Chapter

9

Embankments – Analysis and Design

9.1 General

This chapter addresses the analysis and design of rock and earth embankments. Also addressed briefly are the use of lightweight fill, settlement and stability mitigation techniques. Bridge approach embankments, are not covered in this chapter, but are addressed in Chapter 8 and in Chapter 6. For the purposes of this chapter, embankments include the following:

- Rock embankments, also known as all-weather embankments, are defined as fills in which the material is non-moisture-density testable and is composed of durable granular materials.
- Earth embankments are fills that are typically composed of onsite or imported borrow, and could include a wide variety of materials from fine to coarse grain. The material is usually moisture-density testable.

9.2 Design Considerations

9.2.1 Embankment Materials and Compaction

New embankments and embankment widening require suitable fill materials be used and properly compacted with correct equipment based on the material type. The *ODOT Standard Specifications for Construction* provides embankment construction methods for soil, non-durable rock and rock materials. Non-durable rock materials may require additional compaction effort beyond standard construction methods to prevent long-term settlement of an embankment. The geotechnical designer should determine during the exploration program if any of the material from planned earthwork excavations will be suitable for re-use as embankment. Consideration should be given as to whether the material is moisture sensitive and difficult to compact during wet weather.

9.2.1.1 All-Weather Embankment Materials

ODOT projects frequently require embankment fill construction during the wet-weather months (typically October through May). Clean, granular, all-weather embankment materials improve the contractor's ability to properly place and compact fill materials during the wet-weather months. *ODOT Standard Specifications* identify include two materials generally suitable for wet-weather construction: Selected Stone Backfill (*00330.15*), and Stone Embankment Material (*00330.16*).

9.2.1.2 Durable and Non-Durable Rock Materials

Special consideration should be given during design to the type of material that will be used in rock embankments. In some areas of the state, moderately weathered or very soft rock may be encountered in cuts and used as embankment fill. Follow these guidelines:

- Degradable fine-grained sandstone and siltstone are often encountered in the cuts and the use of this material in embankments can result in significant long-term settlement and stability problems as the rock degrades, unless properly compacted with heavy tamping foot rollers (Machan, et al., 1989). The slake durability test (ASTM D4644) should be performed if the geologic nature of the rock source proposed indicates that poor durability rock is likely to be encountered.
- When the rock is found to be non-durable, it should be physically broken down and compacted as earth embankment provided the material meets or exceeds common borrow requirements. Special compaction requirements, defined by method specification, may be needed for these materials. In general, tamping foot rollers work best for breaking down the rock fragments. The minimum size roller should be about 30 tons. Specifications should include the maximum size of the rock fragments and maximum lift thickness. These requirements will depend on the hardness of the rock, and a test section should be incorporated into the contract to verify that the Contractor's methods will achieve compaction and successfully break down the material. In general, both the particle size and lift thickness should be limited to 12 inches.

9.2.2 Embankment Stability

Embankment stability design should be consistent with state-of-the-practice design guidelines, including but not limited to the referenced publications in Section 9.5. Stability design shall be evaluated using conventional limit equilibrium methods, and analyses should be performed using a state-of-the-practice slope stability computer program such as the most current versions of Slope/W® (Geo-Slope International), Slide® (Rocscience, Inc.), and/or ReSSA® (ADAMA Engineering, Inc.).

9.2.2.1 Safety Factors

For embankments adjacent to but not directly supporting structures, a maximum resistance factor of 0.75 should be used. Where embankments support structures such as bridges, end panels, retaining walls, and minor structures, a maximum resistance factor of 0.65 should be used. These resistance factors of 0.75 and 0.65 are generally equivalent to a safety factor of 1.3 and 1.5, respectively.

9.2.2.2 Strength Parameters

Strength parameters are required for any stability analysis. Strength parameters appropriate for the different types of stability analyses are determined based on Chapter 5 and *FHWA Geotechnical Engineering Circular No. 5 (Sabatini, et al., 2002*). Both short (undrained) and long term (drained) stability need to be assessed.

9.2.3 Embankment Settlement

Embankment settlement analysis should be based on the methods in *FHWA Soils and Foundation Reference Manual,* (Samtani and Nowatzki, 2006) and Section 10 of the *AASHTO LRFD Bridge Design Specifications*. Because primary consolidation and secondary compression can continue to occur long after the embankment is constructed (post construction settlement), they represent the principal settlement concerns for embankment design and construction. Post construction settlement can damage structures and utilities located within the embankment, especially if those facilities are also supported by adjacent soils or foundations that do not settle appreciably, leading to differential settlements. Many construction projects cannot absorb the scheduling impacts associated with waiting for primary consolidation and/or secondary compression to occur. Therefore, estimating the time-rate of settlement is often as important as estimating the magnitude of settlement.

Key parameters required to calculate the time-rate and magnitude of embankment settlement include:

- The subsurface profile including soil types, layering, groundwater levels and unit weights.
- The indexes for recompression. Primary and secondary compression from laboratory consolidation test data, correlations from index properties, and results from settlement monitoring programs at nearby sites with similar soil conditions.
- The geometry of proposed fill embankments, including fill unit weight and any long-term surcharge loads.

Analysis of primary consolidation and secondary compression settlements should be performed by hand-calculation, using Excel spreadsheet or MathCAD, or with a state-of-the-practice computer program such as the most current versions of FoSSA® (ADAMA Engineering, Inc.).

9.3 Stability Mitigation

Varieties of techniques are available to mitigate inadequate slope stability for new embankments or embankment widening. These techniques include staged construction to allow the underlying soils to gain strength, base reinforcement, ground improvement, and construction of toe berms (counterweights) and shear keys. An overview of these instability mitigation techniques is presented below.

9.3.1 Staged Construction

Where soft compressible soils are present below a new embankment location and it is not economical to remove and replace these soils with compacted fill, the embankment can be constructed in stages to allow the strength of the compressible soils to increase under the weight of new fill. Construction of the second and subsequent stages commences when the strength of the compressible soils is sufficient to maintain stability. In order to define the allowable height of fill for each stage and maximum rate of construction, detailed geotechnical analysis is required. The analysis to define the height of fill placed during each stage and the rate at which the fill is placed is typically completed using a limit equilibrium slope stability program along with time rate of settlement analysis to estimate the percent consolidation required for stability. Field monitoring of settlement and pore water pressures are usually required during construction.

9.3.2 Base Reinforcement

Base reinforcement may be used to increase the factor of safety against slope failure. Base reinforcement typically consists of placing at least two, closely spaced geogrid layers near the embankment base with a high-strength geotextile used as a separator between the embankment and foundations soils. . Base reinforcement is particularly effective where soft/weak soils are present below a planned embankment location. The base reinforcement can be designed for either temporary or permanent applications. Since the reinforcement is needed only until the foundation soil has developed sufficient shear strength to maintain stability, the base reinforcement geogrid design does not require application of the full strength reduction factor for creep effects. Holtz, et al. (1995) provides a suitable design methodology for embankment base reinforcement.

9.3.3 Ground Improvement

Refer to Chapter 11 for references and information on ground improvement design.

9.3.4 Toe Berms and Shear keys

Toe berms and shear keys are methods to improve the stability of an embankment by increasing the resistance along potential failure surfaces. Toe berms are typically constructed of granular materials that can be placed quickly, do not require much compaction, and have relatively high shear strength. ODOT would typically specify the use of Stone Embankment Material when toe berms and shear keys are required.

9.4 Settlement Mitigation

9.4.1 Acceleration Using Wick Drains

Wick drains, or prefabricated drains, are in essence, vertical drainage paths that can be installed into compressible soils to decrease the overall time required for completion of primary consolidation. Wick drain design considerations, example designs, guideline specifications, and installation considerations are provided by reference in Chapter 11. Section 00435 of the *ODOT Standard Specifications* addresses installation of wick drains.

9.4.2 Acceleration Using Surcharges

Surcharge loads are additional loads placed on the fill embankment above and beyond the finish grades. The primary purpose of a surcharge is to speed up the consolidation process. Two significant design and construction considerations for using surcharges include embankment stability and re-use of the additional fill materials. New embankments over soft soils can result in stability problems. Adding additional surcharge fill could exacerbate the stability problem. Furthermore, after the settlement objectives have been met, the surcharge will need to be removed. If the surcharge material cannot be moved to another part of the project site for use as site fill or as another surcharge, it is often not economical to bring the extra surcharge fill to the site only to haul it away again. Also, when fill soils must be handled multiple times (such as with a “rolling” surcharge), it is advantageous to use gravel borrow to reduce workability issues during wet weather conditions.

9.4.3 Lightweight Fills

Lightweight fills can also be used to mitigate settlement issues as indicated in Section 9.3.4. Lightweight fills reduce the new loads imposed on the underlying compressible soils, thereby reducing the magnitude of the settlement.

9.4.4 Subexcavation

Subexcavation refers to excavating the soft compressible or unsuitable soils from below the embankment footprint and replacing these materials with higher quality, less compressible material. Because of the high costs associated with excavating and disposing of unsuitable soils as well as the difficulties associated with excavating below the water table, sub excavation and replacement typically only makes economic sense under certain conditions. Some of these conditions include, but are not limited to:

- The area requiring over excavation is limited;
- The unsuitable soils are near the ground surface and do not extend very deep (typically, even in the most favorable of construction conditions, sub excavation depths greater than about 10 ft. are in general not economical);
- Temporary shoring and dewatering are not required to support or facilitate the excavation and;
- Suitable materials are readily available to replace the over-excavated unsuitable soils.

9.5 References

- Federal Highway Administration, 1992, "EMBANK, Computer Program, User's Manual Publication," *Publication No. FHWA-SA-92-045*.
- Holtz, R. D., Christopher, B. R., and Berg, R. R., 1995, Geosynthetic Design and Construction Guidelines, Federal Highway Administration, FHWA HI-95-038.
- Machan, G., Szymoniak, T. and Siel, B., 1989, Evaluation of Shale Embankment Construction Criteria, *Experimental Feature Final Report OR 83-02*," Oregon State Highway Division, Geotechnical Engineering Group.
- Sabatini, P.J, Bachus, R.C, Mayne, P.W., Schneider, J.A., Zettler, T.E. (2002), Geotechnical Engineering Circular No. 5, Evaluation of Soil and Rock Properties, Report No FHWA-IF-02-034.
- Samtani, N. and Nowatzki, E. (2006), *Soils and Foundation Reference Manual, Volumes I and II*, Report No. FHWA NHI-06-088.
- *Collin, J.G., et al, 2005, U.S. Department of Transportation, Federal Highway Administration, Soil Slope and Embankment Design Reference Manual, FHWA-NHI-05-123.*
- *Samtani, N.C. and Nowatzki, E. A., 2006, U.S. Department of Transportation, Federal Highway Administration, Soils and Foundations Reference Manual, FHWA-NHI-06-088.*