02 Jun 1993, 2:30 pm - 5:00 pm

Foundation Soil Preparation for Landfills in Karst Terrain

Kou-Roung Chang
CH2M Hill, Gainesville, Florida

John Carter
Department of Public Works, Alchua County, Florida

Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 7.17

Foundation Soil Preparation for Landfills in Karst Terrain

Kou-Roung Chang and Curt Basnett
CH2M Hill, Gainesville, Florida

John Carter
Assistant Director, Department of Public Works, Alchua County, Florida

SYNOPSIS: Stabilizing sand-filled solution chimneys in karst terrain for the construction of sanitary landfills is challenging for geotechnical engineers. A ground water contamination assessment conducted at a sanitary landfill in north central Florida indicated that landfill leachate was contaminating the Floridan Aquifer. To expand the landfill, the Florida Department of Environmental Regulation (FDER) required that a liner system be constructed and that stringent landfill subgrade preparation be performed to minimize the potential for sinkhole formation and subsequent damage to the liner system. To meet the requirements, the following foundation soil preparations were performed: (1) prerolling the subgrade with vibratory rollers, (2) scanning the subgrade with ground-penetrating radar (GPR) to locate potential subgrade anomalies, (3) confirming the GPR results with cone penetrometer tests (CPTs), (4) densifying loose sand with compaction grouting in solution chimneys identified by GPR and CPTs, (5) confirming the compaction grouting results with CPTs, and (6) proof-rolling the subgrade.

INTRODUCTION

The Southwest Landfill, a 192-acre Class I sanitary landfill located in the southwest corner of Alachua County, has been in operation since the early 1970s. In early 1985, monitoring showed that ground water near the site was contaminated. A contamination assessment was performed, which concluded that the landfill was a source of the ground water contamination. In October 1986, FDER and Alachua County entered into a consent order that provided for the development and implementation of a remedial action plan for the landfill, while allowing it to continue operation.

Because the Southwest Landfill is located in well-developed karst terrain, expansion of the Class I disposal area required foundation soil preparation to minimize the direct flow of leachate into the ground water. This technical paper presents a detailed description of the foundation soil preparation activities conducted at the landfill.

LOCAL GEOLOGY

Stratigraphy

The Geologic stratigraphy of western Alachua County generally consists of 30 to 50 feet of Brooksville Ridge Sand, overlying 10 to 20 feet of Alachua Formation, overlying the Crystal River Formation of the Ocala Group (see Figure 1). The Brooksville Ridge Sand mainly consists of fine to medium-grained, pale orange-to-tan quartz sand. Typically, the sand contains 0 to 5 percent of fines passing the No. 200 sieve, indicating that it is relatively clean. The thickness of the formation is variable and locally discontinuous because of karstic erosion.

The Alachua Formation is generally classified as alluvial material, deposited by rivers and streams on top of the karstified Eocene limestones. It consists mainly of clay and reddish brown-to-gray, silty-to-clayey sand. The depth to the Alachua Formation ranges from 0 to approximately 14 feet below the bottom of the landfill. The formation, which is exposed in the northwest corner of the disposal area, is shallowest on the west side of the disposal area and deepest on the east side.

The Crystal River Formation is overlain in most places by the Alachua Formation, a predominantly soft, white, chalky limestone. The thickness of the formation is variable and the formation is locally discontinuous because of karstic erosion. A karst topography, which includes such features as filled and open sinks, sinkhole lakes, and solution pipes and basins, is typical of areas underlain by the Crystal River Formation.

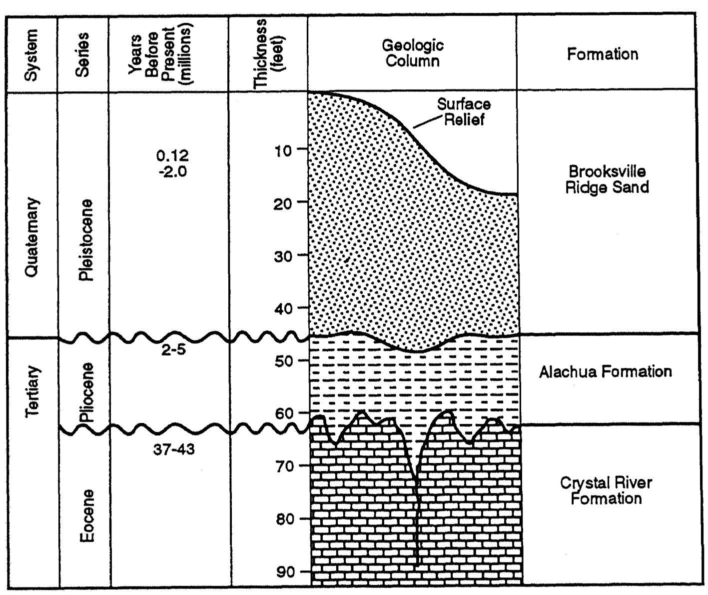

Figure 1. Stratigraphy at the Southwest Landfill (from Wilson and Beck, 1987).

Field Exploration and Subsurface Conditions

Fourteen Standard Penetration Test (SPT) borings, eight CPT soundings, and twelve ground water monitoring wells have been installed within the property boundary of the landfill (see Figure 2).

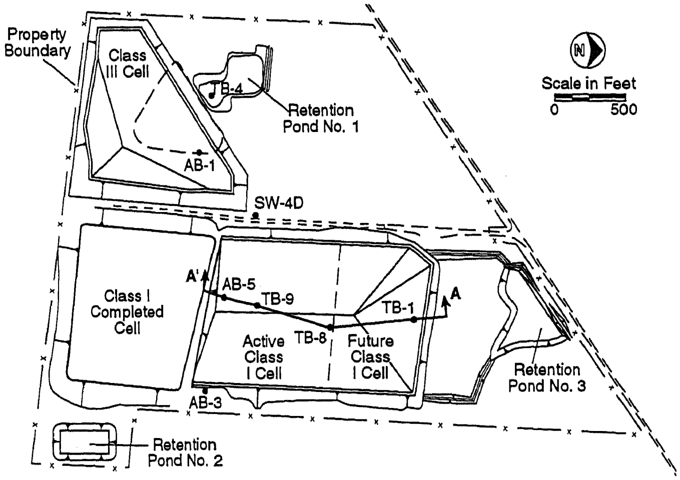

Figure 2. Soil borings in the expanded Class I disposal area.

Subsurface soils in the Class I cell expansion area consist of three soil strata underlain by limestone bedrock (see Figure 3). Stratum I consists of very fine sand, ranging in color from brown and grayish brown to orange brown. This soil is classified as SP (poorly graded sand) according to the Unified Soil Classification System (USCS). Stratum I was encountered in all borings and extends to 8.5 to 63.5 feet below original ground surface. No ground water was encountered in Stratum I.

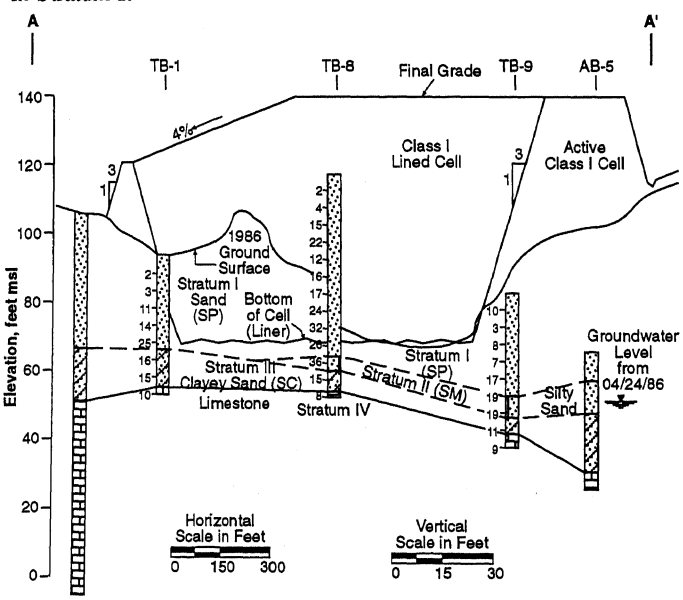

Figure 3. Typical soil profile along Section A-A'.

Stratum II, which consists of an orange-brown to gray silty fine sand, was encountered in all but three borings. The relative density of the stratum ranges from very loose to very dense.

Stratum III is a dark brown to orange-brown to gray clayey fine sand, with occasional limerock fragments and pockets of sandy clay. This soil is classified as SC (clayey sand) according to the USCS.

Limestone was encountered at the site at depths of 25 to 85 feet below land surface (bls). The limestone, which is known as the Ocala Formation, forms the upper unit of the Floridan Aquifer system. The Ocala Limestone has a consistency that ranges from very soft to hard and is identified in Figure 3 as Stratum IV.

Losses of drilling fluid at or near the top of the limestone were recorded during drilling some of the borings. This indicates that karst features of the Ocala Limestone, such as sinks, joints, and solution cavities, are common at the site.

METHODS OF FOUNDATION SOIL PREPARATION

Compaction Using a Vibratory Roller

Vibratory rollers have been used to compact foundation soil for large industrial complexes on land reclamation fill and coastal deposits, as well as to minimize settlement induced by machinery foundation. In sinkhole-prone areas, vibratory rollers have been used to densify the overburden sand and to induce the collapse of small sinkholes.

D'Appolonia (1969) recorded that a 12.5-Kip vibratory roller compacts loose, fine sand to 65 percent relative density to a depth of 4 feet after 15 passes of the roller. He also reported that increasing the number of roller passes increases the maximum compacted density at any given depth. Nathan (1991) reported that ten to twelve passes of a 23,700-pound vibratory roller over a submerged, 6-foot-thick layer of clean, gravelly sand resulted in relative densities of approximately 55 percent to more than 100 percent throughout the layer.

Cone Penetration Test

The CPT is a quasi-static method of determining in-situ parameters for establishing soil stratification and engineering properties (Schmertmann, 1978). Because of its continuous, rapid measurement of soil penetration resistance, CPT is a popular in-situ test for site investigation and geotechnical design and is particularly effective in delineating stratigraphy in Florida. The test is conducted by hydraulically advancing the penetrometer at a rate of 2 cm per second. Load cells in the penetrometer measure cone resistance and friction sleeve resistance separately.

Ground-Penetrating Radar

GPR detects the presence and depth of subsurface features using high-frequency electromagnetic radiation transmitted from an antenna moving across the ground surface. The result is a continuous, cross-sectional profile of shallow subsurface conditions created by radar wave reflections from the interfacing of materials with different dielectric properties. The reflections are often associated with natural geohydrologic conditions, such as bedding, cementation, moisture, clay content, voids, fractures, and intrusions, as well as man-made objects.

GPR provides the highest resolution of all surface geophysical methods. It has been used at numerous sites in north-central Florida to evaluate natural soil and rock conditions by soil layer mapping and the determination of bedrock depth, rock fractures, and cavities in natural Landfill. The landfill site was scanned with an SIR-3 control unit/profiling record and a 120-megahertz (MHz) transducer made by Geophysical Survey System Inc.

Compaction Grouting

Compaction grouting involves the injection of a stiff, mortar-like, sand-cement grout. The theory of the process was described by Graf (1969) and Mitchell (1970); case histories of both actual and experimental work using the process were reported by Warner (1974). When under pressure, the grout remains in a homogeneous mass that fills the void and compacts the soil in place. This is because the grout is stiff and does not enter the soil pore spaces, but rather remains in a homogeneous mass with a distinct grout-soil interface. However, because of the grout's stiff consistency, grouting pressures must be substantially greater than for conventional penetration-type grouting.

To begin compaction grouting, a hole is drilled from the surface to the bottom of the zone to be densified. A steel casing is then inserted in the hole and grout is injected until a predetermined pressure or grout volume is reached. The steel casing is raised 3 to 5 feet and grouting is continued until a slight movement on the surface is noted. The most frequently encountered factor limiting grout placement is surface movement. Measurable deflection generally can be monitored by conventional survey equipment.

FOUNDATION SOIL PREPARATION

The foundation soil of the Class I disposal area at the Southwest Landfill was prepared using the following procedures: (1) pre-rolling the subgrade with vibratory rollers, (2) scanning the subgrade with GPR to locate subgrade anomalies, (3) confirming the GPR results with CPT tests, (4) densifying the loose sand in solution chimneys, which were identified by GPR and CPT, with compaction grouting, (5) confirming the compaction grouting results with CPT, (6) proof-rolling the subgrade, and (7) installing reinforcing geotextile, clay, and high-density polyethylene liners.

Subgrade Pre-Rolling

After the bottom of the landfill disposal area was excavated to design elevations, the subgrade was compacted with a 15-ton or heavier vibratory roller that made at least 10 overlapping passes in two perpendicular directions. The upper 12 inches of the subgrade was compacted to at least 95 percent of the maximum dry density, as determined by ASTM D-1557. Field density tests were conducted to confirm the pre-rolling results. Pre-rolling increased the CPT penetration resistances of the upper 4 feet of sand from 10 to 20 tons per square foot (TSF) to 100 to 150 TSF, or from 30 to 50 percent of relative density to 80 to 100 percent of relative density (see Figure 4).

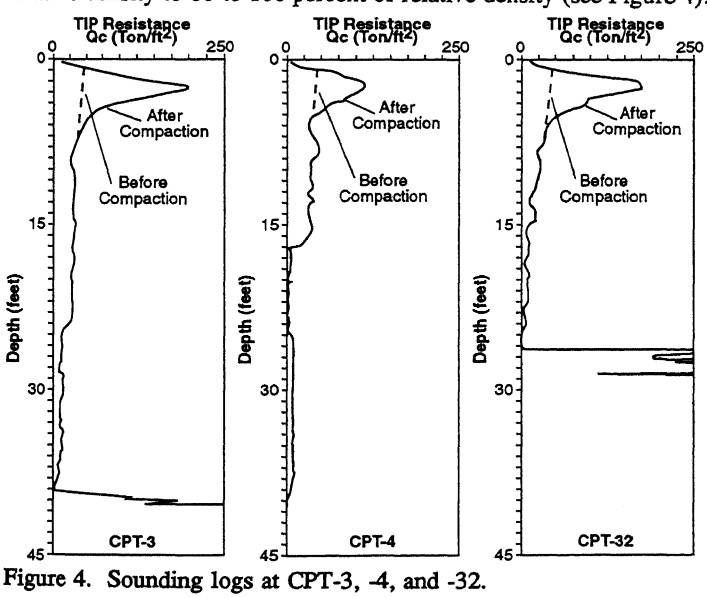

Figure 4. Sounding logs at CPT-3, -4, and -32.

GPR Scanning

The site was scanned using as SR-3 control unit/profiling record and 120-MHz transducer made by Survey Systems Inc. The 120-MHz transducer was selected for its balanced capacities of penetration and resolution. The transducer was towed, at a walking pace, behind a four-wheel-drive vehicle.

A total of 107 radar transects (15.6 miles) was scanned over the bottom of the new cell. The scanned area is a rectangle approximately 550 feet wide from north to south, and 700 feet long from east to west (8.8 acres). Reflections on the radar profiles that correspond to sinkholes and cavities are referred to as anomalies. In general, excellent radar reflections were obtained after elapsed times that correspond to depths of up to approximately 28 feet bls. Some cross-bedding was observed in the Brooksville Ridge Sand. The first, generally continuous reflection was correlated to the top of the Alachua Formation, which, in most areas, has a gently rolling to nearly horizontal surface.

Forty-three anomalies were observed that show the Alachua Formation to be either discontinuous or underlain by an isolated hyperbola that might represent a sediment void (see Figure 4). The discontinuities, which probably represent sand-filled breeches in the Alachua Formation, were usually larger at the top than the bottom. The upper part of the discontinuities ranged from 6 to 50 feet wide (average, 18 feet), while the lower part ranged from 3 to 50 feet wide (average, 9 feet). The discontinuities in the Alachua Formation are thought to be partially or completely filled with Brooksville Ridge Sand.

Given the karstic nature of the site and the generally circular or elliptical nature of the suspected discontinuities, the anomalies appear to represent buried sinkholes. These sinkholes are ancient features, generally ranging in age from o.1 to 5 million years, that probably developed after the sandy clay was deposited and before the surficial sand was deposited.

Confirmation by CPT

The anomalies shown in Figure 5 indicate areas of discontinuity in the clayey sand layer and do not necessarily represent areas of ground instability. To investigate the stability and soil-bearing capacity of the soils, 43 CPTs were conducted at the center of the anomalies. The CPTs were conducted 5 to 10 feet into the limestone or until penetration refusal. The depth of penetration varied from 30 to 45 feet deep.

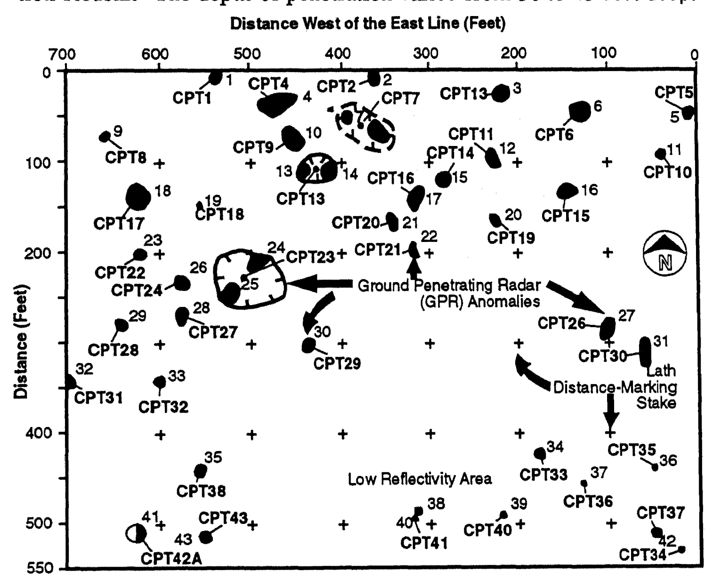

Figure 5. Potential anomalies and CPT sounding locations.

Figure 4 shows the representative penetration resistance profiles of CPT conducted at the center of the anomalies. The penetration resistance profiles encountered loose to very loose sand from 5 feet bls to the limestone surface at approximately 25 to 35 feet bls (CPT-3 and CPT-32) and 16 feet of loose to medium-dense sand overlying very loose sand to approximately 40 feet bls (at CPT-4, probably at the center of solution chimneys). Compaction grouting was used to densify the loose sand in areas where CPT profiles were similar to those encountered in CPT-3, CPT-4, and CPT-32.

Compaction Grouting

Based on the GPR and CPT results, 43 grouting locations were established. In areas where the anomalies were estimated to be less than 15 feet in diameter, one primary grout hole was drilled; where they were estimated to be 15 to 20 feet in diameter, two grout holes were drilled. For diameters greater than 20 feet, one primary grout hole at the center of the anomaly and three secondary grout holes around the circumference were drilled.

The compaction grouting was prepared by mixing one part cement and four parts sand with water to less than 3 inches of slump. The grout pipes had a nominal 3-inch diameter. The compaction grouting was designed to densify the sand in and around the solution chimney, preventing the continual ravelling of the chimney. Because the limestone cavities in the Crystal River Formation are generally massive, grouting the cavities is not economically feasible.

The grouting procedure consisted of driving the grout pipe to approximately 1 foot above the soil-limestone interface. Grout was pumped continuously until a minimum pressure of 200 pounds per square inch (psi) was obtained. The grout pipes were then withdrawn in 1-foot increments and grout was injected at each increment until the required pressure was obtained. Grouting was stopped when the tip of the grout pipe was at 15 feet bls or when ground surface heaving exceeded 0.25 feet, whichever occurred first. For grout holes with grout intake greater than 50 cubic yards, grouting was suspended for 24 hours before being attempted again. A total of 635 cubic yards of grout was pumped, with grout intake generally proportional to the estimated diameter of the anomalies.

Post-Grouting CPT Results

Six CPTs were conducted in areas where anomalies were detected after compaction grouting to confirm the effectiveness of the procedure. Figures 6, 7, and 8 compare the CPT penetration resistance of the foundation soil before and after compaction grouting at representative locations. In general, compaction grouting significantly increased the penetration resistance of the very loose sand and subsequently increased the estimated relative densities of the sand in the compacted zone from 30 to 50 percent to 50 to 80 percent.

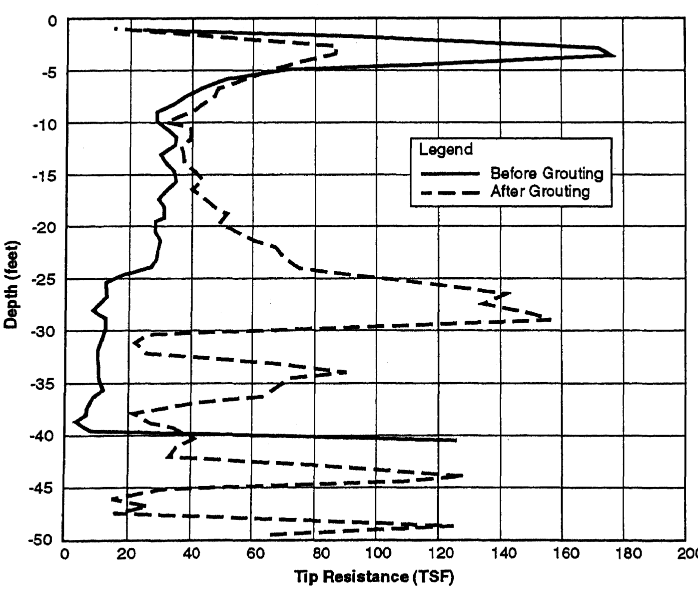

Figure 6. Comparison of tip resistances at CPT-3.

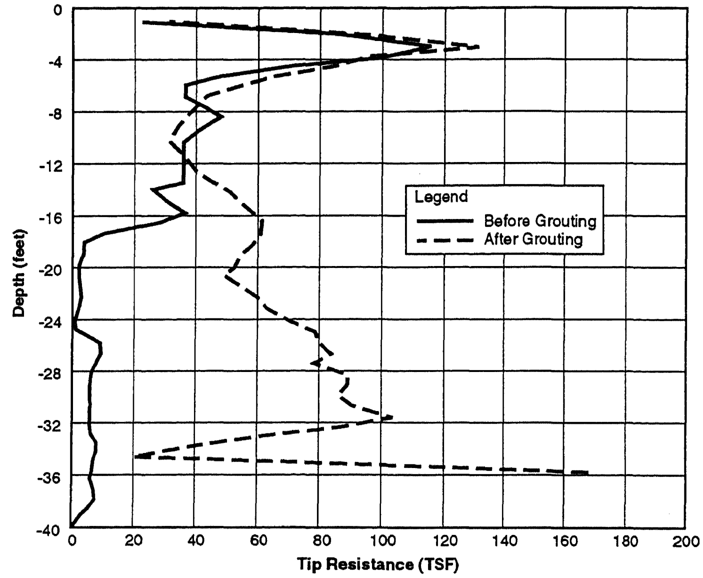

Figure 7. Comparison of tip resistances at CPT-4.

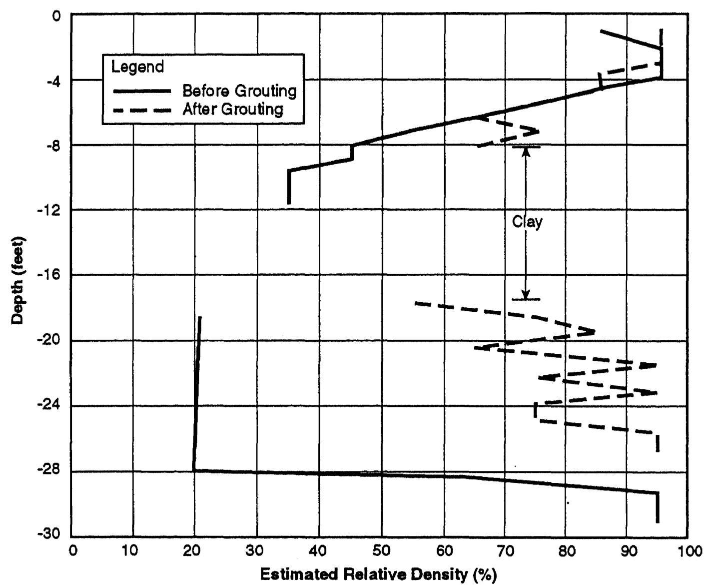

Figure 8. Comparison of relative densities at CPT-32.

Post-Grouting Vibratory Compaction

Heaving of the ground surface from compaction grouting loosened the u upper 5 feet of sand; therefore, the subgrade was recompacted with a 15-ton vibratory roller. The upper 12 inches of the subgrade was compacted to 95 percent of the maximum dry density, as determined by ASTM-D1557. Approximately 3 months after completion of compaction grouting, a severe rainfall filled the landfill disposal area with 1 to 2 feet of water, however, no solution chimney developed during flooding.

Reinforcement with Geotextile

Because the GPR transects traveled in only one direction and were spaced at 5-foot intervals, GPR may not have detected anomalies smaller than 3 to 4 feet in diameter. Therefore, in addition to compacting the subgrade with a vibratory roller, the entire subgrade was reinforced with geotextile having a grab tensile strength of 300 pounds and trapezoid tear strength of 100 pounds.

CONCLUSION

The foundation soil for the Class I disposal area at the Southwest Landfill was prepared using vibratory compaction, GPR, CPT, and compaction grouting, which appeared to significantly stabilize the solution chimneys. This preparation had the following results:

- Pre-rolling the subgrade increased the relative densities of the upper 4 feet of sand from 30 to 50 percent to 80 to 100 percent, or to dense to very dense.
- Because the moisture content of the overburden sand is low and the ground water table is located below the limestone surface, GPR was effective for detection of subsurface anomalies under the landfill disposal area.
- Forty-three anomalies were identified by GPR. CPT results confirmed that most of the anomalies were sand-filled solution chimneys or cavities.
- A relatively large volume of sand-cement grout (485 cubic yards) was injected to compact the loose sand in and around the solution chimneys. Compaction grouting, as confirmed by post-grouting CPT, appears to have increased the relative densities of the loose sand from 30 to 50 percent to 50 to 80 percent.
- After completion of the foundation soil preparation, the landfill disposal area was flooded with 1 to 2 feet of rainwater for over a week. No subsidence was observed.

REFERENCES

1. Clark, W.E., R.H. Musgrove, C.G. Menke, and J.W. Cagle (1964). Water Resources of Alachua, Bradford, Clay, and Union Counties, Florida. Report of Investigations, No. 35. United States Geological Survey. 1964.

2. D'Appolonia D.J., R.V. Whitman, and E. D'Appolonia (1969). Sand Compaction with Vibratory Roller. *Journal of the Soil Mechanics and Foundations Division.* American Society of Civil Engineers, Vol. 95, No. SM1.

3. Graf, E.D. Compaction Grouting Technique (1969). *Journal of the Soil Mechanics and Foundations Division.* American Society of Civil Engineers, Vol. 95, No. SM5.

4. Mitchell, J.K (1970). In-Place Treatment of Foundation Soil. *Journal of the Soil Mechanics and Foundations Division.* American Society of Civil Engineers, Vol. 96, No. SM1.

5. Schmertman, J.H (1977). Guidelines for CPT Performance and Design. Federal Highway Administration.

6. Warren, J. and D.R. Brown (1974). Planning and Performing Compaction Grouting. *Journal of the Soil Mechanics and Foundation Division.* American Society of Civil Engineers, Vol. 100, No. GT6.

7. Whetten, N.L. and J.W. Weaver (1991). Densification of Gravelly Sand Fill Using Intensive Surface Compaction. *Journal of the Soil Mechanics and Foundation Division.* American Society of Civil Engineers, Vol. 7.

8. Wilson, W.L. and B.F. Beck (1987). Investigation of Karst-Related Subsidences near the Southwest Landfill, Alachua County, Florida, Using Ground Penetrating Radar. Florida Sinkhole Research Institute, Report No. 87-88-1. University of Central Florida, Orlando, Florida.