Fall 2002

Hydrological and geotechnical investigation of a Sparta, New Jersey landslide

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Recommended Citation

Talerico, James, "Hydrological and geotechnical investigation of a Sparta, New Jersey landslide" (2002). *Theses*. 606.
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ABSTRACT

HYDROLOGICAL AND GEOTECHNICAL INVESTIGATION OF A SPARTA, NEW JERSEY LANDSLIDE

by
James Talerico

On August 13, 2000, a massive landslide occurred in Northern New Jersey following an extreme rainfall event during which 14.1 inches of precipitation fell locally during a 24-hour period. The slide, with an estimated volume of 22,000ft^3, traveled up to 1500ft in a short period. While landslides do occasionally occur along the coastal bluffs of the Atlantic Coastal Plain, slides of this magnitude are uncommon in the glacial soils of the New Jersey Highland section.

The investigation of this landslide was compiled through rainfall data and geotechnical data, which was used to determine the triggering mechanism of the landslide. The information supplied herein consists of a hydrological study, a geological/geotechnical study, a topographic survey, and slope stability analyses.

The results of the data obtained and analyses performed determined that the triggering mechanism was a result of extreme pore-water pressures developed from the rainfall event and an abrupt change in permeability between two soil strata. This paper takes the results of this information to support the causative factors contributing towards the slope failure.

HYDROLOGICAL AND GEOTECHNICAL INVESTIGATION OF A SPARTA, NEW JERSEY LANDSLIDE

by
James Talerico

A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
In Partial Fulfillment of the Requirements for the Degree of
Masters of Science in Civil Engineering

Department of Civil and Environmental Engineering

January 2003

APPROVAL PAGE

HYDROLOGICAL AND GEOTECHNICAL INVESTIGATION OF A SPARTA, NEW JERSEY LANDSLIDE

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There are no secrets to success.
It is the result of preparation, hard work, learning from failure. - Colin Powell

ACKNOWLEDGEMENTS

The author would like to thank his advisor, Dr. Raj Khera, for his assistance and support during the completion of this thesis. Thanks also to Dr. John R. Schuring and Prof. Walter Konon for participating in my committee. Dr. John R. Schuring, and Dr. Dorairaja Raghu, are also due thanks for their technical assistance in various parts of this research.

I would also like to thank P&P Excavating and Robert Laner for using their equipment to aid in the site investigation end of the project. Thank you Edgardo Perez for assisting in the landslide survey. And thanks also go to the owner Mr. Robert Viersma, for giving me the opportunity to study his property.

Thanks also go to my family, James, Carol and Lauren, for their emotional support, without them I would not be at this point in my life today.

And special thanks to my wife, Heather, for her patience, motivation, and confidence in seeing me succeed. Without her, this thesis may have never been completed.

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DEFINITION OF TERMS

g = Moist Unit Weight of Soil
γ_{sat} = Saturated Unit Weight of Soil
γ_w = Unit Weight of Water
γ_d = Dry Unit Weight of Soil
h = Height of Soil Strata
h_w = Height of Water
i = Slope of Terrain
α = Angle of Active Wedge
β = Angle of Passive Wedge
$c = c_m = c_{im}$ = Cohesion of Soil
T = Factor of Safety of Geogrid
F = Factor of Safety
L_a = Length of Active Wedge
L_c = Length of Central Wedge
L_p = Length of Passive Wedge
$\Phi = \Phi_m = \Phi_{im}$ = Angle of Internal Friction
G_s = Specific Gravity of Soil
e = Void Ratio
Σ = Total Stress
σ' = Effective Stress

DEFINITION OF TERMS

u = Pore Pressure

τ_f = Shear Strength of Soil

k = Permeability of Soil

C_1 = Constant

CHAPTER 1

INTRODUCTION

1.1 Objective

The objective of this thesis is to investigate a slope failure in a development currently under construction that occurred in Sparta, New Jersey during an extreme rainfall event.

In order to determine the triggering factor in the cause of the landslide, several key factors were analyzed. The factors that are considered in this analysis are a hydrological study, a geological/geotechnical study, and a slope stability analysis. A hydrological study was performed to determine the drainage area, amount of rainfall, volume of rainfall, and amount of flow tributary to the landslide. The geological/geotechnical investigation was performed to determine different types of soils located within and around the landslide, the history of the geologic features in the area, and their relevant soil properties.

Upon determining the classification and studying the various features of the landslide, a slope stability analysis is performed to reinforce the data obtained from the hydrological and geological/geotechnical study. Based on field observations, after the landslide had occurred, and comparison with other landslides, a classification of this landslide was established.

In light of hydrologic data and geotechnical studies a slope stability analysis was used in arriving at the factors contributing to the slope failure.

1.2 Background Information

During the days of August 11-14, 2000, Sparta, New Jersey experienced an extreme rainfall event that devastated the area. Doppler radar estimates of total rainfall for the 4-day period reached approximately 15 inches along the border between Sussex and Morris Counties (National Weather Service, 2002). As a result of this extreme rainfall event, the Sussex County area was decimated by extreme flooding, dam failures and landslides. All of these took their toll on the Township of Sparta and other towns. This extreme rainfall event was the main cause of the landslide analyzed within this thesis.

The landslide occurred on the morning of August 13, 2000, shortly after the rainfall had subsided. The landslide occurred in Sparta, NJ just off Route 517 (Glen Road) in a residential development which was under construction [Figure 1.1].

Figure 1.1 Aerial photograph of Sparta Mountain Sparta, Sparta, NJ (4-meter resolution) (Courtesy of teraserver.microsoft.com) (USGS 1991).

The area in which the landslide occurred, is located on the lower portion of the Sparta Mountains. The aerial photographs are shown in Figures 1.1 and 1.2. As seen in Figure 1.1 photograph, some areas of the Sparta Mountains were used as farming even though existing topography were sometimes in excess of 15% grade. A close-up shows the location of the landslide and how the area in which the landslide occurred was most likely used for agricultural purposes [Figure 1.2]. According to one source, the soil was once used for hay, pasture, woodland, and infrequent row crops (Fletcher 1975).

Figure 1.2 Aerial photograph of Sparta Mountain Sparta, Sparta, NJ (1-meter resolution) (Courtesy of teraserver.microsoft.com) (USGS 1991).

By using the aerial maps in Figures 1.1 and 1.2, USGS Quad maps [Figure 1.3], and countless site investigations, determining the actual location of the landslide became quite intuitive. Although the landslide was topographically surveyed, no survey control was found in the area to tie the landslide into a horizontal datum.

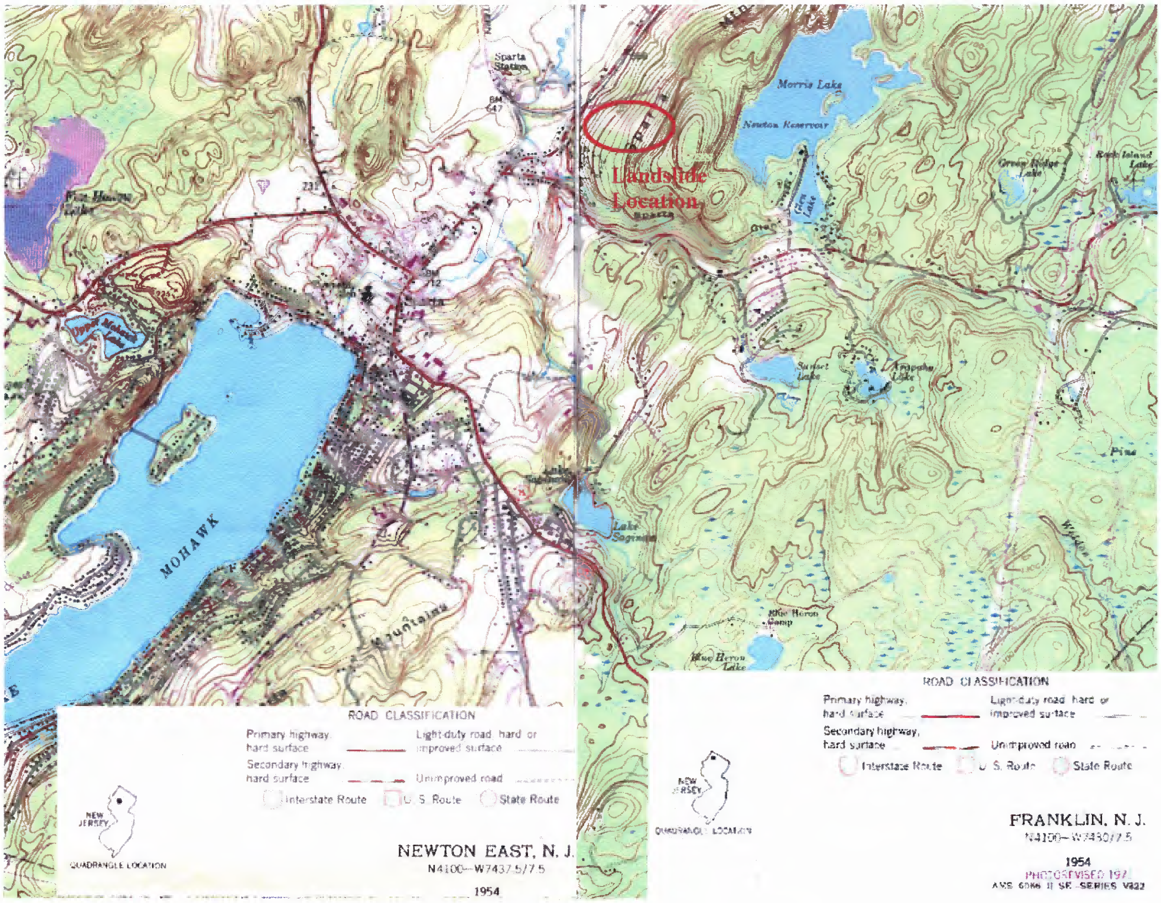


Figure 1.3 USGS aerial topography of Sparta Mountain, Sparta, NJ.

Residential construction had commenced on the parcel of land on which the landslide occurred. Roadways were cut into existing slope and the slope failure occurred just above one of the proposed roadways. However, construction had met all the town requirements for grading, and construction was being followed according to the most recent approved set of site plans. Although the new road cut may have aided in a premature failure of the slope, the information provided herein will justify that regardless of the new road failure was eminent.

CHAPTER 2

HYDROLOGICAL STUDY

2.1 Rainfall Data

A civil engineer, in many aspects, is a person that designs against the natural elements of the earth in order to increase our natural well being. In this case, our natural element is water, in the form of precipitation. Engineers are constantly designing drainage structures, storm pipe networks, and other drainage infrastructure, in order to develop the surrounding areas. In doing this, designs are based on data that are used to develop specific areas, but must also take into account the surrounding areas and future development opportunities by not increasing the existing runoff. However, even designing to the most stringent standards required by engineers, mother nature has still proven that no design is indestructible, much to the agreement of many residents in the Township of Sparta.

On the day of August 12, 2000, rainfall data was obtained from rain gauges all over the northern state of New Jersey. Town, County, and State records were set for the amount of rainfall in a 24-hour period, which can be seen in the Doppler Radar [Figure 2.1]. The reason for the unusual rainfall event can be explained by meteorological data. A deep and unstable layer of extreme humid, tropical air carried a combination of east to southeast winds both at the ground surface and at several layers of the atmosphere up to 15,000 feet, converged (Lombardo 2000). The continuous southeasterly stream of moisture produced slow moving thunderstorms that would generate rainfall in record proportion (Lombardo 2000). Data was obtained by local meteorologists' rain gauges

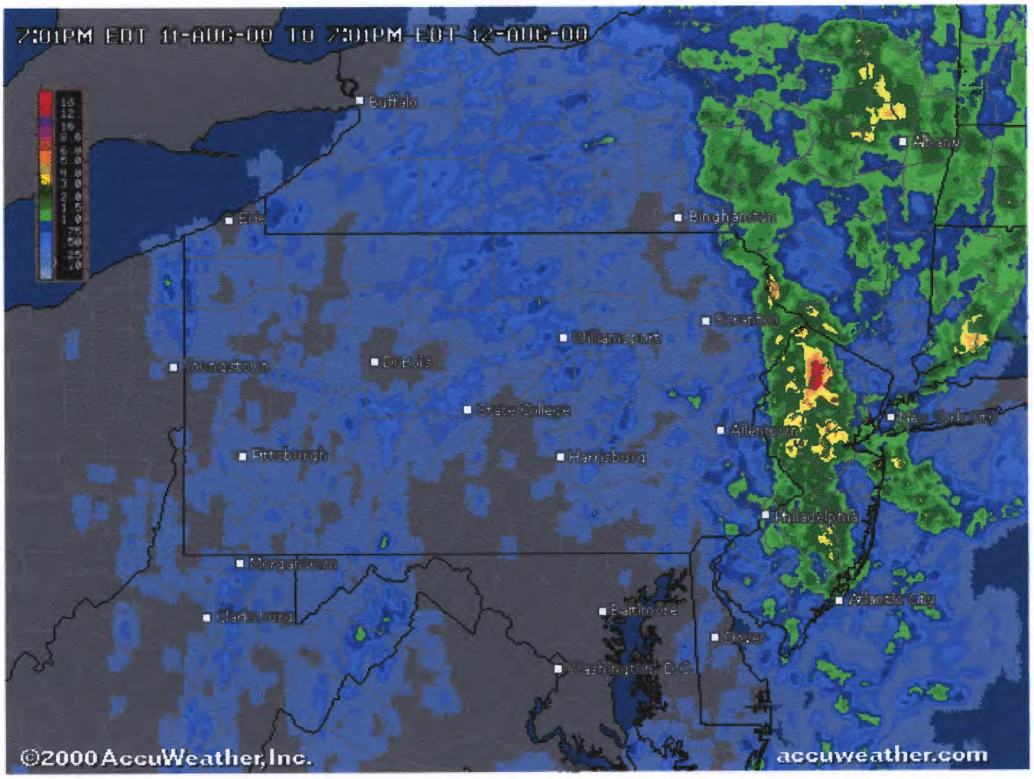


Figure 2.1 Doppler radar of August 12, 2000 storm event (Accuweather 2000).

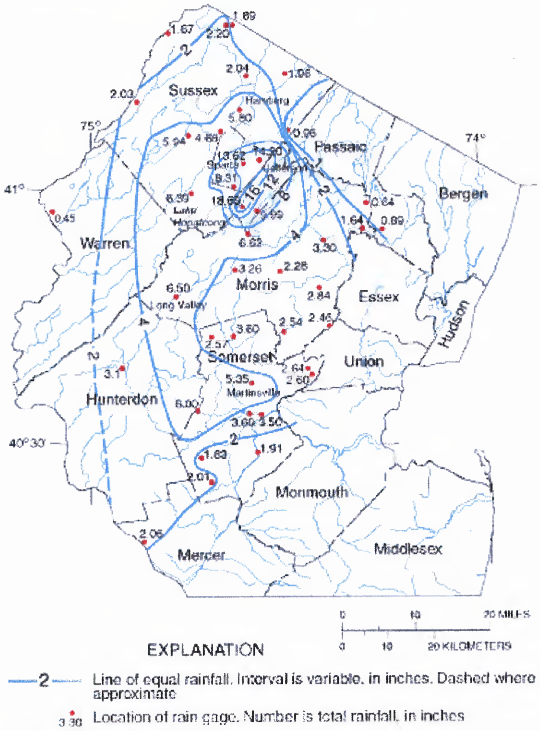
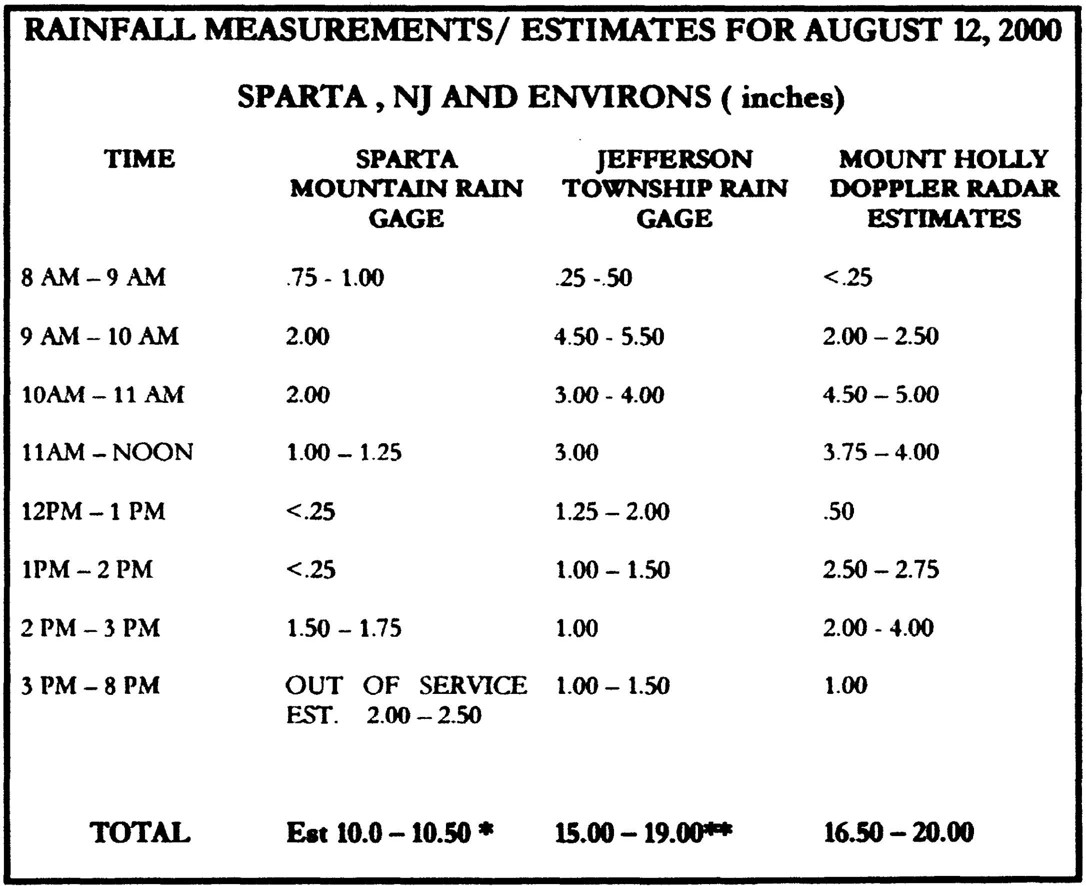


Figure 2.2 Total rainfall at 41 rain gages in Northern New Jersey (USGS 2002).

from the area to produce a contour map of rain fall in the Northern New Jersey Area [Figure 2.2 USGS 2002]. This information along with rain gauge data obtained from a private Sparta rain gauge [Table 2.1] (Lombardo 2000) a 24-hour rainfall event was generated to perform a drainage analysis. Since the private rain gauge only held accurate data until 3pm and total rainfall is only an estimate, the 14.1 inches of rain that was recorded by the National Weather Service is used to determine an average rainfall for the time between 3pm to 8pm (USGS 2002).

This data best serves its purpose in running a storm analysis to better determine how much flow and volume of water that was tributary to the landslide.

Table 2.1 Rainfall Measurements/Estimates for August 12, 2000 (Lombardo 2000)



RAINFALL MEASUREMENTS/ ESTIMATES FOR AUGUST 12, 2000

SPARTA , NJ AND ENVIRONS (inches)

TIME	SPARTA MOUNTAIN RAIN GAGE	JEFFERSON TOWNSHIP RAIN GAGE	MOUNT HOLLY DOPPLER RADAR ESTIMATES
8 AM – 9 AM	.75 - 1.00	.25 -.50	<.25
9 AM – 10 AM	2.00	4.50 - 5.50	2.00 – 2.50
10AM – 11 AM	2.00	3.00 - 4.00	4.50 – 5.00
11AM – NOON	1.00 – 1.25	3.00	3.75 – 4.00
12PM – 1 PM	<.25	1.25 – 2.00	.50
1PM – 2 PM	<.25	1.00 – 1.50	2.50 – 2.75
2 PM – 3 PM	1.50 – 1.75	1.00	2.00 - 4.00
3 PM – 8 PM	OUT OF SERVICE EST. 2.00 – 2.50	1.00 – 1.50	1.00
TOTAL	**Est 10.0 – 10.50 ***	**15.00 – 19.00****	**16.50 – 20.00**

*** rain gage was hit by lightning and missed several hours of operation during the mid-afternoon Amounts were estimated after 3 p.m.**

**** amounts from various rain gages at the same site.**

2.2 Storm Analysis

The rainfall data obtained is a crucial aspect in running an actual storm analysis for a specific rainfall event. From the data obtained in the previous section, an analysis was created using a software program called "Hydroflow Hydrographs 2002," by Intelisolve.

This software runs the TR-55 method, which is a method that computes the time of concentration, t_c. Time of concentration is defined as the amount of time need for runoff to flow from the most remote point in the drainage area to the point of analysis (Gribbin 1997). The software also runs the analysis, called the SCS Method, which is necessary for computing the hydrograph for a storm event in order to determine the flow of runoff versus time and the overall volume created by the storm event. The SCS Method is defined as a procedure for computing a synthetic hydrograph based upon empirically determined factors developed research conducted by the Soil Conservation Service (Gribbin 1997).

In order to run this part of the analysis accurately, there were a number of variables that were necessary in order to run the program. The first part of the analysis, the TR-55 Method, uses several variables needed to determine the time of concentration. The time of concentration is broken into three types of flow: Sheet Flow, Shallow Concentrated Flow, and Channel Flow. In the analysis performed, only sheet flow and shallow concentrated flow were used since there was no channel flow. Sheet flow and shallow concentrated flow was obtained using USGS maps to obtain slopes and flow length for the two types of flow. For sheet flow, a Manning n-value is required to determine the travel time. The Manning n-value that was utilized was 0.59. This number was determined by using the runoff coefficients table (NJDEP 1995) [Table A.1]. Using the hydrologic soil group "C" which was obtained from the Soil Survey of Sussex County, New Jersey, and using the land-use description of wood or forest land with poor cover, yields the runoff coefficient 0.59 (Fletcher 1975). Poor ground cover was chose instead of good cover, because rock outcrops are very pronounced in the area. The data for time of concentration yield a result of 171.6 minutes for the total travel time [Appendix A, Table A.3].

In order to obtain a hydrograph, a drainage area that is tributary to the landslide is necessary. Using a USGS quad map, a delineation of the overall drainage area yielded an 8.32-acre spread. Of those 8.32 acres, 5.95 acres of the drainage area is woods in a poor hydrologic condition and 2.37 acres of the drainage area is brush in a good hydrologic condition.

This information is also used to determine a curve number (CN). Based on the area break down above, a weighted CN was calculated. A weighted CN is based upon the total drainage and the break down of each type of cover type and its respective CN [Table A.2]. By inputting the aforementioned data to the program, a weighted CN was determined to be 74.

Once the above information was obtained along with the rainfall data complied from the Sparta Mountain rain gauge [Figure 2.3, 2.4], the SCS Method is ready to compute the peak flow, overall hydrograph volume, and a hydrograph that produces flow vs. time data.

Upon completion of entering the final data into Hydroflow, a hydrograph was generated [Appendix A, Figure A.2]. The results yield astounding data, which clearly

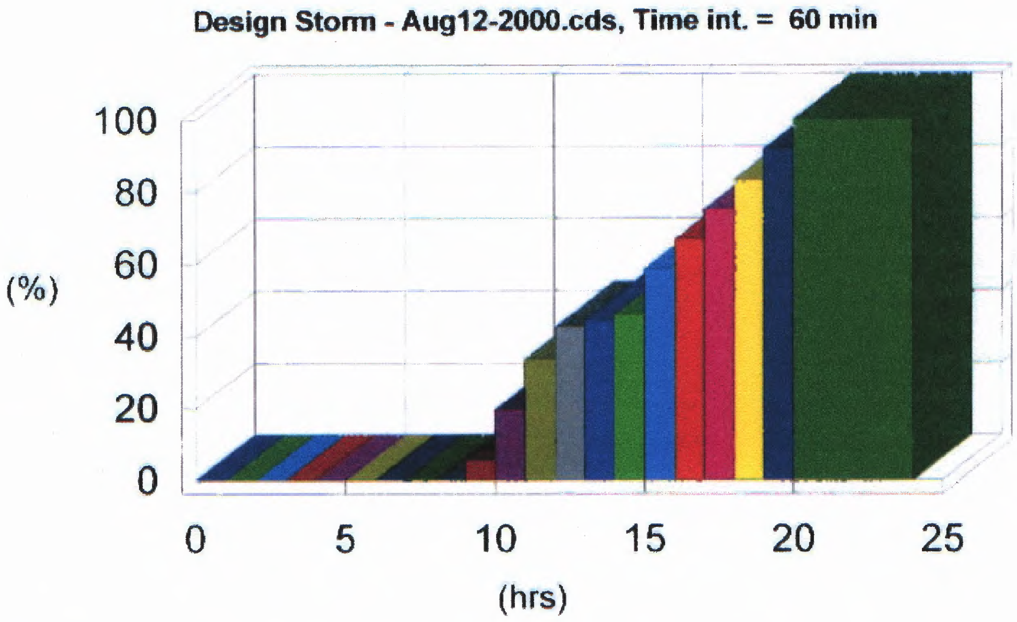


Figure 2.3 Total precipitation (%) vs. time.

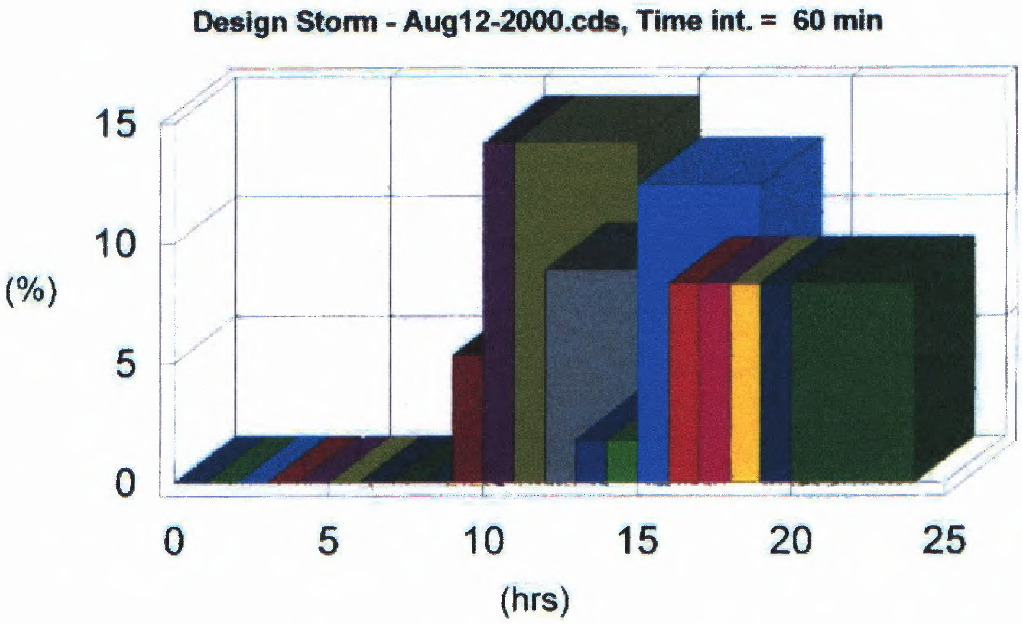


Figure 2.4 Total precipitation per hour (%) vs. time.

show what an intense rainfall can generate for a relatively small drainage area. The peak runoff generated was 13.23 cfs at the 12th hour of the rainfall event, which directly correlates to the most intense part of the storm event. From the 8th hour of the storm to the 22nd hour, an average of 8 cfs per hour was generated by this storm event. This hydrograph was then able to generate the volume of rainfall, in cubic feet, for the entire drainage area. The volume computed was 399,035 cu. ft., which is based on the amount of rainfall and the overall drainage area.

2.3 Discussion of Results

Storms that produce intense rainfall for periods as short as several hours or have a more moderate intensity lasting several days have triggered abundant landslides in many regions (Landslides 1996). Based on the rainfall data and storm analysis for this landslide, the amount of rainfall that inundated the landslide location, created a tremendous amount of saturation and pore pressures. Terazaghi argued that seasonal variations in rainfall can give rise to seasonal variations in the fluid pressure, thereby reducing the shearing resistance independent of any effect on the angle of sliding friction (Terazaghi 1950). Thus during periods of heavy or prolonged rainfall, such as this rainfall event, slopes become more susceptible to failure because of the attendant increases in fluid pressures for water levels and decreases in effective stress (Domenico 1998).

The rapid infiltration of rainfall, causing soil saturation and a temporary rise in pore-water pressures, is generally believed to be the mechanism by which most shallow landslides are generated during storms (Landslides 1996). Chapter four of the thesis, which demonstrates the slope stability analysis, will further support the effects of this major rainfall event and how the seepage forces and decrease in effective stress was one of the principal factors in triggering this landslide.

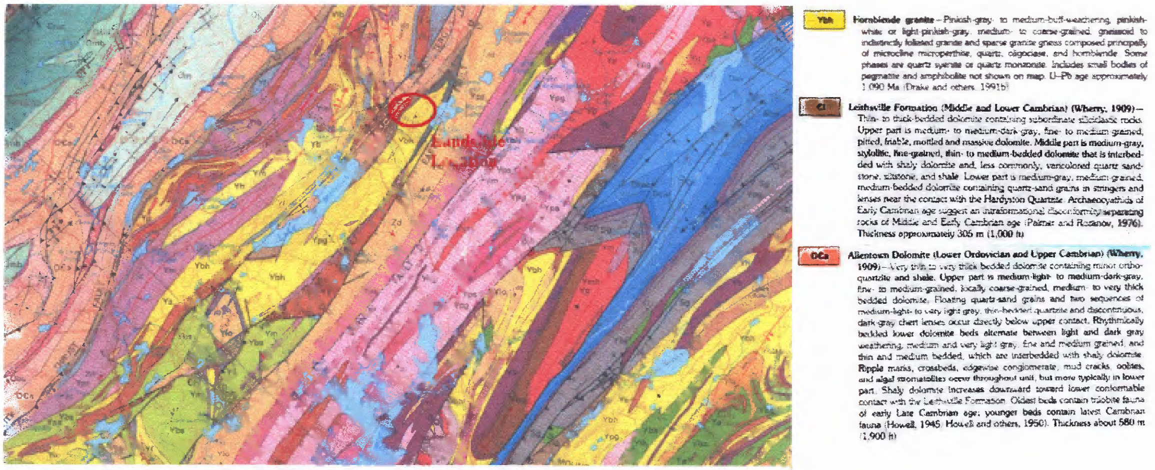
CHAPTER 3

GEOLOGIC & GEOTECHNICAL STUDY

3.1 Geologic Background

The geologic features of the site for landslide sites are more important for slides that have potential failure planes along the bedrock surface. Although other geological features, such as glacial till, can represent a failure plane if a significant change in permeability takes place. The formation of the site is very important in investigating potential or existing slide surfaces. Bedrock maps are normally available for most states and can help in determining the underlying factors of the type of bedrock based on the formations on the maps (Figure 3.1). However, borings and test pits are excellent ways in determining the depth at which the bedrock formation may lie. Significant changes in the landmass can have significant consequences on the failure surface.

According to the Bedrock Geologic Map of Northern New Jersey, the landslide site is located above the Leithville Formation. The bedrock above the crown of the slide



Hornblende granite—Pinkish-gray- to medium-buff-weathering, pinkish-white or light-pinkish-gray, medium- to coarse-grained, gneissoid to indistinctly foliated granite and sparse granite gneiss composed principally of microcline microperthite, quartz, oligoclase, and hornblende. Some phases are quartz syenite or quartz monzonite. Includes small bodies of pegmatite and amphibolite not shown on map. U–Pb age approximately 1,090 Ma (Drake and others, 1991b)

Leithsville Formation (Middle and Lower Cambrian) (Wherry, 1909)—Thin- to thick-bedded dolomite containing subordinate siliciclastic rocks. Upper part is medium- to medium-dark-gray, fine- to medium-grained, pitted, friable, mottled and massive dolomite. Middle part is medium-gray, stylolitic, fine-grained, thin- to medium-bedded dolomite that is interbedded with shaly dolomite and, less commonly, varicolored quartz sandstone, siltstone, and shale. Lower part is medium-gray, medium-grained, medium-bedded dolomite containing quartz-sand grains in stringers and lenses near the contact with the Hardyston Quartzite. Archaeocyathids of Early Cambrian age suggest an intraformational disconformity separating rocks of Middle and Early Cambrian age (Palmer and Rozanov, 1976). Thickness approximately 305 m (1,000 ft)

Allentown Dolomite (Lower Ordovician and Upper Cambrian) (Wherry, 1909)—Very thin to very thick bedded dolomite containing minor orthoquartzite and shale. Upper part is medium-light- to medium-dark-gray, fine- to medium-grained, locally coarse-grained, medium- to very thick bedded dolomite. Floating quartz-sand grains and two sequences of medium-light- to very light gray, thin-bedded quartzite and discontinuous, dark-gray chert lenses occur directly below upper contact. Rhythmically bedded lower dolomite beds alternate between light and dark gray weathering, medium and very light gray, fine and medium grained, and thin and medium bedded, which are interbedded with shaly dolomite. Ripple marks, crossbeds, edgewise conglomerate, mud cracks, oolites, and algal stromatolites occur throughout unit, but more typically in lower part. Shaly dolomite increases downward toward lower conformable contact with the Leithsville Formation. Oldest beds contain trilobite fauna of early Late Cambrian age; younger beds contain latest Cambrian fauna (Howell, 1945; Howell and others, 1950). Thickness about 580 m (1,900 ft)

BEDROCK GEOLOGIC MAP OF NORTHERN NEW JERSEY

By

Avery Ala Drake, Jr.,[1] Richard A. Volkert,[2] Donald H. Monteverde,[2] Gregory C. Herman,[2]
Hugh F. Houghton,[2] Ronald A. Parker,[1] and Richard F. Dalton[2]

1996

Figure 3.1 Partial view of Bedrock Geologic Map of Northern New Jersey.

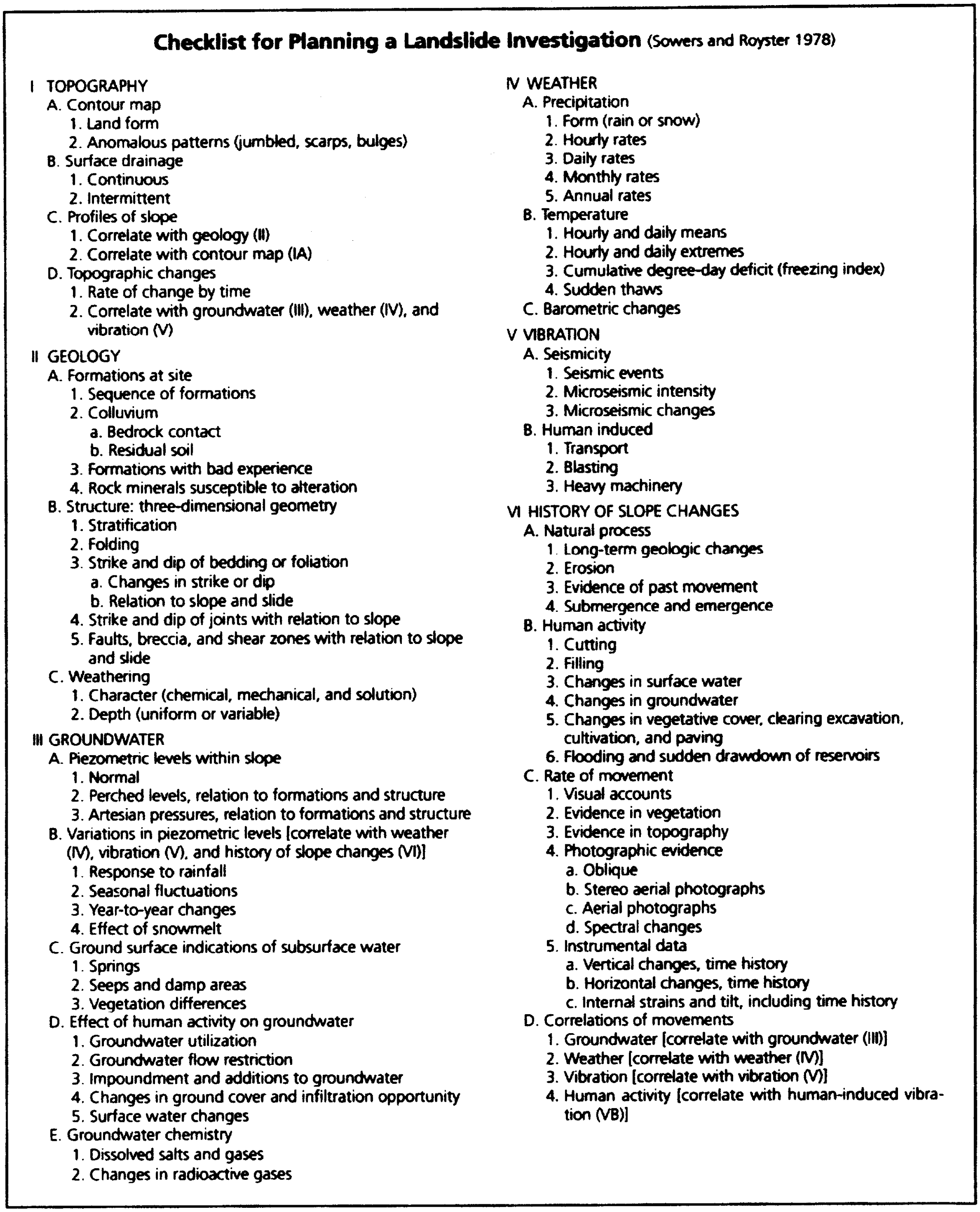
is a Hornblende Granite. Although the shown formations are not an exact indication of the triggering mechanism of the landslide, the characteristics of the Leithville formation were essential in determining the landslide location. Soils investigations, which will be discussed soon after this section, that were performed for the landslide site, prove that the bedrock was not the failure plane. However, a light gray glacial till was reached, which had the characteristics of bedrock. The color and geology of the till had similar characteristics of the Leithville formation. The Hornblende granite located above the crown of the landslide was also verified through site investigations. Many bedrock outcrops were located above the crown of the landslide, and had similar characteristics of the Hornblende granite called out by the bedrock map.

3.2 Site Investigation

Field investigation has long been recognized as the central and decisive part of a study of landslides and landslide-prone regions (Philbrick & Cleaves 1958, Sowers & Royster 1978). Even though this is not a landslide prone region, it becomes even more imperative that a thorough site investigation be completed. This investigation has many factors and elements that need to be explored. A landslide checklist as shown in Table 3.1, can provide a thorough and concise outline to guide in the investigation.

The particular landslide studied in Sparta, did not require the checklist in its entirety. The factors necessary for this investigation from the checklist are as follows: 1) Topography, 2) Geology (depth of bedrock), 3) Groundwater, 4) Weather, and 5) History of slope change (construction).

Table 3.1 Checklist for Planning a Landslide Investigation (Landslides 1996)



Checklist for Planning a Landslide Investigation (Sowers and Royster 1978)

- I TOPOGRAPHY
  - A. Contour map
    - 1. Land form
    - 2. Anomalous patterns (jumbled, scarps, bulges)
  - B. Surface drainage
    - 1. Continuous
    - 2. Intermittent
  - C. Profiles of slope
    - 1. Correlate with geology (II)
    - 2. Correlate with contour map (IA)
  - D. Topographic changes
    - 1. Rate of change by time
    - 2. Correlate with groundwater (III), weather (IV), and vibration (V)
- II GEOLOGY
  - A. Formations at site
    - 1. Sequence of formations
    - 2. Colluvium
      - a. Bedrock contact
      - b. Residual soil
    - 3. Formations with bad experience
    - 4. Rock minerals susceptible to alteration
  - B. Structure: three-dimensional geometry
    - 1. Stratification
    - 2. Folding
    - 3. Strike and dip of bedding or foliation
      - a. Changes in strike or dip
      - b. Relation to slope and slide
    - 4. Strike and dip of joints with relation to slope
    - 5. Faults, breccia, and shear zones with relation to slope and slide
  - C. Weathering
    - 1. Character (chemical, mechanical, and solution)
    - 2. Depth (uniform or variable)
- III GROUNDWATER
  - A. Piezometric levels within slope
    - 1. Normal
    - 2. Perched levels, relation to formations and structure
    - 3. Artesian pressures, relation to formations and structure
  - B. Variations in piezometric levels [correlate with weather (IV), vibration (V), and history of slope changes (VI)]
    - 1. Response to rainfall
    - 2. Seasonal fluctuations
    - 3. Year-to-year changes
    - 4. Effect of snowmelt
  - C. Ground surface indications of subsurface water
    - 1. Springs
    - 2. Seeps and damp areas
    - 3. Vegetation differences
  - D. Effect of human activity on groundwater
    - 1. Groundwater utilization
    - 2. Groundwater flow restriction
    - 3. Impoundment and additions to groundwater
    - 4. Changes in ground cover and infiltration opportunity
    - 5. Surface water changes
  - E. Groundwater chemistry
    - 1. Dissolved salts and gases
    - 2. Changes in radioactive gases
- IV WEATHER
  - A. Precipitation
    - 1. Form (rain or snow)
    - 2. Hourly rates
    - 3. Daily rates
    - 4. Monthly rates
    - 5. Annual rates
  - B. Temperature
    - 1. Hourly and daily means
    - 2. Hourly and daily extremes
    - 3. Cumulative degree-day deficit (freezing index)
    - 4. Sudden thaws
  - C. Barometric changes
- V VIBRATION
  - A. Seismicity
    - 1. Seismic events
    - 2. Microseismic intensity
    - 3. Microseismic changes
  - B. Human induced
    - 1. Transport
    - 2. Blasting
    - 3. Heavy machinery
- VI HISTORY OF SLOPE CHANGES
  - A. Natural process
    - 1. Long-term geologic changes
    - 2. Erosion
    - 3. Evidence of past movement
    - 4. Submergence and emergence
  - B. Human activity
    - 1. Cutting
    - 2. Filling
    - 3. Changes in surface water
    - 4. Changes in groundwater
    - 5. Changes in vegetative cover, clearing excavation, cultivation, and paving
    - 6. Flooding and sudden drawdown of reservoirs
  - C. Rate of movement
    - 1. Visual accounts
    - 2. Evidence in vegetation
    - 3. Evidence in topography
    - 4. Photographic evidence
      - a. Oblique
      - b. Stereo aerial photographs
      - c. Aerial photographs
      - d. Spectral changes
    - 5. Instrumental data
      - a. Vertical changes, time history
      - b. Horizontal changes, time history
      - c. Internal strains and tilt, including time history
  - D. Correlations of movements
    - 1. Groundwater [correlate with groundwater (III)]
    - 2. Weather [correlate with weather (IV)]
    - 3. Vibration [correlate with vibration (V)]
    - 4. Human activity [correlate with human-induced vibration (VB)]

Prior to any investigations, background knowledge of the Sparta area is necessary to better understand the geological and geotechnical conditions. The *Soil Survey for Sussex County* provided information of existing soil conditions based upon extensive soil testing performed in the 1970's. This information provides a general guideline of what kind of soil conditions to expect, how the soil properties react under certain conditions and what type of environment is best suited for that particular soil. From the first *General Soil Map* Sussex, New Jersey, a general soil association has been designated throughout Sussex County (Fletcher 1975). The map delineates the landslide location as a number 10 on the legend. A number 10 is defined as a soil formed in glacial till or in material weathered from bedrock, and is classified as a Rockaway-Rock outcrop-Whitman association. This type of classification is described as a steep and very steep, deep, well drained gravelly to very stony loamy soils; rock outcrops; and nearly level deep, very poorly drained extremely stony loamy soils on upland (Fletcher 1975). This gives a general overview of what to expect in the field.

Delving further into the soil survey, more properties are revealed to show that the Rockaway series soils formed in coarse-textured or moderately coarse textured glacial till (Fletcher 1975). Permeability is moderately rapid above the fragipan and slow in the pan (Fletcher 1975). Root penetration is restricted in the fragipan (Fletcher 1975).

A more specific classification of soils is depicted in other soils maps with in the soil survey. These maps are flown aerial maps with zones of soils superimposed and labeled on them [Figure 3.3]. The area in where the slide occurred is RoC (Rockaway Gravelly Loam) and the soil located directly above the slide is RvE (Rock

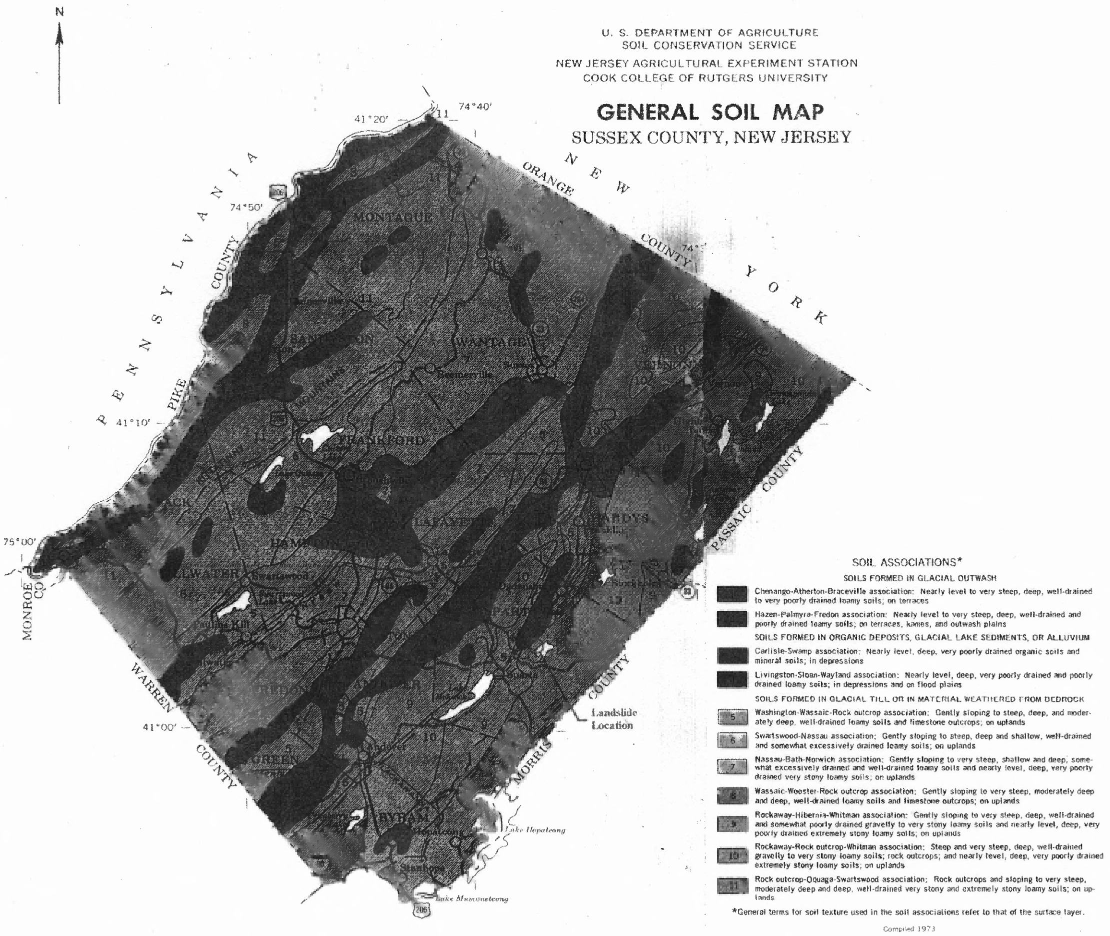


Figure 3.2 General soil map of Sussex County, New Jersey (Fletcher 1975).

Gravelly Loam) and the soil located directly above the slide is RvE (Rock outcrop-Rockaway association. The Rockaway gravelly loam is normally underlain by a fragipan and located in slopes of 8 to 15 percent. In areas where there are significant slope changes small seep areas are created. The Rock outcrop-Rockaway association consists of 70 to 90 percent bedrock outcrops, rock rubble or soil material less than 10 inches thick (Fletcher 1975). The slope range is 25 to 35+ percent.

The above soil information was an essential tool in aiding in the overall site investigation, since the investigation process for this study did not start until 7 months

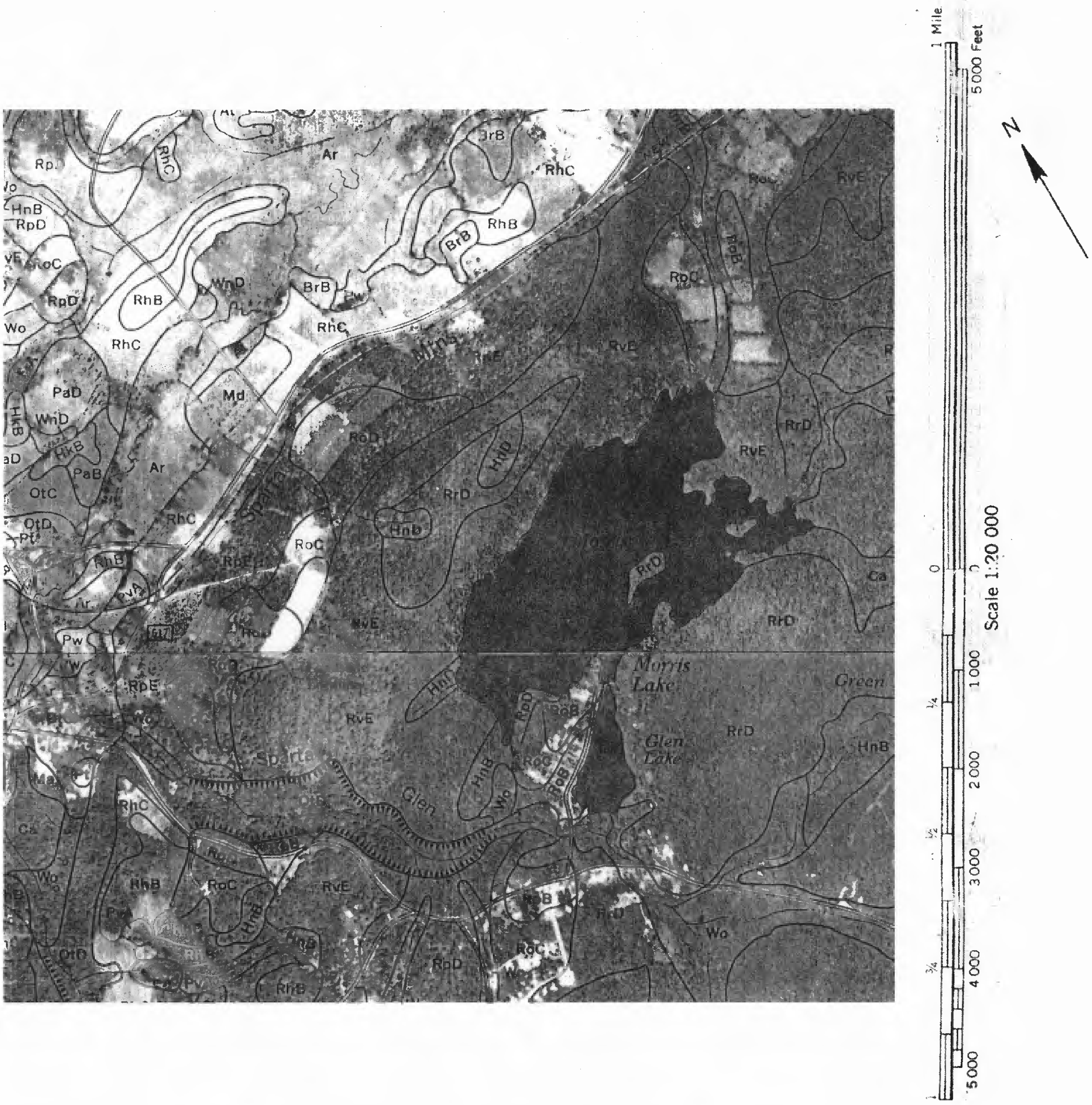
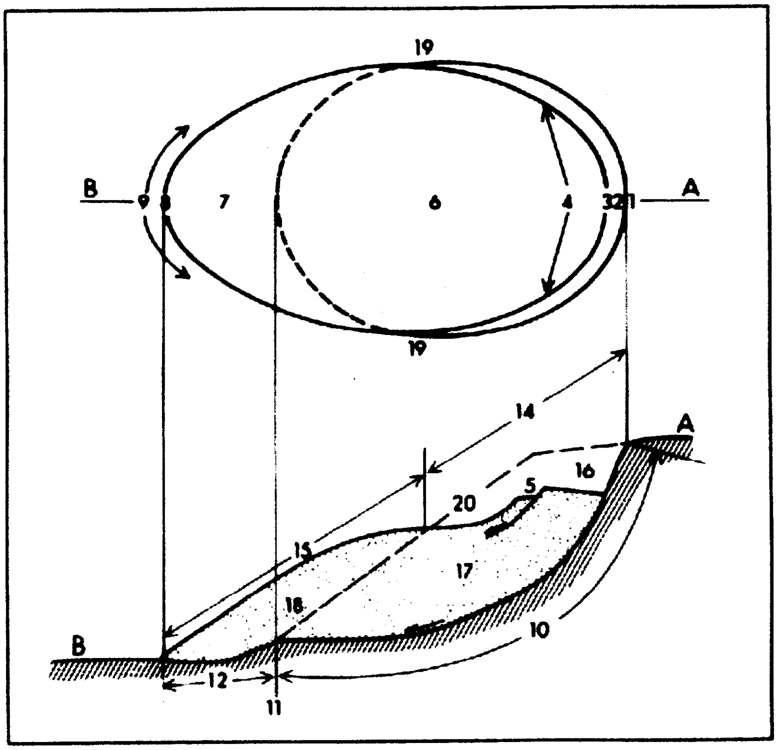


Figure 3.3 Soils map of Sparta Mountain range (Fletcher 1975).

after the landslide occurred. The various site investigations consisted of photographs, soil sampling, nuclear densometer testing, and topographic surveying of the landslide.

The photographs taken of the site show the various features of the landslide. Based on the observations of the site, discussion of the features must be represented properly. When discussing various aspects of a landslide, it is important that the landslide features are referenced. A landslide feature map explains all features of a landslide, which will help in understanding the overall observations [Figure 3.4].



Landslide features: *upper portion,* plan of typical landslide in which dashed line indicates trace of rupture surface on original ground surface; *lower portion,* section in which hatching indicates undisturbed ground and stippling shows extent of displaced material. Numbers refer to features defined in Table 3-3 (IAEG Commission on Landslides 1990).

Definitions of Landslide Features

NUMBER	NAME	DEFINITION
1	Crown	Practically undisplaced material adjacent to highest parts of main scarp
2	Main scarp	Steep surface on undisturbed ground at upper edge of landslide caused by movement of displaced material (*13*, stippled area) away from undisturbed ground; it is visible part of surface of rupture (*10*)
3	Top	Highest point of contact between displaced material (*13*) and main scarp (*2*)
4	Head	Upper parts of landslide along contact between displaced material and main scarp (2)
5	Minor scarp	Steep surface on displaced material of landslide produced by differential movements within displaced material
6	Main body	Part of displaced material of landslide that overlies surface of rupture between main scarp (*2*) and toe of surface of rupture (*11*)
7	Foot	Portion of landslide that has moved beyond toe of surface of rupture (*11*) and overlies original ground surface (*20*)
8	Tip	Point on toe (9) farthest from top (*3*) of landslide
9	Toe	Lower, usually curved margin of displaced material of a landslide, most distant from main scarp (*2*)
10	Surface of rupture	Surface that forms (or that has formed) lower boundary of displaced material (*13*) below original ground surface (*20*); mechanical idealization of surface of rupture is called *slip surface* in Chapter 13
11	Toe of surface of rupture	Intersection (usually buried) between lower part of surface of rupture (*10*) of a landslide and original ground surface (*20*)
12	Surface of separation	Part of original ground surface (*20*) now overlain by foot (*7*) of landslide
13	Displaced material	Material displaced from its original position on slope by movement in landslide; forms both depleted mass (*17*) and accumulation (*18*); it is stippled in Figure 3-4
14	Zone of depletion	Area of landslide within which displaced material (*13*) lies below original ground surface (*20*)
15	Zone of accumulation	Area of landslide within which displaced material lies above original ground surface (*20*)
16	Depletion	Volume bounded by main scarp (*2*), depleted mass (*17*), and original ground surface (*20*)
17	Depleted mass	Volume of displaced material that overlies surface of rupture (*10*) but underlies original ground surface (*20*)
18	Accumulation	Volume of displaced material (*13*) that lies above original ground surface (*20*)
19	Flank	Undisplaced material adjacent to sides of surface of rupture; compass directions are preferable in describing flanks, but if left and right are used, they refer to flanks as viewed from crown
20	Original ground surface	Surface of slope that existed before landslide took place

Figure 3.4 Definitions of landslide features (Landslides 1996).

The tip and toe of the landslide as well as part of the foot were cleaned up prior to the first site investigation. Information from eye witnesses stated that the foot of the landslide had traveled across Glen Road (Rt. 517). The partially constructed road that led to the future development had also been cleared. One of the Sparta Pump Houses is also located on this road and was affected by the slide [Figure 3.5]. As seen in the photograph, the landslide residue stained the building. The soil rose as high as 4 feet around the pump house which was powerful enough to damage the existing door and window, but not powerful enough to damage the buildings foundation.

Figure 3.5 Photograph of Sparta pump house after partial clean up of landslide.

Figure 3.6 Photograph of landslide depicting the path of the foot.

Advancing up the foot of the slide, areas had been cleared for new construction, however the slide was powerful enough to uproot small caliper tress and brush [Figure 3.6]. The landslide seemed to lose most of its energy towards the bottom slope of the mountain, where the landslide encountered an area of dense woods in which no tree damage was apparent.

The next photograph depicts the Toe of Surface of Rupture [Figure 3.7]. The far left of the photograph depicts the new slope introduced by the newly constructed roadway. Small trees and debris were also seen in the center of the rupture surface. The soil in the surrounding area was 100% saturated at the time of investigation due to a recent snow storm. The overall width of the surface of rupture was approximately 25 feet wide.

Figure 3.7 Photograph of toe of surface of rupture.

The left flank is depicted in the next photograph [Figure 3.8]. The wooded area located on the left flank had substantial root reinforcement and mostly likely prevented a larger area of failure. The failure on both flanks was near a vertical plane failure, which suggests a very high degree of saturation. The average width between the flanks was approximately 175 feet.

Figure 3.8 Photograph of left flank of landslide.

Standing from the top of the crown, looking into the body of the landslide, it was evident that the depleted mass was quite large due to the fact that a fairly shallow slope failure existed [Figure 3.9]. The main scarp and the area of depleted mass near the scarp were 100% saturated and still unstable. Daylighting was seen at the base of the scarp as well as parts of the head of both the right and left flank. The depleted mass and foot soil were homogenous and had similar soil properties. Visual classification of the soil appeared to be a Silty Sand with gravel. A very small portion of clay may be in this layer. Throughout the landslide there were no visual signs of the actual surface of rupture except along the flanks and scarp. It appeared the extreme saturation of the soil and lack of root reinforcement may have created the actual failure.

Figure 3.9 Photograph of main body (Taken from crown of landslide).

Traveling above the crown, major rock outcrops, dense vegetation, and poor ground cover were evident. Permeability seemed to be poor in the areas above the slide. Extreme slopes in some areas seemed to be in excess of 45%. Small drainage swales were present and may have increased runoff velocities and created small point discharges towards crown of slide [Figure 3.10]. Small topographic deviations such as the one being discussed are often the most critical with regard to fluid pressures and slope stability, especially in areas of groundwater discharge (Domenico 1998). Extreme runoff also seemed to be a contributing factor and a possible triggering mechanism of slide.

Figure 3.10 Photograph of natural swale located above the crown of landslide.

After the walkthrough of the site, soil samples were taken. Samples were also obtained from the day of the slide, which were also thoroughly investigated. Five samples were taken at various depths within the slide. The samples were taken at depths of 18 inches, 3 feet, 8 feet, and the final sample which was excavated using a hydraulic excavator at a depth of 16 feet. The change in soil became apparent at a depth of 14 feet, when the color had changed from brown to gray and the soil was much more firmly compacted. The soil appeared to be a glacial till. Excavation within the slide continued to a depth of 32 feet below existing grade, which concluded that bedrock was not the underlying factor. Within the 18 foot excavation, another layer change was evident at an approximate a depth of 24 feet below existing grade, but the characteristics in compaction grain size did not change much. However, the extreme change in compaction at around the depth of 14 feet became a major point of concern, which seemed to be the surface of rupture. Permeability almost seemed non-existent within the glaciated layer.

Other variables such as specific weights of soil layers are also important when determining slope stability. Severe differences within unit weights between layers are often a sign of a change in permeability and soil composition. The use of a nuclear densometer, a gauge that can detect dry unit weights of soil and moisture contents, can accurately determine the *in-situ* conditions of the soil. Nuclear densometer readings were taken on the landslide site in three different locations. The first reading was taken at one foot below existing grade just outside the right flank. The second reading was taken inside the slide approximately seven feet down on the right flank. In order to perform this test a level shelf was created using a hand shovel approximately 3 feet into the right flank. The third test was taken at a depth of 14 feet where the abrupt change in soil composition was detected. The dry unit weight and moisture content results were as follows: 1) 1 foot – 95 lb/ft^3 and 16% moisture, 2) 7 feet – 110 lb/ft^3 and 20% moisture, 3) 14 feet – 130 lb/ft^3 and 12% moisture. However, the data obtained for moisture content is not accurate, because these moisture contents would yield degrees of saturation all over 1.

The final site visit consisted of topographic survey. The details of the survey are included in the next section of this chapter, where the procedure, methodology, and information obtained are extremely pertinent to the landslide investigation.

3.3 Site Survey Data

To achieve a truly accurate depiction of a landslide, a topographic survey is an excellent tool that will not only lend accuracy towards your final product but also represents a visual tool that can be expressed in a 3-D model. This can help in answering questions that are sometimes approximated by empirical formulas. A prime example of how a survey can benefit a landslide analysis and investigation is by determining the landslide volume displaced outside the main body as well as to achieve a highly accurate determination of overall slide volume and depleted mass volume. The difficulty in calculating the volume of declared landslides arises mostly from the fact that we know very little about the surface of the rupture, its shape or depth (Casale 1999).

The survey completed for this particular landslide was a bit complicated. Since there was no vertical or horizontal control in the area, data including aerial photography, USGS topography maps, and general observations, were necessary to determine the approximate vertical elevation and horizontal location. This information was crucial in determining the approximate location and elevation of this site. Ideally, a flown topographic aerial would be the most ideal and cost effective manner if testing was performed on a higher level. By checking the soil samples tested against the soil survey, using site investigation compared to old aerial photography, and overlaying USGS quad maps with existing aerial, a degree of accuracy suitable for this project was verified.

Using a Total Station, the site was surveyed by taking spot elevations along the perimeter of the slide at an offset of 15 feet from the top of the slide. Spot elevations were taken every 20 feet at the top and bottom of the slide and spot elevations were also taken with the depleted mass. This information was stored in a data collector and then downloaded to a computer-aided drafting program call Land Development Desktop 3 (LDD).

The information surveyed was then rendered into a topographic view of the slide using a triangulation method generated by LDD. [Appendix B, Figure B.1] By using the perimeter spot elevations an accurate representation of the existing topography can then be generated. [Appendix B, Figure B.2] The information created by the survey also generates a main profile of the landslide, which starts from the toe of surface of rupture to the crown. This information was important to determine the type of failure that had occurred. Looking at the profile in Appendix B, Figure B.3, the existing conditions are shown along with the profile of the landslide and glacial till below. The glacial till profile below is an approximation that was based upon several test holes taken on the site. From this information it is deduced that the failure plane is non-circular, which will be beneficial when determining which type of method of slope stability method to analyze.

The second important data drawn from the survey analysis is the determination of landslide volume. Utilizing LDD, earthwork calculations were generated by three different methods. They consist of an average-end area method, grid method, and composite method. The average-end area method uses cross-sections [Appendix B, Figure B.4] generated by LDD and takes the average area of each section and multiplies those averages by the distance between each of the two sections that are being modeled at that time. The Grid method calculates volumes using a grid overlaid on the two surfaces that comprise the current stratum. This method calculates the volumes by using the prismoidal volume of all grids and summarizing. The Composite method re-triangulates a new surface based on points from both surfaces, as well as any location where the triangle edges between the two surfaces cross. The command then calculates the new composite surface elevations based on the difference in the elevations of the two surfaces. By using all three methods above, a higher degree of accuracy can be achieved in addition to error checking for any inconsistencies within the two stratums.

The volumes generated using these methods accurately determined the amount of soil displaced into the foot, which was the most devastating part of the slide. The results yielded as follows: 1) Average-end Area Method – 22,276 cu yds., 2) Grid Method (2-foot grid analysis) – 22,271 cu. yds., 3) Composite Method – 22,274 cu. yds. [Appendix B, Table B.1] Given these figures it was determined that the amount of soil displaced by the landslide was equal to 22,275 cu. yds., which is equivalent to 1,485 dump truck loads. Based on further analysis using LDD, an approximate total landslide amount of soil failed equates to 29,800 cu. yds. In addition, the amount of soil that subsided in the depleted mass was approximately 7,525 cu. yds.

3.4 Soils Investigation & Testing

Soil sampling is the most important part in analyzing a landslide. By knowing the properties of the soil strata of the landslide, a great deal of information can be obtained to determine the triggering mechanisms of the landslide. Soil tests that are ideal to analyze landslides are particle size analysis (sieve and hydrometer), Atterberg limits, specific gravity, moisture content, permeability, and triaxial shear test. However, the equipment was not available to take an undisturbed soil sample, an accurate permeability test and a triaxial shear test were not able to be performed. Therefore, testing the soil samples grain size and plasticity is necessary to classify the soil. By obtaining an accurate classification of the soil samples, a permeability range and angle of internal friction range can be obtained from typical values of those types of soil. Classifying the soil also helps back check the nuclear density meter readings that were taken in the field with general values that are normal obtained in the field.

The samples that were taken during the field investigation and the samples that were obtained from the day of the slide were all tested for particle size analysis (sieve and hydrometer). Moisture content was taken on all three samples the day of the landslide. However, they do not portray the actual moisture content that occurred the day of the landslide, because the samples were tested several months after the landslide. Specific gravity tests were also taken on the three samples from the day of the slide. Atterberg limits were also performed on the samples.

Seven samples were taken from the landslide. Samples 1A, 1B, and 1C were all taken at the toe of landslide at a depth of 12 inches. Samples S-1, S-2, S-3, and S-4 were all sampled inside the slide at depths of 3 feet, 1.5 feet, 8 feet, and 14 feet respectively. Samples S-1, S-2, and S-3 were all sampled from the right flank of the slide. Sample S-4 was taken approximately from the middle of the depleted mass of the landslide.

All samples were tested following the *Annual Book of ASTM Standards 2000.* Utilizing the ASTM standards, the following lab results can be seen in Appendix C. Atterberg Limits were run on only two samples, which were S-2 and S-4. The limits yield neither a Liquid Limit, nor a Plastic Limit which would classify all soils sampled as non-cohesive soils. Specific gravity tests were also run on samples 1A, 1B, and 1C, which all yielded the same result of 2.68-2.69. Sieve analysis and hydrometer analysis were both performed on all of the samples, which all produced similar results. [Appendix

C, Grain Size Overlay] Therefore, the same specific gravity values were used on all samples.

An observation based on the grain size overlay graph is the three samples taken from the toe were taken at shallow depths, and the grain sizes of those samples were much coarser, approximately 6-10% coarser, compared to the other in-situ samples taken within the landslide. One can hypothesize that as the soil traveled down the slope the finer particles segregated from the coarser particles.

Based on the soil samples taken, samples 1A, 1B, 1C, S-1, S-2, and S-3 are all the same type of soil within range which indicates that the first 14 feet of soil is homogenous. The soil samples had gravel content between 5 and 12 percent, a coarse sand content between 4 and 5 percent, a medium sand content between 12 to 15 percent, a fine sand content between 30 and 31 percent, and a fine content between 37 to 48 percent. Using these numbers and ATSM Code *D2488*, a soil classification is made using the *Unified Classification System.* Since the amount of fines is less than 50 percent, the soil is considered a coarse grained soil. The next step was to determine whether the coarse grain material is a gravelly or sandy soil. Since all of the samples had a larger amount of fines than one-half the coarse material it is considered a sandy soil. Based upon this conclusion, ASTM requires the use of the bottom half of Figure 3.11. [ASTM 2000] Since there is greater than 15 percent fines and the fines are equivalent to a ML or MH (Non-plastic soil) and less then 15 percent gravel, the classification for all of the above samples would be SM – Silty Sand.

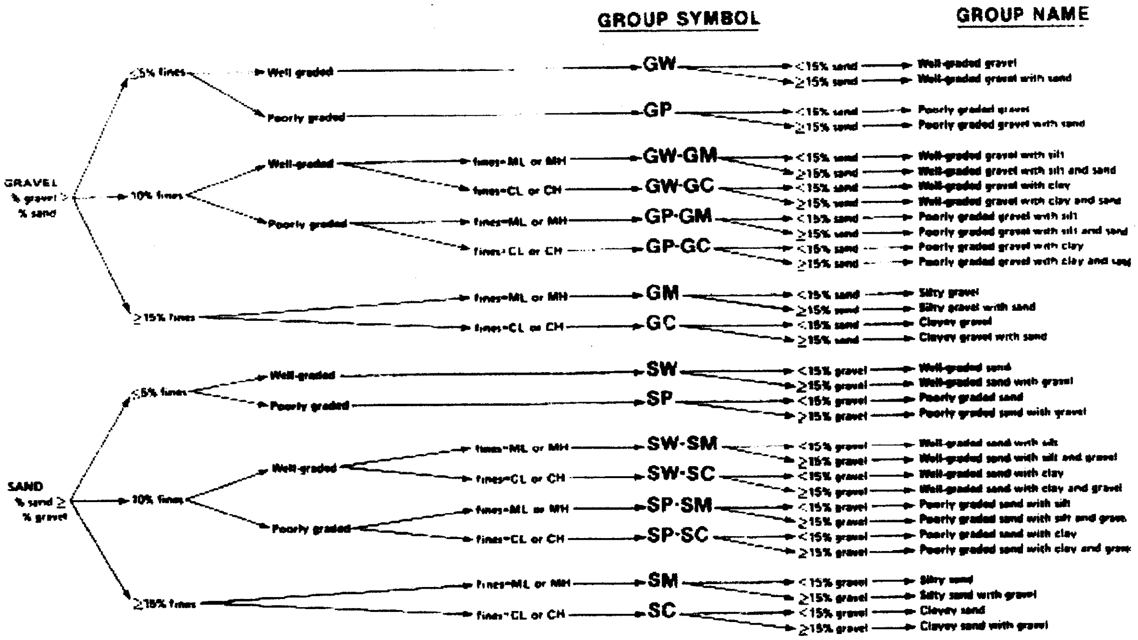


Figure 3.11 Flow chart for identifying coarse-grained soils (ASTM 2000).

As for sample S-4, which from the site investigation seemed to be a different type of soil, is actually a different type of soil, but in particle size there is not much of a difference except in gravel. Sample S-4 contained 22 percent gravel, 5 percent coarse sand, 12 percent medium sand, 23 percent fine sand, and 37 percent fines. Based on that data for the glacial till layer, the soil classification is SM- Silty sand with gravel.

Taking this information obtained from the grain size analyses, can also be applied to the U.S. Department of Agriculture textural classification [Figure 3.12]. The triangle is generally used for classification, which in this landslides case the soil would be classified as a sandy loam. However this figure depicts other debris and earth flows that have occurred in similar types of rainfall events that have occurred in the San Francisco Bay Region. The results, although thousands of miles away yielded similar soil characteristics to the Sparta, New Jersey Landslide, which is another indication that other areas in the New Jersey area with similar soil may be prone to slope failure.

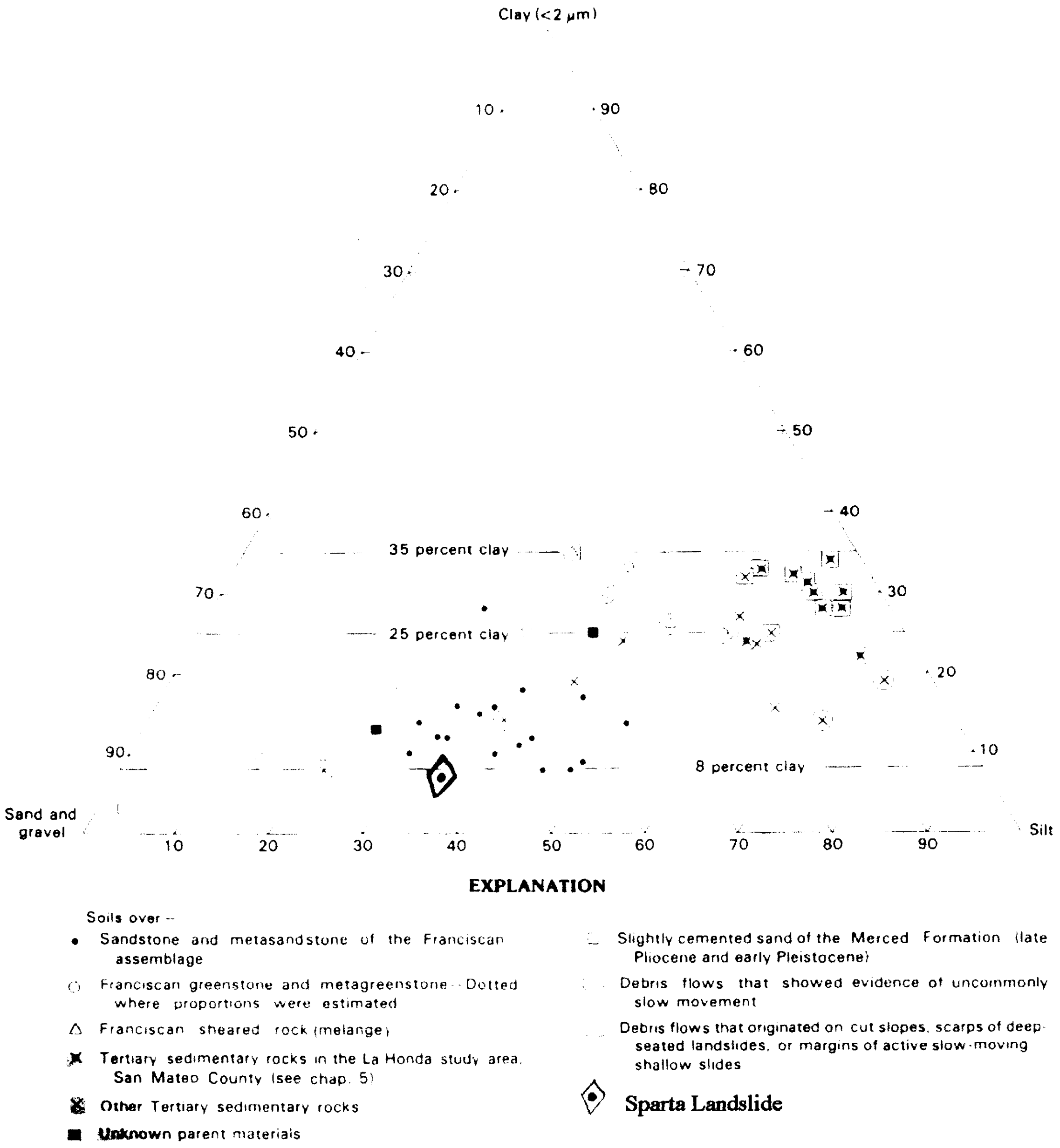


Figure 3.12 Correlation of landslide occurrences to soil classification (Ellen 1988).

Comparing the field data results to typical values obtained for general soil types is an excellent way to back check results. Table 3.2 illustrates typical unit weights of soil both above and below the groundwater table. Using the soil classification of silty sand and silty sand with gravel, unit weights of 110 lb./ft.^{3} and 130 lb./ft.^{3} respectively, and above the groundwater table in comparison to Table 3.2, the results fall in the range of a typical silty sand. Although permeability tests and triaxial were not performed for this thesis, using typical properties for this type of soil will lend a general range of values which will be adequate for slope stability analyses.

Table 3.2 Typical Unit Weights of Soils (Coduto 1994)

TYPICAL UNIT WEIGHTS OF SOIL

Soil Type	Typical Unit Weight, γ			
	Above Groundwater Table		Below Groundwater Table	
	(lb/ft^3)	(kN/m^3)	(lb/ft^3)	(kN/m^3)
GP — Poorly graded gravel	110 - 130	17.5 - 20.5	125 - 140	19.5 - 22.0
GW — Well graded gravel	110 - 140	17.5 - 22.0	125 - 150	19.5 - 23.5
GM — Silty gravel	100 - 130	16.0 - 20.5	125 - 140	19.5 - 22.0
GC — Clayey gravel	100 - 130	16.0 - 20.5	125 - 140	19.5 - 22.0
SP — Poorly graded sand	95 - 125	15.0 - 19.5	120 - 135	19.0 - 21.0
SW — Well graded sand	95 - 135	15.0 - 21.0	120 - 145	19.0 - 23.0
SM — Silty sand	80 - 135	12.5 - 21.0	110 - 140	17.5 - 22.0
SC — Clayey sand	85 - 130	13.5 - 20.5	110 - 135	17.5 - 21.0
ML — Low plasticity silt	75 - 110	11.5 - 17.5	80 - 130	12.5 - 20.5
MH — High plasticity silt	75 - 110	11.5 - 17.5	75 - 130	11.5 - 20.5
CL — Low plasticity clay	80 - 110	12.5 - 17.5	75 - 130	11.5 - 20.5
CH — High plasticity clay	80 - 110	12.5 - 17.5	70 - 125	11.0 - 19.5

Permeability between the two layers can be deduced based on the dry unit soil weight. Referring back to the soil survey of Sussex County, which stated that the soils near the surface experience moderate permeability whereas the soil that is located in the fragipan area, which would be the silty sand with gravel, would experience very poor permeability. The *in-situ* results of the nuclear density readings correlate with the soil survey of Sussex County quite well. Since the soils are very similar and the unit weights differ by 20 lb./ft.^{3}, a void ratio difference is apparent which directly correlates to permeability.

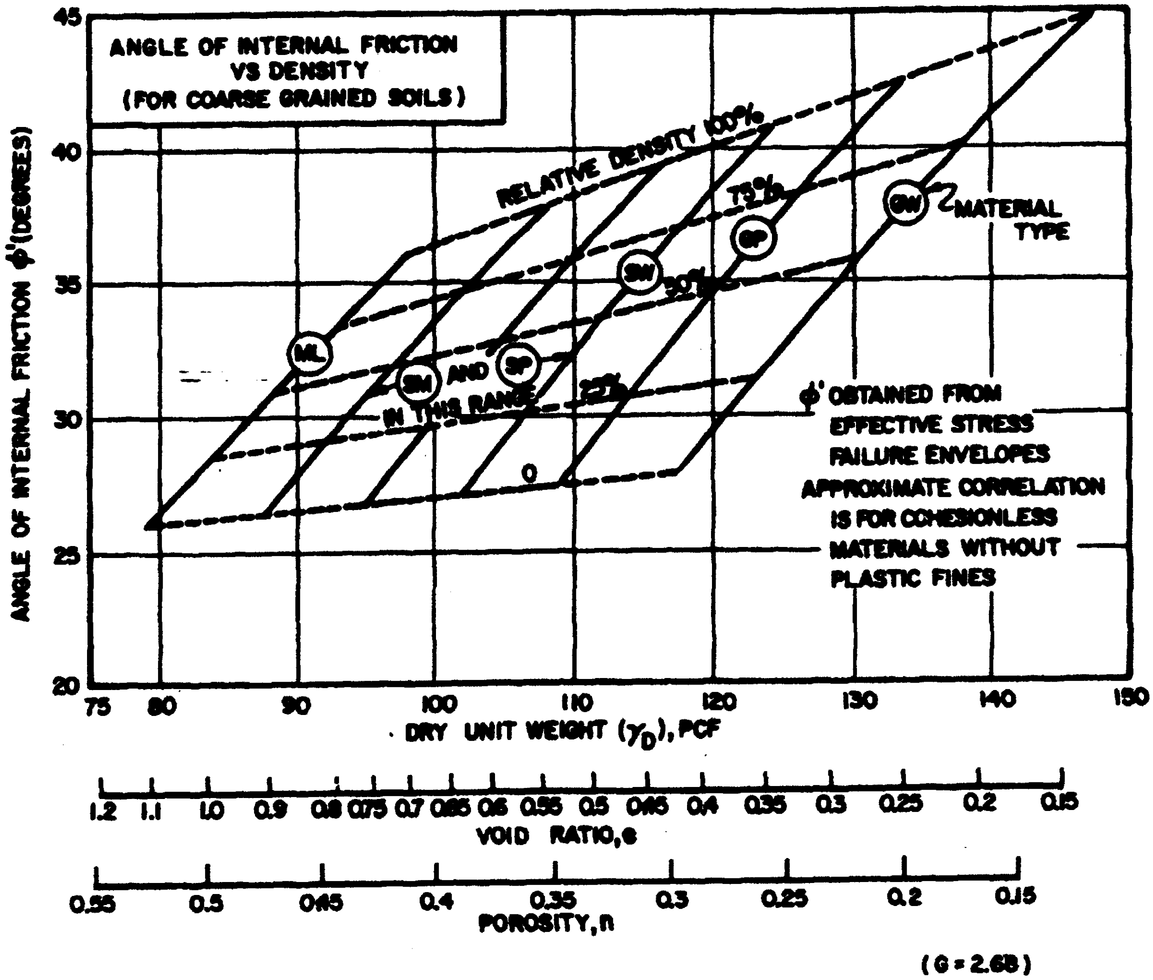


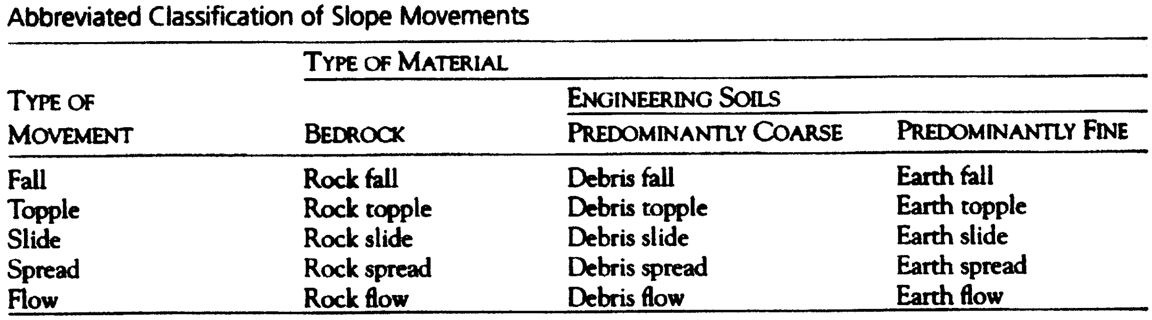
Figure 3.13 Conditions of strength characteristics for granular soils (U.S. Naval 1986).

The other information that is important to slope stability is the angle of internal friction. Since a triaxial test could not be performed, a range of friction angles were determined based upon the soil type [Figure 3.13]. Based upon of soil type of SM, the internal friction angle will typically fall between 26 to 41 degrees. Therefore 26, 30 and 35 degrees will be used in the slope stability analysis, which is discussed in Chapter 4, to determine the pore pressure developed in the upper soil strata. These values used tend to represent a realistic *in-situ* condition. Using the above information along with the theories based on the soil strata, a slope stability analysis can be performed.

3.5 Landslide Background & Classification

Landslides are a general term that is defined as "the movement of a mass of rock, debris or earth down a slope" (Cruden 1991). However in 1978, Varnes created a criteria, which would expand upon the definition of a landslide by breaking them down into classifications. The classification emphasizes the type of movement and type of material (Landslides 1996). Table 3.3, shown below, is the abbreviated classification of slope movements that Varnes created.

Table 3.3 Abbreviated Classifications of Slope Movements (Landslides 1996)



Abbreviated Classification of Slope Movements

	TYPE OF MATERIAL		
		ENGINEERING SOILS	
TYPE OF MOVEMENT	BEDROCK	PREDOMINANTLY COARSE	PREDOMINANTLY FINE
Fall	Rock fall	Debris fall	Earth fall
Topple	Rock topple	Debris topple	Earth topple
Slide	Rock slide	Debris slide	Earth slide
Spread	Rock spread	Debris spread	Earth spread
Flow	Rock flow	Debris flow	Earth flow

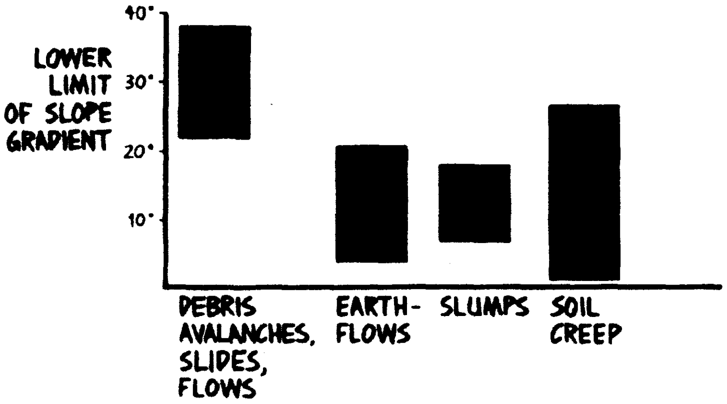
Using this type of classification provides more than just a name, the classification defines how the soil moved and what type of material moved. The first step to classifying a slide is to determine the material, which is as follows: 1) Rock, 2) Earth, and 3) Debris. The second step to classifying a slide is to determine the type of movement. There are five types of movement and are as follows: 1) Fall, 2) Topple, 3) Slide, 4) Spread, and 5) Flow.

Rock is considered a hard or firm mass that was intact and in its natural place before the initiation of movement (Landslides 1996). Soil is divided into earth and debris. Earth describes material in which 80 percent or more of the particles are smaller than 2mm, the upper limit of sand-size particles recognized by most geologists (Bates and

Jackson 1987). Debris contains a significant proportion of coarse material; 20 to 80 percent of the particles are larger than 2mm, and the remainders are less than 2mm (Landslides 1996).

Modes of movement start off with a fall. A fall starts with a detachment of soil or rock from a steep slope along a surface on which little or no shear displacement takes place (Landslides 1996). A topple is a rotational failure that peels away from the existing slope. A slide is a downslope movement of a soil or rock mass occurring dominantly on surfaces of rupture or on relatively thin zones of intense shear strain (Landslides 1996). The term spread is an extension of a cohesive soil or rock mass combined with a general subsidence of the fractured mass of cohesive material into softer underlying material (Landslides 1996). Finally, a flow is defined as a spatially continuous movement in which surfaces of shear are short-lived, closely spaced and usually not preserved.

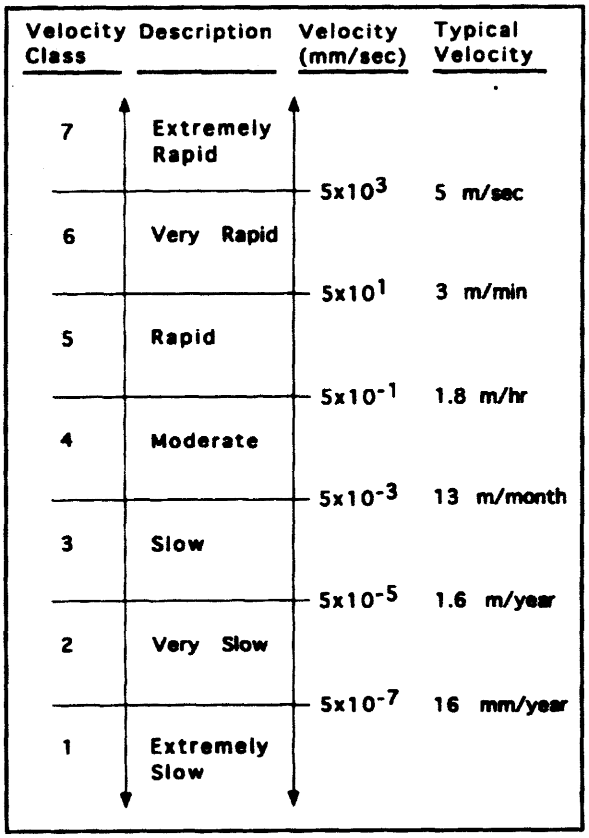
Using Varnes's criteria and applying the relevant information for this landslide, the landslide classification is an earth flow. A more specific type of flow that existed would be a channelized flow. A debris flow is often of high density, with over 80 percent solids by weight, and may exceed the density of wet concrete (Hutchinson 1988). Soils on steep slopes unprotected by vegetation are prone to debris flows (Landslides 1996). Flow movements may be in pulses, presumably caused by periodic mobilization of material or by formation and bursting of dams of debris in the channel (Landslides 1996). A general guide in determining the type of landslide is provided in Figure 3.14. It is quite useful in predicting types of landslides in certain terrain and slopes. This particular landslide had a slope gradient of approximately 10 degrees which coincides with the original classification of earth flow.



Lower limit of slope gradient, generally measured in a representative portion of the scouring zone, for various soil mass movements (data compiled from many sources).

Figure 3.14 Lower limit of slope gradients vs. types of landslides (Sidle 1985).

Another important factor in landslides is the velocity. Landslides with quick velocities, between 1.8 m/hr to 5 m/sec+, are normally based upon eye witness reports. According to eye witnesses the day of this slide, a few people stated that the slide moved quickly but slow enough that a human being could outrun the landslide. Using Figure 3.15, based upon eye witness accounts, the landslide would be classified as a very rapid landslide, which would make the slide a category 6 out of a possible 7. A category 6 is defined as some lives lost; velocity to permit all persons to escape. Therefore, in the event that construction had been completed for homes downslope of the landslide, there may have been some lives lost.



Velocity Class	Description	Velocity (mm/sec)	Typical Velocity
7	Extremely Rapid		
		5×10^{3}	5 m/sec
6	Very Rapid		
		5×10^{1}	3 m/min
5	Rapid		
		5×10^{-1}	1.8 m/hr
4	Moderate		
		5×10^{-3}	13 m/month
3	Slow		
		5×10^{-5}	1.6 m/year
2	Very Slow		
		5×10^{-7}	16 mm/year
1	Extremely Slow		

Proposed landslide velocity scale.

Definition of Probable Destructive Significance of Landslides of Different Velocity Classes

LANDSLIDE VELOCITY CLASS	PROBABLE DESTRUCTIVE SIGNIFICANCE
7	Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely
6	Some lives lost; velocity too great to permit all persons to escape
5	Escape evacuation possible; structures, possessions, and equipment destroyed
4	Some temporary and insensitive structures can be temporarily maintained
3	Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase
2	Some permanent structures undamaged by movement
1	Imperceptible without instruments; construction possible with precautions

Figure 3.15 Proposed landslide velocity scale (Landslides 1996).

3.6 Discussion of Results

The information in this section lends great insight into the background of the site, the type of landslide, and the determination of the probable triggering mechanisms of the landslide. Like most geotechnical projects, unknowns to the project are inevitable and must be theorized on known data.

Within this project, unknowns such as the angle of internal friction and permeability could only be deduced from existing data. However, there is enough supporting data to authenticate the hypothesis herein.

The theory of this landslide is based upon the geotechnical and hydrological data generated and hypothesized. Based on this information, the landslide that occurred was created by an extreme rainfall event, which precipitated 14.1 inches of rain in a 24-hour period over a drainage area tributary to the landslide of 8.32 acres. The intense amount of rainfall inundated an area that was heavily wooded and littered with rock outcrops, along with a smaller area downslope, which was only covered by brush and contained no root reinforcement. Due to little or no permeability upslope of the brush area, a much smaller area experienced an intense soil saturation.

The intense soil saturation created pore pressures in the soil strata below. Rainfall which now turns into groundwater is traveling down and along with the natural gradient. This is believed to have generated considerably high access pore water pressure, above and beyond that one would expect from surface water and seepage.

An instability point in the soil strata was reached when the resisting forces could not support the active forces and the surface of rupture was created along the glacial till plane where permeability was at is lowest. The toe of surface of rupture was created at point of where the newly constructed road was located. However without performing a slope stability analysis on the landslide, the toe of surface of rupture could not be attributed to the change in grade created by the new roadway. In the next section, the final aspects of the toe of surface of rupture will be analyzed to prove whether or not the toe of the slope was undermined by the newly constructed road.

CHAPTER 4

SLOPE STABILITY STUDY

4.1 Infinite Slope with Seepage Analysis

Analyses of slopes can be divided into two categories: those used to evaluate the stability of slopes and those used to estimate slope movement (Landslides 1996). The slope stability analysis, in this case, was used to determine pore pressure head based upon a range of values for the angle of internal friction. Appendix D.1 shows all equations for analyses, Appendix D.2 depicts solutions for soil properties and infinite slope analyses, and Appendix D.3 shows the solutions of the slope stability equilibrium analyses.

The void ratio of the two soil strata was determined based upon the dry unit weight calculated by the nuclear density meter and the specific gravity of the soil which was determined from laboratory results. The information yielded void ratios of 0.526 and 0.291 respectively, for the silty sand strata and the glacial till. Using the Kozeny-Carman [Appendix D.1] empirical formula for permeability, a ratio can be established since a known permeability for strata can not be determined. The permeability ratio established is based on the premise that the two soil layers have essentially the same grain size characteristics. From the Kozeny-Carman equation, the permeability ratio between the two soil strata is approximately 5 to 1, which demonstrates that the upper soil strata's permeability is 5 times more rapid then the lower glacial till strata [Appendix D.2].

Based on the void ratios obtained, a saturated unit weight was obtained for the two soil strata. The saturated unit weight of the silty sand and glacial till were 131.5

lb/ft^3 and 144.1 lb/ft^3. This information was used to equate, using the infinite slope stability with seepage analysis and the angle of internal friction based upon a factor of safety of 1, which yielded a result just as failure would have occurred. Since the soil is a saturated cohesionless soil, such as a gravel, sand, and non-plastic silts, they have a stress failure envelope that passes through the origin, which will equate cohesion to zero (Landslides 1996). The value of the angle of internal friction, Φ, ranges from 27 to 45 degrees, more or less and depends on several factors (Landslides 1996). However, three analyses were computed using angles of internal friction of 26, 30, and 35 degrees, which is more representative range for this soil.

The infinite slope stability with seepage analysis takes into account the pore pressures that are created normally by runoff or groundwater tables along a slope that is infinite in length. Based on the premise of failure occurring when the factor of safety is equivalent to one and the angles of internal friction used for each analysis were 26, 30, and 35 degrees, the height of water from these analyses yielded heads of 18.9 ft., 20.6 ft., and 22.2 ft. respectively [Appendix D.2].

Stresses on the soil were also computed for each variation of pore pressure, which was based on the results of the infinite slope with seepage analyses. The pore pressure, effective stress, and total stress of the three scenarios are as follows:

Table 4.1 Stresses in Silty Sand Soil Strata

Φ	Σ	μ	σ'
26	662.7 lb/ft^2	1179.4 lb/ft^2	1841.1 lb/ft^2
30	555.7 lb/ft^2	1285.4 lb/ft^2	1841.1 lb/ft^2
35	458.9 lb/ft^2	1382.2 lb/ft^2	1841.1 lb/ft^2

4.2 Wedge-Plane Force Equilibrium Analysis

The wedge-plane force equilibrium analysis applies to a finite slope which consists of a three wedge system, where the forces of the active wedge and central wedge must be less than the forces of the passive wedge in order to insure slope stability. Those forces are composed of the weight of the wedge and the pore pressures of the wedge. The analyses consisted of six different conditions, which can be seen in Appendix D.3.

Conditions one, three, and five were analyzed to obtain the height of water without the new roadway cut utilizing angles of internal friction which were 26, 30, and 35 degrees. Conditions two, four, and six used the angle of internal friction that was used in conditions one, three, and five respectively, except these conditions have a modified weight of the passive wedge to simulate the new roadway cut to obtain a factor of safety based on the roadway cut and a modified angle of internal friction.

The results of condition one, three, and five yielded a height of water of 18.73 ft, 20.49 ft., and 22.18 ft. Conditions two, four, and six resulted in a slight change in the angles of internal friction which were 25.95, 29.86, and 34.65 degrees, and also demonstrated the roadway cut analyses had a factor of safety of one.

4.3 Discussion of Results

The results of the infinite slope with seepage analyses and the wedge-plane force equilibrium analyses yielded, demonstrated how extreme pore pressures were the triggering factor which caused failure. When rapid infiltration of rainfall occurs, such as this landslide, it causes soil saturations and a temporary rise in pore water pressure which ultimately causes a shallow landslide (Landslides 1996). The results illustrated within this chapter support this statement by showing that extreme pore pressures developed during this landslide event. These high pore pressures along with the abrupt change in permeability between the two soil strata cause the silty sand layer to fail.

The wedge-plane equilibrium analyses performed illustrates that the factor of safety on the new roadway construction is so close to the analyses with no roadway construction. Therefore the roadway cut had no triggering mechanisms leading to the slope instability. Using the same angles of internal friction from the infinite slope stability analysis and the shear failure law in a saturated soil the ultimate shear strength range was approximately 900 lb/ft^2 to 1290 lb/ft^2 [Appendix D.2].

An infinite slope without seepage analysis was performed using an average moist unit weight of silty soil of 120 lb/ft^3 and an angle of internal friction of 35 degrees. This analysis was performed to determine an approximate existing factor of safety during normal conditions. The results yielded a factor of safety of 4.0, which demonstrates that the soil conditions existed on a safe gradient.

CHAPTER 5

CONCLUSION

The information and data compiled within this thesis was used to determine the type of landslide and the triggering mechanism that ultimately caused the failure of the slope. The hydrological, geological/geotechnical and slope stability study all were important aspects of the study that were necessary in determining a hypothesis for slope failure.

Based on the storm data, which produced a storm event of approximately a 1000-year storm, was determined using the New Jersey Rainfall Intensity curve [Appendix A, Figure A.1]. The rainfall data and hydrological study were enough evidence to reveal that the 14.1 inches of rainfall was the sole cause of the landslide. The analyses on the slope instability which took the road cut into account clearly demonstrate that there was no adverse affects from the road cut.

The main triggering mechanism was determined to be extreme pore-water pressures created by the rainfall event. This was deduced by the analyses performed in Chapter 4. The surface of rupture was caused by a significant difference in the permeability between the two soil strata. This was deduced by obtaining soil property data from the tested soil sample, and using the information to correlate a ratio of permeability between the two layers to help support the hypothesis.

The classification of the landslide was determined by the use of the field investigations and soil testing for particle size distribution. Based upon that information, the landslide is classified as an earth flow.

In cases such as these, ways of alleviating a potential landslide is an important task. Underground drainage in areas of large seep zones and areas that incorporate large drainage areas should be supplied to stop the cause of completely saturating a soil area. In areas that are know to have soils that may be a potential landslide zone, large root reinforcing trees may be planted or removal of soil and installing a retaining wall with tie backs may be key. However without thoroughly investigating sites on steeper terrain, which have future human development, landslides can always occur and can be life threatening.

The insight that can be obtained through this paper can aid greatly in developing land in steeper terrain. In the northern New Jersey area, development has been reduced to building on much more challenging pieces of land. In areas of steeper terrain such as this site, more caution should be put forth when developing in these areas. Although the rainfall event that occurred on August 12, 2000 was a most unlikely rainfall, it should be an eye opener to towns and counties in the state of New Jersey to adopt more stringent geotechnical designs in order to ensure that upon completion of development accidents in these areas do not occur.

APPENDIX A

HYDROLOGICAL STUDY DATA

This appendix depicts the tables and figures necessary to analyze the storm event that occurred on August 12, 2000. Following those tables and figures is the tabulated results of the storm event.

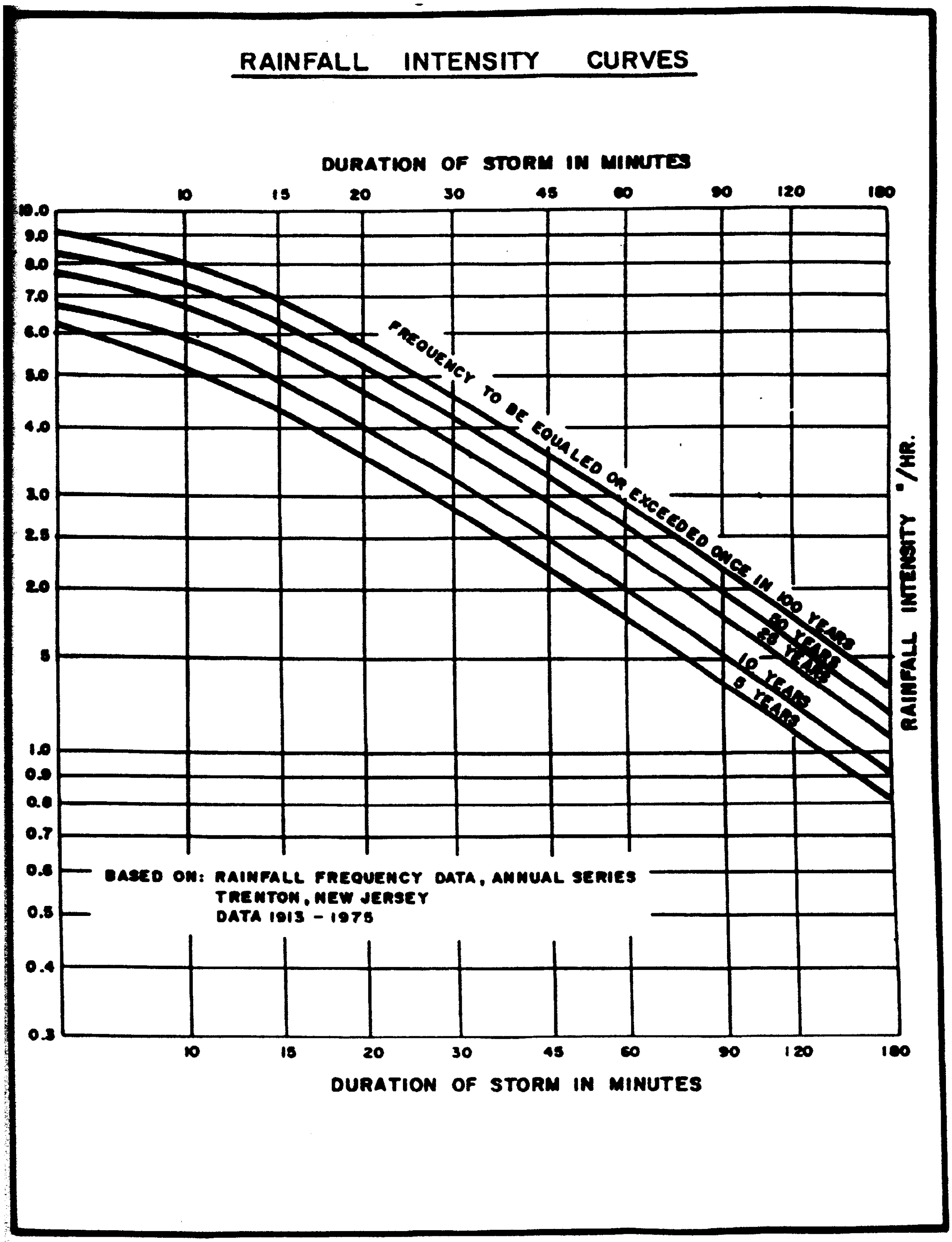
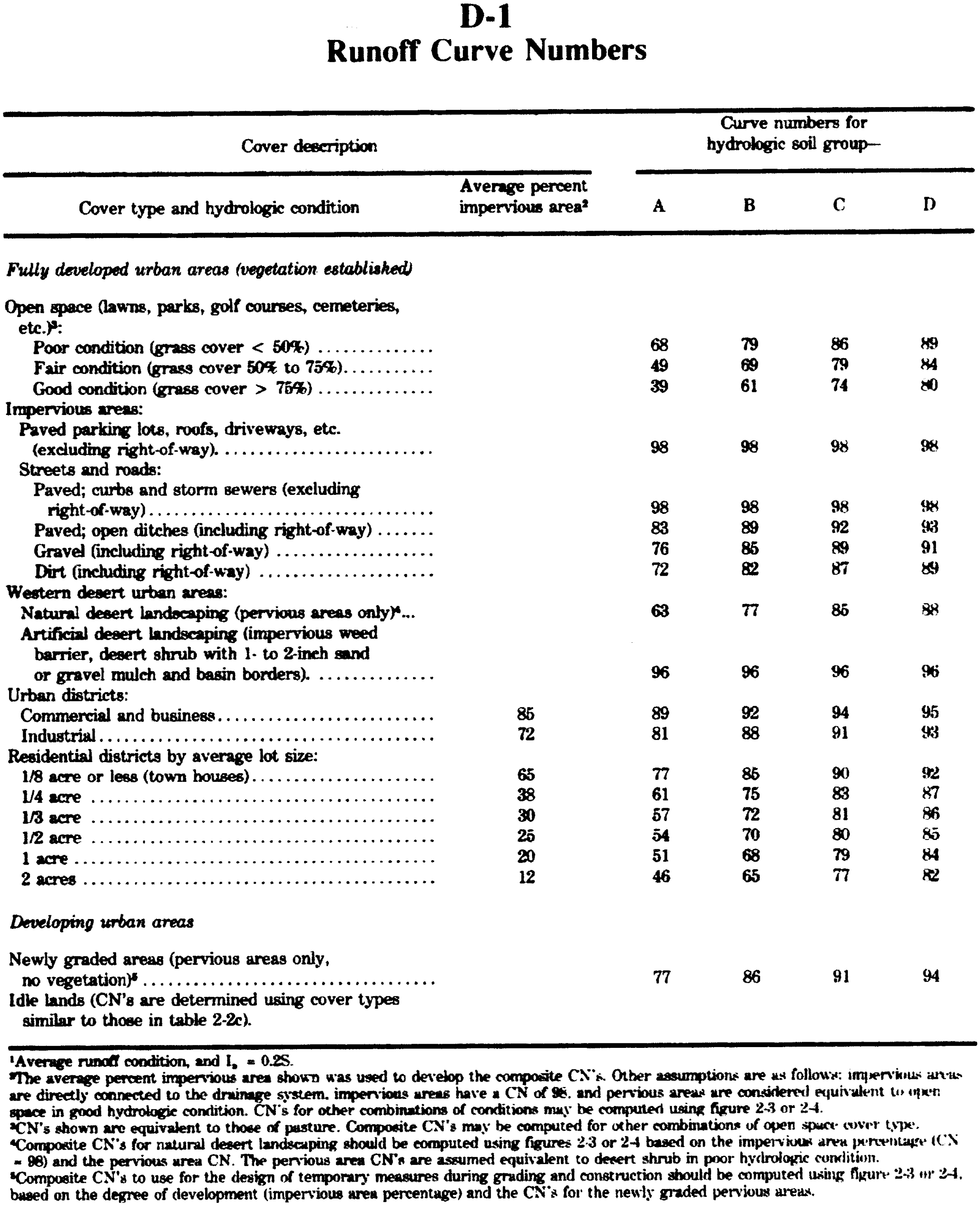


Figure A.1 Rainfall intensity curve, New Jersey (NJDCA 1999).

Table A.1 Runoff Curve Numbers (Gribbin 1997)



D-1
Runoff Curve Numbers

Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1] Average runoff condition, and $I_a = 0.2S$.
[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Runoff curve numbers. *(Courtesy of Soil Conservation Service, Technical Release 55.)*

Table A.1 Runoff Curve Numbers (Gribbin 1997) (continued)

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition	A	B	C	D
ture, grassland, or range—continuous rage for grazing.[3]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
adow—continuous grass, protected from razing and generally mowed for hay.	—	30	58	71	78
sh—brush-weed-grass mixture with brush he major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	[4]30	48	65	73
oods—grass combination (orchard r tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
oods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	[4]30	55	70	77
rmsteads—buildings, lanes, driveways, nd surrounding lots.	—	59	74	82	86

verage runoff condition, and $I_a = 0.2S$.

oor: <50% ground cover or heavily grazed with no mulch.
air: 50 to 75% ground cover and not heavily grazed.
ood: >75% ground cover and lightly or only occasionally grazed.

Poor: <50% ground cover.
air: 50 to 75% ground cover.
Good: >75% ground cover.

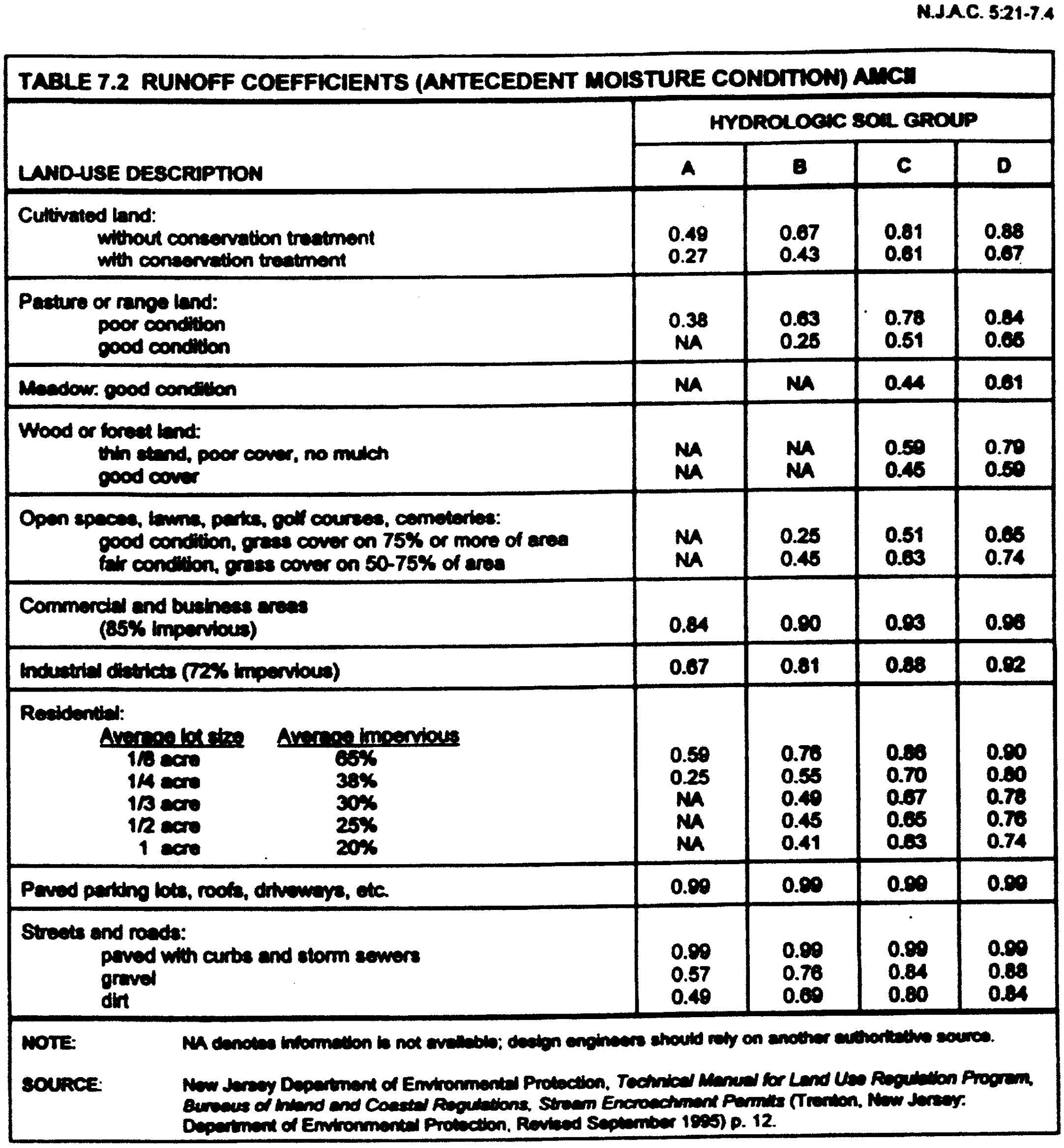
ctual curve number is less than 30; use CN = 30 for runoff computations.

CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed om the CN's for woods and pasture.

Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Runoff curve numbers. *(Courtesy of Soil Conservation Service, Technical Release 55.)*

Table A.2 Coefficients (Antecedent Moisture Condition) AMCII (Gribbin 1997)



N.J.A.C. 5:21-7.4

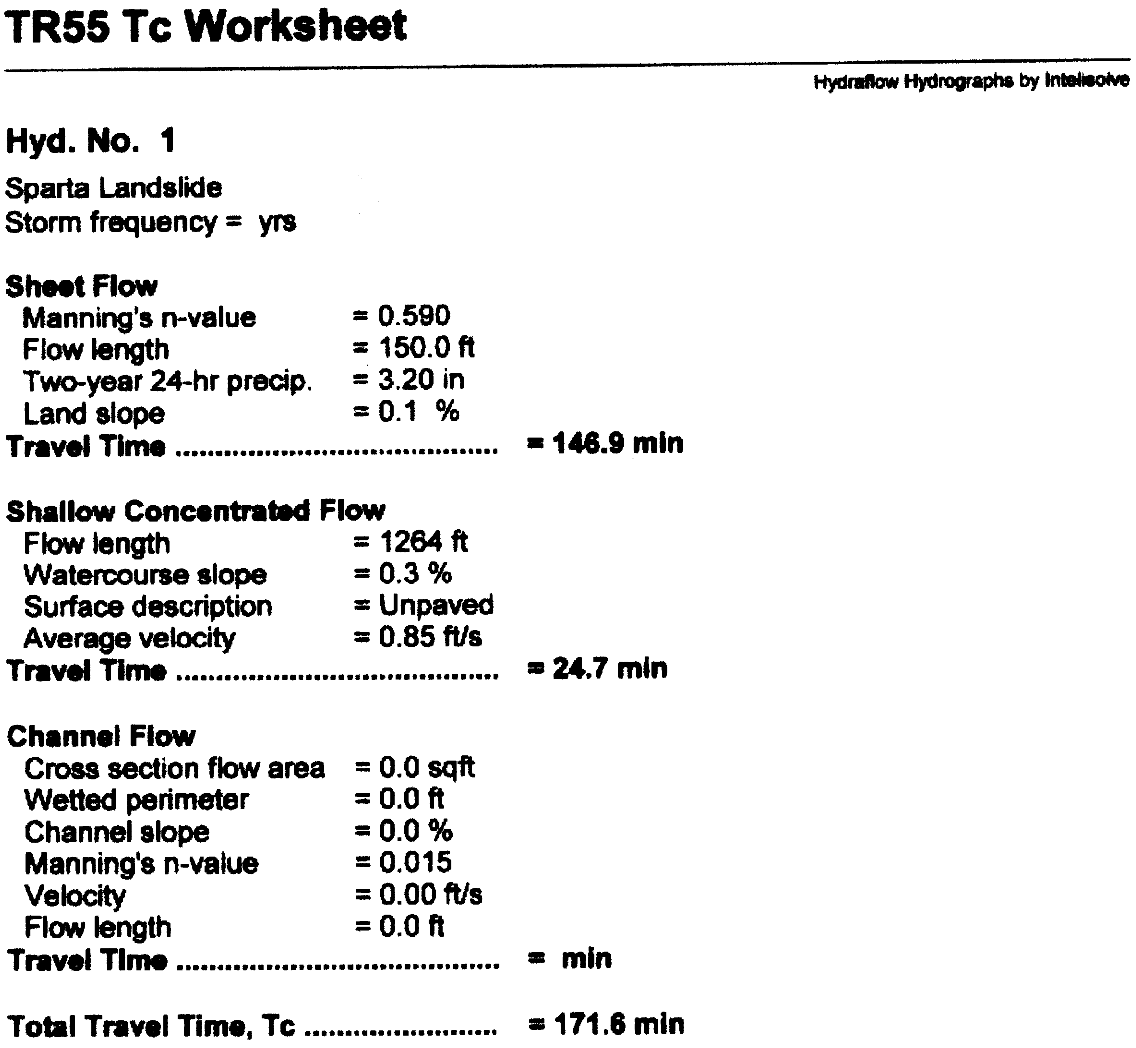
TABLE 7.2 RUNOFF COEFFICIENTS (ANTECEDENT MOISTURE CONDITION) AMCII

LAND-USE DESCRIPTION	HYDROLOGIC SOIL GROUP A	B	C	D
Cultivated land:				
without conservation treatment	0.49	0.67	0.81	0.88
with conservation treatment	0.27	0.43	0.61	0.67
Pasture or range land:				
poor condition	0.38	0.63	0.78	0.84
good condition	NA	0.25	0.51	0.65
Meadow: good condition	NA	NA	0.44	0.61
Wood or forest land:				
thin stand, poor cover, no mulch	NA	NA	0.59	0.79
good cover	NA	NA	0.45	0.59
Open spaces, lawns, parks, golf courses, cemeteries:				
good condition, grass cover on 75% or more of area	NA	0.25	0.51	0.65
fair condition, grass cover on 50-75% of area	NA	0.45	0.63	0.74
Commercial and business areas (85% impervious)	0.84	0.90	0.93	0.96
Industrial districts (72% impervious)	0.67	0.81	0.88	0.92
Residential:				
Average lot size — Average impervious				
1/8 acre — 65%	0.59	0.76	0.86	0.90
1/4 acre — 38%	0.25	0.55	0.70	0.80
1/3 acre — 30%	NA	0.49	0.67	0.78
1/2 acre — 25%	NA	0.45	0.65	0.76
1 acre — 20%	NA	0.41	0.63	0.74
Paved parking lots, roofs, driveways, etc.	0.99	0.99	0.99	0.99
Streets and roads:				
paved with curbs and storm sewers	0.99	0.99	0.99	0.99
gravel	0.57	0.76	0.84	0.88
dirt	0.49	0.69	0.80	0.84

NOTE: NA denotes information is not available; design engineers should rely on another authoritative source.

SOURCE: New Jersey Department of Environmental Protection, *Technical Manual for Land Use Regulation Program, Bureaus of Inland and Coastal Regulations, Stream Encroachment Permits* (Trenton, New Jersey: Department of Environmental Protection, Revised September 1995) p. 12.

Table A.3 Total Time of Concentration



TR55 Tc Worksheet

Hydraflow Hydrographs by Intelisolve

Hyd. No. 1

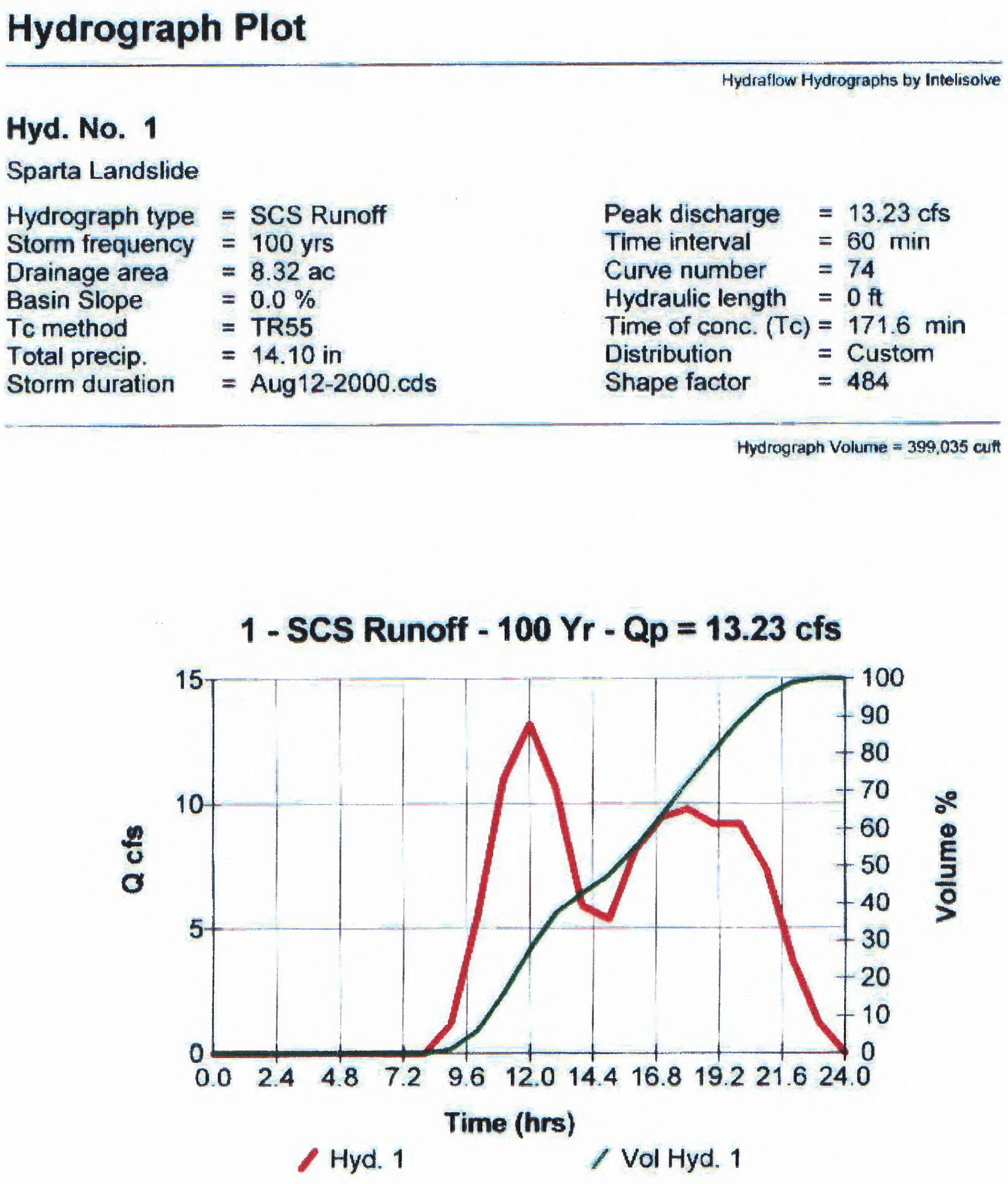
Sparta Landslide
Storm frequency = yrs

Sheet Flow
Manning's n-value = 0.590
Flow length = 150.0 ft
Two-year 24-hr precip. = 3.20 in
Land slope = 0.1 %
Travel Time .... = 146.9 min

Shallow Concentrated Flow
Flow length = 1264 ft
Watercourse slope = 0.3 %
Surface description = Unpaved
Average velocity = 0.85 ft/s
Travel Time .... = 24.7 min

Channel Flow
Cross section flow area = 0.0 sqft
Wetted perimeter = 0.0 ft
Channel slope = 0.0 %
Manning's n-value = 0.015
Velocity = 0.00 ft/s
Flow length = 0.0 ft
Travel Time .... = min

Total Travel Time, Tc .... = 171.6 min



Hydrograph Plot

Hydraflow Hydrographs by Intelisolve

Hyd. No. 1

Sparta Landslide

Hydrograph type = SCS Runoff
Storm frequency = 100 yrs
Drainage area = 8.32 ac
Basin Slope = 0.0 %
Tc method = TR55
Total precip. = 14.10 in
Storm duration = Aug12-2000.cds

Peak discharge = 13.23 cfs
Time interval = 60 min
Curve number = 74
Hydraulic length = 0 ft
Time of conc. (Tc) = 171.6 min
Distribution = Custom
Shape factor = 484

Hydrograph Volume = 399,035 cuft

Figure A.2 24-hour hydrograph for Sparta landslide.

APPENDIX B

SURVEY & VOLUMETRIC DATA

This appendix contains the topographic survey of the landslide. This information shows the existing and proposed topography, a centerline profile, and 50 foot cross sections of the landslide area. This information was then used to generate the overall volume of the landslide which is also included herein.

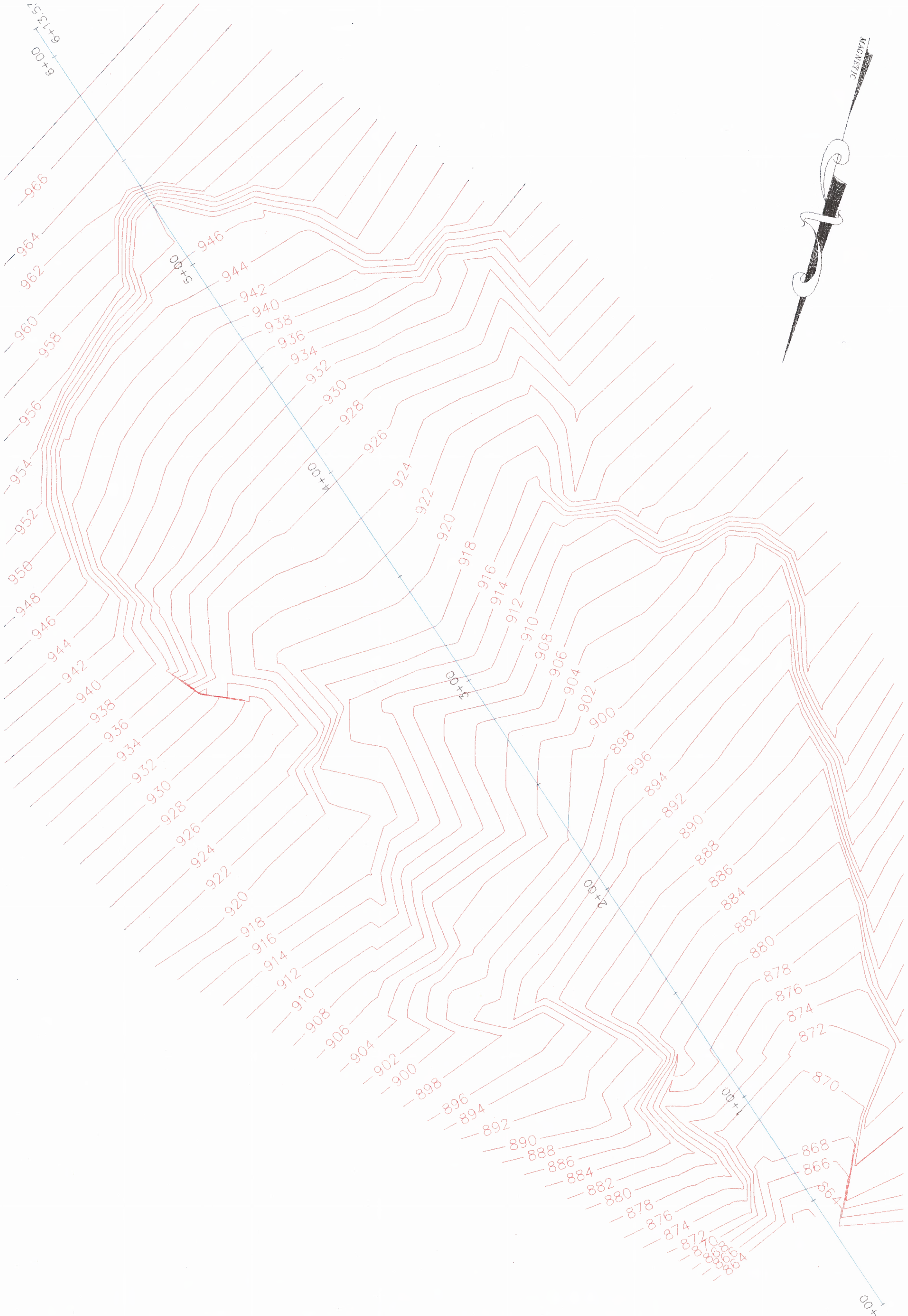


Figure B.1 Topographic survey of Sparta Mountain landslide.

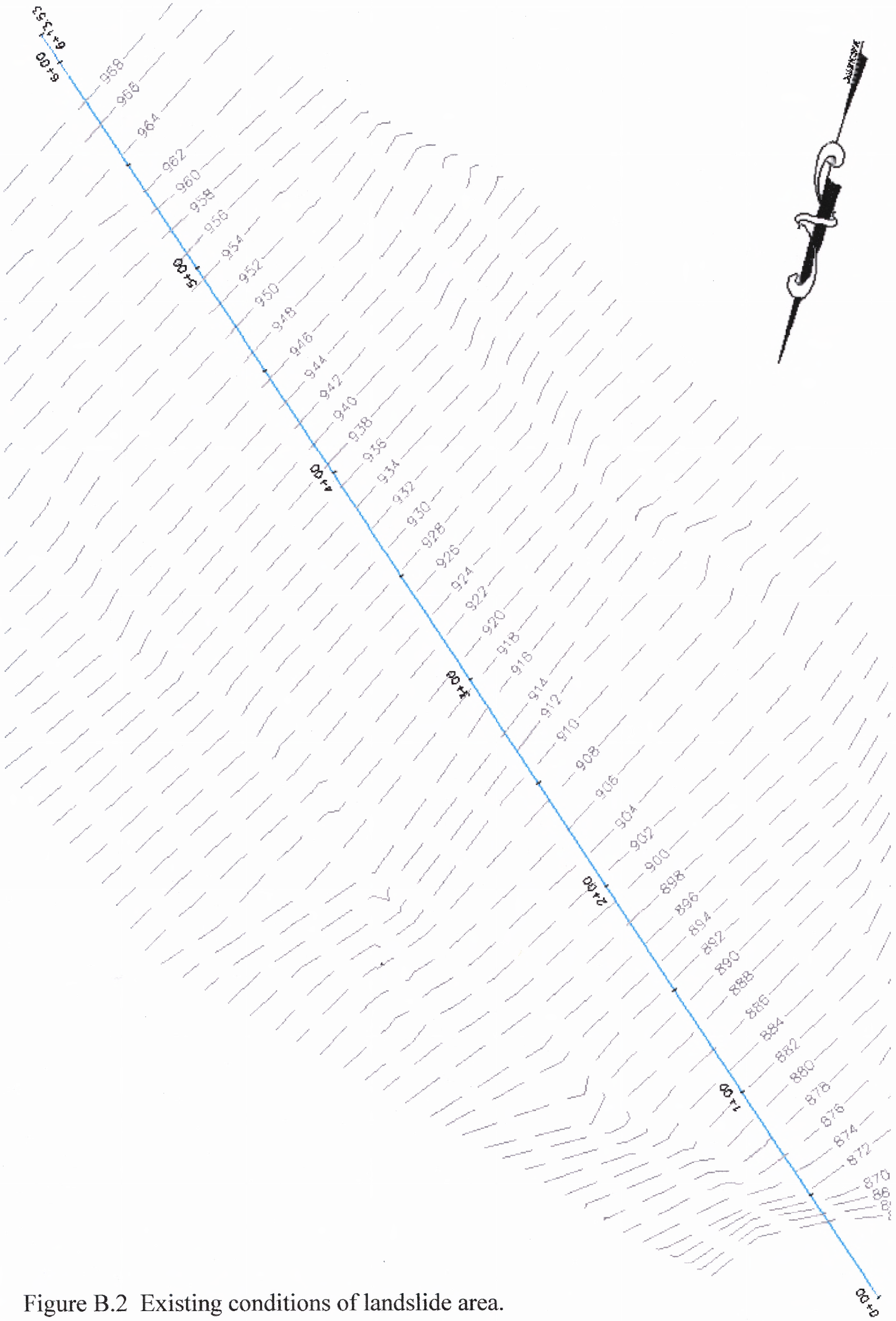


Figure B.2 Existing conditions of landslide area.

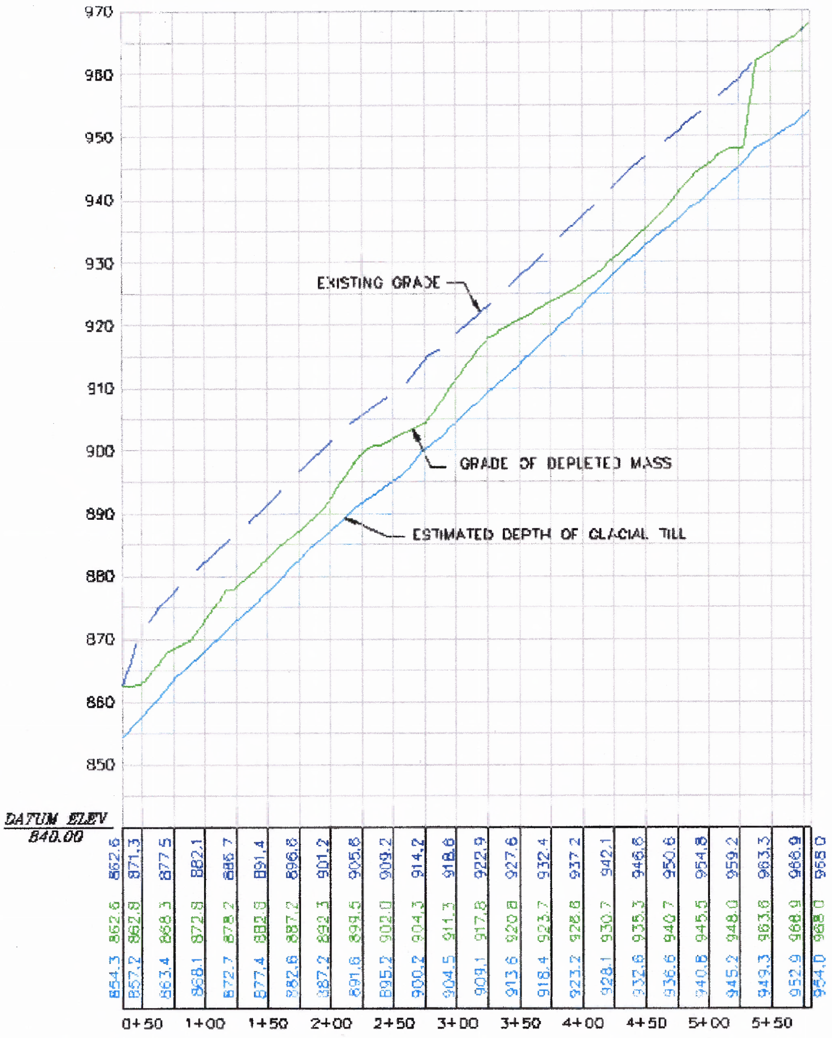


Figure B.3 Centerline profile of landslide.

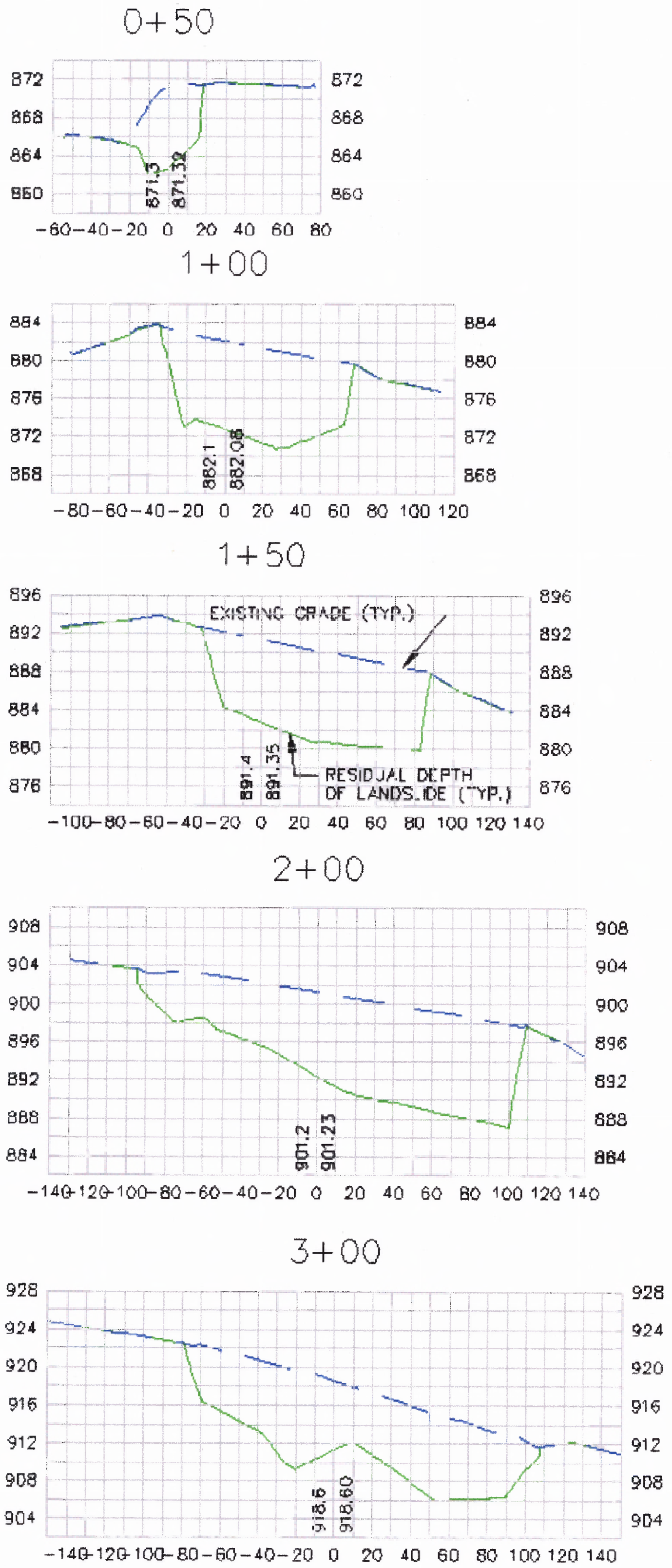


Figure B.4 Cross Sections at 50 feet stations of landslide.

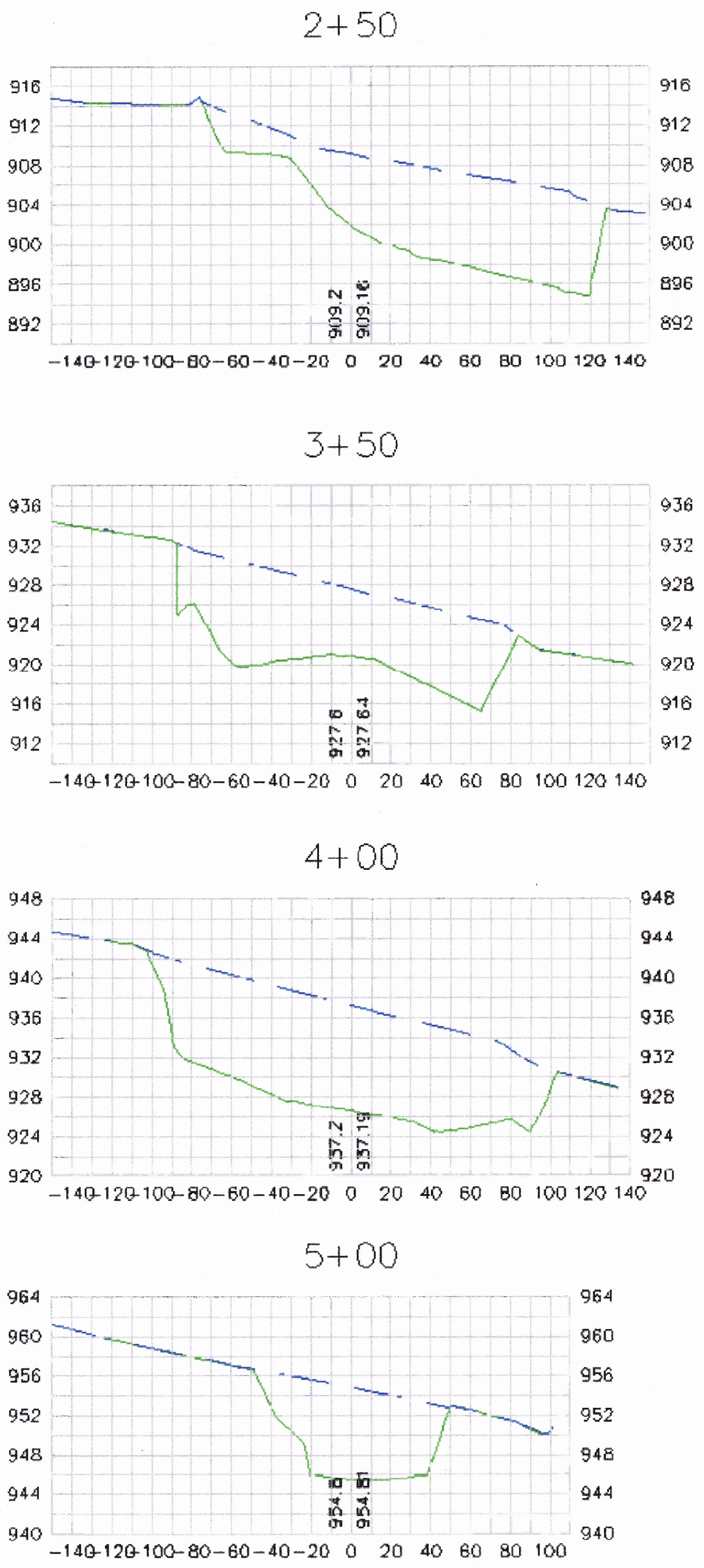


Figure B.4 Cross Sections at 50 feet stations of landslide (continued).

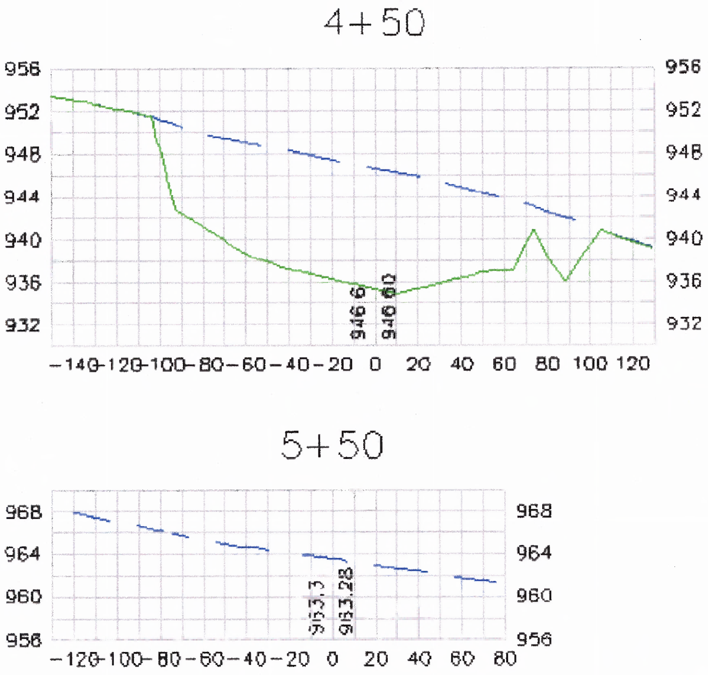


Figure B.4 Cross Sections at 50 feet stations of landslide (continued).

Table B.1 Landslide Volume Calculations

AVERAGE-END AREA METHOD –
GENERATED USING LAND DEVELOPMENT DESKTOP

Project: SPARTA LANDSLIDE Sat November 16 14:38:57 2002
Site: SLIDE2 Surface 1: existing conditions
Surface 2: landslide-usgs-final-adjusted
Volume tag: VOLUME CALCULATION

END AREA VOLUME LISTING

Station	Cut Area (sq.ft.)	Fill Area (sq.ft.)	Cut Volume (cu. Yds.)	Fill Volume (cu. Yds.)	Cut Tot. Vol. (cu. Yds.)	Fill Tot. Vol. (cu. Yds.)	Mass Ordinate (cu. Yds.)
0+00	0	0					
			0	0	0	0	0
0+25	1	0					
			116	0	117	0	117
0+50	250	0					
			356	0	473	0	473
0+75	519	0					
			636	0	1108	0	1108
1+00	854	0					
			802	0	1911	0	1911
1+25	879	0					
			863	0	2773	0	2773
1+50	985	0					
			1089	0	3862	0	3862
1+75	1367	0					
			1386	0	5248	0	5248
2+00	1627	0					
			1427	0	6676	0	6676
2+25	1456	0					
			1335	0	8011	0	8011
2+50	1428	0					
			1315	0	9326	0	9326
2+75	1412	0					
			1247	0	10573	0	10573
3+00	1282	0					
			1093	0	11666	0	11666
3+25	1078	0					
			1105	0	12770	0	12770
3+50	1308	0					
			1405	0	14175	0	14175

Table B.1 Landslide Volume Calculations (continued)

END AREA VOLUME LISTING (cont'd)

Station	Cut Area (sq.ft.)	Fill Area (sq.ft.)	Cut Volume (cu. Yds.)	Fill Volume (cu. Yds.)	Cut Tot Vol (cu. Yds.)	Fill Tot Vol (cu. Yds.)	Mass Ordinate (cu. Yds.)
3+75	1726	0					
			1680	0	15856	0	15856
4+00	1903	0					
			1800	0	17656	0	17656
4+25	1985	0					
			1706	0	19362	0	19362
4+50	1699	0					
			1385	0	20746	0	20746
4+75	1292	0					
			923	0	21669	0	21669
5+00	701	0					
			462	0	22131	0	22131
5+25	296	0					
			141	0	22272	0	22272
5+50	8	0					
			4	0	22276	0	22276
5+75	1	0					
			0	0	22276	0	22276
6+00	0	0					
			0	0	22276	0	22276
6+25	0	0					

GRID VOLUME ANALYSIS (2-FOOT GRID ANALYSIS)–
GENERATED USING LAND DEVELOPMENT DESKTOP

Cut = 22271 cu.yds Fill = 0 cu.yds
Net = 22271 cu.yds CUT

COMPOSITE VOLUME ANALYSIS –
GENERATED USING LAND DEVELOPMENT DESKTOP

Cut = 22274 cu.yds Fill = 0 cu.yds
Net = 22274 cu.yds CUT

APPENDIX C

SOILS TESTING DATA

This appendix contains all soil laboratory data obtained for each field soil sample. The tests that were performed were grain size analysis (sieve and hydrometer analysis), specific gravity, and moisture content. This information was then used to generate individual grain size charts as well as an overall grain size overlay.

Table C.1 Soil Sample Data 1A

Grain Size Data Sheet

Project: Sparta Landslide
Job No.: -
Location of Project: Sparta, New Jersey Rt. 517
Boring No.: -
Sample No.: 1A
Description of Soil: Brown Silty Sand
Depth of Sample: 12"
Tested by: James Talerico
Date of Testing: 3/27/2001

Mass of Dry Sample + Dish	414.4
Mass of Dish	107.2
Mass of Dry Sample	307.2

Sieve No.	Sieve/Bowl Mass (g)	Diam. (mm)	Total Mass	Mass retained	% retained	% passing
4	355.2	4.75	390.9	35.7	11.62%	88.38%
10	355.2	2.00	371.7	16.5	5.37%	83.01%
20	373.7	0.840	395.4	21.7	7.06%	75.94%
40	572.0	0.425	596.0	24.0	7.81%	68.13%
60	553.3	0.250	582.5	29.2	9.51%	58.63%
140	474.9	0.150	522.9	48.0	15.63%	43.00%
200	512.0	0.075	529.6	17.6	5.73%	37.27%
Pan	9.2	-	121.6	112.4	-	-
			S=	305.1		

Percent Accuracy= 99.31%

D_{60}= 0.27
D_{30}= 0.04
D_{10}= 0.004

C_u= 67.50
C_c= 1.48

Table C.1 Soil Sample Data 1A (continued)

Hydrometer Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. Sample No. 1A
Description of Soil Brown Silty Sand Depth of Sample 12"
Tested by James Talerico Date of Testing 4/2/2001

General Data: Hydrometer Type 152H Zero Corection= 8.0 Meniscus= 1.0

Dispersing Agent $NaPO_3$ (Calgon) Amount Used 4% & 125mL

G_s of Solids= 2.69 CF *a* = 0.992 *w* (if air-dry)= --- %

Mass soil (wet, dry)= 50 g % Finer = 37.27% Control Sieve no. 200

C_T @ 22°C= 0.4

Date	Time of Reading	Elapsed time, min	Temp., °C	Actual Hyd. Reading, R_a	Corr. Hyd. Reading, R_c	Act. % Finer	Adj. % Finer	Hyd. Corr. Only for Meniscus, R	L from Table 6-5	L/t	K from Table 6-4	D, mm
2-Apr-01	10:00 AM	0	22	-	-	-	-	-	-	-	-	-
		2	22	42.5	34.9	69.24%	25.81%	43.5	9.2	4.6	0.01314	0.028182
		4	22	38.5	30.9	61.31%	22.85%	39.5	9.9	2.475	0.01314	0.020672
		8	22	34.5	26.9	53.37%	19.89%	35.5	10.4	1.3	0.01314	0.014982
		16	22	31	23.4	46.43%	17.30%	32	10.9	0.68125	0.01314	0.010845
		30	22	28	20.4	40.47%	15.09%	29	11.4	0.38	0.01314	0.0081
		60	22	25	17.4	34.52%	12.87%	26	11.9	0.198333	0.01314	0.005852
		125	22	21	13.4	26.59%	9.91%	22	12.5	0.1	0.01314	0.004155
		330	22	18.5	10.9	21.63%	8.06%	19.5	13	0.039394	0.01314	0.002608
		990	22	16.5	8.9	17.66%	6.58%	17.5	13.3	0.013434	0.01314	0.001523
3-Apr-01	10:00 AM	1410	22	15	7.4	14.68%	5.47%	16	13.5	0.009574	0.01314	0.001286
4-Apr-01	10:00 AM	2850	22	13.5	5.9	11.71%	4.36%	14.5	13.8	0.004842	0.01314	0.000914

Table C.1 Soil Sample Data 1A (continued)

Specific Gravity Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. 1A
Description of Soil BrownSilty Sand Depth of Sample 12"
Tested by James Talerico Date of Testing 3/28/2001

Test no.	1	2
Vol. Of Flask @ 20 °C	500 mL	500 mL
Method of air removal	Vacuum	Vacuum
Mass flask + water + soil = M_{bws}	744.95	743.89
Temperature, °C	24°	23°
Mass flask + water = M_{bw}	681.79	681.79
Mass dish + drysoil	455.87	454.91
Mass of Dish	355.7	355.7
Mass of dry soil = M_s	100.17	99.21
$M_w = M_s + M_{bw} - M_{bws}$	37.01	37.11
$a = r_T / r_{20^\circ C}$	0.9991	0.9993
$G_s = a\,M_s/M_w$	2.70	2.67

Average specific gravity of soil solids (G_s) = 2.69

Table C.1 Soil Sample Data 1A (continued)

Moisture Content Data Sheet

Project: Sparta Landslide — Job No. -

Location of Project: Sparta, New Jersey Rt. 517 — Boring No. - — Sample No. 1A

Description of Soil: Brown Silty Sand — Depth of Sample 12"

Tested by: James Talerico — Date of Testing 3/2/2001

Sample No.	1A	1A
Container No.	1A-1	1A-2
Mass of cup + wet soil	107.58	105.12
Mass of cup + dry soil	95.47	93.51
Mass of cup	36.88	37.21
Mass of Dry Soil, M_s	58.59	56.3
Mass of Water, M_w	12.11	11.61
Water Content, *w* %	20.67%	20.62%

Average Moisture Content, w_{avg}% = 20.65%

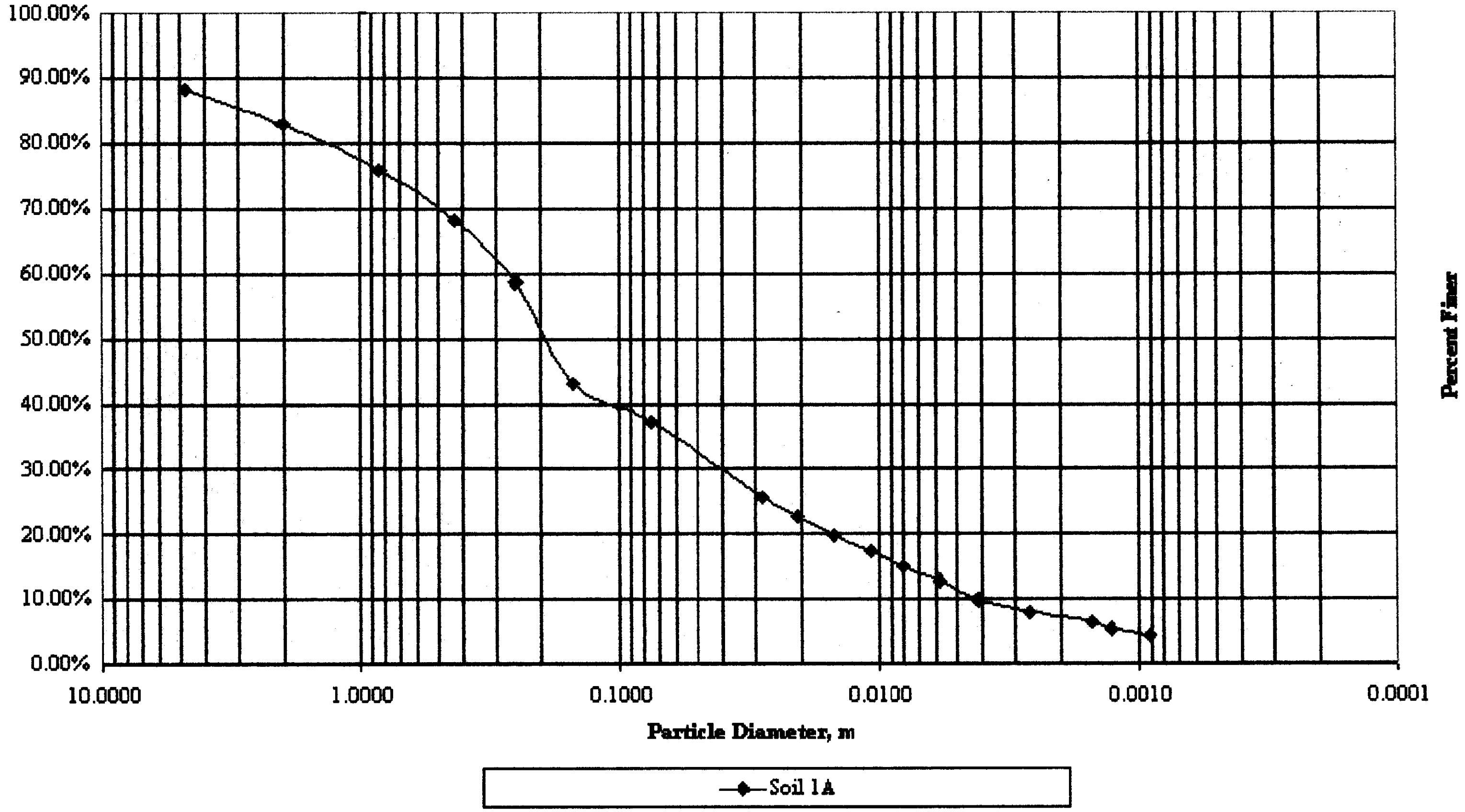


Figure C.1 Grain size chart sample 1A.

Table C.2 Soil Sample Data 1B

Grain Size Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. 1B
Description of Soil Brown Silty Sand Depth of Sample 12"
Tested by James Talerico Date of Testing 3/28/2001

Mass of Dry Sample + Dish	462.9
Mass of Dish	103.0
Mass of Dry Sample	359.9

Sieve No.	Sieve/Bowl Mass (g)	Diam. (mm)	Total Mass	Mass retained	% retained	% passing
4	755.8	4.75	784.4	28.6	7.95%	92.05%
10	435.8	2.00	456.2	20.4	5.67%	86.39%
20	373.8	0.840	399.6	25.8	7.17%	79.22%
40	571.8	0.425	600.6	28.8	8.00%	71.21%
60	553.4	0.250	587.3	33.9	9.42%	61.79%
140	474.9	0.150	533.8	58.9	16.37%	45.43%
200	512.1	0.075	533.2	21.1	5.86%	39.57%
Pan	9.1	-	148.33	139.23	-	-
			S=	356.73		

Percent Accuracy= 99.12%

D_{60}= 0.24
D_{30}= 0.038
D_{10}= 0.004

C_u= 60.00
C_c= 1.50

Table C.2 Soil Sample Data 1B (continued)

Hydrometer Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. 1B
Description of Soil Brown Silty Sand Depth of Sample 12"
Tested by James Talerico Date of Testing 4/2/2001

General Data: Hydrometer Type 152H Zero Corection= 8.0 Meniscus= 1.0

Dispersing Agent $NaPO_3$ (Calgon) Amount Used 4% & 125mL

G_s of Solids= 2.69 CF a = 0.992 w (if air-dry)= --- %

Mass soil (wet, dry)= 50 g % Finer = 39.57% Control Sieve no. 200

C_T @ 22°C= 0.4

Date	Time of Reading	Elapsed time, min	Temp., °C	Actual Hyd. Reading, R_a	Corr. Hyd. Reading, R_c	Act. % Finer	Adj. % Finer	Hyd. Corr. Only for Meniscus, R	L from Table 6-5	L/t	K from Table 6-4	D, mm
4/2/2001	10:26 AM	0	22	-	-	-	-	-	-	-	-	-
		2	22	41.5	33.9	67.26%	26.61%	42.5	9.3	4.65	0.01314	0.028335
		4	22	38	30.4	60.31%	23.86%	39	9.9	2.475	0.01314	0.020672
		8	22	34.5	26.9	53.37%	21.12%	35.5	10.4	1.3	0.01314	0.014982
		16	22	29.5	21.9	43.45%	17.19%	30.5	11.3	0.70625	0.01314	0.011043
		30	22	26.5	18.9	37.50%	14.84%	27.5	11.8	0.393333	0.01314	0.008241
		60	22	24	16.4	32.54%	12.87%	25	12.2	0.203333	0.01314	0.005925
		125	22	20.5	12.9	25.59%	10.13%	21.5	12.8	0.1024	0.01314	0.004205
		330	22	17.5	9.9	19.64%	7.77%	18.5	13.25	0.040152	0.01314	0.002633
		990	22	16	8.4	16.67%	6.59%	17	13.5	0.013636	0.01314	0.001534
4/3/2001	10:26 AM	1410	22	14.5	6.9	13.69%	5.42%	15.5	13.75	0.009752	0.01314	0.001298
4/4/2001	10:26 AM	2850	22	14	6.4	12.70%	5.02%	15	13.8	0.004842	0.01314	0.000914

Table C.2 Soil Sample Data 1B (continued)

Specific Gravity Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. 1B
Description of Soil Brown Silty Sand Depth of Sample 12"
Tested by James Talerico Date of Testing 4/5/2001

Test no.	1	2
Vol. Of Flask @ 20 °C	500 mL	500 mL
Method of air removal	Vacuum	Vacuum
Mass flask + water + soil = M_{bws}	787.42	785.01
Temperature, °C	23°	24°
Mass flask + water = M_{bw}	681.79	681.79
Mass dish + drysoil	502.93	498.87
Mass of Dish	334.9	334.9
Mass of dry soil = M_s	168.03	163.97
$M_w = M_s + M_{bw} - M_{bws}$	62.4	60.75
$a = r_T/r_{20^\circ C}$	0.99935	0.9991
$G_s = a\,M_s/M_w$	2.69	2.70

Average specific gravity of soil solids (G_s) = 2.69

Table C.2 Soil Sample Data 1B (continued)

Moisture Content Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. 1B
Description of Soil Brown Silty Sand Depth of Sample 12"
Tested by James Talerico Date of Testing 3/6/2001

Sample No.	1B	1B
Container No.	1B-1	1B-2
Mass of cup + wet soil	118.64	137.21
Mass of cup + dry soil	104.73	119.86
Mass of cup	36.88	37.2
Mass of Dry Soil, M_s	67.85	82.66
Mass of Water, M_w	13.91	17.35
Water Content, w %	20.50%	20.99%

Average Moisture Content, w_{ave}% = 20.75%

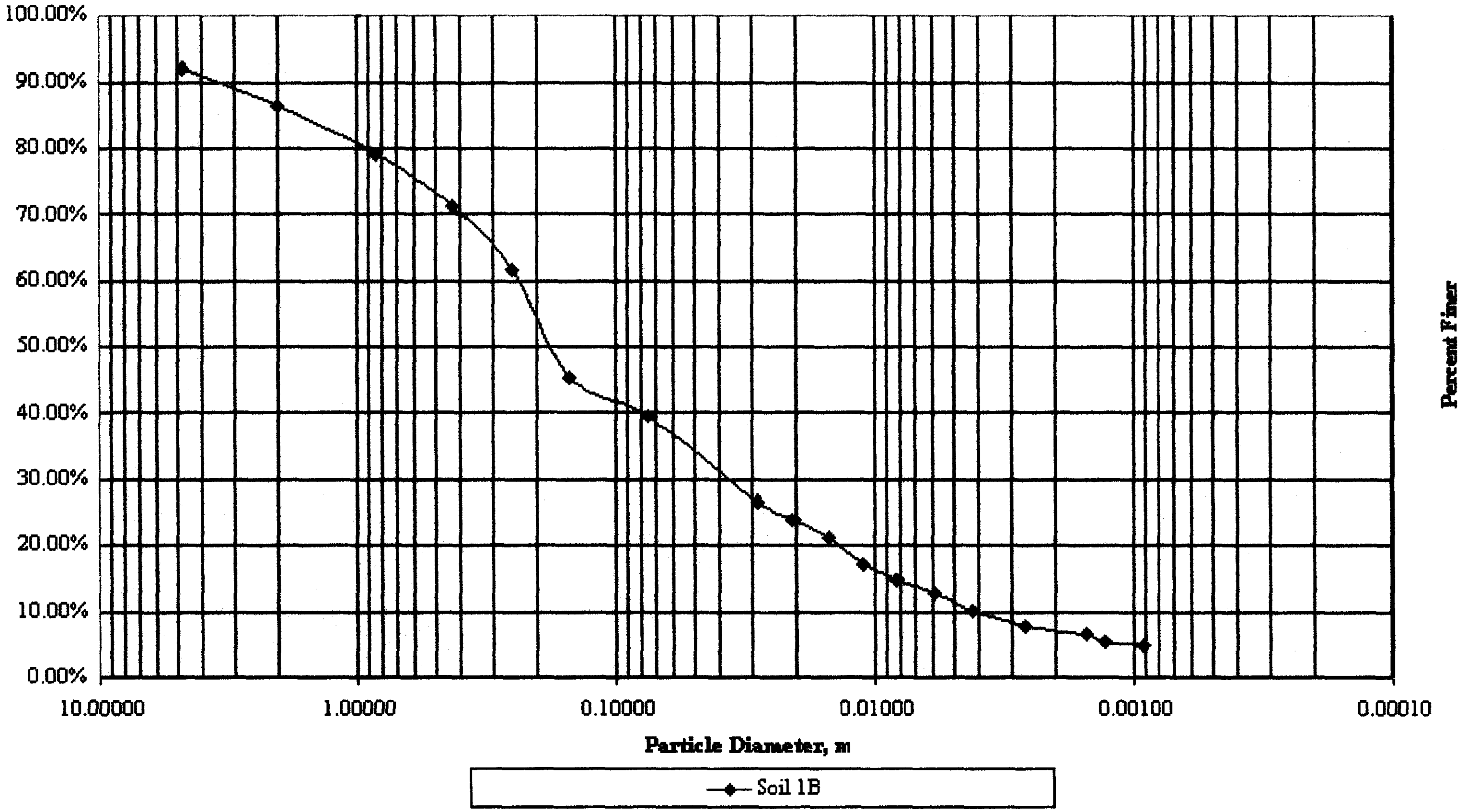


Figure C.2 Grain size chart sample 1B.

Table C.3 Soil Sample Data 1C

Grain Size Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. 1C
Description of Soil Brown Silty Sand Depth of Sample 12"
Tested by James Talerico Date of Testing 3/30/2001

Mass of Dry Sample + Dish	444.8
Mass of Dish	102.6
Mass of Dry Sample	342.2

Sieve No.	Sieve/Bowl Mass (g)	Diam. (mm)	Total Mass	Mass retained	% retained	% passing
4	753.1	4.75	777.2	24.1	7.04%	92.96%
10	703.8	2.00	722.6	18.8	5.49%	87.46%
20	368.5	0.840	394.1	25.6	7.48%	79.98%
40	564.1	0.425	592.6	28.5	8.33%	71.65%
60	531.6	0.250	564.5	32.9	9.61%	62.04%
140	474.3	0.150	531.2	56.9	16.63%	45.41%
200	508.1	0.075	527.5	19.4	5.67%	39.74%
Pan	9.3	-	144.3	135	-	-
			S=	341.2		

Percent Accuracy= 99.71%

D_{60}= 0.23
D_{30}= 0.037
D_{10}= 0.0057

C_u= 40.35
C_c= 1.04

Table C.3 Soil Sample Data 1C (continued)

Hydrometer Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. Sample No. 1C
Description of Soil Brown Silty Sand Depth of Sample 12"
Tested by James Talerico Date of Testing 4/2/2001

General Data: Hydrometer Type 152H Zero Corection= 8.0 Meniscus 1.0

Dispersing Agent $NaPO_3$ (Calgon) Amount Used 4% & 125mL

G_s of Solids= 2.68 CF *a* = 0.994 *w* (if air-dry)= --- %

Mass soil (wet, dry)= 50 g % Finer = 39.74% Control Sieve no. 200

C_T @ 22°C= 0.4

Date	Time of Reading	Elapsed time, min	Temp., °C	Actual Hyd. Reading, R_a	Corr. Hyd. Reading, R_c	Act. % Finer	Adj. % Finer	Hyd. Corr. Only for Meniscus, R	L from Table 6-5	L/t	K from Table 6-4	D, mm
2-Apr	11:02 AM	0	22	-	-	-	-	-	-	-	-	-
		2	22	41.5	33.9	67.39%	26.78%	42.5	9.3	4.65	0.01318	0.028421
		4	22	36	28.4	56.46%	22.44%	37	10.2	2.55	0.01318	0.021047
		8	22	31.5	23.9	47.51%	18.88%	32.5	11	1.375	0.01318	0.015455
		16	22	27.5	19.9	39.56%	15.72%	28.5	11.6	0.725	0.01318	0.011222
		30	22	24	16.4	32.60%	12.96%	25	12.2	0.406667	0.01318	0.008405
		60	22	21	13.4	26.64%	10.59%	22	12.7	0.211667	0.01318	0.006064
		125	22	18	10.4	20.68%	8.22%	19	13.2	0.1056	0.01318	0.004283
		330	22	15.5	7.9	15.71%	6.24%	16.5	13.6	0.041212	0.01318	0.002676
		990	22	14	6.4	12.72%	5.06%	15	13.8	0.013939	0.01318	0.001556
3-Apr	11:02 AM	1410	22	13	5.4	10.74%	4.27%	14	14	0.009929	0.01318	0.001313
4-Apr	11:02 AM	2850	22	12	4.4	8.75%	3.48%	13	14.2	0.004982	0.01318	0.00093

Table C.3 Soil Sample Data 1C (continued)

Specific Gravity Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. 1C
Description of Soil Brown Silty Sand Depth of Sample 12"
Tested by James Talerico Date of Testing 3/28/2001

Test no.	1	2
Vol. Of Flask @ 20 °C	500 mL	500 mL
Method of air removal	Vacuum	Vacuum
Mass flask + water + soil = M_{bws}	800.23	798.07
Temperature, °C	23°	24°
Mass flask + water = M_{bw}	681.79	681.79
Mass dish + drysoil	548.9	547.38
Mass of Dish	361	361
Mass of dry soil = M_s	187.9	186.38
$M_w = M_s + M_{bw} - M_{bws}$	69.46	70.1
$a = r_T / r_{20^\circ C}$	0.99935	0.9991
$G_s = a M_s / M_w$	2.70	2.66

Average specific gravity of soil solids (G_s) = 2.68

Table C.3 Soil Sample Data 1C (continued)

Moisture Content Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. 1C
Description of Soil Brown Silty Sand Depth of Sample 12"
Tested by James Talerico Date of Testing 3/6/2001

Sample No.	1C	1C
Container No.	1C-1	1C-2
Mass of cup + wet soil	87.73	88.15
Mass of cup + dry soil	79.65	80.13
Mass of cup	37.23	36.74
Mass of Dry Soil, M_s	42.42	43.39
Mass of Water, M_w	8.08	8.02
Water Content, w%	19.05%	18.48%

Average Moisture Content, w_{ave}% = 18.77%

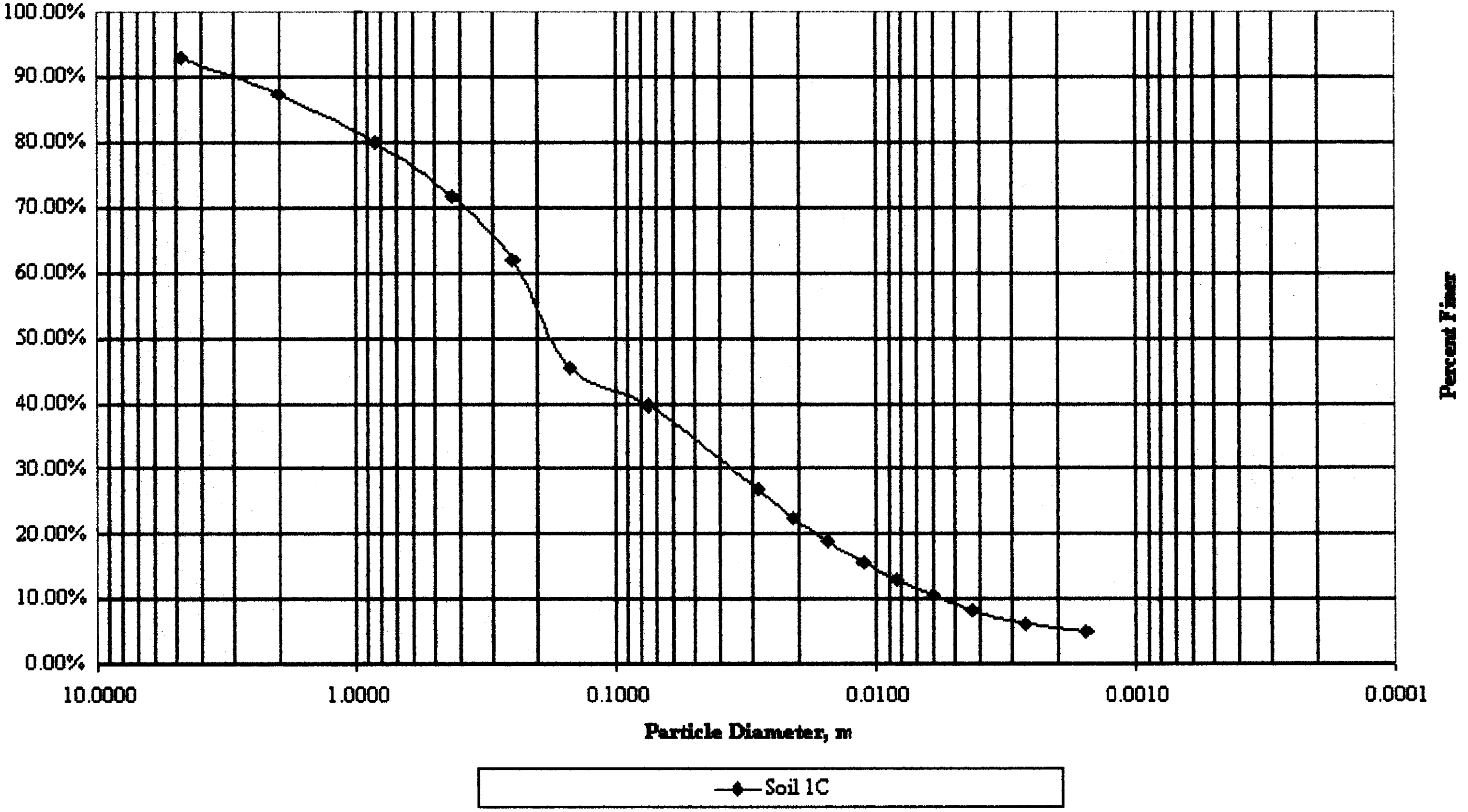


Figure C.3 Grain size chart sample 1C.

Table C.4 Soil Sample Data S-1

Grain Size Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. S-1
Description of Soil Brown Silty Sand - Side Slope Depth of Sample 3'
Tested by James Talerico Date of Testing 3/23/2001

Mass of Dry Sample + Dish	818
Mass of Dish	386.8
Mass of Dry Sample	431.2

Sieve No.	Sieve/Bowl Mass (g)	Diam. (mm)	Total Mass	Mass retained	% retained	% passing
4	755.8	4.75	783.7	27.9	6.47%	93.53%
10	435.6	2.00	455.1	19.5	4.52%	89.01%
20	373.6	0.840	401.8	28.2	6.54%	82.47%
40	571.8	0.425	604.5	32.7	7.58%	74.88%
60	553.3	0.250	593.8	40.5	9.39%	65.49%
140	475	0.150	551	76	17.63%	47.87%
200	512	0.075	541.4	29.4	6.82%	41.05%
Pan	388.3	-	564.6	176.3	-	-
			S=	430.5		

Percent Accuracy= 99.84%

D_{60}= 0.22
D_{30}= 0.035
D_{10}= 0.0034

C_u= 64.71
C_c= 1.64

Table C.4 Soil Sample Data S-1 (continued)

Hydrometer Data Sheet

Project: Sparta Landslide — Job No. -
Location of Project: Sparta, New Jersey Rt. 517 — Boring No. - — Sample No. S-1
Description of Soil: Brown Silty Sand - Side Slope — Depth of Sample 3'
Tested by: James Talerico — Date of Testing 3/23/2001

General Data: Hydrometer Type 152H — Zero Corection= 9.0 — Meniscus 1.0

Dispersing Agent $NaPO_3$ (Calgon) — Amount Used 4% & 125mL

G_s of Solids= 2.69 — CF *a* = 0.992 — *w* (if air-dry)= --- %

Mass soil (wet, dry)= 50 g — % Finer = 41.05% — Control Sieve no. 200

C_T @ 22.5°C= 0.55
C_T @ 24°C= 1.00

Date	Time of Reading	Elapsed time, min	Temp., °C	Actual Hyd. Reading, R_a	Corr. Hyd. Reading, R_c	Act. % Finer	Adj. % Finer	Hyd. Corr. Only for Meniscus, R	L from Table 6-5	L/t	K from Table 6-4	D, mm
22-Apr	2:03 PM	0	22.5	-	-	-	-	-	-	-	-	-
		2	22.5	42	33.6	66.56%	27.32%	43	9.3	4.65	0.01318	0.028421
		4	22.5	38	29.6	58.63%	24.07%	39	10.2	2.55	0.01318	0.021047
		8	22.5	35	26.6	52.68%	21.62%	36	11	1.375	0.01318	0.015455
		16	22.5	32	23.6	46.72%	19.18%	33	11.6	0.725	0.01318	0.011222
		30	22.5	29.5	21.1	41.76%	17.14%	30.5	12.2	0.406667	0.01318	0.008405
		60	22.5	26	17.6	34.82%	14.29%	27	12.7	0.211667	0.01318	0.006064
		125	22.5	23	14.6	28.87%	11.85%	24	13.2	0.1056	0.01318	0.004283
		330	22.5	19	10.6	20.93%	8.59%	20	13.6	0.041212	0.01318	0.002676
		1170	24	16	8	15.87%	6.52%	17	13.8	0.011795	0.01318	0.001431
23-Apr	2:03 PM	1410	24	16	8	15.87%	6.52%	17	14	0.009929	0.01318	0.001313
24-Apr	2:03 PM	2850	24	15	7	13.89%	5.70%	16	14.2	0.004982	0.01318	0.00093

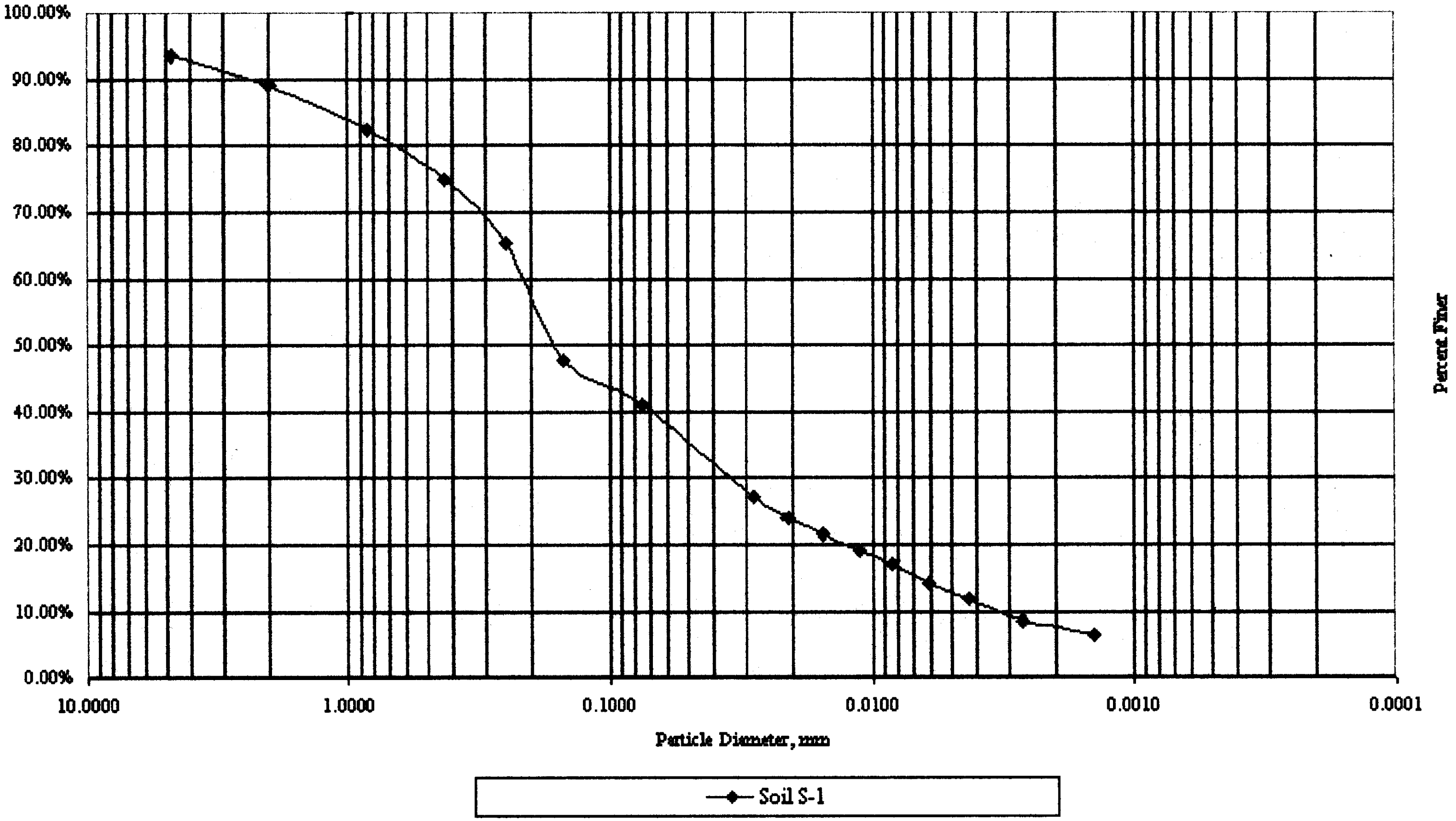


Figure C.4 Grain size chart sample S-1.

Table C.5 Soil Sample Data S-2

Grain Size Data Sheet

Project	Sparta Landslide			Job No.	-
Location of Project	Sparta, New Jersey Rt. 517	Boring No.	-	Sample No.	S-2
Description of Soil	Brownish/Tan Silty Sand - Side Slope			Depth of Sample	1.5'
Tested by	James Talerico	Date of Testing	3/23/2001		

Mass of Dry Sample + Dish	767.7
Mass of Dish	355.6
Mass of Dry Sample	412.1

Sieve No.	Sieve/Bowl Mass (g)	Diam. (mm)	Total Mass	Mass retained	% retained	% passing
4	471.4	4.75	489.1	17.7	4.30%	95.70%
10	695.4	2.00	715.7	20.3	4.93%	90.78%
20	372.6	0.840	399.2	26.6	6.45%	84.32%
40	555.5	0.425	584.9	29.4	7.13%	77.19%
60	546.3	0.250	581.3	35	8.49%	68.70%
140	472.2	0.150	538.7	66.5	16.14%	52.56%
200	291.2	0.075	314.4	23.2	5.63%	46.93%
Pan	388.3	-	579.3	191	-	-
			S=	409.7		

Percent Accuracy= 99.42%

D_{60}= 0.19

D_{30}= 0.022

D_{10}= 0.002

C_u= 95.00

C_c= 1.27

Table C.5 Soil Sample Data S-2 (continued)

Hydrometer Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. S-2
Description of Soil Brownish/Tan Silty Sand - Side Slope Depth of Sample 1.5'
Tested by James Talerico Date of Testing 3/23/2001

General Data: Hydrometer Type 152H Zero Corection= 9.0 Meniscus 1.0

Dispersing Agent $NaPO_3$ (Calgon) Amount Used 4% & 125mL

G_s of Solids= 2.69 CF a = 0.992 w (if air-dry)= --- %

Mass soil (wet, dry)= 50 g % Finer = 46.93% Control Sieve no. 200

C_T @ 22.5°C= 0.55
C_T @ 24°C= 1.00

Date	Time of Reading	Elapsed time, min	Temp., °C	Actual Hyd. Reading, R_a	Corr. Hyd. Reading, R_c	Act. % Finer	Adj. % Finer	Hyd. Corr. Only for Meniscus, R	L from Table 6-5	L/t	K from Table 6-4	D, mm
22-Apr	2:07 PM	0	22.5	-	-	-	-	-	-	-	-	-
		2	22.5	43	34.6	68.55%	32.17%	44	9.3	4.65	0.01318	0.028421
		4	22.5	40	31.6	62.60%	29.38%	41	10.2	2.55	0.01318	0.021047
		8	22.5	36	27.6	54.66%	25.65%	37	11	1.375	0.01318	0.015455
		16	22.5	33	24.6	48.71%	22.86%	34	11.6	0.725	0.01318	0.011222
		30	22.5	30	21.6	42.76%	20.07%	31	12.2	0.406667	0.01318	0.008405
		60	22.5	26.5	18.1	35.81%	16.81%	27.5	12.7	0.211667	0.01318	0.006064
		125	22.5	24	15.6	30.85%	14.48%	25	13.2	0.1056	0.01318	0.004283
		330	22.5	20	11.6	22.92%	10.75%	21	13.6	0.041212	0.01318	0.002676
		1170	24	18	10	19.84%	9.31%	19	13.8	0.011795	0.01318	0.001431
23-Apr	2:07 PM	1410	24	17	9	17.86%	8.38%	18	14	0.009929	0.01318	0.001313
24-Apr	2:07 PM	2850	24	15	7	13.89%	6.52%	16	14.2	0.004982	0.01318	0.00093

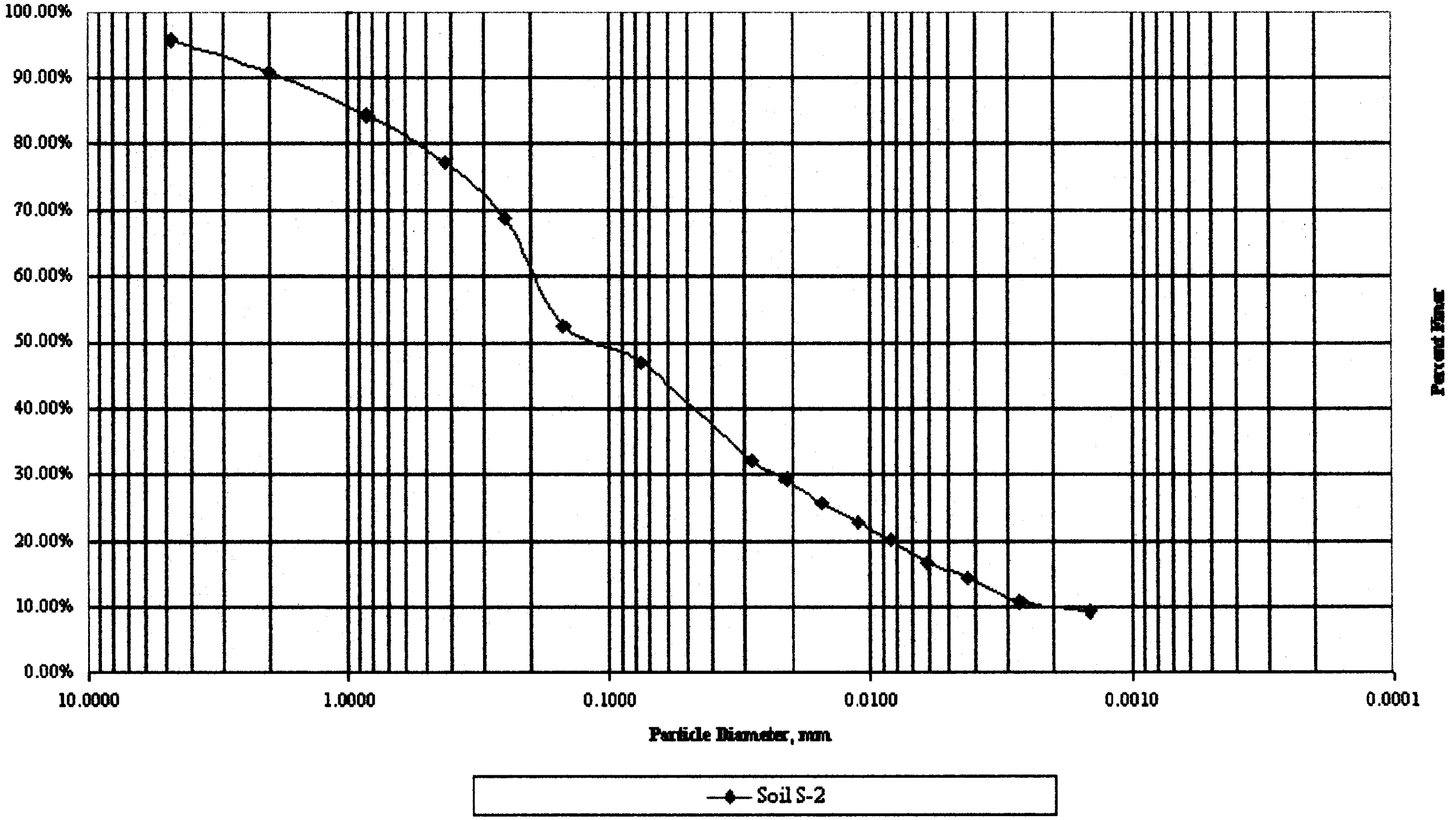


Figure C.5 Grain size chart sample S-2.

Table C.6 Soil Sample Data S-3

Grain Size Data Sheet

Project: Sparta Landslide — Job No. -
Location of Project: Sparta, New Jersey Rt. 517 — Boring No. - — Sample No. S-3
Description of Soil: Brownish Silty Sand - Side Slope — Depth of Sample 8'
Tested by: James Talerico — Date of Testing 3/23/2001

Mass of Dry Sample + Dish	965.6
Mass of Dish	340.9
Mass of Dry Sample	624.7

Sieve No.	Sieve/Bowl Mass (g)	Diam. (mm)	Total Mass	Mass retained	% retained	% passing
4	753.1	4.75	785.2	32.1	5.14%	94.86%
10	703.8	2.00	729.9	26.1	4.18%	90.68%
20	368.6	0.840	403.7	35.1	5.62%	85.06%
40	564.1	0.425	605.6	41.5	6.64%	78.42%
60	531.9	0.250	584	52.1	8.34%	70.08%
140	474.2	0.150	574.1	99.9	15.99%	54.09%
200	507.9	0.075	543.4	35.5	5.68%	48.41%
Pan	388.3	-	682.4	294.1	-	-
			S=	616.4		

Percent Accuracy= 98.67%

D_{60}= 0.19
D_{30}= 0.024
D_{10}= 0.003

C_u= 63.33
C_c= 1.01

Table C.6 Soil Sample Data S-3 (continued)

Hydrometer Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. S-3
Description of Soil Brownish Silty Sand - Side Slope Depth of Sample 8'
Tested by James Talerico Date of Testing 3/23/2001

General Data: Hydrometer Type 152H Zero Corection= 9.0 Meniscus 1.0

Dispersing Agent $NaPO_3$ (Calgon) Amount Used 4% & 125mL

G_s of Solids= 2.69 CF *a* = 0.992 *w* (if air-dry)= --- %

Mass soil (wet, dry)= 50 g % Finer = 48.41% Control Sieve no. 200

C_T @ 22.5°C= 0.55
C_T @ 24°C= 1.00

Date	Time of Reading	Elapsed time, min	Temp., °C	Actual Hyd. Reading, R_a	Corr. Hyd. Reading, R_c	Act. % Finer	Adj. % Finer	Hyd. Corr. Only for Meniscus, R	L from Table 6-5	L/t	K from Table 6-4	D, mm
22-Apr	2:13 PM	0	22.5	-	-	-	-	-	-	-	-	-
		2	22.5	43	34.6	68.55%	33.18%	44	9.3	4.65	0.01318	0.028421
		4	22.5	38	29.6	58.63%	28.38%	39	10.2	2.55	0.01318	0.021047
		8.5	22.5	36	27.6	54.66%	26.46%	37	11	1.294118	0.01318	0.014993
		16	22.5	32	23.6	46.72%	22.62%	33	11.6	0.725	0.01318	0.011222
		30	22.5	29.5	21.1	41.76%	20.22%	30.5	12.2	0.406667	0.01318	0.008405
		60	22.5	25	16.6	32.84%	15.89%	26	12.7	0.211667	0.01318	0.006064
		125	22.5	22	13.6	26.88%	13.01%	23	13.2	0.1056	0.01318	0.004283
		330	22.5	18	9.6	18.95%	9.17%	19	13.6	0.041212	0.01318	0.002676
		1170	24	15	7	13.89%	6.72%	16	13.8	0.011795	0.01318	0.001431
23-Apr	2:13 PM	1410	24	15	7	13.89%	6.72%	16	14	0.009929	0.01318	0.001313
24-Apr	2:13 PM	2850	24	14	6	11.90%	5.76%	15	14.2	0.004982	0.01318	0.00093

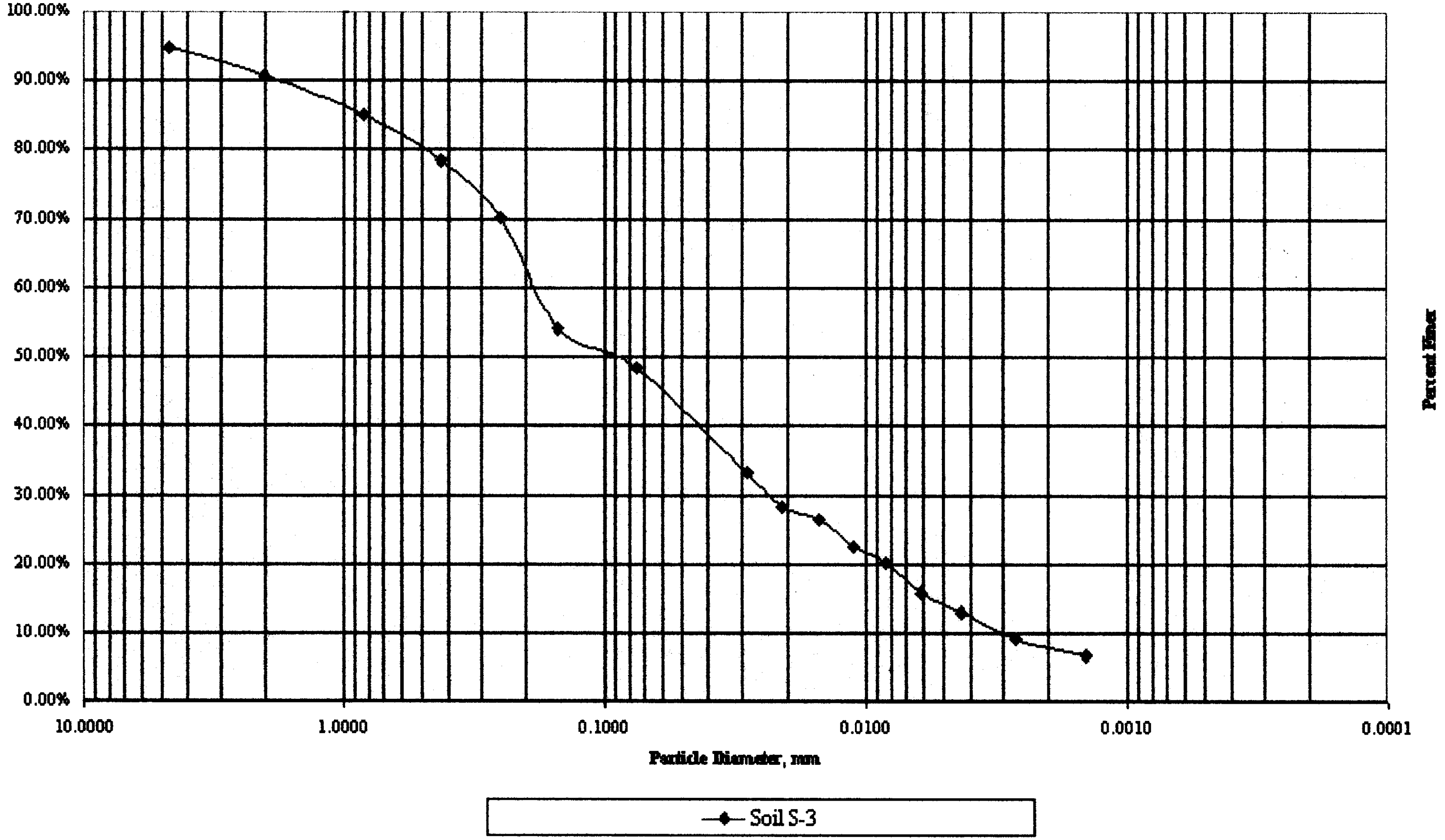


Figure C.6 Grain size chart sample S-3.

Table C.7 Soil Sample Data S-4

Grain Size Data Sheet

Project	Sparta Landslide	Job No.	-
Location of Project	Sparta, New Jersey Rt. 517	Boring No.	-
		Sample No.	S-4
Description of Soil	Gray Gravelly Silt	Depth of Sample	14'
Tested by	James Talerico	Date of Testing	11/18/2002

Mass of Dry Sample + Dish	2254.5
Mass of Dish	149
Mass of Dry Sample	2105.5

Sieve No.	Sieve/Bowl Mass (g)	Diam. (mm)	Total Mass	Mass retained	% retained	% passing
19mm	511.1	19	826.4	315.3	14.98%	85.02%
4	755.6	4.75	914.5	158.9	7.55%	77.48%
10	716.5	2.00	827.7	111.2	5.28%	72.20%
20	372.6	0.840	481.4	108.8	5.17%	67.03%
40	554.8	0.425	693.7	138.9	6.60%	60.43%
60	545.9	0.250	709.6	163.7	7.77%	52.66%
140	472.3	0.150	735.3	263	12.49%	40.17%
200	291	0.075	351.4	60.4	2.87%	37.30%
Pan	0	-	1004.9	1100.6	-	-
			S=	2105.5		

D_{60}= 0.43

D_{30}= 0.03

D_{10}= 0.0061

C_u= 70.49

C_c= 0.34

Table C.7 Soil Sample Data S-4 (continued)

Hydrometer Data Sheet

Project Sparta Landslide Job No. -
Location of Project Sparta, New Jersey Rt. 517 Boring No. - Sample No. S-4
Description of Soil Gray Gravelly Silt Depth of Sample 14'
Tested by James Talerico Date of Testing 11/18/2002

General Data: Hydrometer Type 152H Zero Corection= 9.0 Meniscus 1.0

Dispersing Agent $NaPO_3$ (Calgon) Amount Used 4% & 125mL

G_s of Solids= 2.69 CF a = 0.992 w (if air-dry)= --- %

Mass soil (wet, dry)= 50 g % Finer = 37.30% Control Sieve no. 200

C_T @ 22.5°C= 0.55
C_T @ 24°C= 1.00

Date	Time of Reading	Elapsed time, min	Temp., °C	Actual Hyd. Reading, R_a	Corr. Hyd. Reading, R_c	Act. % Finer	Adj. % Finer	Corr. Only for Meniscus, R	L from Table 6-5	L/t	K from Table 6-4	D, mm
22-Apr	2:19 PM	0	22.5	-	-	-	-	-	-	-	-	-
		2	22.5	43	34.6	68.55%	25.57%	44	9.3	4.65	0.01318	0.028421
		4	22.5	40	31.6	62.60%	23.35%	41	10.2	2.55	0.01318	0.021047
		8.5	22.5	36	27.6	54.66%	20.39%	37	11	1.294118	0.01318	0.014993
		16	22.5	32	23.6	46.72%	17.43%	33	11.6	0.725	0.01318	0.011222
		30	22.5	28	19.6	38.79%	14.47%	29	12.2	0.406667	0.01318	0.008405
		60	22.5	22	13.6	26.88%	10.03%	23	12.7	0.211667	0.01318	0.006064
		125	22.5	20	11.6	22.92%	8.55%	21	13.2	0.1056	0.01318	0.004283
		330	22.5	18	9.6	18.95%	7.07%	19	13.6	0.041212	0.01318	0.002676
		1170	24	15	7	13.89%	5.18%	16	13.8	0.011795	0.01318	0.001431
23-Apr	2:19 PM	1410	24	15	7	13.89%	5.18%	16	14	0.009929	0.01318	0.001313
24-Apr	2:19 PM	2850	24	14	6	11.90%	4.44%	15	14.2	0.004982	0.01318	0.00093

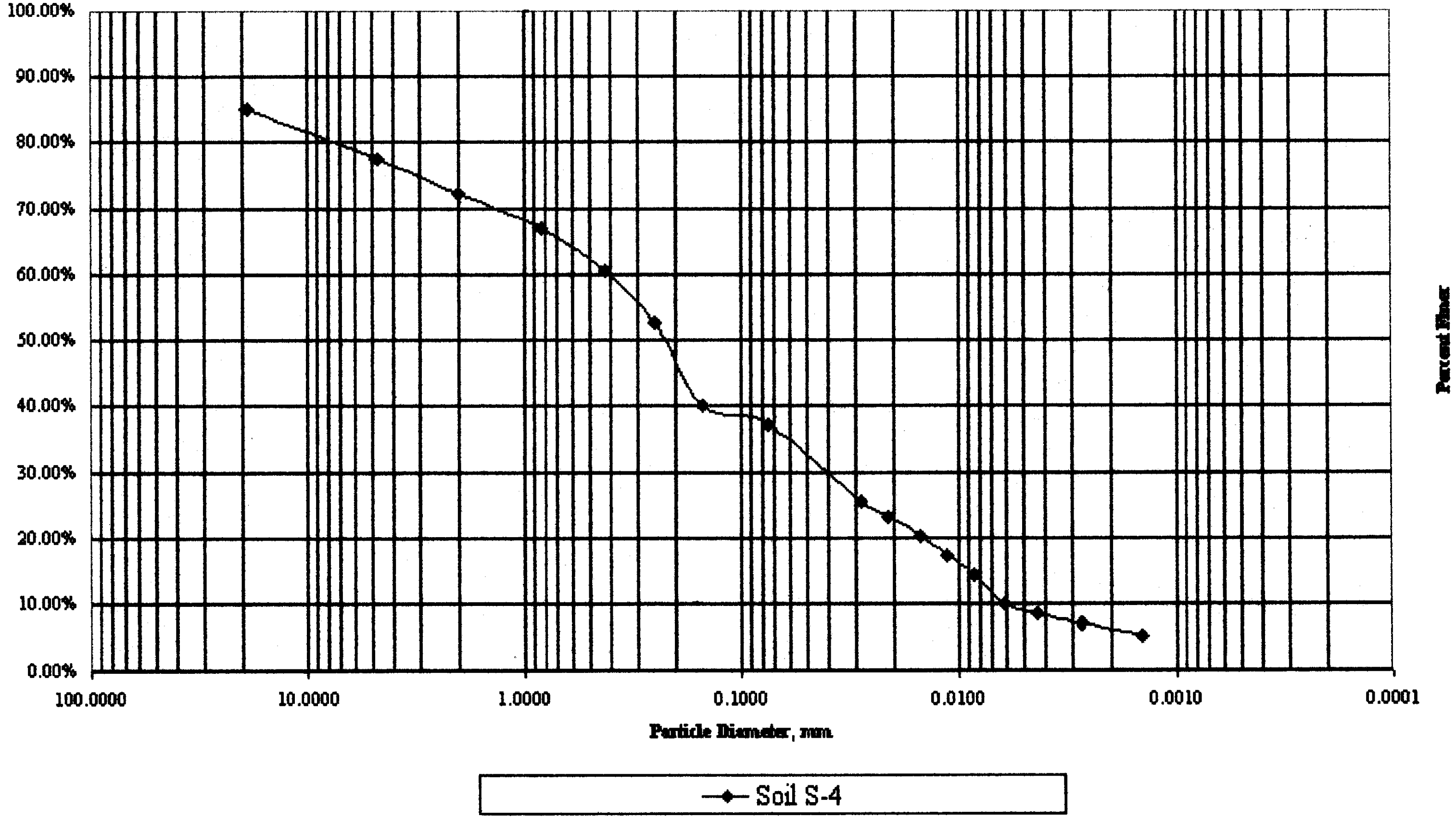


Figure C.7 Grain size chart sample S-4.

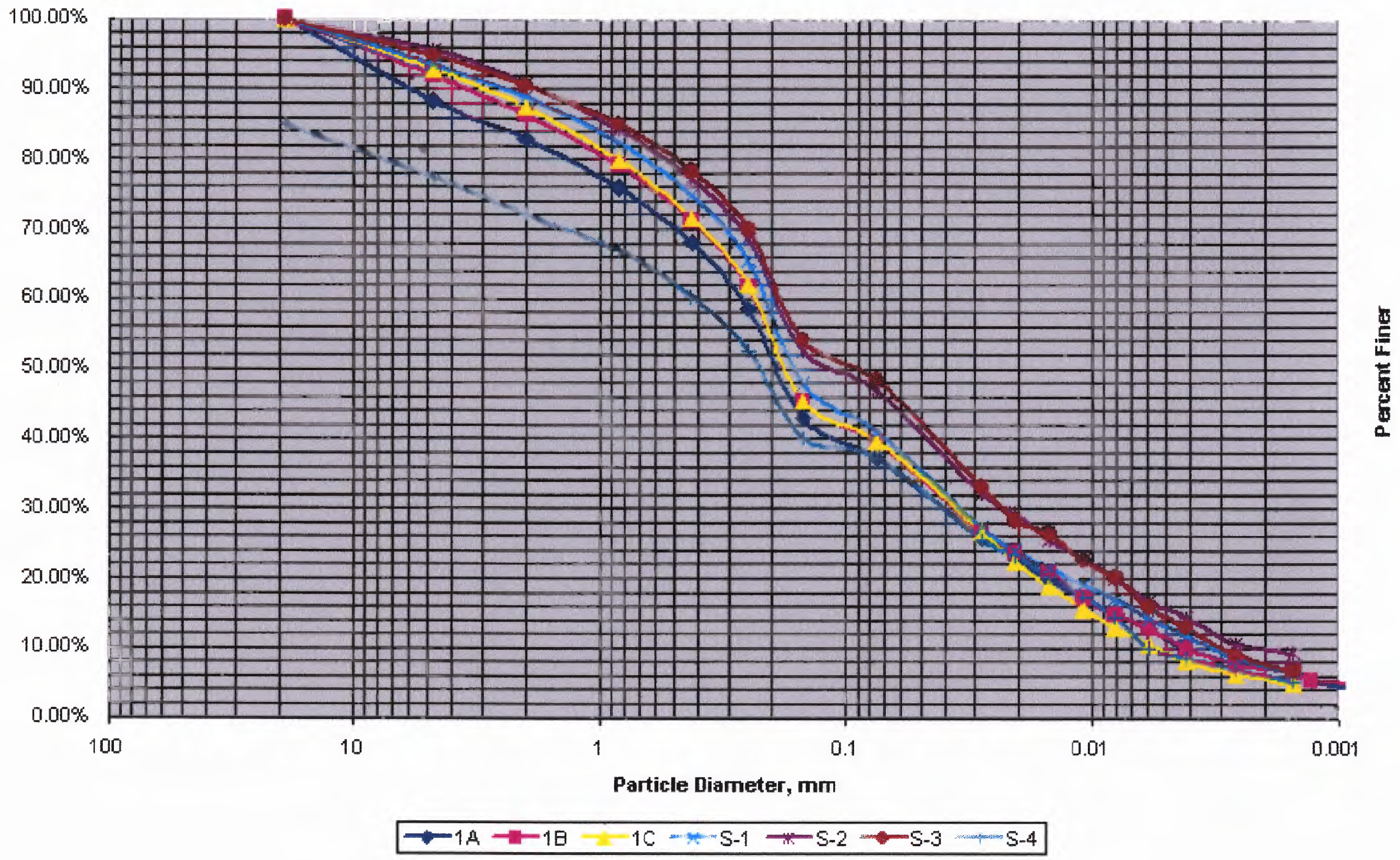


Figure C.8 Grain size overlay.

APPENDIX D

SLOPE STABILITY ANALYSIS DATA

This appendix is broken down into three subsections, which are D.1, D.2 and D.3. Subsection D.1 lists all equations used for analysis. Their variables can be viewed under the terms of definitions. Subsection D.2 is the solutions for all soil property calculations and infinite slope analyses. Subsection D.3 is the computations and solutions for the equilibrium analyses, which consist of six different conditions that analyzed the variation of the angle of internal friction as well as analyzed the road cut.

D.1 Equations for Analyses

Void Ratio

$$e = [(G_s \gamma_w) / \gamma_d] - 1$$

Unit Weight of Saturated Soil

$$\gamma_{sat} = [(G_s + e) \gamma_w] / (1 + e)$$

Stresses in a Saturated Soil

$$\sigma = \sigma' + u$$

Shear Failure Law in Saturated Soil

$$\tau_f = c + (\sigma - u) \tan \Phi = c + \sigma' \tan \Phi$$

Empirical Formula for Permeability (Kozeny – Carman)

$$k = C_1 [e^3 / (1 + e)]$$

Infinite Slope with Seepage

$$F = [c / (\gamma_{sat} h \cos^2 i \tan i)] + [(\gamma' \tan \Phi) / (\gamma_{sat} \tan i)]$$

Slope Stability Equilibrium Analysis – Wedge Method

$$P_a + P_c = P_p$$

where:

Force of Wedges:

$P_a = ((W_a - c_m L_a \sin \alpha - P_{wa} \cos \alpha) \tan(\alpha - \Phi_m)) - (c_m L_a \cos \alpha - P_{wa} \sin \alpha)$

$P_c = ((W_c - c_{im} L_c \sin i - T \sin i - P_{wc} \cos i) \tan(i - \Phi_{im}))$

$- ((c_{im} L_c + T)\cos i - P_{wc} \sin i)$

$P_p = ((W_p + c_m L_p \sin \beta - P_{wp} \cos \beta) \tan(\beta - \Phi_m)) + (c_m L_p \cos \beta + P_{wp} \sin \beta)$

Weight of Wedges:

$W_a = ([\gamma h^2 / 2] \cos i \cos \alpha) / \sin (\alpha - i)$

$W_c = \gamma h^2 L_c \cos i$

$W_a = ([\gamma h^2 / 2] \cos i \cos \beta) / \sin (\beta - i)$

Pore Pressure of Wedges:

$P_{wa} = (\gamma_w h_w \cos^3 i) / (2\sin (\alpha - i)$

$P_{wc} = \gamma_w {h_w}^2 L_c \cos^2 i$

$P_{wp} = (\gamma_w h_w \cos^3 i) / (2\sin (\beta - i)$

$\tan \Phi_m = \tan \Phi / F$

$c_m = c / F$

$\tan \Phi_{im} = \tan \Phi_i / F$

$c_{im} = c_i / F$

$\tan \alpha = \tan \Phi + \sqrt{} [1 + \tan^2 \Phi - (\tan i / (\sin \Phi \cos \Phi)]$

$\tan \beta = -\tan \Phi + \sqrt{} [1 + \tan^2 \Phi - (\tan i / (\sin \Phi \cos \Phi)]$

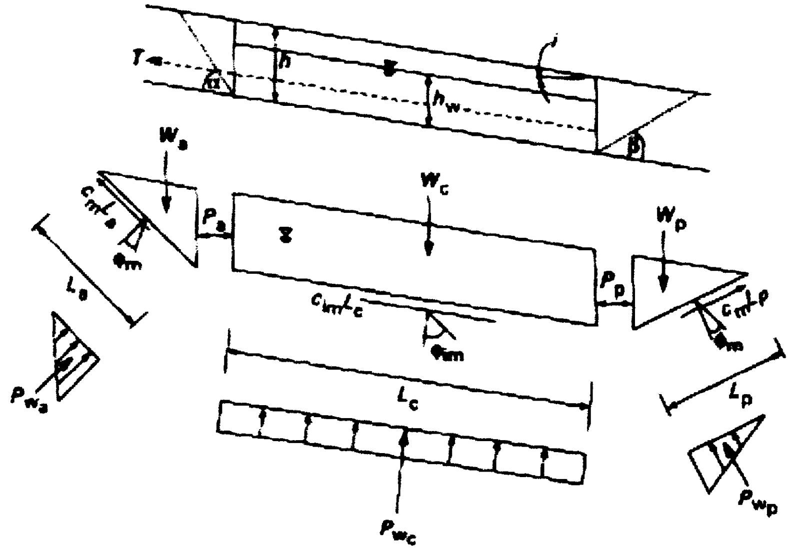


Figure D.1 Free body diagram of equilibrium analysis (Oweis 1998).

D.2 solutions for soil properties and infinite slope analyses

Void Ratio of Silty Sand

Given:

$G_s =$ 2.69
$\gamma_w =$ 62.4 lb/ft^3
$\gamma_d =$ 110 lb/ft^3

Solve:

e= 0.526

Void Ratio of Silty Sand with Gravel

Given:

$G_s =$ 2.69
$\gamma_w =$ 62.4 lb/ft^3
$\gamma_d =$ 130 lb/ft^3

Solve:

e= 0.291

Unit Weight of Saturated Soil of Silty Sand

Given:

$G_s =$ 2.69
e= 0.526
$\gamma_w =$ 62.4 lb/ft^3

Solve:

$\gamma_{sat} =$ 131.51 lb/ft^3

Unit Weight of Saturated Soil of Silty Sand

Given:

G_s= 2.69

e= 0.291

γ_w= 62.4 lb/ft^3

Solve:

γ_{sat}= 144.07 lb/ft^3

Empirical Formula for Permeability (Kozeny – Carman)
(ratio of permeability of Silty Sand to Silty Sand with Gravel)

4.99 : 1

Infinite Slope Stability with Seepage for Silty Sand Soil Strata
(Assumed Phi=26)

Given:

c= 0

γ_{sat}= 131.51 lb/ft^3

h= 14 ft

i= 9.91 degrees

Φ= 26.0 degrees

γ_w= 62.4 lb/ft^3

F= 1.00

Solve:

h_w= 18.9 ft

Stresses at Bottom of Silty Sand
(water level at 4.9ft above grade)

Pore Pressure

Given:

$\gamma_w =$ 62.4 lb/ft^3
$h_w =$ 18.9 ft

Solve:

$u =$ 1179.4 lb/ft^2

Effective Stress

Given:

$\gamma_{sat} =$ 131.51 lb/ft^3
$h =$ 14 ft

Solve:

$\sigma' =$ 1841.1 lb/ft^2

Total Stress

$\sigma =$ 661.75 lb/ft^2

Shear Failure Law in Saturated Silty Sand Soil

Given:

$c =$ 0
$\sigma' =$ 1841.1 lb/ft^2
$\Phi =$ 26.0 degrees

Solve:

$\tau_f =$ 897.97 lb/ft^2 (Φ is from Infinite Slope Analysis)

Infinite Slope Stability with Seepage for Silty Sand Soil Strata
(Assumed Phi=30)

Given:

$c=$ 0

$\gamma_{sat}=$ 131.51 lb/ft^3

$h=$ 14 ft

$i=$ 9.91 degrees

$\Phi=$ 30.0 degrees

$\gamma_w=$ 62.4 lb/ft^3

$F=$ 1.00

Solve:

$h_w=$ 20.6 ft

Stresses at Bottom of Silty Sand
(water level at 6.6ft above grade)

Pore Pressure

Given:

$\gamma_w=$ 62.4 lb/ft^3

$h_w=$ 20.6 ft

Solve:

$u=$ 1285.4 lb/ft^2

Effective Stress

Given:

$\gamma_{sat}=$ 131.51 lb/ft^3

$h=$ 14 ft

Solve:

$\sigma'=$ 1841.1 lb/ft^2

Total Stress

$\sigma=$ 555.7 lb/ft^2 (Φ is from Infinite Slope Analysis)

Shear Failure Law in Saturated Silty Sand Soil

Given:

$c =$ 0

$\sigma' =$ 1841.1 lb/ft^2

$\Phi =$ 30.0 degrees

Solve:

$\tau_f =$ 1063 lb/ft^2 (Φ is from Infinite Slope Analysis)

Infinite Slope Stability with Seepage for Silty Sand Soil Strata (Assumed Phi=35)

Given:

$c =$ 0

$\gamma_{sat} =$ 131.51 lb/ft^3

$h =$ 14 ft

$i =$ 9.91 degrees

$\Phi =$ 35.0 degrees

$\gamma_w =$ 62.4 lb/ft^3

$F =$ 1.00

Solve:

$h_w =$ 22.15 ft

Stresses at Bottom of Silty Sand
(water level at 8.15ft above grade)

Pore Pressure

Given:

γ_w= 62.4 lb/ft^3
h$_w$= 22.15 ft

Solve:

u= 1382.2 lb/ft^2

Effective Stress

Given:

γ_{sat}= 131.51 lb/ft^3
h= 14 ft

Solve:

σ'= 1841.1 lb/ft^2

Total Stress

σ= 458.98 lb/ft^2 (Φ is from Infinite Slope Analysis)

Shear Failure Law in Saturated Silty Sand Soil

Given:

c= 0
σ'= 1841.1 lb/ft^2
Φ= 35.0 degrees

Solve:

τ_f= 1289.2 lb/ft^2 (Φ is from Infinite Slope Analysis)

Infinite Slope Stability without Seepage for Silty Sand Soil Strata (average moist unit weight for Silty Sand)

Given:

c= 0

γ= 120 lb/ft^3

h= 14 ft

i= 9.91 degrees

Φ= 35 degrees

Solve:

F= 4.0

D.3 solutions for slope stability equilibrium analyses

Slope Stability Equilibrium Analysis/Wedge Condition #1

Angle of Internal Friction $\Phi = \Phi_m = \Phi_{im}$= 26 degrees
Depth of Strata (h)= 14 ft.
Unit Weight of Strata (γ_{sat})= 131.5 lb/ft3
Height of Water (hw)= 18.73 ft.
Unit Weight of Water (γw)= 62.4 lb/ft3
Factor of Safety Assumed= 1.00
L_c= 482.20 ft.
Length of Central Wedge= 475 ft.
Elevation Change in Central Wedge= 83 ft.
Angle of Slope (i)= 9.91 degrees
Angle α for Active Wedge= 52.90 degrees **
Angle β for Passive Wedge= 21.98 degrees

Weight of Wedges:

Weight of Active Wedge (Wa)= 11230.50 lb/ft
Weight of Central Wedge (Wc)= 861422.98 lb/ft
Weight of Passive Wedge (Wp)= 22284.57 lb/ft

Pore Pressures of Wedges:

Pore Pressure of Active Wedge (Pwa)= 819.17 lb/ft
Pore Pressure of Central Wedge (Pwc)= 546822.87 lb/ft
Pore Pressure of Passive Wedge (Pwp)= 19801.92 lb/ft

Total Forces of Wedges:

Force of Active Wedge (Pa)= 6100.23 lb/ft
Force of Central Wedge (Pc)= 1034.45 lb/ft
Force of Passive Wedge (Pp)= 7134.68 lb/ft

Σ of Pa + Pc= 7134.68 lb/ft
Pp= 7134.68 lb/ft

** computed using profile from survey

Slope Stability Equilibrium Analysis/Wedge Condition #2

Angle of Internal Friction Φ= 26 degrees
Depth of Strata (h)= 14 ft.
Unit Weight of Strata (γ_{sat})= 131.5 lb/ft3
Height of Water (hw)= 18.73 ft.
Unit Weight of Water (γw)= 62.4 lb/ft3
Factor of Safety = 1.00
L_c= 482.20 ft.
Length of Central Wedge= 475 ft.
Elevation Change in Central Wedge= 83 ft.
Angle of Slope (i)= 9.91 degrees
Angle α for Active Wedge= 52.90 degrees **
Angle β for Passive Wedge= 21.98 degrees
Actual Angle of Internal Friction Φ_i= Φ_{im}= 25.95 degrees

Weight of Wedges:
Weight of Active Wedge (Wa)= 11230.50 lb/ft
Weight of Central Wedge (Wc)= 861422.98 lb/ft
Weight of Passive Wedge (Wp)= 17648.64 lb/ft

Pore Pressures of Wedges:
Pore Pressure of Active Wedge (Pwa)= 819.17 lb/ft
Pore Pressure of Central Wedge (Pwc)= 546822.87 lb/ft
Pore Pressure of Passive Wedge (Pwp)= 19801.92 lb/ft

Total Forces of Wedges:
Force of Active Wedge (Pa)= 6112.33 lb/ft
Force of Central Wedge (Pc)= 1347.77 lb/ft
Force of Passive Wedge (Pp)= 7460.10 lb/ft

Σ of Pa + Pc= 7460.10 lb/ft
Pp= 7460.10 lb/ft

** computed using profile from survey

Slope Stability Equilibrium Analysis/Wedge Condition #3

Angle of Internal Friction $\Phi = \Phi_m = \Phi_{im}$= 30 degrees
Depth of Strata (h)= 14 ft.
Unit Weight of Strata (γ_{sat})= 131.5 lb/ft3
Height of Water (hw)= 20.49 ft.
Unit Weight of Water (γw)= 62.4 lb/ft3
Factor of Safety Assumed= 1.00
L_c= 482.20 ft.
Length of Central Wedge= 475 ft.
Elevation Change in Central Wedge= 83 ft.
Angle of Slope (i)= 9.91 degrees
Angle α for Active Wedge= 52.90 degrees **
Angle β for Passive Wedge= 21.15 degrees

Weight of Wedges:

Weight of Active Wedge (Wa)= 11230.50 lb/ft
Weight of Central Wedge (Wc)= 861422.98 lb/ft
Weight of Passive Wedge (Wp)= 22945.07 lb/ft

Pore Pressures of Wedges:

Pore Pressure of Active Wedge (Pwa)= 896.25 lb/ft
Pore Pressure of Central Wedge (Pwc)= 598277.31 lb/ft
Pore Pressure of Passive Wedge (Pwp)= 24267.93 lb/ft

Total Forces of Wedges:

Force of Active Wedge (Pa)= 5230.41 lb/ft
Force of Central Wedge (Pc)= 3477.88 lb/ft
Force of Passive Wedge (Pp)= 8708.29 lb/ft

Σ of Pa + Pc= 8708.29 lb/ft
Pp= 8708.29 lb/ft

** computed using profile from survey

Slope Stability Equilibrium Analysis/Wedge Condition #4

Angle of Internal Friction Φ= 30 degrees
Depth of Strata (h)= 14 ft.
Unit Weight of Strata (γ_{sat})= 131.5 lb/ft3
Height of Water (hw)= 20.49 ft.
Unit Weight of Water (γw)= 62.4 lb/ft3
Factor of Safety = 1.01
L_c= 482.20 ft.
Length of Central Wedge= 475 ft.
Elevation Change in Central Wedge= 83 ft.
Angle of Slope (i)= 9.91 degrees
Angle α for Active Wedge= 52.90 degrees **
Angle β for Passive Wedge= 21.15 degrees
Actual Angle of Internal Friction Φ_i= Φ_{im}= 29.86 degrees

Weight of Wedges:

Weight of Active Wedge (Wa)= 11230.50 lb/ft
Weight of Central Wedge (Wc)= 861422.98 lb/ft
Weight of Passive Wedge (Wp)= 17648.64 lb/ft

Pore Pressures of Wedges:

Pore Pressure of Active Wedge (Pwa)= 896.25 lb/ft
Pore Pressure of Central Wedge (Pwc)= 598277.31 lb/ft
Pore Pressure of Passive Wedge (Pwp)= 24267.93 lb/ft

Total Forces of Wedges:

Force of Active Wedge (Pa)= 5262.32 lb/ft
Force of Central Wedge (Pc)= 4257.56 lb/ft
Force of Passive Wedge (Pp)= 9519.87 lb/ft

Σ of Pa + Pc= 9519.87 lb/ft
Pp= 9519.87 lb/ft

** computed using profile from survey

Slope Stability Equilibrium Analysis/Wedge Condition #5

Angle of Internal Friction $\Phi = \Phi_m = \Phi_{im}$= 35 degrees
Depth of Strata (h)= 14 ft.
Unit Weight of Strata (γ_{sat})= 131.5 lb/ft3
Height of Water (hw)= 22.18 ft.
Unit Weight of Water (γw)= 62.4 lb/ft3
Factor of Safety Assumed= 1.00
L_c= 482.20 ft.
Length of Central Wedge= 475 ft.
Elevation Change in Central Wedge= 83 ft.
Angle of Slope (i)= 9.91 degrees
Angle α for Active Wedge= 52.90 degrees **
Angle β for Passive Wedge= 19.66 degrees

Weight of Wedges:

Weight of Active Wedge (Wa)= 11230.50 lb/ft
Weight of Central Wedge (Wc)= 861422.98 lb/ft
Weight of Passive Wedge (Wp)= 24220.58 lb/ft

Pore Pressures of Wedges:

Pore Pressure of Active Wedge (Pwa)= 970.11 lb/ft
Pore Pressure of Central Wedge (Pwc)= 647581.05 lb/ft
Pore Pressure of Passive Wedge (Pwp)= 29724.41 lb/ft

Total Forces of Wedges:

Force of Active Wedge (Pa)= 4212.09 lb/ft
Force of Central Wedge (Pc)= 6824.06 lb/ft
Force of Passive Wedge (Pp)= 11036.15 lb/ft

Σ of Pa + Pc= 11036.15 lb/ft
Pp= 11036.15 lb/ft

** computed using profile from survey

Slope Stability Equilibrium Analysis/Wedge Condition #6

Angle of Internal Friction Φ= 35 degrees
Depth of Strata (h)= 14 ft.
Unit Weight of Strata (γ_{sat})= 131.5 lb/ft3
Height of Water (hw)= 22.18 ft.
Unit Weight of Water (γw)= 62.4 lb/ft3
Factor of Safety = 1.01
L_c= 482.20 ft.
Length of Central Wedge= 475 ft.
Elevation Change in Central Wedge= 83 ft.
Angle of Slope (i)= 9.91 degrees
Angle α for Active Wedge= 52.90 degrees **
Angle β for Passive Wedge= 19.66 degrees
Actual Angle of Internal Friction $\Phi_i = \Phi_{im}$= 34.65 degrees

Weight of Wedges:

Weight of Active Wedge (Wa)= 11230.50 lb/ft
Weight of Central Wedge (Wc)= 861422.98 lb/ft
Weight of Passive Wedge (Wp)= 17648.64 lb/ft

Pore Pressures of Wedges:

Pore Pressure of Active Wedge (Pwa)= 970.11 lb/ft
Pore Pressure of Central Wedge (Pwc)= 647581.05 lb/ft
Pore Pressure of Passive Wedge (Pwp)= 29724.41 lb/ft

Total Forces of Wedges:

Force of Active Wedge (Pa)= 4284.15 lb/ft
Force of Central Wedge (Pc)= 8486.47 lb/ft
Force of Passive Wedge (Pp)= 12770.62 lb/ft

Σ of Pa + Pc= 12770.62 lb/ft
Pp= 12770.62 lb/ft

** computed using profile from survey

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