Chapter 10 Soil Cut Design

10.1 Overview and Data Acquisition

10.1.1 Overview

During the project definition phase, the project designer provides a description of the proposed cuts to the Region Materials Engineer (RME) as outlined in the *Design Manual* M 22-01 Chapter 510. The designer may prepare preliminary cross sections using the criteria presented in *Design Manual* M 22-01 Section 640.07. For side hill conditions the cross sections should extend up to the top of the hill or a controlling feature such as a rock outcrop or level bench. The RME with assistance from the HQ Geotechnical Division as needed, reviews existing information, performs a site reconnaissance and provides conceptual recommendations.

During the project design phase the subsurface investigation is completed and the cut slope design recommendations are prepared. Included in the recommendations are the slope inclinations required for stability, mitigation requirements if needed and the usability of excavated cut material. Typically for cut slope design, adequate geotechnical information is provided during the project design phase to complete the PS&E Development. Additional geotechnical work might be needed when right of way cannot be obtained or design requirements change.

10.1.2 Site Reconnaissance

General procedures for site reconnaissance are presented in Chapter 2. Special considerations for cut slopes should be made during the office and site review. The office review of aerial photos from different dates may reveal if there has been any change in slope angle or vegetation over time. Landforms identified on the photos should be field checked to determine if they can be related to geologic processes and soil type.

The existing natural and cut slopes in the project vicinity should be inspected for performance. Measure the inclination and height of existing cut slopes, and look for erosion or slope stability problems. Ask the regional maintenance engineer about any stability/erosion problems with the existing cut slopes. In general, if stable slopes will be cut back into an existing slope 10 feet or less and at the same or flatter angle of inclination, the slope height does not increase significantly because of the cut, there is no evidence of instability, there is no evidence the material type is likely to be different at the excavation face, and there is no potential for seepage to be encountered in the cut, then typically no further exploration will be required.

Observation of existing slopes should include vegetation, in particular the types of vegetation that may indicate wet soil. Indirect relationships, such as subsurface drainage characteristics may be indicated by vegetative pattern. Assess whether tree roots may be providing anchoring of the soil and if there are any existing trees near the top of the proposed cut that may become a hazard after the cut is completed.

Changes in ground surface slope angle may reflect differences in physical characteristics of soil and rock materials or the presence of water.

For cuts that are projected to be less than 10 feet in height, determine if further exploration is warranted based on soil type and extent.

10.1.3 Field Exploration

10.1.3.1 Test Borings

A minimum of one boring should be performed for each proposed soil cut slope greater than about 10 feet in height. For longer cuts, horizontal spacing for borings parallel to the cut should generally be between 200 to 400 feet, based on site geology. Wider spacing may be considered if, based on existing data and site geology, conditions are likely to be uniform and of low impact to construction and long-term cut slope performance. Each landform should be explored, and the borings should be spaced so that the extent of each soil type present is reasonably determined. At critical locations where slope stability analysis is necessary, additional borings perpendicular to the cut should be provided in order to model existing geologic conditions for use in slope stability analysis. The exploration program should also be developed with consideration to the potential for use of the removed material as a source for fill material elsewhere on the project. If the construction contract is set up with the assumption that the cut material can be used as a materials source for fill or other uses on the project, it is important to have adequate subsurface information to assess how much of the cut material is useable for that purpose. A key to the establishment of exploration frequency for embankments is the potential for the subsurface conditions to impact the construction of the cut, the construction contract in general, and the long-term performance of the finished project. The exploration program should be developed and conducted in a manner that these potential problems, in terms of cost, time, and performance, are reduced to an acceptable level. The boring frequency described above may need to be adjusted by the geotechnical designer to address the risk of such problems for the specific project.

Borings should extend a minimum of 15 feet below the anticipated depth of the cut at the ditch line to allow for possible downward grade revision and to provide adequate information for slope stability analysis. Boring depths should be increased at locations where base stability is a concern due to groundwater and/or soft or weak soil zones. Borings should extend through any weak zones into competent material.

Hand augers, test pits, trenches or other similar means of exploration may be used for investigating subsurface conditions for sliver cuts (additional cut in an existing natural or cut slope) or shallow cuts, if the soil conditions are known to be fairly uniform.

10.1.3.2 Sampling

For soil cuts, it is important to obtain soil samples in order to perform laboratory index tests such as grain size analysis, natural moisture content and Atterberg limits. This is generally the best way to define site stratigraphy. In situ testing can be used to augment the exploration program. However, information obtained from site specific samples is necessary to verify and place in proper context soil classification, strength and compressibility parameters obtained from in situ tests. Sampling should be performed for the purpose of cut stability assessment and assessment of the cut material as a materials source, if the cut material is needed as a materials source. Special considerations for loess slopes are discussed later in this chapter.

For granular soils, SPT samples at 5 feet intervals and at changes in strata are generally sufficient. A combination of SPTs and undisturbed thin-wall push tube (i.e. WSDOT undisturbed or Shelby tube) should be used in cohesive soil. The vane shear test (VST) may also be performed in very soft to soft cohesive soil. In general, the VST should be used in conjunction with laboratory triaxial testing unless there is previous experience with the VST at the site. The pressuremeter test (PMT) and dilatometer test (DMT) are expensive and generally have limited applicability for cut slope design, but are useful for determining shear strength and overconsolidation ratio in stiff to hard cohesive soil.

Because it is generally desirable to obtain samples for laboratory testing, the static cone penetration test (CPT) is not often used for routine exploration of cut slopes. However, the CPT provides continuous data on the stratigraphic profile and can be used to evaluate in situ strength parameters in very soft to medium stiff cohesive soil and very loose to medium dense sands.

10.1.3.3 Groundwater Measurement

Knowledge of groundwater elevations is critical for the design of cut slopes. The presence of groundwater within or just below a proposed cut will affect the slope angle required to achieve and maintain stability. For example, the presence of groundwater near the base of a proposed cut slope in loess will preclude making a near vertical slope. Substantially more right-of-way may be required to construct a flatter slope. Measurement of groundwater and estimates of its fluctuations are also important for the design of appropriate drainage facilities. Groundwater that daylights within a proposed cut slope may require installation of horizontal drains (generally for coarser grained cohesionless soils) or other types of drainage facilities. Groundwater near the toe of slopes may require installation of underdrains. Groundwater measurements are also important if slope stability analysis is required.

In granular soil with medium to high permeability, reliable groundwater levels can sometimes be obtained during the drilling program. At a minimum, groundwater levels should be obtained at completion of drilling after the water level has stabilized and 12 hours after drilling is completed for holes located in medium to high permeability soils. In low permeability soils false water levels can be recorded, as it often takes days for water levels to reach equilibrium; the water level is further obscured when drilling fluid is used. In this case piezometers should be installed to obtain water levels after equilibrium has been reached. Piezometers should be installed for any major cuts, or as determined by the geotechnical designer, to obtain accurate water level information.

If slope stability analysis is required or if water levels might be present near the face of a cut slope, piezometers should be installed in order to monitor seasonal fluctuations in water levels. Monitoring of piezometers should extend through at least one wet season (typically November through April). Continuous monitoring can be achieved by using electrical piezometers such as vibrating wire type in conjunction with digital data loggers.

Values of permeability and infiltration rates are generally determined based on correlations with grain size and/or knowledge of the site soil based on previous experience. However, borehole permeability tests, such as slug or pump tests, may be performed in order to design drainage facilities, especially if horizontal drains may be used.

10.1.4 Laboratory Testing

Standard classification tests should be performed on representative samples for all soil cut slopes. These tests include gradation analysis, moisture content, and Atterberg limits. These tests will provide information to aid in determining appropriate slope inclinations, drainage design, and usability of the cut material as a materials source for earthwork on the project. Additional tests will often be required to determine the suitability of reusing soil excavated from a cut for other purposes throughout the project. Examples include organic content to determine if a soil should be classified as unsuitable and compaction testing to aid in determining the optimum moisture content and shrink/swell factors for earthwork calculations. pH and corrosivity tests should also be performed on samples at locations for proposed drainage structures.

If it is determined by the geotechnical designer that slope stability analysis should be performed, laboratory strength testing on undisturbed samples may be required. Slope stability analysis requires accurate information of soil stratigraphy and strength parameters, including cohesion ($\underline{c}$'), friction angle (ϕ'), undrained shear strength (S_u), and unit weight for each layer. In-place density measurements can be determined from WSDOT undisturbed, Dames and Moore, or Shelby tube samples.

Cohesive soil shear strength parameters should be obtained from undisturbed soil samples using consolidated undrained triaxial tests with pore pressure measurement if portions of the proposed slope are saturated or might become saturated in the future. Effective strength parameters from these tests should be used to analyze cohesive soil cut slopes and evaluate long term effects of soil rebound upon unloading. Unconsolidated undrained (UU) triaxial tests or direct shear tests can be used to obtain undrained shear strength parameters for short term stability analysis, or when it is determined by the geotechnical designer that total stress/strength parameters are sufficient. The choice of which test to perform should be determined by the expected stress condition in the soil in relation to the anticipated failure surface. It should be understood, however, that strength parameters obtained from unsaturated tests are dependent on the moisture content at which the tests are performed. If the moisture content of the soil in question increases in the future, even to levels still below saturation, the shear strength might be significantly reduced, especially for cohesive soils. <u>Ring</u> shear tests can be performed to determine residual shear strength parameters for soils located in existing landslide areas. <u>Repeated direct shear tests have been used in the past to obtain residual strength parameters, but research has shown that this approach tends to over-estimate the residual strength, unless a slickensided surface in the specimen can be oriented such that the direct shear test fails the specimen on that pre-existing surface (Sabatini, et al., 2002).</u> Residual strength parameters should also be obtained for cuts in heavily overconsolidated clays, such as the Seattle clays (e.g., Lawton formation), as the removal of soil can release locked in stresses and allow the clay to deform, causing its strength to drop to a residual value.

It should be noted that for unsaturated soils, particularly cohesive soils, the natural moisture content of the soil at the time of testing must be determined since this will affect the results. Consideration should be given during stability analysis to adjusting strength parameters to account for future changes in moisture content, particularly if field testing was performed during the dry summer months and it is possible that the moisture content of the soil will likely increase at some point in the future. In this case using the values obtained from the field directly may lead to unconservative estimates of shear strength.

10.2 Overall Design Considerations

10.2.1 Overview

Small cut slopes are generally designed based on past experience with similar soils and on engineering judgment. Cut slopes greater than 10 feet in height usually require a more detailed geotechnical analysis. Relatively flat (2H:1V or flatter) cuts in granular soil when groundwater is not present above the ditch line, will probably not require rigorous analysis. Any cut slope where failure would result in large rehabilitation costs or threaten public safety should obviously be designed using more rigorous techniques. Situations that will warrant more in-depth analysis include large cuts, cuts with irregular geometry, cuts with varying stratigraphy (especially if weak zones are present), cuts where high groundwater or seepage forces are likely, cuts involving soils with questionable strength, or cuts in old landslides or in formations known to be susceptible to landsliding.

A major cause of cut slope failures is related to the release of stress within the soil upon excavation. This includes undermining the toe of the slope and oversteepening the slope angle, or as mentioned previously, cutting into heavily overconsolidated clays. Careful consideration should be given to preventing these situations for cut slopes by keeping the base of the slope as loaded as possible, by choosing an appropriate slope angle (i.e. not oversteepening), and by keeping drainage ditches near the toe a reasonable distance away. For heavily overconsolidated clays, retaining walls rather than an open cut may be needed that will prevent the deformation necessary to allow the soil strength to go to a residual value.

Consideration should also be given to establishing vegetation on the slope to prevent long-term erosion. It may be difficult to establish vegetation on slopes with inclinations greater than 2H:1V without the use of erosion mats or other stabilization method.

10.2.2 Design Parameters

The major parameters in relation to design of cut slopes are the slope angle and height of the cut. For dry cohesionless soil, stability of a cut slope is independent of height and therefore slope angle becomes the only parameter of concern. For purely cohesive (ϕ= 0) soils, the height of the cut becomes the critical design parameter. For c’-ϕ’ and saturated soils, slope stability is dependent on both slope angle and height of cut. Also critical to the proper design of cut slopes is the incorporation of adequate drainage facilities to ensure that future stability or erosional problems do not occur.

10.3 Soil Cut Design

10.3.1 Design Approach and Methodology

Safe design of cut slopes is based either on past experience or on more in-depth analysis. Both approaches require accurate information regarding geologic conditions obtained from standard field and laboratory classification procedures. Cut slope heights and inclinations provided in the *Design Manual* M 22-01 can be used unless indicated otherwise by the Geotechnical Designer. If the Geotechnical Designer determines that a slope stability study is necessary, information that will be needed for analysis include: an accurate cross section showing topography, proposed grade, soil unit profiles, unit weight and strength parameters (c', ϕ'), (c, ϕ), or S_u (depending on soil type and drainage and loading conditions) for each soil unit, and location of the water table and flow characteristics.

Generally, the design factor of safety for static slope stability is 1.25. For pseudo-static seismic analysis the factor of safety can be decreased to 1.1. Cut slopes are generally not designed for seismic conditions unless slope failure could impact adjacent structures. These factors of safety should be considered as minimum values. The geotechnical designer should decide on a case by case basis whether or not higher factors of safety should be used based the consequences of failure, past experience with similar soils, and uncertainties in analysis related to site and laboratory investigation.

Initial slope stability analysis can be performed using simple stability charts. See Abramson et al. (1996) for example charts. These charts can be used to determine if a proposed cut slope might be subject to slope failure. If slope instability appears possible, or if complex conditions exist beyond the scope of the charts, more rigorous computer methods such XSTABL, PCSTABL, SLOPE/W, etc. can be employed (see Chapter 7). As stated previously, effective use of these programs requires accurate determination of site geometry including surface profiles, soil unit boundaries, and location of the water table, as well as unit weight and strength parameters for each soil type.

Because of the geology of Washington, many soil cuts will likely be in one of five typical types of deposits. These soils can be grouped based on geologic history and engineering properties into residual soil, alluvial sand and gravel, glacially overconsolidated soil, colluvial deposits, and loess deposits. A design procedure has been developed for loess slopes and is presented later in this chapter. A brief discussion of the other three soil types follows:

Residual Soil – The most typical residual soil is encountered in the Coast Range in the southwest part of the state. Other residual soil units weathered from rock formations such as the Renton, Cowlitz, Ellensburg and Ringold are also encountered in other parts of the state. However, the soil in the coast range is the most extensive residual soil found in the state and is the focus of this discussion. These soils have formed from weathering of siltstone, sandstone, claystone and tuff, and typically consist of soft to stiff silt, elastic silt and lean clay with varying amounts of rock fragments, sand and fat clay. Because of the cohesive nature of the soil and the angular rock fragments, the soils often form fairly steep natural slopes. Root strength from dense vegetation also contributes to the steep slopes. Logging a slope can often cause it to become unstable within a few years. These slopes are likely to become at least partially saturated during the winter and spring months. Groundwater also tends to move unevenly through the soil mass following zones of higher permeability such as sand layers and relict bedding and joint planes. For this reason, determination of representative groundwater elevations with the use of open standpipe piezometers may be difficult.

These slopes should generally be designed using total stress parameters to assess short-term strength during initial loading, and also using effective stress parameters to assess long-term stability; however, laboratory testing in these soils can be problematic because of variability and the presence of rock fragments. Shallow surface failures and weak zones are common. Typical design slopes should generally be 2H:1V or flatter. Vegetation should be established on cut slopes as soon as possible.

Alluvial Sand and Gravel Deposits – Normally consolidated sand and gravel deposits in Washington are the result of several different geologic processes. Post glacial alluvial deposits are located along existing rivers and streams and generally consist of loose to medium dense combinations of sand, gravel, silt and cobbles. In the Puget Sound region, extensive recessional outwash deposits were formed during the retreat of glacial ice. These deposits generally consist of medium to very dense, poorly graded sand and gravel with cobbles, boulders and varying amounts of silt.

In eastern Washington, extensive sand and gravel deposits were deposited during catastrophic outburst floods from glacially dammed lakes in Montana. These deposits often consist of loose to dense, poorly graded sand and gravel with cobbles and boulders and varying amounts of silt. Slopes in sand and gravel deposits are generally stable at inclinations of from 1.5H:1V to 2H:1V, with the steeper inclinations used in the more granular soil units with higher relative densities. Perched water can be a problem, especially in western Washington, when water collects along zones of silty soil during wet months. These perched zones can cause shallow slope failures. If significant amounts of silt are not present in the soil, vegetation is often difficult to establish.

Glacially Overconsolidated Deposits – Glacially consolidated soils are found mainly in the Puget Sound Lowland and the glacial valleys of the Cascades. For engineering purposes, these deposits can generally be divided into cohesionless and cohesive soil. The cohesionless soil deposits are poorly sorted and consist of very dense sand and gravel with silt, cobbles, and boulders. The soil units exhibit some apparent cohesion because of the overconsolidation and fines content. If little or no groundwater is present, slopes will stand at near vertical inclinations for fairly long periods of time. However, perched groundwater on low permeability layers is very often present in these slopes and can contribute to instability. Typical inclinations in these soils range from 1.75H:1V to 1H:1V; although, the steeper slope inclinations should be limited to slopes with heights of about 20 feet or less. These slopes also work well with rockeries at slopes of 1H:6V to 1H:4V.

Overconsolidated cohesive soils such as described in Section 5.13.3 consist of very stiff to very hard silt and clay of varying, and may contain fissures and slickensides. These soils may stand at near vertical inclinations for very limited periods of time.

The relaxation of the horizontal stresses cause creep and may lead to fairly rapid failure. Slopes in these soils should be designed based on their residual friction angle and often need to be laid back at inclinations of 4H:1V to 6H:1V. See Section 5.13.3 for specific requirements regarding the design of slopes in this type of deposit.

10.3.2 Seepage Analysis and Impact on Design

The introduction of water to a slope is a common cause of slope failures. The addition of water often results in a reduction in shear strength of unsaturated soils. It raises the water table and adds to seepage forces, raising pore pressures and causing a corresponding reduction in effective stress and shear strength in saturated soil. Finally, it adds weight to the soil mass, increasing driving forces for slope failures. In addition, it can cause shallow failures and surface sloughing and raveling. These problems are most common in clay or silt slopes. It is important to identify and accurately model seepage within proposed cut slopes so that adequate slope and drainage designs are employed.

For slope stability analysis requiring effective stress/strength parameters, pore pressures have to be known or estimated. This can be done using several methods. The phreatic (water table) surface can be determined by installing open standpipes or observation wells. This is the most common approach. Piezometric data from piezometers can be used to estimate the phreatic surface, or peizometric surface if confined flow conditions exist. A manually prepared flow net or a numerical method such as finite element analysis can be used provided sufficient boundary information is available. The pore pressure ratio (r_u) can also be used. However, this method is generally limited to use with stability charts or for determining the factor of safety for a single failure surface.

10.3.3 Drainage Considerations and Design

The importance of adequate drainage cannot be overstated when designing cut slopes. Surface drainage can be accomplished through the use of drainage ditches and berms located above the top of the cut, around the sides of the cut, and at the base of the cut. The following section on cut slopes in loess contains a more in-depth discussion on surface drainage.

Subsurface drainage can be employed to reduce driving forces and increase soil shear strength by lowering the water table, thereby increasing the factor of safety against a slope failure. Subsurface conditions along cut slopes are often heterogeneous. Thus, it is important to accurately determine the geologic and hydrologic conditions at a site in order to place drainage systems where they will be the most effective. Subsurface drainage techniques available include cut-off trenches, horizontal drains and relief wells.

Cut-off trenches are constructed by digging a lateral ditch near the top of the cut slope to intercept ground water and convey it around the slope. They are effective for shallow groundwater depths. If the groundwater table needs to be lowered to a greater depth, horizontal drains can be installed, if the soils are cohesionless and granular in nature. Horizontal drains are generally not very effective in finer grained soils. Horizontal drains consist of small diameter holes drilled at slight angles into a slope face and backfilled with perforated pipe wrapped in drainage geotextile. Installation might be difficult in soils containing boulders, cobbles or cavities. Horizontal drains require periodic maintenance as they tend to become clogged over time. Relief wells can be used in situations where the water table is at a great depth. They consist of vertical holes cased with perforated pipe connected to a disposal system such as submersible pumps or discharge channels similar to horizontal drains. They are generally not common in the construction of cut slopes.

Whatever subsurface drainage system is used, monitoring should be implemented to determine its effectiveness. Typically, piezometers or observation wells are installed during exploration. These should be left in place and periodic site readings should be taken to determine groundwater levels or pore pressures depending on the type of installation. High readings would indicate potential problems that should be mitigated before a failure occurs.

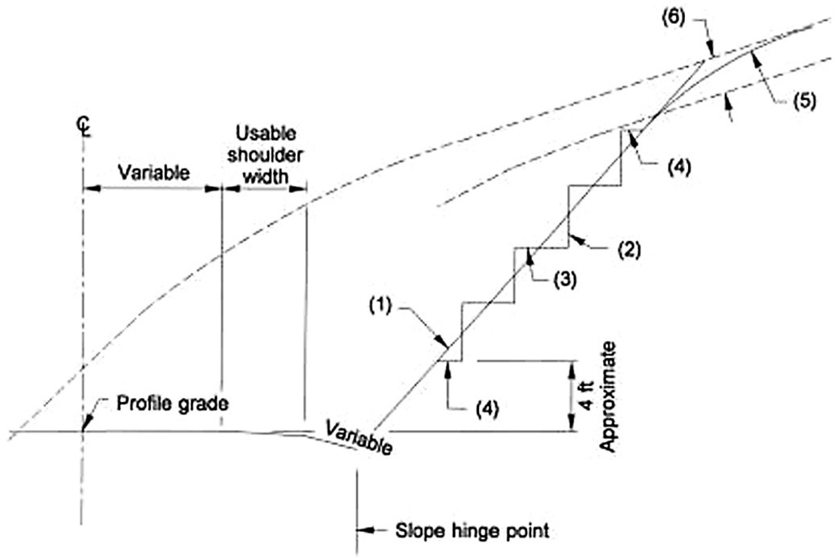
Surface drainage, such as brow ditches at the top of the slope, and controlling seepage areas as the cut progresses and conveying that seepage to the ditch at the toe of the cut, should be applied to all cut slopes. Subsurface drainage is more expensive and should be used when stability analysis indicates pore pressures need to be lowered in order to provide a safe slope. The inclusion of subsurface drainage for stability improvement should be considered in conjunction with other techniques outlined below to develop the most cost effective design meeting the required factor of safety.

10.3.4 Stability Improvement Techniques

There are a number of options that can be used in order to increase the stability of a cut slope. Techniques include:

- Flattening slopes
- Benching slopes
- Lowering the water table (discussed previously)
- Structural systems such as retaining walls or reinforced slopes.

Changing the geometry of a cut slope is often the first technique considered when looking at improving stability. For flattening a slope, enough right-of-way must be available. As mentioned previously, stability in purely dry cohesionless soils depends on the slope angle, while the height of the cut is often the most critical parameter for cohesive soils. Thus, flattening slopes usually proves more effective for granular soils with a large frictional component. Benching will often prove more effective for cohesive soils. Benching also reduces the amount of exposed face along a slope, thereby reducing erosion. Figure 10.1 shows the typical configuration of a benched slope. Structural systems are generally more expensive than the other techniques, but might be the only option when space is limited.



Notes:
(1) Staked slope line - Maximum slope 1H:1V.
(2) Step rise - heaight variable 1 foot to 2 feet.
(3) Step tread - width = staked slope ratio × step rise.
(4) Step termini - width = 1/2 step tread width.
(5) Slope rouding.
(6) Overburden area - variable slope ratio.

Typical Roadway Section With Stepped Slopes
(From Design Manual Figure 1230-8)
Figure 10-1

Shallow failures and sloughing can be mitigated by placing 2 to 3-foot thick rock drainage blanket over the slope in seepage areas. Moderate to high survivability permanent erosion control geotextile should be placed between native soil and drain rock to keep fines from washing out and/or clogging the drain rock.

In addition, soil bioengineering can be used to stabilize cut slopes against shallow failures (generally less than 3 feet deep), surface sloughing and erosion along cut faces. Refer to the *Design Manual* M 22-01 Chapter 940 for uses and design considerations of soil bioengineering.

10.3.5 Erosion and Piping Considerations

Surface erosion and subsurface piping are most common in clean sand, nonplastic silt and dispersive clays. Loess is particularly susceptible. However, all cut slopes should be designed with adequate drainage and temporary and permanent erosion control facilities to limit erosion and piping as much as possible. See Sections *10.3.3* and *10.5* for more information on drainage structures.

The amount of erosion that occurs along a slope is a factor of soil type, rainfall intensity, slope angle, length of slope, and vegetative cover. The first two factors cannot be controlled by the designer, but the last three factors can. Longer slopes can be terraced at approximate 15- to 30-foot intervals with drainage ditches installed to collect water. Best Management Practices (BMPs) for temporary and permanent erosion and stormwater control as outlined in the WSDOT *Highway Runoff Manual* and WSDOT *Roadside Manual* should always be used. Construction practices should be specified that limit the extent and duration of exposed soil. For cut slopes, consideration should be given to limiting earthwork during the wet season and requiring that slopes be covered as they are exposed, particularly for highly erodable soils mentioned above.

10.4 Use of Excavated Materials

The suitability of soil excavated from a roadway cut section for reuse should be determined by a combination of site reconnaissance, boring information and laboratory testing. Soil samples obtained from SPT testing are generally too small to be used for classifying soils as gravel borrow, select borrow, etc. Bulk soil samples obtained from test pits are more appropriate to determine the appropriate engineering characteristics, including compaction characteristics, of all soil units.

Based on the exploration and laboratory testing program, the geotechnical designer should determine the extent of each soil unit, the preferred uses for each unit (i.e. common fill, structural fill, drain rock, riprap, etc.), and any measures necessary for improvement of soil units to meet a particular specification. Soil excavated from within the roadway prism intended for use as embankment fill should generally meet, as a minimum, *Standard Specification* 9-03.14(3) for common borrow. However, both common borrow and select borrow are not usable as an all weather material. If all weather use is desired, the material should meet the specifications for gravel borrow per the WSDOT Standard Specifications. Any soil units considered unsuitable for reuse such as highly plastic soil, peat, and muck should be identified.

Consideration should be given to the location and time of year that construction will likely take place. In western Washington, in place soil that is more than a few percentage points over optimum moisture content is often impractical to aerate and dry back and must be wasted, stockpiled for later use or conditioned with admixtures. Even glacially overconsolidated soil with a high fines content that is near the optimum moisture content may become too wet for proper compaction during excavation, haul and placement. Laboratory testing consisting of the standard and modified Proctor (ASSHTO T 99 and T 180, respectively) tests should be performed on bulk samples, if the fines content indicates the soil may be moisture sensitive (generally more than about 10 percent). The *Standard Specification Section* 2-03.3(14)D requires that maximum density for soil with more than 30 percent by weight retained on the U.S. No. 4 sieve be determined by WSDOT Test Method 606. Test Method 606 does not provide reliable information on the optimum moisture content for placement. Therefore, the modified Proctor test should be performed to determine the optimum moisture.

Techniques such as adding portland cement to stabilize wet soil have been used on WSDOT projects in the past. The addition of cement can lower the moisture content of soil a few percent and provide some strength. However, concerns regarding the pH of runoff water from the project site may limit the use of this technique on some sites. The FHWA Publication "Soil and Base Stabilization and Associated Drainage Considerations, Volumes 1 and 2" (SA-93-004 & SA-93-005) provide additional information on soil amendments.

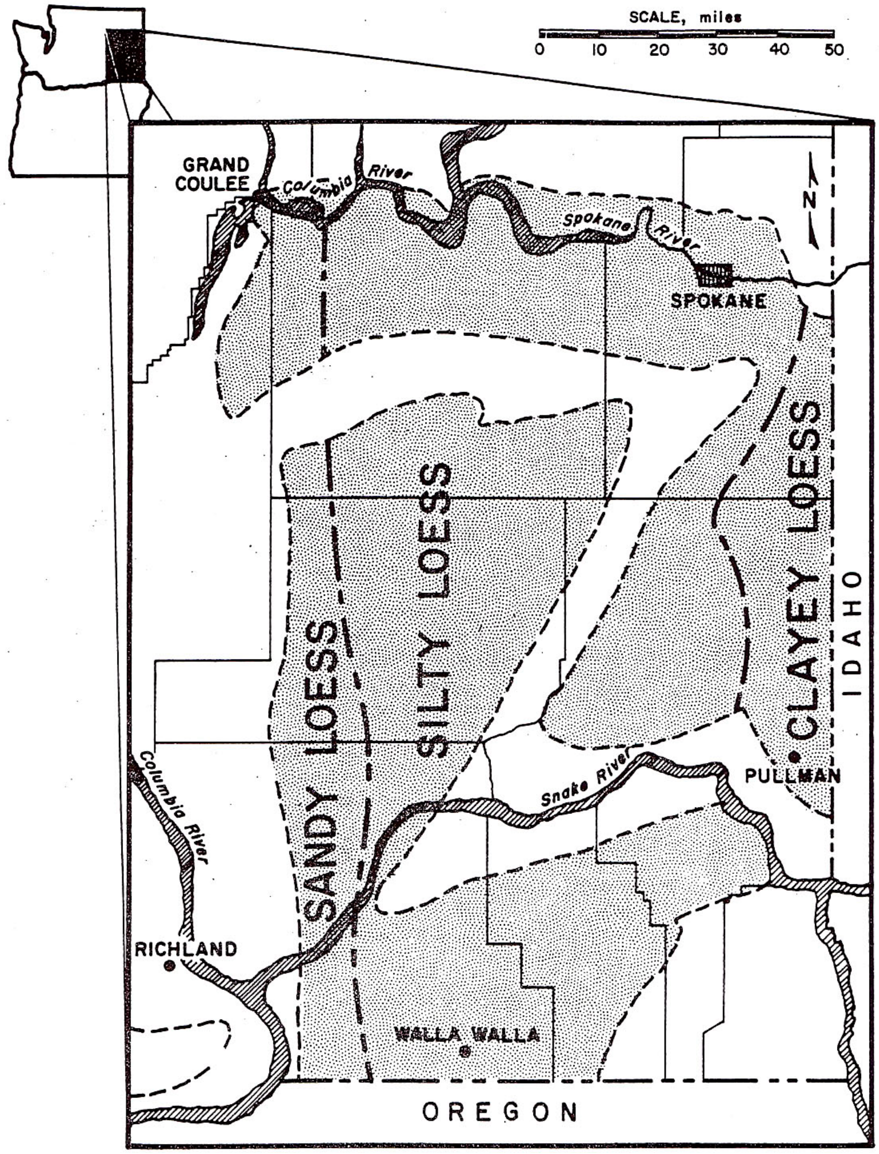
The RME or geotechnical designer should provide guidance in determining shrink/swell factors for earthwork computations. Soil excavated from cuts and then compacted for embankment construction typically has a shrinkage factor. Values vary based on soil type, in-place density, method of fill construction and compactive effort. Soil wasted typically has a swell factor because material is often end-dumped at the waste site. The shrink/swell factor for soil that will be reused can be estimated by determining the ratio of in situ density versus compacted density determined from Proctor tests. Corrections may need to be applied for oversize particles screened out of xcavated material. Local experience with similar soil also can be used to determine shrink/swell factors. Typical shrink/swell factors for various soils and rock are presented in Table 10-1.

Material	In situ wet unit weight (pcf)	Percent Swell	Loose Condition wet unit weight (pcf)	Percent Shrink (-) or Swell (+)	Compacted wet unit weight (pcf)
Sand	114	5	109	-11	129
Sandy Gravel	131	5	124	-7	141
Silt	107	35	79	-17	129
Loess	91	35	67	-25	120
Rock/Earth Mixtures					
75% R/25 % E	153	25	122	+12	136
50% R/50% E	139	29	108	-5	146
25% R/75% E	125	26	99	-8	136
Granite	168	72	98	+28	131
Limestone	162	63	100	+31	124
Sandstone	151	61	94	+29	117
Shale-Siliceous	165	40	118	+25	132
Siltstone	139	45	96	+9	127

Approximate Shrink/Swell Factors
(From Alaska DOT Geotechnical Procedures Manual, 1983)
Table 10-1

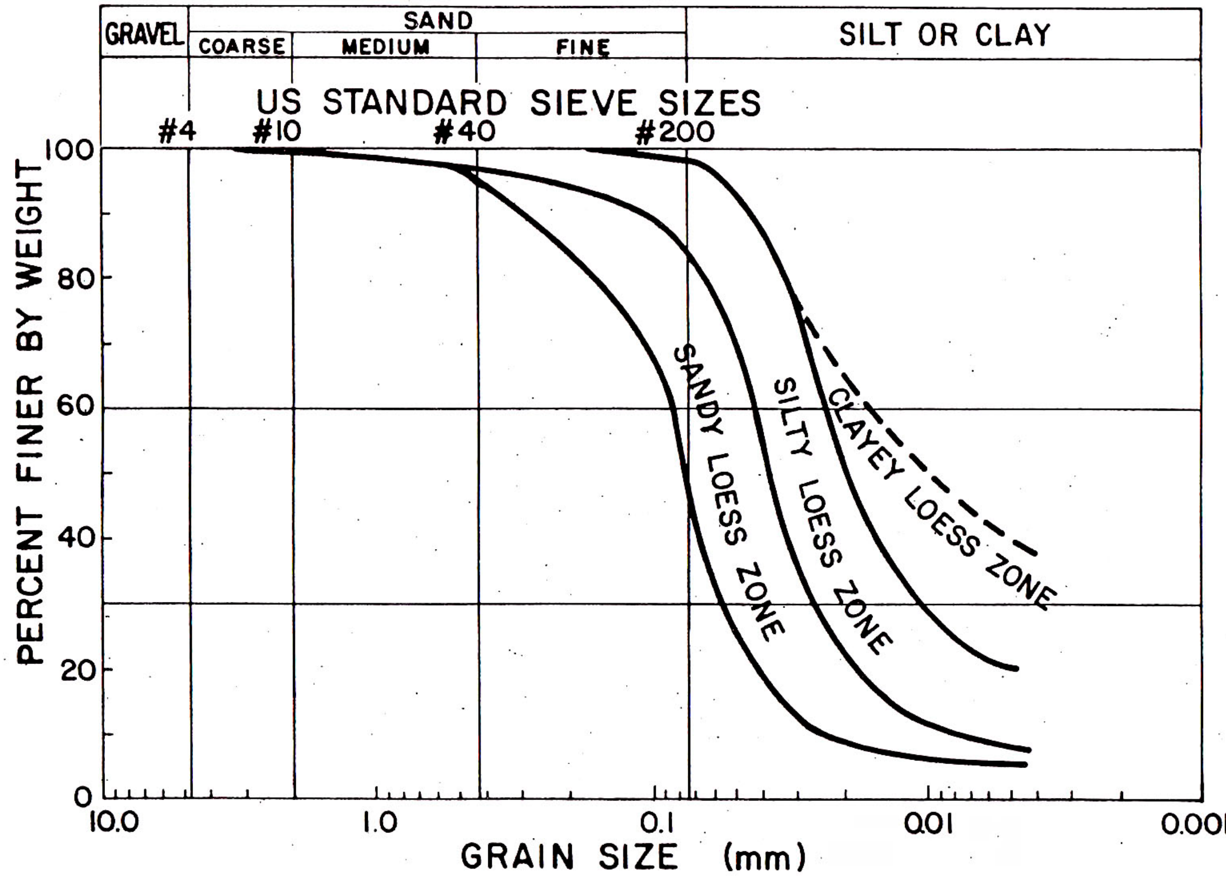
10.5 Special Considerations for Loess

Loess is an aeolian (wind deposited) soil consisting primarily of silt with fine sand and clay, generally found in the southeastern part of the state. See Figure 10-2 for general extents of loess deposits found within Washington state. Loess contains a large amount of void space, and particles are held together by the clay component. It can stand at near vertical slopes indefinitely provided its moisture content remains low. However, upon wetting it loses strength and because of its open structure can experience large rapid deformations that can result in slope failures. Slope failures in loess soil can occur as either shallow slides or flows or rotational slides. Loess is also highly prone to erosion and piping.



Approximate Gradation of Boundaries for Washington Loess (After Higgins and Fragaszy, WA-RD 145.2)
Figure 10-2

Loess Can be Broken Down into Three Main Types – Clayey loess, silty loess, and sandy loess, based on grain size analysis (see Figure 10-3). Past research indicates that cuts in silty loess deposits with low moisture contents can stand at near vertical slopes (0.25H:1V), while cuts in clayey loess deposits perform best at maximum slopes of 2.5H:1V. Soils characterized as sandy loess can be designed using conventional methods. WSDOT manual "Design Guide for Cut Slopes in Loess of Southeastern Washington" (WA-RD 145.2) provides an in-depth discussion on design of cut slopes in loess.



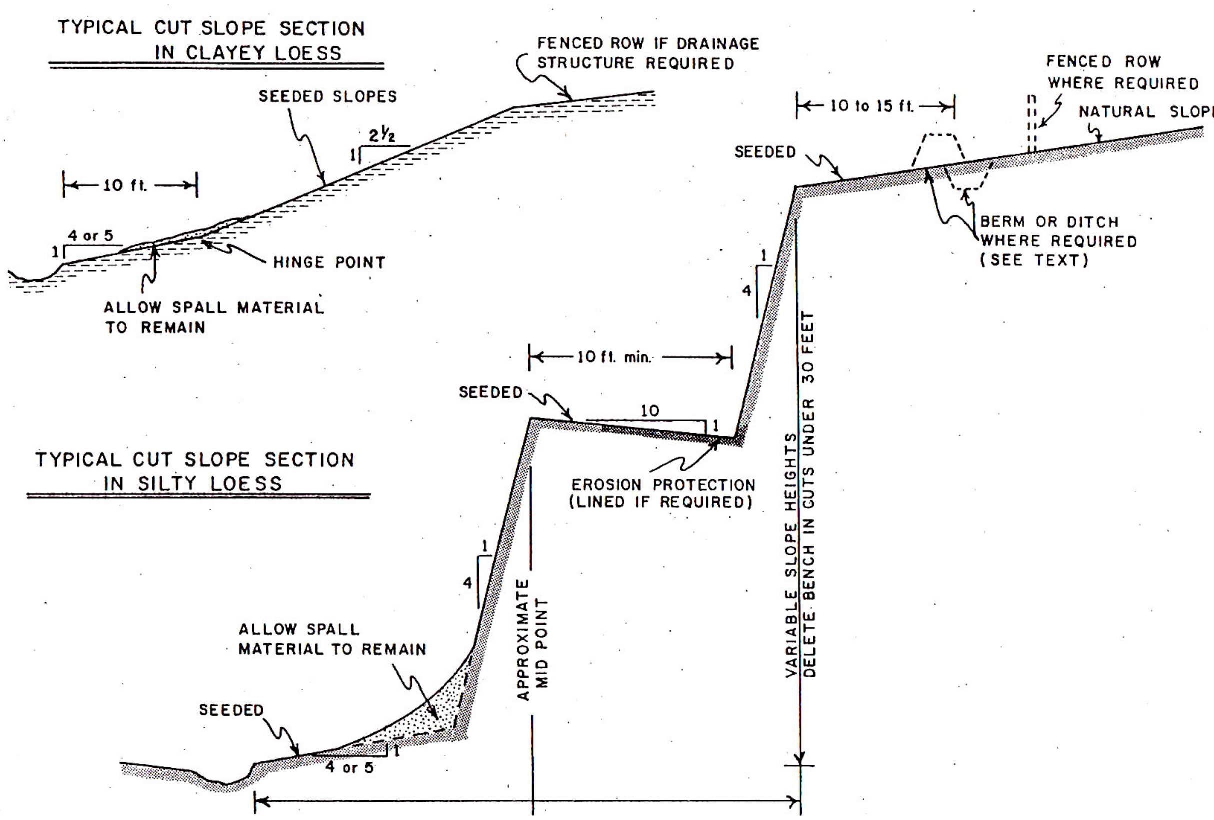
Definition of Sandy, Silty, and Clayey Loess for Southeastern Washington (After Higgins and Fragaszy, 1988)
Figure 10-3

The two most important factors affecting performance of cut slopes in loess are gradation and moisture content. Moisture content for near vertical slopes is crucial. It should not be over 17 percent. There should be no seepage along the cut face, especially near the base. If there is a possibility of groundwater in the cut, near vertical slopes should not be used. Maintenance of moisture contents below critical values requires adequate drainage facilities to prevent moisture migration into the cut via groundwater or infiltration from the surface.

The design of cut slopes in loess should include the following procedures that have been adapted from WA-RD 145.2 (Higgins and Fragaszy, 1988):

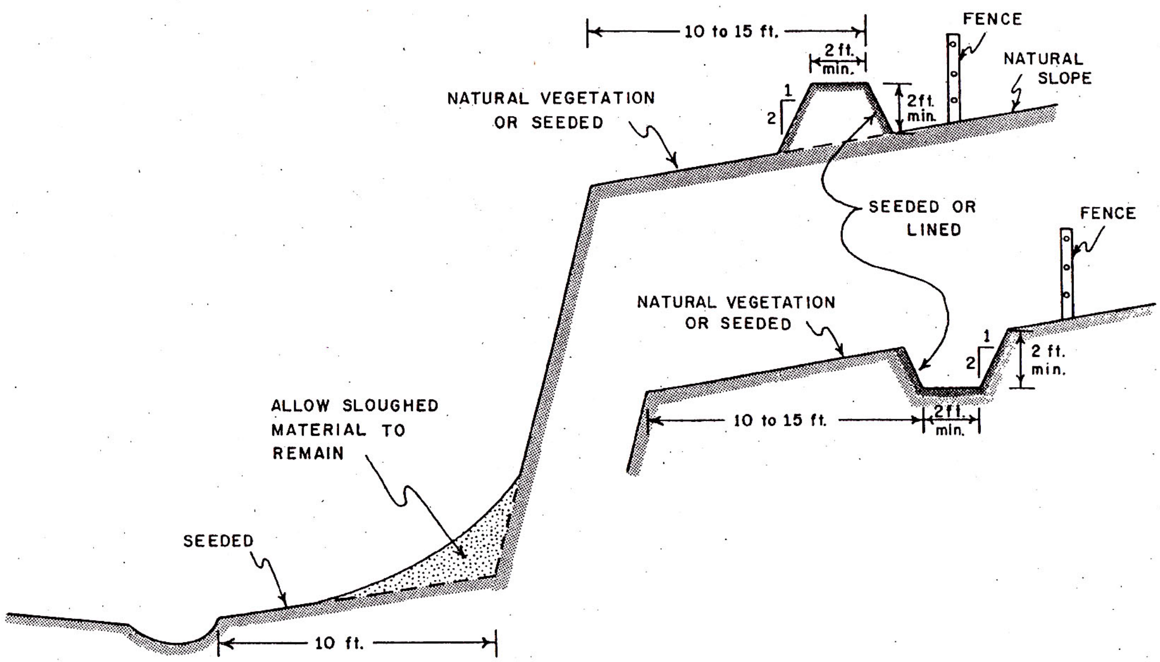
1. Perform office studies to determine possible extents of loess deposits along the proposed road alignment.
2. Perform field reconnaissance including observation of conditions of existing cut slopes in the project area.
3. Perform field exploration at appropriate locations. For loess slope design, continuous sampling in the top 6 feet and at 5 foot intervals thereafter should be used.

4. Perform laboratory grain-size analysis on representative samples throughout the depth of the proposed cut and compare the results with Figure 10-3. If the soil falls within the zone of sandy loess, or if sandy layers or other soils are encountered that do not classify as silty or clayey loess, design using conventional soil mechanics methods. If the soil falls within the zone of clayey loess, design using a maximum slope inclination of 2.5H:1V. If the soil falls within the zone of silty loess, the slope may be designed using a 0.25H:1V inclination provided that moisture contents will be within allowable levels as described in subsequent steps. See Figure 10-4 for typical sections in silty and clayey loess. If deep cuts (greater than about 50 feet) are to be used, or if moisture contents during the design life of the slope greater than 17 percent are expected, it is recommended that laboratory shear strength testing be run in order to perform slope stability analysis. If moisture contents below 17 percent are expected, total stress analysis can be used. If moisture contents above 17 percent are expected, effective stress analysis should be used. Care should be taken when using laboratory shear strength data because of the difficulty obtaining undisturbed samples in loess.
5. Determine if groundwater or seasonal perched water might be present. If so, the cut slope should be designed for a maximum slope of 2.5H:1V and appropriate drainage design applied. Slopes flatter than 2.5H:1V might be necessary because of seepage forces. In this case a drainage blanket may be required. See step 4 if slope stability analysis is required.
6. Perform moisture content analysis on representative samples. Moisture contents within the proposed slope above 17 percent indicate the soil structure is potentially unstable and prone to collapse. If moisture contents are below 17 percent and the soil classifies as silty loess, design for near vertical slopes. Otherwise, design for maximum slopes of 2.5H:1V. See step 4 if slope stability analysis is required.
7. Near vertical slopes should be benched on approximately 20 feet vertical intervals when the total height of the cut exceeds 30 feet. Benches should be 10 to 15 feet wide and gently sloped (10H:1V) towards the back of the cut to prevent water from flowing over the cut face. Benches should maintain a gradient for drainage not exceeding 3 to 5 percent. See number 4 if slope stability analysis is required.
8. Adequate drainage control is extremely important in loess soil due to its strength dependence on moisture content and high potential for erosion. The following section outlines general drainage design considerations for loess slopes. These designs can also be employed for cut slope design in other soils. However, as stated previously, loess soils are generally more susceptible to erosion and wetting induced slope failures, so the design of drainage structures for loess slopes might be overconservative when applied to other soils.



Typical Sections for Cut Slopes in Silty and Clayey Loess
(After Higgins and Fragaszy, 1988)
Figure 10-4

Drainage at Head of Slopes – For silty loess, a drainage ditch or berm should be constructed 10 to 15 feet behind the top of the slope prior to excavation. Provided the gradient is less than about 5 percent, a flat bottomed, seeded drainageway will be adequate. A mulch or geotextile mat should be used to protect the initial seeding. If the slope is located where adequate vegetation will not grow, a permanent erosion control geotextile covered with crushed rock or coarse sand can be used. The sizing of cover material should be based on flow velocities. The geotextile should be chosen to prevent erosion or piping of the underlying loess and strong enough to withstand placement of the cover material. Gradients greater than about 5 percent will require a liner similar to those used to convey water around the sides of cut slopes as described below. For clayey loess a drainage way behind the top of a cut slope is necessary only when concentrated flows would otherwise be directed over the slope face. In this case drainage should be the same as for silty loess. See Figure 10-5 for drainage details at the head of cut slopes in silty loess.



Drainage Above a Cut Slope in Silty Loess (After Higgins and Fragaszy, 1988)
Figure 10-5

Drainage Around Sides of Cut Slopes – Drainageways around the sides of slopes generally have higher gradients (about 5 to 10 percent) than those at the tops of slopes. WSDOT WA-RD 145.2 (Higgins and Fragaszy, 1988) recommends four general designs for drainageways within this gradient range:

1. Line the drainageway with permanent erosion control geotextile and cover with coarse crushed rock.
2. Line the drainageway with permanent erosion control geotextile under a gabion blanket.
3. Construct the drainageway with a half-rounded pipe. The pipe should be keyed into the top of the slope to prevent erosional failure, and adequate compaction should be provided around the pipe to prevent erosion along the soil/pipe interface. Care should be taken to prevent leakage at pipe joints.
4. Line the drainageway with asphalt or concrete. This approach is expensive, and leakage can lead to piping and eventual collapse of the channel.

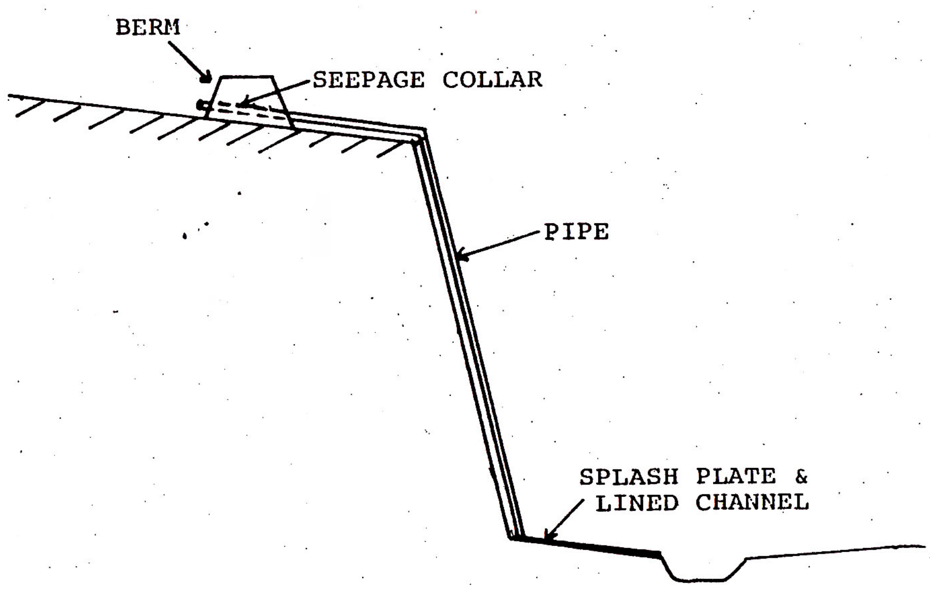
Drainage Over the Face of Cut Slopes – Where cuts will truncate an existing natural drainage basin, it is often necessary to convey water directly over the face of slopes due to the excessive ROW required to convey water around the sides. At no point should water be allowed to flow freely over the unprotected face of a cut slope. WSDOT WA-RD145.2 (Higgins and Fragaszy, 1988) lists three possible designs for this scenario in clayey loess and two possible designs in silty loess. For clayey loess:

1. Cut a shallow, flat bottomed ditch into the slope face. The ditch should be lined with permanent erosion control geotextile and covered with a gabion mat or coarse rock

2. Use a half-rounded pipe as described previously.
3. Use an asphalt or concrete liner.

For silty loess with a near vertical slope:

1. Intercept the drainage high enough above the cut to channel it around the sides using techniques described previously for drainage around the sides of cut slopes.
2. Convey water over the slope face using a PVC pipe connected to a collection area impounded by a berm located above the head of the slope. The pipe should be installed above the ground and sealed against the berm to prevent seepage along the outside of the pipe. The pipe also should be anchored both above and below the slope face, and a splash plate should be provided at the bottom to prevent undercutting of the slope. Figure 10-6 shows details of drainage over a cut face. This design is best suited for low to moderate flow volumes in conjunction with berm drainage. It should not be used with ditches.



Drainage Over a Cut Slope
(After Higgins and Fragaszy, 1988)
Figure 10-6

Drainage at the Toe of slopes – Drainage ditches along the roadway should be constructed at least 10 feet from the toe of the slope, and the ground surface should be gently sloped toward the ditch.

Sufficient right-of-way should be available to ensure that future agricultural activities are kept away from the top of the cut slope to keep drainageways from being filled in and to limit excessive disturbance around the cut slope.

Finally, proper construction control should be implemented. Construction equipment should be kept away from the top of the slope once the cut has been made. The following recommendations all have the same focus, to limit the amount of water that might reach the slope face. Construction should be performed during the summer, if possible. Drainage ways above the top of the cut should be constructed prior to opening up the cut. Seeding or other slope protection should be implemented immediately following construction of the cut. All cut slopes should be uniform, i.e. compound slopes should not be allowed. If animal holes are present that would create avenues for piping, they should be backfilled with low permeability fines or grout.

A design checklist taken from WA-RD 145.2 (Higgins and Fragaszy, 1988) is included in *Appendix 10-A*.

10.6 PS&E Considerations

Considerations concerning PS&E and construction generally consist of specifying the extents and periods during which earthwork is permitted in order to limit soil disturbance and erosion. Specifications should also be included that require construction of adequate drainage structures prior to grubbing and that construction equipment stay away from the tops of completed cut slopes.

In general, excavation for slopes should proceed in the uphill direction to allow surface or subsurface water exposed during excavation to drain without becoming ponded. Cut slopes should not be cut initially steeper, and then trimmed back after mass excavation. This procedure can result in cracks and fissures opening up in the oversteepened slope, allowing infiltration of surface water and a reduction in soil shear strength.

Both permanent and temporary cuts in highly erodable soil should be covered as they are excavated. Vegetation should be established on permanent slopes as soon as feasible. Only uniform slopes should be constructed in loess or other erodable soil (no compound slopes) in order to prevent erosion and undercutting.

10.7 References

AASHTO "Standard Specifications for Transportation Materials and Methods of Sampling and Testing," Part 2: Tests.

Alaska DOT, *Geotechnical Procedures Manual*, 1983.

Abramson, L., Boyce, G., Lee, T., and Sharma, S., 1996, *Slope Stability and Stabilization Methods*, Wiley, ISBN 0471106224.

FHWA, 1993, *Soil and Base Stabilization and Associated Drainage Considerations*, Vol 1, FHWA-SA-93-004.

FHWA, 1993, *Soil and Base Stabilization and Associated Drainage Considerations*, Vol 2, FHWA-SA-93-005

Higgins, J. D., and Fragaszy, R. J., and Martin, T., 1987, *Engineering Design in Loess Soils of Southeastern Washington*, WSDOT Research Report WA-RD 145.1, 121 pp.

Higgins, J. D., and Fragaszy, R. J., 1988, *Design Guide for Cut Slopes in Loess of Southeastern Washington*, WSDOT Research Report WA-RD 145.2, 57 pp.

Design Manual M 22-01

Highway Runoff Manual M 31-16, 2004

Roadside Manual.

Standard Specifications for Road, Bridge, and Municipal Construction M 21-01, 2004

Appendix 10-A — 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 was adapted from the Design Guide for Cut Slopes in Loess of Southeastern Washington, WA-RD 142.5 (Higgins and Fragaszy, 1988).

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

Project Definition	Yes	No	N/A
1. Is the proposed construction within a loess region?	❒	❒	❒
If yes, what loess type is present? (Figure 10.3) ❒ 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 the proposed route been identified?	❒	❒	❒
b. Have important soil parameters of those major soil types been identified? i.e. grain size distribution, percent 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 Region: ____ ¼:1 ____2.5:1 or ____other If other, identify proposed cut slope angle and reason.	❒	❒	❒
6. If ¼:1 cuts area 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 of 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 groundwater encountered in any of the test borings?	❒	❒	❒
If yes, were piezometers installed for monitoring purposes?	❒	❒	❒
9. Is the groundwater perched on an impermeable layer (i.e. bedrock)?	❒	❒	❒
10. Will the proposed cut daylight the groundwater 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 percent clay vs. depth, and percent field moisture with depth?	❒	❒	❒
2. Based on criteria in Figure 10.3 and Section 10.5 of this chapter has the project loess soil been appropriately classified as to type and critical moisture?	❒	❒	❒
3. Are the recommended cuts based on guidelines in Section 10.5 of this chapter?	❒	❒	❒
If answer is no, is a justification given?			
4. Were there specific recommendations made of erosion control, e.g. backslopes, sideslopes, ditches? (This is absolutely critical to the successful use of cut slopes in loess; surface runoff must be collected and discharge so as not to saturate and erode the cut face.)	❒	❒	❒
5. If ¼:1 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 percent is there the provision for ditch erosion protection i.e. asphalt or concrete or rock/geotextile 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 ¼:1 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?	❒	❒	❒