Design Guide for Cut Slopes in Loess of Southeastern Washington

WA-RD 145.2

January 1988

Washington State Department of Transportation
Planning, Research and Public Transportation Division

in cooperation with the
United States Department of Transportation
Federal Highway Administration

17. KEY WORDS	18. DISTRIBUTION STATEMENT		
Loess, cut slope, design			
19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 145.2		

4. TITLE AND SUBTITLE
DESIGN GUIDE FOR CUT SLOPES IN LOESS OF SOUTHEASTERN WASHINGTON

5. REPORT DATE
May 1938

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Dr. Jerry D. Higgins
Dr. Richard J. Fragaszy

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Washington State Transportation Center
Washington State University
Pullman, WA 99164-2910

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.
Y-3400, T1

12. SPONSORING AGENCY NAME AND ADDRESS
Washington State Dept. of Transportation
Olympia, WA 98504

13. TYPE OF REPORT AN PERIOD COVERED
Draft

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. ABSTRACT
This guide presents criteria for site exploration, laboratory testing, and design of cut slopes in loessial soils for southeastern Washington State. Design schemes for slope drainage systems are presented also. A design checklist keyed to this guide is included in the appendix. A summary of typical soil properties and cut slope behavior is included.

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DESIGN GUIDE FOR CUT SLOPES IN LOESS OF SOUTHEASTERN WASHINGTON

by

Dr. Jerry D. Higgins, Principal Investigator*
Dr. Richard J. Fragaszy, Co-investigator**

*Department of Geological Engineering
Colorado School of Mines
Golden, CO 80401

Washington State Transportation Center
**Department of Civil Engineering
Washington State University
Pullman, WA 99164-2902

WSDOT Technical Monitor
Alan P. Kilian
Chief Geotechnical Engineer
Materials Laboratory

Report
Research Project Y-3400
Task 1

Prepared for
Washington State Transportation Commission
Department of Transportation
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

January 1988

The work upon which this report is based was supported by the Washington State Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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INTRODUCTION

Loess is a wind deposited soil composed primarily of silt-size particles. While the most extensive deposits in the United States are located in the midwest, loessial deposits blanket the majority of southeastern Washington and extend into northeastern Oregon and northern Idaho. Traditionally this part of the country has been a fertile farming area with thick, rich soils.

Recent emphasis on soil conservation in southeastern Washington has prompted farmers and government agencies to examine their routine practices. The Washington State Department of Transportation (WSDOT) is concerned with the performance of cut slopes along highways and county roads that cross the loess area. Also of concern, is that some of these cut slopes have been rapidly deteriorating due to erosion and/or slope failures and threaten private land.

This guide is based on two phases of research on the design and performance of cut slopes in loessial soils (Higgins et al., 1985 and 1987). The objectives of this guide are to describe: (1) the important engineering properties of southeastern Washington loess with respect to cut slope design, (2) the failure mechanisms of cut slopes in this loess deposit, (3) the site characterization and laboratory testing program for cut slope design in loess, and (4) slope and drainage designs for cut slopes in loess.

Most of the recommendations for cut slope design are based on the 1985 reconnaissance study of road cuts which included observations of slope degradation processes and the analysis of 40 soil samples to determine physical properties of the deposit. The 1985 and 1987 research reports should be reviewed for additional information concerning the basis of this guide.

The appendix to this guide includes a "Loess Slope Design Checklist" to aid in the entire process of slope design. The checklist includes sections on project definition, field data, geotechnical investigation, laboratory testing, and design evaluation and recommendations. The checklist should be used on loess slope design projects in combination with this design guide.

CHAPTER 1

HISTORICAL PROBLEMS WITH LOESSIAL SOILS

Loess is characterized by its loose structure which consists of silt and fine sand particles coated by a clay binder. In some cases, this structure allows vertical or near vertical cuts exceeding 50 ft in height to perform exceptionally well, provided the water content remains low. Conversely, upon wetting loess becomes relatively unstable and slump failures can occur in slopes as flat as 2:1 (H:V).

Erosion in loess is a common problem due to its structure. Some of the most severe erosion in the United States is in southeastern Washington, i.e., losses of 1.0 to 1.4 lb/sq ft/yr are common and 4.5 to 9.0 lb/sq ft/yr frequently occur on some steep slopes. In addition to the loss of fertile soil for agriculture, the sediment load to streams is extremely high.

CHAPTER 2

ENGINEERING PROPERTIES & BEHAVIOR OF WASHINGTON LOESS

Origin

Loessial deposits blanket the majority of southeastern Washington and extend into northern Idaho and northeastern Oregon. The source material for the southeastern Washington loess deposit is still a matter of debate. Various investigators have proposed sources ranging from northwest to southwest of the deposit; the Ringold formation, centered in the Pasco Basin west of the deposit, is the most widely accepted origin.

Gradation

A typical range in grain size distribution of Washington loess is shown in Figure 1 and is classified as sandy, silty, and clayey loess. The change in grain size distribution is a primary indicator of variation in physical properties and engineering behavior with location for loessial soils. Clay-size content, water content, and density all tend to increase with distance from the source. Therefore, definition of directional variation within the deposit becomes extremely important.

Limited sampling and testing has supplied sufficient data to establish general trends in grain-size variation within the deposit that should be very helpful to engineering geologists and geotechnical engineers. Figure 2 shows the locations of

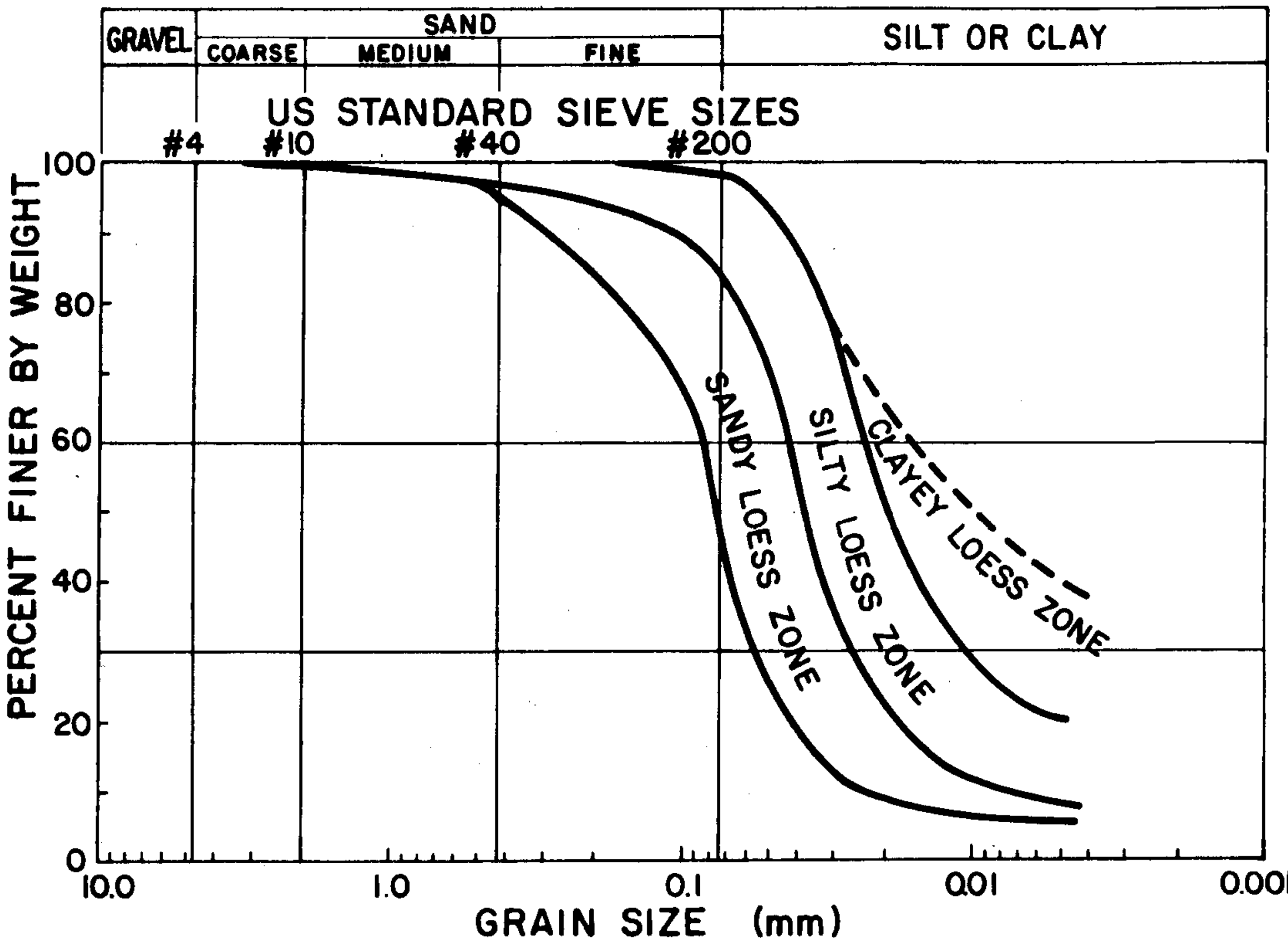

Figure 1. Definition of sandy, silty, and clayey loess for southeastern Washington.

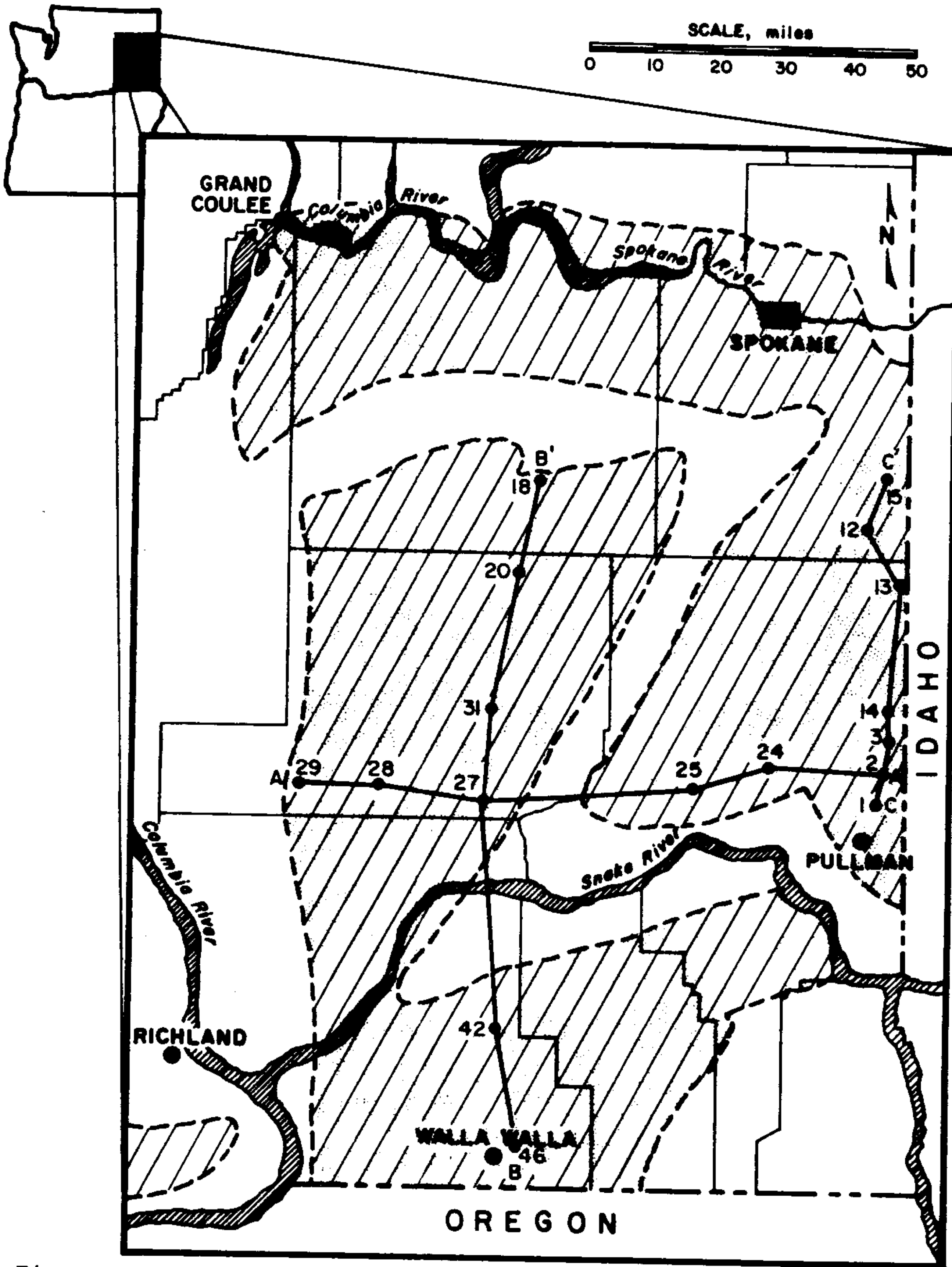

Figure 2. Location map for cross sections A-A', B-B', and C-C'.

three generalized cross sections constructed through the deposits, one trends east-west and the other two north-south. In Figure 3, the east-west cross section A-A′, a general increase in clay-size content and a decrease in sand to the east are shown. In Figure 4, the north-south cross section B-B′, fairly constant clay-silt-sand ratios are revealed with only local fluctuations. The north-south cross section C-C′ (Figure 5) is similar to that in Figure 4 in that the relative percentages of sand, silt, and clay size remain fairly constant. However, cross section C-C′ has a higher clay-size content and lower sand content than B-B′.

Clay-size content (< 0.002 mm) was contoured for the study area and is shown in Figure 6. Although anomalies are present, a definite trend of increasing content of clay-size material to the east is apparent. As established earlier, sand content decreases from west to east. These facts in conjunction with the cross sections suggest that the source material was to the west of the deposit with no major north or south directional component.

Figure 7 shows very approximate gradation boundaries for southeastern Washington loess based on limited sampling. <u>This figure should be used only as a general guide.</u> Figure 8 shows a typical vertical profile at a sampling site determined from five discrete sampling points. Little variation in the relative percentages of the sand, silt, and clay fractions is shown. Although the percentage of sand-size particles varies by less than 1 percent, the clay-size material (< 0.002 mm)

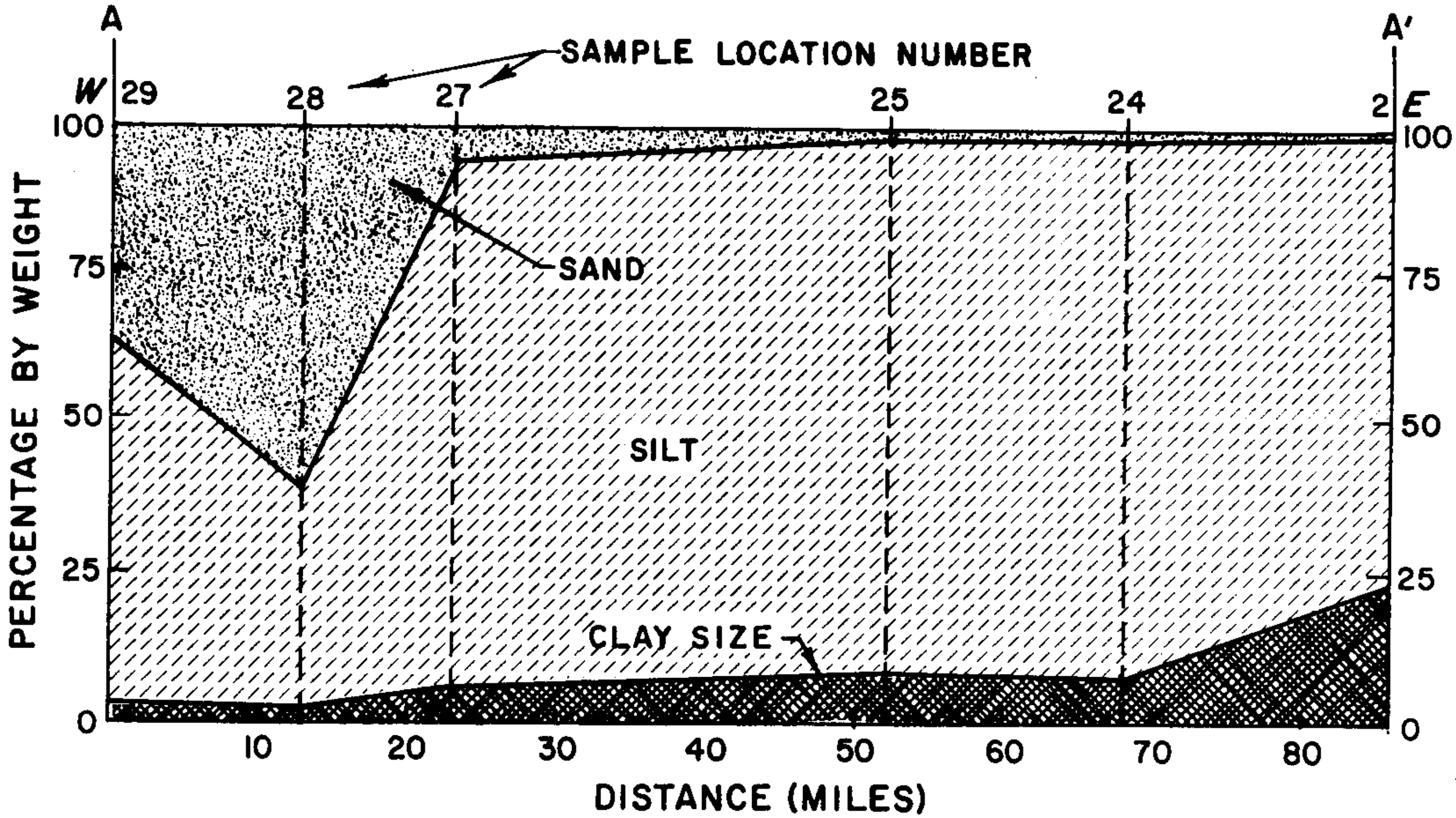

Figure 3. Cross section A-A'.

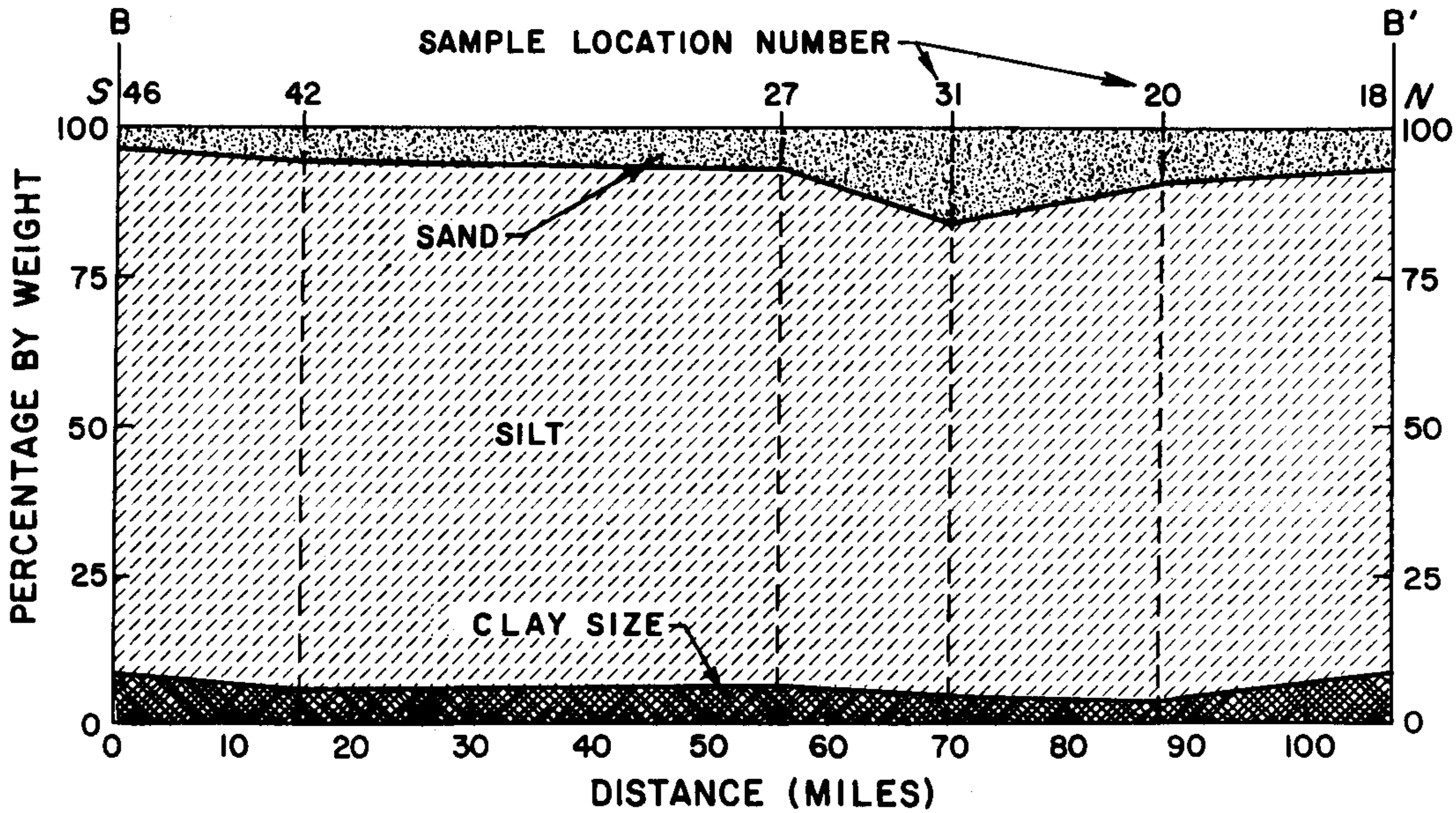

Figure 4. Cross section B-B'.

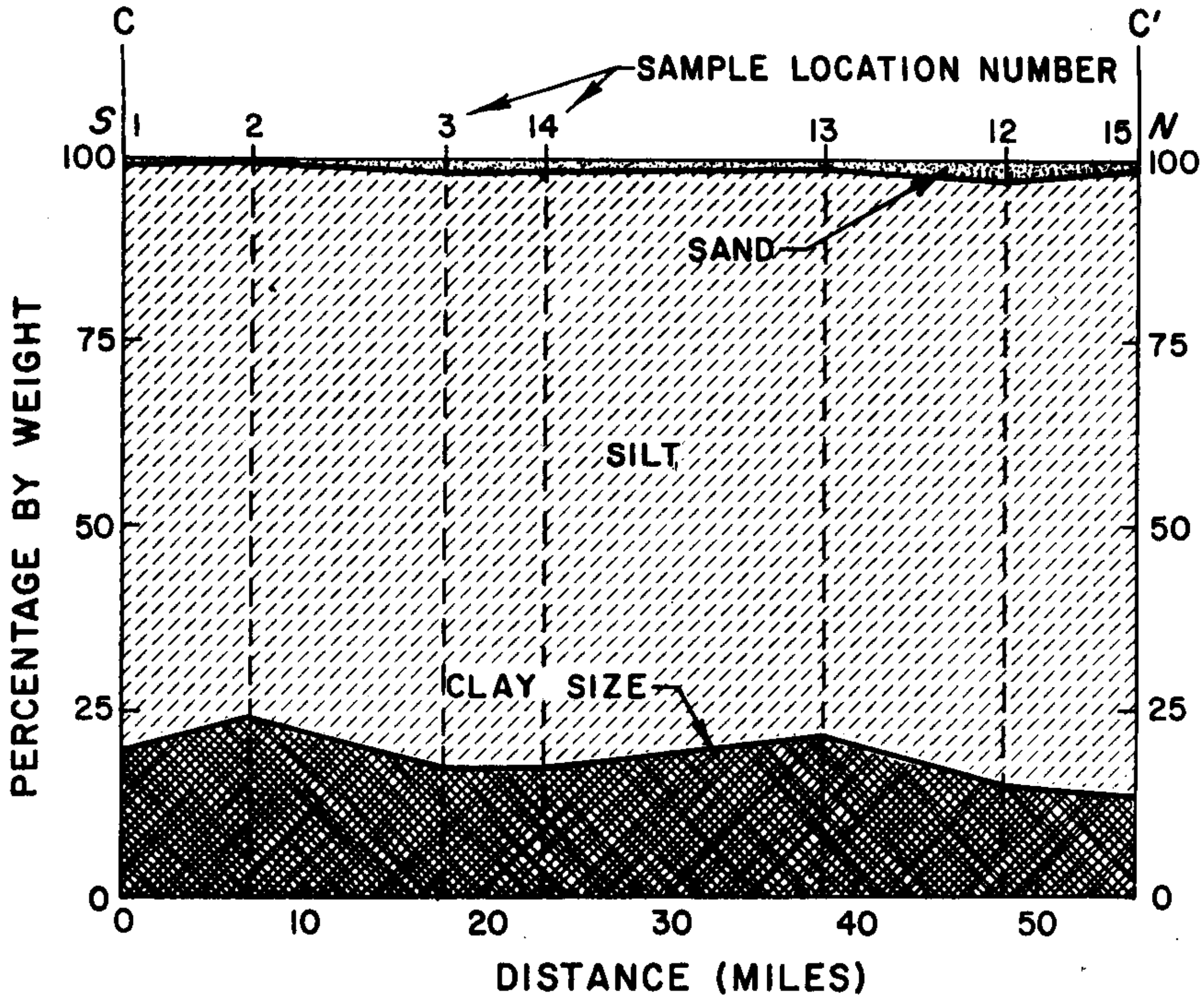

Figure 5. Cross section C-C'.

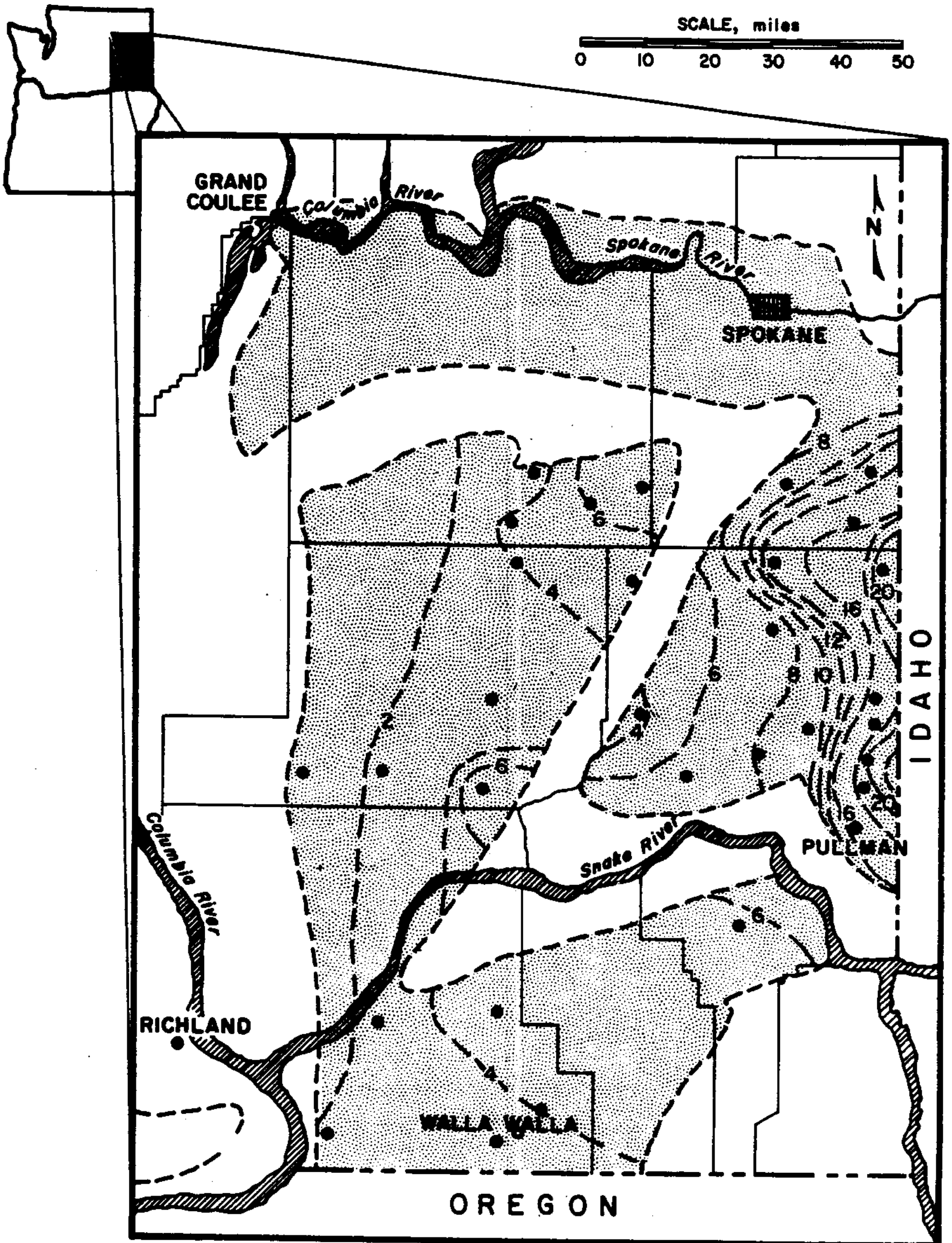

Figure 6. Generalized contour map of percentage of clay-size particles.

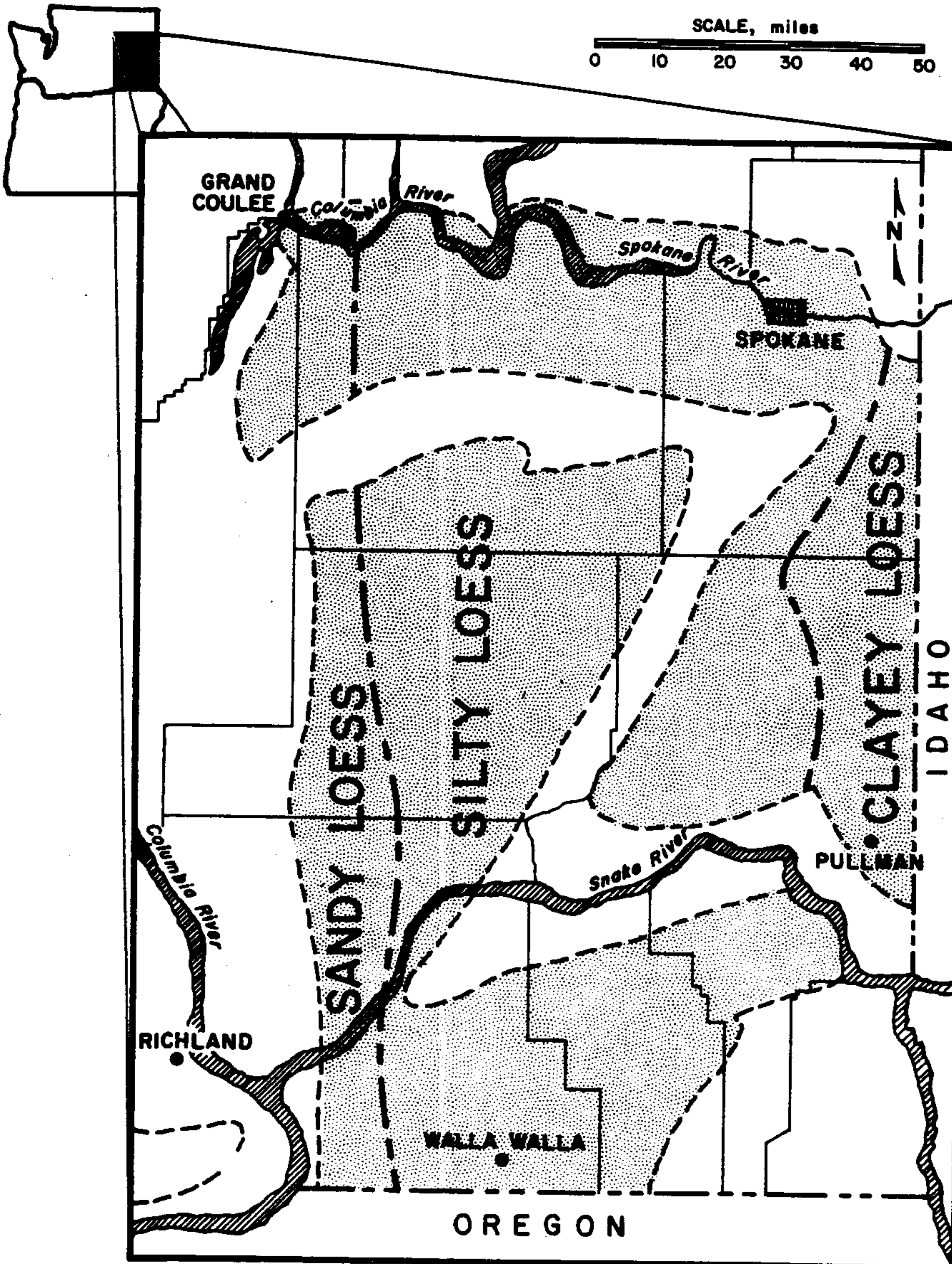

Figure 7. Approximate gradation boundaries for Washington loess.

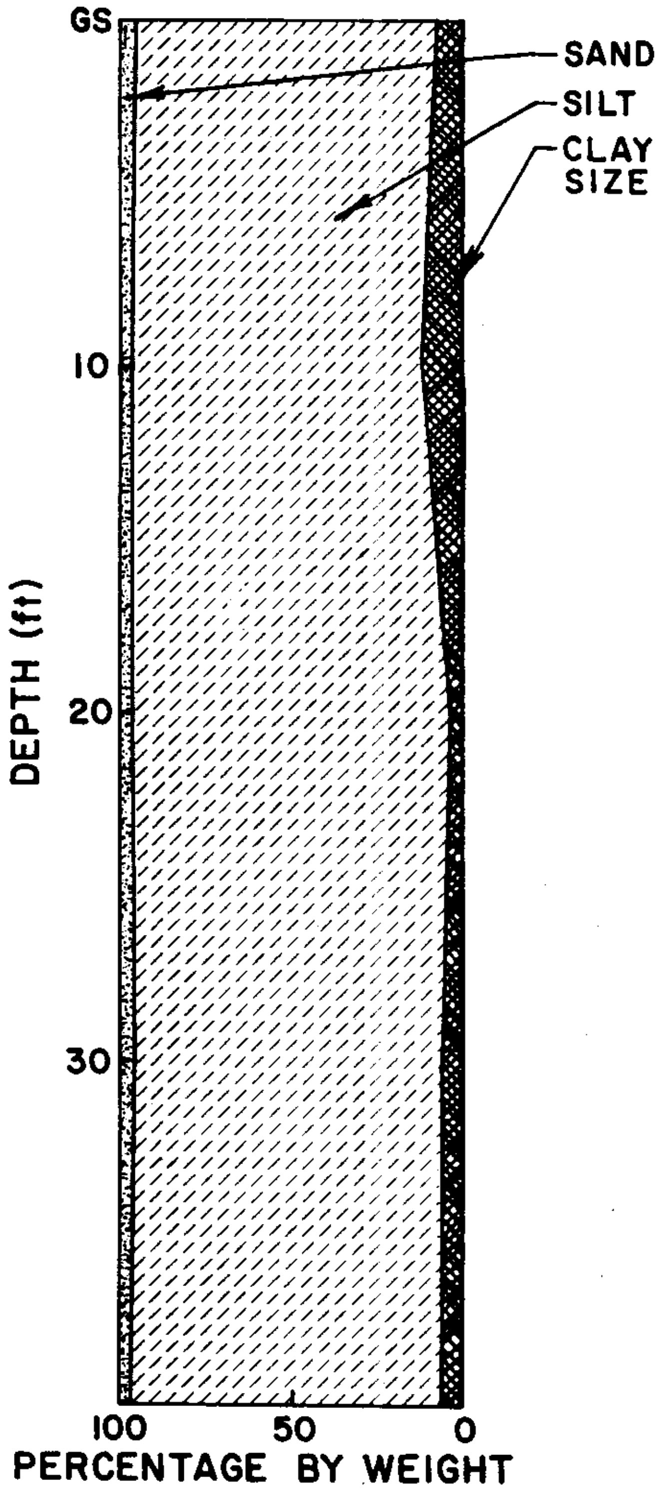

Figure 8. Typical variation in textural composition with depth.

varies up to 5 percent, which is still relatively minor for a natural soil. Although this appears to be the general configuration of Washington loess profiles, some highly stratified profiles may be encountered; therefore, subsurface sampling at proposed excavation sites is warranted.

Density

Dry densities ranging between 95 and 98 lb/cu ft have been reported for clayey loess from an excavation site at Washington State University. Additional dry densities determined for triaxial tests are tabulated in Table 1 (later in the manual) for reference purposes.

Water Content

Natural water content was obtained for 22 sites throughout the loessial soil area. Water content ranged from 4.5 to 27.7 percent. As might be expected, water content shows a high degree of variability from location to location. Even so, water content generally tends to increase from west to east. The directional variation in water content may be attributed to two factors. First, content of clay-size material increases from west to east as determined by the grain size analysis. Water content should be expected to increase with increasing clay-size content. Second, mean annual precipitation tends to increase from west to east by as much as 100 percent.

The silty loess tends to have a very low water content (most of the deposit is located in an area of low precipitation) which allows it to stand in near vertical cuts. Based on experience in the midwestern U.S., if the water content were increased above approximately 17% in silty loess, near vertical slopes may fail. Therefore, observation of natural water content and any conditions that could increase the water content of the soil are important to the designer.

Plasticity

Figure 9 is presented to illustrate a typical range in the plastic and liquid limits of loess. Examination of the plot and the grain size distributions reveals two groupings of the data. Silty loess tends to have liquid limits ranging from 14 to 32 and plasticity indexes of 0 (nonplastic) to 11. Clayey loess has liquid limits that vary between 33 and 49 with plasticity indexes ranging from 11 to 27. The two sandy loesses tested were nonplastic. Atterberg limits should be performed on samples from proposed cut slope sites to aid in the determination of loess type and behavior.

Calcium Carbonate

During field sampling, various forms of calcium carbonate may be encountered. Calcite may be present as either root fillings or nodules. To a lesser extent calcite may be found to exist as indurated sheets lying 6 in. to 1 ft behind the surface of a cut face. This appears to be an evaporation

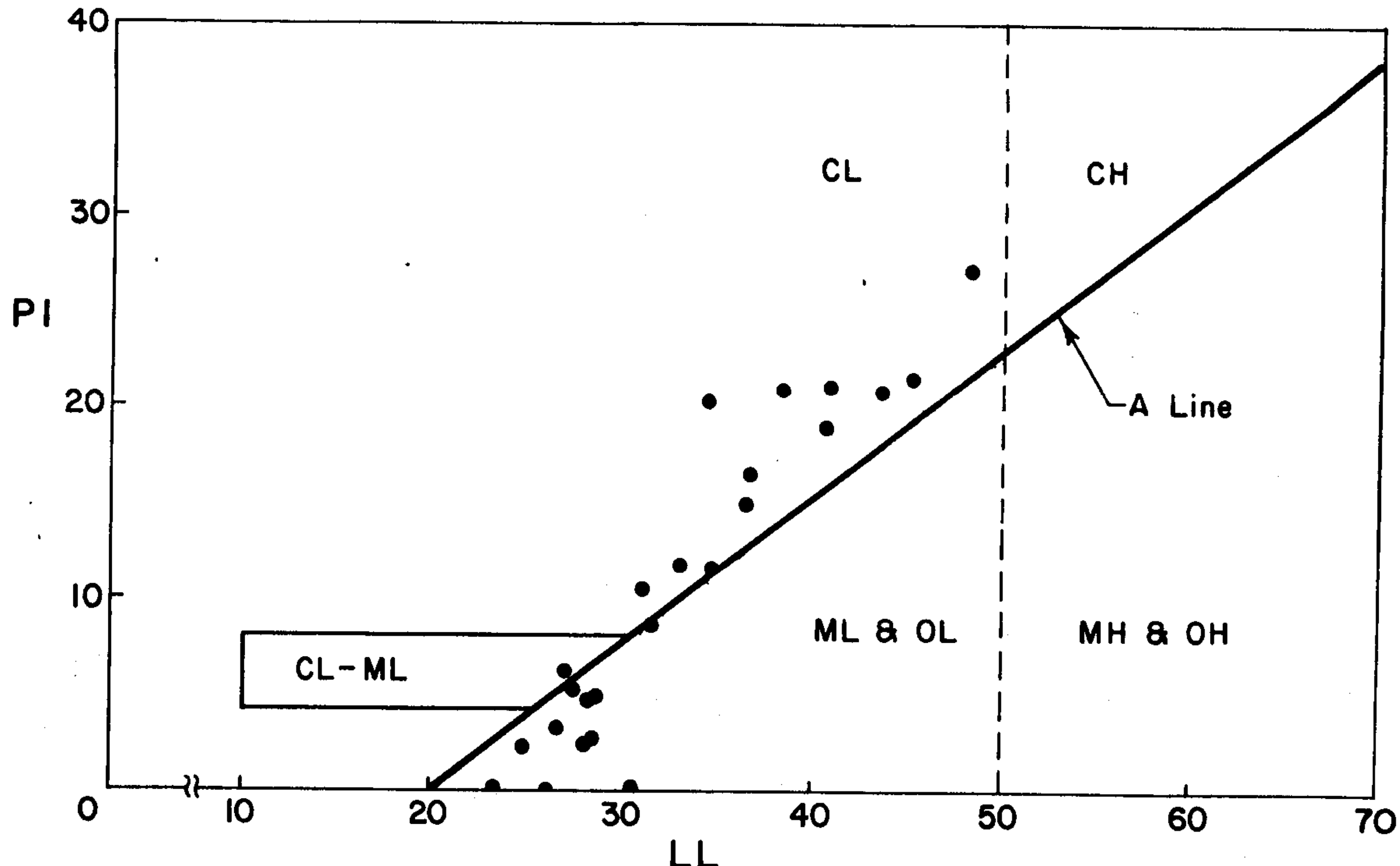

Figure 9. Plasticity data for southeastern Washington loess.

phenomenon. Because of the discrete nature of most calcite deposits, the absence of calcium carbonate in an area where it might be expected does not necessarily imply that it is absent from the area as a whole.

It would appear that the presence or absence of calcium carbonate is related to mean annual precipitation. In areas averaging more than 20 in. of precipitation per year, no samples containing calcium carbonate were encountered. Conversely, a large majority of samples collected in the area where mean precipitation was less than 15 in. contained significant quantities of calcite.

Shear Strength of Loess

During the 1987 research, shear strength parameters were determined for several representative samples of clayey and silty loess. These are presented in Table 1 as a guide to expected values.

Failure Mechanisms Associated with Southeastern Washington Loess

The following section describes the most common problems experienced with slope cuts in southeastern Washington loess and the causes. Deterioration of these cut slopes can be attributed to three factors: erosion, shallow slides or flows, and rotational slides. The designer should be aware of these failure mechanisms and their causes when designing cut slopes.

TABLE 1

STRENGTH PROPERTIES OF SILTY & CLAYEY LOESS OF EASTERN WASHINGTON

Water Content (%)	Dry Density (g/cc)	CU c	CU phi	IBST c	IBST phi	UCU c	UCU phi	Specific Gravity
		(c in psi, phi in degrees)						
				Silty Loess				
14.7	1.19	0.3	34.5	4.5	29.4	8.5	19.9	2.74
13.8	1.22			6.2	19.4	9.1	20.9	2.73
22.2	1.31			4.2	17.9			2.70
22.2	1.31			2.9	26.2			2.70
18.9	1.13			3.5	27.6	10.1	19.0	2.67
				Clayey Loess				
19.5	1.37	0	28	3.1	26.9			2.74
19.1	1.36			3.5	22.5	9.5	20.3	2.73
23.4	1.38			3.1	22.6	8.4	19.2	2.72
31.4	1.33			4.2	21.6	3.6	8.6	2.71

CU - effective strength parameters
IBST & UCU - total strength parameters
CU = consolidated-undrained triaxial test
IBST = Iowa borehole shear test
UCU = unsaturated-consolidated-undrained triaxial test

Erosion Damage in Silty Loess

Erosion (including piping) is by far the most common form of slope degradation noted by the authors in the silty loess of eastern Washington. Piping is a phenomenon where seeping water progressively erodes or washes away soil particles, leaving large voids (pipes) in the soil. As the piping process continues, the voids enlarge and work their way backwards from the face of the cut. In many cases large erosion gullies are initiated by small piping failures originating 5 to 10 ft behind the top of the cut face. As the pipe enlarges, the surface tends to cave, forming a gully. Once a gully forms, running water enlarges it rapidly. In some cases animal burrows which intersected the cut face were the origin of the piping problem.

Typically, major erosional features are the result of insufficient drainage around the cut slope or insufficient erosion protection of existing drainage systems. The vast majority of serious erosion problems were observed in long cuts transecting small drainage areas with no provisions made for conveying excess runoff away from the slope face. The highly erosive nature of silty loess requires the diversion of runoff from what would normally be considered insignificant drainage areas.

Figure 10 illustrates the result of truncating a small drainage area without providing a means of conveying excess runoff from the slope or providing any erosion protection on

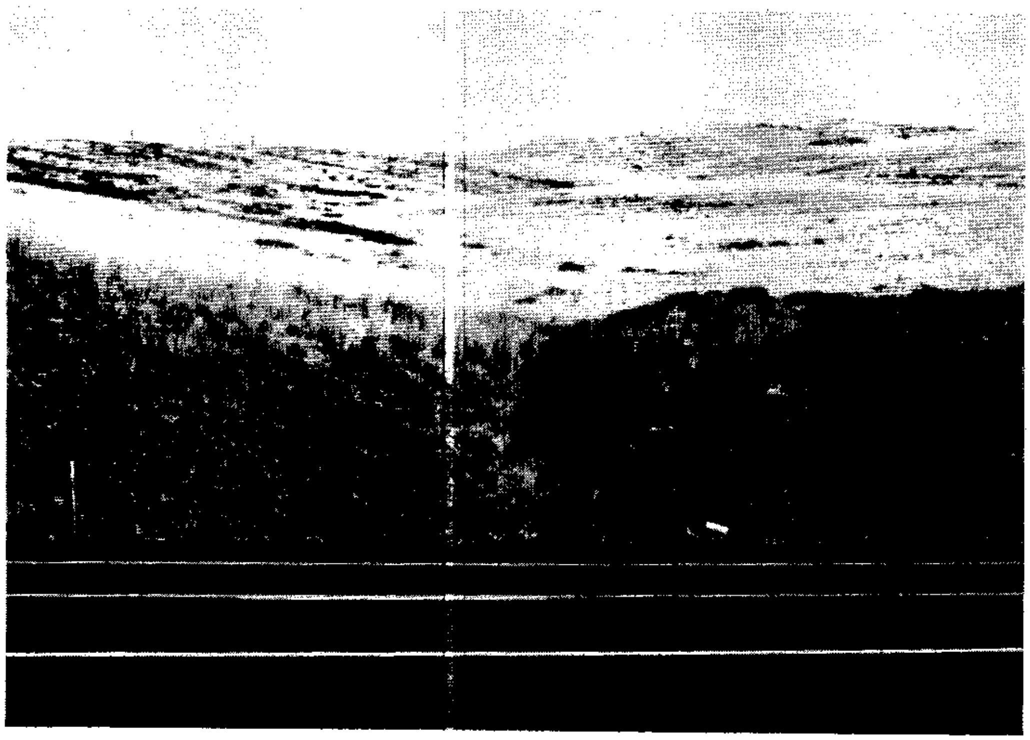

Figure 10 Erosion of Loess by Flow Over the Face of a Cut Slope

the slope face. Although this is a rather small cut, the principle is well illustrated.

Figure 11, located in silty loess near Walla Walla, demonstrates the progressive nature of erosion in loessial soils. Erosion was initiated where this small side drainage was truncated by the highway cut to the right (of photograph) and has progressed rapidly up gradient. Erosion will continue until the overall gradient is decreased below that causing channel scour. Although this photograph illustrates the erosion of a natural channel, it also serves as an example of the high erodibility of silty loess where flow is concentrated; therefore, the need for channel protection for a surface drainage system is obvious.

Figures 12 and 13 illustrate two separate points. In Figure 12 the majority of the erosion in the upper portion of the cut slope is due to piping. Below the pipes, gully erosion is beginning to develop. Vegetation in the base of the depression as well as the shape of the developing gully indicate that it originated as a pipe. When the pipe enlarged to the point where the overlying material could no longer be supported, caving occurred and the overlying vegetation was deposited in the depression. This was found to be a very common mechanism in the formation of erosion gullies in silty loess.

The second point that should be noted is that small drainage areas can initiate erosion. Figure 13 shows the rather small, gently sloping drainage area above the erosion

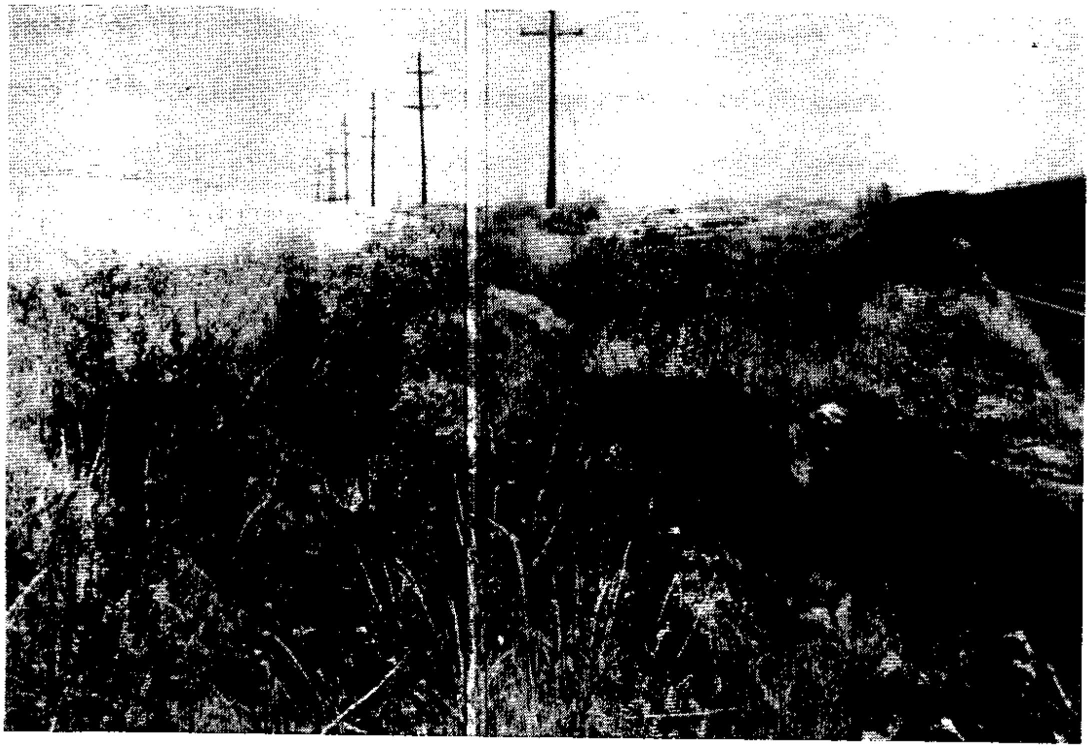

Figure 11 Gully Erosion in a Side Ditch Due to Insufficient Channel Protection

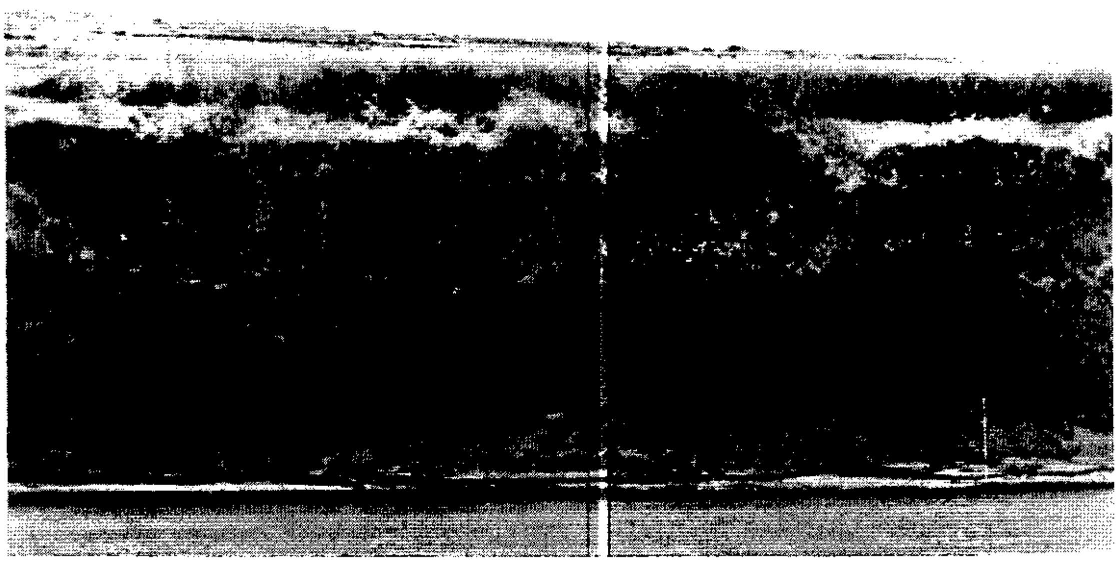

Figure 12 Erosion Pipes Developing Into Gullies

Figure 13 Low Area at Center is the Source of Runoff Causing Erosion in the Previous Photo

in Figure 12. Extensive erosional problems may develop from extremely small drainage areas due to the fact that silty loess is highly susceptible to rapid erosion.

The above observations indicate slope erosion can become severe when runoff is allowed to flow over the cut face or concentrate near the top of the face in silty loess. In these cases piping and gullying of the cut face begin rapidly. Erosion also may be extensive where flow is concentrated. From this experience, it appears that maintaining the natural slope of the land and allowing land use up to the top of the cut is not a good practice for near vertical cuts in silty loess. Instead, due to the high erosion potential of a cut face in silty loess, surface drainage should be an integral part of the cut slope design. Diversion of flow away from the cut face should keep it from rapidly deteriorating by piping and gullying. Also, the diversion channels should be protected from gullying.

In the same area as Figure 12, several large, near vertical cuts were observed where the natural drainage diverted water away from the cut face. These cuts appeared to be performing very well and showed little erosion even though they were the same age and material (silty loess) as the adjacent eroded slopes.

Another serious erosional problem in loessial soils, more specifically on flattened slopes, is surface erosion during construction and up to the time of establishment of a good vegetative cover. Extensive and rapid damage in the form of deep rills was observed on new slopes cut in silty and clayey loess. Even with adequate drainage, extensive damage may result from raindrop impact and rill erosion. Although these observations were made with respect to cut slopes, the general principles should be applicable to any earth construction project.

Shallow Slides and Flows

Shallow slides and flows are common forms of slope degradation in the eastern part of the loess deposit primarily within the clayey loess zone where most of the larger cut slopes have been cut at approximately 2:1 (H:V). This type of failure is largely due to late winter and early spring climatic conditions. It is common to get precipitation or snow melt at this time of year, which results in a thin layer of thawed, saturated soil overlying either frozen or unsaturated soil. The layer of thawed, saturated soil along with any overlying vegetation tends to slide (or flow) downslope.

The form in which this type of failure manifests itself within the study area is primarily due to the amount of precipitation, clay-size content, and slope angle. In the western two-thirds of the study area, where precipitation is less than 15 in. annually, shallow slides or flows were rarely observed. Clay content increases from west to east as does precipitation. Increases in clay content (which results in lower permeability) combined with increased precipitation, raises the likelihood of the near surface saturated conditions required for failure.

Two different forms of shallow slope failure were observed and appear to be related to soil type. In silty loess it is not uncommon to observe sheets of vegetative cover and soil, 2 to 6 in. thick with an arcuate upper boundary, move downslope. In this form, only minor damage was observed with no cases of extensive degradation noted.

In clayey loess shallow slides and flows are common and result in major slope degradation. Movement appears to be a mud flow phenomenon with both large and small scale failures observed. At least minor damage is common in many of the existing clayey loess slopes over 10 ft high, and numerous cuts have experienced major loss of vegetative cover. Small scale mudflows, such as in Figure 14, are by far the most common form of failure. Failures are typically 1 to 10 ft wide with the depth of failure ranging between centimeters and 4 ft. In most cases the initial failure is followed by increased erosion due to the loss of vegetative cover with severe gully erosion a common result.

Although not as common, larger slide and/or flows have been observed. The failure mechanism is thought to be the same as for smaller scale failures with a low depth to width ratio for the failure surface. Figure 15 illustrates a larger failure. In all cases where extensive damage from slides or flows was observed, slopes were 2:1 or steeper. No

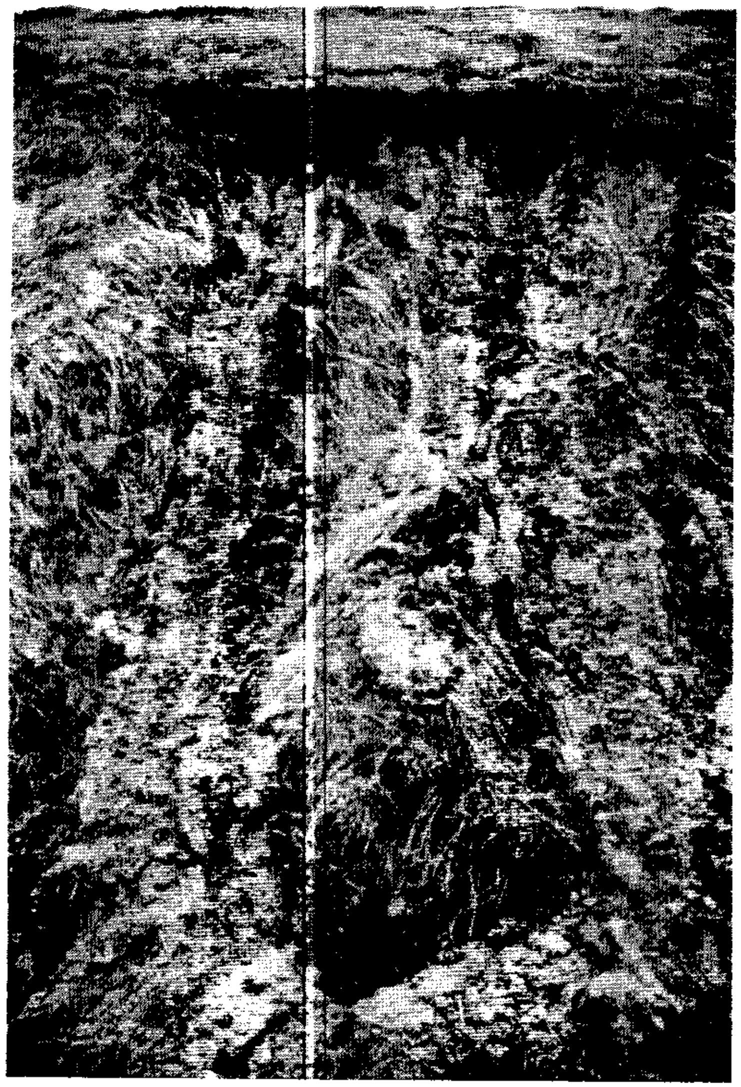

Figure 14 Small Flow of Soil and Vegetation in a Cut Slope

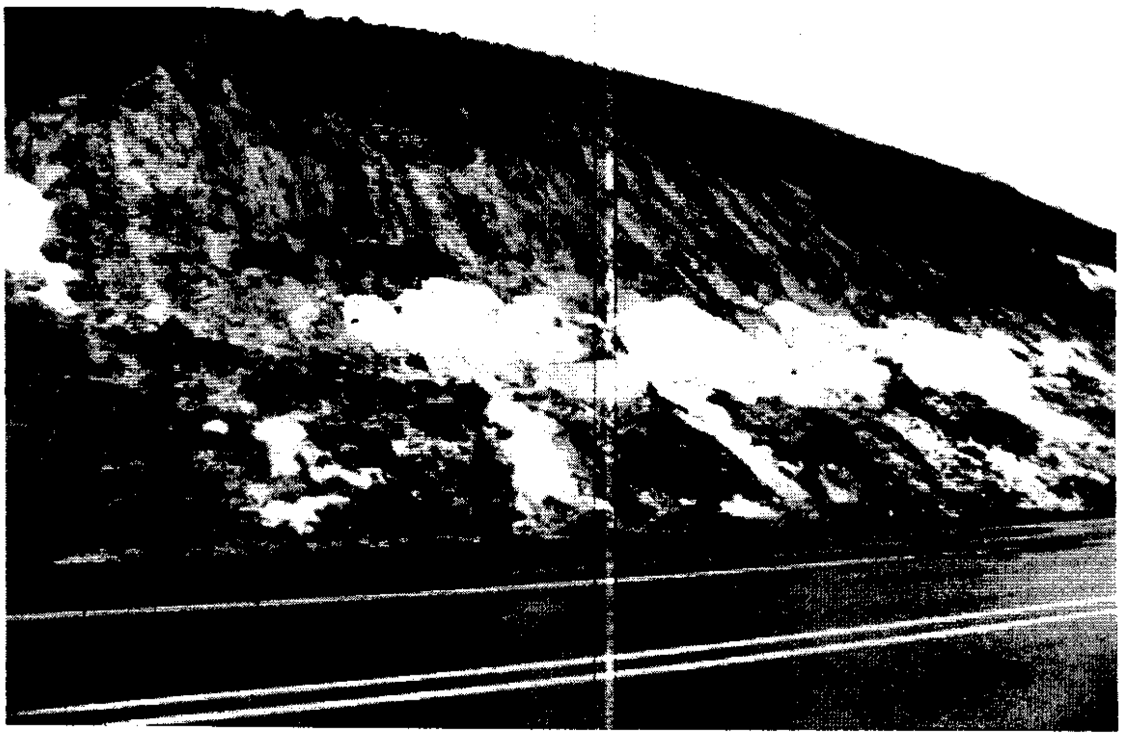

Figure 15 Failure of Cut Slope in Clayey Loess

instances of failure were observed for slopes flatter than 2.5:1. These observations agree with past investigations of similar deposits which found slopes greater than 2.5:1 too steep to maintain good vegetative cover in loessial soils. These are discussed in Higgins and others (1985).

Exposure has an influence on these shallow failures. It is not uncommon to find two opposing cuts with similar slopes and drainage, one facing north and the other south, to exhibit extremely different performance. The north facing slope will invariably demonstrate a greater degree of degradation due to shallow slides and flows than the south facing slope. This is not surprising as slopes facing to the north typically have higher average water contents than any other orientation. Figures 16 and 17 show south and north facing slopes (respectively) cut in clayey loess at 2:1. Note in Figure 16 that some erosion has occurred where small patches of vegetation and soil have slipped away. However, the north facing slope (Figure 17) has experienced numerous shallow failures which have stripped the vegetation. Obscured by the snow drift are scarps from larger failures, which have occurred over the past several years, that have significantly steepened the crest of the slope. The result of the shallow slides is exposure of bare soil and rapid formation of erosion gullies, some of which range up to 1.5 ft in depth in Figure 17.

The practice of constructing drainage ditches immediately below the toe of slopes appears to contribute to this type of

Figure 16 South Facing Slope Shows Little Degradation

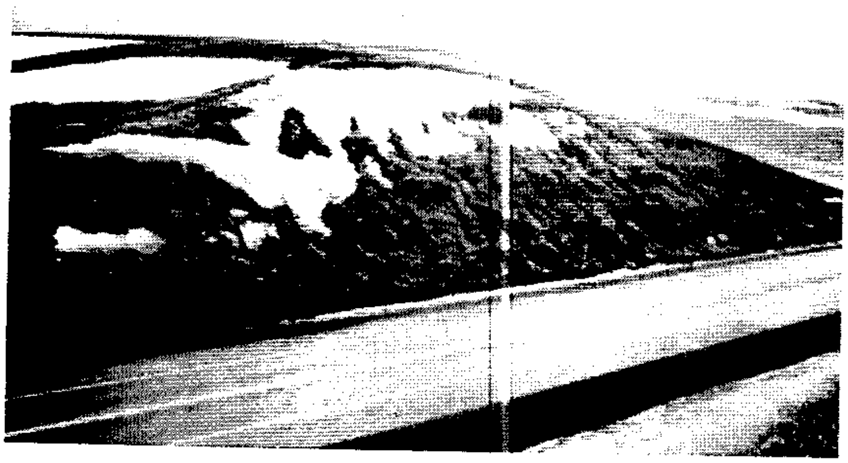

Figure 17 North Facing Slope Exhibits Slide Scar and Severe Gully Erosion

failure. Periodic highway maintenance requires removal of sediment from the ditches which may result in undercutting the toe. Additionally, drainage ditches located directly adjacent to the toe often raise the water content, further encouraging failure. This problem may be reduced by placement of drainage ditches approximately 10 ft away from the toe of the slope.

Rotational Failures

Occasional rotational failures have been observed in clayey loess in the extreme eastern section of the study area. Failures of this type have taken place primarily during the spring when soils were at or near saturation. The reason rotational failures are so limited may be due to the fact that loessial soils in eastern Washington generally do not reach saturation at depths much greater than 3 ft. Although complete saturation is not a requirement for producing a rotational failure in loess, it is likely that near saturated conditions are necessary to reduce strength sufficiently to produce a deep seated failure of any geometry.

Figure 18 is an example of a rotational failure, i.e., a slump/earth flow in a natural slope in clayey loess soils. The slope was inclined approximately 2:1, the head scarp was approximately 15 ft high, and the failed material flowed about 50 ft from the toe of the scarp. The failure occurred in an area where runoff and ground-water seepage from the surrounding field could be expected to collect and saturate the soils. Ground-water conditions such as these should be watched for during the geotechnical investigation.

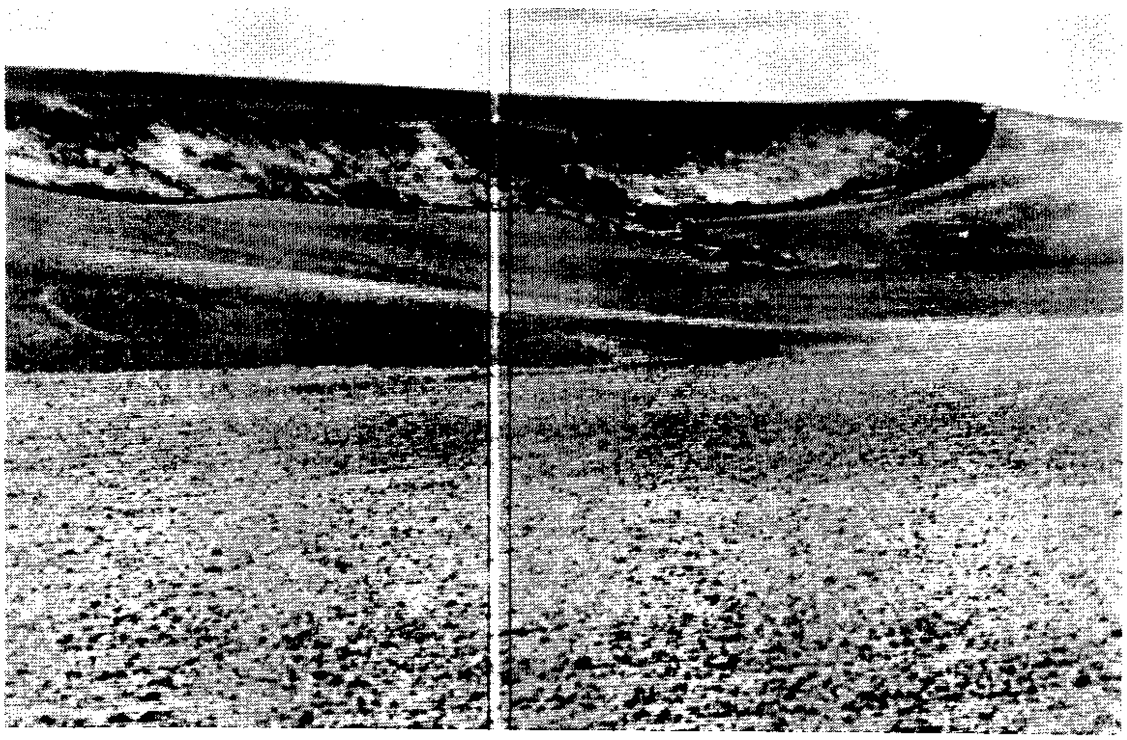

Figure 18 A Slump/Earth Flow in Clayey Loess

CHAPTER 3

SITE CHARACTERIZATION FOR LOESS SLOPE DESIGN

Office Study

Before a site visit, published information on the project area should be reviewed. Often much can be learned about the geotechnical properties of a site prior to a site visit, which will then help the slope designer plan the site visit and field investigation program.

Typical sources of information on site conditions for loessial soils in southeastern Washington may be found in the research reports listed in the reference section, a U.S. Department of Agriculture county soil survey, or geologic maps published by the U.S. Geological Survey or the Washington Department of Natural Resources. Also, the county soil conservation agent should be a good source of information. These sources should give the designer a general knowledge of soil properties at the proposed site such as grain size distribution, percent clay-size material, soil stratigraphy, permeability, drainage character, depth to bedrock, agricultural use, and irrigation potential. The general knowledge gained from this data collection should be used to plan an efficient field investigation to define the specific site conditions.

Field Reconnaissance

After the office study, the site should be visited to verify information gained in that study and to determine such things as soil type and stratigraphy, natural drainage conditions, agricultural use, whether there are any structures or activities near the top of the backslope, and potential for land-use changes. Observations of any geologic processes at or near the site that could affect the project are important. These may include erosion problems on nearby slopes, seeps at the site, and condition of existing cut slopes in the general area. A checklist is provided in the appendix of this manual to aid in this task. These observed conditions should be considered in the cut slope design.

Field Exploration Program

Sampling should be done in the most efficient manner which is dependent on the size and type of cut slope that is proposed. The checklist in the appendix should be used as a guide to this phase of the site characterization program.

Soil samples are required for determination of the natural water content, grain size distribution, and Atterberg limits for standard cut slope projects. Ground-water conditions should be recorded. Cuts in excess of 50 ft or sites with nonuniform stratigraphy may require a stability analysis, and therefore undisturbed samples may be needed for shear strength tests.

Sampling for sliver cuts and shallow cuts may be accomplished with hand auger tools. Sampling along the face of an existing cut must extend a minimum of 4 ft into the face and should be spaced so that the soil stratigraphy and groundwater conditions are characterized. For major cuts, sample with test holes to 10 ft below grade. Sampling should be continuous in the top 6 ft of hole and then every 5 ft thereafter. There should be a minimum of 2 holes per cut, normally spaced 200 to 300 ft apart (500 ft maximum).

CHAPTER 4

LABORATORY TESTING FOR DESIGN

Laboratory tests are used to evaluate index and engineering properties of soil which are related to the ultimate engineering behavior of a cut slope and the recommended design. For cut slopes greater than 50 ft in height or for nonuniform stratigraphy, strength tests may be required.

Routine laboratory tests required for cut slope design include Atterberg limits, sieve analysis, hydrometer analysis, and loess classification. Also, natural moisture content is required. These soil properties determine the appropriate slope design for cuts no greater than 50 ft in height.

If deep cuts are planned (greater than 50 ft) or if water contents are expected to be greater than critical (17%), it may be necessary to run strength tests on undisturbed samples. When ground-water conditions are such that achieving a moisture content above 17% is considered unlikely, a total stress analysis is the preferable approach. Conversely, where water contents in excess of 17% may be anticipated, an effective stress analysis on saturated samples should offer the best results.

CHAPTER 5

LOESS SLOPE DESIGN

Factors Affecting Stability

Observations of cut slope performance discussed in Chapter 2 suggest that water content and grain size distribution have a primary influence on stability, provided adequate drainage is supplied for cut slopes less than 50 ft in height. Dry silty loess soils in eastern Washington should perform well in near vertical cuts (1/4:1, H:V) if they are protected by surface drainage structures and low natural moisture contents (< 17%) are maintained. Cuts in clayey loess should perform well if they do not exceed approximately 2.5 to 1 (H:V), are protected by a cover of vegetation, and if concentrated flows from gullies, swallows, etc., are not directed onto the slope face. It was established in Chapter 2 that major performance problems are due to poor or inadequate surface drainage systems for cuts in silty loess (and in a few cases for cuts in clayey loess) and oversteepened slopes for cuts in clayey loess. Sandy loess should be treated as a common soil cut using conventional design methods.

Effects of Water on Slope Stability

The designer of structures in eastern Washington loess should be fully aware of the following soil properties and should design cut slopes to avoid these problems.

1. Loess is highly erodible. The flow of water, even at low to moderate volumes and gradients (less than 5%, 5 to 10% respectively) can cause severe erosion.
2. Disturbance of the natural soil structure by grading, heavy equipment operation, farming activities, etc., makes the soil more susceptible to erosion.
3. Saturation of the soil softens the clay binder and greatly decreases the strength. This can lead to slope failure or accelerated erosion.
4. Silty loess soils are highly susceptible to failure by piping.

Stability Analysis

A slope stability analysis may be required when slope cuts exceed 50 ft, when the natural water content approaches saturation, or when a water table is intercepted by the cut. When ground-water conditions are such that achieving a saturated condition is unlikely, a total stress analysis is the recommended approach. Conversely, when ground-water conditions make saturation possible an effective stress analysis should be used.

If a slope stability analysis is to be performed on a silty loess which maintains a water content below critical (17%), a wedge type of failure is perhaps the most likely geometry. When saturation at depth is encountered for either silty or clayey loess, a rotational failure may occur; although, due to possible anisotropy of the soils, the geometry of the failure surface may deviate from circular. Subsurface data from boreholes should be used to evaluate whether a circular or preferred failure surface is appropriate for the stability analysis.

Typically, the slope should be designed with a factor of safety of 1.25 for cuts and 1.5 for structures.

Recommended Designs for Cut Slopes

If the soil at the site of the proposed cut is a silty loess with water content below critical (< 17%), near vertical cuts (1/4:1 H:V) may be considered. If near vertical cuts are utilized, they should be benched on approximately 20 ft vertical intervals (or at the approximate midpoint) when the total height of the cut exceeds 30 ft. Benches should be 10 to 15 ft wide and gently sloped (10:1 H:V) toward the back of the cut (figure 19). In cases where benched cuts are required, the benches should be seeded or sodded. Benches should maintain a gradient for drainage, but should not exceed 3 to 5%. If the upper drainage system is properly constructed (discussed below), it should not be necessary to employ erosion control methods in excess of vegetative cover unless extremely long cuts are made.

If either water content exceeds critical (17%) or the soil is a clayey loess, flattened slopes should be utilized. Generally 2.5:1 (H:V) slopes should perform adequately, but if

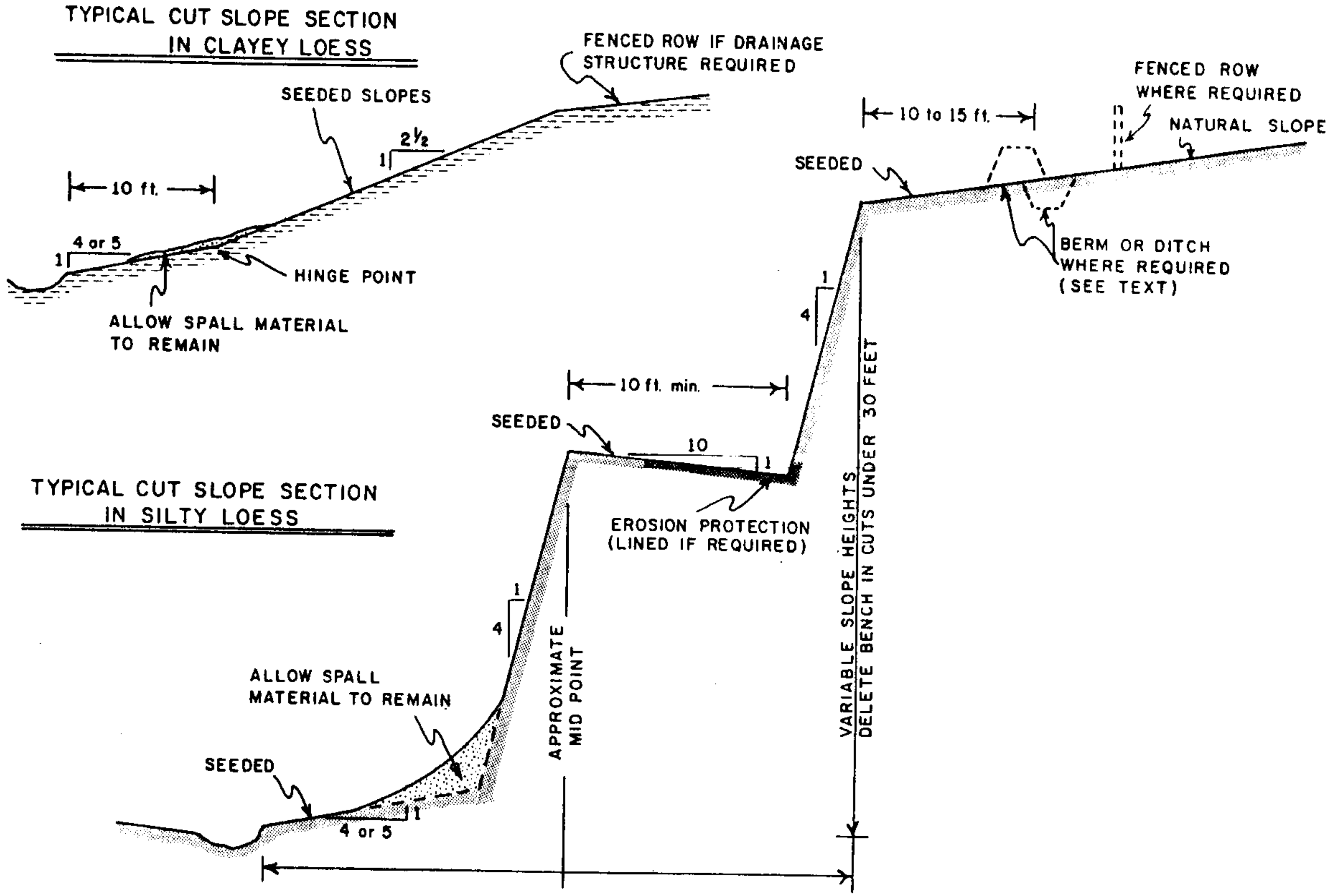

Figure 19. Typical sections for cut slopes in silty and clayey loess.

a water table is intercepted, flatter slopes may be required due to seepage forces. A flattened cut should be seeded immediately following construction. In addition, a protective cover should be placed over the slope, either a straw mulch or a proper synthetic material (figure 19). These covers serve the dual purpose of preventing raindrop erosion, a major cause of erosion on newly opened cuts, and help retain moisture required to initiate a vegetative cover.

These design recommendations are based on observations made during the two research projects. The limit of experience for these slope designs is approximately 50 ft cuts; therefore, deeper cuts require a more detailed stability analysis.

These design recommendations are for homogenous materials and do not account for sandy layers or sandy loess such as might be encountered in the western area of the loess deposit. Under these conditions a conventional soil mechanics approach should be applied.

CHAPTER 6

DRAINAGE DESIGN

Objectives of Drainage Design

Designers of surface water drainage systems around cut slopes in loess should use the following objectives as a basis for design.

1. Prevent water (sheet wash) from flowing over the face of a cut if in silty loess. Prevent concentrated flows from flowing over a cut face in silty and clayey loess.
2. Do not allow water to collect and/or saturate the soil within 10 to 15 ft of the top of the cut face in silty loess. This has been observed as a potential cause of piping.
3. Do not allow water to collect against the toe of the cut in silty or clayey loess. Saturation of the soils in the toe can cause sloughing of the slope.
4. Do not direct flow into unprotected channels (line with vegetation, artificial, or natural materials) in silty or clayey loess. Deep gullies often appear within a short period of time i.e., 1 to 4 years.
5. Avoid disturbance of soil structure and natural vegetation at the crest of the slope cut as much as possible during and after construction to maintain soil strength and erosion resistance.

General Recommendations for Drainage Systems

Based on observations of erosion problems around slope cuts discussed in Chapter 2, the following suggestions are made concerning the drainage required for cut slopes in loess.

Damage from sheetwash over the face of flattened slopes (2 1/2:1 H:V) in clayey loess has been minor if a vegetation cover is maintained. Therefore, surface water diversion above the cut is not necessary unless gullies, swales, channels, and etc., will concentrate flow onto the slope face. For cuts in silty loess (1/4:1 H:V), drainage ditches or berms are recommended to be placed 10 to 15 ft. behind the top of a cut slope, if the drainage area above the cut is inclined toward the cut. This drainageway should be u-shaped or flat bottomed and be lined by some means to protect it from erosion (figure 20). Also, a gradient must be maintained so that water does not stand and saturate the slope.

Drainageways that convey surface water around the sides of cut slopes will often have moderate (5 to 10%) to steep (greater than 10%) gradients. In many cases the required erosion protection in these channels will be more substantial than those at the head of cuts. Specific designs are suggested below.

If natural drainage channels are truncated by a cut, the drainage system should be adequate to transmit the flow around (may require considerable right-of-way, ROW) or over the cut face in lined channels or structures. Direct flow over the

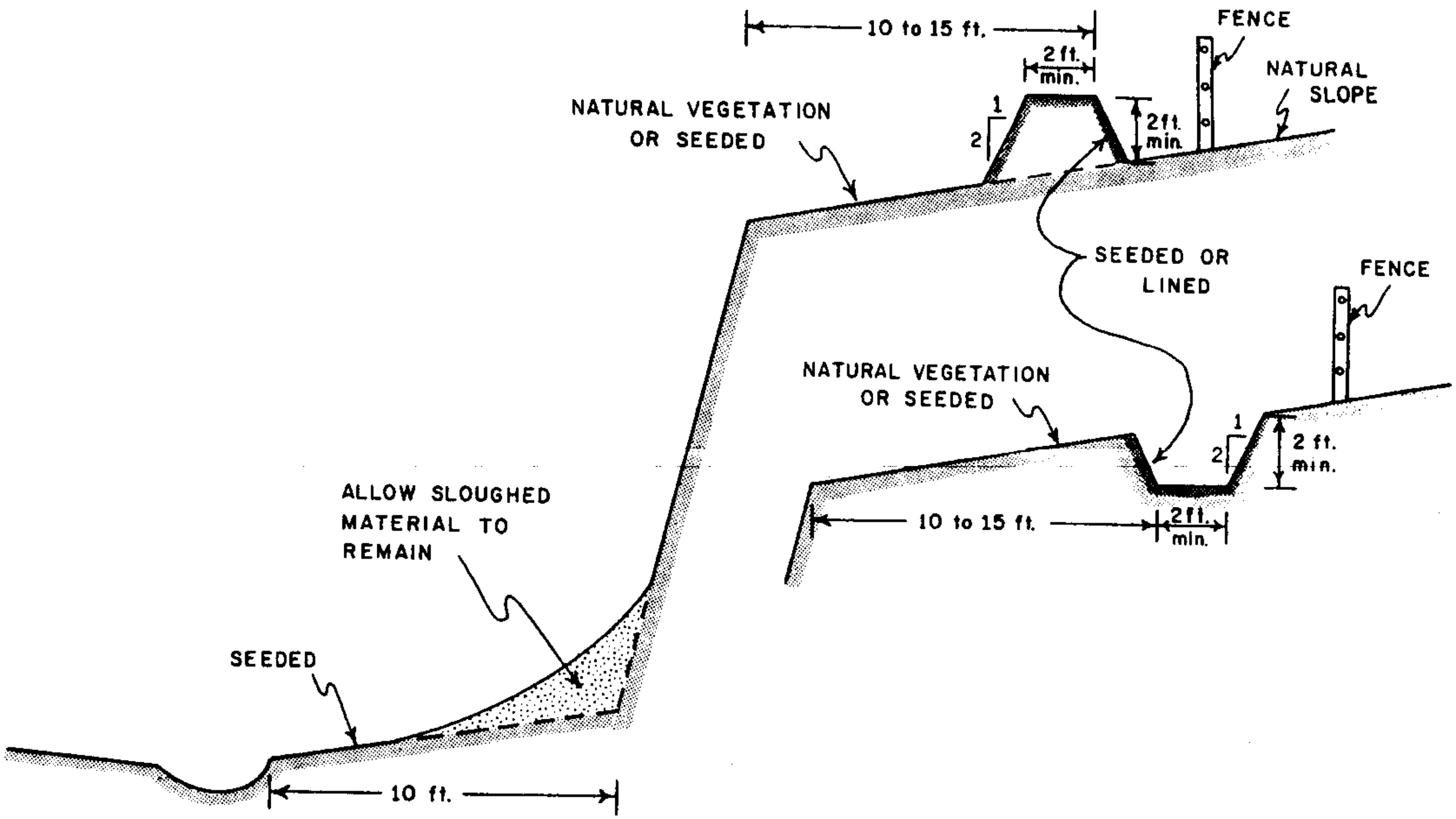

Figure 20. Drainge above a cut slope in silty loess.

cut face must be avoided. All of the drainage structures should be located in a fenced ROW for protection, and the area should be seeded or have the natural vegetation preserved to maintain the soil structure and strength. Access by farm equipment would soon damage or destroy the drainage system and protective cover.

Toe drainage should be accomplished with ditches (u-shaped or flat bottomed) located approximately 10 ft. away from the toe of the slope. The ground slope between the toe of the slope and ditch should be gently inclined toward the ditch (recommended slopes between 4:1 and 5:1 H:V). Any material that spalls downslope between the toe and the ditch should be left in place to protect the toe.

Design Schemes for Surface Drainage

Some of the following drainage designs have been used successfully in other states and some have not. These designs should be incorporated in new construction and monitored for performance. The results of this monitoring should be used to modify this design manual.

Drainageway Above Head of Cut Slope in Silty Loess

Generally, a ditch or berm above the head of a cut slope will have a low (0 to 5%) gradient and flows could be expected to be low in volume and velocity unless a drainage channel or gully is intersected. In this case, a flat bottomed, seeded drainageway should be adequate (assuming that climatic conditions allow a fairly thick vegetative cover to be developed). A mulch or geotextile mat or mesh should be applied to protect the seed. In areas of low rainfall where it is doubtful that a vegetative cover can be maintained, a filter fabric covered with crushed rock or coarse sand can be used. The vegetation and/or filter fabric will hold the soil particles in place and protect against channel scour and piping. The sizing of the material used to cover the fabric should be chosen on the basis of expected flow velocities and should adequately cover the fabric to protect it from damaging ultra violet rays. The filter fabric size should be chosen to prevent scour and piping erosion problems in the underlying loess and be strong enough to survive placement of the rock cover. The maximum gradient at which vegetation (grasses) will provide adequate erosion protection is unknown for these deposits, although a 5% gradient is probably near the upper bound (depending on flow velocities and volumes). WSDOT should experiment in order to optimize this design.

Drainageway Above Cut Slopes in Clayey Loess

Based on observation of performance of the clayey loess slopes, erosion damage by sheetwash over the cut slope is minor if a good vegetation cover is maintained. A drainage structure is necessary only when concentrated flows (gullies, channels, etc.) are directed over the cut face. In this case the drainage design for cuts in silty loess (above) should be followed. Drainage structures over the cut face are discussed below.

Drainageway Around the Sides of Cut Slopes

Drainageways around the sides of cut slopes tend to have moderate (5 to 10%) to high (greater than 10%) gradients, steeper than drainageways above the cut slope. Therefore, these structures may require more erosion protection than for drainageways with low gradients. Four general design schemes are suggested.

a) The drainageway can be lined with filter fabric covered with coarse crushed rock (size dependent on expected flow velocities). This is probably the simplest and cheapest design.

b) The drainage channel can be lined with filter fabric under a gabion blanket. This would accomplish the same task as (a) above, except the gabion structure will allow anchoring of the mat on steep slopes and will hold the individual rocks in place. However, construction of the mat is time consuming.

c) The drainageway can be constructed of a half-round pipe. The pipe would have to be keyed into the upper reaches of the channel to prevent erosion failure. Too, the pipe would have to be placed so that a good seal (compaction) is made between the pipe and soil to prevent erosion along the soil/pipe interface. The compaction activities would tend to disturb (and weaken) the surrounding soil structure. Pipe joints would require a tight seal and seepage collars would be required to prevent leakage and possible piping.

d) Drainage channels can be lined with asphalt or concrete. This approach has been used successfully in Missouri and Illinois; however, it is expensive. Leakage along joints can allow water to seep along the concrete or asphalt/soil interface forming pipes and eventual collapse.

Drainageway Over the Face of a Cut Slope

If a cut slope truncates a drainage basin, it is difficult to channel the surface water around the cut unless enough ROW is acquired to intersect the water substantially up-gradient of the cut. In many cases, this could be 100 to 200 ft or more. Therefore, sometimes a drainage structure is required over the face of the cut.

In the clayey loess area of the state where cuts are 2:1 or flatter (new cuts are recommended to be constructed at 2.5:1 H:V), road cuts often truncate small drainages. Three possible design schemes for drainage over the face of a 2.5:1 or flatter cut slopes in clayey loess are suggested.

a) A shallow ditch can be cut into the cut slope face. It should be flat bottomed and lined with a filter fabric, covered with a gabion mat or coarse rock. The filter fabric should be selected according to the grain size of the underlying soil to prevent erosion or piping under the mat or rock. The mat or rock cover will provide protection for the filter fabric from UV light and will anchor it in place during high flows. Also, the rock and mat blend with the surrounding soil and vegetation.

b) Drainage over a slope face can be accomplished with a half-round pipe. The pipe would need to be keyed into the drainageway above the cut slope to prevent washout of the pipe. The same requirements and disadvantages for placement of the half-round listed above apply in this case.

c) An asphalt or concrete lined drainageway is feasible, but the problems listed above must be considered.

Slope cuts in silty loessial soils of eastern Washington are usually cut near vertical (1/4:1 H:V). Also, silty loess is more susceptible to damage by erosion (scour and piping) than the clayey loess. Therefore, truncation of a drainage by a near vertical cut in silty loess presents some special design problems. Two drainage schemes are suggested in this case.

a) Intercept the drainage high enough above the cut so that it can be channeled around the side of the cut face. In some cases the natural slope (above the cut slope) may be gentle enough that little ROW is required to accomplish this design; however, more often this is not the case and 100 to 200 ft or more of ROW may be required.

b) Water can be routed over the slope face in a PVC pipe which is connected to a collection area (area behind a berm) above the head of the slope cut. If this type of drainage structure is installed, the pipe should be mounted above the ground surface, where possible, to avoid seepage along the outside of the pipe, and the cut slope face should not be disturbed. Therefore, the PVC pipe will need to be anchored above and below the cut face. Also, a splash plate should be installed at the toe of the slope to prevent undercutting and the pipe should be slotted to prevent clogging by ice. This design would be best suited for low to moderate volumes of flow. It is best suited to be combined with a berm drainage system above the cut slope and not recommended for a ditch system (figure 21).

Protection of Right-of-Way (ROW)

The drainage structures should be located in a fenced ROW. A vegetation cover should be maintained in the ROW to protect the soil structure (and strength) near the slope crest. Farming activity up to the edge of a cut slope would rapidly damage or destroy the drainage structures resulting in erosion damage. Also, movement of heavy farm equipment near the crest of a cut tends to disturb the natural soil structure which results in a lower strength, a lower resistance to erosion, and could lead to sudden slope failure along the edge of a near vertical cut. A fenced ROW serves as a protective device for the drainage system as well as a safety measure. For near vertical cuts where drainage structures are not needed, a fenced ROW is also recommended. This will act as a buffer zone to protect the soils and vegetation from disturbance and help maintain the strength of the slope crest for the same reasons as stated above. Cuts in clayey loess

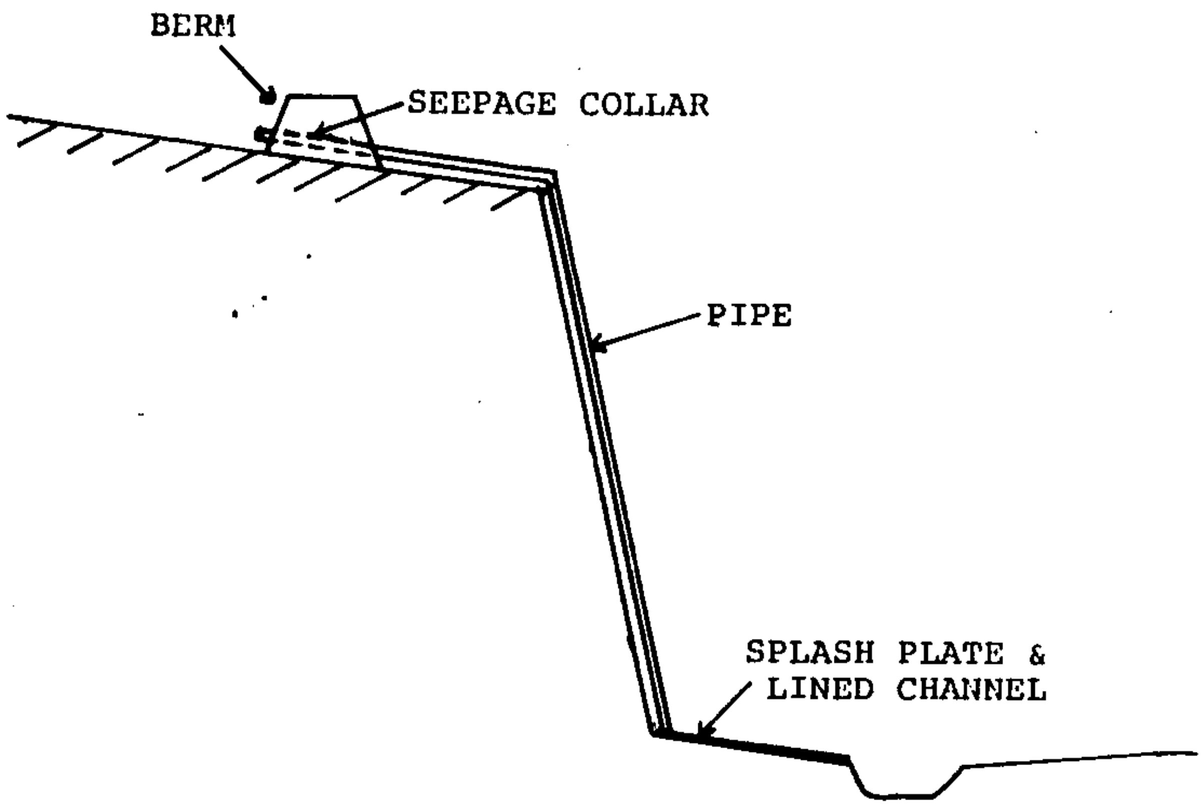

Figure 21. Drainage Over a Cut Face.

(2.5:1 H:V) not requiring a drainage structure may not require a protected ROW; although, some minor damage has been observed because of plowing along the slope crest.

CHAPTER 7

CONSTRUCTION CONTROL CONSIDERATIONS

Considering the adverse effects water has on the stability of loess, construction of cut slopes is best suited for the dry season. The drainage structure above the crest of the cut should be constructed prior to opening of the cut and with as little disturbance to the surrounding vegetation as possible. Once the cut is made, construction equipment should be kept away from the crest.

A flattened cut should be seeded immediately following construction. In addition, a protective cover should be placed over the slope, either a straw mulch or a proper synthetic material. Any area stripped of vegetation, such as a ditch or berm, should be covered with the appropriate material as soon as possible to avoid excessive erosion.

Slopes should be cut uniformally (no compound slopes) to avoid concentration of erosion and undercutting. Also, if animal holes intersected by the cut daylight above the crest where water may easily enter (such as in the drainage structure), they should be backfilled with low permeability fines or grouted behind the crest of the cut. This action is needed in order to avoid development of erosion pipes.

CHAPTER 8

MAINTENANCE

Due to its highly erosive nature, loess slopes will deteriorate very rapidly once erosion is initiated. Thus it is very important to repair any erosion damage as soon as it is discovered. Maintenance may require repairs to, enlargement of, and removal of siltation from existing ditches. Increased erosion protection, such as installation of liners in ditches, or in some cases construction of drainage facilities where they were previously believed to be unnecessary may be required.

Vegetative cover requires periodic attention. In order to maintain a heavy ground cover, fertilizer must be applied every 3 to 5 years (based on midwest experience). In addition, some areas will not seed well the first time and may require a second and possibly third seeding. Also, even small damaged spots should be seeded immediately.

Removal of sediment from toe ditches on existing slopes should be done carefully to avoid undercutting of the toe of the slope. Even minor undercutting will cause at least some sloughing, and therefore the grader blade should not contact the slope cut.

REFERENCES

Higgins, J.D., Fragaszy, R.J., and Martin, T., 1987, Engineering Design in Loess Soils of Southeastern Washington. Washington State Department of Transportation Report WA-RD 145.1, Olympia WA, 121 p.

Higgins, J.D., Fragaszy, R.J., and Beard, L.D., 1985, Development of Guidelines for Cuts in Loess Soils (Phase 1). Washington State Department of Transportation Report WA-RD69.1, Olympia, WA, 90 p.

APPENDIX

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

LOESS SLOPE DESIGN CHECKLIST

The Loess Site Design Checklist has been prepared to aid the geotechnical engineer in the preliminary site investigation, field investigation layout, and design evaluation of highway construction in a loess soil region where cut slopes are required. This checklist must be used in conjunction with the Design Manual For Cut Slopes in Loess and the Washington State Department of Transportation (WSDOT) Geotechnical Report Guidelines.

The checklist has been organized into five categories. The five categories include:

1) Project Definition
2) Project Field Data
3) Geotechnical Investigation
4) Laboratory Testing
5) Design Evaluation and Recommendations

<u>Project Definition</u>

		Yes	No	N/A
1.	Is the proposed construction within a loess region?	___	___	___
	If yes, what loess type is present? (Figure 1, Design Manual)	___ Sandy Loess ___ Silty Loess ___ Clayey Loess		
2.	Does the proposed construction involve complete realignment?	___	___	___
3.	Does the proposed construction involve minor realignment?	___	___	___
4.	Has an assessment been made of the current land management activities, e.g. review recent aerial photography?	___	___	___
5.	Has an assessment been made of the potential for land use changes, e.g. converting dryland farming to irrigation farming?	___	___	___

Project Field Data

	Yes	No	N/A
1. Is a county soil survey report available for review?	___	___	___
If yes, answer the following:			
a. Have major soil types along proposed route been identified?	___	___	___
b. Have important soil parameters of those major soil types been identified? i.e. grain size distribution, % clay vs. depth, permeability, drainage, depth to bedrock, agricultural use, irrigation potential.	___	___	___
2. Have plans, profiles and cross sections been reviewed?	___	___	___
3. Do the cross sections show the existing ground line beyond the top of the proposed cut?	___	___	___
4. Have all major cut and fill slopes been located?	___	___	___
5. What cut slope inclinations are desired by the District:			
___1/4:1 ___2.5:1 or ___other			
If other, identify what cut slope angle is proposed and why.			
6. If 1/4:1 cuts are proposed, is there sufficient right-of-way to accommodate the required drainage facilities and fencing?	___	___	___
7. Are there any existing or proposed structures present near the top of the proposed backslope?	___	___	___

Geotechnical Investigation

		Yes	No	N/A
1.	Does the site investigation meet the minimum requirements established by WSDOT and FHWA, e.g. frequency of sampling holes, depth of holes, sample frequency, hole locations, etc.?	___	___	___
2.	Were all major cuts represented by samples taken at depth in the loess?	___	___	___
3.	Were all cut slope aspects represented in the sampling process?	___	___	___
4.	On projects where minor sliver cuts are required, did sampling (hand auger holes) along the face of the existing cut extend a minimum of 4 feet into the face?	___	___	___
5.	Has the soil sampling been continuous in the top 6 feet and then every 5 feet thereafter?	___	___	___
6.	Was the soil investigation conducted during the wet time of year?	___	___	___
7.	Was natural field moisture determined from samples sealed in soil sample cans?	___	___	___
8.	Was ground water encountered in any of the test borings?	___	___	___
	If yes, were piezometers installed for monitoring purposes?	___	___	___
9.	Is the ground water perched on an impermeable layer (i.e. bedrock)?	___	___	___
10.	Will the proposed cut daylight the ground-water table?	___	___	___
11.	Has a field review of the condition of existing loess slope cuts been made?	___	___	___
12.	What is the repose of the existing cuts in the vicinity of the proposed project?	___	___	___

13. Are the existing cuts in
___good, ___average, ___poor condition?
Explain in detail.

Laboratory Testing

	Yes	No	N/A
1. Have Atterberg limits been performed?	___	___	___
2. Have hydrometer tests been performed?	___	___	___
3. Have sieve analyses been performed?	___	___	___
4. Has field moisture been calculated?	___	___	___
5. Has the shear strength been determined on representative samples from cuts exceeding 50 feet in height?	___	___	___

Design Evaluation and Recommendations

	Yes	No	N/A
1. Has the laboratory data been summarized, i.e. graphs representing % clay vs depth, and % field moisture with depth?	___	___	___
2. Based on criteria in Chapter 4 and Figure 1 of Design Manual for Cut Slopes in Loess has the project loess soil been appropriately classified as to type and critical moisture?	___	___	___
3. Are the recommended cuts based on guidelines in Chapter 5 of the Design Manual?	___	___	___
If answer is no, is a justification given?	___	___	___
4. Were there specific recommendations made for erosion control, e.g. backslopes, sideslopes, ditches? (This is <u>absolutely critical</u> to the successful use of cutslopes in loess; surface runoff must be collected and discharged so as not to saturate and erode the cut face.)	___	___	___

	Yes	No	N/A
5. If 1/4:1 cut slopes are recommended, answer the following:			
a. Has a drainage profile along the proposed ditch been established?	___	___	___
b. Does the ditch extend to a cut/fill transition or to a drainage structure?	___	___	___
c. If the gradient of the ditch exceeds 5% is there the provision for ditch erosion protection i.e. asphalt or concrete or rock/fabric lined ditch?	___	___	___
d. Is there the provision for discharging water (without saturating the cut slope) from the ditch to the road grade line at low water collection points along the ditch profile?	___	___	___
e. Is the proposed drainage ditch a minimum of 10 feet from the face of the 1/4:1 cut slope?	___	___	___
f. Does the design include the construction of a controlled access fence?	___	___	___
6. If 2.5:1 cut slopes are recommended answer the following:			
a. If the cut intersects a natural drainageway have provisions been made to discharge the water over or around the face?	___	___	___
b. Where soil is exposed to concentrated flow, such as in a ditch, is there provision for erosion protection?	___	___	___