

Soil Cuts - Analysis and Design

10.1 General

Soil cut slope design must consider many factors such as the materials and conditions present in the slope, materials available or required for construction on a project, space available to make the slopes, minimization of future maintenance and slope erosion. Soil slopes less 10 feet high are generally designed based on past experience with similar soils and on engineering judgment. Cut slopes greater than 6 to 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 land sliding.

A major cause of cut slope failure is related to reduced confining stress within the soil upon excavation. Undermining the toe of the slope, increasing the slope angle, and cutting into heavily over consolidated clays have also resulted in slope failures. Careful consideration should be given to preventing these situations by surcharging or buttressing the base of the slope, choosing an appropriate slope angle (i.e., not over steepening), and by keeping drainage ditches a reasonable distance away from the toe of slope. Cut slopes in heavily over consolidated clays may require special mitigation measures, such as retaining walls rather than an open cut in order to prevent slope deformation and reduction of soil strength 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 steeper than 2H:1V without the use of erosion mats or other stabilization methods.

10.1.1 Design Parameters

The major cut slope design parameters are slope geometry, soil shear strength and predicted or measured groundwater levels. For cohesionless soil, stability of a cut slope is independent of height and therefore slope angle becomes the key parameter of concern. For cohesive ($\phi = 0$) 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 surface and subsurface drainage facilities to reduce the potential for future stability or erosional problems.

Establishment of design parameters is done by a thorough site reconnaissance, sufficient exploration and sampling, and a laboratory testing program designed to identify the material soil strength properties to be used in analysis. Back analysis methods may also be used to determine the appropriate shear strength for design. The geotechnical designer should be familiar with the state of the practice in determining the design parameters for analysis. References are presented in Section 10.3.

10.2 Soil Cut Design

10.2.1 Design Approach and Methodology

Safe design of cut slopes is typically based on past experience or on more in-depth analysis. Both approaches require accurate site specific information regarding geologic conditions obtained from standard field and laboratory classification procedures. Design guidance for simple projects is provided in the *ODOT Highway Design Manual*, located on the ODOT website, and can be used unless indicated otherwise by the geotechnical designer. Slopes less than 6 to 10 feet high, with slopes flatter than 2:1, may be used without in-depth analysis if no special concerns are noted by the geotechnical designer. If the geotechnical designer determines that a slope stability study is necessary, information that will be needed for analysis includes:

- 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.

The design factor of safety for static slope stability is 1.25. This safety factor should be increased to a minimum of 1.30 for slopes where failure would cause significant impact to adjacent structures. 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.

Preliminary slope stability analysis can be performed using simple stability charts. See Abramson, et al. (1994) 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 as XSTABL, PCSTABL, and SLOPE/W can be employed see [Chapter 7](#) 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.

10.2.2 Seepage Analysis and Impact on Design

The introduction of groundwater to a slope is a common cause of slope failures. The addition of groundwater often results in a reduction in the shear strength of soils. A higher groundwater table results in higher pore pressures, causing a corresponding reduction in effective stress and soil shear strength. A cut slope below the groundwater table results in destabilizing seepage forces, adds weight to the soil mass, increasing driving forces for slope failures. 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 parameters, pore pressures have to be known or estimated. This can best be done by measuring the phreatic (water table) surface with open standpipes or observation wells. Piezometric data from piezometers can be used to estimate the phreatic surface or piezometric 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 (ru) 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.

10.2.3 Surface and Subsurface 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. Surface drainage facilities should direct surface water to suitable collection facilities.

Subsurface drainage should 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:** Cut-off trenches, also known as French drains, are a gravel filled trench near the top of the cut slope to intercept groundwater and convey it around the slope. They are effective for shallow groundwater depths from 2 to 15 feet deep.
- **Horizontal drains:** If the groundwater table needs to be lowered to a greater depth, horizontal drains can be installed, if the soils are non-cohesive 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:** 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.

10.2.4 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.

Structural systems are generally more expensive than the other techniques, but might be the only option when space is limited. Shallow failures and sloughing can be mitigated by placing a 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.

10.2.5 Erosion and Piping Considerations

Surface erosion and subsurface piping are most common in clean sands, neoplastic silts and dispersive clays. Loess and volcanic ash are 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. 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 storm water control as outlined in the *ODOT Highway Design 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 the highly erodible soils mentioned above.

10.2.6 Sliver Cuts

A sliver cut is defined as slope excavation less than 10 feet wide over some or all of its height. Sliver cuts in soils should be avoided because they are difficult to build. Cuts at least 10 feet wide over the full height of the cut require the use of conventional earth moving machinery to maximize production. Cuts less than 10 feet wide and up to 25 feet high measured along the slope can be excavated with a large backhoe but at the expense of production. If a sliver cut is used, consider how it will be built and be sure to account for the difficulty in the cost estimate.

10.3 References

Abramson, L., Boyce, G., Lee, T., and Sharma, S., 1994, *Advanced Technology for Soil Slope Stability*, Vol. 1, FHWA-SA-94-005.

FHWA, 1993, *Soils and Foundations Workshop Manual*, Second Edition, FHWA-HI-88-009.

[ODOT Highway Design Manual](#), 2012.

Turner, A., and Schuster, R., 1996, *Landslides: Investigation and Mitigation*, TRB Special Report 247.