Chapter 10 - Soil Cuts - Analysis and Design

Chapter Contents

10.1 General

Soil cut slope design must consider many factors such as the materials and conditions present in the slope, grade and right of way constraints, minimization of future maintenance, and slope erosion. Soil slopes less than 10 feet high are generally designed based on past experience with similar soils and the application of engineering judgment. Cut slopes greater than 10 feet in height 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, would generally not require rigorous analysis. Any cut slope where failure would result in large rehabilitation costs or threaten public safety is designed using more rigorous techniques. Other situations that warrant more in-depth analysis include:

- 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.

Common causes of cut slope failures include the use of excessive slope angles, failure to address seepage in design, and the presence of overconsolidated clays or unfavorably bedded formations. Careful consideration should be given to preventing these situations by choosing appropriate design details.

The design of a cut slope in soil requires knowledge of slope geometry constraints, shear strength, and groundwater and seepage levels. Further consideration must be given to adequate surface and subsurface drainage facilities to reduce the potential for future stability or erosional problems.

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*. This simplified approach can be used on ODOT projects except where indicated otherwise by the geotechnical designer. Slopes less than 10 feet high, at gradients flatter than 2H:1V 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 for each soil unit, and

- Location of the water table and seepage 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 can be employed (see Chapter 8).

10.2.2 Seepage Analysis and Impact on Design

Groundwater seepage is perhaps the most common cause of slope failures. 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. In turn it adds weight to the soil mass and increases 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 analyses 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 electronic piezometers, open standpipes, or observation wells. Piezometric data 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 to provide sufficient boundary information.

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 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 and seepage control, should be applied to all cut slopes as the cut progresses. Furthermore, the surface drainage should be conveyed to the toe of the cut slope. The use of subsurface drainage structures is an effective way to improve the stability of cut slopes where water and/or seepage is present. However, it should be noted that subsurface drainage can be expensive and requires maintenance. it should be used in conjunction with other techniques (outlined below) to develop the most cost effective design that meets 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 or 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-foot to 30-foot intervals with drainage ditches installed to collect water. Best Management Practices (BMPs) for temporary, permanent erosion and storm water control are outlined in the *ODOT Highway Design Manual* and should always be used. Construction practicesspecify the limit,extent and duration of exposed soil where erosion is a concern. 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 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

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