameter during the drilling process. In general, the reading sets appear accurate due to the low standard deviations of the check sums, and no movements have been detected.

Terracon Inclinometer Casings

These inclinometers were installed under the direction of the Canyon Meadows Association and are located within their subdivision. The data shows no signs of shear movement, but existing data is based on 5-foot measurement intervals. This reading interval may not capture slide movement accurately because the 5-foot reading interval is significantly larger than the 2-foot length of the instrument probe. As evidenced in other inclinometer casings in local active slide areas, the slide plane is on the order of 2 to 4 feet thick. If similar shear movement were occurring in these casings, the 5-foot reading interval might skip the zone of movement and not capture this information. It is our understanding that new initial readings based on a 2-foot reading interval have been measured.

Evaluation of Interpretations by Others

The report by AGRA (Ref 5, 1997) contains a review of inclinometer data. AGRA's report states, "The inclinometer casings located upslope of the existing Highway 189, on and adjacent to the Canyon Meadows area, show dispersed movement of small magnitude with inconsistent direction that we believe are within the range of measurement error of the instrument." In Landslide Technology's opinion, the 'dispersed movements' are not related to slide movement. The AGRA report further stated that they "conclude that the movement occurring at Hoover Slide area is restricted to the area along and adjacent to the Highway 189." Landslide Technology concurs with this latter interpretation; however, the upper area might be marginally stable and might experience movements in the future.

Terracon installed two inclinometers (Ref 43, 1998). They concluded that their inclinometer (HCT02) and UDOT's (HC018) showed some shear displacement. They also concluded that their inclinometer (HCT01) and UDOT's (HC020) showed "possible" movements. In our opinion, the apparent movements indicated are not related to landslide movement, but are deviations that are likely caused by bias-shift and sensor alignment shift (rotation error).

AGEC (Ref 4, 1998) provided an analysis of inclinometer data. Their findings are unusual in that they interpret movements in the inclinometers in Canyon Meadows with an average movement rate of 0.69 inches per year. This would translate to about 3 inches in 5 years. This magnitude is difficult to believe, based on the lack of apparent slide-related problems in the internal road system, the buried water pipeline, and older homes. AGEC goes on further with an attempted correlation of these apparent movements to average monthly precipitation. Landslide Technology found no inclinometer instrumentation evidence that supports AGEC's slide movement interpretations.

Both the Delta and PB geotechnical reports (Ref's 21 and 39) interpret ground movement in some of the inclinometers located upslope of the existing highway. As previously stated, Landslide Technology's review of inclinometer data concludes that no landslide shear zone movement is evident yet in these upslope borings.

Table 1: Hoover Slide Inclinometer Review Summary

Inclinometer Hole Number	Depth of Hole	Depth of Shear	Comments
UDOT Borings			
HC001	96'	No Observed Shear in SI data to 78'	Casing is blocked at 78', therefore the Shear Zone is below 78'.
HC002	88'	~18'	
HC003	118'	~32'	
HC004	58'	~47'	
HC005	38'	No Observed Shear	Is Shear Zone Below Bottom of Casing?
HC006	64'	~54'	
HC007	78'	No Observed Shear	Is Shear Zone Below Bottom of Casing?
HC008	72'	~20'	
HC009	76'	~44'	
HC010	66'	~26'	
HC011	92'	No Observed Shear	
HC012	94'	No Observed Shear	
HC012C	92'	No Observed Shear	High Standard Deviations in Check Sums
HC013	118'	No Observed Shear	High Standard Deviations in Check Sums
HC014		NO SI Casing	
HC015	78'	~52'	
HC016	98'	No Observed Shear	High Standard Deviations in Check Sums
HC017	88'	~28'	
HC017A	88'	~30'	
HC018	144'	No Observed Shear	
HC018A	206'	No Observed Shear	High Standard Deviations in Check Sums
HC019	94'	~40'	
HC020	148'	No Observed Shear	High Standard Deviations in Check Sums
HC021	102'	~20'	
HC022	114'	Insufficient Data	
HC023	58'	Insufficient Data	
HC024	58'	Insufficient Data	
PB/Delta Borings			
HPB01	130'	No Observed Shear	Region of Backfill Movement
HPB02	144'	No Observed Shear	
HPB03	108'	No Observed Shear	Region of Backfill Movement
HPB04	80'	No Observed Shear	Region of Backfill Movement
HPB05	116'	No Observed Shear	Region of Backfill Movement
HPB06	124'	No Observed Shear	
HPB07	74'	No Observed Shear	
HPB08	116'	No Observed Shear	Region of Backfill Movement
HPB09	56'	No Observed Shear	Region of Backfill Movement
HPB10	78'	No Observed Shear	Region of Backfill Movement
HPB11	112'	No Observed Shear	
HPB12	58'	No Observed Shear	
HPB13	58	No Observed Shear	
HPB14	144'	No Observed Shear	
HPB15	98'	No Observed Shear	
Terracon Borings			
HCT01	90'	No Observed Shear	Evaluate New Data on 2-foot Intervals
HCT02	150'	No Observed Shear	Evaluate New Data on 2-foot Intervals

STABILITY STUDIES

The objective of the analyses is to evaluate the approximate static level of slide stability, before and after highway realignment. The landslide parameters were approximated, given that the existing data and ancient slide geometry is incomplete. Several slide mitigation concepts were analyzed to evaluate the relative benefits and applicability of mitigation measures. The XSTABL program was used for the comparative stability analyses.

Assumptions used in stability studies included:

- Slide shear zone residual shear strength phi (angle of internal friction) equals 10 to 15 degrees (no cohesive intercept for residual condition). The existing laboratory test data for this project show remolded sample shear strengths in the order of 13° to 20°. However, these tests might not have measured the true residual strength, which could be lower.
- Slide mass shear strength (first time sliding) of 30 to 35 degrees (active and passive areas).
- Groundwater (assumed at the ground surface during critical stability; there could be a localized artesian influence on the slide shear zone, so a 3-meter rise in pore pressures was also analyzed).
- Seismic effects are qualitatively evaluated.

Horseshoe Bend Fill Section (Sta. 19+800 to 20+300)

The proposed highway alignment climbs eastward up the steep sidehill above Horseshoe Bend. This hillside is interpreted to be a remnant of ancient landslide debris, probably associated with the larger Hoover Slide. It is located near the westerly fringe of the mapped Sulfur Springs Window and is affected by a series of pre-historic faults. Manning Canyon Shale overlain by disturbed materials are evident in the logs of nearby borings. The disturbed materials could be fault-related (gouge, shear zone, secondary fractures, etc.) and/or slide-related (slide debris, float blocks, etc.).

A drainage area runs through this section, probably forming a zone of shallow groundwater. The drainage area crosses the preferred alignment at about Station 20+120. An old scarp and slump block are interpreted in a sag in the ground slope close to the new highway alignment (mapped by Lund, Ref 28). There are two small active slides along the existing highway, which appear to extend down to the Provo River. The larger zone of interpreted ancient slide debris could be marginally stable. Changes in ground topography, loading, and/or drainage could reactivate ground movements.

During haul road construction, cuts and fills (including disposal fill) were made in this area.

Two cross-sections at Stations 20+115 and 20+240 were analyzed to study the potential change in slope stability. Assumed failure surfaces were interpreted utilizing subsurface information from three nearby borings and previously mapped features. Many variations of subsurface conditions and failure surfaces are possible; therefore these studies are limited to indicate preliminary trends only.

The preliminary analyses demonstrate that slope stability could decrease if an earthfill embankment is placed upslope of the existing highway. Decreases in the Factor of Safety of up to 11 % were calculated. If the existing Factor of Safety is marginal, i.e. less than 1.2, instability could result from embankment placement. The likelihood of instability would increase if the embankment foundation were subjected to critical groundwater conditions in an extremely wet season. Figure 5 presents a representative conceptual stability analysis cross section, with assumed parameters.

Side hill cuts made in ancient slide debris could also be potentially unstable. Cut slopes can remove critical lateral support from slide debris hillsides. Cuts slopes might also be locally unstable if available shear resistance is poor or if the groundwater level is near the surface.

Saddle Area (Sta. 20+300 to 20+700)

The 'Saddle Area' is generally interpreted as ancient slide debris that has collected behind a displaced block of Oquirrh limestone. This area may also have been subjected to erosion by historic streamflows. Surficial materials are granular and recent localized small cut slopes currently appear stable. However, these cut slopes have only existed a few years and have not been subjected to extreme wet seasons.

The interpreted slide debris above the Saddle Area may extend as much as a kilometer upslope. There is insufficient data to evaluate stability of existing and proposed cut slopes. There is a risk that this slope might become unstable when lateral support is removed resulting in raveling and slumping, and possible slide retrogression upslope.

Central Hoover Slide Area (Sta. 20+700 to 21+900)

This section is within the Sulfur Springs Window, where the Oquirrh Formation is missing and the Manning Canyon Shale and interpreted slide debris is exposed. The ground slope is relatively flat averaging about 8 to 10 % and is conspicuously flatter than the surrounding natural terrain. Springs are evident across this area, which suggests a groundwater discharge area. Some springs appear to be influenced by artesian pressures, with water heads affected by groundwater within the nearby foothills.

In our opinion, this area has likely experienced ground movements in geologic time; however there is no evidence of movement in the Canyon Meadows area over the past five decades, including any seismic ground motions during that time span. Several displaced blocks of Oquirrh limestone appear within the interpreted slide debris. It is possible that the interpreted slide debris is not actually slide-related; however, the clay and mixed materials can represent a low strength condition and therefore would still be a potential stability concern. Local slides have occurred along the existing highway, towards the Provo River (Ref 28, 48, 49, 51). These localized slides extend (downslope of new alignment stationing) from about Sta. 21+100 to 21+600, with one other small slide at Sta. 21+850.

Issues affecting stability at these highway slide areas include concentrated groundwater conditions, low shear strength clays, and increased loading from embankment fills, as well as preexisting conditions caused by historic undercutting by the Provo River. Two cross-sections were studied to analyze the potential change in slope stability (Sta. 21+310 and 21+470). Assumed shear zones were interpreted utilizing subsurface information from the UDOT borings in the active slide areas and previously mapped features. Upslope of the existing highway, the subsurface conditions and possible slide debris depths (about 20 meters) were interpreted from borings made by PB, UDOT, and Terracon. For conceptual analyses, the groundwater level was assumed at the ground surface. The assumed residual shear strength of the clay was $\phi_r = 15^0$ (Ref's 21, 39 and 48).

Many variations of subsurface conditions and failure surfaces are possible, but only a few were modeled at this time. These studies are limited to indicate preliminary trends only. The preliminary analyses confirm that unstable conditions can be modeled at the existing highway slides. However, relatively high values of calculated Factors of Safety (FS possibly 1.5 to 1.9, assuming a residual shear strength of 15 degrees) were obtained for the ground extending upslope into Canyon Meadows because of the relatively flat ground surface and large mass involved. Back-analyses were performed for the ancient slide mass (assuming marginal stability) for a FS of 1.0 and 1.2; the back-calculated residual shear strength would need to be about 8 and 9.5 degrees, respectively. These back-calculated values are lower than the published strengths previously tested for this landslide clay (about 13 to 15 degrees), but are not unreasonable. The range of possible residual strength could therefore be 8 to 15 degrees.

Preliminary analyses at the new highway alignment demonstrate that localized slope stability could decrease if an embankment is placed upslope of the existing highway. Decreases in the Factor of Safety of up to 12 % were calculated for the few preliminary analyses performed (assumed embankment height of 10m). Unknown is the current level of stability and whether a 12 % decrease would result in marginal levels of stability. Fortunately, the current alignment does not have many embankment sections, and where embankments are planned, the heights are not very large.

If the existing Factor of Safety is marginal, instability could result from embankment placement, especially when subjected to critical groundwater conditions during an extremely wet season. Fills could also consolidate the underlying ground and slightly decrease permeability, which could cause a build-up of groundwater upslope (and a resultant decrease in ground stability).

Preliminary analysis of proposed cuts for the new highway alignment indicate that the stability of the area upslope could decrease about 7 to 13 %, based on excavation depths of 5 to 10 meters, respectively. A key assumption that influences the stability analyses is the strength of the soils in the passive block underlying the cut slope and roadway. The current shear strength assumption is an angle of internal friction of 30^0. The Factor of Safety would be further reduced if groundwater levels increase. Conversely, mitigation measures to lower the groundwater levels could raise the calculated Factors of Safety.

Northeast Ridge, Hoover Slide Area to Weeks Bench (Sta. 21+900 to 22+000)

There are no borings along the ridge; therefore no analysis section could be interpreted. Borings PB-11 and PB-10 are located on either side of this ridge, along the proposed highway alignment. PB-10, at the Weeks Bench side of the ridge, shows that Great Blue Limestone Formation is located 6 meters below the ground surface. The exposed conditions in the cut slope show highly fractured limestone layers, possibly interfingered with shale layers. In our current opinion, this material appears to be part of the Manning Canyon Shale Formation. The geology map prepared by Delta Consultants (Ref 21) has mapped the ridge as Mmc (sh), indicating the shale member of the Manning Canyon Formation. If these are the correct interpretations, then this ridge may be outside the zone of landsliding.

If instead the limestone is associated with the Oquirrh Formation and involved in the low-angle thrust faulting, then a weak basal contact may exist with the underlying Manning Canyon Shale. It is possible that the delta and alluvial deposits in Weeks Bench have a buttressing effect on this ridge. There is no evidence of recent movement.

Seismic Considerations

Several normal and thrust faults have been mapped in this vicinity, and are considered to be old. There are no known active faults in the immediate Hoover Slide area. The upper Provo Canyon is located within the Intermountain Seismic Belt (ISB), a 100-km wide zone of active seismicity. Two earthquakes of magnitude M>7 and about twenty M>6 have occurred since the 1880's (see Ref 21, Delta). The Wasatch Front fault zone (Olmstead) is considered to be recently active (Ref 22). Another seismic source is the Round Valley faults (Ref 21). A large regional earthquake could cause seismically induced ground shaking at the Hoover Slide area.

In our opinion, large-scale seismically induced ground motions may have a significant impact on slope stability in Provo Canyon, regardless of whether further highway construction occurs. Ancient slide areas can be particularly vulnerable. The Hoover Slide area is difficult to quantitatively model for stability under seismic conditions because not much is known about the subsurface geometry of the ancient landslide or the key variables of groundwater and shear strength during the seismic events. The dynamic shear strength along the ancient shear zone could be higher than the residual angle of internal friction. Temporary cohesive undrained strengths could be mobilized due to rapid seismic ground motions.

On the other hand, seismically induced pore pressures could result in higher levels of buoyant forces acting on the slide shear zone and could redistribute over several days/weeks, which could reactivate slide movements. Analyses would need to evaluate many possibilities, preferably augmented with more extensive and precise subsurface data and special laboratory testing. At this time, seismic analysis of the Hoover Slide would be premature and conjectural. Parametric and sophisticated analyses have been performed by others; however, some of the inputs are well beyond what is known about this slide and assumptions are used without adequate basis. Even with additional data, such analyses would be subject to a broad range of results and interpretations.

The basic conclusion that we can make at this time is the Hoover Slide is an ancient slide that is marginally stable and that large seismic events might cause portions of the slide to move. If the static Factor of Safety of the ancient landslide is not reduced by highway construction, then it can be reasoned that the seismic behavior of the ancient landslide also would not be affected by the highway.

Large Scale Landslides

It is possible that extreme wet weather conditions can cause increases in regional and perched groundwater levels that could cause slow reactivation or even rapid flow landslides to occur. An example is the Thistle Slide (US-6). The ancient Hoover Slide is bounded by foothills that appear to have slumped a significant time ago. These slump blocks might move if subjected to a significant change in earth and water pressures, as well as external forces.

If such large-scale landsliding occurs, the Hoover Slide area and Canyon Meadows could experience ground movements, cracks, distortions, and changes in groundwater patterns. Based on available information, the Canyon Meadows and foothills area did not experience large slide movements during the record wet season of 1982/83. This appears to be favorable information. However, it is difficult and speculative to predict the possibility, level and consequence of larger landsliding at this site.

CONCEPTUAL MITIGATION MEASURES

The various alignments considered for the 4-lane facility would have landslide and slope stability risks. The design approach should be to reduce the risks and to anticipate long-term maintenance. Since actual Factors of Safety of existing conditions are difficult to determine accurately, and because of ancient and recent slide conditions, we recommend that new construction be designed to avoid decreasing the Factor of Safety below existing levels. Based on the apparent stable ground performance during the record wet season of 1982/83, this status quo approach should be prudent.

The following mitigations are suggested at this conceptual phase. We recommend that additional explorations be performed to verify assumptions and to provide specific parameters for Final Design.

Horseshoe Bend Fill Section (Sta. 19+800 to 20+300)

The slope appears to be marginally stable. There is a risk that landslide movements could retrogress uphill and affect the new roadway. Avoid placing weight on the slope and existing roadway. Consider extending foundations into bedrock, below materials suspected to be slide debris, to support added loads from the new road embankment. This may consist of deep pier foundations to support a viaduct or bridge. The deep piers would need to be designed to resist lateral forces from potential future slide creep. Alternatively, embankments or MSE walls could be founded on deep foundations that transfer the loading down to bedrock, such as stone columns or piles. Lightweight fills and deep drainage systems might be reasonable alternatives to maintain ground stability. Design of drainage systems would require sufficient measurements of the groundwater level over time and determination of the relative overall permeability.

The use of temporary or permanent cuts should be minimized to avoid a reduction in stability upslope. Cut slope reinforcement might be needed.

Saddle Area (Sta. 20+300 to 20+700)

The excavation depth and cut slopes could be minimized to reduce the risk of triggering slope instability above the highway. Specific mitigation methods may need to be developed after additional explorations identify actual subsurface conditions.

It is not certain whether drainage systems would help improve stability because the existing groundwater levels are not known. Groundwater instrumentation is recommended. An option would be to accept the uncertainty of slope performance, given that the cut slope materials (upper slide debris) appear to be granular and because no residences exist in the immediate area.

A ground anchor system could be considered to restore lateral support in large cut slopes. Anchors may need to be relatively long to extend through the anticipated deep thickness of slide debris and into undisturbed Manning Canyon Shale. Subsurface conditions should be investigated to determine the lateral extent for tiebacks to be anchored into stable bedrock. We recommend not using soil nails in slide debris materials, because slope movements can cause loss of internal stability.

A permanent easement should be obtained for possible underground reinforcement and drainage. The easement would extend to the north of the alignment, possibly up to 200 meters.

Central Hoover Slide Area (Sta. 20+700 to 21+900)

The earthwork should be balanced within the areas that are suspected to be more vulnerable to sliding. For planning purposes, we recommend that cuts/fills be balanced within each 100 meter segment along the alignment. This would require the adjustment of vertical and horizontal alignments. Lightweight fills could be used where fill crossings are unavoidable in order to keep the weight balanced.

In addition, deep drainage trench measures are recommended to facilitate the flow of groundwater beneath the new roadway as well as to improve stability. One drainage measure could consist of a network of deep (4-5-meter) trench drains, placed upslope of road cuts and beneath the roadway, with positive discharge down to the river. Horizontal drains might be beneficial as a supplementary method (second tier), but could perform erratically due to the poor permeability of the plastic clay soils.

The small dam and pond at Station 20+930 are located in an area of groundwater seepage, which presents potentially difficult conditions for the new highway alignment. Measures to reduce groundwater impacts, such as deep drainage trench systems, embankment reinforcement, and possibly drainage of the pond should be considered. Another option for the pond, but not as effective as drainage, would be to provide a permanent geosynthetic liner to prevent infiltration.

An apparent slide block is traversed by the preferred alignment from Sta. 20+970 to 21+050. Cut slopes in this block will likely encounter weathered and fractured Oquirrh formation. The angle of the cut slope will depend on the condition of the materials and the level of groundwater.

We understand that many new houses are planned for construction in Canyon Meadows (possibly 80 more). These homes each will have septic systems with relatively shallow drain fields, which could result in some infiltration and contribute to groundwater levels across the Hoover Slide. Runoff from developed property will be another potential contributor to changes in groundwater conditions. The Canyon Meadows Homeowners Association is also planning to create landscaping stream channels by intercepting sulphur springs and pumping the water upslope to feed the new streams. The likelihood of further development should be considered in highway drainage system design, since future groundwater flow rates might increase and critically high water levels might occur more often. Such conditions could have a destabilizing effect.

A special stabilization design might be required near Station 21+800 because the new alignment comes close to the existing highway and an existing local slide area. Subexcavation with a localized buttress, along with subdrainage, should be considered for support of the new roadway. Alternatives include lightweight fill and MSE walls with subdrainage systems.

We recommend not using soil nailed walls in slide debris materials. Slide movements can cause loss of internal stability. Also, tieback anchors installed in large ancient slide masses would be vulnerable to overstressing failures in the event of large-scale landsliding and seismic events. Designs can account for anticipated seismic motions.

Northeast Ridge, Hoover Slide Area to Weeks Bench (Sta. 21+900 to 22+000)

At this time, no special mitigation measures are recommended, based on the performance of the existing Haul Road cut slope and the interpretation that favorable Manning Canyon Shale and Great Blue Limestone conditions exist. However, this interpretation needs to be verified. There is a slight possibility that this ridge may be comprised of the Oquirrh formation limestone, as interpreted in the geologic literature. If it is, it may be a rafted block with a weakened contact zone with the Manning Canyon formation and the cut slopes may require special stability mitigations.

ADDITIONAL OBSERVATIONS AND OPINIONS

Landslide Technology also made a brief review of the slope conditions west of Horseshoe Bend; particularly two slide areas at Stations 18+800 and 19+230. In general, cut slopes may encounter highly fractured and weathered rock conditions. Structural conditions and discontinuities will influence cut slope performance. Final Design should include geotechnical verification of the slope conditions and the preliminary recommendations in the PB reports (Ref's 39 and 40).

Where cut slopes are not practical (because of high sliver cuts), alternative support may be needed. Options include rockbolts and tieback walls.

Soil nailed walls should be carefully evaluated since they may not be dependable in slide-prone areas, particularly when the ground experiences movement.

Design of rock cut slopes should be refined based on verified structural conditions of the rock units (bedding, joints, etc.).

The talus slope slide area from Sta. 18+760 to 18+910 should preferably be avoided (should not remove lateral support from the toe of the slope). This could be accomplished by widening the roadway towards the railroad with a fill wall or possibly by raising the road grade. Rockfall from the loose and irregular talus should be expected and therefore rockfall mitigation measures should be included. If a cut must be made into the talus slope toe, then a special tieback wall and a rockfall catch fence may be required.

There is a slide above the roadway in the existing cut at Sta. 19+230 known locally as the Blue Mud Slide. Consider avoiding this cut by realigning closer to the railroad. If the cut slope must be encroached, then special stabilization will be required. Tieback walls should be considered for the upper portion of the cut (overburden and weathered fractured rock). Rock bolts may be required in the lower portion of the cut in the jointed limestone bedrock. We recommend against soil nails in this marginally stable soil because ground movements could cause loss of reinforcement. A rock inlay might be an alternative mitigation method. Evaluations should be made to identify whether seepage exists so that appropriate protection can be provided.

Additional explorations may be required for cut slope/wall designs, as well as for fill walls. Soil and rock cut slopes, including associated walls, in this project section should be evaluated for overall stability and hazards. The rock slope kinematic and CRSP analyses should be studied and PB's recommendations for the Preferred Alignment should be re-evaluated.

The Preferred Alignment east of Station 22+000 crosses Weeks Bench immediately upslope of the existing highway. This area appears stable; however, major changes should be evaluated to verify that unstable conditions are not created. Further northeast, the alignment crosses over the highway and railroad as it traverses across the Deer Creek Dam spillway. The proposed embankment section on the downstream face of Deer Creek Dam, with MSE walls and structure crossing the spillway, should also be evaluated with more detailed stability analyses.

Studies are currently being performed by the Bureau of Reclamation to improve the stability of the Deer Creek Dam to resist seismic motions (Ref's 15 & 16). The Bureau of Reclamation and UDOT are evaluating design issues and options that are common to both projects. The highway alignment alternatives east of the dam consist of a viaduct in the reservoir and a rockfall/avalanche protection shed against the existing road cut. These alignments will require geotechnical explorations for Final Design.

RECOMMENDED FURTHER STUDIES AND INVESTIGATIONS

The recommended mitigation measures herein are at a concept level, based on limited and incomplete data. While many borings have been drilled, they do not provide sufficient data for Final Design. Some borings did not extend deep enough to identify the bedrock contact beneath the slide debris. In some other cases, it appears the rock unit was possibly encountered (judging by the high SPT blow counts obtained), but the material classification reads as though it is slide debris when it might be stressed from ancient faulting. Various designs and mitigation measures will require additional subsurface explorations, testing, monitoring, and analysis. We recommend that investigation locations that benefit from 1 to 2 years of instrument monitoring be implemented this summer. Critical information would include the range of groundwater levels and possible ground movements that could occur during spring snowmelt. The following issues should be evaluated in further detail.

1. Foundation conditions for the proposed ramped highway northeast of Horseshoe Bend should be explored with continuous sampling because of the suspected landslide materials. There are no existing borings on centerline where fill is proposed. Groundwater could be elevated in this location and therefore could influence stability. Reliable geologic cross-sections are required to perform reasonable stability analyses. Instrumentation should determine the highest groundwater levels that likely occur during springtime and confirm that no ground movements are occurring. Options for this highway section could include a viaduct/bridge with deep pier foundations into bedrock, embankment foundation improvement, drainage systems, or a lightweight fill. Testing and evaluation of drainage system effectiveness should be performed. The designs would also need to address lateral loading if creep occurs or if slide movements are reactivated.

2. The construction of the ramped highway northeast of Horseshoe Bend should be evaluated for feasibility while maintaining one or two lanes of highway traffic. The set of cross sections we were provided shows the MSE wall using most of the available highway width. An alternative design would be to use a viaduct structure for the ramped highway and to align it so that center piers could be located between the existing highway and the railroad. This suggested alignment would probably leave at least one lane open to traffic during construction, and might be able to accommodate 2 lanes if stage-constructed. The viaduct option would satisfy the stability concerns raised in Item 1 above by extending the pier foundations into bedrock. Additional subsurface explorations during Final Design would be needed to identify foundation conditions at each pier location.

3. The proposed cut slope in the Saddle area should be further explored with borings down to bedrock. The previous borings did not penetrate into bedrock and therefore new deeper borings are recommended. An interpreted geologic cross-section should be developed to understand the stratigraphy that could be impacted by the large excavation. Using the new information, local and global stability analyses should be performed. It is possible that additional right-of-way (or subsurface easement) will be needed if high-capacity ground anchors are used to offset the impact of removing lateral support. Groundwater levels will be a factor in the stability of cut slopes.

4. A small dam and drainage swale exists to the east of the Saddle area. This area is also underlain by slide debris. The previous borings did not penetrate into bedrock and therefore new deeper borings are recommended. Groundwater levels should be measured at depths corresponding to interpreted slide shear zones. Stability analyses should be performed to verify that the new embankment will not reduce stability locally and that lightweight fill is not needed. Piezometric pressures in this area are important, given the significant seepage path associated with the sulphur springs. Testing and evaluation of drainage system effectiveness should be included.

5. The central area of the Hoover Slide should be investigated with several deeper borings (down to river elevation) to reliably develop interpreted geologic cross-sections for stability analyses. Continuous sampling should be performed to identify various clay layers and potential slide zones. When SPT values exceed about 40 blows per 0.3m (1-foot), coring should be performed to check where Manning Canyon Shale or other firm strata occur.

   Deep piezometers (at various depths) should be installed to determine groundwater pressures along potential slide zones. Triaxial shear strength testing should be performed on undisturbed samples obtained from the new explorations, since the strength assumption in the passive block beneath the roadway could be an important stability parameter. Shear strength testing could be performed during Preliminary or Final Design. Stability analyses and mitigation design will be necessary.

6. The small slide area near Station 21+800 should be further investigated and instrumented since the new roadway comes very close to the active head scarp. Stability analyses and mitigation design will be necessary.
7. The ridge along the northeast side of the Hoover Slide should be evaluated with mapping of the haul road cut slope and by drilling a deeper boring from the haul road. Tests should be performed on the limestone layers found in the cut slope to determine whether this ridge is in-place Manning Canyon Shale or a translational slide block of Oquirrh limestone.
8. Check classification of existing soil and rock samples would help to evaluate whether the materials are in-place or disturbed. Initial evaluation of boring logs leads us to question whether deeper (>20m) materials are actually slide debris or soil zones in the Manning Canyon Shale Formation. Another explanation might be distortion and fracturing due to forces from pre-historic faults. The results of this check classification would help in the interpretation of potential slide shear zones for stability analyses.
9. In general, an evaluation of the constructibility of the proposed geotechnical design elements should be completed. Maintaining traffic on US 189 during construction will be a major design criterion. In several cases, the proposed locations of cut slopes, embankments and walls will have a dramatic effect on possible construction staging. Staging limitations could require adjustments to the final selected alignment and changes to the design elements used. Making these decisions now would allow the environmental evaluation process to be properly applied and avoid complications later.

Recommended Explorations and Instrumentation

Deep borings should be drilled in critical locations to determine detailed stratigraphy and piezometric pressures at depth. Many of the borings should be continuously sampled. Where instrumentation is recommended, the borings should be drilled as soon as possible in order to accumulate data for at least one full year prior to construction (preferable to have more monitoring time since some years are drier than normal). In addition, some design issues may need to be evaluated before the final alignment can be resolved with confidence.

Some investigations should be performed at least 1 to 2 years prior to Final Design in order to collect time-dependent data across various seasons, and for clarifying greater risk issues prior to advertising for Design-Build proposals. The borings would include a program of piezometers to improve understanding of groundwater levels and artesian influences, preferably at the estimated slide shear zone depth. Since the depth of the shear zone is not usually known, several piezometers should be installed at different depths to bracket the probable depth range. Permeability testing using packer equipment inside the boreholes could be performed to evaluate the relative permeability of areas identified for possible groundwater lowering measures. We recommend conducting instrumented test horizontal drain programs to determine the effectiveness of this subdrainage mitigation measure. This test program would need upslope piezometers to measure the effectiveness of the groundwater lowering measure. Other explorations and testing are likely to be performed during Final Design to obtain site-specific data for foundations, anchors, slopes, walls, etc.

CONCLUSIONS

This peer review study has evaluated significant geotechnical landslide / stability issues and concerns along the Preferred Alignment from Station 20+000 to 22+000. This report includes recommendations for conceptual mitigation measures and immediate SEIS-level and Final Design investigations.

The project is situated in a complex geologic environment affected by several ancient faults that have displaced and sheared the rock units. Extensive erosion of the Oquirrh Formation has created the Sulphur Springs Window, with associated down dropping and sliding (rafting) of rock blocks and sedimentation by streams and debris/earth flows. Exacerbating this marginally-stable condition is the presence of shallow groundwater, numerous springs and several artesian zones. A goal for project development is to develop a roadway design that will maintain the level of stability that currently exists where the Canyon Meadows subdivision is located.

The project alignment and widening will necessitate new cuts and embankments that could require special construction considerations given the geologic complexity and hazards. Previous experience from the highway improvements made to the west of Wildwood, as well as slide repairs and maintenance in the Hoover Slide area, can provide valuable insights for development of the current highway section.

There are landslide and stability risks along both the existing highway and the Preferred Alignment; however, the effort to maintain stability along the Preferred Alignment appears to be less costly and less risky. The difficult geotechnical issues for the Preferred Alignment include: ramping up the west flank of the Hoover Slide area, large cut slopes in the Saddle area, fills in wet areas, and excavation cuts downslope of Canyon Meadows.

The difficult geotechnical issues for widening the existing highway include: potential impacts to the Provo River, cuts and fills near Horseshoe Bend, rockfall concerns in the area of the exposed block of fractured Oquirrh Limestone (existing and with new cut slopes), excavation cuts downslope of Canyon Meadows, fills in active slide areas, and mitigation of active slides affecting the roadway. The lengths of existing roadway currently impacted by active slides add up to about 700 meters (2,300 feet). In comparison, the lengths of active slides crossed or potentially impacted by the Preferred Alignment is less than 200 meters (650 feet).

Based on our geotechnical peer review of the Preferred Alignment, the general alignment appears reasonable and feasible. Some small adjustments to the vertical and horizontal alignments are recommended to achieve the balanced cut/fill weights to maintain ground and slope stability. Also, mitigations to maintain stability are feasible. Changes to the vertical and horizontal alignment near Horseshoe Bend should be evaluated to address construction staging, landslide, and cut slope issues.

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44. UDOT District 6, "Report of Preliminary Design Field Review / Design Study Report, Provo Canyon, Upper Falls to Wildwood, Project No. *NH-0189(3)12," August 11, 1993.

45. UDOT, Preliminary Plans for US Highway 189 Wildwood to Deer Creek State Park Roadway Widening Project, *NH-0189(5)14; 1994.

46. UDOT Geotechnical Section (Heppler); "Provo Canyon Inclinometers, Hoover Slide Area;" June 22, 1999.

47. UDOT Geotechnical Section (Heppler); "Provo Canyon Inclinometers, Upper Falls to Wildwood;" June 27, 2000.

48. Utah Department of Highways; "Geotechnical Report: Slide Investigation on New Highway between County Line and Deer Creek Reservoir (Station 783 to 787)"; June 1960.

49. Utah Department of Highways; "Geotechnical Report: Provo Canyon Slide Area and Waste Site near Hoover Cabins, Highway 189 Wasatch County, Utah County Line to Deer Creek Reservoir"; April 17, 1961.

50. Utah Department of Highways, Materials & Testing; Memo: "Road Section 26-7-1 & 2, Utah County Line to Charleston"; July 1970.

51. Utah Department of Highways, Geological Engineering Section; Memo: "Slope Stability at Station 692, Wasatch County Line to Charleston"; December 1971.

52. Utah Department of Highways; "Chronological Outline of Geological Work in Provo Canyon for a Proposed Improvement"; December 18, 1972.

Cornforth Consultants, Inc.
Landslide Technology

Limitations in the Use and Interpretation of This Geotechnical Report

Our professional services were performed, our findings obtained, and our recommendations prepared in accordance with generally accepted engineering principles and practices. This warranty is in lieu of all other warranties, either expressed or implied.

The geotechnical report was prepared for the use of the Owner in the design of the subject facility and should be made available to potential contractors and/or the Contractor for information on factual data only. This report should not be used for contractual purposes as a warranty of interpreted subsurface conditions such as those indicated by the interpretive boring and test pit logs, cross-sections, or discussion of subsurface conditions contained herein.

The analyses, conclusions and recommendations contained in the report are based on site conditions as they presently exist and assume that the exploratory borings, test pits, and/or probes are representative of the subsurface conditions of the site. If, during construction, subsurface conditions are found which are significantly different from those observed in the exploratory borings and test pits, or assumed to exist in the excavations, we should be advised at once so that we can review these conditions and reconsider our recommendations where necessary. If there is a substantial lapse of time between the submission of this report and the start of work at the site, or if conditions have changed due to natural causes or construction operations at or adjacent to the site, this report should be reviewed to determine the applicability of the conclusions and recommendations considering the changed conditions and time lapse.

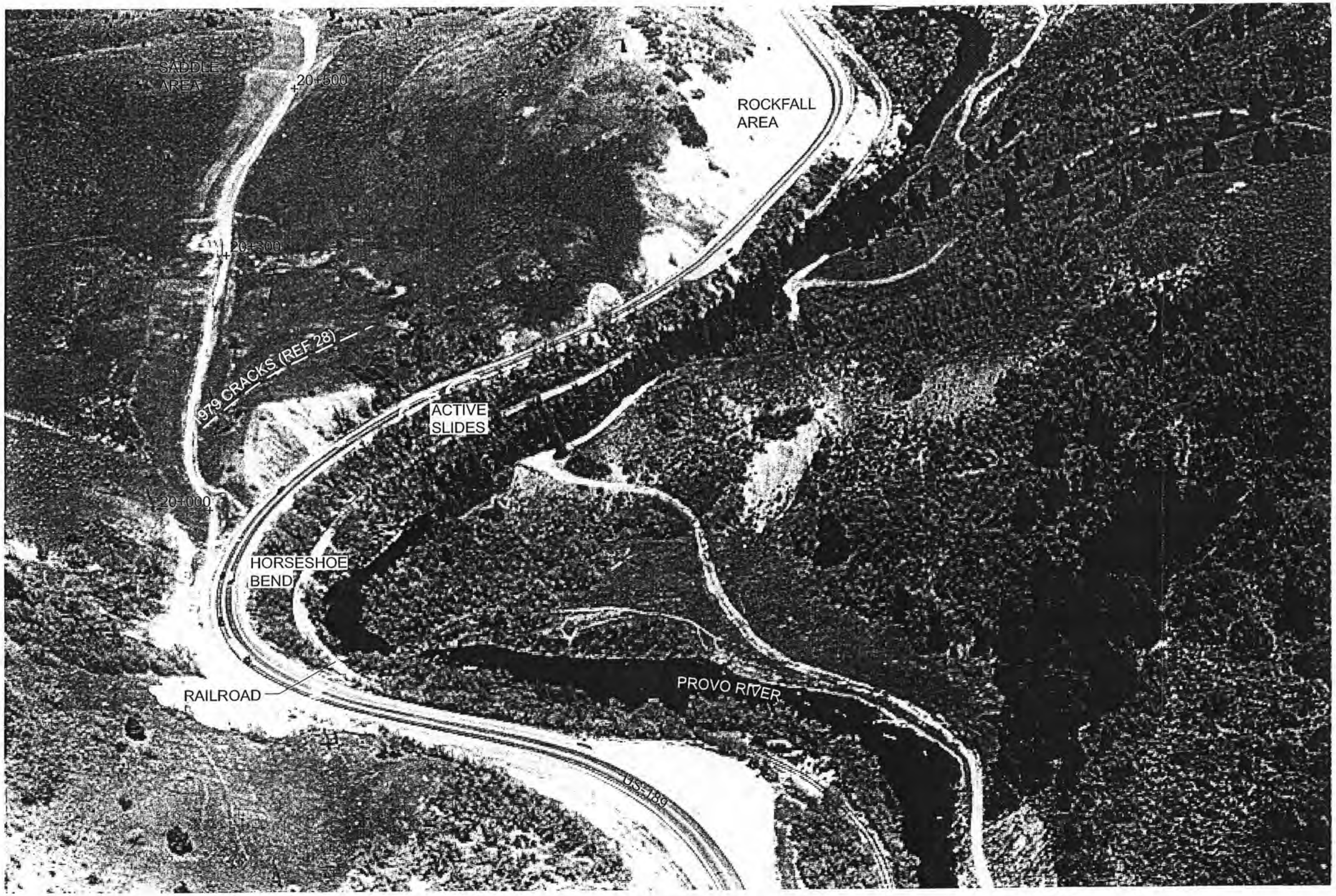
The Summary Boring Logs are our opinion of the subsurface conditions revealed by periodic sampling of the ground as the borings progressed. The soil descriptions and interfaces between strata are interpretive and actual changes may be gradual.

The boring logs and related information depict subsurface conditions only at these specific locations and at the particular time designated on the logs. Soil conditions at other locations may differ from conditions occurring at these boring locations. Also, the passage of time may result in a change in the soil conditions at these boring locations.

Groundwater levels often vary seasonally. Groundwater levels reported on the boring logs or in the body of the report are factual data only for the dates shown.

Unanticipated soil conditions are commonly encountered on construction sites and cannot be fully anticipated by merely taking soil samples, borings or test pits. Such unexpected conditions frequently require that additional expenditures be made to attain a properly constructed project. It is recommended that the Owner consider providing a contingency fund to accommodate such potential extra costs.

This firm cannot be responsible for any deviation from the intent of this report including, but not restricted to, any changes to the scheduled time of construction, the nature of the project or the specific construction methods or means indicated in this report; nor can our firm be responsible for any construction activity on sites other than the specific site referred to in this report.



VIEW LOOKING EAST

APPROXIMATE STATIONING SHOWN FOR PREFERRED ALIGNMENT, WHICH IS CLOSE TO HAUL ROAD.

1315\F01_MWT

LANDSLIDE TECHNOLOGY
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OBLIQUE AERIAL PHOTO LOOKING EAST (1)

US-189 HOOVER SLIDE SECTION
WILDWOOD TO DEER CREEK STATE PARK

JUL 2001

PROJ. 1315

FIG. 1

VIEW LOOKING EAST

APPROXIMATE STATIONING SHOWN FOR PREFERRED ALIGNMENT, WHICH IS CLOSE TO HAUL ROAD

1315\F02_MWT

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OBLIQUE AERIAL PHOTO LOOKING EAST (2)

US-189 HOOVER SLIDE SECTION
WILDWOOD TO DEER CREEK STATE PARK

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FIG. 2

VIEW LOOKING NORTH

APPROXIMATE STATIONING SHOWN FOR PREFERRED ALIGNMENT, WHICH IS CLOSE TO HAUL ROAD

1315\F03_MWT

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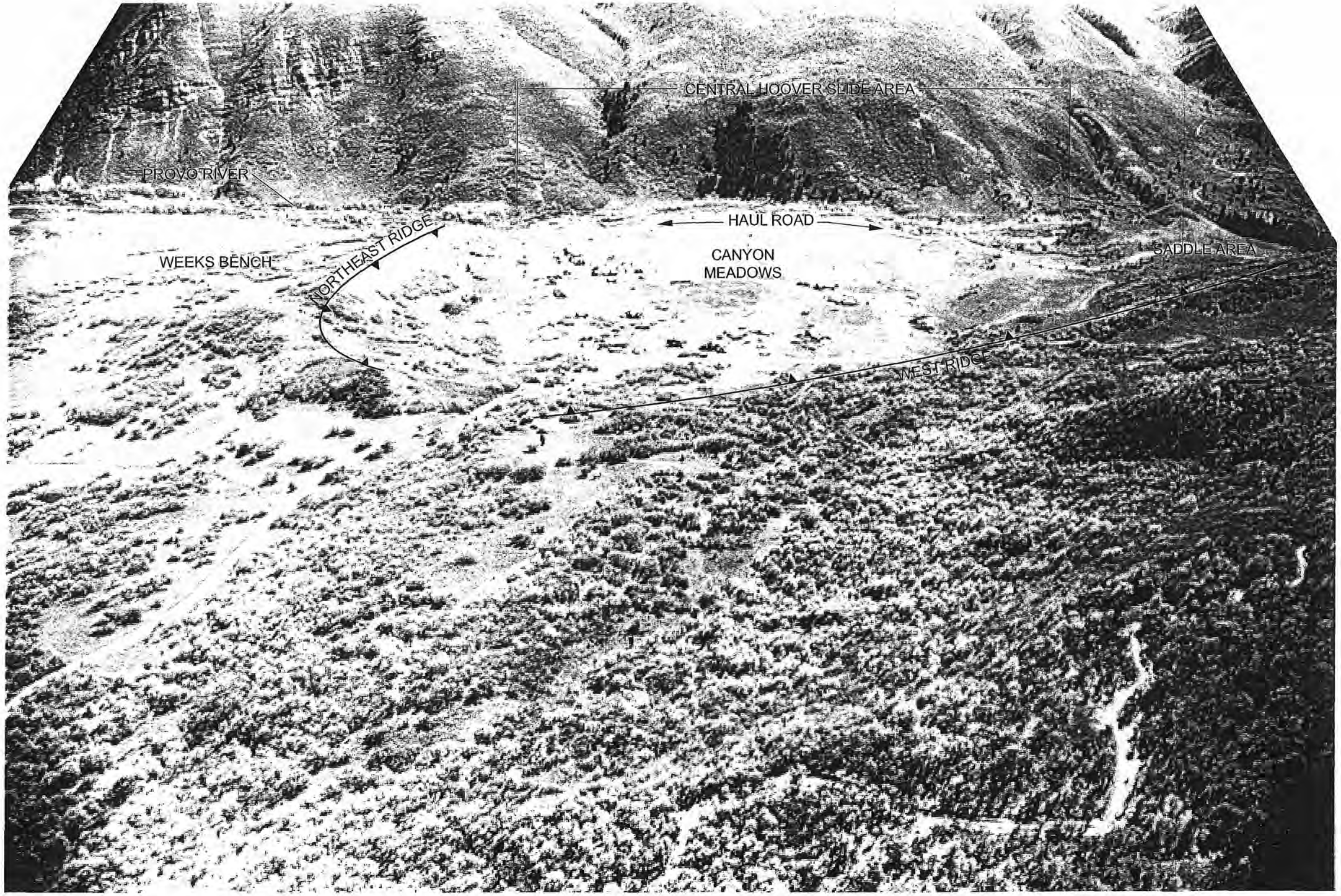
OBLIQUE AERIAL PHOTO LOOKING NORTH

US-189 HOOVER SLIDE SECTION
WILDWOOD TO DEER CREEK STATE PARK

JUL 2001

PROJ. 1315

FIG. 3



VIEW LOOKING SOUTH

1315\F04_MWT

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OBLIQUE AERIAL PHOTO LOOKING SOUTH

US-189 HOOVER SLIDE SECTION
WILDWOOD TO DEER CREEK STATE PARK

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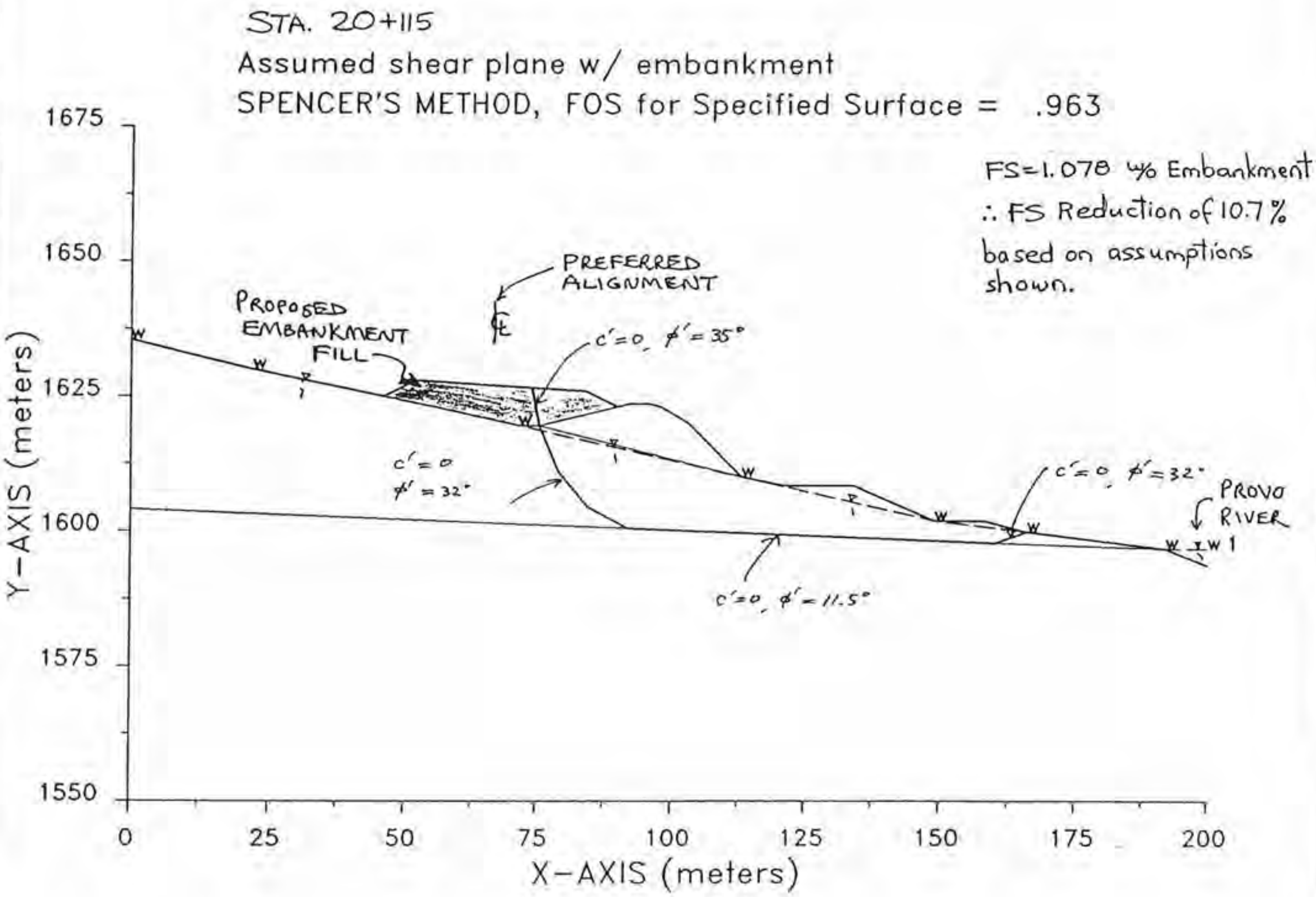
FIG. 4



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CONCEPTUAL STABILITY ANALYSIS
HORSESHOE BEND

US-189 HOOVER SLIDE SECTION
WILDWOOD TO DEER CREEK STATE PARK

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PROJ. 1315
FIG. 5

1315\F05_MWT

APPENDIX A

SITE PLANS

(Provided by Washington Infrastructure Services, Inc.)

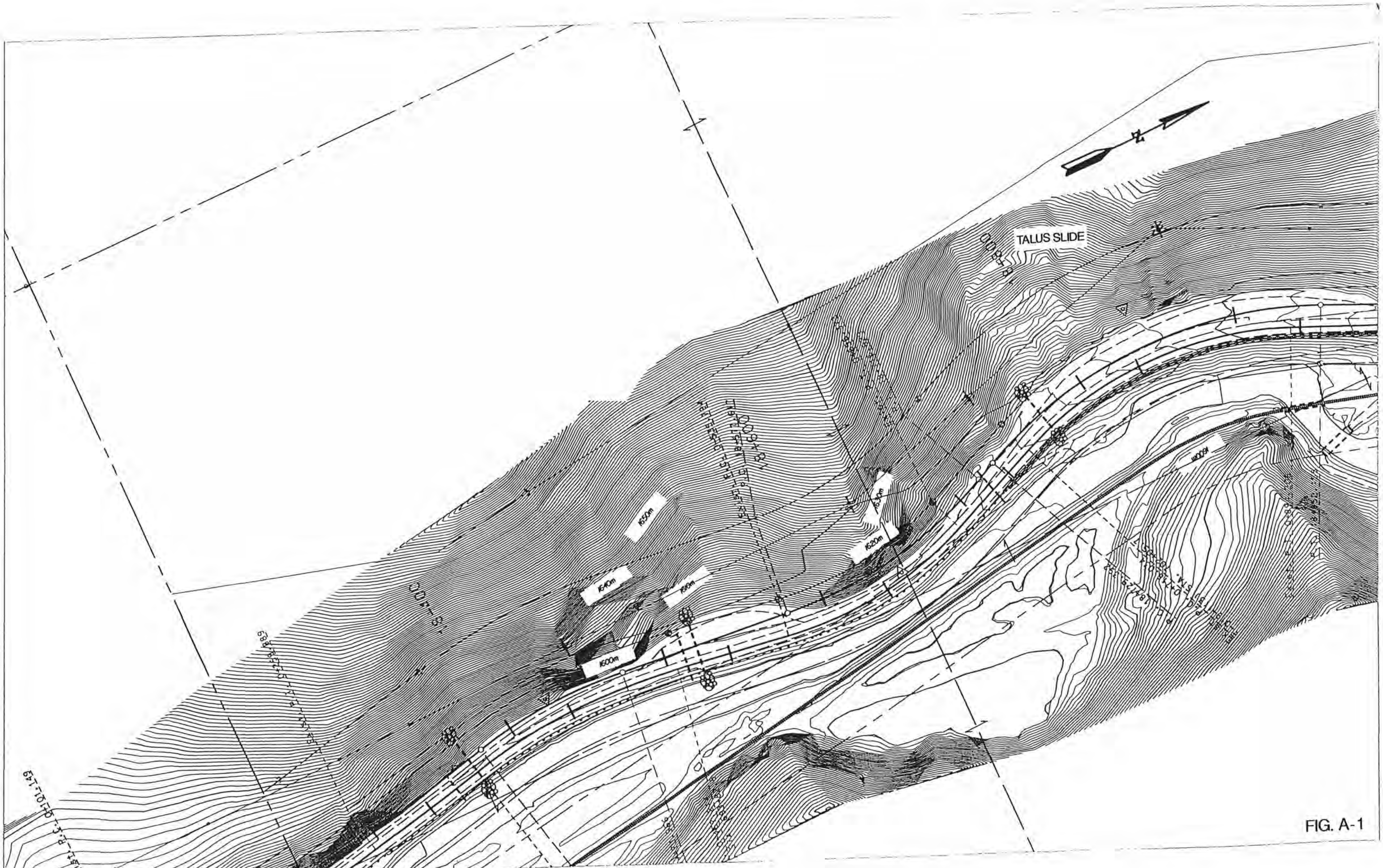

FIG. A-1

...\1344.00\Concept\BRET_COLOR.dgn 07/09/01 05:57:34 PM

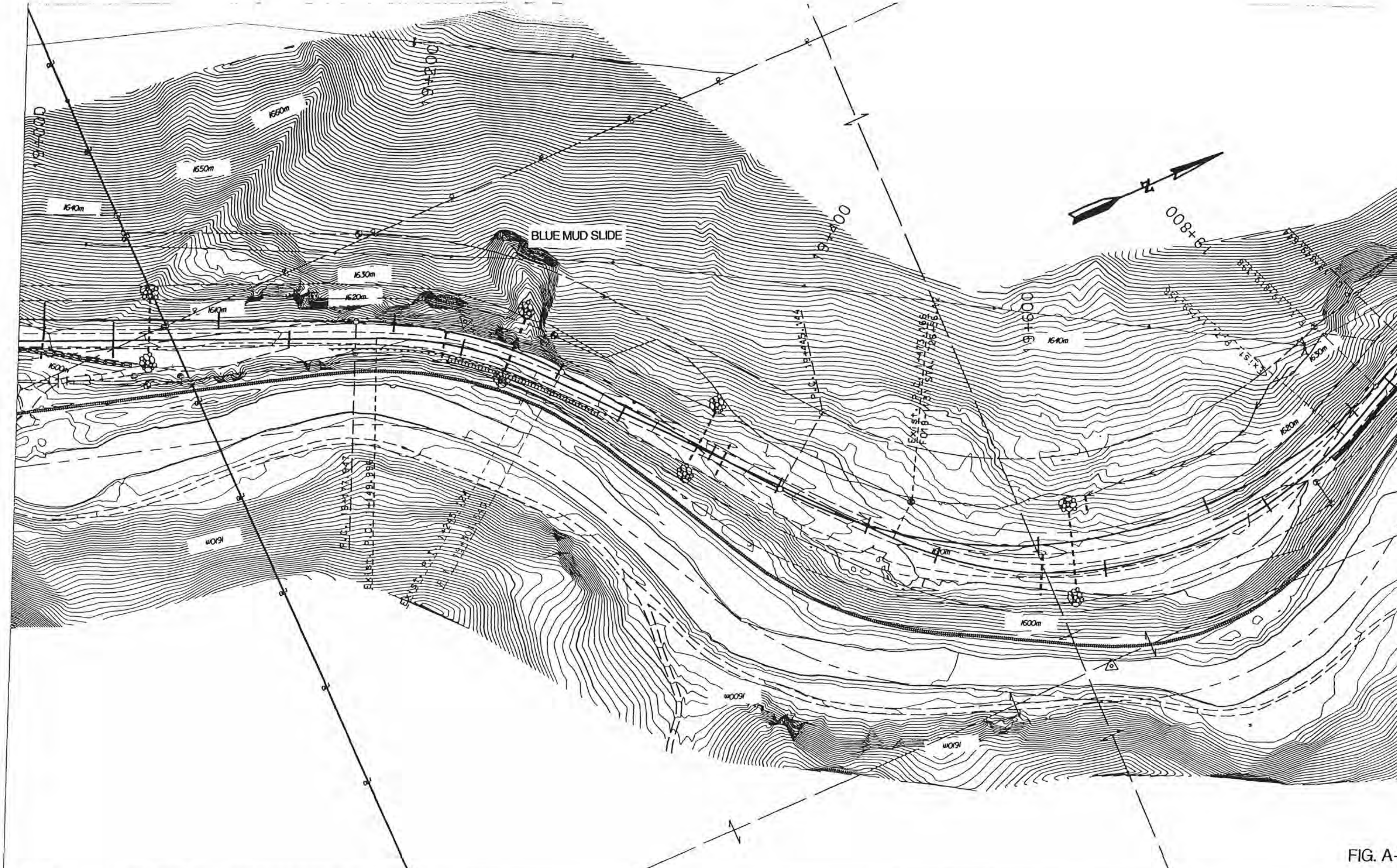
BLUE MUD SLIDE
1660m
1650m
1640m
1630m
1620m
1600m
19+400
19+600
N

FIG. A-2

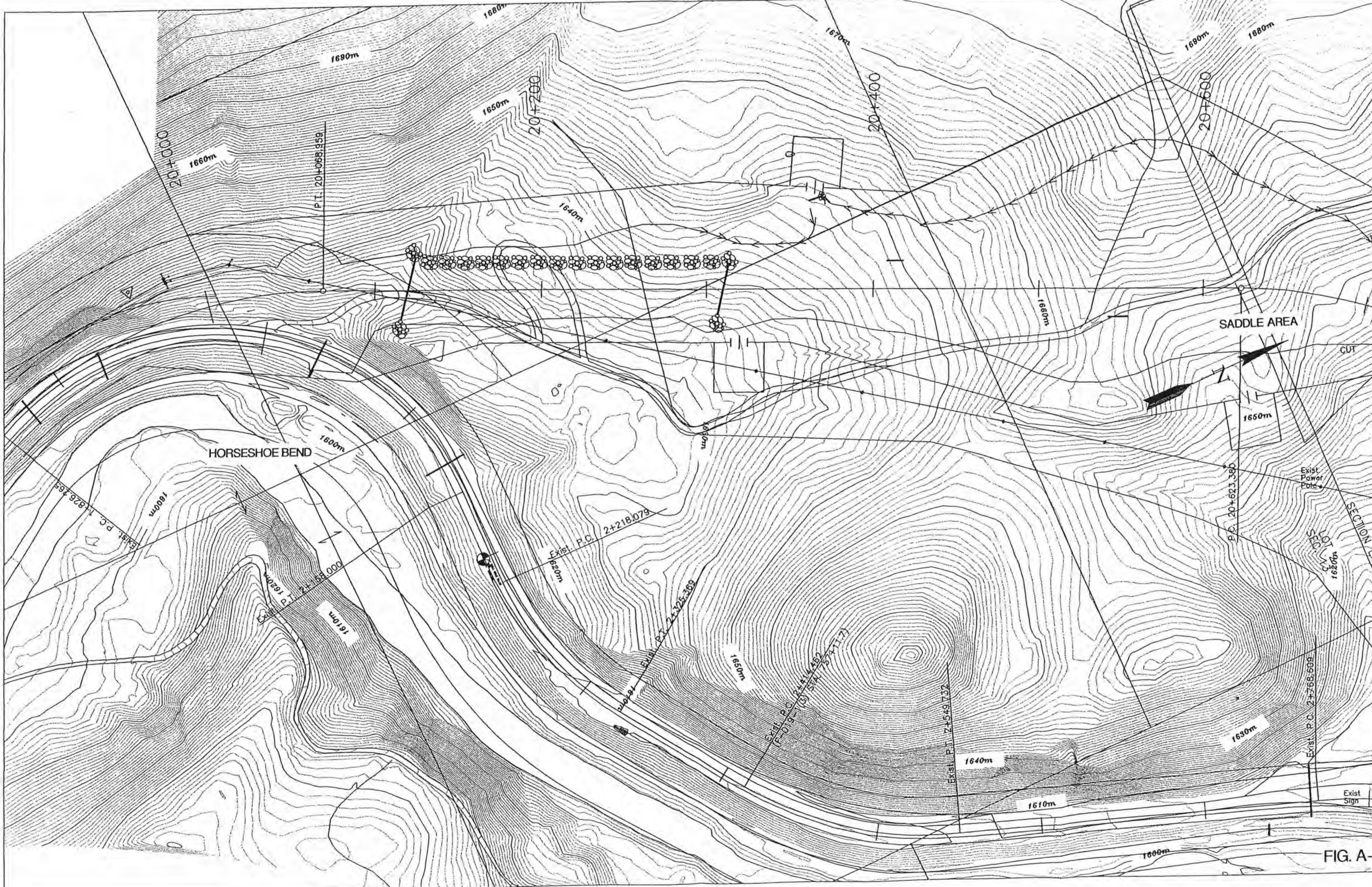
HORSESHOE BEND
SADDLE AREA
CUT
20+000
20+200
20+400
20+600
P.T. 20+068.359
P.C. 20+623.380
Exist. P.C. 2+218.079
Exist. P.T. 2+165.000
Exist. P.T. 2+325.369
Exist. P.T. 2+549.732
Exist. P.C. 2+768.609
Exist Power Pole
Exist Sign
SECTION LINE
1690m
1680m
1670m
1660m
1650m
1640m
1630m
1620m
1610m
1600m

FIG. A-3

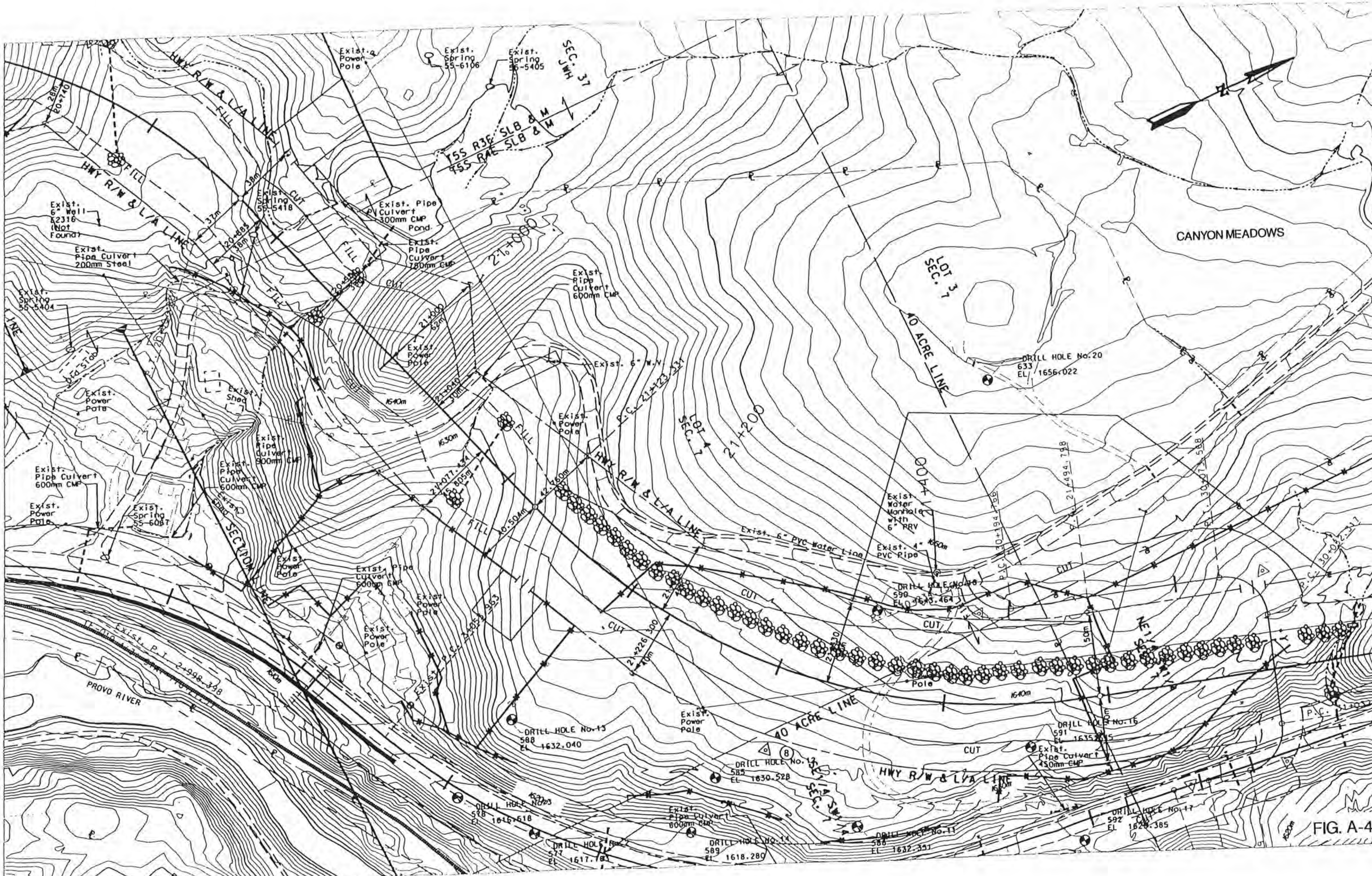

FIG. A-4

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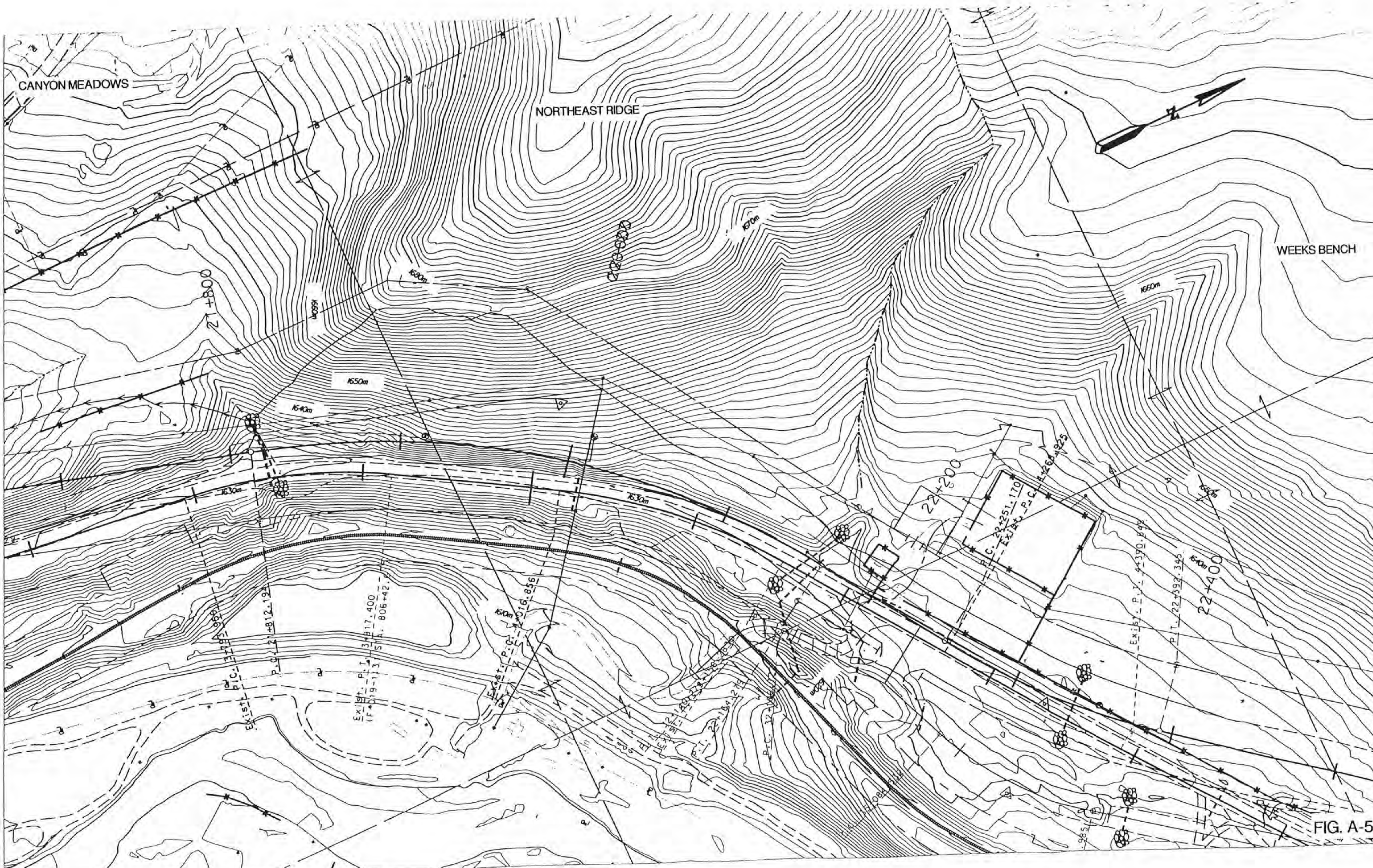

FIG. A-5

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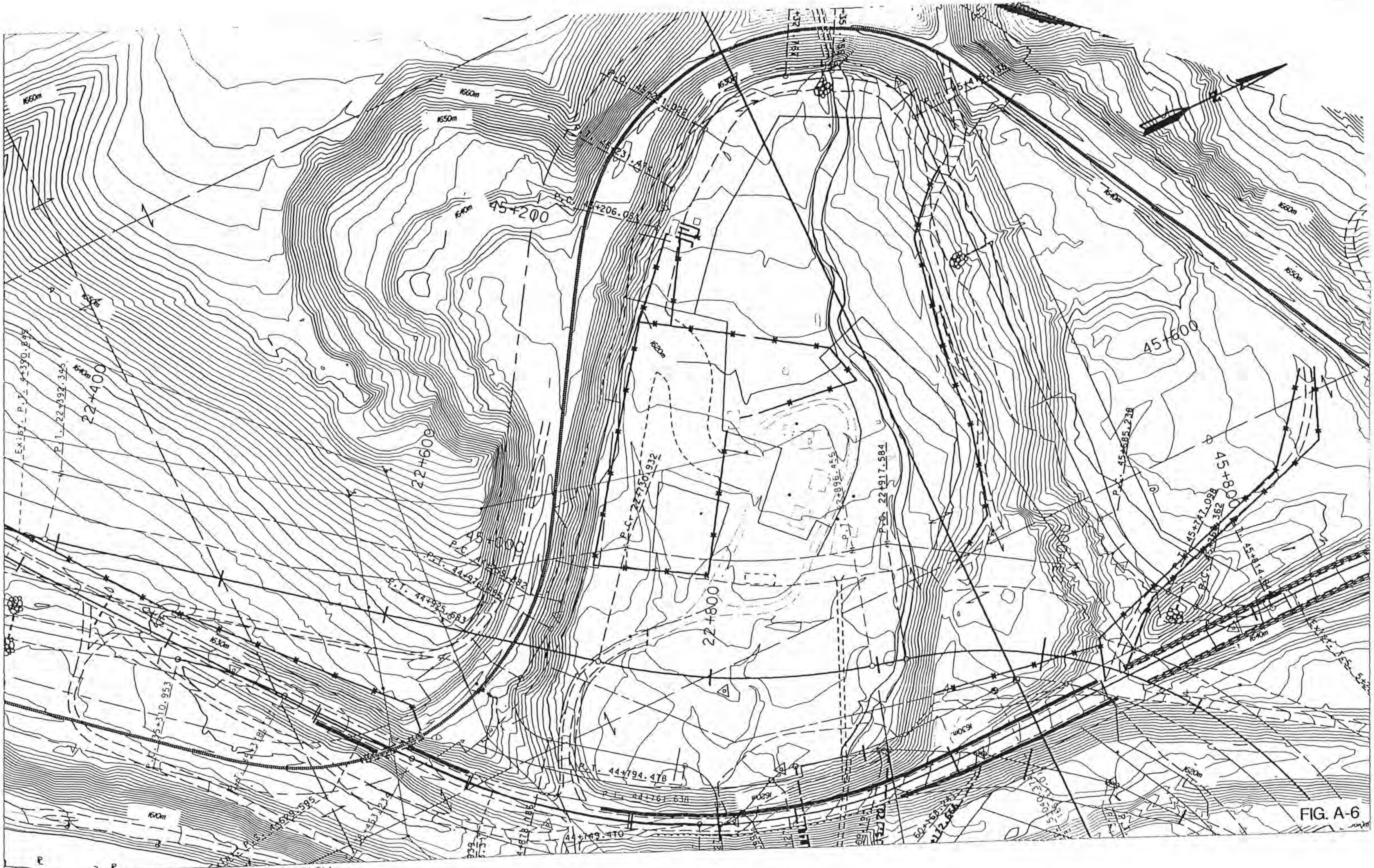

FIG. A-6

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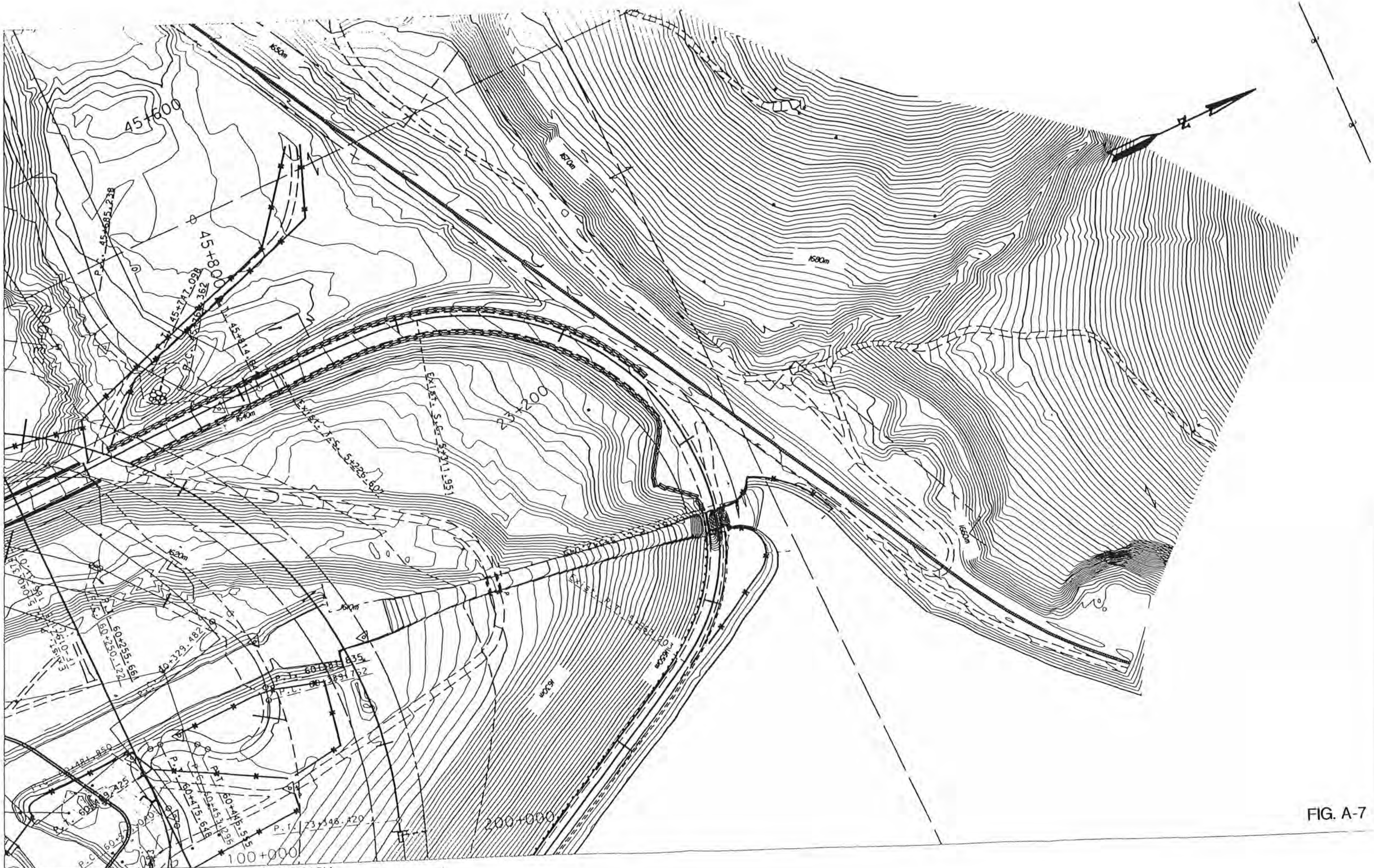

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