ER-3110

SLOPE STABILITY ANALYSIS
OF THE
WOLCOTT LANDSLIDE
EAGLE COUNTY, COLORADO

By

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ER-3110

An engineering report submitted to the faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Engineering (Geological Engineer).

Golden, Colorado

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ABSTRACT

The Wolcott landslide is located along I-70, two miles southeast of Wolcott and 15 miles west of Vail along Interstate-70. For the last few years, this active landslide has been causing severe damage to both Interstate-70 and the U.S.6 frontage road. The costs of maintaining both highways have greatly increased, and the possible blockage of these routes appears more likely. Accordingly, a study of the engineering characteristics of the failure was initiated to determine the most appropriate means of stabilization.

The landslide is located on the long slope of Bellyache Ridge, above where a meander of the Eagle River is cutting into the slope. It occurs in the interbedded shales, siltstones and sandstones of the lower Benton formation. The slide occurs near the axis of the Wolcott syncline were artesian or near artesian conditions prevail.

The slide was defined by delineating its geometry and mapping its topography using plane table mapping techniques. The potentiometric surface was located by measuring water levels in eight observation wells and by locating seeps and

standing water bodies. Surface movements were monitored by the installation of a series of survey points. These were measured with differential levelling, transit traverses, and other surveying techniques. Subsurface correlations were done using borehole logs, core samples obtained at the site, and deflection measurements in the inclinometers and piezometer tubes.

Correlations of the geologic, hydrologic and movement data suggest that the Wolcott landslide is a dip slope landslide with two shallow failure surfaces along which the movement is translational at an angle of 11 degrees. The upper failure surface is 12 feet deep while the lower is 19 feet below the surface.

The STABL3 computer program was used to evaluate the stability of the Wolcott landslide. The generated failure surfaces correspond closely to those mapped in the field. With maximum observed groundwater saturation, a factor of safety of 0.994 was calculated for the shallower failure surface and 0.949 for the deeper.

The effects of the installation of an interceptor drain at the slide was analysed using Glover's solution for flow towards an open trench. Water tables corresponding to different hydraulic conductivity values were determined using a computer program to solve Glover's equation. The resulting drained profiles were analysed using STABL3. The corresponding factor of safety for all the permeability ranges are above 1.0, indicating that an appropriate drain will probably dewater the slide efficiently. A French drain located at a sufficient distance above I-70 to allow for interception of water moving through the full depth of the slide and drainage into existing culverts under I-70 is therefore recommended as the primary remedial measure. Other remedial measures include realignment of the irrigation ditch to stop its current overflowing and saturation of the landslide toe area, and protection and regrading of the Eagle River bank in the toe area.

The cost of the installation of the new drainage system was estimated at around $ 35,000.00. The realignment of the irrigation ditch could be done at a price of $ 16,500.00. The regrading of the highly disturbed zone, the supply and emplacement of the rip-rap costs $ 4,500.00.

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1.0 INTRODUCTION

For the last few years the Wolcott landslide has been of major concern to the Colorado Division of Highways. This active landslide is located on the south side of the Eagle Valley, two miles southeast of the town of Wolcott, or 115 miles west of Denver and 15 miles west of Vail along Interstate-70, (Figure 1). The landslide is located on the long slope of Bellyache Ridge, above where a meander of the Eagle River is cutting into the slope. Figure 2 shows an aerial photograph of the slide area. Movements have affected both lanes of Interstate-70 and the U.S.6 frontage road, repeatedly causing severe tilting and cracking for both highways, and requiring constant maintenance to keep them both safe and usable. An irrigation ditch located between the highways and the river has also been affected.

During the winter of 1984-85, Mr. Robert K. Barrett of the Colorado Division of Highways began a drilling program on the Wolcott landslide and two other landslides-one along Interstate-70 near Vail, and the other along U.S.24 south of the town of Minturn. The Colorado Division of Highways contracted with the Colorado School of Mines for Dr. A. K. Turner and graduate students in Geological Engineering to conduct water level and movement monitoring programs at

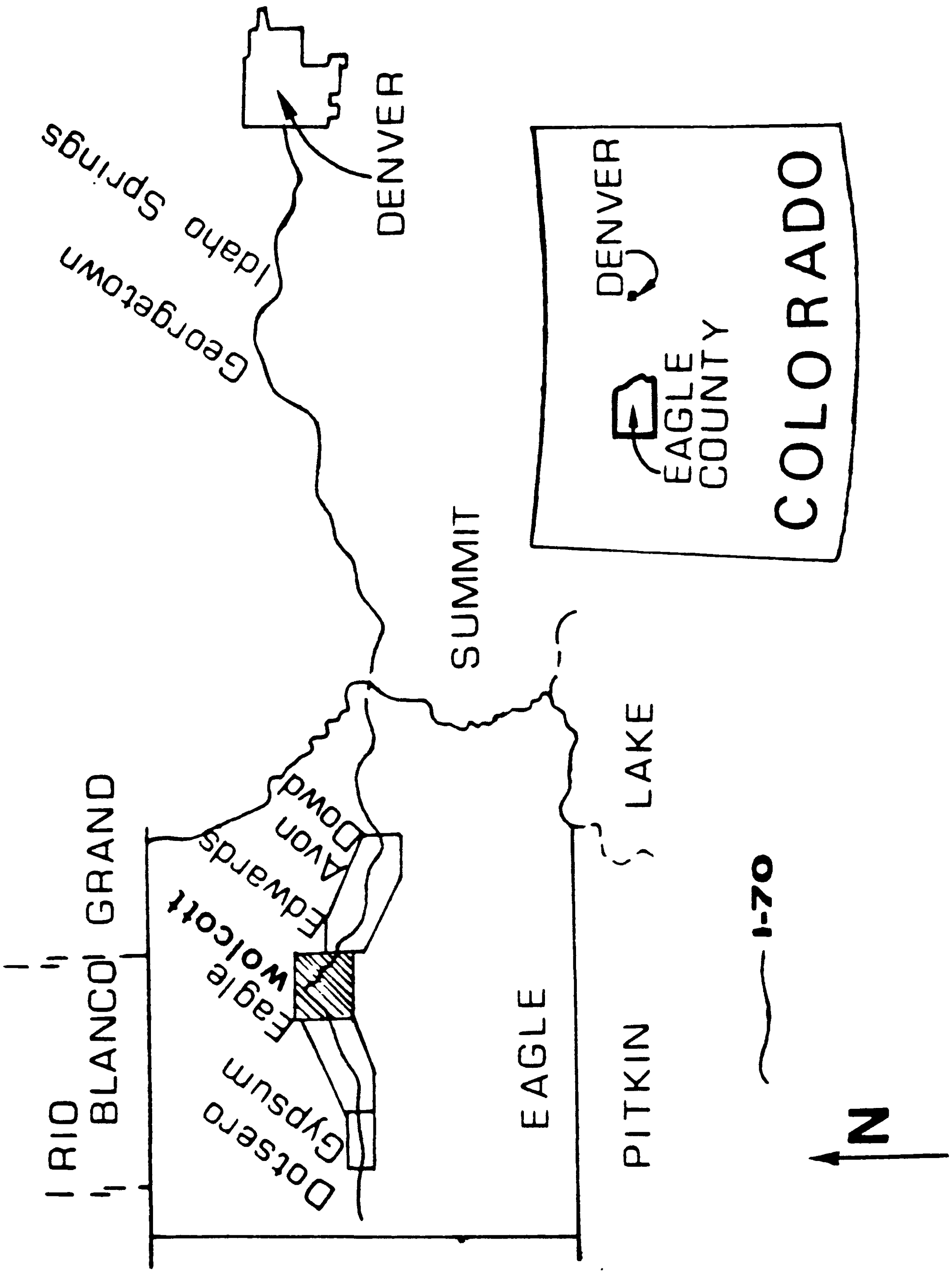


Figure 1 : Location Map of the Study Area.

(After Johnstone, 1965)

Figure 2 : Aerial Photograph Over the Site.

each slide over the next year. This report describes the engineering characteristics of the Wolcott landslide based on the field investigations and the data analysis completed during the year 1985-1986.

1.1 Objectives

This study was part of a larger project commissioned by the Colorado Division of Highways to monitor three landslides in the Vail area. All monitoring work was conducted under the supervision of Dr. A. Keith Turner. This study has the following seven objectives:

1) Determination of the physical characteristics of the landslide using plane table survey techniques;
2) Investigation of the local geologic conditions affecting the landslide;
3) Documentation of hydrogeologic conditions;
4) Documentation of mass movement characteristics;
5) Analysis of geologic, hydrologic and movement data;
6) Performance of slope stability analysis using the STABL3 computer program; and
7) Recommendation of appropriate, cost effective, remedial measures to reduce the damage caused to the highways.

1.2 Methods of Study

The Wolcott landslide was defined by delineating its geometry, mapping its topography and potentiometric surface, and by determining the location of the failure surface or surfaces.

A plane table map at a scale of 1 inch = 50 feet and a contour interval of 10 feet was completed in May, 1985, by the author and Mr. John Post of the Colorado Division of Highways. It defined the topography of the landslide, and was used as a base map to locate all slide features and monitoring data.

The potentiometric surface was located by measuring water levels in eight observation wells and by locating seeps, springs and standing water bodies. Observations were made on a monthly basis from February to the end of May, 1985. Readings were then taken three times a week during the month of May.

Surface movements were monitored by the installation of a series of survey points. These were measured with differential levelling, transit traverses, and other survey techniques, including direct measurements across movement zones in the slide. Data on pavement deformation and crack elongation along Interstate-70 and U.S.6 were also collected on a regular weekly basis during the month of May 1985, when the movements were believed to be at their highest rate.

Data on subsurface movements were obtained by the examination of cores from two drilled observation wells, and by the inclinometer measurements taken by highway personnel on a regular monthly basis from April to June 1985. Two gouge zones in the core samples were readily identified as two failure surfaces. These failure surfaces were also evident in the data analysis of two inclinometers (CSMW4 and CSMW9) located in the slide area. A third inclinometer (CSMW2) was drilled outside the slide area and so gave no useful data.

The data analysis included three main phases:

1) Data evaluation, including the correlation of topography, geology, hydrology and movements observed on the landslide;
2) Stability analysis of the landslide using the STABL3 computer program; and
3) Evaluation of the possible remedial measures to stabilize the slide.

These phases are discussed later in this report.

1.3 Physiography

The Wolcott area is structurally low and surrounded by the Gore and Park ranges towards the east and the northeast, the Sawatch range to the south, and the White River Plateau to the west. Figure 3 shows the general topography at the immediate landslide area.

The Eagle River is the main drainage feature in the area. It flows west through the Eagle Valley and joins the Colorado River near Dotsero. The terrain on either side of the Eagle Valley is mountainous and many tributaries to Eagle River drain the area. The toe of the Wolcott landslide is being undercut by a high to moderate energy meander of Eagle River. From this low point the slide rises around 250 feet towards the south over a distance of 1400 feet making an average topographic slope of 11 degrees. The landslide is characterized by elongated hummocks with a predominant east-west trend, parallel to the topographic contours, and perpendicular to the direction of movement. Plate 1 shows the topography of the immediate slide area.

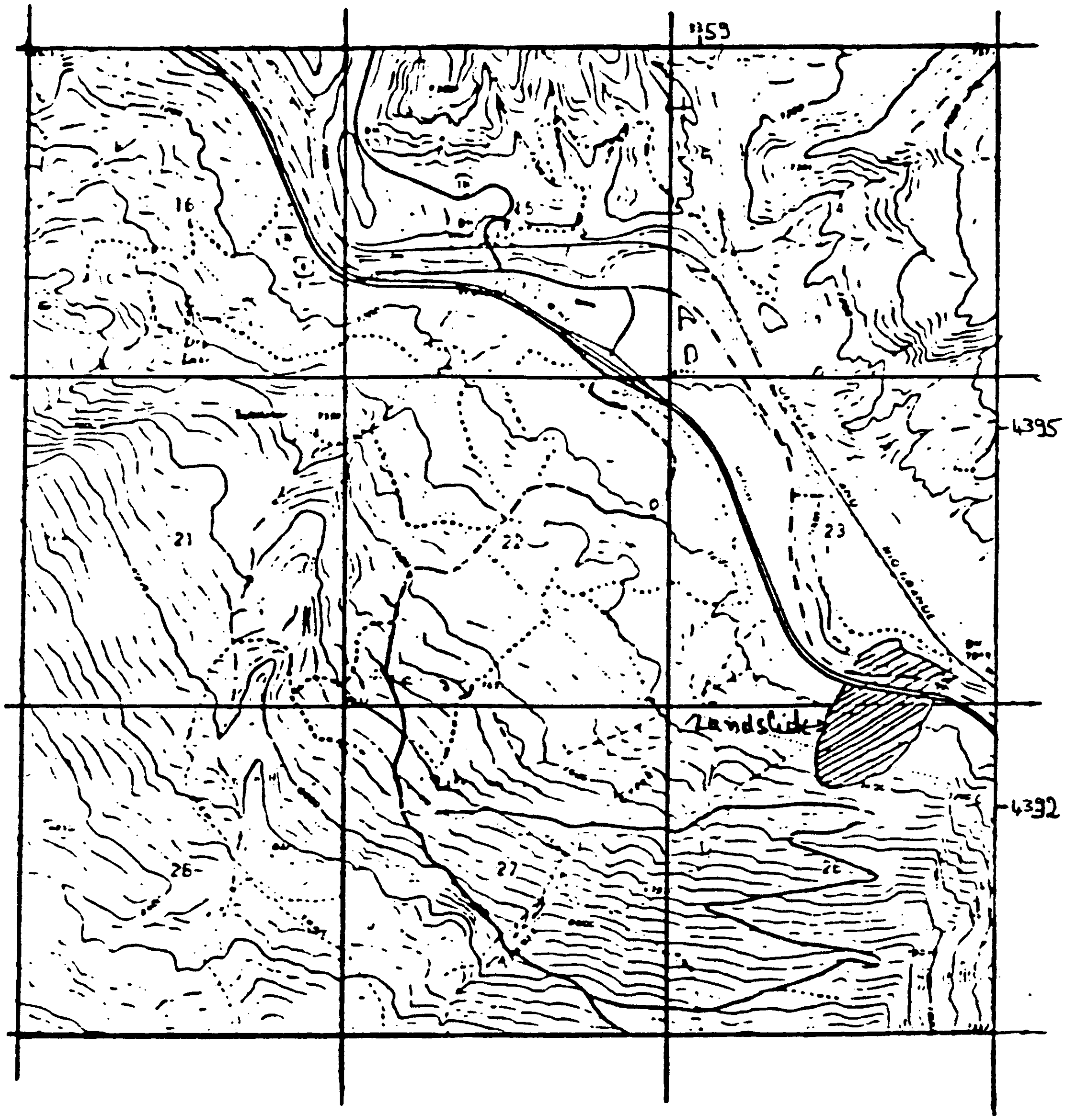


Figure 3 : Topography at the Immediate Landslide Area.

1.4 Previous Work

The first report dealing with the engineering characteristics of the geologic formations along I-70 in Eagle County was published by the Colorado School of Mines (Johnstone, 1965). Many other reports pertaining to the construction of I-70 in Eagle County and specifically in the Vail Pass area were submitted to the Colorado Division of Highways. The latest report by Mears, dealt with mudflows, rockfalls and landslides in the Vail area, (Mears, 1985).

A tremendous amount of work is available concerning the stability analysis of landslides. Terzaghi studied the properties of soils and their applications in engineering practice (Terzaghi, 1967). Deer and Patton (1971) and Hough (1969) contributed to slope stability evaluations and control. The Highway (and subsequenly Transportation) Research Board has published a series of reports concerning treatment of landslides (Shuster and Krizek, 1978). A report on computer aided analysis of slope failures was published by the School of Civil Engineering at Purdue University, (Carpenter, et al., 1985).

2.0 GEOLOGIC ENVIRONMENT

The first detailed geologic mapping in the area was done in 1952 (Wanek, 1952). Prior to that date, Hayden (1881), George (1913) and Lovering (1935) all mapped the area in reconnaissance, but no direct reference to the immediate Wolcott area appears in their publications. Wanek (1952), studied the geology and structures in the area of concern and produced a detailed geologic map. Charles Robinson and Associates (1972), mapped the area as part of the requirements for the Eagle-Piney project, Colorado.

The geologic setting of the landslide was critically evaluated during this investigation; an existing 1:24000 scale geologic map by Wanek (1952) and aerial photos were used to guide the field mapping. Detailed geologic field work was completed by the author during the month of August 1985. The bedding attitudes and stratigraphy were checked and corrected to accurately relocate the axis of the Wolcott syncline, the main structural feature in the area. The resulting updated geologic map is shown in Figure 4.

The structurally low Wolcott area is surrounded by areas of high relief. These include the Gore and Park ranges towards the east and northeast, the Sawatch range to

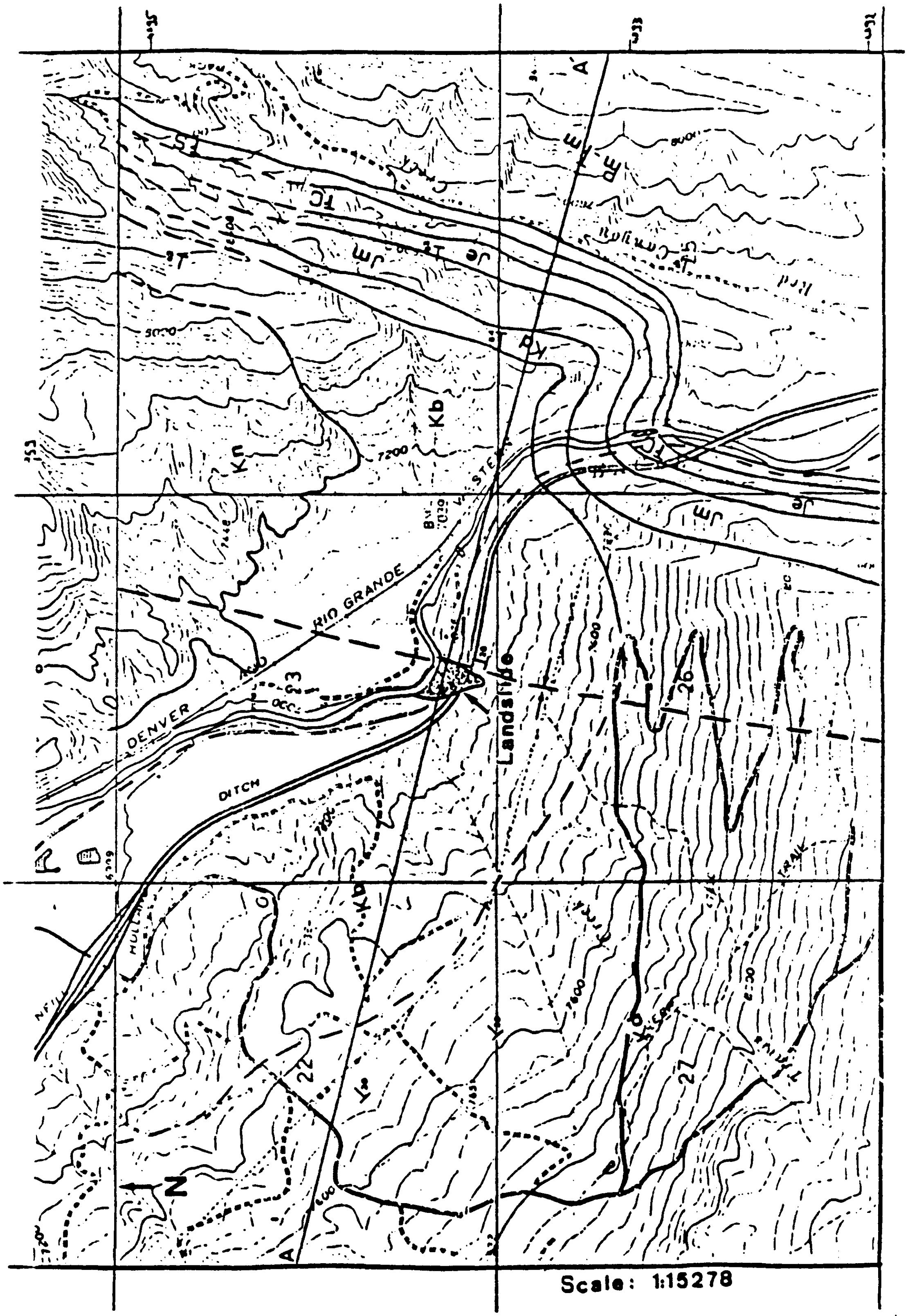


Figure 4 : Geologic Map of the Study Area.

the south and the White River Plateau to the west. While Precambrian rocks crop out in each of these uplifts, a great thickness of tilted rocks is preserved in the Wolcott area.

Sedimentary rocks examined and mapped in the field range in age from the Upper Triassic Shinarump formation to the Upper Cretaceous Niobrara formation. Figure 5 is a generalized stratigraphic section of the study area.

The Shinarump, Chinle, Entrada and Morrison formations, and the lower part of the Dakota formation which resulted from continental deposition, consist mainly of sandstones and shales. Whereas the younger Benton, Niobrara and Pierre formations are predominantly shales of marine origin (Wanek, 1952). Breaks in sedimentation are marked by erosional unconformities at the base of the Shinarump, the Entrada and the Dakota formations.

The lower sections of Bellyache Ridge are underlain by the Benton formation while the upper sections are underlain by the Dakota sandstone. The contact between the two formations is covered and could not be precisely located in the field (see figure 4). The landslide occurs in the interbedded sandstones, siltstones and shales of the Benton formation. It is located near the axis of the Wolcott

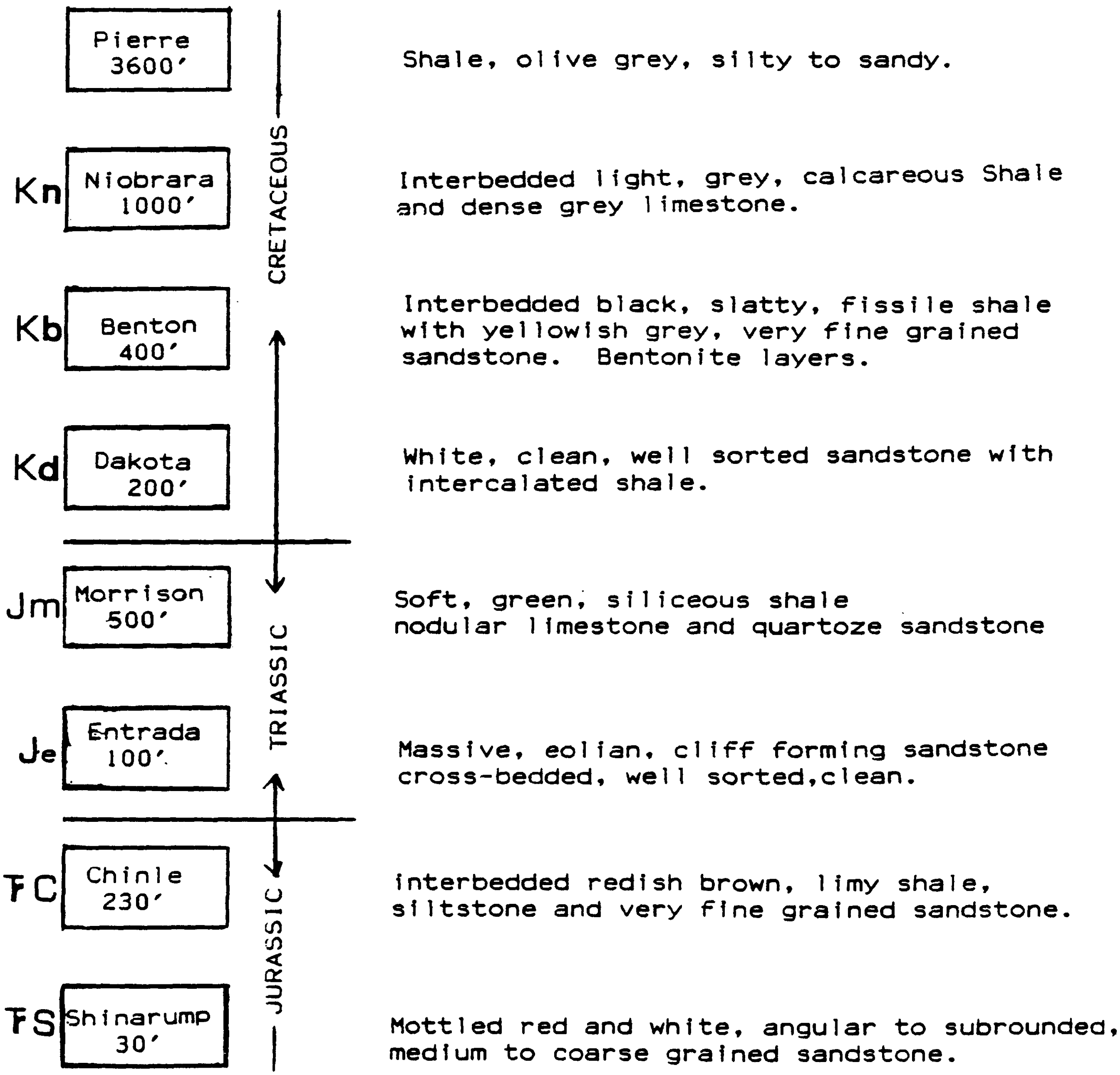


Figure 5 : Generalized Stratigraphic Section of the area.

(After Wanek, 1952).

syncline, the main structural feature in the area.

The Wolcott syncline plunges towards the north with its axis passing near the distinctive meander of Eagle River that faces the toe of the landslide. Dips on the western limb of the Wolcott syncline range from 8 to 25 degrees northeastward, while beds on the eastern limb rise gradually away from the synclinal axis until they steepen very abruptly to nearly vertical attitudes at the east of the map area. Figure 6 is a structural cross section across line A-A' indicated on the geologic map (Figure 4).

The possibility exists that artesian or near artesian conditions prevail at the Wolcott landslide as a consequence of the regional flow regime controlled by the Wolcott syncline in the area. The recharge probably occurs at the outcrops in the eastern hills where the beds are almost vertical in attitude. Elsewhere, recharge will occur where aquifers outcrop below the alluvium of small ephemeral streams. Ground water flow in the area is believed to be directed from the south, west and east towards the synclinal axis and diverted northward toward the Eagle River.

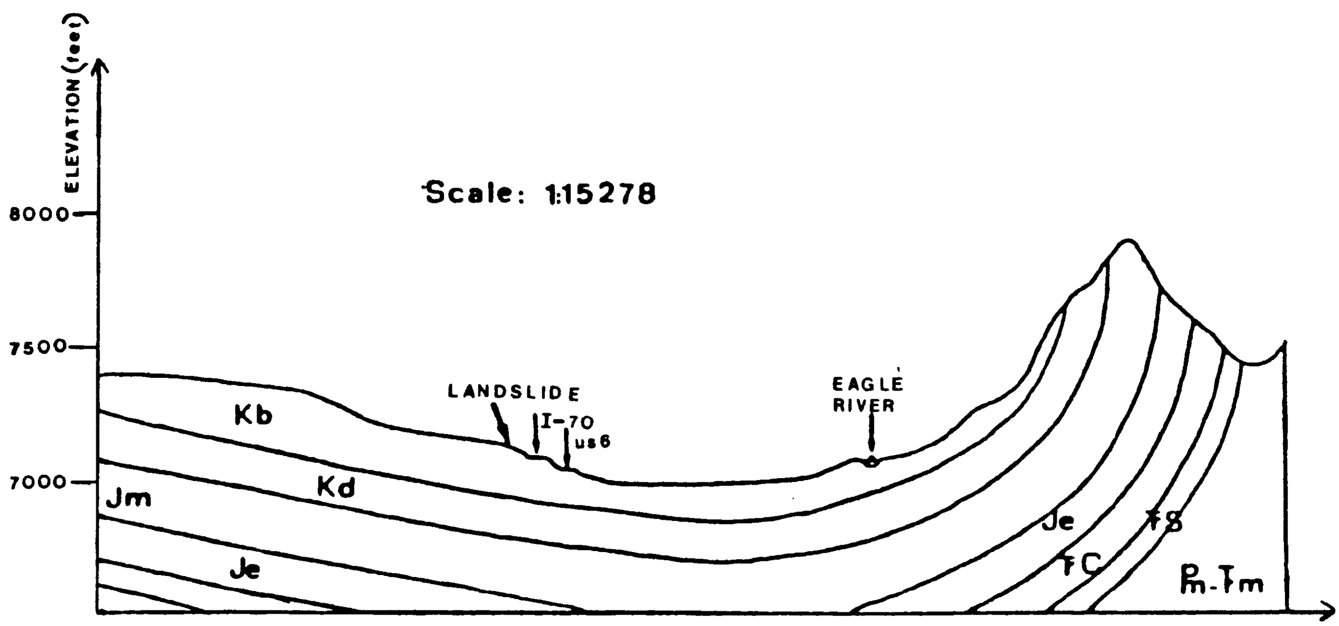


Figure 6 : Structural Cross-Section along Line A-A' Shown on Figure 4.

3.0 FIELD INVESTIGATIONS AT THE WOLCOTT LANDSLIDE

The monitoring activities at the Wolcott landslide started early in January 1985, when the highway department drilled for eight observation wells including three inclinometers at the site. Surveying and monitoring at the site continued until August 1985, with intensive work concentrated over a six week period between May and early June 1985, when the movements were expected to be at their highest rate.

The field investigations are described under the following four categories:

1) Observation wells and inclinometer installation;
2) Plane table mapping;
3) Hydrologic observations; and
4) Movement monitoring.

3.1 Observation Wells and Inclinometer Installation

In the fall of 1984, and at the end of November, the Colorado Division of Highways installed five observation wells identified as CSMW3, CSMW5, CSMW6, CSMW7 and CSMW8; Three inclinometers, CSMW2, CSMW4 and CSMW9 were also installed. These holes were located and drilled prior to the involvment of any CSM personnel. Field reconaissance at the landslide determined that observation well CSMW5, and inclinometers CSMW2 and CSMW4 were located outside the slide area. All the holes were logged, but by several different personnel, some from Colorado School of Mines and some from the Colorado Division of Highways. These logs are recorded in Appendix A.

The five observation wells were drilled using a 4 inch rotary bit with compressed air used to flush the cuttings. The wells were cased with a half inch inside diameter steel pipe, backfilled with sand and capped with bentonite. Core samples were taken from hole CSMW3 (19.3 feet, total depth) and from CSMW9 (14 feet, total depth). These cores were used to interpret subsurface conditions. For some reason, records on the perforated sections of the well casings were not kept.

The inclinometer borings, CSMW2, CSMW4 and CSMW9 were also drilled using a 4 inch rotary bit and compressed air. They were cased with Sinco three inch PVC inclinometer pipe and backfilled with sand and bentonite.

3.2 Plane Table Mapping

Plane table mapping of the Wolcott landslide was undertaken during the month of May, 1985 by the author and Mr. John Post of the Colorado Division of Highways, to produce an original map of the slide at a scale of 1 inch = 50 feet and a 10 feet contour interval. Scarps defining the surficial boundaries of the slide mass were delineated in the field and plotted on the map.

This map was further used as a base map to indicate various features associated with the landslide that were observed and monitored in the field. The plane table map of the landslide will be referred to as Plate 1.

3.3 Hydrologic Observations

The hydrologic observations at the landslide included the monitoring of both the surface and the subsurface hydrology. The subsurface hydrology was evaluated using the eight observation wells labeled (CSMW2-CSMW9). These are shown on Plate 1.

3.3.1 Water Level Measurements

Potentiometric measurements were taken on a monthly basis from wells CSMW2 through CSMW9 starting in February until early June, 1985. Three measurements a week were taken through the month of May, 1985.

Water level measurements were taken using a Slope Indicator Co. water level indicator, model # 51453, a wireline device that gives an audio signal when the water level is reached in the observation well. Levels were taken with a tape measure to the nearest eighth of an inch to the top of the well casing pipe and then converted to a ground level datum. Water level data from the observation wells are summarized in Table 1, the water level versus time plots for each well are shown on Plate 2.

3.3.2 Potentiometric Surface

A potentiometric surface map was constructed based on the data obtained on May 10, 1985, when the most complete and representative potentiometric information was collected. This surface is shown on Plate 3.

The details of ground water flow in the Wolcott landslide are not entirely unambiguous from the available data. However, as one would expect, local flow is generally

Table 1

Water Depth Observations, February-May, 1985.

Date	CSMW2	CSMW3	CSMW4	CSMW5	CSMW6	CSMW7	CSMW8	CSMW9
	(Note all depths are below top of casing)							
Feb. 3	29′	13′5"	17′	40′5"	-	20′5"	11′	18′5"
Mar.19	29′	16′	16′5"	47′	20′	58′	-	18′7"
Apr. 2	29′11"	17′	16′5"	51′4"	17′7"	56′11"	-	18′7"
Apr.16	29′6"	15′6"	17′6"	47′6"	14′	28′8"	-	18′6"
May 7	28′	12′8"	17′	40′	Out of Shape	19′	6′6"	17′6"
May 10	28′5"	12′9"	16′11"	39′9"		19′8"	8′4"	18′
May 13	28′	12′6"	17′	38′		Dry & Sheared	9′6"	18′
May 16	12′4"	11′8"	18′11"	38′9"			12′4"	19′3"
May 21	27′11"	12′3"	16′10"	37′10"			11′8"	17′8"
May 27	27′9"	12′	17′	37′6"			11′6"	18′2"
May 30	27′9"	12′6"	17′	32′6"			9′6"	17′9"
Elev. top of casing	7103.6′	7104.0′	7106.4′	7152.8′	7164.4′	7173.6′	7089.0′	7072.0′

to the north-northeast, directed basically towards the Eagle River. The potentiometric surface was observed to be deeper towards the west of the landslide where the water level was recorded at a depth of 40-45 feet on average at CSMW5. It gradually becomes shallower towards the east, where near artesian conditions prevail. The water level was recorded at an average depth of 20 feet near the head of the slide. The potentiometric surface gradually becomes shallower towards the toe. The potentiometric level below I-70, as recorded from CSMW8, was at 8 feet below ground surface. Plate 4 shows the relationship of the water table to the failure surfaces of the slide.

The ground water flow within the slide mass is essentially part of a larger regional groundwater flow regime shown in Figure 7. The area is characterized by a series of low transmitting capacity aquifers (Lohman, 1979) that are confined by very low permeability beds of siltstone, mudstone and/or shale. The main aquifer in the area is the Entrada formation.

The regional ground water flow appears to be directed toward the Wolcott syncline axis. Groundwater, coupled with seepage and infiltration of large volumes of water from precipitation through the heavily broken siltstone.

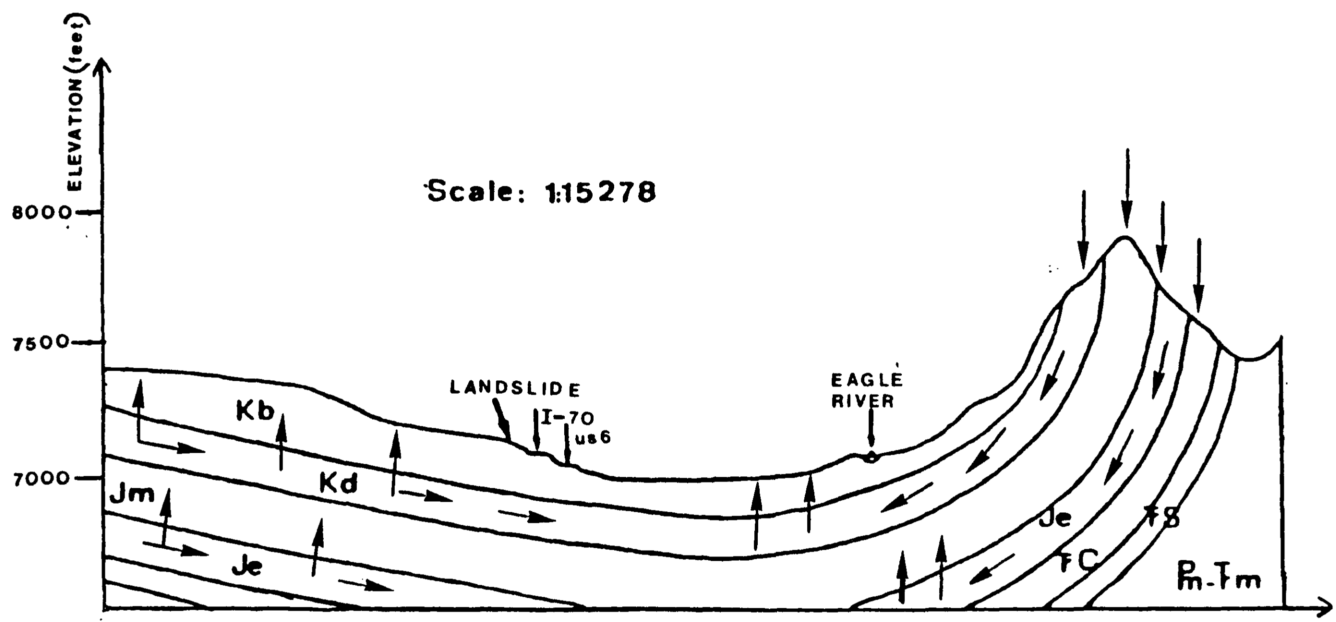


Figure 7 : Regional Groundwater Flow Conditions near the Slide Area Suggested by Field Observations.

composing the surface over much of Bellyache Ridge uphill from the slide, caused a marked rise in the potentiometric surface during April and early May. The net result is a high level of saturation through the landslide material which undoubtably contributed to its instability.

Except during this peak infiltration period, the observed potentiometric surface in the wells corresponds to the upper part of the Dakota formation which consists mainly of white, clean, well sorted sandstone.

3.3.3 Surface Hydrology

During the spring melt period, two drainages were observed flowing at or near the slide. The flow in both channels ceased early in May, when all the snow in the hillside had melted. The location of both of these channels is shown in Plate 1.

One drainage flowed northward west of, and outside the slide mass, and was diverted through a system of culverts below Interstate-70 into the Eagle River. A second drainage flowed along the western scarp of the landslide. This water disappeared into the slide mass near CSMW3, providing a constant flow of water into the slide material, and presumably contributing to its saturation. The infiltration rate into the slide was estimated at around 18 gallons per minute but could not be quantified accurately due to the difficulty in controlling the water discharge.

Table 2 shows the rainfall and snowfall data from September 1984 to May 1985 obtained from NOAA climatological records. These data are for the town of Eagle, the closest available station to the study area. A plot of this data is shown in Figure 8. The increase in precipitation during the months of April and May, 1985, correlated with the increase in the piezometric water levels at that time, suggesting that rainfall and snowmelt contributed to the recharge in the slide. This is probably due to the heavily fractured and broken character of the siltstone forming the surface of the slide. This probably facilitates water percolation into the slide material rather than allowing it to flow across the surface and via local drainages directly into Eagle River.

Snowmelt seems to contribute more to the recharge than rainfall. The melt water is constrained from flowing away by the snowpack and percolates directly into the slide material. Thus there is a constant source of water to the slide material during the spring thaw.

Table 2

Precipitation Data, 1984-1985, NOAA Climatological Records.

Date	Rainfall(in.)	Snowfall(in.)
Sept. 1984	1.54	0
Oct. 1984	1.46	0
Nov. 1984	0.26	0.23
Dec. 1984	0.84	0.42
Jan. 1985	0.36	4.9
Feb. 1985	0.39	5.5
Mar. 1985	3.52	19.0
Apr. 1985	1.81	7.1
May. 1985	0.81	0.41

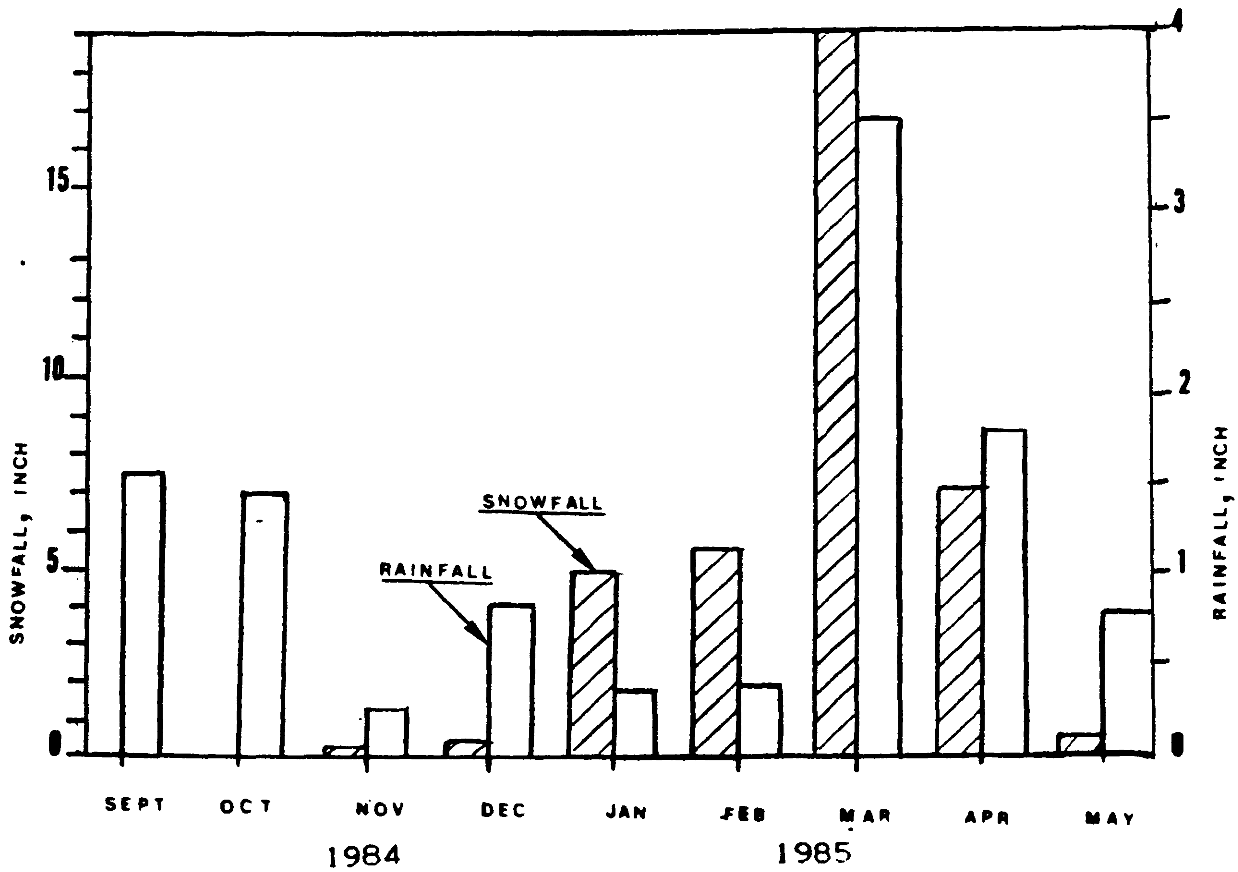


Figure 8 : Precipitation Data, Year 1984-1985.

(NOAA Climatological Records)

3.3.4 Seepage and Ponding at the Surface

Seepage was observed at several locations early in May. The largest seepage was observed near CSMW4 adjacent to the eastern scarp of the landslide. Other seepages were observed on the scarp face above the Eagle River meander at the toe of the landslide. The discharge at the seep near CSMW4 was measured by averaging the times required to fill a known volume of a container. These flow rates at different dates are shown in Table 3 and Figure 9. The flow rate decreased dramatically by the middle of May as most of the snow had melted from the hillside. Flow completly ceased by the beginning of August.

Standing water was observed at different locations early in the month of May. Ponds were observed along the southern edge of I-70 near the seepage area at CSMW4 and in the I-70 median. These ponds were probably associated with the malfunctioning of the French drain installed between CSMW4 and culvert C-1(see Plate 1). In fact, water seeping out of the slide material was not carried by the French drain to culvert C-1; rather, culvert C-1 remained dry and the seepage was recharged into the slide material, locally raising the potentiometric surface.

Table 3

Discharge Rates at the seep near CSMW4.

Date	Flow Rate(gpm)
May 4	18
May 15	15
May 20	3
May 22	1.6
June 6	1
July 3	0

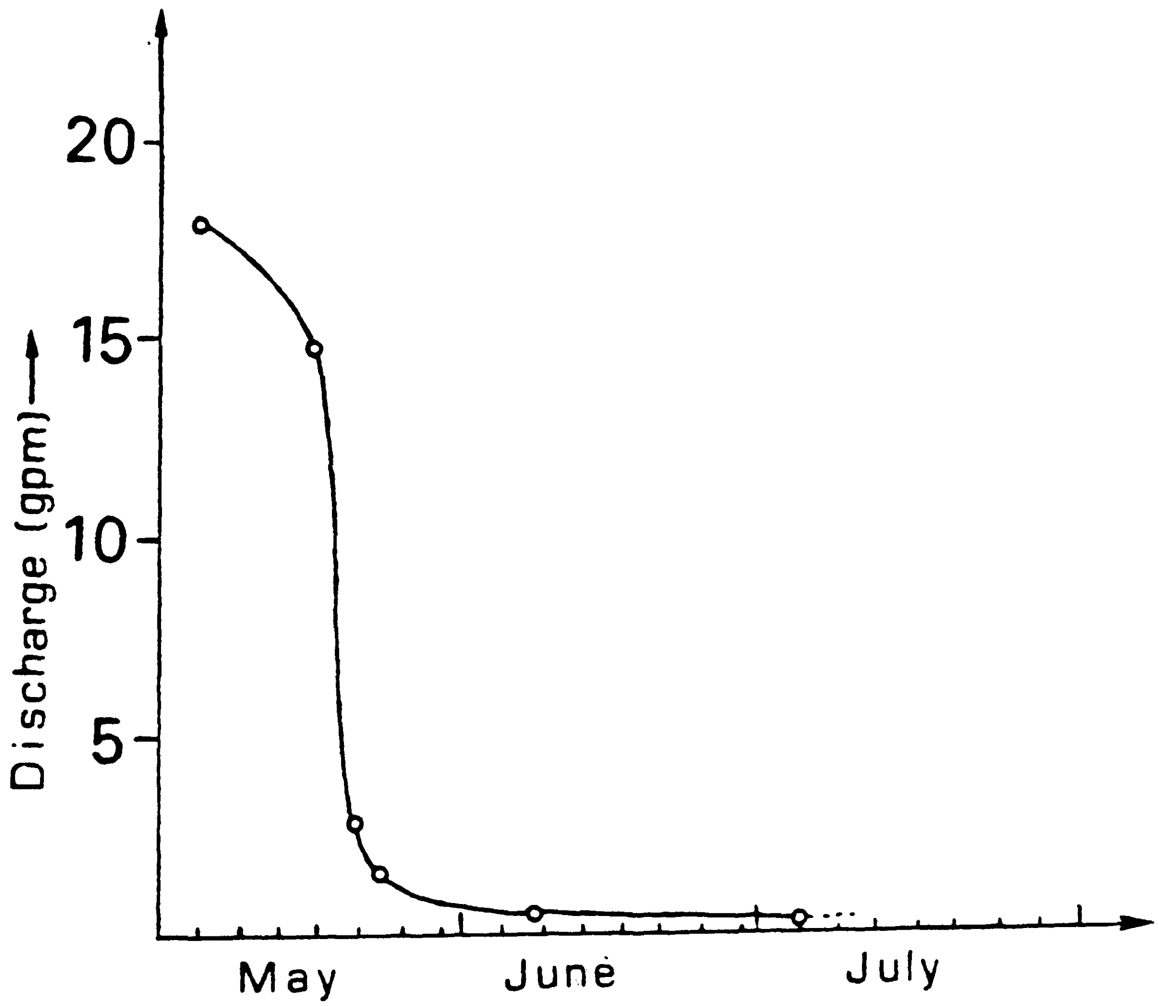


Figure 9 : Flow Rates versus Time near Inclinometer CSMW4.

Ponding was also observed near the toe of the landslide. This pond started in May 9, 1985 because the irrigation ditch passing above the toe was distorted due to the slide movement and began leaking water. This water recharged locally and probably triggered the renewed movement near the toe of the slide that migrated up to Interstate-70 by the end of May. This later movement cycle is believed to be the result of the ditch ponding, since the overall movement of the landslide had stopped by that time. The pond disappeared by May 22, 1985 when the water level in the ditch was lowered by highway department personnel and the ditch fixed temporarily. The pond and seep locations are shown in Figure 10.

3.4 Movement Monitoring

Slide movements were quantified as follows:

1) Subsurface movements evaluated by inclinometer data;
2) Monitoring and mapping of pavement cracks along Interstate 70 and U.S.6;
3) A simple extensometer system, using heavy rubber bands, installed across the major landslide scarp;
4) Measurements of survey points located on the sliding material; and

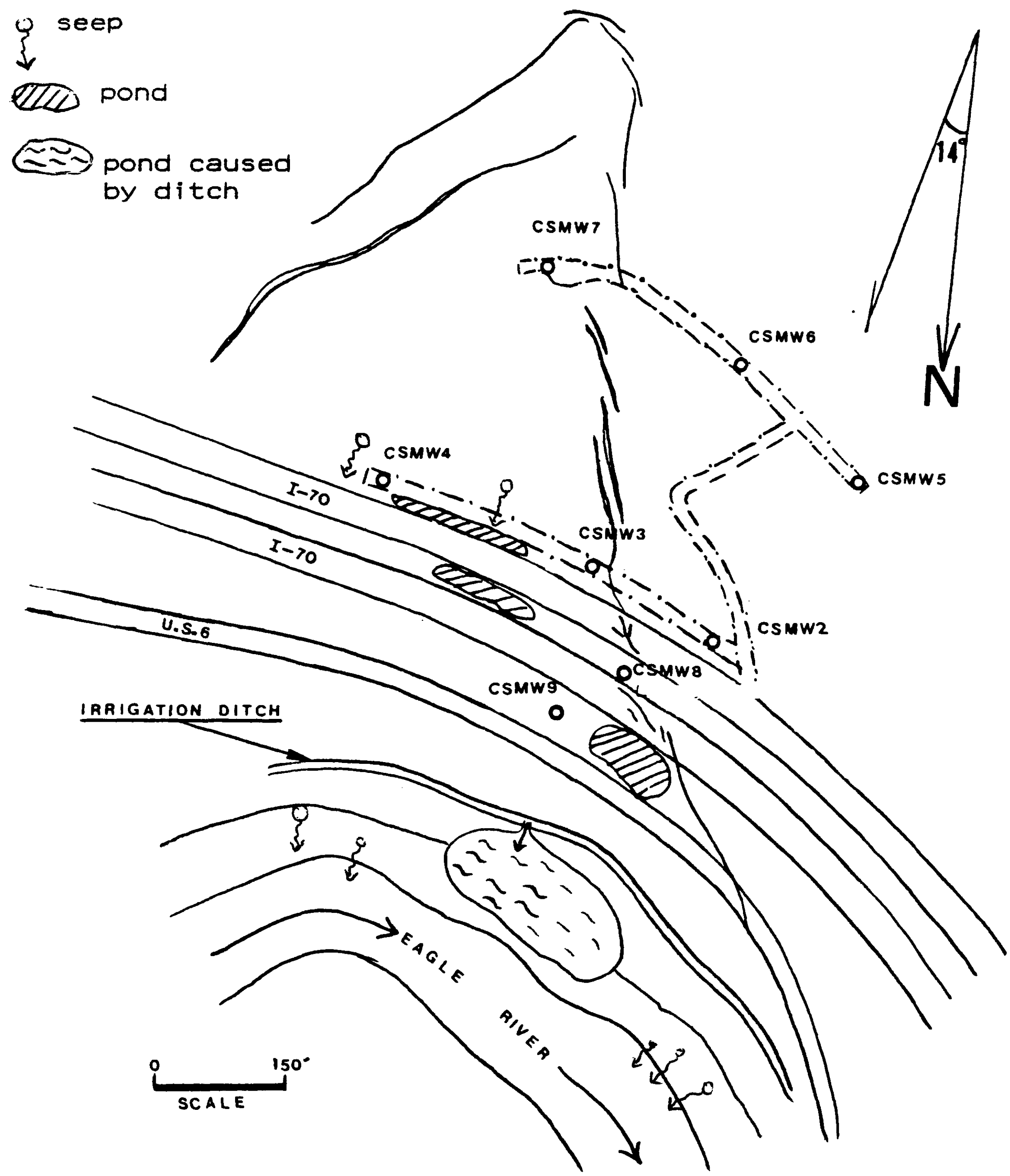


Figure 10 : Pond and Seep Areas at the Slide Mass.

5) Direct measurements across active cracks and scarps

3.4.1 Subsurface Movements

The subsurface movements were evaluated using the data from inclinometers CSMW2, CSMW4 and CSMW9 provided by the Division of Highways. The inclinometer readings were adjusted by a computer program that reduced the raw data. It uses the greatest depth reached by the probe as the stable bottom of the hole, regardless of whether or not the casing is sheared. It then compares these data with the original readings. If the casing is sheared, it adds the last known displacement at the shear depth to the data taken after the shearing had occured. Total displacement is the distance the inclinometer casing has moved from its original position based on original readings taken on April 18, 1985.

Inclinometer CSMW4 sheared off just below the ground surface on May 24, 1985. The probe could not get below 10 feet into inclinometer CSMW9 on May 24, 1985. Complete data were taken from inclinometer CSMW2 from April to June 1985. A plot of these data is shown in Figure 11. However, inclinometer CSMW2 gave no useful data because it is located outside the slide mass.

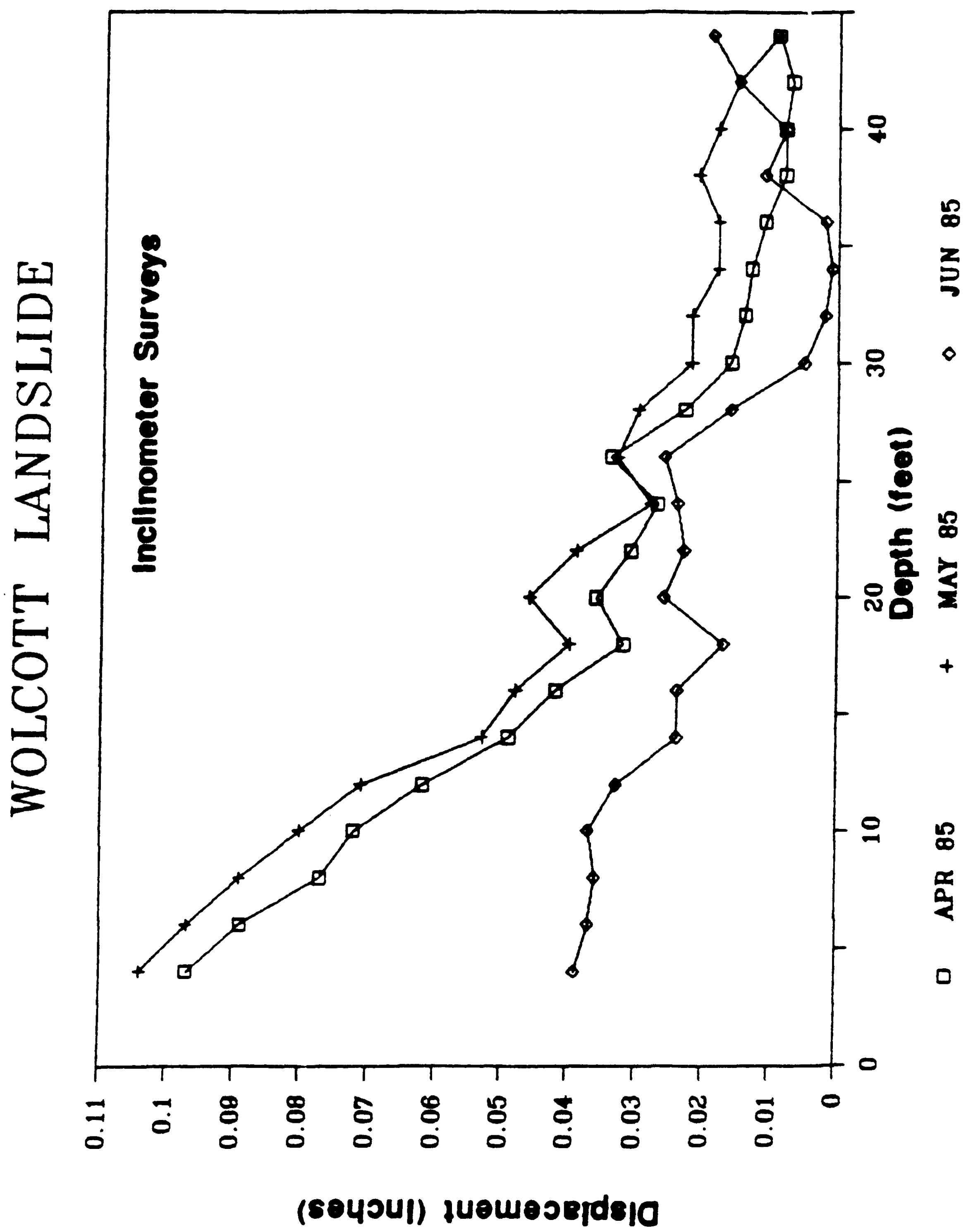


Figure 11 : Inclinometer CSMW2 Data.

The inclinometer data only suggested that the sliding occurs along a shallow failure surface. However, an accurate location of the failure surface using these data was impossible. Additional data on the location of the failure surface were taken from the observation wells although they were not designed as inclinometers. These wells would bend or break at shearing zones. Accordingly, a"Dead-man", shown in Figure 12, was lowered down these holes to locate such bends. The results obtained are summarized in Table 4, and were used to locate the shallower failure surface. The deeper failure surface was identified in the field at nearby bedrocks outcrops, and by observation of the subsurface cores.

3.4.2 Definition of the Failure Surfaces

Well logs of the eight bore holes were examined and correlated to identify the subsurface lithologies of the sliding material. Core samples obtained from two drill holes in the slide mass were also used for this purpose. Examination of the subsurface lithologies allowed the identification of two gouge zones that were correlated with the failure surfaces identified by the inclinometer and the dead-man data.

One failure surface is at an average depth of 12 feet,

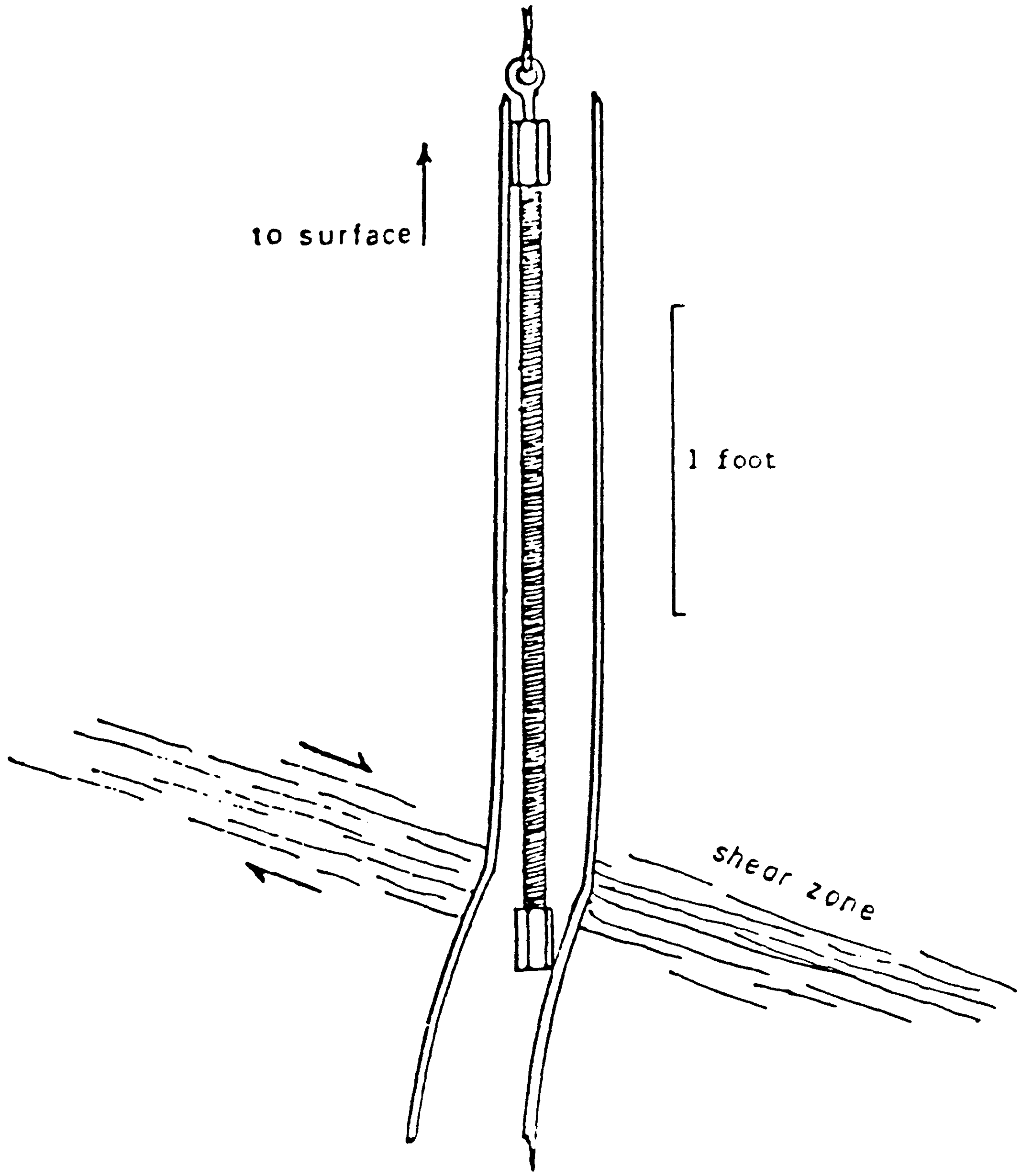


Figure 12 : The Dead-man Probe.

Table 4

Deadman Data, May 21, 1985.

Borehole number	Depth reached by the Dead-Man
CSMW2	No bending observed
CSMW3	12'35"
CSMW4	6'51"
CSMW5	No bending observed
CSMW6	Bent out of shape
CSMW7	17'25"
CSMW8	No bending observed
CSMW9	16'85"

Table 4 : Deadman Data, May 21, 1985.

another deeper one was identified at 19 feet. The failure surfaces are believed to involve bentonite layers that characterize the Benton formation.

3.4.3 Mapping and Monitoring of Pavement Cracks

The failure surfaces of the landslide caused major scarps and cracks where they intersected the surface. Those cracks observed along I-70 and U.S.6 were mapped and their evolution with time was monitored. First mapping of these cracks started on May 2, 1985 and their monitoring continued until the end of May on a weekly basis. Plates 5 and 6 show the evolution of the cracks through the month of May.

Monitoring of the cracks included mapping and direct measurements across major scarps. Measurements across pin points located on opposite sides of the cracks along the highways were taken. Data from the major crack along U.S.6, at the western margin of the slide (Figure 20), are summarized in Table 5. Differential leveling was used to evaluate the vertical offsets of the cracks.

3.4.4 The Rubber Band Extensometer System

The rubber band system was designed by the author in an attempt to evaluate the horizontral, vertical and lateral directions and amount of movements at various locations

Table 5

Movement Data from an Opening Crack along U.S.6.

Date	Horizontal	Vertical
May 2	0.8"	1.2"
May 8	1.2"	1.5"
May 15	2.0"	1.9"
May 22	2.2"	2.3"

along the major scarps of the landslide. The steps followed to install a rubber band system across a major scarp are described below:

1) Two vertical rebars were installed vertically each on one side of the crack.
2) A horizontal rubber band was connected between the two rebars and stretched to a maximum. Horizontality was checked using a brunton. Measurements of the initial bearing length of the rubber band were taken.
3) Length, bearing of the rubber band and its angle with the horizontal were then taken at weekly basis.

Figure 14 shows the Rubber Band Extensometer system. The data gathered was reduced and recorded in Table 6, it gives values of lateral, horizontal and vertical offsets across the major scarps of the slide. Plate 7 shows the amounts and directions of the recorded movements. The location of the four sets of extensometers is shown in Plate 8. The data reduction is documented in APPENDIX B.

3.4.5 Surveying of Selected Points

Three stake lines, A, B, and C, were installed across the sliding mass, these are shown in Plate 8. These lines

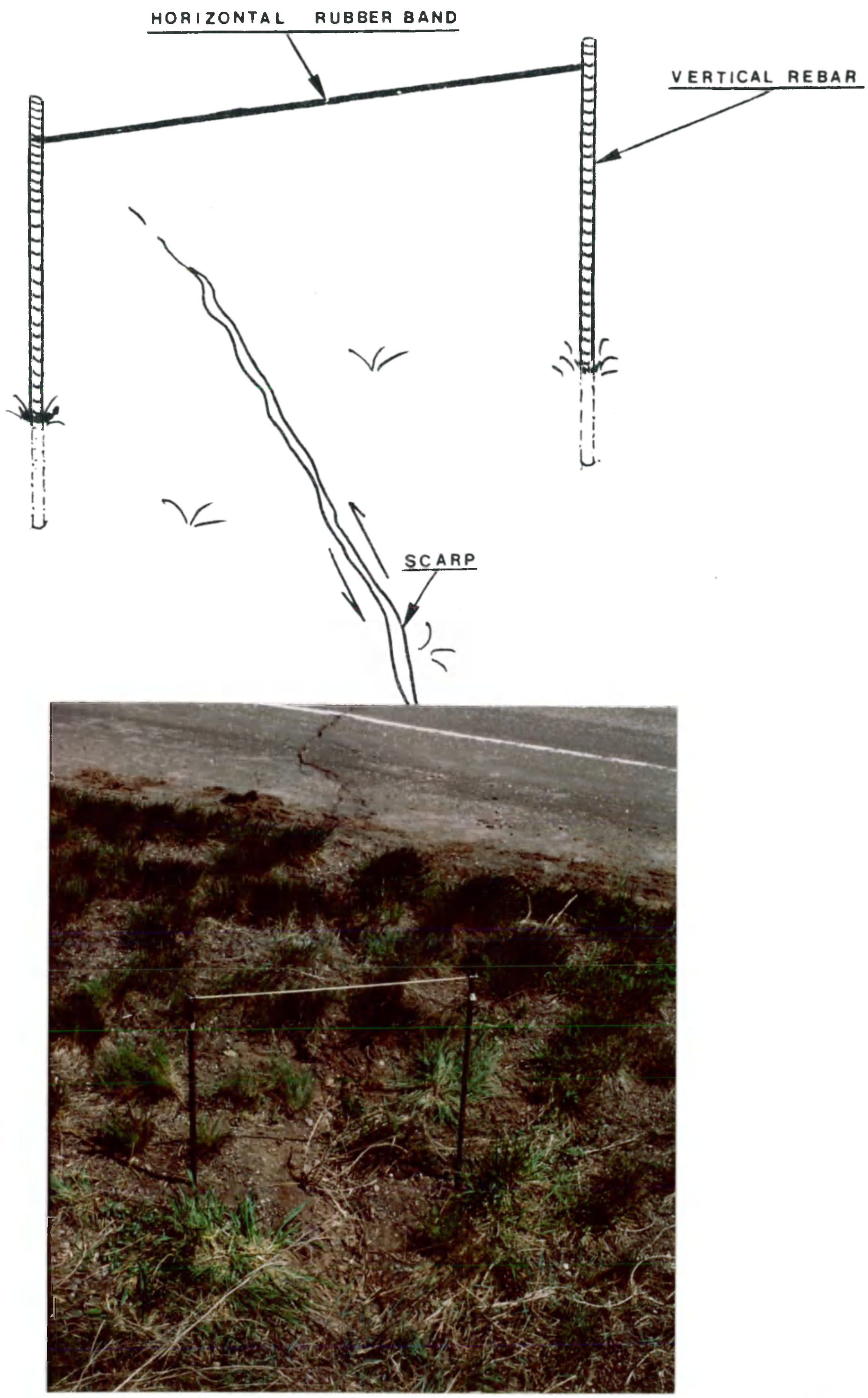


Figure 13 : The Rubber Band Extensometer.

Table 6

The Rubber Band Extensometer Data.

Date		R1-R2	S1-S2	T1-T2	K1-K2	N1-N2
May 2	Z	E-W	N74W	N80E	N-S	N50E
	L	2.86	2.23	3.5	4.3	3.55
	X	0	0	0	0	0
May 9	Z	N85E	N80W	N76E	N-S	N50E
	L	2.87	2.25	3.5	4.37	3.56
	X	3	2	5	6	0
May 15	Z	N80E	N83W	N67E	N-S	N50E
	L	2.87	2.25	3.6	4.45	3.56
	X	3	4	7	6	0
May 22	Z	N80E	N83W	N67E	N-S	N50E
	L	2.87	2.25	3.6	4.55	3.56
	X	3	4	7	6	0

were set by sighting a transit on a specified distant object and installing stakes and nails along the lines of sight. Movement along these lines was measured by resighting the lines and recording the offset distances from the points. Unfortunately, the measurements taken as described above did not give any significant new data, probably because these stake lines were installed late in May after most of the movement had occured. This system may, however, be used for further survey work on the Wolcott landslide when needed.

4.0 DATA INTERPRETATION

The data interpretation involved the following three steps:

1) Correlation of geologic, hydrologic and movement data;
2) Analysis of the mechanical behavior of the landslide;and
3) Computerized slope stability analysis of the landslide using STABL3 computer program. (Lovell, et al., 1985).

4.1 Data correlation

Two gouge zones were observed in the cores recovered from CSMW3 and CSMW9, (Figure 14). As discussed later, these apparently correlate with two clay rich zones which are respectively located at 8 and 18 feet above the base of the Benton formation when observed in an outcrop at half a mile to the west of the slide. They also occur at depths averaging 12 feet and 20 feet in the landslide. When the "deadman" probe was used in the piezometers, it indicated shearing at an average depth of 14 feet,(Figure 15), this appears to correlate with the shallower gouge zone identified in the cores.

Figure 14 : Core Samples Obtained at the Site.

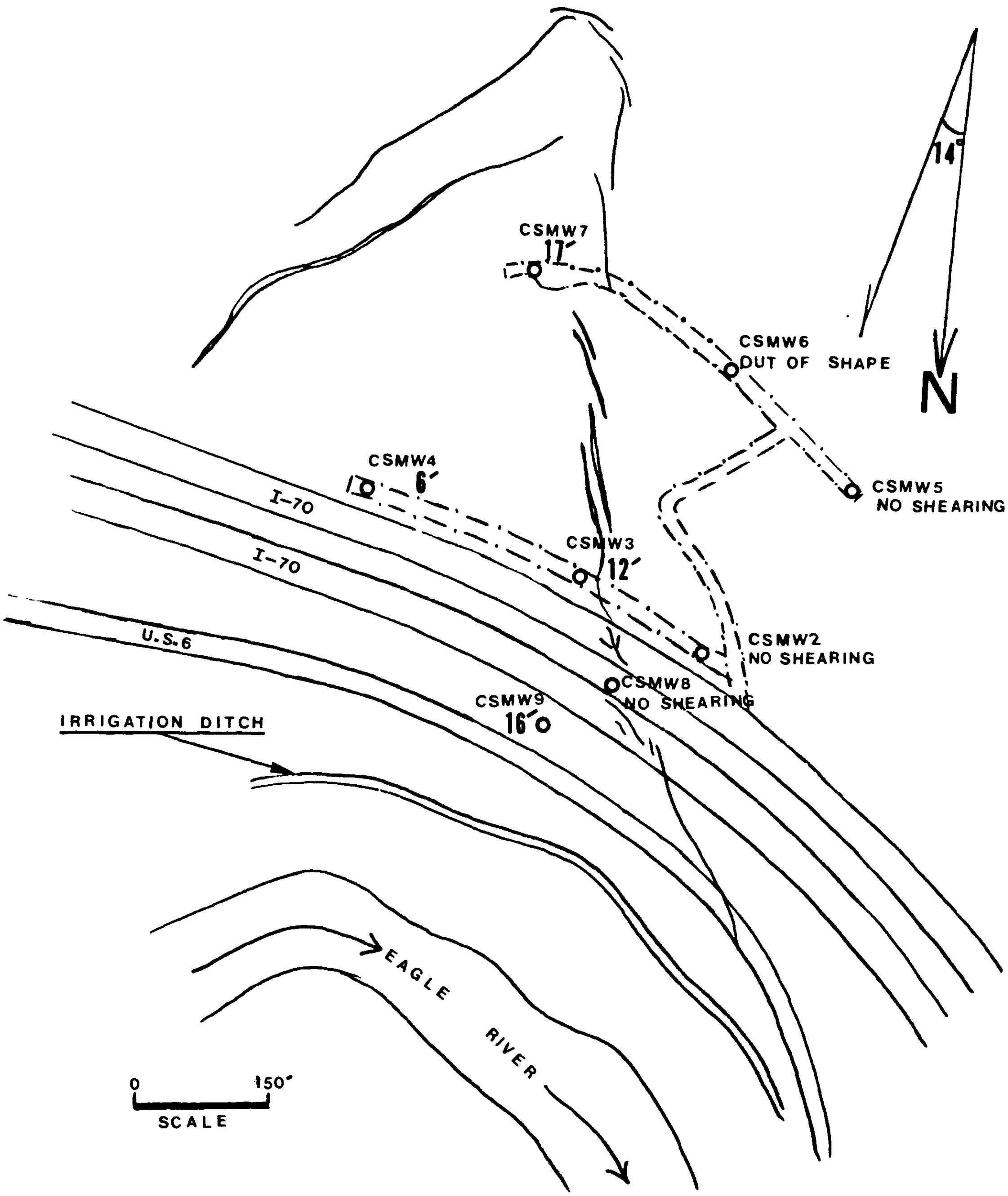


Figure 15 : Shearing Depth of the Piezometers.

The contact between the Benton and the Dakota formation is exposed in an outcrop located half a mile towards the west of the landslide along I-70, (Figure 16). The rocks exposed in this outcrop correspond to the sliding material. This outcrop shows two clay layers above the contact between the Benton and the Dakota formation at elevations which closely correspond to those observed in the core samples. The upper clay layer was therefore correlated with the shallower gouge zone observed in the cores and made evident by the "deadman" probe. The second layer was correlated with the deeper gouge zone that was observed in the cores.

Bentonite is suspected to be in each of these clay layers because they occur in the lower section of the Benton formation that is characterized by numerous thin layers of bentonites (Wanek, 1952). However, attempts to prove its presence by X-Ray diffraction were unsuccessful because the samples were stored by the Colorado Division of Highways in a fashion which allowed drying. It was thus impossible to prepare the samples according to the required procedures.

Bentonite layers act as failure surfaces because they are rich in montmorillonite, a clay mineral with high swelling potential (Hunt, 1985). The montmorillonite structure is characterized by two Al-Mg silicate layers with

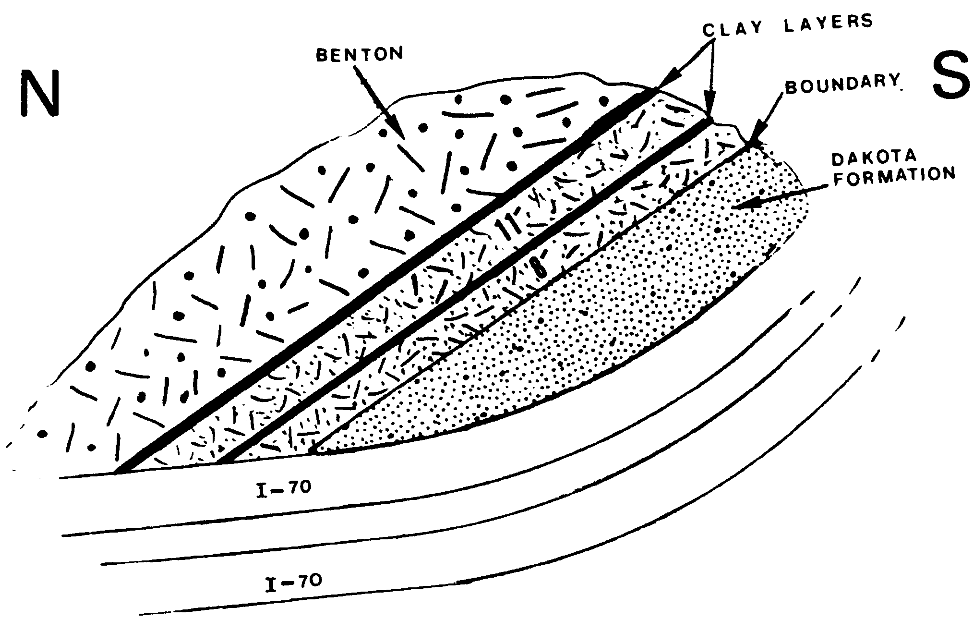


Figure 16 : Outcrop along I-70 Half a Mile West of the Landslide.

a negative charge that is balanced by the positive charge of the cations located in between the silicate layers. Upon water intake between the silicate layers, the cohesive forces decrease dramatically and cause a considerable decrease of the bentonite shear strength (Veder, 1981).

Accordingly, these suspected bentonite layers would readily allow the overlying siltstone beds to slip along the bedding planes which dip at around 11 degrees towards Eagle River. Failure was probably initiated by the undercutting of the toe of the landslide caused by the Eagle River meander.

4.2 Mechanical Behavior of the Landslide

The rates of movement of the landslide correlate with the local rises in the water table (Figure 17). Movement is initiated once a threshold in the ground water level is reached. This threshold appears to occur when the water table rises to about 12 feet below the surface. Even after the water level drops below this threshold, loss of the soil strength and internal structural changes allow the slide to continue to fail.

The Wolcott landslide is a dip slope landslide with two shallow failure surfaces along which the movement is translational. Field reconnaissance at the site, and the

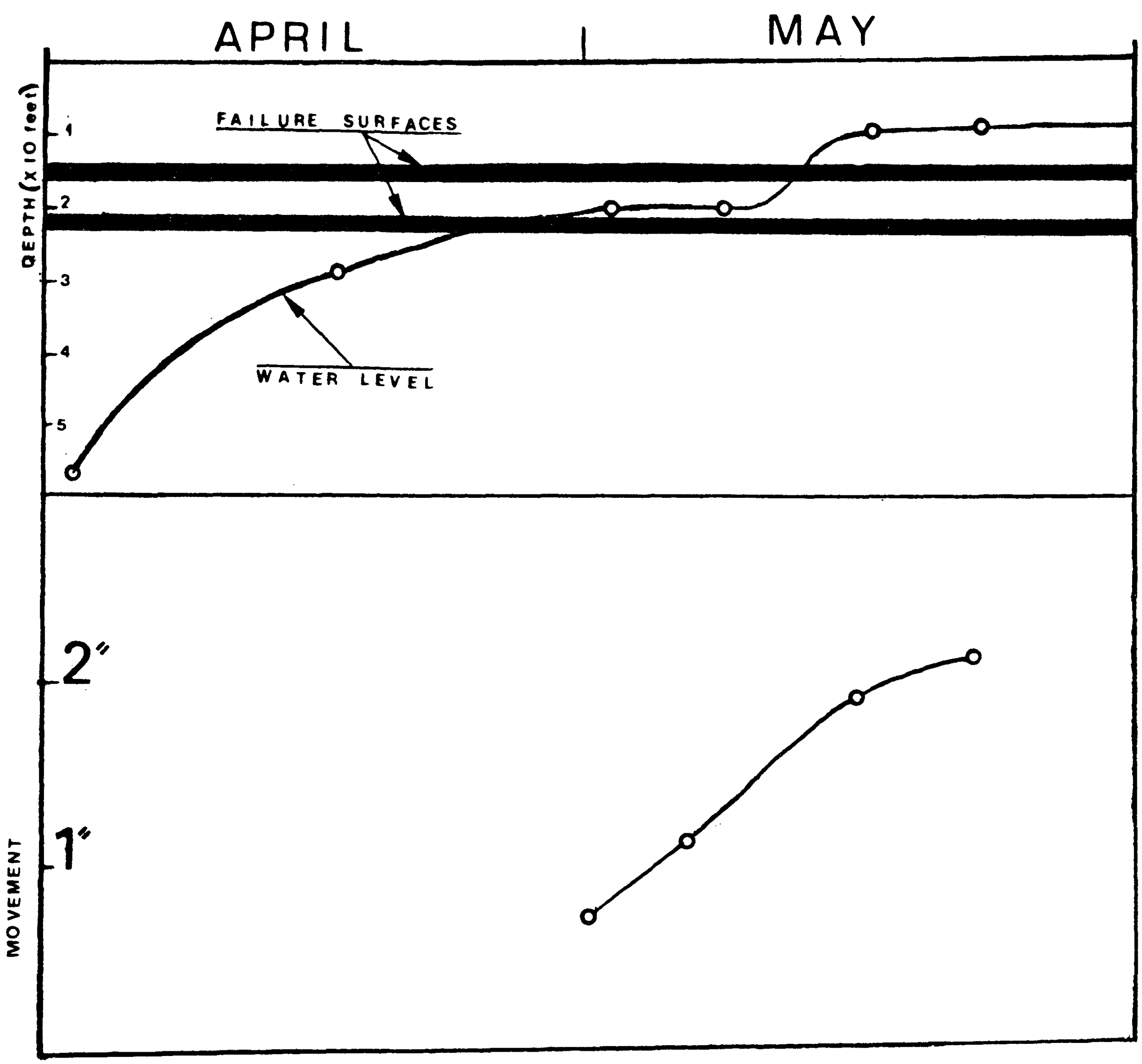


Figure 17 : Water Level and Movement Correlation.

observation of the subsurface cores, suggest that the landslide has two basic parts. Two major scarps were identified in the field. Observations of the subsurface, exposed in the cores, identified two gouge zones that correlate to the failure surfaces identified in the field, with the inner scarp corresponding to failure along the shallower layer. This suggests that one slide occurs within the other. Plate 9 is a detailed north-south cross section of the slide.

The western part of the slide shows movements which have a considerable vertical component, while the eastern part of the slide moves more or less laterally downslope. The movement towards the west of the slide has a larger vertical component while to the east it is more strictly horizontal.

Near the eastern edge of the slide, total lateral movement of 2 inches was measured along a major crack on I-70 by May 15. This was not associated with any vertical movement (see Figure 18). A lateral displacement of 2 inches was observed along a crack on U.S.6 toward the western edge of the slide. This was associated with a vertical offset of 2.4 inches (see figure 19). Movements were noticed to be progressively larger towards Eagle River, especially towards the west. Accordingly damage to U.S.6

Figure 18 : Primarily Horizontal Movement on a Crack along Interstate-70 on the Eastern Margin of the Landslide.

Figure 19 : Combined Vertical and Horizontal Movements on a Crack along Highway U.S.6 at the Western Margin of the Slide.

was especially severe.

4.2.1 Phases of Movement

The failure at the Wolcott landslide consists of two phases, (see Figure 20):

1) Phase I: late in April-May 25, 1985

2) Phase II: May 15-May 30, 1985

The initial phase is associated with saturation of the slide material and made worse by a poor drainage system. The lower failure surface, 19 feet deep, is believed to be always saturated. During the spring thaw, water infiltration increases and the potentiometric surface rises to saturate the upper surface at a depth of about 12 feet , which then acts as another failure surface. Movement then occurs and affects both I-70 and U.S.6 distorting and cracking the pavements. This phase ended by May 25, 1985.

In the middle of May 1985, leakage from an irrigation ditch saturated the toe of the slide. The lower portions of the slide were reactivated, initiating a second phase of retrogressive failure that migrated back up the slide. This caused further cracking of U.S.6 and the west bound lane of Interstate-70 by the end of May (see Plates 5 and 6).

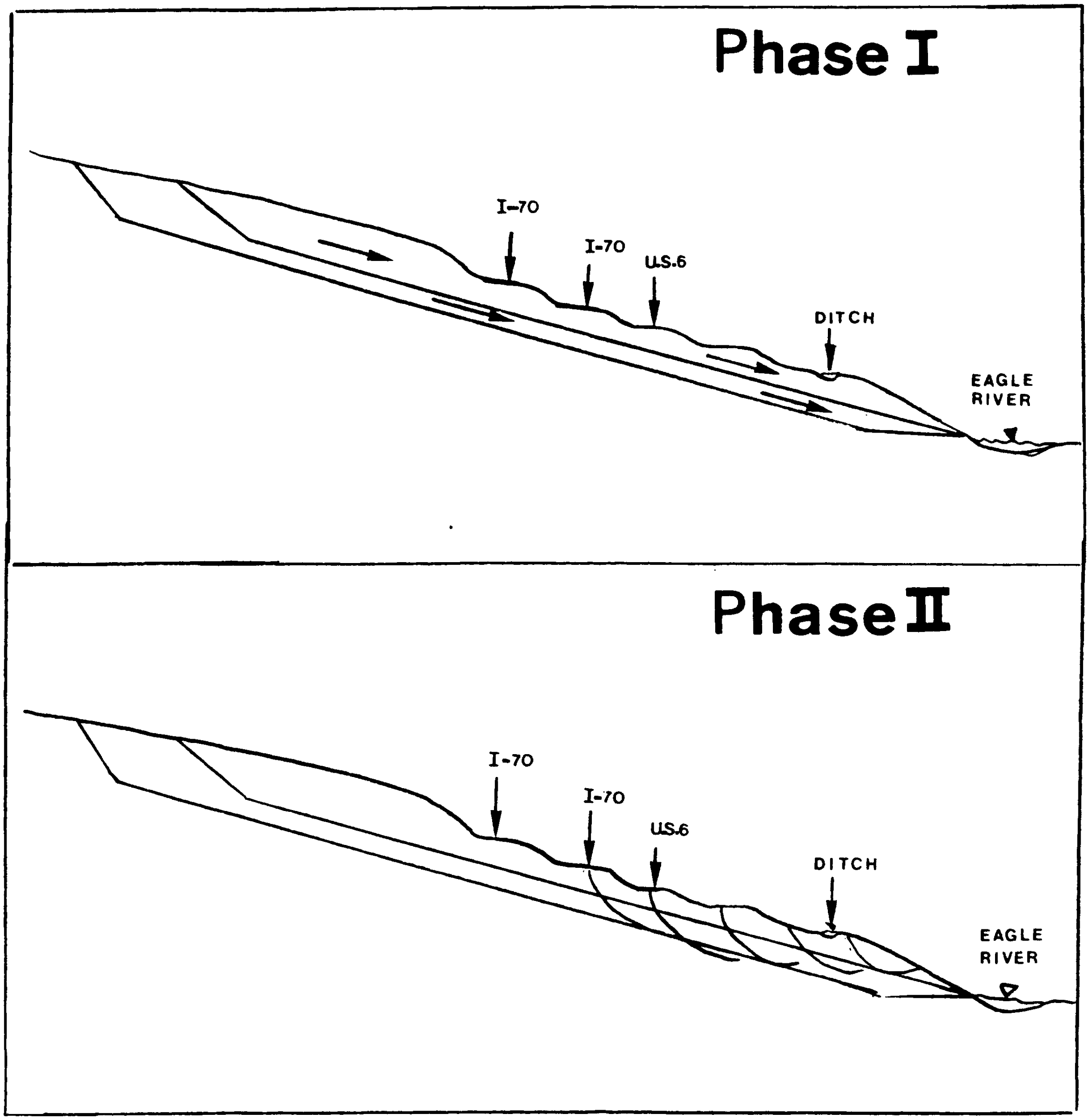


Figure 20 : Phases of Movement.

5.0 COMPUTER ANALYSIS OF THE LANDSLIDE STABILITY

Computers are now considered as an important tool in slope stability analysis because of the large number of variables and calculations involved. One of the state-of-the-art programs written for slope stability analysis was developed over the last ten years at Purdue University (Lovell, et al., 1985). A series of updated versions were issued periodically. All are called STABL with numbers to indicate the version. The STABL3 version of this program was used in the analysis of the Wolcott landslide.

5.1 Description of STABL3 Computer Program

STABL is written in Fortran IV source language for the general solution of slope stability problems using a two-dimensional limiting equilibrium method. The calculation of the factor of safety against instability of a slope is performed by the method of slices. The particular methods employed in STABL3 are the simplified Janbu method and the modified Bishop method of slices. The Bishop method is applicable to circular shaped failure surfaces, while the Janbu method is applicable to failure surfaces of general shape. Surfaces of circular shape, of sliding block character and of irregular shape can be generated.

STABL3 features unique randomization techniques for the generation of potential failure surfaces. Up to hundred trial failure surfaces are generated in a given analysis and the factors of safety for the ten most critical surfaces are calculated. The means for defining and analyzing a specified trial failure surface are also provided.

The slope stability analysis of the Wolcott landslide was performed using the Simplified Janbu Method of Slices for irregular failure surfaces. A critical failure surface searching method using a random technique for generating sliding block surfaces was specified, (Siegel, 1975b).

5.2 Analysis Procedure.

The steps in the computer analysis of the landslide involved:

1) Identification of the appropriate values for the model;
2) Sensitivity analysis;
3) Selection of the characteristic values for cohesion and angle of internal friction for the slide materials;
4) Analysis of the effects of drainage on the water table geometry using Glover's solution; and
5) Analysis of the effect of such dewatering on the

landslide stability.

5.2.1 Data Input File Preparation

A model for the geometry of the landslide was established in order to prepare a data input file for the STABL3 computer program. The ground surface and the existing piezometric surface were defined and the boundaries between the differing soil types were also specified. The block parameters required by the BLOCK routine to generate the active and passive portions of the failure surfaces were also determined.

The engineering properties of the soils were not known and could not be determined in the laboratory because of the inapropriate condition of the available samples. A high amount of variability of these parameters was anticipated due to clay materials locally present in the sliding mass. Thus, any values obtained from the laboratory testing of small samples would probably not be representative of the actual field conditions. Accordingly, values for the strength properties of the soils were estimated from the standard engineering tables (Hunt, 1985).

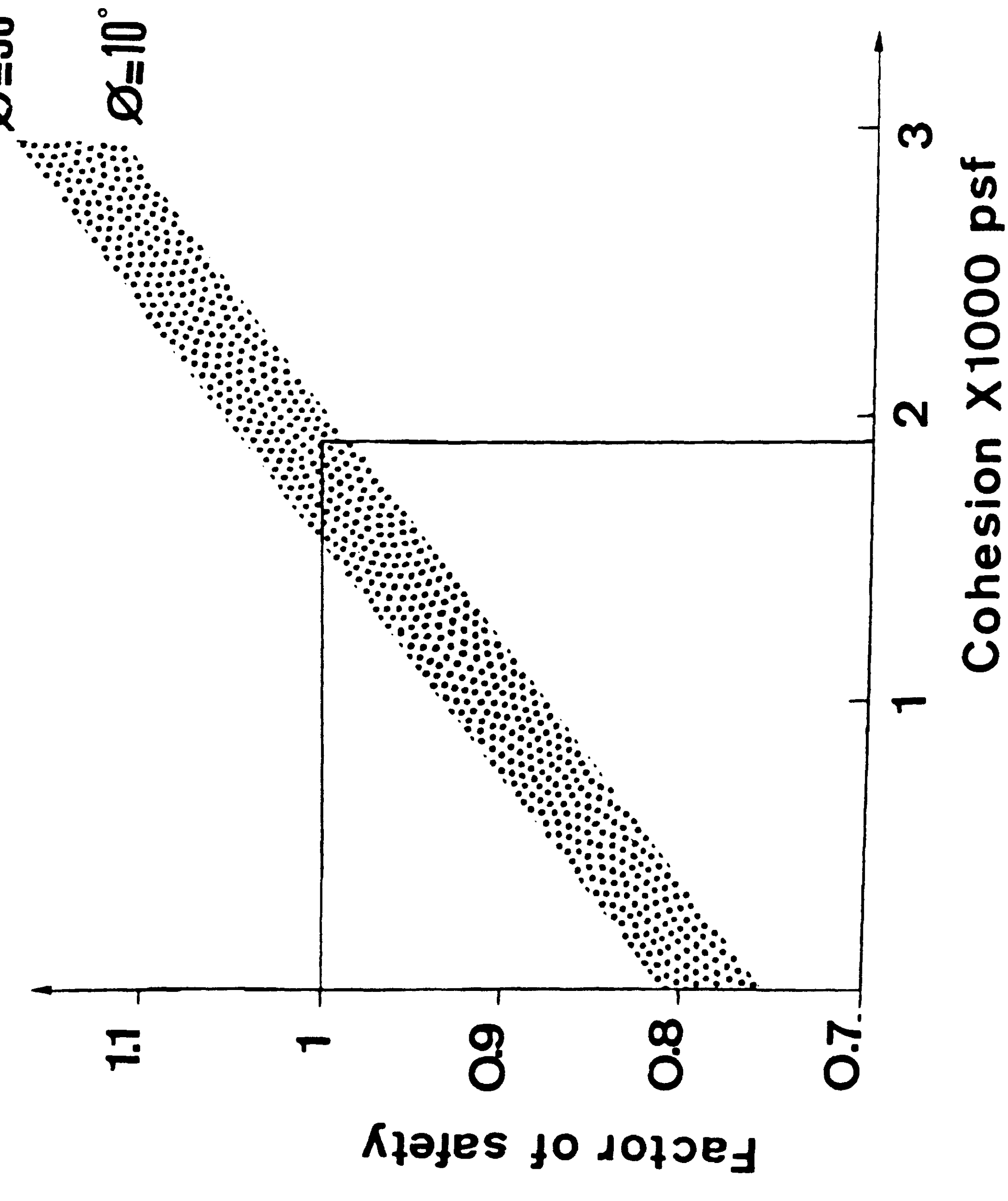
The data were all stored in a free form input file that was executed by STABL3. Several runs were performed to provide a sensitivity analysis. An example run is documented in APPENDIX C.

5.2.2 Sensitivity Analysis

A sensitivity analysis was conducted using values of soil cohesion ranging between zero and 3000 pounds per square foot (psf), and values for the angle of internal friction ranging between 10 and 30 degrees. These values were obtained from standard engineering tables (Hunt, 1985).

Figure 21 shows the relationship between the cohesion and the factor of safety for various angles of internal friction. The limits of the shaded area cover all likely subsurface conditions. By examination of Figure 21, it is apparent that the cohesion affects the factor of safety much more than the angle of internal friction. As the angle of friction varies from 10 to 30 degrees, the factor of safety changes only about 5 to 7 %, while a change in cohesion from zero to 3000 psf causes the factor of safety to increase by about 25 %.

Figure 21 : Sensitivity Analysis.



5.2.3 Selection of Characteristic Soil Parameters

Based on the sensitivity analysis a value of 14 degrees for the angle of internal friction and a cohesion of 1900 psf were selected for the landslide material. However two marked failure surfaces were observed and believed to contain bentonite. Accordingly, values of 200 psf and 6 degrees were selected for these layers. These values were chosen from published data on a bentonite zone involved in a landslide in Minneapolis (Wilson, 1974).

These soil parameters and the specified geometry were used to generate the ten most critical failure surfaces using STABL3. The first generated critical failure surface corresponds closely to the deeper failure surface identified and mapped in the field, while the eighth generated surface corresponds to the shallower gouge zone mapped in the field. The factors of safety of the first and the eighth generated surfaces were 0.949 and 0.994 respectively.

This suggested that the above specified soil parameters are probably representative values of the subsurface conditions

5.2.4 Drainage Effects on the Water Table Geometry

Interceptor drains are frequenly used to drain groundwater in landslide zones. They are installed perpendicular to the groundwater flow direction, and create a continuous zone where groundwater flows towards the drain with a resulted lowering of the water table. Figure 22 shows the effect of an interceptor drain in altering the configuration of the groundwater table.

In order to assess the effect of an interceptor drain on the stability of the landslide, a reasonable estimate of the upgradient and the downgradient influence of the drain was required . For this purpose Glover's solution for the groundwater flow towards an open trench, as described in McWhorter and Sunada (1974),was used.

Glover determined that a value of the drawdown at a certain distance upgradient from a drain for a specified time is:

$$s=s'\{1-\mathrm{erf}(x/\sqrt{4\alpha t})\}$$

s : Drawdown at distance x

s': Drawdown at the trench

x : Distance upgradient from the trench

t : Time

erf : Error function(McWhorter and Sunada, 1974)

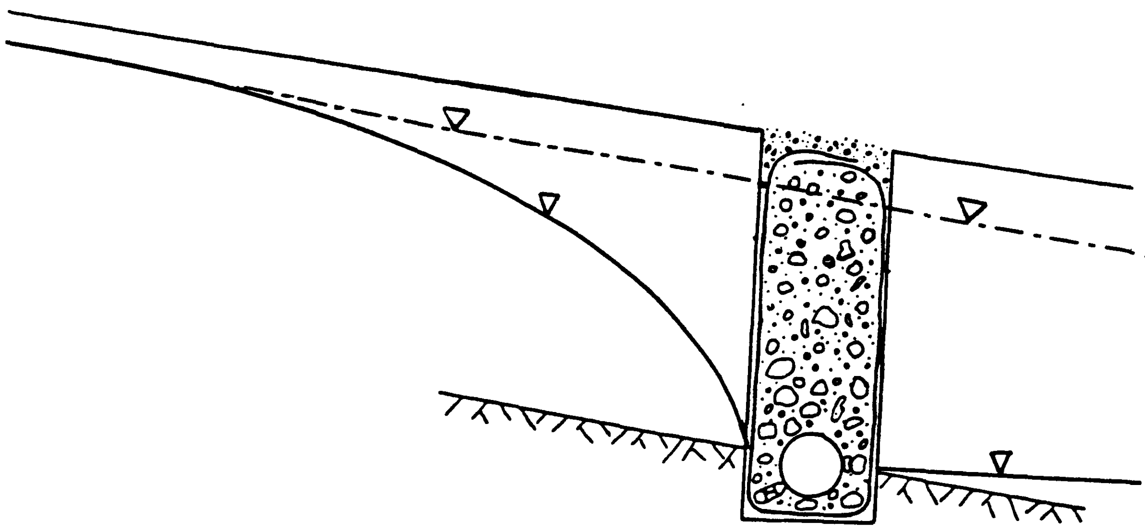


Figure 22 : Effect of Drain Installation on the Groundwater Table.

His solution assumes unsteady flow in a homogeneous, isotropic aquifer of infinite extent. Drawdown values are also assumed to be everywhere smaller than the saturated thickness. Although these assumption only approximate the existing field conditions, this solution provides a reasonably good estimate of the zone of influence of a drain.

A computer program to solve Glover's equation (Hydrosearch, 1986), was used to analyze the effect of the installation of a French drain at the Wolcott landslide. Data input included values of the hydraulic conductivity, average saturated thickness, drainable formation porosity, and drawdown at the drain. Values of drawdown up to an upgradient distance of 900 feet, at different time intervals, were generated.

Drawdown data was generated for a hydraulic condutivity ranging from 0.001 to 10 feet per day, after one and two years of the installation of the french drain. These data are summarized in Table 7. All other parameters were assumed to be constant. These data show how the radius of influence of the drain increases with increasing hydraulic conductivity, with a corresponding increase in the dewatering efficiency of the drain. As will be shown in the

Table 7

Drawdown Data Using Glover's Equation.

Distance, (ft)	Drawdown, (ft)					
	K=0.01 ft/day		K=0.1 ft/day		K=1 ft/day	
	t=1 year	t=2 years	t=1 year	t=2 years	t=1 year	t=2 years
50	1.9576	4.8367	12.013	14.225	17.370	18.136
100	0.0186	0.3848	5.903	9.183	14.812	16.298
200	0.0000	0.0000	0.725	2.774	10.158	12.793
300	0	0	0.037	0.527	6.413	9.650
400	0	0	0.000	0.061	3.708	6.982
500	0	0	0.000	0.004	1.957	4.836
600	0	0	0	0.000	0.940	3.203
700	0	0	0	0.000	0.409	2.026
800	0	0	0	0	1.617	1.222
900	0	0	0	0	0.058	0.703

Average saturated thickness: 25 feet
Drainable formation porosity: 0.02
Drawdown at interface: 20 feet

next section, such a drain will substantially raise the landslide factor of safety for all the permeabilities tested. Thus, the data in Table 7 merely suggest how efficiently such a drain is likely to operate under the actual field conditions.

5.2.5 Effect of the Dewatering on the Landslide Stability

The effect of dewatering the landslide using the French drain was analysed using STABL3. A factor of safety for the slide was calculated for the specified water table corresponding to each hydraulic conductivity (Table 8) .

Figure 23 shows the relationship between the hydraulic conductivity and the factor of safety of the landslide. The factor of safety for both failure surfaces increased with increasing hydraulic conductivity. Higher hydraulic conductivity increases the radius of influence of the drain, thus increasing its efficiency in dewatering the landslide, and this in turn causes an increase in the factor of safety of the landslide. Even with the minimum value for hydraulic conductivity, the factor of safety of both failure surfaces increased above 1.0. The drain is thus believed to be of major importance for stabilization of the landslide.

Table 8

Stability Analysis of the Wolcott Landslide
Assuming C = 1900 psf and ϕ = 14°

Failure Surface	Factor of Safety	Factor of Safety		
	At Maximum Observed water table	Drained After 1 Year		
		K=0.01	K=0.1	K=1 (ft/Day)
Deeper	0.949	1.003	1.015	1.045
Shallower	0.994	1.034	1.042	1.063

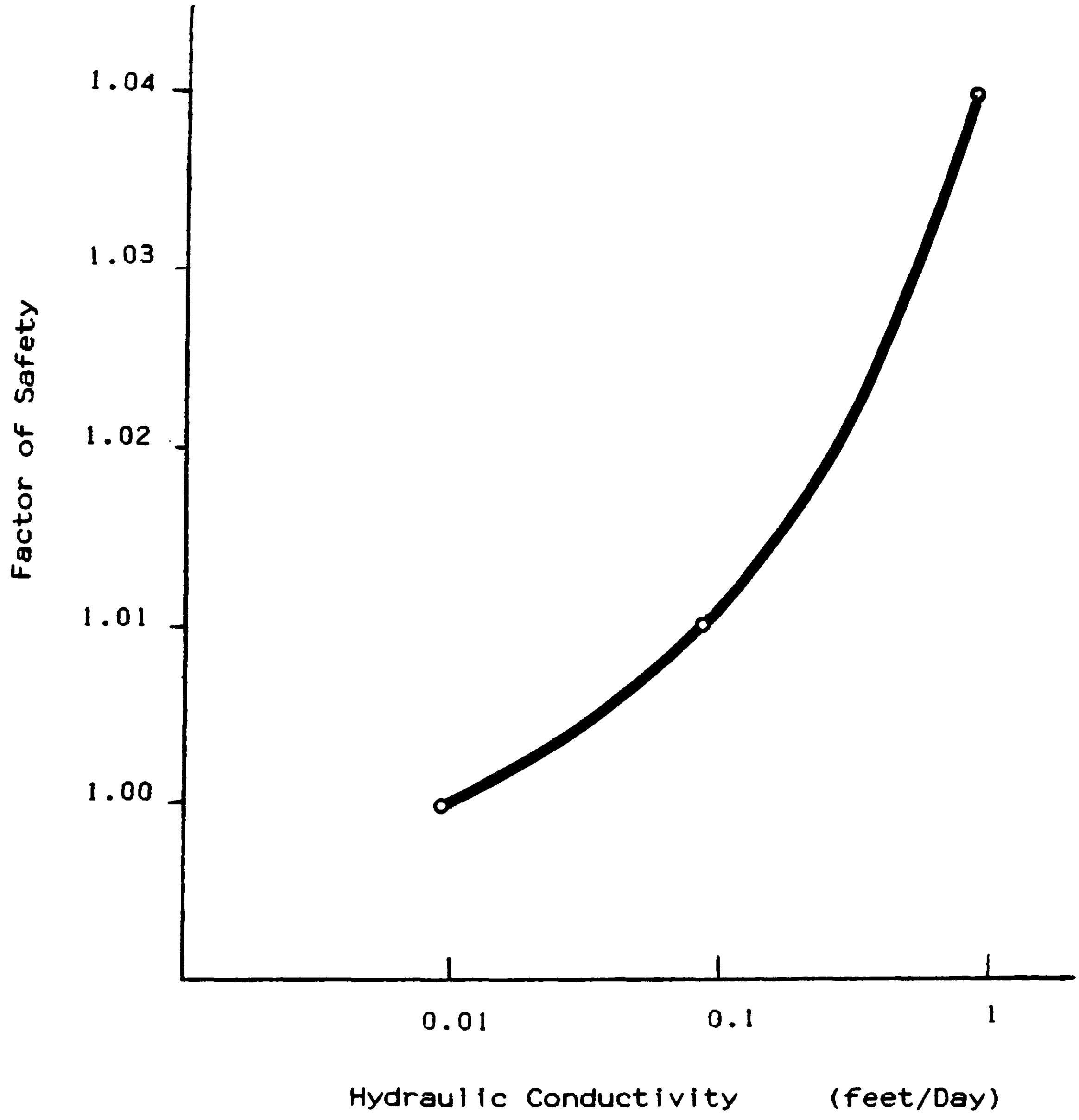


Figure 23 : Factor of Safety Vs Hydraulic Conductivity.

Such a drain could be located anywhere within the lower portion of the landslide above I-70. The actual location will be controlled by the elevations of the existing I-70 culverts, as described in section 6.1.

6.0 SUGGESTED REMEDIAL MEASURES

A major objective of this study was to determine the most effective and economic method to stabilize the Wolcott landslide. It was found that various factors contributed to the instability at the site. In addition to the geology, man-made disturbances contributed to the phenomena and are believed to be the major trigger to the movements. The recommended remedial measures are the following:

1) Reconstruction of the drainage system, including:
   - Extension of the culvert C-1, and
   - Installation of a new French drain above I-70;
2) Realignment of the irrigation ditch;
3) Regrading the toe and straightening of Eagle River meander.

These remedial measures are listed by order of priority as suggested by the cost-benefit evaluation.

6.1 Reconstruction of the Drainage System

An old French drain was located at the southern edge of east bound lane of I-70. This drain is connected to culvert C-1 that diverts the intercepted groundwater into the Eagle River (See Plate 10). Culvert C-1 was observed to be dry during and after the snowmelt season suggesting that the presently located subsurface drain system is not functioning properly. Ponding observed near the French drain and at the median of I-70, suggested that the water was recharging to the slide material instead of being properly diverted to the Eagle River.

A new French drain extending below the deeper failure surface should be installed to intercept the seepage moving through the slide above the highways. Culvert C-1 should then be extended southward (upslope) to properly collect and divert the intercepted water (see Figure 24). Such an extension must have an adequate slope and capacity to carry the expected volumes. It must also extend far enough so that it intersects the deeper failure surface (Figure 24). Assuming the use of a clay tile or concrete pipe as an extension for culvert C-1, a typical Manning coefficient of the pipe will be 0.015. To maintain a velocity of 1.4 feet per second, and allowing a pipe capacity of 2 cubic feet per second, it was determined using Manning's equation that an 18 inch diameter pipe should be installed at a gradient of 0.09 %. A 100 feet extension is required for C-1 to intercept the deeper failure surface.

The French drain should be installed 110 feet upslope from the existing old drain. It should extend to a depth of 35 feet below the surface or one foot into the less

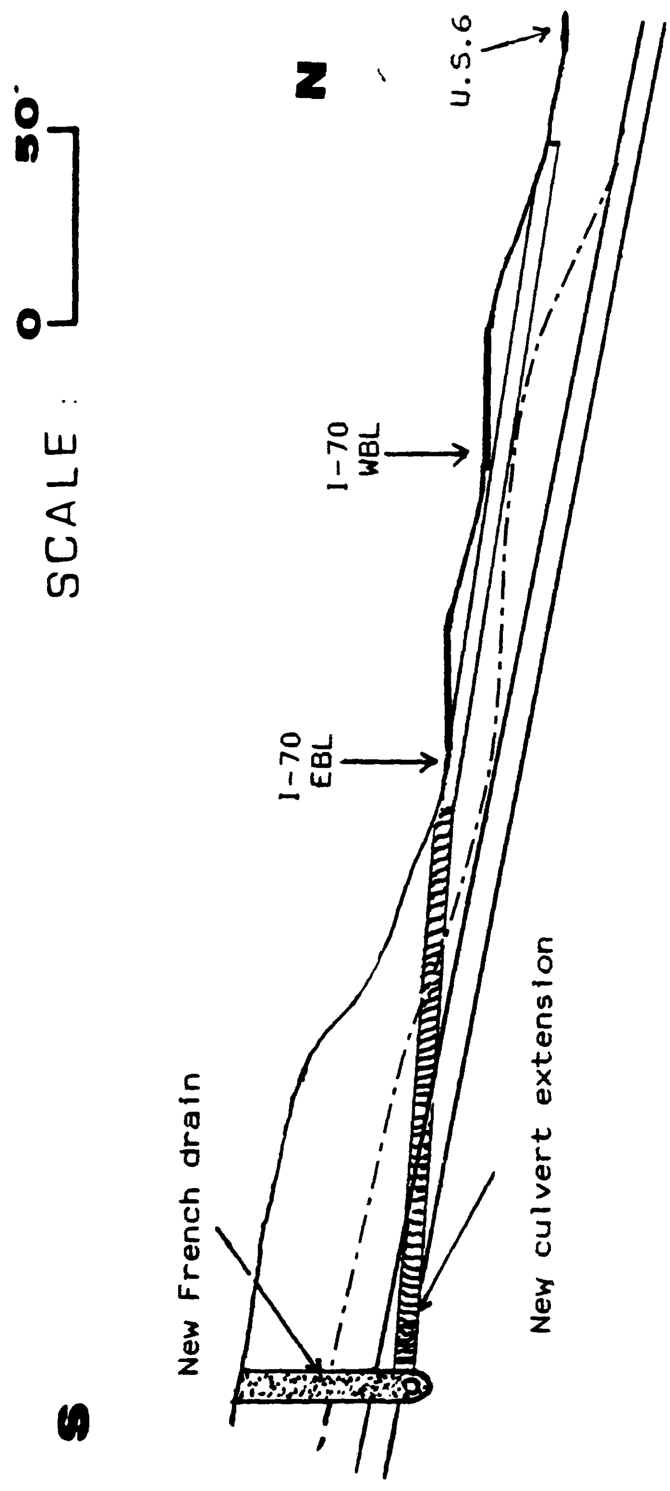


Figure 24 : The New Proposed Drainage System.

permeable Dakota sandstone, whichever is less. With an assumed Manning coefficient for the slotted pipe, and allowing a velocity of 1.4 feet per second and a capacity of one cubic feet per second, a 12 inch diameter pipe should be installed at an 0.13 % gradient towards culvert C-1. This drain should extend over a length of 325 feet to the east of C-1, with a N70W trend to efficiently intercept the major seepage zones located in the area (while maintaining the required 0.13 % gradient), and 200 feet west of culvert c-1 with an east-west trend. It should be lined with suitable permeable geotextile to prevent infiltration of fines and extend its life expectancy. Similar installations have been successfully used on the Colorado Highway 91 realignment on Fremont Pass in similar geologic conditions(. Figure 25 shows the design of the drain proposed at the Wolcott landslide.

This action will require about 3000 cubic yards of trench excavation and backfilling with 1500 cubic yards of gravel and 1500 cubic yards of slide material to close the trench. Around 1500 cubic yards of material must then be disposed of off the site. The cost of the installation of this drain together with the culvert extension is estimated to be about $ 35,000.00 (Godfrey, 1984).

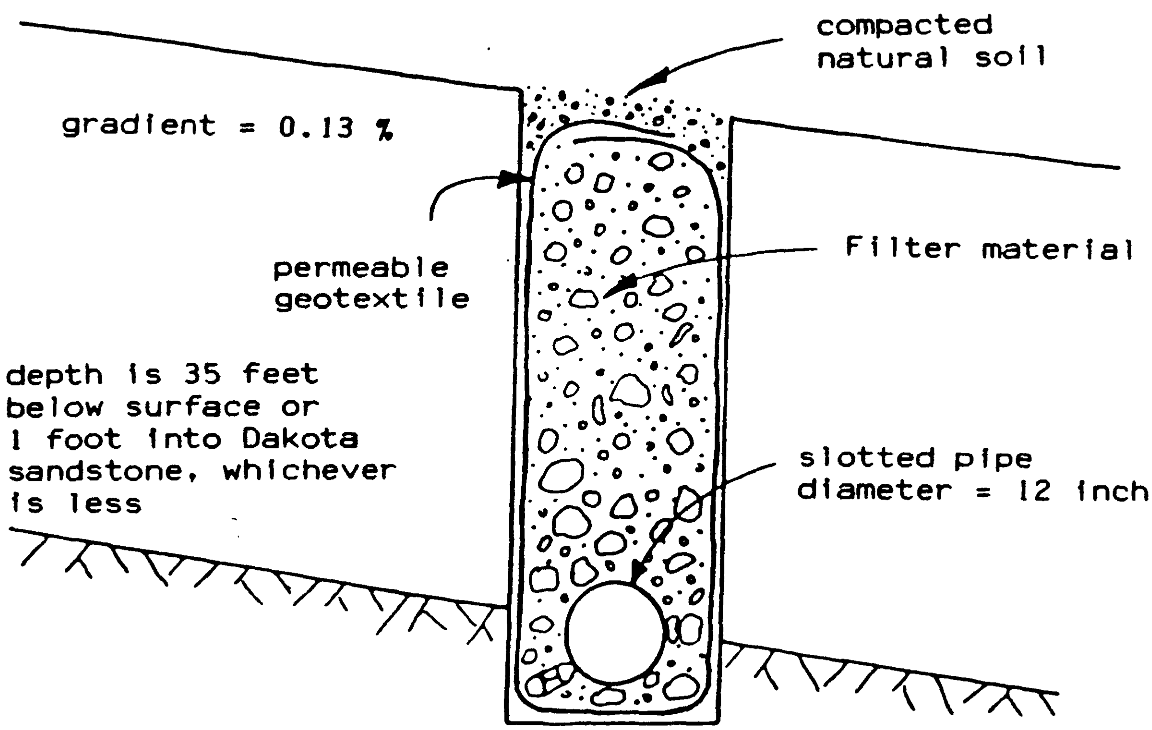


Figure 25 : Design of the Proposed French Drain.

6.2 Realignment of the Irrigation Ditch

The realignment of the irrigation ditch is necessary to prevent leakage of its water and saturation at the landslide toe. About 550 feet of the existing ditch has had its grade disturbed so that overflow now occurs or is imminent. The new ditch should be constructed with materials that would prevent seepage into the landslide even if some additional movements occur. Thus flexible material such as impermeable membranes or bentonite clay should be considered and the new banks should have adequate freeboard.

With a unit price of $ 30.00 per feet, (Godfrey, 1984), The cost of realigning the ditch was estimated at around $ 16,500.00.

6.3 Toe Protection

Further, erosion by the Eagle River meander could be reduced by regrading the highly disturbed zone and by rip-rap emplacement. It is estimated that an area of around 900 square feet of bank requires treatment, and 200 cubic yards of rip-rap needs to be placed. A unit price of $ 21 per cubic yard (Godfrey,1984) is suggested as reasonable for regrading, supplying and placing rip-rap. Accordingly, the cost of this remedial measure is estimated at $ 4,500.00.

Straightening of the river course at the meander could help prevent the high rates of erosion at the slide toe. This appears to be feasible by excavating through the inside of the meander which is mostly gravel and near the river level. However, while this measure would assist in increasing the long term stability of the Wolcott landslide, its cost-effectiveness and logistics suggest that the drainage control measures should be undertaken first, because movements which would damage the highways would continue without such drainage improvements.

7.0 CONCLUSION

The Wolcott landslide is located near the axis of the Wolcott syncline, in the siltstones and shales of the Benton formation. The regional structure tends to direct groundwater toward the slide, and artesian or near artesian conditions may exist in the Dakota sandstone units immediately below the slide.

The landslide is a dip slope landslide with two failure surfaces at 12 and 19 feet below the surface. Translational movement occurs within layers containing bentonite dipping at 11 degrees toward the Eagle River. Undercutting of the toe of the slide by the meander of the Eagle River, probably initiated the instability.

Two phases of movement were observed during the Spring of 1985. The first occured in May, and was due to saturation of the slide by recharge from snowmelt which was not drained by the existing drainage system. The second phase occured in late May, and resulted from saturation of the toe area by leakage and overflow of the irrigation ditch.

Thus the following measures are recommended to increase the stability of the slide:

1) Reconstruction of the drainage system including the installation of a new French drain around 110 feet southward of east bound lane of I-70, and the extension of the existing culvert C-1 below I-70 over a distance of 100 feet southward. The cost of this measure was estimated to be around $ 35,000.00

2) Realignment of 550 feet of the irrigation ditch at a cost of $ 16,500.00.

3) Regrading the toe and rip-rap emplacement to reduce the erosion caused by the Eagle River meander. This remedial measure was estimated to cost $ 4,500.00; the possible straightening at the meander of Eagle River could assist in increasing the long term stability of the slide

These remedial measures are listed in their order of priority as was understood in this study. However, the reconstruction of the drainage system seems to be the most urgent and cost effective method. The computer aided analysis of the effects of the drain installation on the stability of the landslide showed a promising increase of the factor of safety to a value above 1.0 upon dewatering.

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APPENDIX A

Observation Well Logs

MEMORANDUM

DEPARTMENT OF HIGHWAYS
714 Grand Ave., P O Box 298
Eagle, Colorado 81631-0298
(303) 328-6385

DATE: March 11, 1985

TO: ~~R. Barrett~~ D. Pitts

IR 70-2(131)
East of Wolcott

FROM: ~~M. J. Smith~~ R. Barrett

SUBJECT: Topography for drill holes.

Attached is one cross section sheet and two 8½" x 11" sheets with information on drill holes for project IR 70-2(131), East of Wolcott. If more information is needed please advise.

R. D. Sherman
Construction Engineer

M. J. Smith
M. J. Smith
Resident Engineer

Attachments

xc: Moston
Leonard
Sherman
Smith

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No. 287
Revised, September, 1978

Project: Wolcott Slide
Location: [illegible]
Structure: Slide
Route: I-70 County: Eagle
Date Drilled: 12/13/84
@ 1:30 P.

FOUNDATION BORING LOG

1 of 2

Top Hole Elev. ______ Geologist: P. Markha[illegible] Station ______ Boring No. INCLINOMETER #2

Elev.	Depth	Description of Material	BPF*	Remarks
	0.0 - .5	silty clay; some gravel < 1" dia.; moist dk brown		CME 75; 4.5" TC w/ [illegible] to 5'; 3 7/8" TC to 11.5' – 4" casing
	.5 - 1.2	as above, more gravel, dry; light brown chips of dk grey shale/siltst		drilled w/ air.
	1.2 - 5.0	v. fast drilling; chips of dk grey siltstone; brittle chips; in a clayed dk brn matrix dry		
	5.0 - 6.5	as above, dry (2A) 9/17/37	54	sample kept
	5.0 - 6.3	as above		
	6.3 - 6.7	dk grey siltstone. hard slow drilling		
	6.7 - 10.0	f. drilling clayey gravel gravel - .5" dia dk grey siltstone clay dk brn dry		
	10.0 - 11.5	clayey gravel dry [illegible] (2B) 11/15/20	35	caving at 11.5 dry hole at top [illegible]; H2O came in over[night] [illegible] from 11.5
	11.5 - 15.0	dk grey silty shale sparkles bedrock slow drilling		
	14.0 -	sample (2C) off of drill stem (stub + drill stem) of gravelly clay (pink shale) after soaking overnight from water coming in at 11.5' not much water in hole		
	15.0 - 15.5	as above.		
	15.5 - 16.2	fast drilling softer shale		
	16.2 - 17.2	med. drilling silty shale interbedded w/ siltstone. dk-med grey → milky white		
	17.2 - 18.2	softer unit more ss – faster drilling – same color gradational change		

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion ______ Elev. ______ Date ______ Time ______
Water level (24 hrs.) ______ Elev. ______ Date ______ Time ______

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No. 267
Revised. September, 1978

Project: Wolcott Slide
Location: near Wolcott
Structure: Slide
Route: I-70 County: Eagle
Date Drilled: 8/14

FOUNDATION BORING LOG

(2) of 2
INCLINOMETER

Top Hole Elev. ______ Geologist: P. Martin Station ______ Boring No. 2

Elev.	Depth	Description of Material	BPF*	Remarks
	18.2–20.0	as before ~~silty [illegible]~~ siltstone, ss interbedded		damp at 18.3'
		slow drilling dr-med gray chips - white powder		cuttings showing water.
		[illegible]		-> siltstone/shale.
	20.0–23.0	fine grained silty ss. (as above) white powder.		
		damp prob leaking in from above at 18.3'		

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion ______ Elev. ______ Date ______ Time ______
Water level (24 hrs.) ______ Elev. ______ Date ______ Time ______

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No 267
Revised September 1978

Project
Location Walcott Slide
Structure
Route I-70 County Eagle
Date Drilled

Conolough

FOUNDATION BORING LOG

inclinometer

Top Hole Elev. 7103.7 Geologist D. Pitts Station Boring No. 2

	Elev.	Depth	Description of Material	BPF*	Remarks
Tues. Feb. 19 1985	7081.7	22.0-28.0	Siltstone, Lt. Grey		
	7075.2	28.5	H_2O		
	7075.7	28.0-29.0	Siltstone, Dk. Grey & black shale		
	7074.7	29.0-32.0	Ss: Dirty Grey, very fine grain,		
			subangular to subrounded		
Wed. Feb. 20 1985	7071.7	32.0-42.0	Ss: White, very fine grain, subangular		
			to subrounded		
	7061.7	42.0-43.5	Coal		
	7060.2	43.5-45.0	Ss as above		
	7058.7	45.0 TD			

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion ________ Elev.________ Date________ Time________
Water level (24 hrs.)________ Elev.________ Date________ Time________

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No 267
Revised September 1978

Project ____________
Location Walcott Slide
Structure ____________
Route I-70 County Eagle
Date Drilled Wed. Feb. 20, 1985

FOUNDATION BORING LOG

1 of 2 pages

CSHW3

Top Hole Elev. 7104.1 Geologist D. Pitts Station ____________ Boring No. #3

	Elev	Depth	Description of Material	BPF*	Remarks
	7104.1	0.0-4.5	Core #1 Recovered 3'± Siltstone: Black		
			and Brown, badly broken. Trace yellow		
			clay like material on some pieces		
	7099.6	4.5-9.5	Core #2 Recovered 2.5'± Siltstone as		
			above. No yellow clay like material but		
			has .2' zone ± (near top of recovery)		
			of Grey, dirty, grainy clay		
THUR. FEB. 21 1985	7094.6	9.5-14.5	Core #3 Recovered 2.5'± 1' siltstone		
			as above, badly broken w/ yellow clay		
			like material thru out. 1.5' siltstone		
			as above partically broken, no yellow		
			clay like material		
	7089.6	14.5-19.5	Core #4 Recovered 5' .2' Clay, Dr grey		
			dirty + gritty. 1' siltstone: Grey + Black, laminated		
	Bed Rock 7087.4	16.7	1' Siltstone + clay: Grey + yellowish, intermixed		
			decomposed. 2.8' Siltstone Grey + Black laminated		
	7084.6	19.5-24.5	Core #5 Recovered 5' Ss: White to Grey		
			very fine grain, sub L to sub O w/ 20%± black		
			siltstone partings @ Top grading to 5%±		
			black siltstone partings @ base		
	7079.6	24.5-29.5	Core #6 Recovered 5' Ss as above, 5 to 10%± black siltstone partings thru out		

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion ______ Elev. ______ Date ______ Time ______
Water level (24 hrs.) ______ Elev. ______ Date ______ Time ______

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No 267
Revised September 1978

Project ____
Location Walcott Slide
Structure ____
Route I-70 County Eagle
Date Drilled Wed. Feb. 20, 1985

FOUNDATION BORING LOG

CSMW3

Top Hole Elev 7104.1 Geologist D. Pitts Station ____ Boring No. #3

Elev	Depth	Description of Material	BPF*	Remarks
7074.6	29.5-34.5	Core #7 Recovered 5' Ss as above w/		
		black siltstone partings		
7069.6	34.5-39.5	Core #8 Recovered 5' Ss white as above		
		No siltstone partings. Massive		
7064.6	TD 39.5'			
		5 sxs. sand 75 lb. sxs.		

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion ____ Elev.____ Date____ Time____
Water level (24 hrs.)____ Elev.____ Date____ Time____

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No 267
Revised. September. 1978

Project Wolcott Slide Monitoring
Location East of Wolcott
Structure Slide
Route I 70 County Eagle
Date Drilled 1/29/85-2/12/85

1 of 2

FOUNDATION BORING LOG

CSMW4
Inclinometer

Top Hole Elev. 7106.5 Geologist P. Macklin Station ____ Boring No. 1

Elev.	Depth	Description of Material	BPF*	Remarks
	0.0-1.0	Silty clay: black, damp from snow		CME 75 drilled w/air
	1.0-2.5	Clayey gravel: gravel 50%, siltstone		20' of 4" casing 3 3/4" TC
		chips, angular-subangular, average		
		diameter 1", clay: Black, sticky		
		damp		
	2.5-9.7	Gravelly clay: black, decreasing		
		amount of gravel with depth		
		clay as above; wet @ 9.7'		wet @ 9.7'
	5.0-6.5	Gravelly clay (as above) 1-3-7	10	
	9.7-11.3	Siltstone, dark grey		
	10.0-10.0	(as above) refusal 25/0	25/0	
	11.3-12.5	Shale, black		
	12.5-13.8	Siltstone/fine grain sandstone		
	13.8-25.2	Shale interbedded with siltstone		
		and very fine grain sandstones		
	15.0-15.0	(As above) refusal 25/0	25/0	
	25.2-36.4	Very fine grained sandy siltstone,		
		white, chalky powder		
	36.4-38.3	Shale; black		38' (pressure head)
	38.3-42.0	Sandstone; orange; much water		H_2O level
	42.0-55.0	Sandstone-siltstone; very fine grained		

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion 9.7' / 38' Elev. ____ Date 1/31/85 / 1/31/85 Time 10:00 A wet / 2:30P
Water level (24 hrs.) 25.3' / 21.1 Elev. ____ Date 2/13/85 / 2/14/85 Time 10:00A / 10:30A

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No 287
Revised. September. 1978

Project Wolcott Slide Monitoring
Location East of Wolcott
Structure Slide
Route I 70 County Eagle
Date Drilled 1/29/85-2/12/85

FOUNDATION BORING LOG

CSMW4
Inclinometer

Top Hole Elev. ______ Geologist P. Macklin Station ______ Boring No. 1

Elev.	Depth	Description of Material	BPF*	Remarks
	55.0-62.5	Sandy shale; very sandy, dark		
		grey to black		
	62.5-71.2	Sandstone; alternating coarsening		
		and firing layers, grey		
	71.2-72.5	Shale, black		
	72.5-82.5	Sandstone; med.-fine grained,		
		dark brown to grey, quartzitic		
	82.5-83.0	Shale, black		
	83.0-85.0	Sandstone (as before)		
	85.0-87.7	Sandy silty shale, gradational		
		contact with above sandstone		
	87.7-100.5	Sandy siltstone; tan-buff colored		
		30% feldspara, 5% black minerals		
		1% pyrite		
	100.5-101.3	Shale, black		
	101.3-103.0	Sandy siltstone		
	103.0-105.5	Shale; black		
	105.5	T.D.		

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion 38' Elev. ______ Date 1/31/85 Time 2:30P
Water level (24 hrs.) 25.3' / 21.1 Elev. ______ Date 2/31/85 / 2/14/85 Time 10:00A / 10:30A

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No 267
Revised September 1976

Project ______
Location Walcott Slide
Structure ______
Route I-70 County Eagle
Date Drilled Tues. Feb. 12, 1985

FOUNDATION BORING LOG

1 of 1 page

CSHW5

Top Hole Elev. 7152.9 Geologist D. Pitts Station ______ Boring No. #5

	Elev	Depth	Description of Material	BPF*	Remarks
	7152.9	0.0-5.0	Brown soil: sl plastic		
	7147.9	5.0-11.0	Brown soil: sl plastic, damp		
	7141.9	11.0-17.0	Brown soil w/ pieces of black shale,		
			damp		
	7135.9	17.0-22.0	Black shale: sl silty		
	7130.9	22.0-29.0	Ss: white, fine grain, subangular to		
			subrounded, hard		
	7123.9	29.0-31.0	Black shale: sl silty		
	7121.9	31.0-35.0	Ss as above		
Wed. Feb. 13 1985	7117.9	35.0-53.0	Ss as above, varies in hardness		
	7099.9	53.0-54.0	Coal		
	7098.9	54.0-59.0	H_2O Siltstone: Brown Hard To very fine sandstone		
	7093.9	59.0-61.0	Coal		
	7091.9	61.0-64.0	Sand: white, fine grain, subangular		
			to subrounded soft		
	7088.9	64.0-74.0	Stringers of Black shale, brown silt		
Thur. Feb. 14 1985			stone and some ss white		
	7078.9	74.0-100.0	20' 4" csg 18' Same as above		
	7052.9	TD 100'			

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion ______ Elev. ______ Date ______ Time ______
Water level (~~24 hrs.~~) 45' Elev. 7107.9 Date 2/18/85 Time 11:00 a.m.

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No 287
Revised September 1978

Project
Location Walcott Slide
Structure
Route I-70 County Eagle
Date Drilled Thur. Feb. 21, 1985

FOUNDATION BORING LOG

1 of 1 page

CSHW6

Top Hole Elev. 7164.5 Geologist D. Pitts Station Boring No. #6

Elev.	Depth	Description of Material	BPF*	Remarks
7164.5	0.0-6.0	Siltstone: Broken, Black and Tan		
7158.5	6.0-9.0	Same as above, damp		
7155.5	9.0-12.0	Same as above		
		4" csg to 15'		
7152.5	12.0-17.0	Ss: white, very fine grain, subangular		
		to subrounded		
7147.5	17.0-36.0	Siltstone: Grey		
7128.5	36.0	Coal, H_2O		
7128.5	36.0-45.0	Ss: white		
7119.5	TD 45.0			
		6 sxs sd 75 lb. sx		
		pipe to 28'		

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion 26' Elev. 7138.5 Date 2/21/85 Time 12:00 Noon
Water level (24 hrs.) Elev. Date Time

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No 267
Revised September 1978

Project ______________________
Location Walcott Slide
Structure ______________________
Route I-70 County Eagle
Date Drilled Tues. Jan. 29, 1985

FOUNDATION BORING LOG

1 of 1 page

CSMW7

Top Hole Elev 7173.7 Geologist D. Pitts Station ______________________ Boring No #7

Date	Elev.	Depth	Description of Material	BPF*	Remarks
	7173.7	0.0-2.0	Siltstone: Black, hard		Acker w/ air + casing advancer
	7171.7	2.0-20.0	Siltstone: Tan and Black, hard		
Wed. Jan. 30 1985					
	7153.7	20.0-31.0	Siltstone as above		Acker w/ air and Tri cone
Tues. Feb. 5 1985	7142.7	31.0-46.0	Ss: white, medium grain, subangular		
			to subrounded, hard		
	7127.7	46.0-46.5	Coal		
	7127.	46.5-49.0	Siltstone: Tan and black, hard		
Mon. Feb. 11 1985	7124.7	49.0-55.0	" " " " "		
	7118.7	55.0-65.0	Ss: white, very fine grain, subangular		
			and subrounded, soft		
	7108.7	65.0-70.0	Shale: Dark grey to black		
Tues. Feb. 12 1985			Abandon hole. Roy's orders		
	7103.7	TD 70.0			
			8 sxs sand 75 lbs.		

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion ________ Elev. ________ Date ________ Time ________
Water level (24 hrs.) ________ Elev. ________ Date ________ Time ________

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No 267
Revised September 1976

Project
Location Walcott Slide
Structure
Route I-70 County Eagle
Date Drilled Thur. Feb. 21, 1985

Conolouge

FOUNDATION BORING LOG

1 of 1 page

Top Hole Elev. 7089.0 Geologist D. Pitts Station Boring No. CSHW8 #8

Elev	Depth	Description of Material	BPF*	Remarks
7089.0	0.0-4.5	Core #1 Recovered 1'± Broken Siltstone:		
		Black w/ Tan clay matrix		
		50-50±. Sod top .2'±		
7084.5	4.5-9.5	Core #2 Recovered 15±		
		Same as above. Clay 30%± No Sod.		
7079.5	9.5-14.5	Core #3 Recovered 3.5'±		
Bed Rock 7078.0	11.0	.8 Siltstone and clay as above		
		2' siltstone + ss laminated black, grey		
		tan siltstone. Grey ss. .2' clay +		
		broken siltstone .5' Ss: white		
7074.5	14.5-19.5	Core #4 Recovered 5'		
		Ss: Grey w/ some black to dark grey		
		siltstone intermixed Bedding approx.		
		30°		
7069.5	19.5-24.5	Core #5 Recovered 5' Same as above		
		also some minor x bedding		
7064.5	24.5-29.5	Core #6 Recovered 5' Same as above		
7059.5	TD 29.5			

* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion ________ Elev.________ Date________ Time________
Water level (24 hrs.)________ Elev.________ Date________ Time________

STATE OF COLORADO
DEPARTMENT OF HIGHWAYS
DIVISION OF HIGHWAYS
DOH Form No 287
Revised September 1978

Project
Location Walcott Slide
Structure
Route I-70 County Eagle
Date Drilled Tues. Feb. 19, 1985

FOUNDATION BORING LOG

1 of 1 page

CSHWg inclino

Top Hole Elev. 7072.8 Geologist D. Pitts Station Boring No. 9

Elev.	Depth	Description of Material	BPF*	Remarks
7072.8	0.0-3.0	Fill		
7069.8	3.0-17.0	Siltstone, black broken		
7055.8	17.0-21.0	Siltstone (some H_2O) Some lt. grey plastic clay mixed in w/ the siltstone		
		15' 4"csg to 15'		
7051.8	21.0-24.0	Siltstone: black		
7048.8	24.0-27.5	Core #1 Recovered 3'+ Siltstone, shaley,		
		sandy. Black + white, laminated. Sand: white,		
		very fine grain, angular. Micaceous, pyritic		
7045.3	27.5-32.5	Core #2 Recovered 5' 3.5' Siltstone		
		as above. Becoming sandier w/ depth		
		1.5' Ss: white, fine to very fine grain,		
		subangular, hard.		
7040.3	32.5-35.5	Core #3 Recovered 3' Ss as above		
		20' 4"csg to 20'		
7037.3	35.5-37.5	Core #4 Recovered 2' ss as above		
7035.3	37.5-40.0	Core #5 Recovered 2' ss as above		
7032.8	40.0-42.5	Core #6 Recovered 2' ss as above but		
		a 6" zone of coal 0+ coal like material		
		between the sand washed away		
7030.3	42.5-47.0	Core #7 Recovered 4.5' .1' grey shale		
		soft 2.4' siltstone black to dk. grey		
		2.0' Ss. Grey: very fine grain, subangular		
7025.8	47.0 TD	w/ dirty black ss streaks thru out		

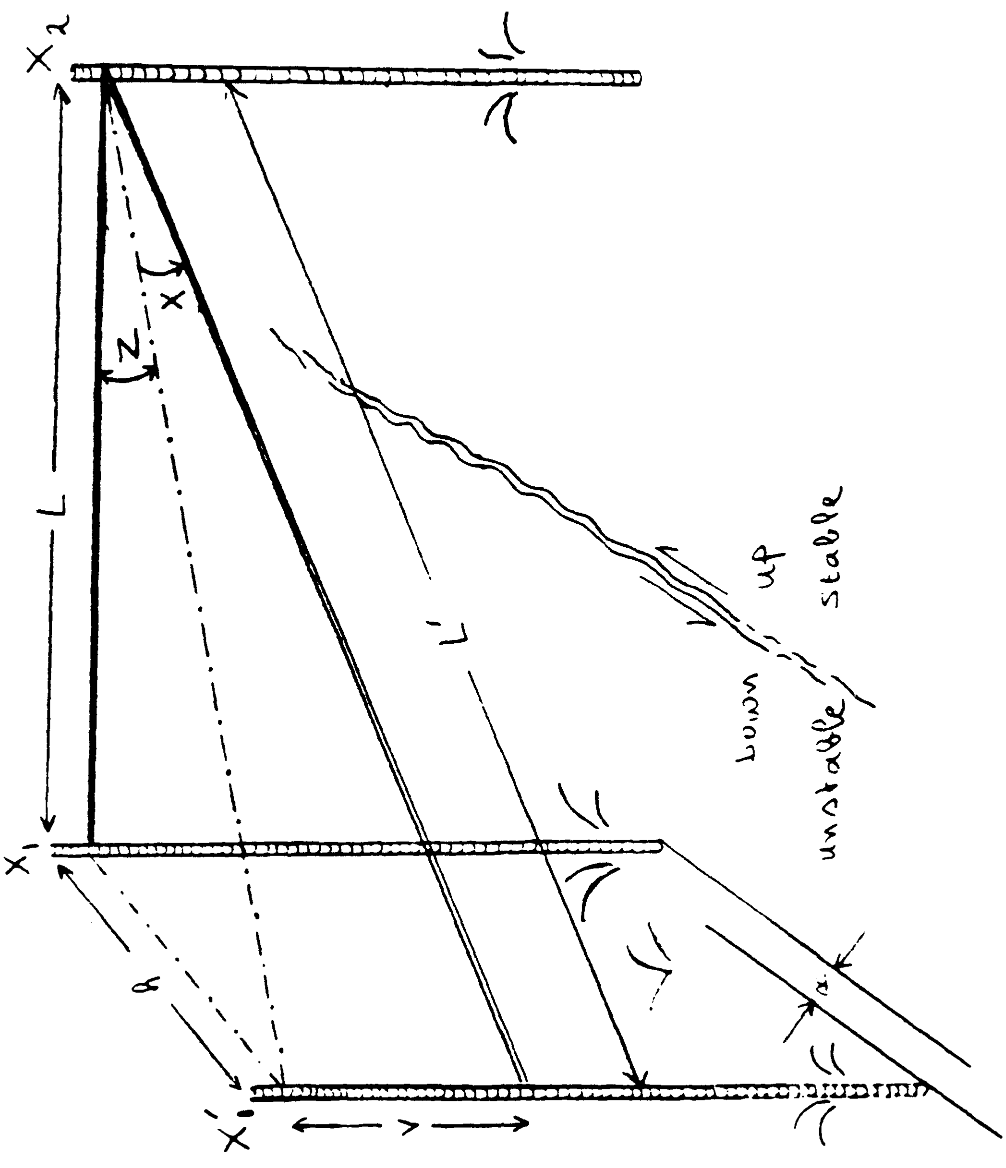
* Standard Penetration Test (AASHTO T 206-74)

Water level upon completion ________ Elev.________ Date________ Time________
Water level (24 hrs.)________ Elev.________ Date________ Time________

APPENDIX B

RUBBER BAND EXTENSOMETER

DATA REDUCTION


L
L'
up
stable
down
unstable

Legend

X1-X2 : Rebars labels

L : Original length of the rubber band

Z : Rubber band bearing

X : Angle of rubber band with the horizontal

L' : New length of rubber band

h : Initial lateral movement

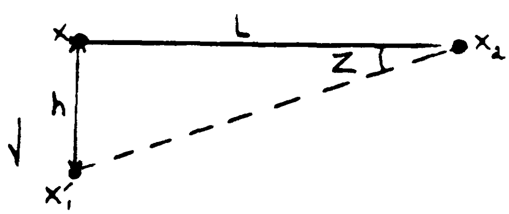
h' : Final lateral movement

H : Total lateral movement

v : Horizontal movement

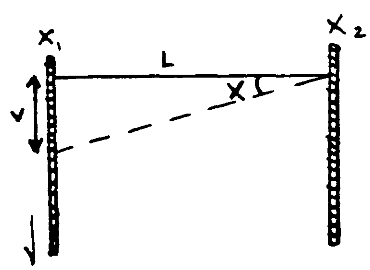
x : Crack opening

Formulas

1) 

top view

$$h = L \tan Z$$

2) 

side view

$$v = L \tan X$$

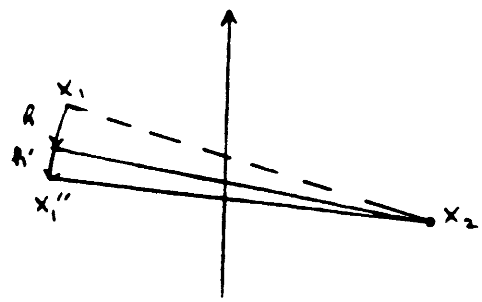
2) S1-S2

a. Lateral displacement

$h = 2.23 \tan 6 = 0.234' = 2.81"$

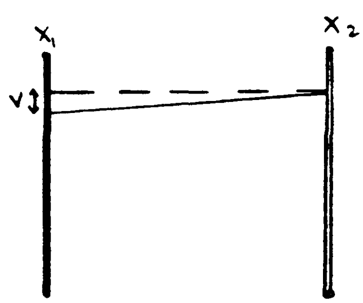
$h' = 2.25 \tan 3 = 0.117' = 1.41"$

$H = h + h' = 1.41 + 2.81 = 4.22"$



b. Vertical displacement

$v = 2.25 \tan 4 = 0.157' = 1.88"$



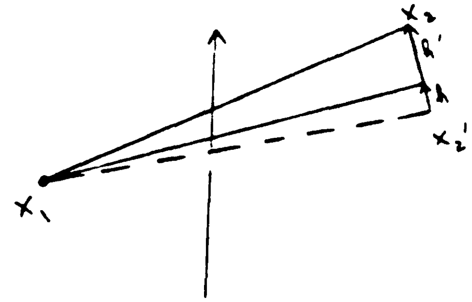
3) T1-T2

a. Lateral displacement

h = 3.5 tan 4 = 0.244′ = 2.93"

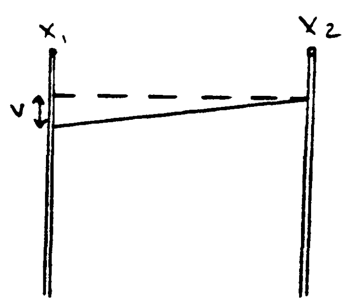
h′= 3.6 tan 9 = 0.570′ = 6.842

H = h + h′ = 6.842 + 2.93 = 9.77"



b. Vertical displacement

v = 3.6 tan 7 = 0.422′ = 5.30"



4) K1-K2

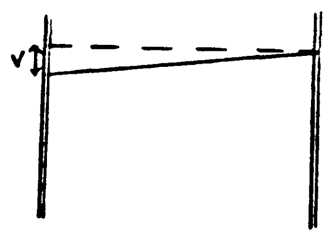
a. Lateral displacement

No lateral displacement observed.

Crack opening of 1.8 inches.

b. Vertical displacement

v = 4.45 tan 6 = 0.467′= 5.61″



5) N1-N2

No movement was observed along this crack.

APPENDIX C

STABL3 Computer Program

Input and Output Example Files

```
PROFIL
run 1

21 17
0. 25. 175. 105. 1
175. 105. 240. 105. 1
240. 105. 255. 115. 1
255. 115. 320. 120. 1
320. 120. 375. 135. 1
375. 135. 420. 135. 1
420. 135. 445. 140. 1
445. 140. 490. 140. 1
490. 140. 505. 150. 1
505. 150. 530. 155. 1
530. 155. 560. 180. 1
560. 180. 707. 195. 1
707. 195. 785. 215. 1
785. 215. 900. 230. 1
900. 230. 995. 250. 1
995. 250. 1170. 275. 1
1170. 275. 1275. 305. 1
55. 55. 1275. 270. 2
62. 52. 1275. 268. 1
40. 43. 1275. 265. 2
35. 40. 1275. 262. 1
SOIL
2
160. 169. 1900. 14. 0. 0. 1
116. 124. 200. 6. 0. 0. 1
WATER
1 0.
12
0. 50.
60. 50.
75. 60.
320. 120.
375. 130.
405. 135.
535. 155.
705. 175.
770. 195.
845. 205.
955. 210.
1275. 270.
LIMITS
1 1
25. 35. 1275. 260.
BLOCK
10 2 1.
67. 46. 80. 49. 1.
975. 208. 1200. 248. 1.
```

--SLOPE STABILITY ANALYSIS--
SIMPLIFIED JANBU METHOD OF SLICES
IRREGULAR FAILURE SURFACES

PROBLEM DESCRIPTION run 1

BOUNDARY COORDINATES

17 TOP BOUNDARIES
21 TOTAL BOUNDARIES

BOUNDARY NO.	X-LEFT (FT)	Y-LEFT (FT)	X-RIGHT (FT)	Y-RIGHT (FT)	SOIL TYPE BELOW BND
1	0.00	25.00	175.00	105.00	1
2	175.00	105.00	240.00	105.00	1
3	240.00	105.00	255.00	115.00	1
4	255.00	115.00	320.00	120.00	1
5	320.00	120.00	375.00	135.00	1
6	375.00	135.00	420.00	135.00	1
7	420.00	135.00	445.00	140.00	1
8	445.00	140.00	490.00	140.00	1
9	490.00	140.00	505.00	150.00	1
10	505.00	150.00	530.00	155.00	1
11	530.00	155.00	560.00	180.00	1
12	560.00	180.00	707.00	195.00	1
13	707.00	195.00	785.00	215.00	1
14	785.00	215.00	900.00	230.00	1
15	900.00	230.00	995.00	250.00	1
16	995.00	250.00	1170.00	275.00	1
17	1170.00	275.00	1275.00	305.00	1
18	65.00	55.00	1275.00	270.00	2
19	62.00	52.00	1275.00	268.00	1
20	40.00	43.00	1275.00	265.00	2
21	35.00	40.00	1275.00	262.00	1

ISOTROPIC SOIL PARAMETERS

2 TYPE(S) OF SOIL

SOIL TYPE NO.	TOTAL UNIT WT. (PCF)	SATURATED UNIT WT. (PCF)	COHESION INTERCEPT (PSF)	FRICTION ANGLE (DEG)	PORE PRESSURE PARAMETER	PRESSURE CONSTANT (PSF)	PIEZOMETRIC SURFACE NO.
1	160.0	169.0	1900.0	14.0	0.00	0.0	1
2	116.0	124.0	200.0	6.0	0.00	0.0	1

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

UNIT WEIGHT OF WATER = 62.40

PIEZOMETRIC SURFACE NO. 1 SPECIFIED BY 12 COORDINATE POINTS

POINT NO.	X-WATER (FT)	Y-WATER (FT)
1	0.00	50.00
2	60.00	50.00
3	75.00	60.00
4	320.00	120.00
5	375.00	130.00
6	405.00	135.00
7	535.00	155.00
8	705.00	175.00
9	770.00	195.00
10	845.00	205.00
11	955.00	210.00
12	1275.00	270.00

SEARCHING ROUTINE WILL BE LIMITED TO AN AREA DEFINED BY 1 BOUNDARIES
OF WHICH THE FIRST 1 BOUNDARIES WILL DEFLECT SURFACES UPWARD

BOUNDARY NO.	X-LEFT (FT)	Y-LEFT (FT)	X-RIGHT (FT)	Y-RIGHT (FT)
1	25.00	35.00	1275.00	260.00

A CRITICAL FAILURE SURFACE SEARCHING METHOD, USING A RANDOM TECHNIQUE FOR GENERATING SLIDING BLOCK SURFACES, HAS BEEN SPECIFIED.

10 TRIAL SURFACES HAVE BEEN GENERATED.

2 BOXES SPECIFIED FOR GENERATION OF CENTRAL BLOCK BASE

LENGTH OF LINE SEGMENTS FOR ACTIVE AND PASSIVE PORTIONS OF SLIDING BLOCK IS 1.0

BOX NO.	X-LEFT (FT)	Y-LEFT (FT)	X-RIGHT (FT)	Y-RIGHT (FT)	WIDTH (FT)
1	67.00	46.00	80.00	49.00	1.00
2	975.00	208.00	1200.00	248.00	1.00

* * SAFETY FACTORS ARE CALCULATED BY THE MODIFIED JANBU METHOD *

FAILURE SURFACE SPECIFIED BY 58 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	63.50	54.03
2	63.86	53.67
3	64.82	53.39
4	65.55	52.70
5	66.38	52.14
6	67.35	51.93
7	68.02	51.24
8	68.79	50.53
9	69.52	49.85
10	70.45	49.59
11	71.37	49.13
12	72.11	48.45
13	72.90	47.84
14	1152.00	239.88
15	1152.66	240.63
16	1152.68	241.63
17	1153.32	242.40
18	1154.03	243.10
19	1154.70	243.84
20	1155.39	244.57
21	1156.09	245.28
22	1156.47	246.21
23	1157.07	247.01
24	1157.77	247.72
25	1157.84	248.72
26	1158.26	249.63
27	1158.86	250.42
28	1159.41	251.26
29	1160.08	252.00
30	1160.18	253.00
31	1160.52	253.77
32	1161.25	254.67
33	1161.49	255.64
34	1162.20	256.35
35	1162.49	257.30
36	1163.13	258.08
37	1163.84	258.78
38	1164.54	259.49
39	1164.78	260.46
40	1164.98	261.44
41	1165.38	262.36
42	1165.99	263.15
43	1166.70	263.96
44	1166.73	264.85
45	1167.42	265.58
46	1168.10	266.31
47	1168.57	267.19
48	1168.59	268.19
49	1169.24	268.95
50	1169.33	269.95
51	1170.01	270.66
52	1170.44	271.56
53	1171.04	272.36
54	1171.40	273.29
55	1171.98	274.11
56	1172.65	274.85
57	1173.26	275.64
58	1173.65	276.04

*** 0.994 ***

FAILURE SURFACE SPECIFIED BY 59 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	62.93	53.77
2	63.09	53.67
3	63.93	53.15
4	64.64	52.44
5	65.41	51.80
6	66.17	51.15
7	67.14	50.93
8	67.90	50.27
9	68.61	49.57
10	69.32	48.86
11	70.25	48.58
12	71.25	48.23
13	72.22	46.18
14	72.93	47.48
15	1100.94	230.75
16	1101.56	231.54
17	1102.16	232.33
18	1102.27	233.33
19	1102.51	234.30
20	1102.99	235.18
21	1103.69	235.90
22	1104.22	236.74
23	1104.57	237.68
24	1104.93	238.61
25	1105.38	239.51
26	1106.00	240.28
27	1106.62	241.07
28	1107.33	241.78
29	1107.69	242.71
30	1107.71	243.71
31	1108.34	244.49
32	1108.98	245.26
33	1109.33	246.19
34	1109.94	246.99
35	1110.27	247.93
36	1110.42	248.92
37	1110.95	249.77
38	1111.64	250.49
39	1112.33	251.21
40	1112.69	252.04
41	1113.48	252.85
42	1114.13	253.61
43	1114.54	254.52
44	1115.15	255.32
45	1115.79	256.09
46	1116.43	256.95
47	1116.58	257.84
48	1117.18	258.64
49	1117.71	259.49
50	1118.35	260.24
51	1118.50	261.23
52	1118.72	262.21
53	1118.89	263.20
54	1119.26	264.12
55	1119.92	264.98
56	1120.52	265.68
57	1120.87	266.61
58	1121.33	267.51
59	1121.92	268.13

*** 1.032 ***

FAILURE SURFACE SPECIFIED BY 59 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	62.93	53.77
2	63.08	53.67
3	63.93	53.15
4	64.64	52.44
5	65.41	51.80
6	66.17	51.15
7	67.14	50.93
8	67.90	50.27
9	68.61	49.57
10	69.32	48.86
11	70.28	48.58
12	71.2[illegible]	48.23
13	72.22	48.16
14	72.93	47.48
15	1100.94	230.75
16	1101.56	231.54
17	1102.16	232.33
18	1102.27	233.33
19	1102.51	234.30
20	1102.99	235.18
21	1103.69	235.90
22	1104.22	236.74
23	1104.57	237.66
24	1104.93	238.61
25	1105.38	239.51
26	1106.00	240.28
27	1106.62	241.07
28	1107.33	241.78
29	1107.69	242.71
30	1107.71	243.71
31	1108.34	244.49
32	1108.98	245.26
33	1109.33	246.19
34	1109.94	246.99
35	1110.27	247.93
36	1110.42	248.92
37	1110.95	249.77
38	1111.64	250.49
39	1112.33	251.21
40	1112.89	252.04
41	1113.46	252.85
42	1114.13	253.61
43	1114.54	254.52
44	1115.15	255.32
45	1115.79	256.09
46	1116.43	256.85
47	1116.58	257.84
48	1117.18	258.64
49	1117.71	259.49
50	1118.36	260.24
51	1118.50	261.23
52	1118.72	262.21
53	1118.89	263.20
54	1119.26	264.12
55	1119.92	264.86
56	1120.52	265.68
57	1120.87	266.61
58	1121.33	267.51
59	1121.92	268.13

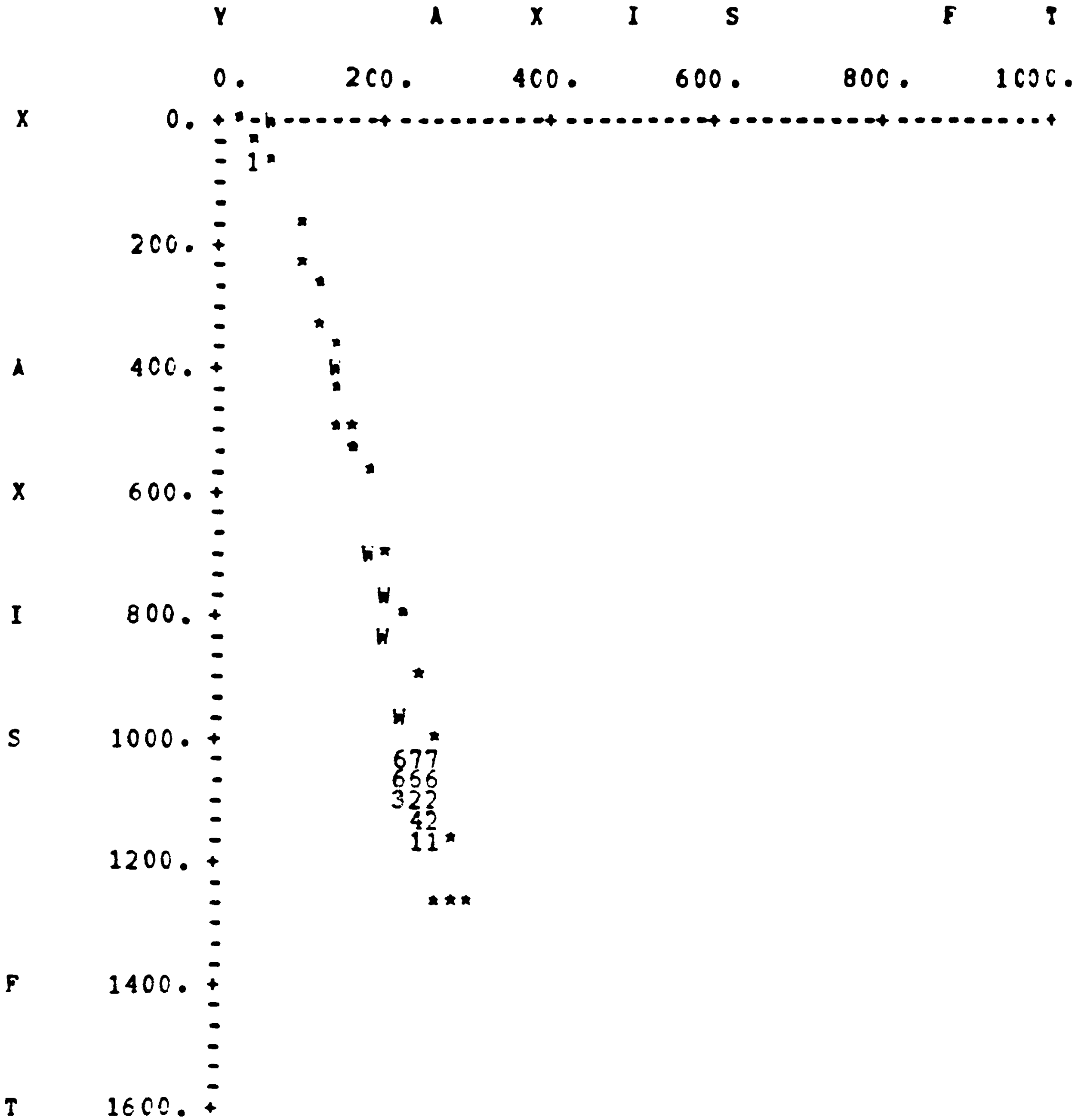
*** 1.166 ***

* * SAFETY FACTORS ARE CALCULATED BY THE MODIFIED JANBU METHOD *

FAILURE SURFACE SPECIFIED BY 58 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	63.50	54.03
2	63.86	53.67
3	64.82	53.39
4	65.55	52.70
5	66.38	52.14
6	67.35	51.93
7	66.08	51.24
8	68.79	50.53
9	69.52	49.85
10	70.42	49.59
11	71.37	49.13
12	72.11	48.45
13	72.90	47.64
14	1152.02	239.88
15	1152.66	240.63
16	1152.68	241.63
17	1153.32	242.40
18	1154.03	243.10
19	1154.70	243.84
20	1155.39	244.57
21	1156.09	245.28
22	1156.47	246.21
23	1157.07	247.01
24	1157.77	247.72
25	1157.84	248.72
26	1158.26	249.63
27	1158.66	250.42
28	1159.41	251.26
29	1160.08	252.00
30	1160.18	253.00
31	1160.62	253.77
32	1161.25	254.67
33	1161.49	255.64
34	1152.20	256.35
35	1162.49	257.30
36	1163.13	258.08
37	1163.84	258.78
38	1164.54	259.49
39	1164.78	260.46
40	1164.98	261.44
41	1165.38	262.36
42	1165.99	263.15
43	1166.70	263.86
44	1166.73	264.86
45	1167.42	265.58
46	1168.10	255.31
47	1168.57	267.19
48	1168.59	268.19
49	1169.24	268.95
50	1169.30	269.95
51	1170.01	270.66
52	1170.44	271.56
53	1171.04	272.36
54	1171.40	273.29
55	1171.98	274.11
56	1172.65	274.85
57	1173.26	275.64
58	1173.66	276.04

*** 1.127 ***


Y AXIS FT
0. 200. 400. 600. 800. 1000.
X AXIS FT
0. 200. 400. 600. 800. 1000. 1200. 1400. 1600.