Cherry Island. Assessing the Behavior of a Large Landfill Using Geotechnical Instrumentation

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ABSTRACT

The 513-acre Cherry Island Landfill is located at the junction of the Delaware and Christina Rivers near Wilmington, Delaware. Today the landfill receives approximately 1,850 tons of waste per day. The landfill was constructed directly on soft dredge materials and river deposits which act as a natural liner. Due to the unique geotechnical characteristics at the site, potentially large deformation and slope stability were concerns during the planning and development of the landfill due to the expected high rates of waste placement.

Slope stability and finite difference analysis were performed to develop adequate filling plans to cope with the expected high rates of waste placement. In addition, approximately 300 geotechnical instruments were installed during and after construction. These instruments include inclinometers, open standpipe piezometers, vibrating wire piezometers, pneumatic piezometers, settlement plates, vibrating wire thermistors, and pneumatic total pressure cells. To process and evaluate the large amount of data collected every month, a Geographical Information System (GIS) was incorporated which allows rapid visualization of important parameters.

The results obtained from the analysis together with the instrumentation data provide a special insight into the behavior of large landfills constructed on soft soils. This paper presents a discussion of the procedures for analysis and monitoring of the landfill and the main results obtained. This paper also describes the issues involved in installing and maintaining instrumentation for this type of application.

INTRODUCTION

The Cherry Island Landfill, or the Northern Solid Waste Management Center at Cherry Island (NSWMC-2), is located in Wilmington, Delaware. The landfill has been operating continuously since October 1985 servicing New Castle County, Delaware. As shown in Figure 1, the landfill is bordered by the Wilmington Wastewater Treatment Plant to the north, the Delaware River to the east, the Christina River to the south, and the dredge disposal area of the United States Army Corps of Engineers and Interstate 495 to the west. The facility is currently used as a landfill with three active municipal solid waste (MSW) disposal areas: Phases III, IV and V, and asbestos disposal area Phase I. In general, the MSW is placed in ten-foot lifts over the existing soft elastic silts. Presently, the waste depth varies between 40 and 100 ft. Barriers between and around the perimeter of the phases generally consist of dikes constructed from desiccated hydraulic fill.

Fig. 1. Cherry Island Aerial View.

Construction of Phase III included geogrid material placed between the waste and the top of the hydraulic fill along the perimeter dike. Phases IV and V included a 100 ft wide wick drainfield installed beneath the perimeter dike, along the eastern and southern edges. These wick drains extended to depths ranging from 75 to 100 ft in a four-foot triangular pattern.

SITE HISTORY

Exploration

A significant amount of exploration has been completed at this site throughout its life. Schnabel Engineering (Schnabel), along with others, has conducted explorations, much of which gathered information for the design of each phase. Additional information has been collected during preliminary site suitability studies, and subsequent evaluation of increase of shear strength of the underlying materials.

Geology

Soft foundation soil is present below the MSW to depths of about 40 to 100 ft (EL -20 to EL -55). The foundation soil generally consists of elastic silt with organic material representing hydraulic fill or "dredge" in the upper portion, and recent alluvial deposits in the lower portion. The soft consistency of the dredge is due to the method of placement. The dredge was pumped from the Delaware and Christina Rivers and discharged at the site; therefore, the initial condition of the dredge was liquid with essentially no shearing resistance. After time, as the water drained from the dredge and the dredge consolidated under self-weight, the material began to assume consistency and gain shear strength.

Around the perimeter of the landfill, dikes of the same silt soil material were incrementally constructed by scraping the desiccated crust from the disposal area and placing it on top of the dike. The consistency of the dike soils is generally stiffer than the dredge, and the recent alluvial deposits in the interior of the landfill. The stiffness of the dike soils can be attributed to the drying and compacting of the material during construction, and the installation of wick drains after construction.

Below the dike soils, dredge, and recent alluvial deposits are dense granular soils of the Columbia Formation of the Quaternary Age. Below the base of the Columbia Formation, stiff Potomac Formation clays of the Cretaceous Age are present. Residual soils and rock are present beneath the Potomac Formation. Figure 2 depicts the typical cross section of the landfill.

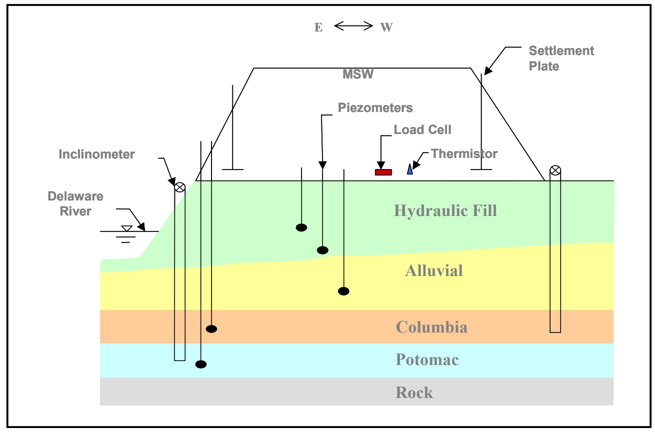

Fig. 2. Typical Landfill Cross Section.

Filling and Changes in Filling Plan

In 1998, Schnabel performed a Composite Stability Analysis for the site. The analysis used the MSW filling rate and estimated strength gain of subsurface soils to provide a plan for filling across the entire site. This plan looked at operations of the site as a unit rather than as isolated phases as initially designed.

In 2001, Schnabel developed a revision to the filling operation plan which addresses stormwater management concerns.

Future filling plans are discussed in the Future Site Enhancements section below.

INSTRUMENTATION

The instrumentation of the landfill was installed by others during the construction of each phase. A location of the instrumentation is shown in Fig. 3. For more information regarding the instruments below see Dunnicliff (1988) and manufacturer's data sheets.

Inclinometers

There are 46 inclinometers around the perimeter of all five phases of the landfill as shown in Table 1. The depths of the inclinometers range from 40 to 120 ft. The inclinometers consist of 2.75-inch and 3.33-inch PVC casings, manufactured by Slope Indicator and RST.

Table 1. Inclinometers

Phase	Inclinometer
I	9
II	4
III	12
IV	8
V	13

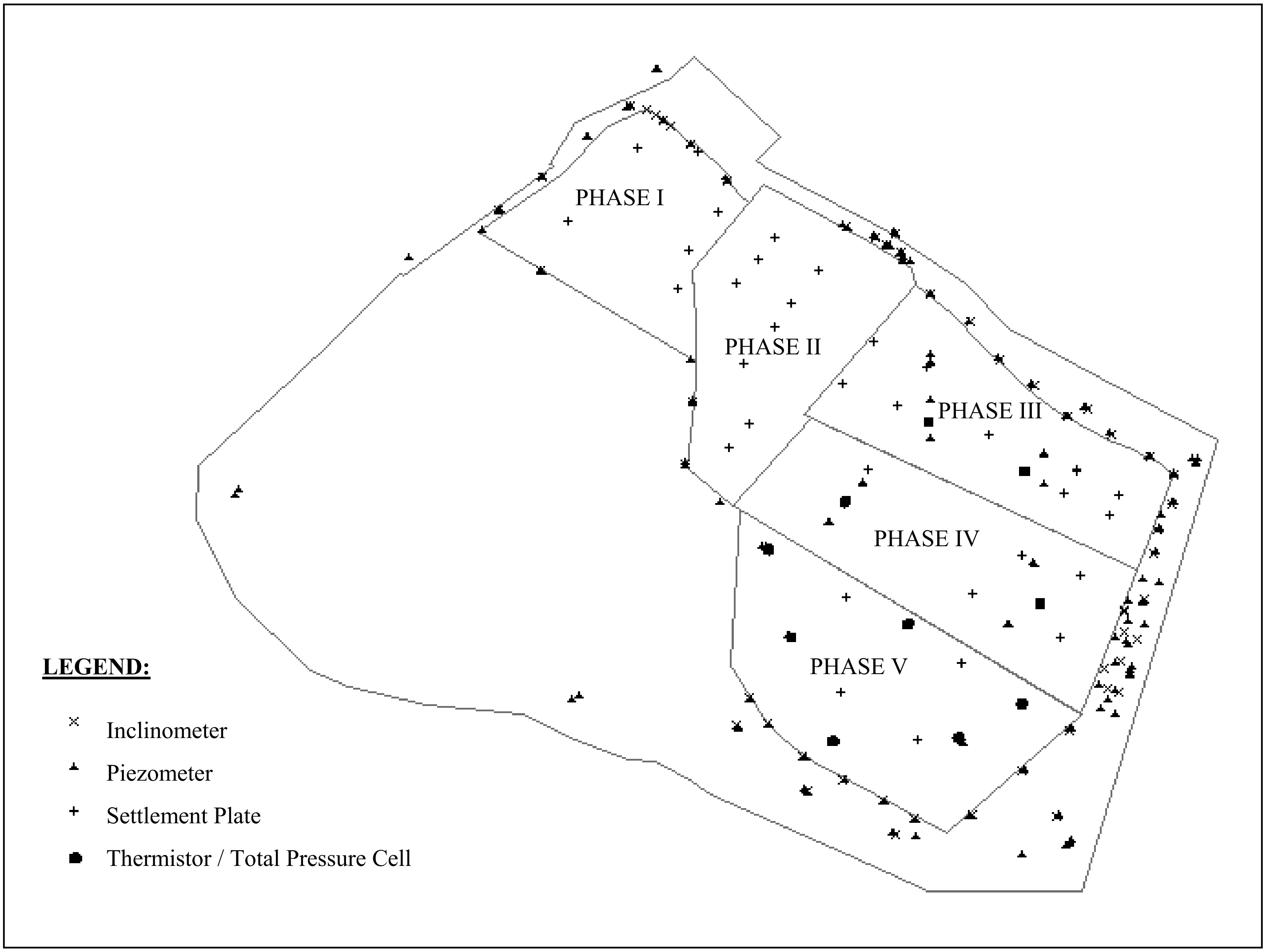

Fig. 3. Instrumentation Location.

Piezometers

A total of 132 piezometers have been installed around the perimeter and in the interior of all five phases of the landfill as shown in Table 2. The piezometer types include open standpipe and pneumatic.

Table 2. Piezometers

Phase	Open Standpipe	Pneumatic
I	14	
II	12	
III	26	15
IV	19	
V	28	18

Six vibrating wire piezometers (two clusters of three) were located in the interior of Phase IV, but have been abandoned.

Settlement Plates

Currently, there are 38 settlement plates in the interior of all five phases of the landfill as shown in Table 3. The settlement plates consist mainly of ¾" galvanized steel inner pipe connected to a steel plate. The outer protective casing consists of either 2" or 4" PVC Schedule 40 pipe.

Table 3. Settlement Plates

Phase	Settlement Plate
I	7
II	9
III	8
IV	4
V	10

Total Pressure Cells and Thermistors

Currently, there are 28 thermistors and 30 total pressure cells in the interior of Phases III, IV, and V of the landfill as shown in Tables 4 and 5. The thermistors consist of RST Instrument YSI 44004 Precision Vibrating Wire Thermistors. The total pressure cells consist of RST Pneumatic Total Earth Pressure Cell, Model TP-101-P-12. The thermistors and total pressure cells were set on the foundation soils, prior to placement of MSW. The thermistors are used to calibrate the total pressure cells.

Table 4. Thermistors

Phase	Thermistor
III	8
IV	8
V	12

Table 5. Total Pressure Cells

Phase	Total Pressure Cell
III	10
IV	8
V	12

Data Collecting and Processing

Monitoring of all the geotechnical instrumentation is performed quarterly. Monitoring of selected instruments is also performed in monthly or weekly intervals depending on the results of the quarterly monitoring or on filling operations in a specific area.

Data collection from the instrumentation is recorded by hand, and compared in the field against previous readings. The data collection is performed by two people and can take anywhere from one to two weeks to complete. This work is heavily influenced by weather and resulting ground surface conditions.

The raw data collected in the field is brought into the office for processing. The inclinometer data is processed and plotted using the DMM and DigiPro software available from Durham Geo Slope Indicator. The inclinometer data from the past year is plotted on the A and B axis for each inclinometer for comparison. The piezometer, settlement plate, thermistor, and total pressure cell data are processed and plotted by a custom program using Microsoft Access® and Excel® applications. Data is input into the computer for each instrument. Piezometers are presented in elevation vs. time, and gradient vs. time format. Settlements are presented in elevation vs. time format. Thermistors are presented in temperature vs. time format, and total pressure cells are presented in corrected pressure vs. time format.

All data is kept in a Microsoft Access® database for use with a GIS database system.

MAINTENANCE

Typical maintenance of the inclinometers and open standpipe piezometers around the perimeter of the landfill includes clearing debris from around the instruments and flushing of the instruments. Several of the inclinometers and piezometers adjacent to access roads around the perimeter of the landfill are located in concrete manhole rings. The concrete rings were placed by Delaware Solid Waste Authority (DSWA) around these instruments to protect them from damage by vehicular traffic. In the summer months, mowing equipment is unable to trim the tall grass and weeds that grow in the rings. As a result, these instruments become breeding grounds for bees and other insects. Also, the rings trap and kill birds that land in them to search for food. The rings typically require clearing by field personnel before they can safely access the instruments.

The open standpipe piezometers are flushed to remove obstructions. These obstructions are encountered when taking readings with a water level probe, and are often the result of insect nests in the standpipe. Four open standpipes around the perimeter of the landfill have been abandoned in the past year due to obstructions that flushing was unable to remove. These obstructions may also result from broken standpipes due to lateral movements of the landfill.

Typical maintenance of the open standpipe, vibrating wire and pneumatic piezometers, settlement plates, thermistors, and total pressure cells in the interior of the landfill include: clearing debris from around the instruments; flushing, and raising instruments; and repairing instruments. As with instruments around the perimeter of the landfill, several of the instruments in the interior of the landfill also have concrete manhole rings around them that require clearing before they can be accessed safely. The open standpipe piezometers in the interior of the landfill also occasionally require flushing of obstructions. Due to on-going filling operations in the interior, the instruments are susceptible to damage by the heavy equipment and trucks that operate on the landfill. The galvanized steel rods used for the settlement plates, pneumatic air lines and vibrating wire cables are often damaged and in need of repair.

The interior instruments are located in the active filling area, and therefore continually require raising. Raising instruments consists of connecting additional lengths of inner steel pipe and outer PVC casing to settlement plates, inner and outer PVC pipes to open standpipe piezometers, pneumatic air lines and PVC casing to pneumatic piezometers and total pressure cells, and vibrating wire cables and PVC casing to vibrating wire piezometers and thermistors. Raises are performed in 10 ft increments; therefore, a hydraulic lift is required to perform a raise event at each instrument, and often requires two people to perform the task.

During the past two years, several instruments in the interior and exterior of the landfill were abandoned for a variety of reasons. To date these instruments have not been replaced due to the future site enhancements planned as described below.

In the past, some of the instrumentation has also been buried due to filling operations and equipment operators not recognizing the instruments. These instruments have had to be abandoned.

Further difficulties recently include instruments in both the interior and exterior of the landfill that required capping to prevent the emission of gases into the atmosphere. The caps tend to deteriorate over time and must often be repaired or replaced.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

Installing, maintaining and obtaining readings from the instrumentation is only the first step in making this information valuable to the facility operations. Given the extensive number of instruments and the variety of indicators being measured, application of the measurements to site conditions is difficult. With the advent of desktop GIS, the storage and retrieval of this information have moved from paper reports to the engineer's desktop where it can be readily related to the geometry of the site. Achieving this milestone for the DSWA facility began in 1998 as a component of the Composite Stability Analysis performed by Schnabel.

Three sets of components were developed for the DSWA's Cherry Island GIS. The first major component in the overall system is a relational database management system (RDBMS) in a Microsoft Access® database format. The second component is a GIS in ESRI's ArcView™ format. The third component consists of two separate Visual Basic™ applications developed using MapObjects™ controls for retrieval and reporting of user defined data sets of piezometer or settlement plate information.

Through these components most of the raw field data can be entered and converted to final measurements of head, settlement, elevation, temperature, pressure or deflection. The records of the instrument condition and maintenance can be logged in a maintenance table, and retrieval of user-desired data sets could be provided. Extensions of the Access database have continued and now include enhanced table and chart plotting features as well as interface data transfer ability with handheld PDA equipment. Figure 4 depicts a typical report containing data, graph and maintenance records.

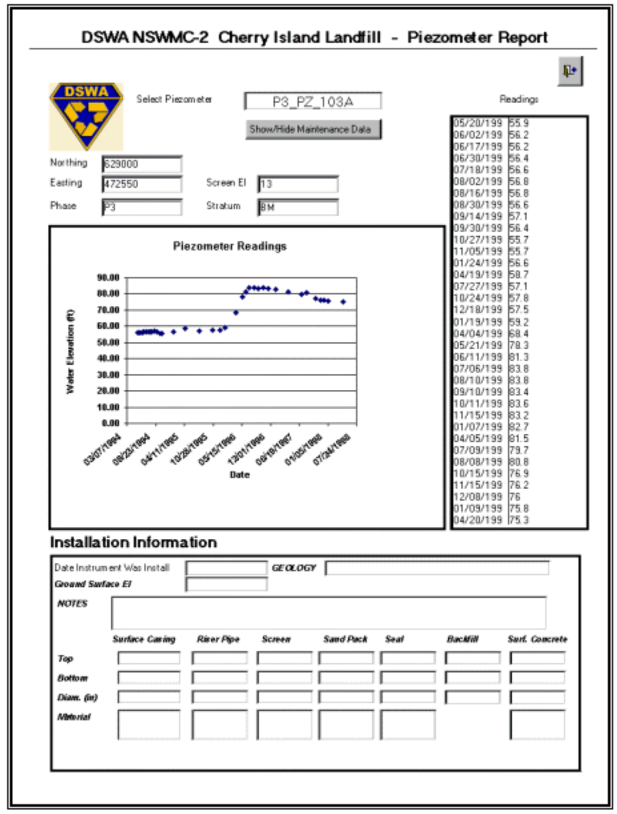

Fig. 4. Typical Data Report.

Additional site data including filling records, soil laboratory, and subsurface exploration data is also included in the system. DSWA personnel have enhanced their use by also linking the groundwater sampling information for the site.

Once this vast database of information was developed and made accessible, it was integrated with the site geometry which makes interpretation much more intuitive. Figure 5 shows an example of how site topography, soil strata, piezometer elevations, and inclinometer deformations can be related spatially and compared to a fence diagram of the subsurface stratification. The scale of the inclinometer deformations is exaggerated.

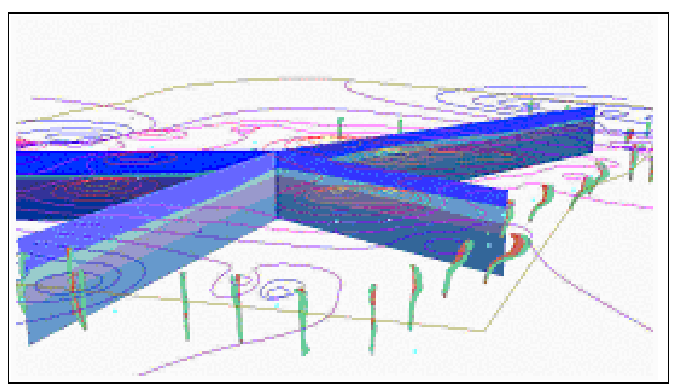

Fig. 5. Typical Fence Diagram.

Using readily available commercial software, future support and ongoing development of applications that will meet the needs of the engineers and owner can readily be provided.

GEOTECHNICAL ASSESSMENTS FROM INSTRUMENTATION

The geotechnical instrumentation is critical to analyzing the slope stability and settlement of the landfill.

Slope stability is analyzed from data obtained from the instrumentation around the perimeter of the landfill. Slope stability is important due to the close proximity of the landfill to the Delaware and Christina Rivers. The data from the perimeter instrumentation provides a picture of how the perimeter dikes are performing to contain the lateral forces from the landfill.

Strength gain of the foundation materials takes place during consolidation. This phenomenon is important for analysis of slope stability and needs to be properly considered.

Piezometers in this facility serve two roles. First, the clusters of piezometers allow gradients to be calculated, which confirm the assumed behavior of the natural soil liner. Second, the clusters of piezometers were intended to provide a good estimate of the in situ effective stresses, and thus facilitate prediction of the strength gain of the underlying soils; however, in situ testing using field vanes and cone penetration tests seems to be a better tool in an active site like Cherry Island.

Settlement is analyzed from data obtained from the instrumentation around the interior of the landfill. The settlement provides an indication to the degree of strength gain of the underlying soft dredge material and river deposits. The strength gain from the analysis of the settlement data is compared with assumed strength conditions from the composite stability analysis, and from strength data obtained from in situ testing.

The total pressure cells and thermistors were installed to estimate the unit weight of the MSW. The total pressure cells are clustered together in groups of five cells. The thermistors are clustered in groups of four at the pressure cell locations for calibration of the pressure cells. Some scatter has been seen, but in general, the average weight of the MSW is about 85 to 100 pcf.

For approximately 15 years, there has been some form of geotechnical instrumentation monitoring in the landfill. The instrumentation tells the story of landfill conditions after filling activities. The monitoring data has not been used to predict how the landfill will react to the filling operations. However, the monitoring data is critical in determining if the filling operations may proceed as planned.

Usefulness and Reliability of Instruments

Large variability in some recent monitoring data, the relative old age of the instruments, and increased maintenance issues have raised some concerns over the usefulness and accuracy of some of the instrumentation at the site. Based on our experience at the site, we have come to recognize that some types of instruments provide accurate data, and others less accurate data in the harsh landfill environment.

The instruments that we consider to provide accurate data are the perimeter open standpipes and inclinometers. Most of these instruments have provided consistent data throughout their 10 to 20 year existence. Furthermore, maintenance is relatively simple, and reading errors are easy to detect in the field.

Some of the open standpipe piezometers in the interior of the landfill have not provided accurate data because they have been easily damaged by filling equipment.

Vibrating wire piezometers located in the interior of the landfill that also had readout stations in the interior were found to be less accurate and have since been abandoned. Because the piezometers did not have protective readout boxes, the ends of the vibrating wire lines became heavily corroded. Also a few of these instruments were buried during filling activities.

The pneumatic piezometers located in the interior of the landfill that have readout stations along the perimeter (Phase V) are mostly accurate. However, pneumatic piezometers located in the interior of the landfill that also have readout stations in the interior (Phases III and IV) are susceptible to damage. Filling equipment and sharp objects in the MSW easily damage the pneumatic pressure lines. Holes in the lines can be difficult to detect, and splicing additional pneumatic lines can be difficult. Because these instruments are in the interior of the landfill and require constant raises, their connectors cannot be located in protected readout boxes like those on the perimeter. The ends of the thermistor and pneumatic lines often become corroded and difficult to use.

Individually the settlement plates are not considered accurate; however, as a whole, the settlement plates can provide a rough estimate of settlement over an entire phase. Many of the settlement plate rods have been pushed over, bent, and broken by the equipment performing filling activities. As the rods are damaged, it becomes impossible to determine an accurate amount and rate of settlement in the area of those plates.

The thermistors and total pressure cells located in the interior of the landfill that also have readout stations along the perimeter (Phase V) have been mostly accurate. However, thermistors and total pressure cells located in the interior of the landfill that also have readout stations in the interior (Phases III and IV) are susceptible to damage. Filling equipment and sharp objects in the MSW easily damage the pneumatic pressure lines. Holes in the lines can be difficult to detect and splicing additional pneumatic lines can be difficult. Because these instruments are in the interior of the landfill, and require constant raises, they cannot be located in protected readout boxes like those on the perimeter.

Possible Instrumentation Improvements

Recent advances in vibrating wire, electrical resistance, and wireless technologies have greatly increased the ability to accurately read, record and analyze geotechnical instrumentation.

There are many upgrades that can be made to geotechnical instrumentation during the future site enhancements to improve the accuracy of the data provided.

The first step would be to change the types of instrumentation used. Although many of the instrumentation types can provide accurate data, instruments using vibrating wire or electrical resistance can stand up best to the harsh and rugged conditions at the site. Replacing the pneumatic instruments with vibrating wire or electrical resistance would be an upgrade to the instrumentation. Also available are in-place inclinometers and settlement sensors, which can provide real-time readings using the vibrating wire and wireless technologies.

With the advances in wireless technologies, it has become easy to relay data over large distances. Several manufacturer-provided systems can automatically read vibrating wire and electrical resistance instruments at defined intervals and store the data in dataloggers. The dataloggers can then relay the data wirelessly to a central PC for storage. These systems can also include software for graphically presenting data in real-time.

Instrument readout stations equipped with dataloggers may be located around the perimeter of the landfill, where they can be easily located, accessed and properly protected from the elements. Many times it is difficult to locate the interior readout stations because the surroundings change so rapidly. The instrument readout stations that are located in the interior of the landfill are not protected from the elements. In addition, moving the instruments to the perimeter of the landfill does away with the need for raising of the instruments.

Another improvement to the monitoring is to revise the way in which the data is analyzed. Currently, monitoring is looked at phase by phase, as a result of the location of the instruments. Future site enhancements should locate the instrumentation to provide data as a composite cross section of the landfill.

FUTURE SITE ENHANCEMENTS

Schnabel's composite stability analysis projected that the life of the landfill was less than originally anticipated by DSWA. As a result, DSWA decided to solicit proposals for enhancements to the landfill design so that waste disposal could continue.

The enhancements, currently being designed, consist of prefabricated vertical drains (PVD) extending from the surface down to the Columbia Aquifer, approximately 100 ft. A large mechanically stabilized earth (MSE) wall will be constructed over the PVDs to surcharge them, and to provide a counterweight to the landfill. The design is currently under review by the Delaware Department of Natural Resources and Environmental Control.

The redesign requires the replacement of most of the geotechnical instruments around Phases III, IV and V. New instruments will be placed around these phases so that they will reflect a particular cross section of the landfill. For example, at a particular station, i.e., 1+00, clusters of instrumentation will be placed within the landfill waste mass, within the berm, and outside the berm. Together these instruments will be able to provide a more unified profile of the landfill.

CONCLUSIONS

The Cherry Island Landfill, or the Northern Solid Waste Management Center at Cherry Island (NSWMC-2), is located in Wilmington, Delaware, and has been operating continuously since October 1985, servicing New Castle County, Delaware. Currently, there are approximately 46 inclinometers, 132 piezometers, 38 settlement plates, 28 thermistors, and 30 total pressure cells around the perimeter of all five phases of the landfill.

Data is manually collected weekly, monthly, and quarterly. Collected data is processed and plotted by a custom program using Microsoft Access® and Excel® applications. Utilizing GIS software, approximately 15 years of some form of geotechnical instrumentation monitoring are now readily retrievable and visually related to site geometry and filling activities.

Typical maintenance of the instrumentation includes clearing debris, flushing, raising, and repairing. We estimate that maintenance requires approximately 30 to 50% of the total field man-hours.

Total load cells do not appear to be accurate for determining effective pressure magnitudes that can be used for estimating unit weight of the MSW, or shear strength for the foundation materials. Estimation of the present strength and/or strength gain of the foundation materials requires the use of field vanes and cone penetration tests.

Pneumatic pressure lines and vibrating wire cables located at readout stations in the interior of the landfill are easily corroded and damaged by the harsh conditions and heavy filling equipment. Locating the readout stations around the perimeter of the landfill can eliminate these issues. Also, perimeter readout stations eliminate the need to raise these instruments during filling operations.

Several of the settlement plate rods have been pushed over, bent, and broken by the equipment performing filling activities. Damage to the settlement plate rods makes it difficult to determine an accurate amount and rate of settlement, and in turn, the degree of strength gain of the underlying soft dredge material and river deposits. To reduce the potential for damage of the settlement plates in landfills, it is advisable to use stronger protective casing.

Recent advances in vibrating wire, electrical resistance, and wireless technologies have greatly increased the ability to accurately read, record and analyze geotechnical instrumentation, and may prove to have a larger and more reliable life. Several manufacturer-provided systems can automatically read vibrating wire and electrical resistance instruments at defined intervals. Replacing the existing instruments during the future site enhancements with vibrating wire or electrical resistance instruments, and locating the readout stations of these instruments around the perimeter of the landfill, away from the filling operations and harsh conditions, combined with wireless technologies, will allow data to be transferred to a central PC for storage and real-time presentation.

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REFERENCES

Cadden, et al. [2000]. *"Composite Stability Analysis, Northern Solid Waste Management Center at Cherry Island (NSWMC-2), Wilmington Delaware."* Schnabel Engineering, Inc., West Chester, PA.

Cadden, et al. [2003]. *"July 2003 Quarterly Monitoring Report for the Northern Solid Waste Management Center at Cherry Island."* Schnabel Engineering, Inc., West Chester, PA.

Dunnicliff, J. [1998]. *"Geotechnical Instrumentation For Monitoring Field Performance."* John Wiley & Sons, Inc., New York, NY.