Monitored Preload Fill over an Inactive Fly Ash Reservoir

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INTRODUCTION

Residual waste landfill Siting study performed at the Cardinal power plant owned by Buckeye Power and American Electric Power (AEP) resulted in selecting a site that is approximately 1.5 mile north of the power plant facility, which is located near the town of Brilliant in Wells Township, Jefferson County, Ohio.

The selected location is within a valley that is bound by a mining highwall on the southwest, a stream at the base of another highwall on the northeast, a 150-ft high earthen dam on the southeast (FAD 1). The selected site is located partially over an inactive fly ash reservoir (FAR1), which comprises a valley filled with 80 ft to 145 ft of very loose, saturated fly ash deposit.

Comprehensive insitu site investigation and laboratory testing program were conducted to better understand the compressibility characteristics of the ponded fly ash and to mitigate for the projected consolidation of the fly ash deposit. Laboratory tests included One-Dimensional (1-D) consolidation test conducted on reconstituted and sluiced fly ash specimens because of the difficulty of obtaining undisturbed soil samples. Field tests on the fly ash deposit included piezocone penetration soundings (CPT) and Standard Penetration Tests (SPT).

Vertical settlement of the fly ash deposit was calculated utilizing methodologies based on the 1-D laboratory consolidation test results as well as existing empirical relation based on the CPT results.

Monitored Preload Fill (MPF) was proposed and built over the ponded ash deposit (Figure 1). Field settlement was measured utilizing a suite of geotechnical instrumentation including surface settlement plates, a vertical extensometer and settlement profiler.

MPF loading results indicate that measured settlement was closely predicted utilizing 1-D consolidation tests results and that using existing empirical relation based on the CPT results. The purpose of this paper is to present a summary of the various testing programs, the corresponding settlement results and a discussion of these results.

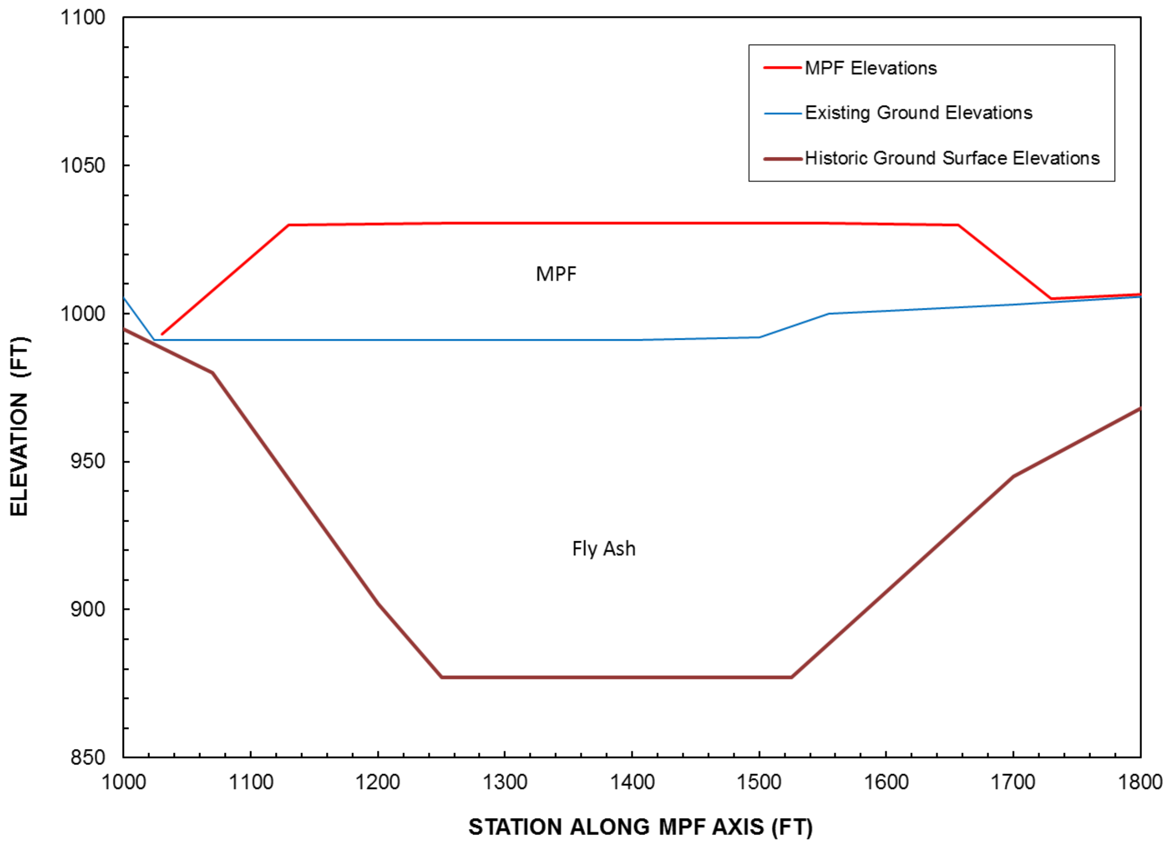

Figure 1 Cross-section across FAR 1 at the location of the MPF.

LABORATORY TESTING PROGRAM AND TESTS RESULTS

Site-specific fly ash settlement parameters were developed from two laboratory testing programs. One program comprised a series of conventional Incremental Loading (IL) 1-D consolidation tests on fly ash specimens reconstituted from material extracted using Shelby tubes. Another laboratory testing program was comprised of Constant Rate of Strain (CRS) 1-D consolidation tests performed in 5.5 inch diameter triaxial chamber wherein the fly ash was sluiced into the cell in attempt to replicate field placement conditions.

For IL tests, the specimen's total unit weight, γ_t, for the in situ fly ash material ranges from approximately 100 to 105 pcf. These values were calculated based on moisture content for saturated fly ash ranging from 30 to 40 percent and the measured dry unit weight. The average specific gravity of 2.24 was evaluated from four laboratory specific gravity tests. For the settlement analyses, the in situ vertical effective stress was calculated using γ_t = 100 pcf.

For CRS tests, all samples were prepared using a slurry method to simulate the method for fly ash impounding. A complete description of the sample preparation methods and testing details is provided in Tu et al 2009[1].

One-dimensional consolidation tests were performed on fly ash samples to evaluate compressibility parameters and time rate of consolidation parameters for settlement analyses. Compression parameters for the in situ fly ash from both test programs were nearly identical. Figure 2 presents the e-log σ'_v for specimens consolidated using the aforementioned two methods.

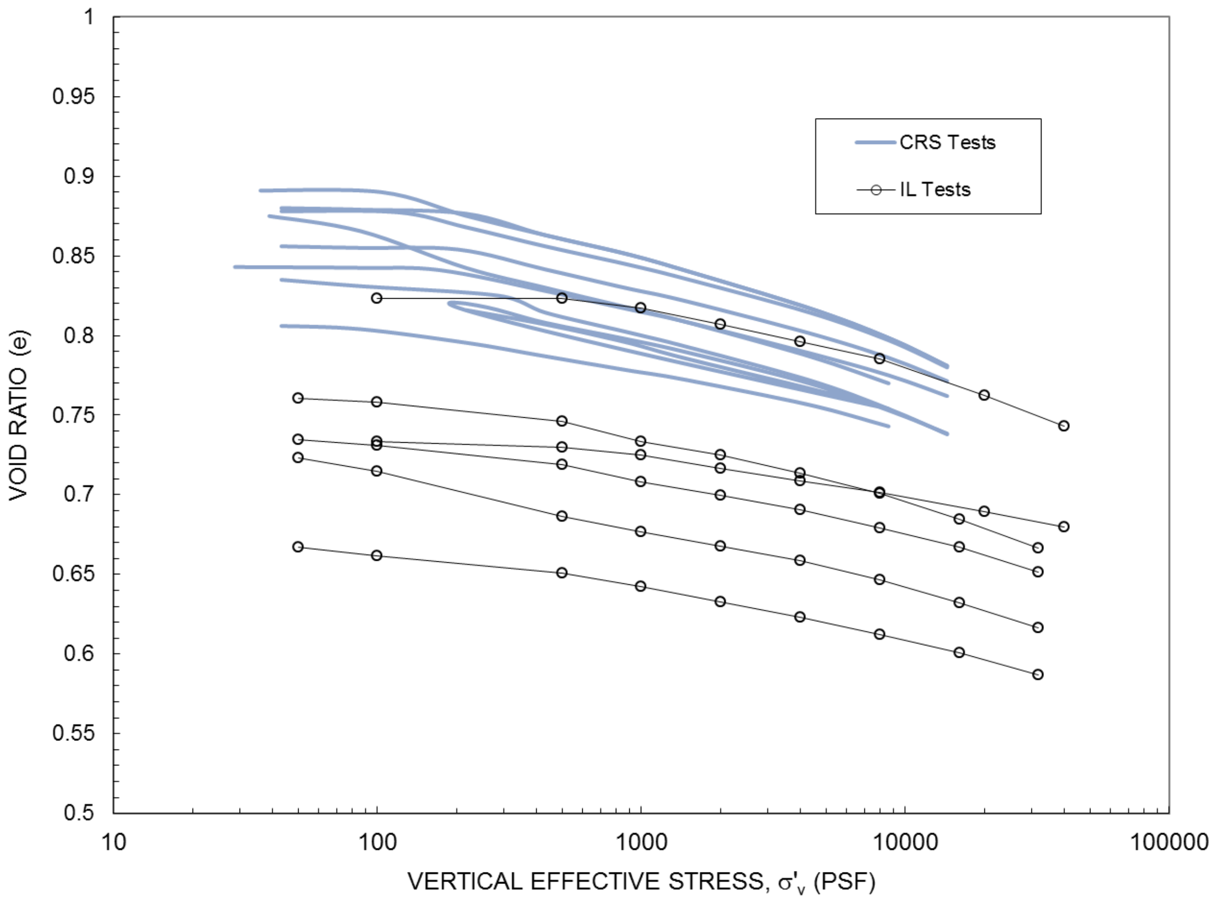

Figure 2 e-log σ'_v for specimens consolidated using various reconstitution methods.

Results shown in figure 2 indicate that samples reconstituted by sluicing the ash into the triaxial chamber possess higher initial void ratio. However, other compression characteristics such as recompression and compression indices appears to be comparable for the two reconstitution methods.

INSITU TESTING PROGRAM AND RESULTS

As a part of the geotechnical site investigation, 14 CPT were performed at the site. The piezocone used utilized 15 cm^2 tip area and a tip/end area ratio of 0.85, in all cases, the piezocone was advanced until refusal which was generally indicated by flexing of the cone rods.
Results of CPT include tip resistance, q_t, sleeve friction f_s, friction ration Rf, pore pressure, u, and soil behavior type, SBT. Figure 3 presents typical representative results of the CPT in the vicinity of the MPF location.

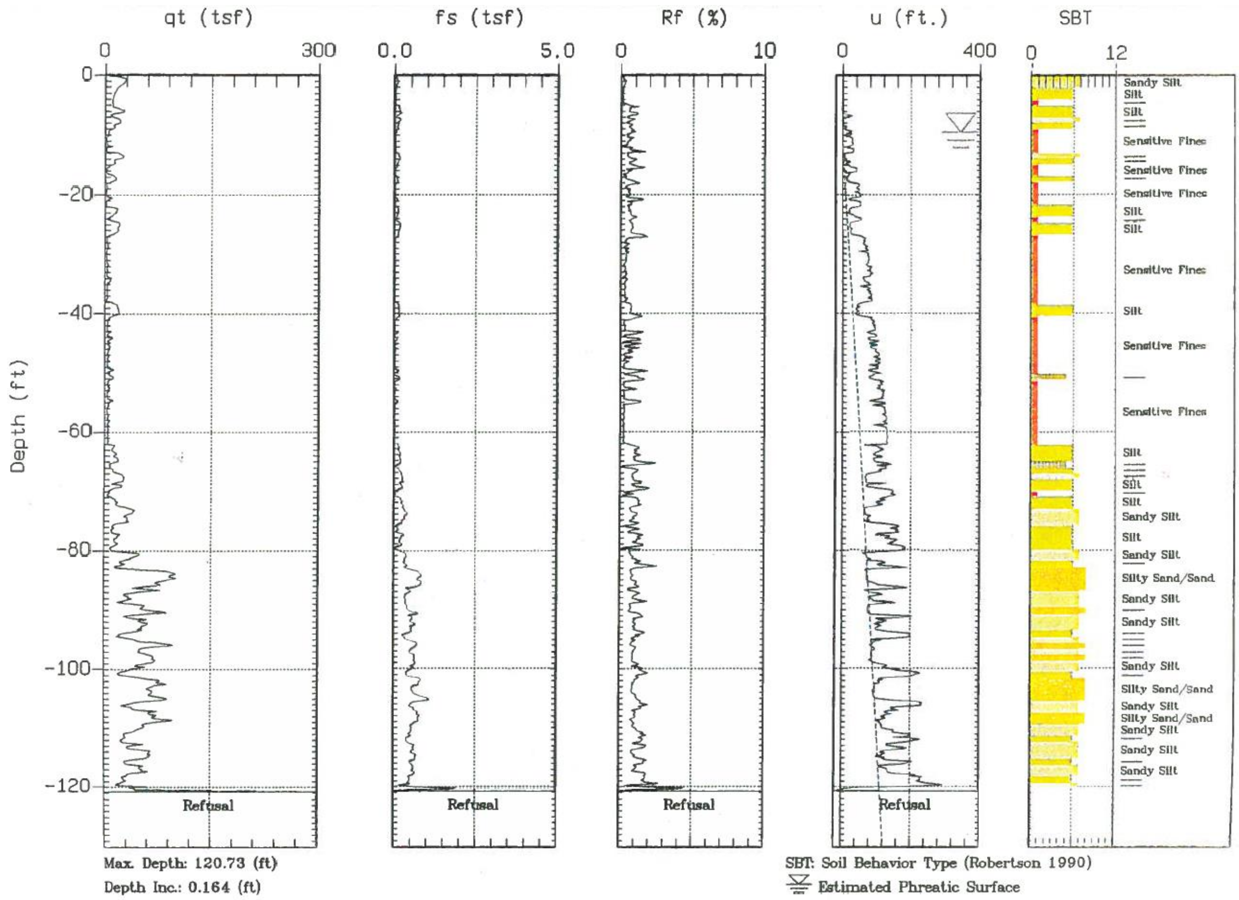

Figure 3 Typical results of the CPT in the vicinity of the MPF location.

The CPT results indicate that the subsurface profile generally consists of very loose to loose, wet, fine-grained fly ash from the ground surface to approximately 80 to 145 ft below ground surface (bgs) (maximum of 110 ft bgs at the location of the MPF). The CPT results also indicate that the fly ash is stiffer with depth as evidenced by the increasing tip resistance with depth. Below a depth of approximately 80 ft, CPT tip resistance, q_t, is consistently greater than 10 tsf indicating a loose to medium dense material

MONITORED PRELOAD FILL

The MPF was part of the design commitments to Ohio EPA to demonstrate the applicability of using the results of laboratory consolidation test for the estimation of the vertical settlement. In addition, MPF would give a better insight to the porewater pressure dissipation as a function of time. This paper deals only with the settlement prediction portion of the MPF construction.

The MPF area was approximately 760 ft by 500 ft (Figure 4). The fill was placed to a height of 34 ft and built with a combination of fly ash and minespoil material. A complete description of the MPF for this project is provided in Haydar et al 2008[2].

The MPF was located within the footprint of the landfill. The MPF was constructed in multiple-controlled lifts. Each lift was approximately 5-ft thick. Drainage ditches were constructed at the eastern and western edges of the MPF area to facilitate filling operations. The total height of the MPF was determined so that the resulting total vertical stress (at the base of the MPF) was approximately 3,800 psf. This vertical stress is consistent with the loading that would be induced by future preload fills that will be constructed in landfill cells prior to liner system construction.

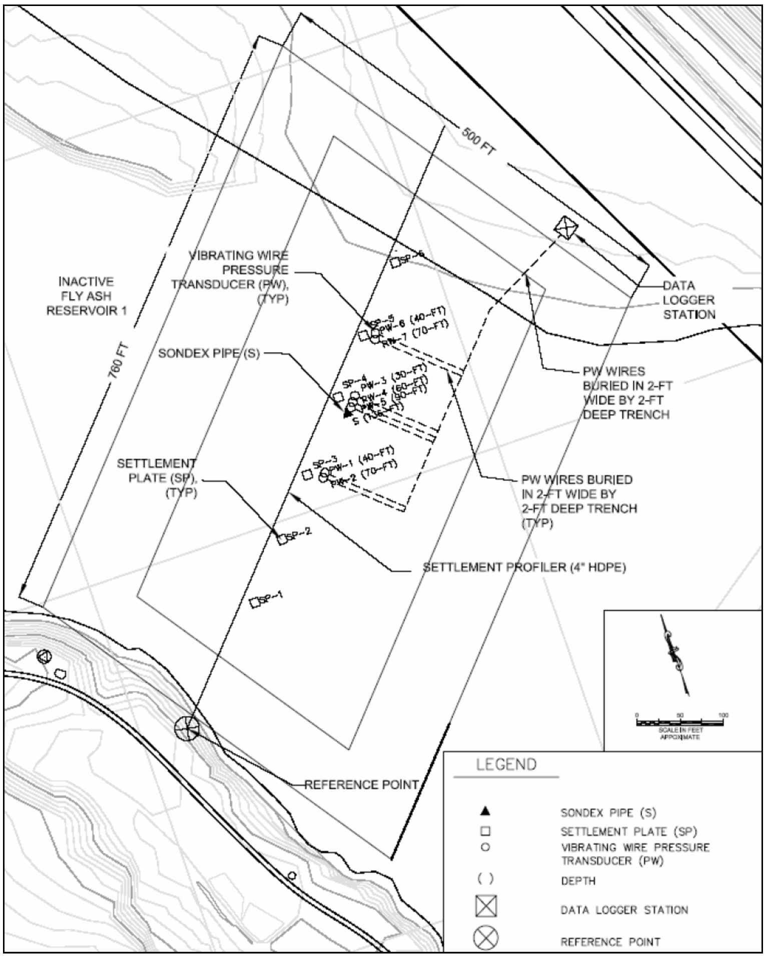

Figure 4 Geometry and Geotechnical Instrumentations of the MPF.

The settlement monitoring program for the MPF included the use of surface settlement plates, a vertical extensometer, a settlement profiler. The base of the MPF was prepared and the settlement monitoring equipment was installed prior to the start of MPF construction. The settlement plates and the settlement profiler access piping were installed to monitor and record compression of the underlying fly ash in FAR 1 resulting from MPF loading. A vertical extensometer (i.e., SONDEX system) was used to evaluate the portion of settlement attributable to specific thickness profiles of the underlying fly ash. Details of the settlement monitoring methods are presented in the following sections.

Settlement Plates
Six (6) surface settlement plates were installed as part of the settlement monitoring plan for the MPF. The locations of the settlements plates (SP-1 through SP-6) are shown on Figure 5. Settlement plate locations were selected such that the existing fly ash beneath the MPF area could be characterized in addition to assessing the spatial variability of the existing fly ash settlement.

Survey measurements prior to MPF construction were made at the center of the base plate and the top of the plate riser. During construction of the MPF, additional sections of settlement plate riser and PVC sleeve were added incrementally such that the top of the settlement plate riser was maintained above the surface elevation of the MPF. Each time a section of settlement plate riser was added, the elevation of the settlement plate riser was surveyed and recorded on field logs. The surveying also included horizontal and vertical locations.

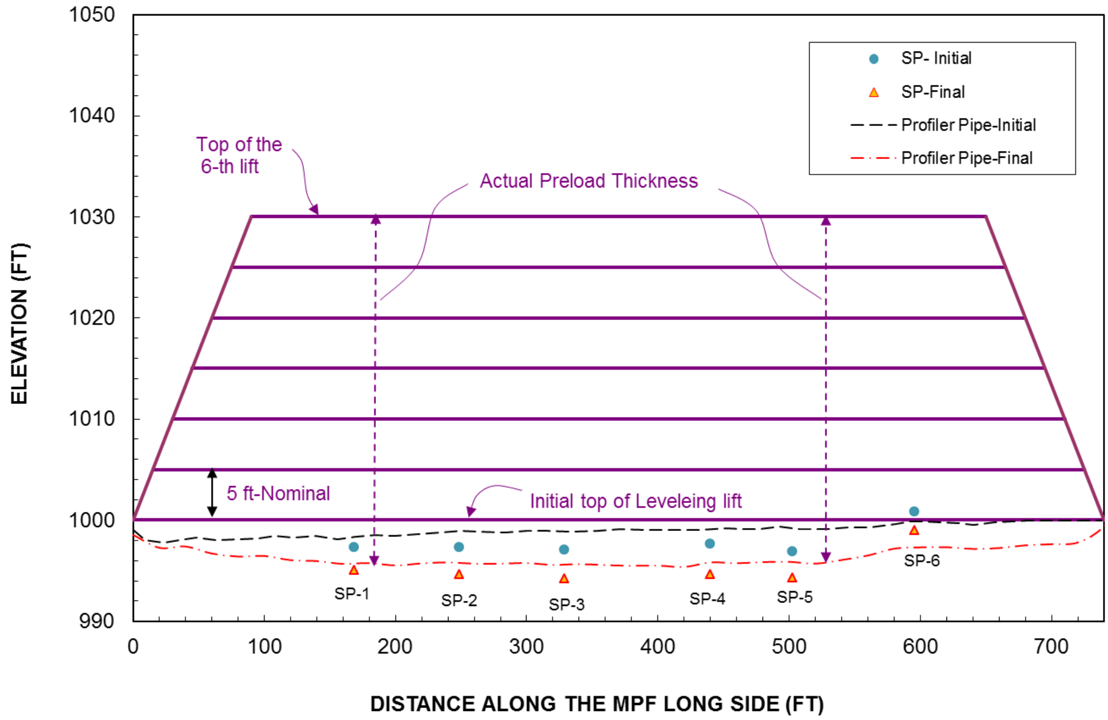

Figure 5 MPF Load Increments and Measured Settlement

Vertical Extensometer (SONDEX pipe)
A vertical extensometer was installed to monitor fly ash settlement with depth at the location shown on Figure 4. This location was approximately beneath the center of the MPF area. The extensometer consisted of a SONDEX pipe that was installed inside a borehole using a 6 ¼- inch hollow-stem auger. The SONDEX pipe was installed inside the boring to a final depth of approximately 128 ft below ground surface. Similar to the settlement plates, the SONDEX pipe was extended vertically during the MPF construction to maintain the top of the pipe above the MPF surface to facilitate settlement measurements.

Settlement along the depth of the SONDEX pipe was measured using magnetic rings installed at pre-determined depths (5-ft intervals) inside the SONDEX pipe. To measure settlement along the SONDEX pipe, a probe was lowered down the pipe, and measurements were taken at each sensing ring. Settlement of a sensing ring was then compared to the previous depth of the ring. The elevation of the tip of the SONDEX pipe was surveyed when settlement measurements were taken. This elevation served to correlate measurement readings taken by the probe with the surveyed tip elevation of the pipe used as a datum.

Figure 6 presents the measured vertical settlement using the Soundex Pipe from which, a maximum settlement of 2.5 ft was measure at the top part of the monitored Soundex pipe.

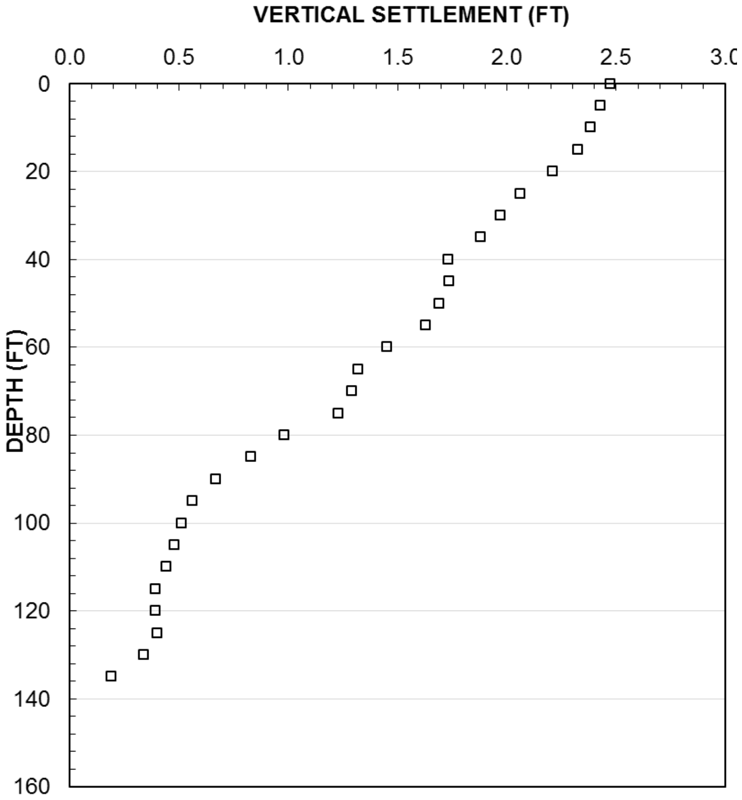

Figure 6 MPF Measured Settlement Using Soundex Pipe

Settlement Profiler

A settlement profiler was installed to measure settlement along a selected line across the base of the MPF. The profiler line was positioned over the underlying original valley. The approximate location of the settlement profiler line is shown on Figure 4. The purpose of the profiler was to evaluate general fly ash settlement characteristics and the consistency (or variability) of fly ash settlement over the underlying original valley. This information is important because differential settlements of the underlying fly ash would be a principal concern for the performance of a liner system and leachate management systems designed to convey leachate from one side of the valley to the other side.

The settlement profiler consisted of a 4-inch diameter high density polyethylene (HDPE) profile pipe installed in a trench prior to fill placement; a profiling device was pulled using polypropylene pull rope placed in the profile pipe. The profiling device relative elevation was read using a digital readout (data acquisition) which measures the water pressure difference between a water reservoir and reference point located at the entrance of the profile pipe; and the level of the profiling device using a pressure transducer. After the placement of the profiler pipe, the top of the pipe was surveyed at 10- to 15-ft intervals.

Settlement measurements of the profiler pipe were conducted prior to MPF construction (baseline) and at least once following the completion of each MPF lift. A reference point of known elevation was installed adjacent to the entrance of the profile pipe, at the southwest end of the MPF, and maintained for the duration of the project (see Figure 4). Measurements were taken at preselected intervals (stations) at a frequency of approximately 20 ft along the profile length (760 ft). At each 20-ft station, multiple readings were taken to ensure that the reading (or pressure change) had stabilized. The liquid reservoir was maintained at a constant elevation throughout each profile measurement.

The relative elevation of the transducer was converted to an absolute elevation by measuring the pressure at the transducer when it was placed on the reference point. Prior to and following each profile survey, pressure transducer readings were recorded by placing the torpedo (and enclosed pressure transducer) on the reference point.

SETTLEMENT CALCULATIONS BASED ON LABORATORY TESTING RESULTS

The in situ fly ash is very loose to loose and saturated (especially in the upper 50 ft of the profile), suggesting that the material is normally consolidated. For the MPF loading settlement analyses, it was assumed that the entire fly ash layer is normally consolidated and it was assumed that fly ash extends to the valley floor. This is a reasonable assumption based on the method of ash deposition and is consistent with the loose and saturated nature of the material. This implies that the preconsolidation stress, σ'_p, of the fly ash and bottom ash in FAR 1 is equal to the vertical effective stress, σ'_v.

Settlement computations were performed using compressibility parameters obtained from the laboratory testing programs described above. Settlements of fly ash were calculated using equations for conventional 1-D compression. It was assumed that the settlements are caused by primary consolidation of fly ash layers due to stresses resulting from the MPF. Secondary compression was assumed to be negligible for the fly ash over the relatively short MPF construction period.

Settlement calculations were performed using a spreadsheet created in Microsoft EXCEL. The spreadsheet calculates the amount of settlement due to one-dimensional consolidation at vertical sections taken every 100 ft along a cross-section along the centerline of the MPF. These locations are labeled as horizontal locations along the cross-section. Calculation layers in the fly ash for each vertical section were at most 10 ft thick.

In the EXCEL spreadsheets, settlements resulting from primary consolidation of soil layers are calculated using the following equations for one-dimensional compression (Lambe, 1969[3]):

$$S_p = \frac{C_c}{1+e_o} H \log\left(\frac{\sigma'_{vo} + \Delta\sigma}{\sigma'_{vo}}\right) \qquad (1)$$

where: S_p = primary settlement (ft);

C_c = compression index = $\dfrac{\Delta e}{\log \dfrac{\sigma'_2}{\sigma'_1}}$;

e_o = initial void ratio;

H = initial thickness of compressible layer (ft);

σ'_{vo} = initial vertical effective stress in the ground (psf);

$\Delta\sigma_v$ = increment of vertical stress (psf).

Alternatively, the modified compression index, $C_{c\varepsilon}$, could substitute for the term $C_c/1+e_o$ used in Equation 1.

For the modified compression index, $C_{c\varepsilon}$, a value of 0.035 was selected as the average value from consolidation tests performed on fly ash samples at a loading interval equal to 4,000 to 32,000 psf. A total unit weight of 100 lb/ft^3 was used for the foundation fly ash.

SETTLEMENT CALCULATIONS BASED ON CPT RESULTS

Several methods for calculating settlement using CPT data have been developed and used with some success. Abu-Farsakh, 2004[4] presented the history of development of methods used to Evaluate of Consolidation Characteristics of Cohesive Soils from CPT results. In addition, the U.S. Army Corps of Engineers summarized settlement analysis methods using CPT tests results in the EM 1110-1-1904.

For the purpose of this paper, settlement of the fly ash as a result of the MPF loadings as well as the final stress loading were evaluated using Schmertmann settlement calculator utilizing Settle3D commercial program produced by ROCSIENCE. “Settle3D is a 3-dimensional program for the analysis of vertical consolidation and settlement under foundations, embankments and surface loads. The program combines the simplicity of one-dimensional analysis with the power and visualization capabilities of more sophisticated three-dimensional programs”[5]. This calculation is based on a simplified stress-strain relationship (Modified Schmertmann’s method 1978)[6].

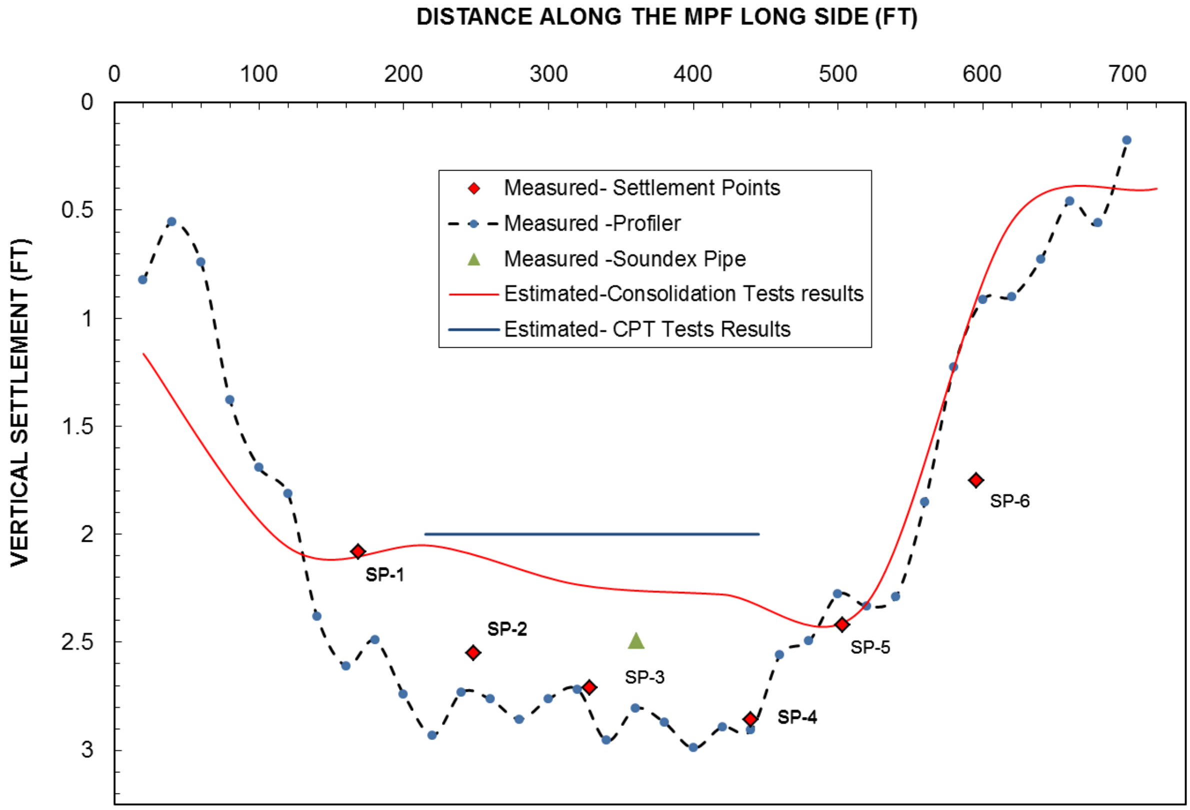

Figure 7 MPF Measured and Estimated Settlement

The CPT predicted consolidation settlements are compared with the measured field settlements from settlement plates and with the laboratory-calculated settlements, as shown in Figure 7. The figure shows that the CPT calculation and the laboratory calculations slightly underestimate the consolidation settlement for the MPF range of applied effective stresses.

The nature of field tests results, similar to SPT or CPT, is that they are related to the pre testing conditions of the tested soils. For properties controlled by the effective stresses, values measured in these field tests applies only over small range of effective stresses in the vicinity of the existing field values. Figure 8 illustrates of applicability of field Measured properties in Estimating vertical settlement. Value of tangent of e-σ'_v at σ'_{v0} (inversely related to Constrained Modulus-M_0) predict change in void ratio (and settlement) over small range of effective stresses (σ'_{v1}), but overestimate the change in void ratio at higher stress levels (σ'_{v2}).

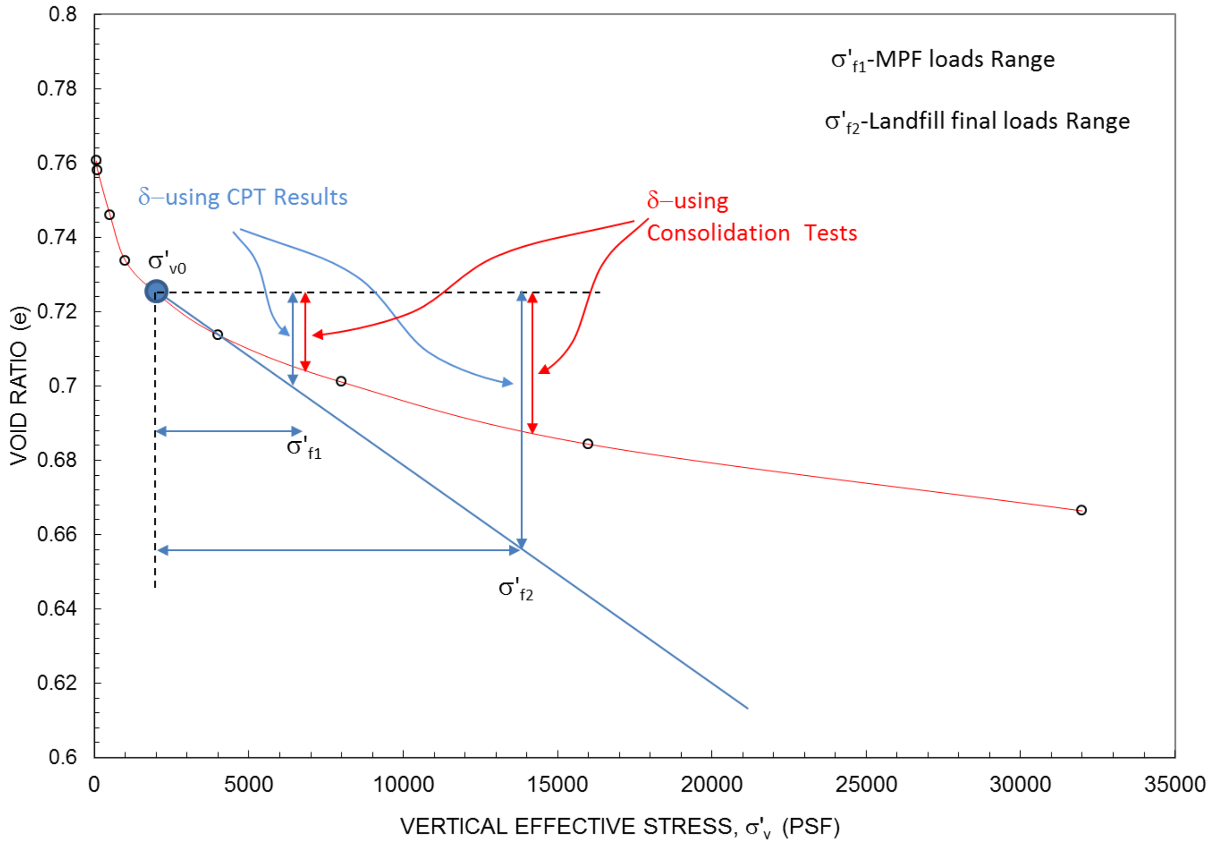

Figure 8 Illustration of Applicability of Field Measured Properties in Estimating Vertical Settlement.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The overall objective of the MPF study was to obtain site-specific data in relation to settlement of sluiced fly ash to confirm the in-place compressibility and drainage characteristics of FAR 1 fly ash.

Measured settlements using settlement plates and the SONDEX system were closely comparable and indicated a total vertical settlement of approximately 2.5 ft for the total MPF height of 34 ft (equivalent to a total calculated vertical stress of approximately 3,800 psf). A settlement profile was established across the valley using a profiler pipe.

The settlement profile was generally consistent with the underlying valley profile; however, measured total settlements using the profiler were greater than those measured by the settlement plates and SONDEX system. Results demonstrate the need to incorporate complimentary (or redundant) measuring systems into a performance monitoring program.

Calculated settlements using Consolidation test results and CPT results were closely comparable and indicated vertical settlement of 2 ft -2.5 ft for the total MPF height of 34 ft. However, at higher vertical stresses levels, CPT calculated settlement was higher than those using consolidation test results since the CPT based estimate does not take in consideration the increase in soil stiffness as a result of the increase in the effective consolidation pressure caused by the staged construction of the landfill.

The data collected as part of the MPF is being used to design an instrumentation program for each preload to be constructed over FAR 1 and to further evaluate compression and drainage parameters used in the original design. The purpose of the preloads is to consolidate and strengthen the fly ash in FAR 1 before constructing cell liner and leachate management systems of the proposed 200 ft high waste disposal facility.

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