Taxiway Embankment Design Across Wetlands Using Dilatometer Shear Strength Parameters

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ABSTRACT: Reliable shear strength parameters are difficult to estimate in soft soils. Dilatometer results from six test locations were correlated with Standard Penetration Resistances to obtain shear strength and modulus values for slope stability and settlement analysis. Limit equilibrium and finite element analysis are used to verify staged construction of 60 feet (18 meters) high embankment fill over soft wetland soils. The analysis results will be used as construction controls for the instrumentation program during fill placement.

1 Project Background

The Piedmont Triad International Airport (PTIA) located in Greensboro, North Carolina is undergoing an approximate $550 million expansion. This expansion is the result of Federal Express selecting this site for a Mid-Atlantic regional hub, scheduled to open in 2009. The hub will operate up to 63 flights per night at final capacity in 2012. The expansion to the PTIA is shown in Photograph 1 and involves four major components as follows:

- The relocation of Bryan Boulevard which currently provides the main access to the airport. This will include 2.5 miles of multi-lane roadway in addition to a major interchange.
- Preparation of a 170-acre site for the new FedEx hub which includes sorting facilities for airplane and truck delivery access.
- New 9,000-foot (2,744-meter) runway 5L/23R and parallel taxiways.
- The new 3,500-foot (1,067-meter) connector Taxiway Echo between existing runway 5/23 and the new runway 5L/23R which also provides primary access to the new FedEx hub.

Taxiway Echo alignment is controlled both horizontally and vertically by existing and planned improvements at the airport. Its alignment from east to west results in cut sections on the order of 25 feet (8 meters), crossing access roads with a proposed tunnel, grade transition to a 60-foot (18-meter) high fill embankment over wetlands, and a taxiway bridge structure crossing existing Bryan Boulevard which will become the single entrance to the airport facility.

Photograph 1. Piedmont Triad International Airport

The wetland crossing portion is approximately 600 feet (183 meters) in length. The final grades in this area require the construction of a 60-foot (18-meter) earth embankment over the existing soft ground. The wetland area contains existing Brush Creek, which is the headwaters for the City of Greensboro water supply. The wetland areas have been permitted by the Corps of Engineers which require on- and off-site mitigation of over 101 acres that was agreed to by all parties prior to the beginning of design. The footprint of the taxiway alignment is restricted by this agreement and other water quality standards, including wildlife habitat re-

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quirements imposed by state agencies. The wetland water quality and flow cannot be impacted by the crossing, which imposes restrictions on design and construction. The flow of Brush Creek will be diverted into a box culvert approximately 525 feet (160 meters) long.

2 PROJECT SCOPE

Thirty-three soil test borings using wash drilling techniques and six dilatometer soundings were performed within the wetland area to depths of between 20 to 50 feet (6 to 10 meters) below the ground surface. The soil types contained within the alluvial materials were highly variable and included micaceous silty medium-to-fine sands or slightly clayey medium-to-fine sandy silts. The Standard Penetration Resistances ranged between Weight of Rod (WOR) to 10 bpf in the alluvial soils. The large variation in density and consistency of the alluvial soils prevented conventional undisturbed sampling and laboratory testing to obtain reliable strength parameters. Figure 1 provides a typical summary of the variability of the subsurface soils. The dilatometer was chosen for in-situ testing since the results would be reliable for undrained shear strength determination or phi (Φ) values for slope stability analysis and would provide information for consolidation properties.

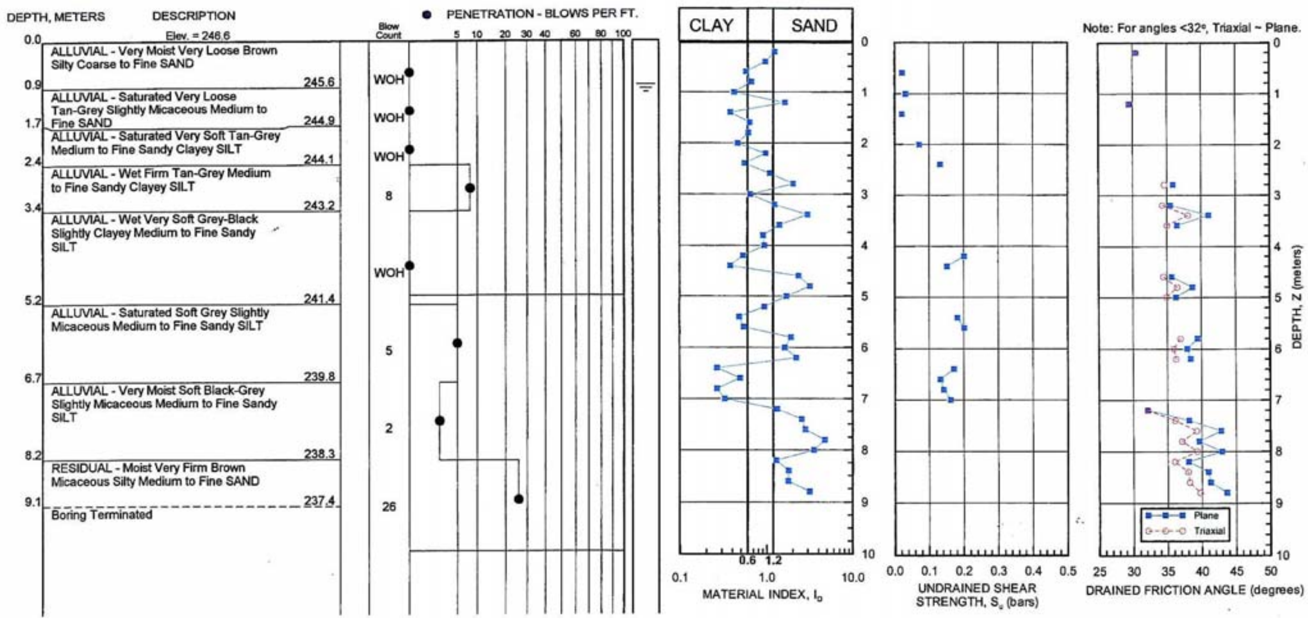

Figure 1. Boring Record

The dilatometer locations were chosen adjacent to six representative soil test borings to correlate the shear strength properties with the Standard Penetration Resistance values. The Weight of Rod (WOR) materials in the upper 10 feet (3 meters) were correlated separately from the Weight of Rod (WOR) material below the 10-foot (3-meter) depth since the undrained shear strength values were apparently higher due to the weight of the rods and hammer. The correlation obtained for the cohesive soils and the micaceous silty medium-to-fine sands with Standard Penetration Resistances are shown in Table A. Less reliability was given for the Φ values versus Standard Penetration Resistances, so this data is not shown. The Φ values appeared greater for these soil types and were not used. The dilatometer modulus values were also used for settlement analysis but not correlated with the Standard Penetration Resistances. Overall, the dilatometer results indicated a significantly larger variation in soil types and density than the soil test borings. Many test values could not differentiate the soil types between silts and sands based on the Material Index since the soil types are generally a combination of Φ-C (phi-cohesive) soils.

Standard Penetration Resistance [blows per foot (bpf)]	Undrained Shear Strength (cohesion) [pounds per square foot (bars)]		
	Average	Range	No. of Readings
WOR (Weight of Rod) Less than 10-foot (3-meter) depth	185(0.1)	62.7(0.03) – 459.5(0.23)	28
WOR* - 4 *Below 10-foot (3-meter) depth	370(0.18)	146.2(0.07) – 793.6(0.40)	54
5 - 10	1204(0.60)	188.0(0.09) – 2130.3(1.06)	27

Table A. Standard Penetration Resistances

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3 EXISTING WETLAND CONDITIONS

Site: The wetland area is fairly flat and comprises the flood plain of Brush Creek. General site conditions are shown in Photograph 2. The creek has a very low gradient through this area with the main channel not distinctively defined. The stream has meandered through this area for many years with the flood plain area very prone to flooding after normal rain events resulting in the deposition of sediment.

The wetland area is currently very thickly vegetated with underbrush and isolated small trees. The groundwater table is at or near the surface which results in very soft conditions, particularly below the upper root mat. Access by self-propelled equipment is very difficult. A track drill CME 850 was utilized to collect subsurface information in this area.

Photograph 2. Wetland Area

Site Geology: Below the alluvial materials, a residual profile is present. The residual soil profile is the product of the chemical and mechanical weathering of the underlying bedrock. At this site, the bedrock is a formation of the Carolinas Slate Belt of the Piedmont Physiological Province of North Carolina and generally consists of metamorphosed granitic bedrock.

Subsurface: The subsurface conditions were determined based on 33 soil test borings using a track-mounted CME 850 due to the difficult site access conditions. Because of the softness and variability of the upper alluvial materials, undisturbed sampling and laboratory testing would be questionable due to sampling and testing disturbance. Therefore, Standard Penetration Tests were supplemented utilizing a dilatometer at six locations for density and strength parameters.

The alluvial soils present at the borings within the wetland area extend from 3 to 27 feet (1 to 8 meters) below the existing ground surface. The alluvial soils are highly variable in classification and density due to the depositional history of the Brush Creek floodplain. In general, the alluvial soils consist of either sandy silts or silty sands with varying amounts of mica and clay. Standard Penetration Resistance values obtained in the alluvial soils range from Weight of Rod (WOR) to 10 blows per foot (bpf). Undrained shear strengths in the fine grained soils measured between 20 (0.01) to 1000 pounds per square foot (0.44 bars).

Below the alluvial materials is a relatively thin veneer of residual soils on the order of 7 to 15 feet (2 to 5 meters) in thickness. The residual soils consist of zones of sandy silts and silty sands with mica. Standard Penetration Resistance ranges between 6 and 9 bpf, with the majority being greater than 15 bpf. Undrained shear strengths are generally between 500 (0.22) and 2500 pounds per square foot (1.11 bars).

Partially weathered rock underlies this area at depths between 21 and 34 feet (6 to 10 meters) exhibiting Standard Penetration Resistances greater than 100 bpf. This is a transition between residual soils and unweathered bedrock.

Groundwater within the wetland areas is generally within 2 feet (0.6 meter) of the ground surface.

4 ANALYSIS

The fill placement over the soft alluvial soils presents slope stability issues from the rapid load application and poor drainage properties of the foundation soils. Even with the placement of vertical wick drains, the authors chose the undrained shear strength parameters for the soil types and subsurface conditions present. This would represent the most critical condition for the construction phase since the factor of safety increases with time due to consolidation.

Various slope configurations, including a vertical retaining wall, were analyzed in a value engineering study. This study included settlement and slope stability analyses. Also, various alternatives were investigated to improve the safety factors for slope stability since failures were predicted due to the soft alluvial soils beneath the embankment. These scenarios included complete removal of alluvial material, partial removal of alluvial material, stone column reinforcement of the foundation soils, and the chosen option of using staged construction. The chosen option included the use of vertical wick drains in the alluvial materials to improve drainage for faster consolidation to allow shear strength improvements within the alluvial soils. Temporary rip rap and soil berms were used beyond the toe of the

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final slopes in the wetlands to obtain the needed shear strength increases for stability purposes. The berm materials outside the slope toe are to be removed in later stages of filling. The final design cross section is shown in Figure 2.

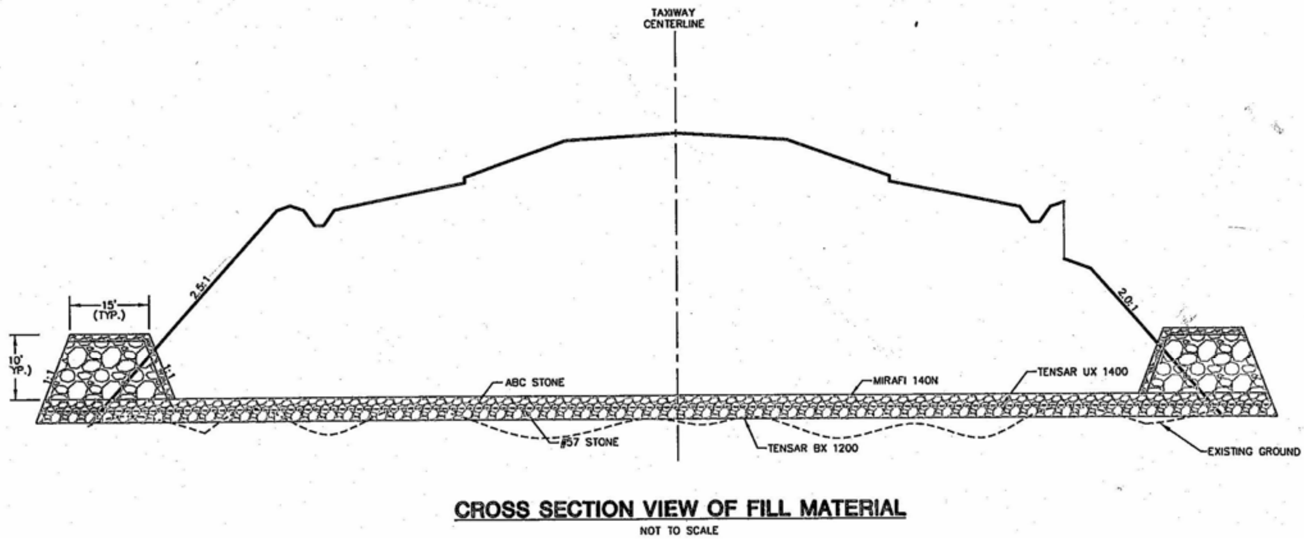

Figure 2. Cross Section View of Fill Material

The settlement potential of the embankments was estimated to range from 3 to 5 feet (1 to 1.5 meters) based on dilatometer data, Schmertmann's method, and finite element analysis using Plaxis. Large deformations were anticipated along the cross section. A high strength uniaxial geogrid was placed near the existing ground surface to produce more uniform deformation and to serve as reinforcing for the outer slope areas. The slope stability analysis was performed using a limit equilibrium method developed by Bishop. Due to the anticipated large deformations, numerical analysis using Plaxis is being performed on the selected cross section. The Plaxis analysis results are being used to confirm the design factor of safety for the different stages of construction. Plaxis also will provide allowable pore pressure increases and allowable horizontal deformation of alluvial soils below the slope toe that will be utilized during construction.

5 CONTROL DURING CONSTRUCTION

The staged construction concept to be utilized for embankment construction will require an instrumentation program during fill placement to prevent slope stability problems. The instrumentation program will consist of pore pressure and settlement monitoring, and slope indicator measurements of the horizontal and vertical deformations. This data will be used to determine the fill placement rate or appropriate waiting periods during fill placement to accommodate consolidation and shear strength increases in the alluvial materials. The horizontal and vertical deformations of the materials will be monitored to prevent slope failures from occurring.

6 CONCLUSIONS

The dilatometer results for undrained shear strength generally correlated with Standard Penetration Resistance in most of the fine grain soils at the site. The micaceous materials generally exhibited Material Indexes that corresponded to silts which are probably more representative of their performance. The Φ-C properties of these soil types have limitations with the interpretation using the dilatometer data. The Φ angles seemed to be overstated for these soil types based on past experience.

Overall, the dilatometer results provided reliable undrained shear strength values used in our analysis. The dilatometer seems to be an excellent application for the undrained shear strength determination for soft fine grained soils.

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