# Predicting settlement and stability of wet coal ash impoundments using dilatometer tests

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ABSTRACT: New environmental regulations in the United States for wet ash handling operations may lead to closing the majority of the wet ash impoundments within the next 10 years. Ash tends to be difficult to sample and to perform laboratory consolidation tests, but yet the geotechnical design of these systems requires predictions of the primary and secondary consolidation of the flyash in the impoundments.

Dilatometer tests (DMT) provide deformation moduli that can accurately predict settlement. By performing DMT at 20-cm depth intervals, the engineer gets accurate and near-continuous deformation data for settlement predictions. Lighter weight drill rigs can access these often difficult terrain areas, yet have sufficient thrust capacity to penetrate ash deposits. The authors present two case studies demonstrating the value and accuracy of dilatometer tests to predict settlement of capped ash ponds and shear strength values to predict stability of their slopes.

## 1 INTRODUCTION

The geotechnical design of ash basin closure projects requires accurate settlement and slope stability predictions. The current US "state of the practice" involves obtaining undisturbed Shelby tube samples of wet ash samples and conducting laboratory consolidation or triaxial shear testing. These methods rely heavily on the skills of the drilling crews and laboratory technicians to obtain, transport and test a limited number of samples of the ash basin profile. This limited number of samples only represents a discrete portion of the wet fly ash profile relative to the total thickness of the compressible fly ash materials. Unfortunately, too often flyash samples become disturbed during the sampling, transport and preparation process that yields a non-representative estimate of the amount of settlement or slope stability. Because of the high variability of the thickness, stiffness and strength of these flyash deposits, the engineer must have numerous test results to accurately predict settlement or slope stability. DMT performed at 20-cm depth intervals can provide enough design information, while laboratory consolidation or triaxial tests cannot.

As more fly ash basins are closed at coal combustion plants, the importance of developing accurate estimates of the final cover settlement will increase. Some of the final cover components that can be influenced by total settlement and/or differential settlement of the saturated fly ash materials include:

- The slope of the stormwater management channels and the drainage system piping;
- The slope and positive drainage of the final cover as it pertains to the grading design;
- Connection to existing stormwater management structures including sumps, stormwater outfalls, and perimeter dam embankments;
- Minimum regulatory requirements for the final cover slopes to reduce infiltration and provide positive drainage of the stormwater.

In addition to an innovative approach for estimating the settlement of fly ash, this paper offers useful information about the immediate settlement and near surface stabilization of soft/wet fly ash under a surcharge load. The design and construction of the final cover system rely on this information. When applying a surcharge load to the surface of saturated fly ash material, the pore water initially supports the load and no compression or settlement takes place. Flyash behaves like a fine grained soil and follows the principles of effective stress of fine particle soils and "soil like" materials such as fly ash. Over time this excess pore water pressure dissipates and the consolidation process or settlement of the fly ash material takes place as the water content decreases. The time rate to remove the porewater and to decrease the volume of the fly ash depends on the stress applied by the surcharge load, the permeability of the fly ash and the drainage conditions beneath and near the surcharge load. As the excess porewater pressure dissipates and the saturated fly ash densifies, the stability of the near surface fly ash and the ability of the saturated ash basin to support the final cover soils noticeably improves.

Until recently the engineer could not measure the rate that the excess porewater pressure dissipates of a surcharge loading on very soft and saturated fly ash due to the concern for safety, the need for special equipment and geosynthetics, and the potential of losing heavy equipment in unstable areas as the surcharge load was placed over the soft/saturated fly ash materials. The following sections provide some practical examples of how to safely load soft/saturated fly ash materials, construct access roads, and measure the rate of stabilization using in-situ porewater pressure reading devices. Of course, drainage conditions and near surface flyash materials vary from site to site. The potential for variable site conditions require interpretation by skilled contractors and experienced geotechnical engineers. At the same time this paper provides useful principles and some general guidelines, for determining *how and when saturated/soft fly ash stabilizes* under the initial surcharge loading conditions.

## 2 TYPICAL ASH BASIN PROFILES

A typical ash basin profile includes a wide range of density and in-place moisture content of the fly ash. In general, high capacity pumps move the wet fly ash slurry from the coal combustion process to the ash basins through large discharge pipes. The flyash settles over time. The heavier bottom ash particles deposit near the slurry discharge pipe, while the lighter fly ash settles in thin layers across the ash basin farther away from this pipe. The fly ash in the deeper portions of most ash basins consolidates under its weight and overburden stress applied by subsequent fly ash layers. As the ash basin fills portions of the fly ash will break the water surface, and the surface will dry creating a surface "crust layer". These "crust layers" range in thickness from several inches to greater than 10 feet (3 m). As the long term result, three distinct layers of differing degrees of compressibility, in-place density, moisture content, and potential for settlement form the ash basin:

- <u>Surface Layer or Crust Layer:</u> Tends to be 1 foot (0.3 m) to greater than 10 feet (3 m) in thickness with relative low compressibility and settlement potential compared to the underlying layers.
- <u>Middle Layer – High Moisture Content and Compressible:</u> Can range in thickness from several feet to up to 70 feet (21 m) in the center of the deeper ash basins. The middle layer tends to have the high moisture content, and relative high compressibility as compared to the Surface and Lower layers.
- <u>Lower Layer – Lower Moisture Content and Less Compressible:</u> Located at the bottom of the ash basin, these layers can range in thickness from several feet up to 20 feet (6 m) depending on the overburden stress created by the over lying fly ash layers.

## 3 SAMPLING AND LABORATORY CONSOLIDATION TESTING FOR PREDICTING SETTLEMENT

The engineer must determine the amount of primary and secondary settlement that will occur during and after the installation of the final cover materials to properly design them. The depth of the fly ash in most ash basin ranges from 20 to 100 feet (6 to 30 m) below the surface, with the greatest thickness of the compressible materials typically being located in the center of the basin. This section describes the different methods available for predicting the amount of settlement in a typical, wet processing fly ash basin.

### 3.1 *Conventional Methods for Predicting Settlement of Fly Ash*

A review of the available literature indicates that there are very few studies on the settlement behavior of saturated, impounded fly ash materials. The conventional method for estimating settlement of fly ash materials typically involves the following step-by-step process:

1. Conduct standard penetration test (SPT) borings to identify the compressible fly ash layers and obtain samples.

2. Attempt to obtain undisturbed Shelby tube samples of the compressible fly ash layers.

3. Transport the undisturbed samples to the laboratory and extract specimens of the compressible fly ash layers.

4. Test the fly ash specimens in a conventional oedometer consolidation test device according to ASTM D2435.

5. Determine the results of Compression index, Cc, Recompression Index, Cr, and the Consolidation Coefficient, Cv for the tested fly ash specimen.

6. Determine the initial void ratio and other input parameters using a combination of field measure and laboratory derived methods. $e_o$ from lab tests, σ' from field derived measurements.

7. Develop a representative soil/fly ash profile for the ash basin, and calculate the amount of settlement for each layer using the lab results and the following relationship:

$$\triangle \delta_c = \frac{C_r}{1+e_0} H \log\left(\frac{\sigma'_{zc}}{\sigma'_{z0}}\right) + \frac{C_c}{1+e_0} H \log\left(\frac{\sigma'_{zf}}{\sigma'_{zc}}\right)$$

### 3.1.1 *Difficulties with the Field Sampling of Fly Ash*

Geotechnical engineers and drillers have difficulty obtaining a representative sample of fly ash material that is saturated, non-cohesive and has relatively low strength. Even if a sample is obtained it is often difficult to get the sample to the surface and transported to the laboratory for testing. Figures 1 and 2 show examples of typical disturbance that can occur during the field sampling of saturated fly ash samples.

Figure 1: "Undisturbed" Fly Ash Sample: Evidence of Vertical Mixing

Figure 2: "Undisturbed" Fly Ash Sample: Evidence of Compression During Sampling

### 3.1.2 *Difficulties with Sample Preparation and Testing*

Many geotechnical engineers and soils laboratory technicians have experienced difficulty getting a sample of low strength, non-cohesive soils or fly ash materials into the consolidation test device. The typical sample for consolidation testing has a height less than 1 to 2 inches, but often the engineer assumes design parameters from this small lab specimen represents several feet of a compressible fly ash layer. Some of the potential sources of error that may occur during the sample preparation and consolidation testing process for fly ash include:

- Selecting a representative sample for testing from a variable and/or heterogeneous undisturbed field sample;
- Inserting a sample with an irregular cross section into a test mold can cause additional disturbance;

- Laboratory loading conditions that do not accurately model the conditions that will be experienced during construction;
- Computing the initial void ratio, $e_o$, for a fly ash sample with a lower specific gravity than what is typical for most fine-grained soils.

## 4 IN-SITU TEST METHODS FOR ESTIMATING SETTLEMENT

Cone penetrometer (CPT) or the flat blade dilatometer (DMT) provide a cost effective method for obtaining more frequent and accurate deformation measurements of the layers in saturated fly ash impoundments, resulting in better settlement predictions by a final cover system and/or embankment constructed over a saturated ash basin. The following sections describe how the CPT and DMT were used to estimate settlement on an ash basin closure design project.

### 4.1 *Muskingum River ash pond project*

On shown on Table 1, this ash basin had the following design requirements and fly ash characteristics:

Table 1: Ash characteristics for Muskingum

| | |
|---|---|
| Area of Ash Basin | Approximately 35 acres |
| Min. Ash Thickness | 5 feet (1.5 m) |
| Max. Ash Thickness | 80 feet (24 m) |
| In-place Wet Unit Weight | 70 to 125 pcf (1.12 to 2.00 $g/cm^3$) |
| In-place Moist.Cont. | 20 to 50 % |
| Final Cover Material | Combination of soil cover and geomembrane – 3 to 10 feet (1 to 3 m) thick |
| Types of Ash Material | Predominately fine grained fly ash, some bottom ash near discharge pipes, and a mixture of sections with a dry crust and soft/saturated fly ash at the surface |

The authors performed several dilatometer and cone penetrometer test soundings within the existing flyash basin using a light-weight drill rig. Figure 3 shows photographs of this set-up and Figure 4 shows the adjacent DMT and CPT results from those soundings.

Figure 3: Photos of field testing at site

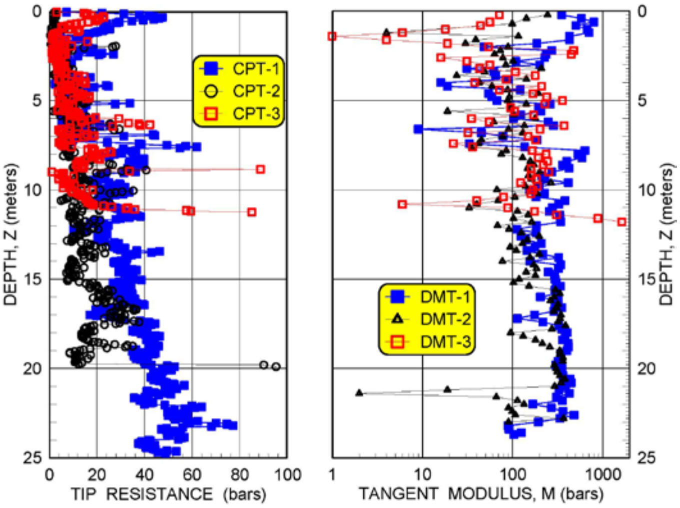

Figure 4: CPT and DMT Results

### 4.1.1 *Settlement predictions*

The contractor placed a 3 meter high berm over geogrid to form access roads. Shown on Table 2, the authors predicted settlement for this surcharge using laboratory consolidation data and Schmertmann's ordinary DMT method.

Table 2: Comparison of Settlement Predictions

| Boring/ Sounding Number | Evaluation Method | Layer Thickness (meters) | SPT Values | Estimated Settlement (mm) |
|---|---|---|---|---|
| B-1 | Conventional | 24.4 | 1 to 23 | 183 |
| B-2 | Conventional | 22.6 | 1 to 12 | 206 |
| DMT-1 | Schmertmann Ordinary | 22.9 | NA | 86 |
| DMT-2 | Schmertmann Ordinary | 23.8 | NA | 178 |
| DMT-3 | Schmertmann Ordinary | 11.9 | NA | 124 |

To confirm these settlement predictions, the design team also installed settlement plates near the DMT, CPT, and SPT test locations. Figures 5A and 5B show installing the settlement plates on the saturated flyash.

Figure 5A: Settlement Plate Installation

Figure 5B: Completed Settlement Plate--Long term Monitoring

The surveyors had difficulty measuring the initial elevations of the settlement plates, as they moved during installation due to the instability of the upper flyash from the vibrations of the construction equipment. These plates settled 3 to 12 inches (75 to 300 mm) during the first three months. Most of the settlement in the near-surface fly ash occurred in the first 24 hours after placing the surcharge. The excess porewater pressures dissipated rapidly as measured by the transducers. The CPT dissipation tests predicted rapid dissipation and generally measuring 50% decay within 2 minutes, which occurred too quickly to measure using DMT dissipation tests. The settlement plates have measured less than 1 inch (25 mm) of additional movement after the first 3 months.

In addition, a review of the DMT settlement computation spreadsheet for the project indicated that almost 70 percent of the settlement will occur in layers where the constrained deformation modulus is less than 100 bars. While we collected and performed laboratory consolidation tests for a few near surface block samples, the driller could not successfully retrieve “undisturbed” samples of these highly compressible and soft/saturated layers with conventional Shelby tube equipment. The large amount of settlement that occurred in these soft/saturated layers confirms the importance of obtaining in-situ constrained deformation modulus data using the DMT.

## 5 IN-SITU TEST METHODS FOR SLOPE STABILITY

Sometimes circular or oval elevated beams, constructed with flyash, form basins or settling ponds to store flyash. The engineer must evaluate the shear strength properties of the flyash at these slopes to evaluate their stability.

Laboratory triaxial tests can evaluate their shear strength, but often the engineer cannot perform enough tests and sampling, transporting, and trimming the specimens cause disturbance and error. Dilatometer tests correlate well with the undrained shear strength when the flyash behaves as cohesive soil and with the angle of internal friction using Schmertmann’s method with thrust measurements when it behaves as cohesionless soil.

### 5.1 *Glen Lyn ash pond*

The existing slopes for the elevated settling ponds consisted of flyash. We performed several dilatometer test soundings through the existing berms and some borehole shear tests in slightly offset boreholes. The angle of internal friction from both tests compared favorably as shown on Table 3:

Table 3: Comparison of DMT and BST shear strength measurements

| Borehole | Depth (m) | BST ϕ’ | DMT txl ϕ’ |
|---|---|---|---|
| BST1/DMT1 | 3.3 | 36.9° | 36.8° |
| | 6.6 | 35.0° | 33.5° |
| | 9.5 | 27.2° | 30.7° |
| | 12.3 | 37.7° | 24.4° |
| BST4/DMT4 | 5.0 | 28.5° | 33.0° |
| | 9.6 | 28.8° | 31.1° |
| BST7/DMT7 | 5.1 | 31.0° | 32.8° |

## 6 CONCLUSIONS

- Generally drillers cannot retrieve “undisturbed” samples of highly compressible and weak flyash. Technicians have difficulty transporting these samples to the laboratory without causing additional disturbance. Laboratory technicians have difficulty extracting and trimming these samples.

- Fortunately, engineers can accurately measure the deformation and shear strength properties of flyash using dilatometer tests.
- Settlement predictions using Schmertmann's ordinary method compared favorably with settlement plate measurements.
- Shear strength measurements of flyash with the dilatometer compared favorably with borehole shear test measurements.

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