CHAPTER 7

DESIGN RECOMMENDATIONS

7.0 INTRODUCTION

The geotechnical design recommendations for any given project should include the description of the existing subgrade conditions, structures, embankment stability, cut slopes, transitional grades (cut and fill), engineering characteristics of borrow soils, ground water conditions and should attempt to predict possible construction difficulties resulting from the subsurface conditions. This will ensure the proper design plans and special provisions (if needed) are created for the construction of the project. Frequently there will be multiple viable recommendations that can be provided for a single issue, in these instances alternate recommendations may be provided with cost benefit studies. The geotechnical recommendations should be comprehensive, practical, cost effective and should be based on accepted engineering practices.

Standard procedures and materials are preferable, unless conditions justify special construction techniques or materials. The design recommendations should include a recommended special provision for all job specific construction techniques, or materials. Construction and material inspection, testing and acceptance (according to INDOT practice and testing capability) must be addressed in the special provision.

7.1 PAVEMENT SUBGRADE

Soil type and moisture content are the major factors influencing subgrade conditions. Thus, moisture content is the primary controlling factor of the subgrade stability for a given soil.

The field reconnaissance, pedological soil information, pavement maintenance history, in-situ density, moisture content, ground water data, drilling and laboratory data and scope of work will dictate the subgrade recommendations. Every effort shall be made to determine the water elevation. Analysis of the existing subgrade must delineate the area of concern during the construction. The recommendations shall be based on cost/benefit, local conditions, construction schedule or other considerations.

Specific recommendations shall be based on previously described considerations. Various subgrade treatments are discussed in INDOT Specifications 207.04. Communication with designers, pavement design engineers, district construction engineer may lead to viable and economical recommendations.

The geotechnical engineer in general shall follow these guidelines:

- A resilient modules (Mr) test will be performed on each major project (for 800-ft. length of pavement construction). The subgrade recommendations should be based upon a Mr test result on a predominant soil.
- On any project (for pavement construction > 2 miles) where subgrade soils differ significantly two Mr values should be given if two subgrade areas clearly delineate.
- Subgrade stabilization shall be considered for soil with Mr values less than 3000 psi.

Subgrade Under Rubblized Pavement. The analysis of subgrade under the existing pavement consists of evaluation of insitu moisture and density. The geotechnical engineer shall consider the proposal based on the existing subgrade conditions. They shall also anticipate its future performance during the design life. Unstable, unsuitable, or lower bearing values soils with constraints shall be delineated in subgrade recommendations and a resilient Modules (Mr) based on the existing conditions shall be recommended for pavement design.

In general, the geotechnical engineer must present specific subgrade treatment recommendations to designers. The recommendation must give the estimated length (usually station to station), with type of treatment. The recommendations must allow the designers to calculate contract quantities. Every attempt shall be made to minimize the unknown during construction of the project. The recommendation shall be justifiable and should involve considerable judgment in order to interpret the field and laboratory data.

The proposed subgrade shall be designed based on Mr values obtained from laboratory test results. For the fill section, the Mr test shall be performed on the predominant soil type based on the best engineering judgment and evidence of geological information. Mr testing shall be similar to what is described in previous treatments.

7.2 UNSUITABLE SOILS

Cohesive soils with high clay content and high plasticity may exhibit relatively large volume changes, with changes in moisture content. Soils with maximum dry density of less than 100 pcf, or LL greater than 50 with PI greater than 25, should be considered unsuitable. If these soils are present in the subgrade, or must be used as embankment material, treatment may be warranted, and specific recommendations should be made. The recommendations may include limiting the use of unsuitable materials within the embankment, removal and replacement; or treatment with chemicals (such as, lime), flattening of the slope, etc.

Loess soils, found primarily in Southwest Indiana, sometimes must be used in embankments, subgrades, and foundation soils. Specific recommendations should be made to deal with these soils.

There are a variety of remedial measures that may be used to deal with unsuitable soils (peat, marl, trash fill, rubble fill, etc.). Each of these methods will require specific recommendations. Recommended methods must be cost-effective and constructible. Some of the methods commonly used are:

Table 7.1 Unstable Soil Problem/Solution

Soil Reinforcement	Pressure Grouting
Soil Bridging	Stone Columns
Excavation and Replacement	Wick Drains
Displacement	Lightweight Fill
Surcharging	Dynamic Compaction
Chemical Soil Modification	Etc.

7.3 EMBANKMENTS

Embankment design recommendations should be cost effective and address short and long-term slope stability, and settlement issues. If any monitoring and/or stage construction is required, then specific recommendations (including Special Provisions) should be included in the Geotechnical Report. The embankment settlement must be tolerable, especially adjacent to rigid structures. Differential settlement is more of a concern than the total settlement.

Special design methodology while using waste materials in construction such as coal ash, slag, and shredded tires, should be described in detail.

7.3.1 EMBANKMENT OVER PEAT/MARL

It is preferable to avoid peat/marl deposits, but there are times when they cannot be avoided. Embankments must be constructed on a stable foundation in these areas. This helps avoid serious problems, which may occur within a short time after completion. The manner in which this is accomplished, and the problems to overcome, depends largely on the type and depth of materials encountered. The presence of peat or marl may sometimes be determined by the surface appearance and vegetation cover. However, a detailed program of boring and sounding is required for accurate identification of peat/marl deposits.

Natural peat/marl deposits often consist of several layers of peat, or combinations of organic and mineral deposits overlying stable mineral soil. While these upper layers may vary markedly in composition and exhibit a range in physical properties, they are entirely unsuitable as a foundation for highways. Therefore, it becomes necessary to treat these materials in such a manner that they do not cause detrimental settlement or failure of the embankments.

When an embankment crosses peat/marl deposits (peat bogs) or swampy areas, stability and/or excessive settlement must be considered. A bridging layer will not be sufficient treatment. Extensive removal and replacement may be needed. Load balancing with lightweight fill is another option.

Unsuitable soils may be removed from the embankment foundation, and replaced by material of higher shear strength. Normally, suitable borrow is satisfactory for replacement. In the case of a wet excavation, B-borrow must be placed to a height of 2 ft. (0.6 m) above the water level observed at the time of placement. The remaining backfill may be accomplished with suitable borrow.

If it is economically feasible, removal should be performed to a point beyond the toe of the slope, a distance equal to the depth of removal as shown in Figure 7.1.

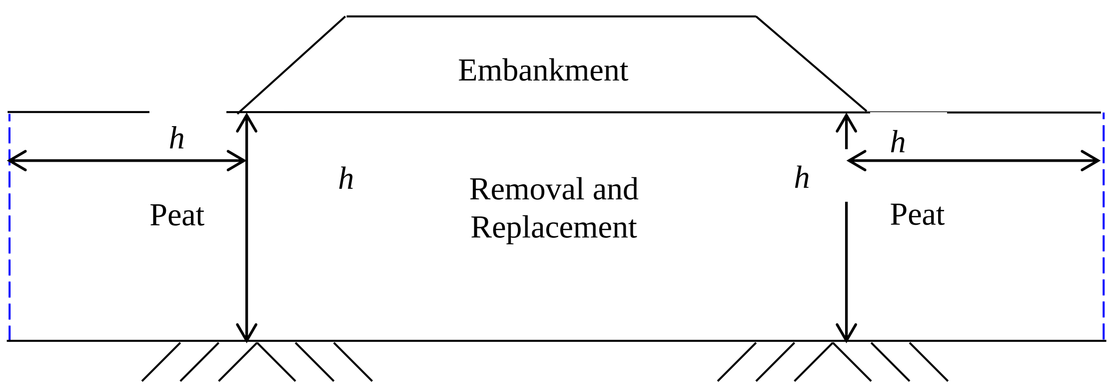

Fig. 7.1 Width of Removal And Replacement in Peat Bogs

Depending on the depth and thickness of peat/marl deposits four removal options are described below:

7.3.1.1 TOTAL EXCAVATION METHOD

This method can usually be used economically for deposits less than 12 ft. (4 m) in depth. This method should only be recommended after considering: a) stability of the excavation slopes; b) the dewatering effect on adjacent pavement and surrounding structures, if needed; c) the difficulty and expense of dewatering; d) the difficulty of placing fill underwater; 5) etc.

7.3.1.2 PARTIAL EXCAVATION

For a small embankment on a peat/marl deposit, where settlement is the only concern, partial removal and replacement may be feasible. The geotechnical engineer must compute the depth to be removed, to reduce the settlement to a tolerable level. This must be based on laboratory tests. In general, the analysis will show that removing one half the peat does not remove half the settlement because the replacement material often weighs much more than the soil removed.

7.3.1.3 DISPLACEMENT

If the peat and marl is too deep to be excavated, it may be possible to remove by the displacement method. The theory of this procedure is to overload the weak material, to such an extent that it is displaced by a rolling surcharge and by backfill material. A forward relief trench, combined with a surcharge, creates the condition of unbalance, which causes displacement. Thus, the effectiveness of the treatment is directly related to the depth of the trench and the height of the surcharge. Failure to maintain adequate dimensions for the surcharge and trench is usually the cause of incomplete removal. An open trench is maintained to facilitate removal of unsuitable soils as described in the INDOT Standard Specifications. Displacement of the peat should be verified by borings with continuous split-spoon sampling.

7.3.1.4 LOAD BALANCING WITH LIGHTWEIGHT FILL

When it is not feasible or economical to remove the peat/marl deposits, it may be possible to "float" the new pavement. Heavier soils are excavated and replaced with lightweight fill in order to compensate for the weight of the new fill and pavement. Therefore, there is no increase in load to the peat. Light weight fills that are available are: a) cellular concrete at 20 to 50 Pcf, b) expanded shale, at 40 to 70 Pcf; c) expanded polystyrene (EPS) blocks at 1 to 4 Pcf, d) light weight slag 70 to 80 Pcf; e) shredded tires 40 to 60 Pcf, f) and other materials.

There are special techniques needed for some of these products, and environmental concerns with others. Before these products are recommended or used, the engineer should be familiar with the cost, special construction techniques, durability, and effects on future construction and maintenance to the roadway. When calculating the depth of excavation, the buoyant weight of the light weight fill and pavement should be considered, to prevent the pavement from floating during periods of high ground water and flooded ditches.

As with partial removal, partial load balancing may reduce settlement to a tolerable level, if the new load cannot be completely balanced.

Lightweight fills do not stabilize or remove the peat; they merely "float" over the problem soils.

7.3.2 EMBANKMENT STABILITY OVER SOFT SOILS

Use of sand or wick drains can accelerate drainage, and speed consolidation and strength gain. Wick drains and sand drains have been successfully used by INDOT.

Many weak subsoils will tend to gain strength during the loading process, as consolidation occurs, and excess pore water pressure dissipates. A controlled rate of loading, or stage construction, may be utilized to take advantage of this strength gain. Maximum height of embankment for stage construction should be recommended in the geotechnical report. Proper instrumentation is desirable to monitor the state of stress in the soil during the loading period, to insure that loading does not proceed so rapidly as to cause a shear failure.

If stage construction is recommended, special provisions must be included in the report.

The slopes can be rendered safer by placing berms on the embankment. In no case, should the berms be narrower than 10 ft. (3 m), in order to provide for adequate maintenance by mechanical equipment.

Geosynthetic products may also be used to stabilize embankment bases over soft and very soft materials. When the primary concern is stability rather than settlement, geotextiles and geogrids can be used separately or together to reinforce the base of the embankment against lateral spread and failure. The design presented in the Geotechnical report must be analyzed for slope stability, bearing capacity, and settlement.

Under special conditions, an area of weak soil may be bridged by a structure, and the concern for a stable embankment circumvented.

7.3.3 EMBANKMENT SETTLEMENT

Embankments constructed over compressible deposits experience settlements that vary in degree of severity and the length of time to reach equilibrium. Laboratory consolidation tests on undisturbed samples will give an estimate of the amount of settlement and the time required to achieve the settlement. The Consultant Geotechnical Engineer shall furnish computations for total estimated settlement (cross-section of up to three points if requested), a plot of percent total estimated settlement vs. time (at the point of maximum settlement unless otherwise approved) assuming the most likely drainage conditions, etc. The Geotechnical Report should describe the situation and present recommendations on various available treatments. The treatment methods should provide the designer with an opportunity to compare the economics of each, and to estimate the time required for achieving the greater part of the settlement, by each method. Each treatment method should be accompanied with backup data, to help the designer compare the alternatives.

Some of the corrective measures INDOT has used to mitigate settlement problems are:

- Removal and replacement of the compressible soil. The economics of this method have to be questioned, when the depth of removal exceeds 12 ft. (4 m.).
- The use of instrumentation and time delays in bridge foundations and approach pavement construction, until an acceptable level of consolidation has taken place.
- The use of sand or wick drains, mostly in conjunction with preloading, to accelerate settlement.
- Preloading the site with a surcharge load.
- Dynamic compaction. This consists of dropping a weight from a certain height to densify the upper 15 to 20 ft. (4.5 to 6 m) of loose, granular deposits.

The compressible deposit may be removed and replaced by a suitable material, if economically feasible. The replacement material placed should be a drainable, granular material placed to a height of 2 ft. (0.6 m) above seepage water in the excavation. The remainder may be constructed with suitable earth borrow.

When settlement problems arise, the time of settlement can be substantially reduced through the construction of a drainage blanket. This blanket should consist of clean, drainable sand or granular material, (No. 8 or No. 53 stone) not less than 24 in. (600 mm) thick. The blanket is placed over the original ground surface and serves as a drainage platform for the embankment. The granular blanket must be day-lighted at the sides of the embankment, or effectively tapped, in order to provide free drainage. Settlement plates along stakes with slope indicators should be installed for future monitoring. The drainage path for surplus moisture in consolidating deposits may also be shortened by the use of vertical sand drains or wick drains, to reduce the settlement time. A successful sand or wick drain operation requires a detailed subsurface analysis, design, and careful installation of the sand or wick drains. The detailed procedures should also consider the nature of the substrata and its influence on the success of the treatment.

The rate of settlement depends upon the thickness and permeability of the consolidating layer, the character of the drainage pattern, and the pore water pressure. Thus, a surcharge can be used to speed up consolidation. However, care must be taken to assure the shear strength of the supporting soil is not exceeded; or a lateral squeeze may result.

7.3.4 EMBANKMENT REINFORCEMENT

Due to the high cost of additional R.O.W. and retaining wall systems, reinforced soil slopes (RSS) may be considered when there is insufficient R.O.W. for a normal embankment side slope. The reinforced soil slope must have both internal and external stability and tolerable settlement. Erosion should also be addressed.

The engineer must analyze external stability and settlement. Also, the engineer should provide any design recommendations necessary to ensure that the RSS system is stable and that settlement is tolerable.

If the geotechnical engineer elects to perform the detailed reinforced soil slope design, complete design recommendations should be provided, including:

- Slope angle.
- Specifications for the geosynthetic material.
- The geosynthetic embedment length.
- Specific geosynthetic vertical locations and soil layer thicknesses.
- Embankment properties, and compaction require
- Slope surface treatment.

A Special Provision should indicate the materials and construction techniques.

7.4 CUT SLOPES

Frequently considerable amounts of cuts are encountered for roadway construction. Current practice utilizes a minimum FOS of 1.5 for cut slopes, based on laboratory testing of undisturbed samples. If the stability analysis is based on the field tests of split-spoon samples, the FOS should be 1.7 or greater. The higher FOS required for backslopes (cutslopes), as compared to embankments, is based upon the knowledge that cut slopes may deteriorate as a result of natural drainage conditions.

Cut slope stability may be improved by the following:

- Flattening of Slopes

- This can most effectively be accomplished by benching. Benches should be at least 10 ft. (3 m) wide [ideally 15 ft (4.5 m)] in order to provide for proper construction and maintenance.

- Improvement of Drainage. Ground water seepage at the face of a cut slope, or a perched water table (due to a soil contact with a less permeable underlying layer) may result in sloughing, or other problems. Drainage cutoff trenches may be designed to intercept the seepage, and thus, render the slope face stable. Horizontal drainage system using geofabric should be considered as a remedial measure for the stability of slope. Under special conditions, stability may be provided by some erosion protection measures or by a properly designed retaining structure, which includes retaining walls, rock buttressed, bin walls, or sheeting walls.

Specific design recommendations must be provided to ensure cut slope stability, if the analysis shows an unacceptable FOS.

7.5 BRIDGE AND RETAINING STRUCTURES

Based on the findings of subsurface exploration and engineering analysis recommendations for the stability of structure are made. The factor of safety of various structures for geotechnical design are presented in Table 6.1.

7.5.1 BRIDGE FOUNDATIONS

In case of deep foundations like H-piles or steel encased piles, it should be analyzed at each pier location. Each pile should be analyzed to determine the embedment lengths for 56, 77 and 98 T factored loads. In case of SEC/pipe piles 14 inch and 16 inch diameters should be considered. In most of the case for design load of higher than 70 T service load PDA (Pile Driving Analyses) tests should be recommended. Test piles are driven to 150% of the total service bearing capacity. The test pile is ordered 10 ft. (3 m) longer than the estimated design length. The production piles for the structure are ordered after a careful review of the test pile record and the foundation borings.

7.5.2 RETAINING WALLS

Based on the engineering analysis of retaining walls (as discussed in Chapter 6) following should be recommended.

- Depth of foundation.
- Allowable bearing capacity of foundation steel.
- Shear strength parameter of friction angle of granular backfill.
- Shear strength parameter of foundation soil.

7.5.3 SOLDIER PILE RETAINING STRUCTURES (WITH AND WITHOUT TIEBACKS)

Based on engineering analysis recommendations should include the following.

- Allowable lateral load.
- Depth of embedment.
- Station limits of structural elements.
- In case of tiebacks, the capacity and spacing of the tiebacks.
- Other required design parameters, etc.

7.6 SPECIAL PROBLEMS

Special problems may require careful evaluation regarding their effect on the final improvement. There are many special cases that require close attention and scrutiny from the geotechnical engineer, they include but are not limited to the following:

- Mine Subsidence
- Reclaimed Mine Lands
- Karst
- Landfills
- Erosion Control

The geotechnical engineer may not be able to present design solutions to every special problem in the Geotechnical Report. The Report, however, may be the only place where such geological hazards are brought to the attention of the designer.