	Ohio Department of Transportation **Division of Production Management** **Office of Geotechnical Engineering** **Geotechnical Bulletin**	**GB 2**

SPECIAL BENCHING AND SIDEHILL EMBANKMENT FILLS

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This Geotechnical Bulletin is intended to provide guidance on the use of special benching in highway embankment construction. Guidance for standard specification benched embankment construction is provided in the ODOT Construction and Material Specifications, Item 203.05. Regarding standard specification benched embankment construction, Item 203.05 states the following:

If the existing slope is steeper than 8:1, bench into the existing slope as follows:

A. Scalp the existing slope according to Item 201.
B. Cut horizontal benches in the existing slope to a sufficient width to blend the new embankment with the existing embankment and to accommodate the placement, and compaction operations and equipment.
C. Bench the slope as the embankment is placed, and compact into layers.
D. Begin each bench at the intersection of the existing slope and the vertical cut of the previous bench. Recompact the cut materials along with the new embankment.

Special benching should be used whenever the designer anticipates that there will be a stability problem and/or weak soils in an existing slope. Special benching is typically utilized to improve stability in a sidehill fill placed on an existing slope or to remediate an unstable existing slope. As opposed to standard specification benching, special benching is always shown on the cross-sections in the project plans. Special benching is performed in addition to, and in place of, standard specification benching, and has pay quantities for both excavation and embankment calculated for the benched areas and added to the plan General Quantities. Whenever special benching is used, Plan Note G109 from the ODOT Location and Design Manual, Volume 3 needs to be included in the General Notes. Plan Note G109 states, “Although cross-sections indicate specific dimensions for proposed benching of the embankment foundations in certain areas, no waiver of the specifications is intended. Bench all other sloped embankment areas as set forth in 203.05. No additional payment will be made for benching required under the provisions of 203.05.”

Where sidehill fills are planned on the face of an existing slope which is steeper than 4H:1V, the Office of Geotechnical Engineering (OGE) typically recommends special benching (as detailed in the ODOT Construction Inspection Manual of Procedures, Section 203.05, "Benching") to assure the embankment is "knitted" together. Compaction of fill soils placed upon an existing embankment, especially thin "sliver" fills of three feet or less thickness, is especially difficult. Conventional compaction equipment cannot be used on slopes as steep as a typical highway embankment, which means that fill placed directly on such a slope will generally be either poorly compacted or uncompacted, which leaves it highly susceptible to erosion or sliding failure. Even if compaction can be assured in such a fill, the sloping interface between the existing surface and the new fill provides a potentially weak continuous plane along which a shear failure may develop. Special benching creates a "stair-stepping" surface, which improves stability by inhibiting the development of a contiguous shear plane along the interface.

The most common method of remediation for an unstable existing slope consists of digging out the failed soil mass in a benched excavation and reconstructing the slope with compacted engineered fill. This removes failed and sloughing material from the slope, and inhibits the development of a shear plane along the interface with the existing ground and the new fill. If the reconstructed fill is well compacted and built with a stable slope, any potential shear surface will be forced deeper, below the special benched fill, thus improving the resistance against shear failure. Benched excavation and replacement is often used in combination with other methods, such as flattening of the slope, groundwater drainage, counter-berms, or retaining structures to further improve stability of the slope.

With regards to LRFD design, the geotechnical stability of soil slopes is termed "overall stability," and is considered to be a Service Limit State condition. Therefore, Load Factors are 1.00, and Resistance Factors are considered to be the inverse of previous governing Factors of Safety (FS). The codification of LRFD load and resistance factors by probabilistic calibrations for the design of slopes are currently being research and developed. Commercial slope stability analysis programs fully compatible with AASHTO LRFD procedures are not readily available. Therefore, in accordance with AASHTO LRFD specifications and FHWA publications, overall stability analysis are still performed by traditional means, utilizing FS, and this bulletin expresses stability with regards to FS. However, in order to agree with LRFD terminology, stability of slopes may be expressed in terms of Capacity to Demand Ratio (CDR), where CDR is equal to the ratio of the factored resistance to the factored load. In traditional terms, when the calculated FS equals the minimum required FS, the CDR = 1.0.

This bulletin and other information may be obtained from the Office of Geotechnical Engineering's Web site (http://www.dot.state.oh.us/Divisions/Engineering/Geotechnical/). This Web site contains other ODOT Geotechnical documents and bulletins and has an online copy of the Geotechnical Engineering Design Checklists, referenced in this bulletin.

A. General Case: Special Benched Embankment Construction

As stated above, OGE typically recommends special benching where sidehill fills are planned on the face of an existing slope which is steeper than 4H:1V. Figure 1 shows the details of a typical special benching scheme for a sidehill embankment fill. A similar detail drawing would be presented on each affected cross-section in the plans. Due to the variability of slope shape, height, steepness, and the position of benches across cross-sections, special benching details should never be shown on a typical cross-section.

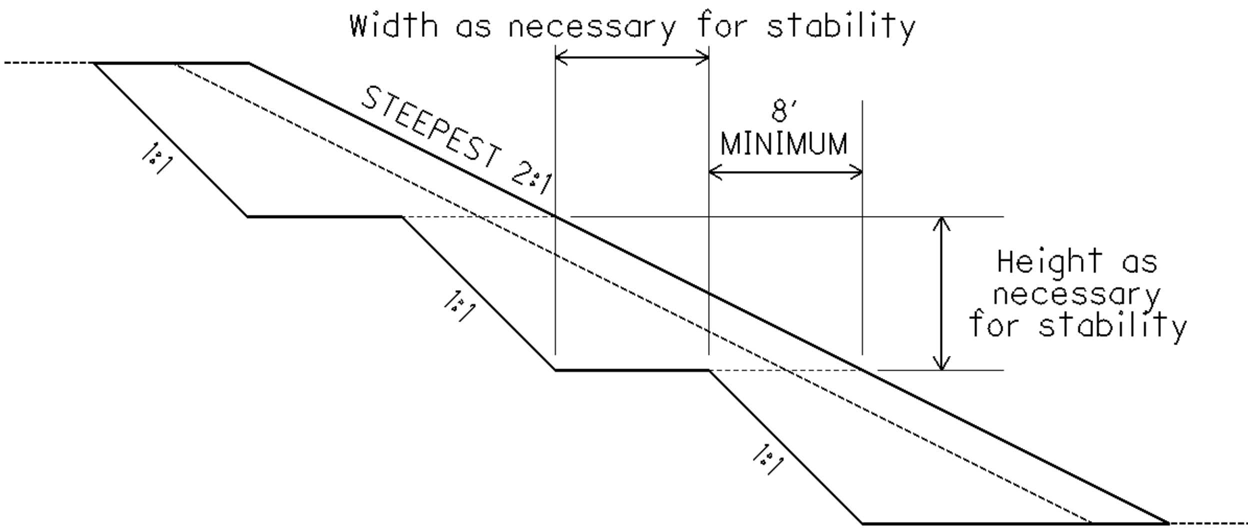


Figure 1
General Case: Special Benched Embankment Construction

The back slope of each bench is cut at a typical 1H:1V slope. This slope may need to be flattened based on the short term stability of the soils in the existing slope. If the existing slope is made up primarily of granular materials, a slope approaching 30° (approximately 1.75 H:1V) may be more appropriate. However, if the existing slope is an embankment constructed of cohesive fill materials, which is typical in Ohio, a 1H:1V slope should stand for the short time period between excavation and placement of new fill material.

The final designed slope, after reconstruction with unreinforced compacted engineered fill, shall never be steeper than 2H:1V. A flatter slope may be desirable or necessary, depending on a stability analysis. If an embankment slope steeper than 2H:1V is required, it must be constructed as a Reinforced Soil Slope (RSS). For guidance on the design and construction of RSS, see document *FHWA Geotechnical Engineering Circular No. 11, Publication FHWA-NHI-10-025, Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volume II* (FHWA GEC 011 – Volume II).

Each bench will be narrower at its top than at its base, as the back slope (typically 1H:1V) will be steeper than the final reconstructed slope (maximum 2H:1V). The top of each bench – the horizontal distance between the top of the back slope and the final reconstructed slope face – shall be at least 8 feet wide, as shown in Figure 1, above. This is to allow compaction and grading equipment to work on a level surface at any elevation from the bottom to the top of each bench. This also generally applies to the top bench, where it "daylights" through the top of the embankment.

However, when designing special benching for highway embankments, it will often be the case that the top bench will daylight through an existing roadway. Due to maintenance of traffic concerns, it is often not practical to cut through pavement on a heavily traveled road. In this situation, consideration needs to be given to adjustment of the benching scheme, to avoid impacting the existing roadway, guardrail, or shoulder, and to allow maintenance of traffic on the roadway during excavation and reconstruction of the embankment. A common method for accomplishing this is through the placement of temporary over-steepened fill (see Figure 1a).

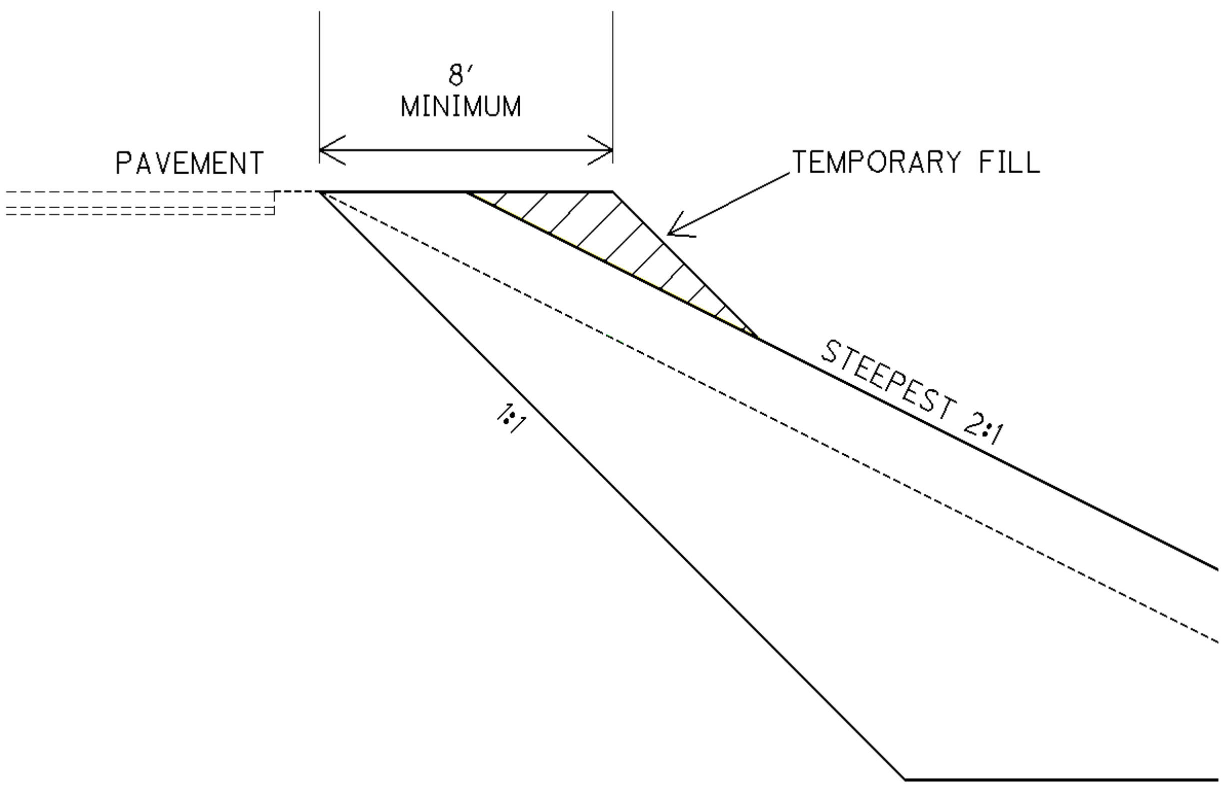


Figure 1a
Special Case: Temporary Over-Steepened Fill

In this method, the back slope of the benched excavation is cut with a width of less than 8 feet between the top of the bench cut and the edge of the proposed fill. Temporary over-steepened fill is placed to make up the additional width. In Figure 1a, this temporary fill is shown with a hatch pattern. The temporary fill is then "shaved" off of the slope, to bring the cross section back to the final proposed grade. The excess removed fill can be pushed to a different section of the embankment and reused.

The height of the back slope of each bench and the width of the base of each bench should be modified based on the geometry of the situation and as necessary based on a stability analysis. In general, the width and height of the benches should be arranged so as to minimize the required cut and fill quantities. Nevertheless, the minimum 8-foot horizontal clearance between the slope face and the back slope of each bench must be maintained, and no bench shall be taller than 20 feet in height, without a stability analysis and design by a Registered Professional Engineer per OSHA requirements.

The proposed new slope created by a sidehill fill may have a different resistance to shear failure than the existing slope. This must be checked with a slope stability analysis, to assure that minimum required FS for slope stability is met, per the ODOT Geotechnical Engineering Design Checklists, Section III.B. Embankments Checklist, Stability. If the FS drops below the minimum required 1.3 (or 1.5 for an embankment supporting a structure), the benches may need to be adjusted deeper and or wider to improve stability.

Each individual bench should not vary greatly in elevation or horizontal location across the profile of the embankment (from station to station). In general, it is best to keep the benches either level or to follow the designed grade of the roadway (at an equal depth from the top of the embankment) along the length of the embankment. This ensures easier construction due to consistent grading. If drainage is to be installed on the back slopes of the benches (see Section D, Special Benching for Landslide Stabilization), the bases of the benches need to have a graded slope of a minimum 1-percent grade, along their length, to allow water to drain along the bases of the benches.

If the embankment varies much in height from one end to the other, it may be necessary to add or subtract benches at the bottom, or vary the height (or depth) of the bottom bench along its length. If this bench is to incorporate drainage, keep in mind the minimum 1-percent slope of the base, and/or provide suitable transverse drainage outlets at all low points. Additionally, the minimum horizontal clearance and/or cut for each bench will need to be increased by the width of the designed slope drain.

Wherever benches begin or end, the ends of the bench should be cut with a typical 1H:1V slope, in a similar manner to the back slope (as described above). This slope may need to be flatter, as defined by the short term stability of the cut soils.

The benched excavation shall be replaced with compacted engineered embankment fill material, per Item 203 of the ODOT Construction and Material Specifications. Proper lift thicknesses and material density are to be maintained in the fill, per Item 203.06.

B. Sidehill Sliver Fill on a Steep Slope

Sidehill sliver fills are sometimes placed on the face of a steep existing slope, widening the base of the embankment, and making the slope flatter. Figure 2 shows an example of this case.

This case only differs from the general case in that the existing slope is being flattened, usually to improve stability. In this case, make sure to run a slope stability analysis, to assure that minimum FS for slope stability are met, per the ODOT Geotechnical Engineering Design Checklists, Section III.B. Embankments Checklist, Stability. If the FS drops below the minimum required 1.3 (or 1.5 for an embankment supporting a structure), the benches may need to be adjusted deeper and or wider to improve stability.

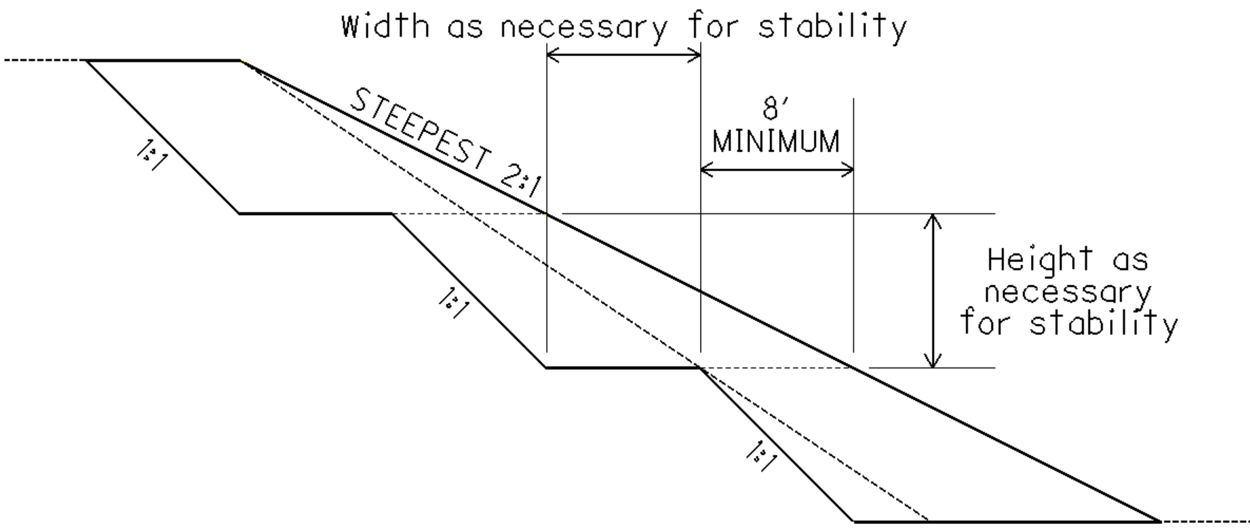


Figure 2
Sidehill Sliver Fill on a Steep Slope

Due to the flattening of the slope, and widening of the base, the upper benches may need to be cut further into the existing slope than the lower benches in order to maintain the minimum 8-foot clearance at the top of each bench.

See Section A, General Case, for additional details on dimensions and construction of special benching.

C. Sidehill Sliver Fill on a Slight Slope

Sidehill sliver fills are sometimes placed on the face of a flatter existing slope, steepening the embankment, and widening the crest. Figure 3 shows an example of this case.

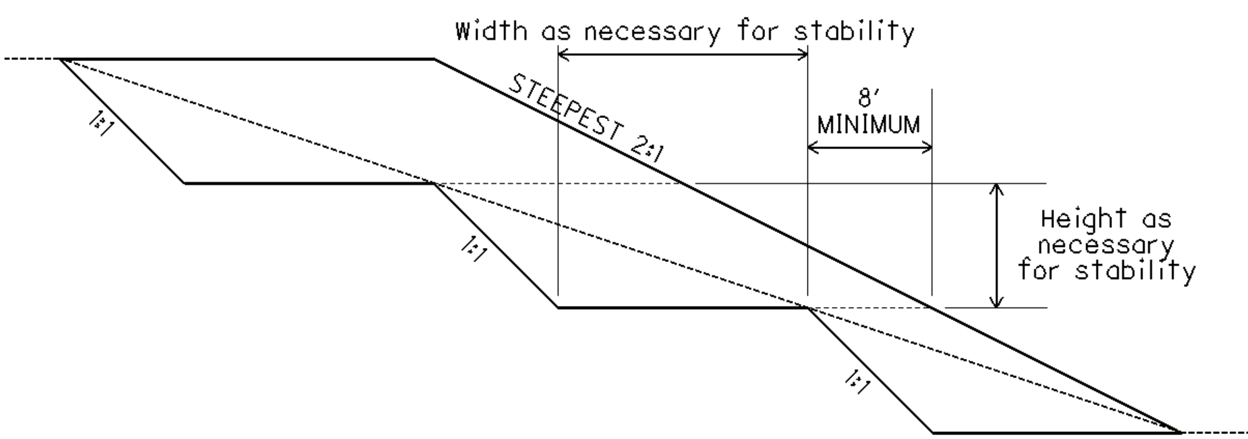


Figure 3
Sidehill Sliver Fill on a Slight Slope

The steepened slope created in this case may have a lower FS against shear failure. This must be checked with a slope stability analysis, to assure that minimum FS for slope stability are met, per the ODOT Geotechnical Engineering Design Checklists, Section III.B. Embankments Checklist, Stability. If the FS drops below the minimum required 1.3

(or 1.5 for an embankment supporting a structure), the benches may need to be adjusted deeper and or wider to improve stability.

In this case, the benches may be cut an equal distance into the existing slope, but will tend to be deeply cut horizontally, due to the large difference between the existing slope and the back slope of the bench.

Due to the geometry of this case, the bottom bench should have the most narrow top. Pay special attention to maintain the minimum 8-foot clearance at the top of this bench.

See Section A, General Case, for additional details on dimensions and construction of special benching.

D. Special Benching for Landslide Stabilization

The most common method of remediation for an unstable existing slope consists of digging out the failed soil mass in a benched excavation, intercepting the failure surface, and reconstructing the slope with compacted engineered fill. If the reconstructed fill is well compacted and built with a stable slope angle, any potential shear surface will be forced deeper, below the benched fill, thus improving the resistance to shear failure. The development of a shear plane along the interface with the existing ground and the new fill is inhibited, in a similar manner to the "knitting" of a benched sidehill fill into an existing slope. Figure 4 shows the case of benching used to stabilize a landslide.

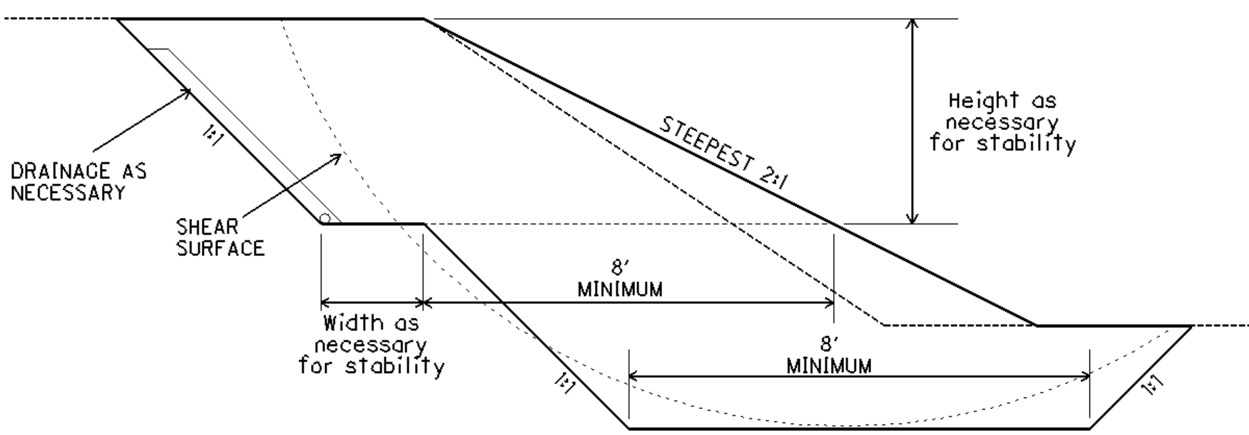


Figure 4
Special Benching for Landslide Stabilization

When designing benching for landslide stabilization, the benches should be designed to intercept the assumed shear failure surface. If excavation and replacement occurs entirely above the failure surface, it will have little to no effect on stability, and the "repaired" slope will merely become a part of the moving soil mass. The benches need to be cut through the existing failure surface, and deepened vertically and widened horizontally into the slope, until adequate stability is achieved.

The stability of the design must be checked with a slope stability analysis, to assure that minimum FS for slope stability are met, per the ODOT Geotechnical Engineering Design

Checklists, Section III.B. Embankments Checklist, Stability. If the FS does not meet the minimum required 1.3 (or 1.5 for an embankment supporting a structure), the depth and/or width of the benches will need to be adjusted again to improve stability. If the minimum required FS cannot be met by benching, additional measures, as discussed below, will be necessary to further improve stability of the slope.

If the FS is not adequate with benching and reconstruction alone, and the shear surface is expected to develop through the new fill material, a rock shear key may be installed at the base of the lowest bench, or the lowest bench itself may be constructed as a rock shear key. Crushed rock fill generally has a higher internal friction angle than typical Item 203 compacted embankment fill material, and therefore has more resistance to shear failure. A rock shear key can force the failure surface lower and improve stability.

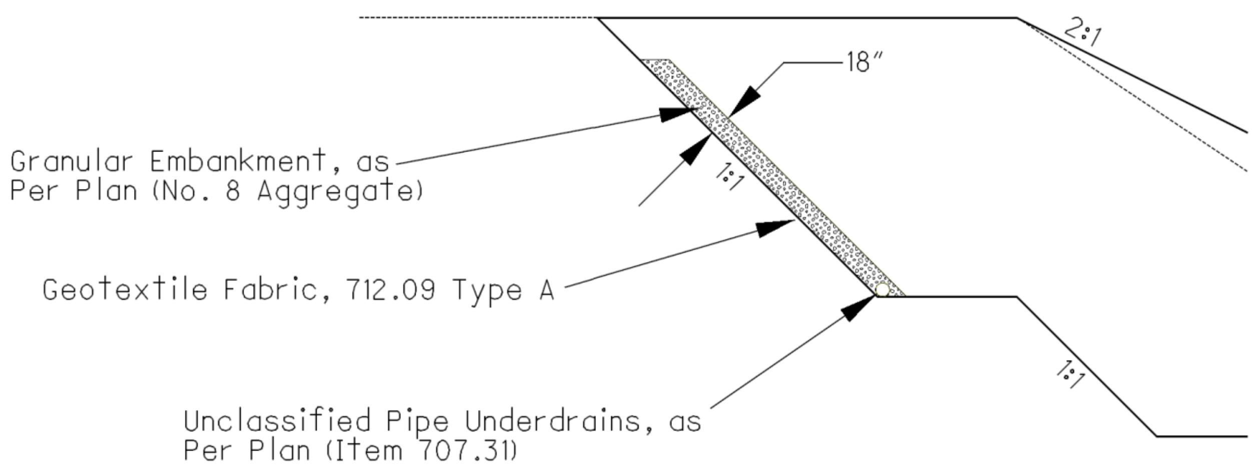
Landslides are very often initiated or aggravated by elevated pore water pressures in the slope soils, either introduced by subsurface groundwater flow or through surface water infiltration. Lowering the groundwater level often increases the stability of the slope appreciably. Therefore, groundwater drainage is often incorporated into any design fix of a landslide with benching.

When groundwater drainage is to be incorporated, the back slope of each appropriate bench should have a slope drain installed along the entire length of the excavation. This slope drain is typically made up of an 18-inch thick layer of Item 203 Granular Embankment, as Per Plan (No. 8 Stone), with Item 690E12010 SPECIAL Geotextile Fabric, 712.09 Type A, to prevent infiltration of fines into the drain. The use of alternative equivalently performing materials may also be considered for installation as a slope drain. If the top bench is drained, the slope drain should stop 3 feet below the ground surface, so that properly compacted fill may be placed above, for pavement support and protection of the drain.

The bases of the draining benches need to have a graded slope of a minimum 1 percent grade, along their length, to allow water to drain along this path. A line of Item 605 Unclassified Pipe Underdrains, As per Plan (Item 707.31 Corrugated Polyethylene Drainage Tubing, (Perforated)) should be installed along the bottom of each slope drain, to allow an easy path for water to flow along the base of the bench. For bench cuts/fills of 10 feet or less in height, a 4-inch diameter drain pipe should be used. For bench cuts/fills of more than 10 feet in height, a 6-inch diameter drain pipe should be used. The larger pipe is preferred with a greater height of fill to prevent the weight of the fill from crushing the pipe.

Transverse outlet drains of Item 611 Conduit Type F, 707.33, should outlet from the aggregate drain at the low end of the benches. These drains should be installed at a minimum 1 percent slope, and outlet through the face of the slope. Outlet drains should utilize Item 611 Precast Reinforced Concrete Outlets. Rock channel protection with filter fabric lining or other erosion protection should be utilized below these outlets, extending to the toe of the slope. Alternately, drain pipes may be extended down the slope, to outlet at the toe. The following Plan Note, with a similar typical cross section detail drawing, should be included in the General Notes whenever special benching slope drains are specified:

SPECIAL BENCHING SLOPE DRAINS
PLACE SPECIAL BENCHING SLOPE DRAINS AT THE LOCATIONS SHOWN ON THE PLAN & PROFILE AND CROSS SECTION SHEETS. THESE DRAINS SHALL CONSIST OF ITEM 203 GRANULAR EMBANKMENT, AS PER PLAN (NO. 8 AGGREGATE), ITEM 690 GEOTEXTILE FABRIC, 712.09 TYPE A, AND ITEM 605 UNCLASSIFIED PIPE UNDERDRAINS, AS PER PLAN (ITEM 707.31 CORRUGATED POLYETHYLENE DRAINAGE TUBING, (PERFORATED)). THE GRANULAR EMBANKMENT SHALL BE PLACED IN LIFTS AS THE SPECIAL BENCHING BACKFILL IS CONSTRUCTED. TRANSVERSE OUTLET DRAINS SHALL BE PROVIDED AT THE LOCATIONS SHOWN ON THE PLAN & PROFILE AND CROSS SECTION SHEETS. THESE OUTLET DRAINS SHALL CONSIST OF ITEM 611 CONDUIT TYPE F, 707.33 WITH ITEM 611 PRECAST REINFORCED CONCRETE OUTLETS.



If special benching is not able to increase stability to the minimum required FS, it may be necessary to flatten the slope of the new benched fill, or to install a counter-berm. Flattening the slope is done identically to the case of a sidehill fill on a steep slope, as described under Section B, above. A counter-berm consists of additional fill placed at the lower end of the slope, adding to the resisting force against the sliding mass of soil. The counter-berm is constructed identically to the replacement of a single bench with engineered fill, and merely increases the width of the base of the fill. When designing a counter-berm, make sure to keep a slope which ensures positive drainage. The top of the counter-berm should never be flat, nor should it have a inclination opposite to the slope on which it is built, otherwise, surface water runoff might be trapped at mid-slope, on top of the counter-berm, where it could negatively impact stability.

If none of the above measures achieve adequate stability, it may be necessary to resort to some sort of retaining structure, such as drilled shafts or a wall. Design of retaining structures, however, is beyond the scope of this Geotechnical Bulletin.

See Section A, General Case, for additional details on dimensions and construction of special benching.

E. Special Benching for Embankment Stability over Soft Foundation Soil

When an embankment is constructed over a layer of soft, weak soil, a shear failure may develop through the soft layer, failing the embankment. This may be remediated by excavating through the soft layer, and keying into a lower, firmer soil layer with a special benched embankment fill. Figure 5 shows an example of this case.

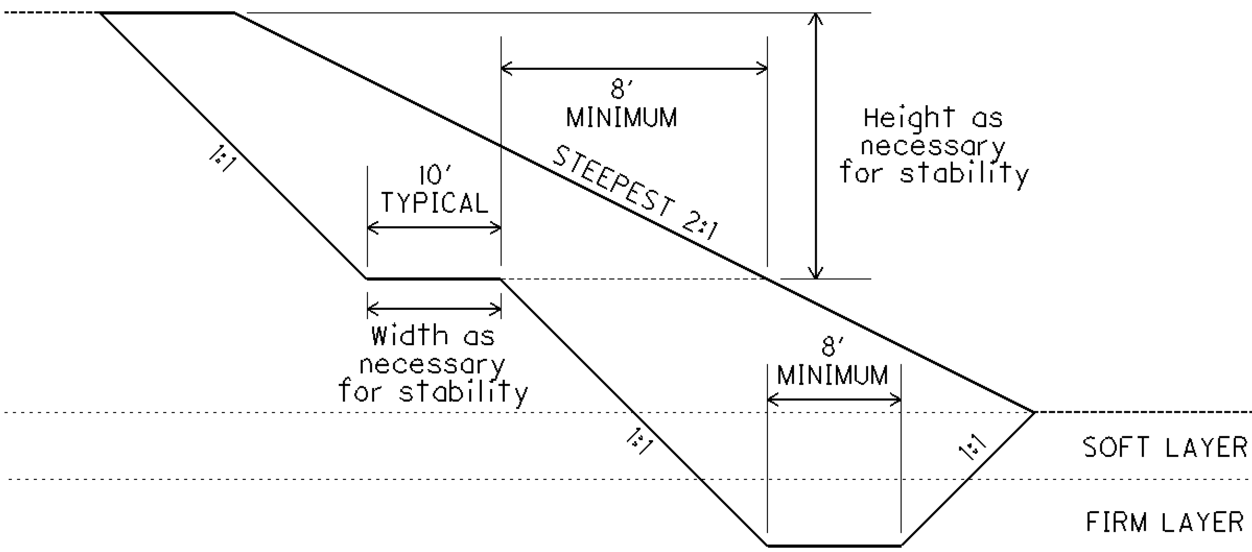


Figure 5
Special Benching for Embankment Stability over Soft Foundation Soil

Special benching is used to correct this problem in a similar manner to the case for Landslide Stabilization, in Section D. If a shear surface has developed through the embankment, the special benching should intercept this shear surface, just as it would for a typical landslide.

In the case of a soft foundation soil, however, the lowest bench should penetrate the soft layer, so that the excavation and replacement forms a key into firmer soil. The base of this key must be at least 8 feet wide, to allow compaction and grading equipment to operate in the confined space. The depth of this key, and the depth of the benches into the embankment, will be defined by stability. The design must be checked with a slope stability analysis, to assure that minimum FS for slope stability are met, per the ODOT Geotechnical Engineering Design Checklists, Section III.B. Embankments Checklist, Stability. If the FS does not meet the minimum required 1.3 (or 1.5 for an embankment supporting a structure), the key, and/or the benches will need to be deepened, vertically and horizontally into the slope, until stability is achieved.

Although the back slope of each bench is typically cut at a 1H:1V slope, this slope may need to be flattened where it extends through the soft layer. The maximum cut slope is based on the short term stability of the existing soils, and the soft layer may not stand at a 1H:1V slope.

If the minimum required FS cannot be met by special benching, additional measures, such as flattening of the slope, groundwater drainage, counter-berms, or retaining structures to further improve stability of the slope will be necessary. See Section D, Landslide Stabilization, for details on these methods. See Section A, General Case, for additional details on dimensions and construction of special benching.

F. Special Benching for Embankment Stability Keying into Bedrock

In Appalachian regions, natural slopes often have rock close to the surface. The residual soils on these slopes, weathered from the underlying parent rock, are typically low in strength. These slopes are often marginally stable or unstable in their natural state. The additional weight of a sidehill embankment fill will only worsen the stability of the existing slope, and shear failures are often induced in this situation, with the soils sliding on top of the bedrock surface. To remediate such a shear failure, it is necessary to key into the shallow bedrock surface with special benching to improve the stability of the slope by intercepting the failure surface at the soil-bedrock interface. Figure 6 shows an example of this case.

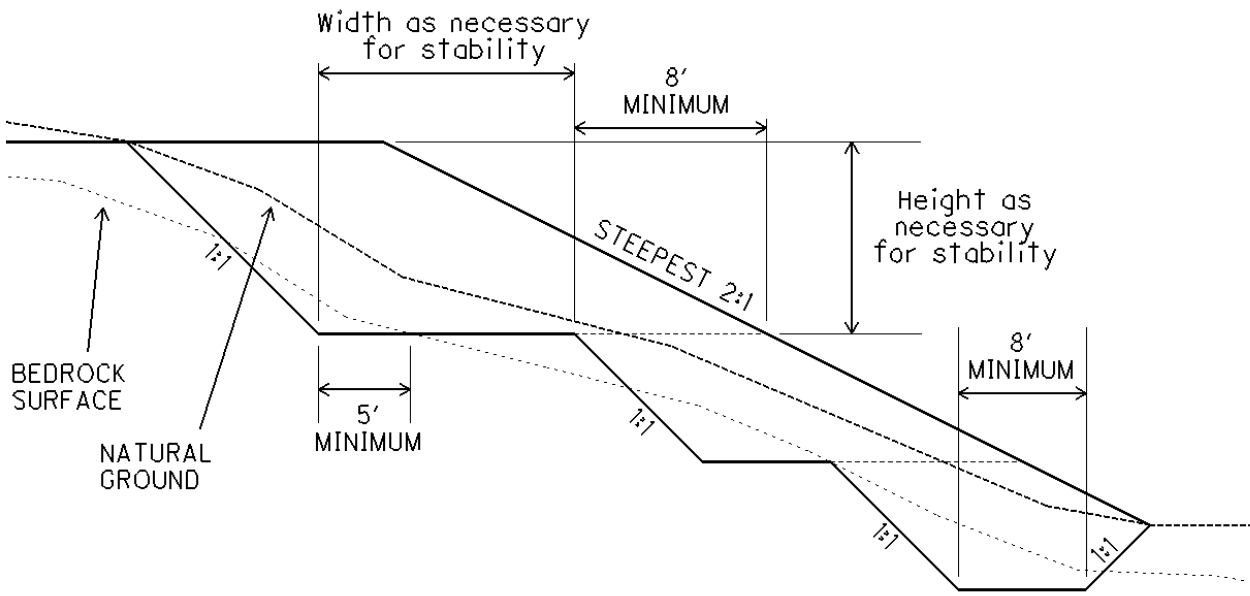


Figure 6
Special Benching for Embankment Stability Keying into Bedrock

When keying benches into bedrock, the base of each bench should extend a minimum of 5 feet into the bedrock to provide a firm key. The designed benches may need to be adjusted in the field, in order to meet the actual bedrock surface. It may be necessary to make a deeper key at the base of the slope, to improve stability. The base of this key must be at least 8 feet wide to allow compaction and grading equipment to operate in the confined space.

The depth of the bedrock key for these benches will be defined by stability. The design must be checked with a slope stability analysis, to assure that minimum FS for slope stability are met, per the ODOT Geotechnical Engineering Design Checklists, Section III.B. Embankments Checklist, Stability. If the FS does not meet the minimum required 1.3 (or 1.5 for an embankment supporting a structure), the key, and/or the benches will need to be deepened, vertically and horizontally into the bedrock, until acceptable stability is achieved.

If the minimum required FS cannot be met by special benching, additional measures, such as flattening of the slope, groundwater drainage, counter-berms, or retaining structures to further improve stability of the slope will be necessary. See Section D, Landslide Stabilization, for details on these methods. See Section A, General Case, for additional details on dimensions and construction of special benching.