The Consolidation Characteristics of Impounded Class F Fly Ash – A Case History

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Abstract: Although the utilization of fly ash has increased over the years, more than 60 percent of the fly ash produced each year continues to be disposed of in the US in ash ponds and landfills. Many disposal facilities are now or will soon be filled to their design capacity. As a result, there is an increasing interest in reclaiming the existing fly ash pond areas. For many electric utilities, an attractive possible reclamation plan is to use the closed fly ash pond as the foundation of a new disposal facility. In 2005, American Electric Power (AEP) decided to build a new landfill on top of an existing fly ash pond at the Cardinal power plant in Brilliant, Ohio to dispose of gypsum from the plant's new flue gas desulfurization (FGD) system. To meet regulatory guidelines, the impounded fly ash area must be closed, compacted and an impervious liner system built for the new landfill. Before the new facility can be constructed, the response of the ponded fly ash to the imposed loads must be determined. In order to measure the settlement of the impounded fly ash resulting from the overburden pressure from the landfill, constant rate of strain (CRS) consolidation tests were performed on medium-scale resedimented Class F fly ash samples in a modified 14 cm (5.5 in) diameter triaxial chamber. Compression index (C_c), recompression index (C_r) and the consolidation coefficient (C_v) were evaluated over the range of the designed landfill loads. Additional specimens were loaded to the maximum consolidation pressure over an extended period of time in a standard oedometer to evaluate the coefficient of secondary compression. The compressibility of the fly ash tested was found to be similar to published results for inorganic sandy silt and poorly graded sand. The value of secondary compression coefficient was found to be small.

Keywords: Class F Fly Ash; Consolidation; Constant Rate of Strain; Secondary Compression

INTRODUCTION

In 2004 more than 64 million tons of fly ash were collected in the United States[1]. While the fly ash utilization has increased over fourfold since 1966, most of the fly ash produced in the United States in 2004 is still disposed of.

Fly ash disposal is generally accomplished in one of the two ways. At many facilities, fly ash is transported in the form of a slurry and deposited in ash ponds where it is allowed to settle. This method is termed as wet disposal. In contrast, the dry disposal method requires the fly ash be conditioned and then placed in a landfill. The placement of conditioned fly ash in landfills is referred to as dry disposal method. The wet disposal method has been the most common disposal method over the past 70 years. Many disposal facilities have been or will soon be filled to their design capacity.

The Cardinal Power Plant is located south of Brilliant in Jefferson County, Ohio along the western bank of the Ohio River. It consists of three units and has a total generating capacity of 1830 megawatts. The power plant is jointly owned by AEP and Buckeye Power. In 2004, the two companies decided to install flue gas desulfurization (FGD) systems on units 1 and 2. The installation of this system will reduce sulfur dioxide emissions by up to 98 percent. In 2005, a preliminary design study was initiated to evaluate the feasibility of building a new landfill for future FGD disposal on the existing fly ash pond which was filled to its capacity in 1988. The fly ash placed in slurry form settles and consolidates under its self-weight and the overburden stress applied by the ash placed afterwards. The upper layer of fly ash deposit from wet disposal has a very low density. Therefore, low bearing capacity, excessive settlement, and liquefaction potential of the reclaimed ground on fly ash deposit are of great concern. Three research projects have been initiated at the Ohio State University to study the consolidation characteristics, liquefaction potential, and the compatibility of the FGD gypsum with Geosynthetic Clay Liner to support the conceptual design of the new landfill. This paper presents the major findings from the laboratory study on the consolidation characteristics of the impounded fly ash.

Over the past decade, a considerable amount of research has been conduced to study different techniques such as vacuum dewatering, electro-osmosis consolidation, vibrocompaction, stone-sand columns[2], blasting compaction[3], lime stabilization[4] to improve the density, stiffness and bearing capacity of fly ash. However, a literature review indicates that very limited information is available regarding the consolidation characteristics of ponded fly ash. Consolidation characteristics concerning the rate and amount of consolidation settlement of the fly ash deposit are essential in the design of any structures built on former ash ponds. Two of the most important properties obtained from a consolidation tests are the compression index, C_c, and the coefficient of consolidation, C_V. The compression index indicates the amount of settlement that the fly ash ground can be expected to undergo while the coefficient of consolidation determines how fast the settlement will take place after loading is applied. Some research has been done to investigate the consolidation characteristics of compacted fly ash[5-6]. Study of consolidation characteristics of sedimented fly ash slurry has rarely been reported in the past.

Consolidation behavior of soils is typically determined using the conventional oedometer tests, which have been used by geotechnical engineers for more than six decades. Specified incremental loads are usually applied to the sample with a loading duration of one day per increment, giving a total testing period of one to two weeks. Sample is usually recompacted to the desired density and moisture content directly into the consolidation ring or trimmed from representative field sample. The interpretation of data is usually time consuming and requires some judgment. Constant rate of strain (CRS) consolidation test is an efficient and relatively rapid alternative method to determine consolidation properties. In the CRS consolidation test, the sample is loaded continuously, rather than incrementally, at a required rate to produce the desired constant rate of strain. Compared with oedometer tests, the saturation of sample can be easily achieved and maintained. During the test, the applied load, corresponding strain and the pore water pressure are monitored continuously. CRS tests, therefore, can produce a continuous compression curve with greater objectivity.

In this study, constant rate of strain (CRS) consolidation tests were performed on medium-scale resedimented Class F fly ash samples that simulated the wet disposal in the field.

BASIC PROPERTIES OF THE FLY ASH

According to ASTM C618, the fly ash from the Cardinal power plant of AEP is classified as a Class F ash. The basic physical properties such as particle size analysis and specific gravity tests were performed on representative samples from the ash pond.

Compared with most soils, fly ash has a lower specific gravity that typically ranges from 2.1 to 2.5 [7]. In this study, the specific gravity of Cardinal fly ash was found to range from 2.1 to 2.4 with an average value of 2.2.

Typically, fly ash is a relatively fine, predominantly silt sized uniform material[7]. Figure 1 shows the grain size distribution curves for the fly ash used in this study. Numerical analysis results of the gradations are presented in Table 1, including the median particle size (D_{50}), the effective particle size (D_{10}), and the coefficient of uniformity ($C_u = D_{60}/D_{10}$). The median particle size describes the average particle size for the sample. Effective particle size reflects the maximum diameter of the smallest 10 percent particle. The coefficient of uniformity is used to relate the size range of the particles. The ponded fly ash consisted predominantly of silt size particles with some clay- and sand-size fraction. The fly ash is poorly grade with the coefficient of uniformity varying from 3.3 to 6.0.

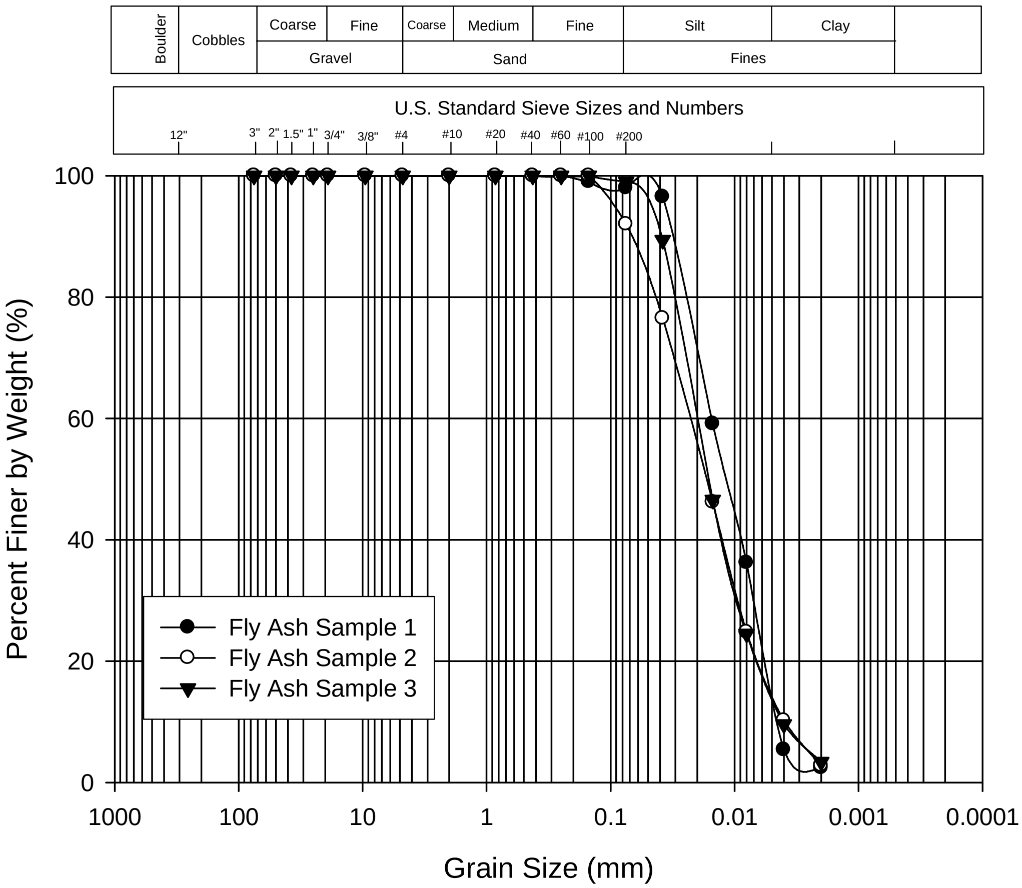

Figure 1 Grain Size Distribution of Fly Ash

Table 1 Gradation Test Results

Sample ID	Particle Size Analysis		
	D_{50} (mm)	D_{10} (mm)	C_u
Fly Ash Sample 1	0.014	0.0045	3.3
Fly Ash Sample 2	0.018	0.0040	6.0
Fly Ash Sample 3	0.018	0.0040	5.0

SAMPLE PREPARATION AND TEST PROCEDURES

All the resedimented samples were prepared as a slurry to simulate the wet disposal method employed in the field. Wet fly ash taken from the pond was combined with distilled water and mixed thoroughly in three flasks. The mixture was saturated by applying a vacuum until no air was drawn out of the slurry. After saturation, the slurry was carefully poured into a consolidometer modified from a 14 cm (5.5 in) diameter triaxial chamber and allowed to sediment for a minimum of two hours.

After the sample settled under its self-weight, a custom-made cap was put on the sample and the triaxial chamber was assembled (Figure 2). The cap consisted of two parts (see details in Figure 3). The top part had a Teflon ring which provided a close fit between the top cap and the chamber to prevent leakage of fly ash material. The flexibility of the Teflon ring kept the cap from tilting without introducing large side friction. The bottom part had a small gap between the cap and the chamber wall to minimize side friction. A water-proof load cell was installed between the two parts to measure the load applied to the sample. The sample was allowed to drain from the two drainage tubes installed in the cap. A sheet of presaturated porous plastic was put on top and bottom of the sample to prevent the fly ash from leaking into the drainage lines.

An LVDT was attached to the loading rod of the triaxial chamber to measure the axial displacement while pore water pressure was monitored at the bottom of the sample.

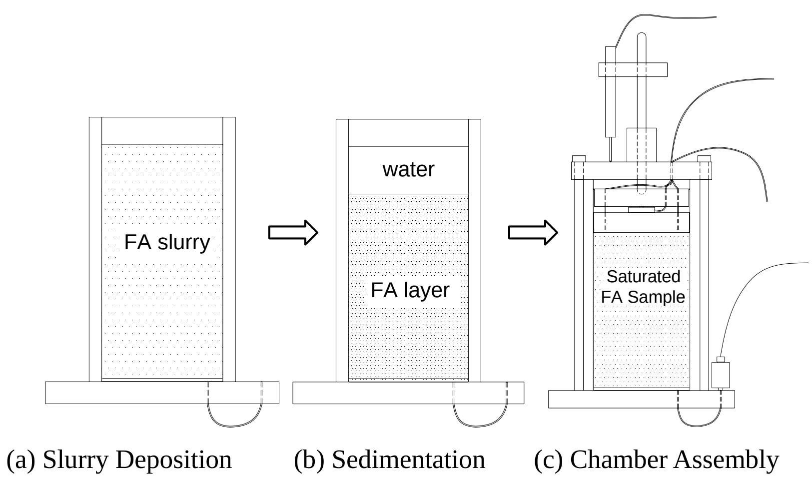

Figure 2 Schematic of Sample Preparation Methodology

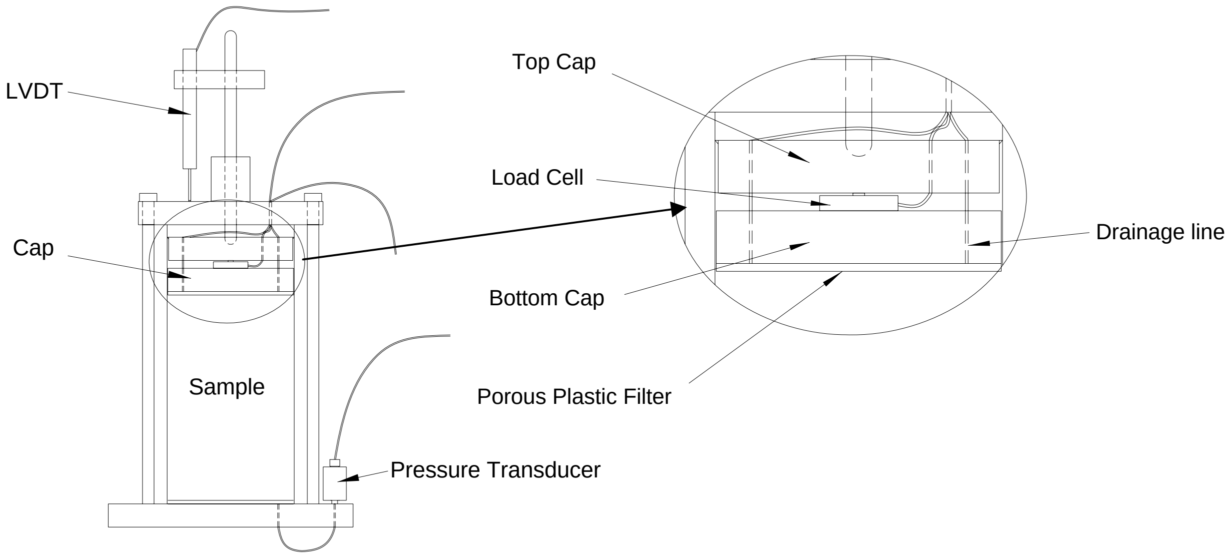

Figure 3 Schematic Cross Section of Instrumented Consolidation Chamber

The height of the sample was measured and the initial void ratio was calculated from the measured moisture content and the specific gravity. The initial height and void ratio of all the samples tested are listed in Table 2. The initial sample height varied between 13.1 and 18.0 cm due to the variation in the amount of fly ash used in the slurry method. The variation in void ratio was only 0.805 to 0.891.

Table 2 List of Initial Sample Height and Void Ratio

Sample ID	Initial Sample Height (cm)	Initial Void Ratio
Test #4	17.5	0.836
Test #5	13.1	0.885
Test #6	17.7	0.855
Test #7	13.9	0.874
Test #8	13.1	0.891
Test #9	17.1	0.873
Test #10	17.0	0.846
Test #11	18.0	0.817
Test #12	13.2	0.873
Test #13	14.9	0.805
Mean	15.6	0.855
Standard Deviation	2.09	0.029
Coefficient of Variation	13.4%	3.4%

After the assembly of the sample in the test chamber, a seating load (1.4, 3.4, or 6.9 kPa) was applied to the sample. Then the test chamber was placed in the load frame to start the constant rate of strain loading. To limit the absolute excess pore water pressure to a value between 3% and 30% of the applied vertical stress[8], a strain rate of 0.002 per min was selected based on three trial tests. Constant strain rate loading to a maximum stress of either 414 kPa or 690 kPa was followed by an unload (rebound) to 1.4 kPa (the stress applied by self-weight of the loading cap). After rebounding and pore water pressure dissipation, the sample was reloaded at constant strain rate to a maximum stress of 1034 kPa. The displacement, load and pore water pressure data were monitored and recorded at a sampling rate of 1 Hz. After the consolidation test, the sample was removed from the test chamber and a moisture content test was performed. For the last two consolidation tests, a small sample was cut from the larger consolidated samples and placed in a conventional oedometer to undergo secondary compression test under a load of 1034 kPa.

TEST RESULTS AND DISCUSSION

Results are presented from the ten CSR consolidation tests performed on the resedimented Class F fly ash. Figure 4 presents the effective vertical stress (σ_p') - void ratio (e) curves, commonly referred as compression curves. The compressibility of the material due to the primary consolidation can be expressed using the slopes of the compression (C_c, compression index) and recompression lines (C_r, recompression index). Figure 5 compares the compression index and recompression index from all ten tests. The values of C_c vary from 0.039 to 0.064 with an average of 0.052 and a standard deviation of 0.0076. The measured C_r values are in the range of 0.0035 to 0.0072.

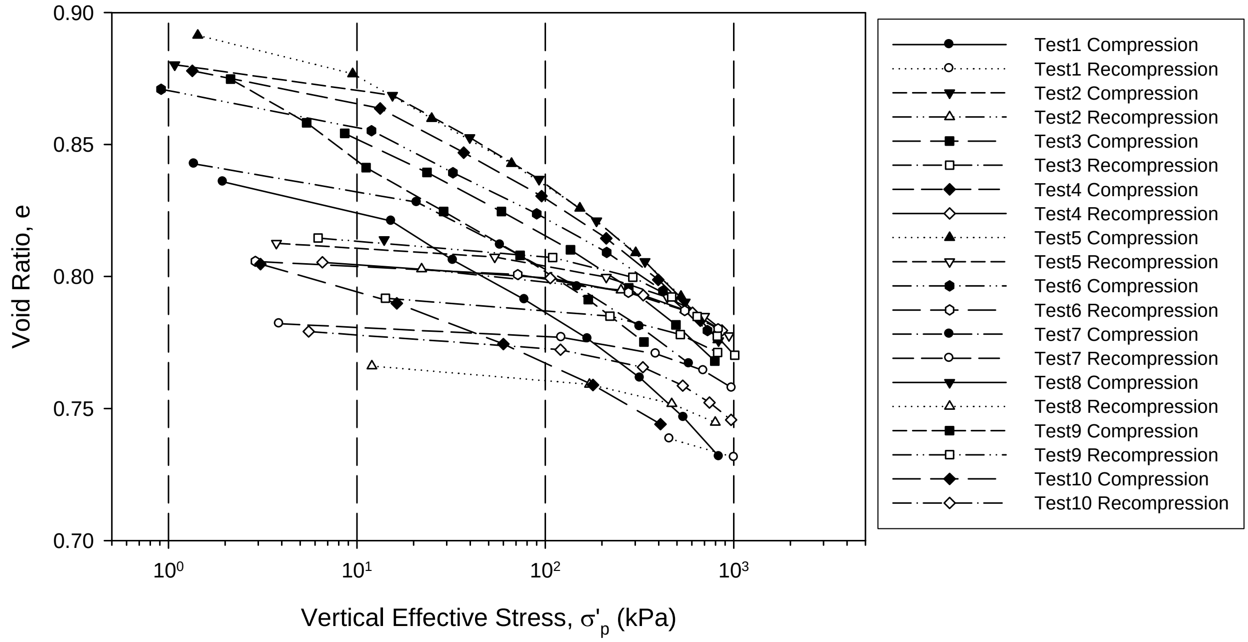

Figure 4 Compression Curves from CSR Tests on Resedimented Class F Fly Ash

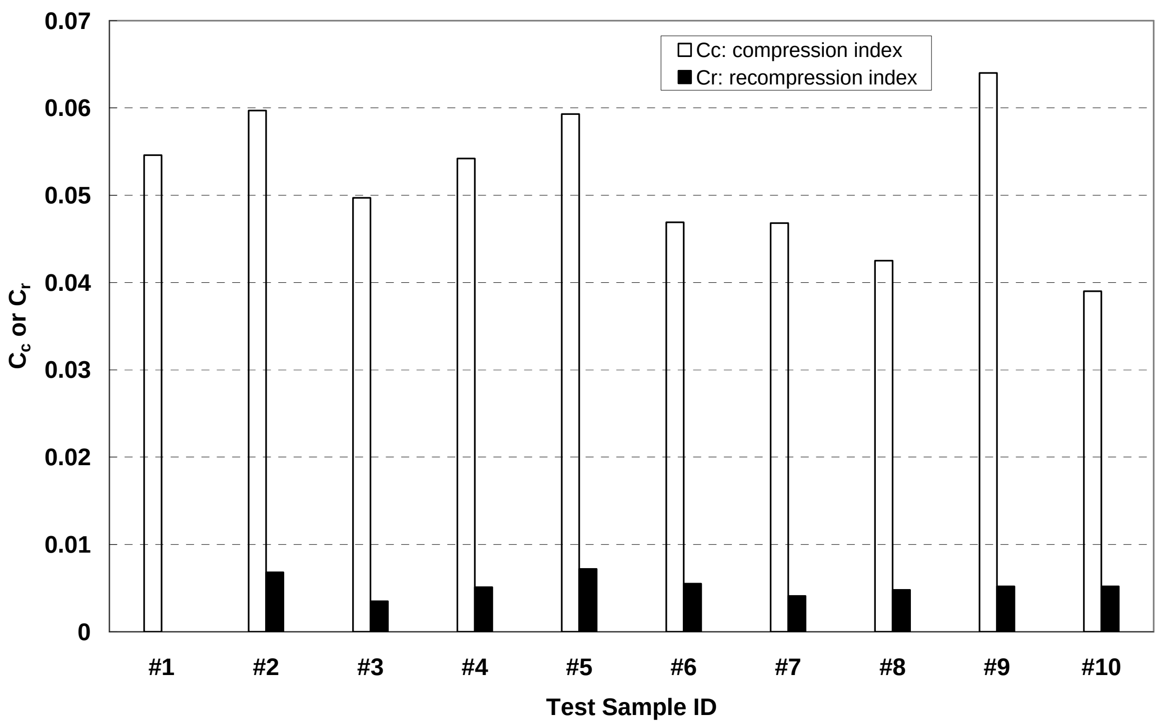

Figure 5 Comparison of Compression Index (C_c) and Recompression Index (C_r)

To obtain a better understanding of the compressibility of Class F fly ash, a database of compressive indices was compiled from published and unpublished sources (total of 16 different samples). Four of these samples were intact samples while the remainder were recompacted in the lab at the optimum moisture content. All the samples except the one from the current study were tested using incremental loading test method with a conventional oedometer. Figure 6 compares the compression curves for the samples in the fly ash consolidation database. The mean value of C_c was 0.089 with a standard deviation of 0.064. The values of C_c are comparable to the typical values of C_c for inorganic sandy silt and poorly graded sand[12].

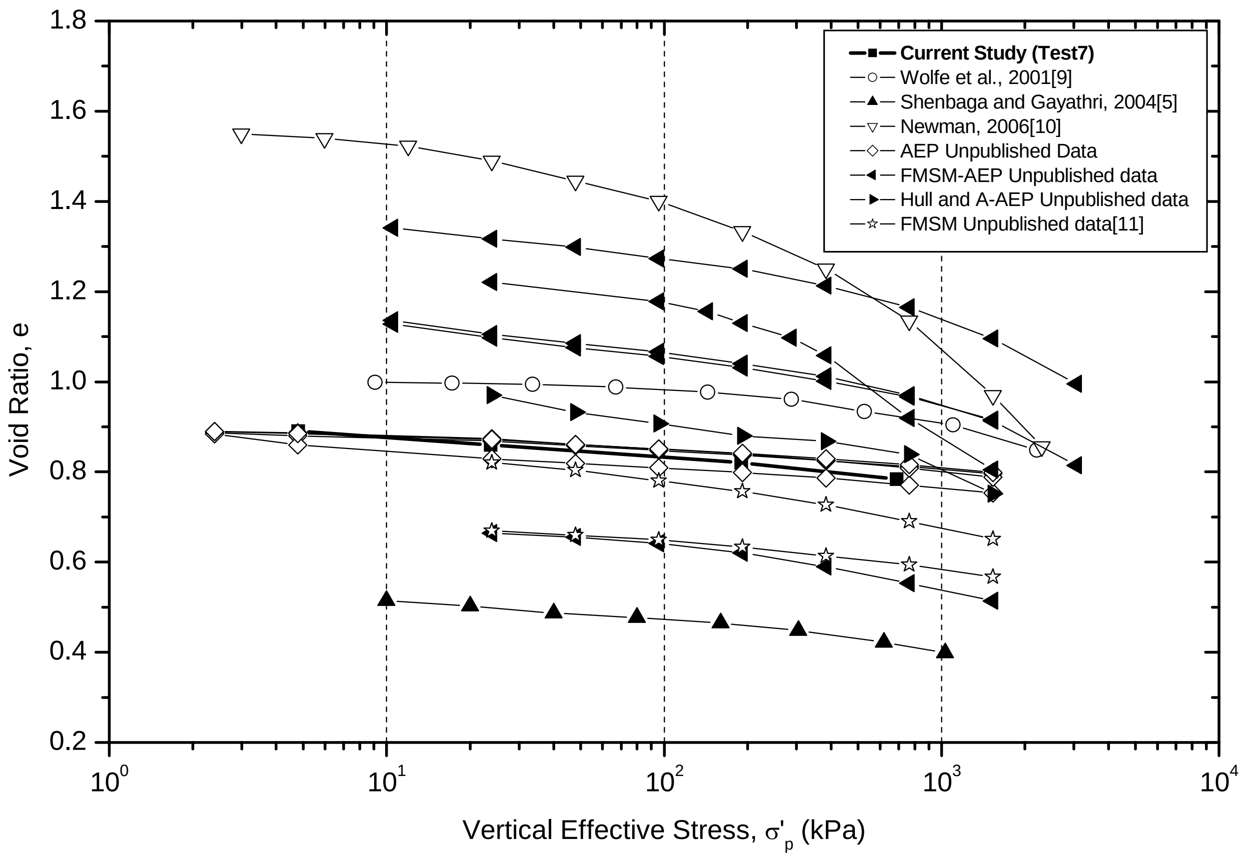

Figure 6 Comparison of Compression Curves from Consolidation Tests on Class F Fly Ash

For conventional oedometer consolidation tests, the consolidation coefficients are typically determined using log-time and square-root-time method. However, these methods can only be used reliably when the primary consolidation take place over a long time. Since consolidation of the fly ash material occurs quickly, it has been recognized that the results obtained from these methods may be questionable[6].

For the CRS consolidation tests, the consolidation coefficients can be calculated based on the nonlinear CRS theory of Wissa et al. (1971)[13], which has been widely used and incorporated in to ASTM D4186. Figures 7 shows the calculated C_V in the range of applied load from CRS tests 3, 7 and 10. The values of C_V vary from 2 cm^2/sec to 70 cm^2/sec. These values are about 20 to 30 times greater than the values reported by Kaniraj and Gayathri (2004). The measured consolidation coefficients from the present study are somewhat higher but consistent with their finding. In their study, the coefficient of consolidation was calculated from measured hydraulic conductivity and the coefficient of volume compressibility.

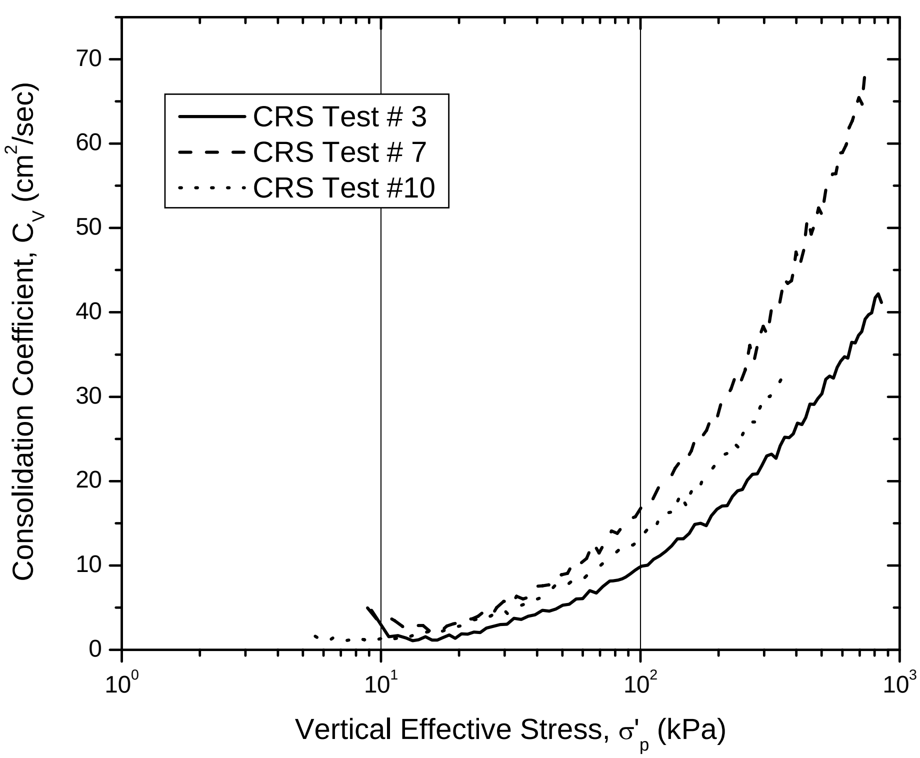

Figure 7 Coefficient of Consolidation C_V vs. Stress Level

Figures 8 shows the calculated hydraulic conductivity, k, in the range of applied load from CRS tests 3, 7 and 10. The values of k vary from 6×10^{-5} cm/sec to 6×10^{-4} cm/sec in the tested stress range, which are comparable to those of very fine sand or inorganic silts[12]. This result is also consistent with the permeability property of compacted fly ash reported by other researchers in the literature[5-7].

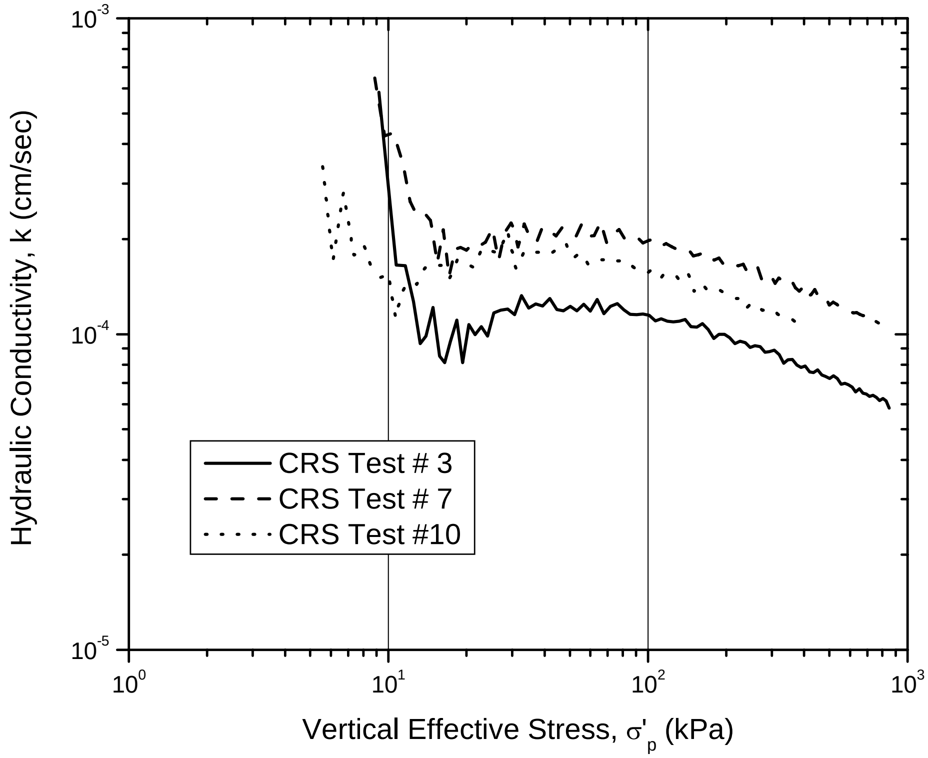

Figure 8 Hydraulic Conductivity vs. Stress Level

Figures 9 shows the results of secondary compression tests on the small-size samples cut from CRS sample 9 and 10 after consolidation tests were completed. The coefficient of secondary compression C_α was found to be between 0.0005 and 0.0002.

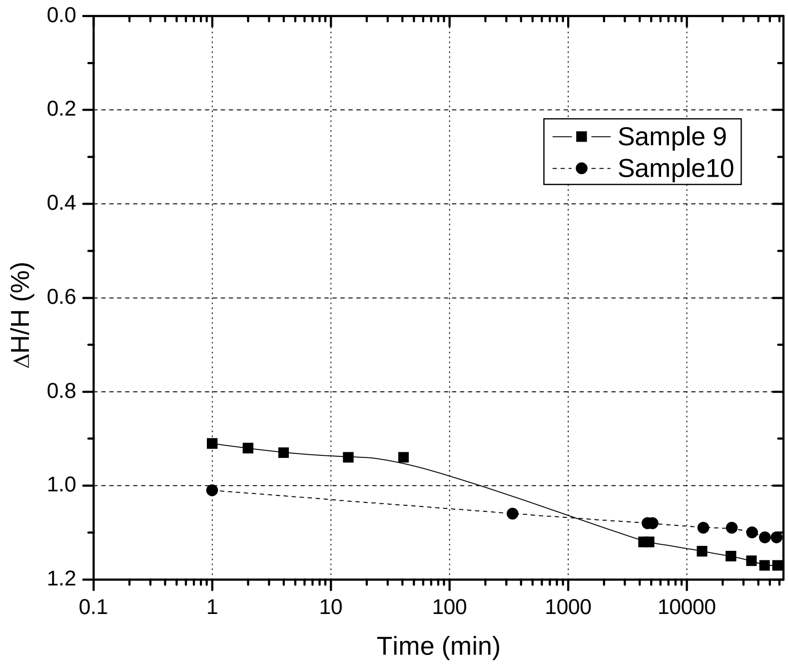

Figure 9 Secondary Compression Curves from Oedometer Tests

SUMMARY AND CONCLUSIONS

The results of an experimental study of the consolidation characteristics of Class F fly ash from the AEP Cardinal power plant in Brilliant, Ohio are presented. Constant rate of strain consolidation tests were performed on medium-scale resedimented Class F fly ash samples that were placed in the test chamber in a way that simulated the wet disposal in the field. Secondary compression tests were also performed to evaluate the long-term settlement of fly ash layer under constant load.

Consistent and reproducible results were obtained from the CRS tests. The values of compression index were found to be small, varying from 0.039 to 0.064 with an average of 0.052 and a standard deviation of 0.0076. Compared with the consolidation tests results on compacted fly ash samples in the literature, the measured C_c values from resedimented fly ash samples in the current study are comparable and somewhat smaller. This indicates that the structures built on the reclaimed fly ash ground would unlikely to suffer excessive settlement.

Large consolidation coefficients were measured from the CRS tests on the resedimented fly ash samples, which indicated that the rate of consolidation of fly ash was very fast. The hydraulic conductivity of fly ash was found to be similar to very fine sands and inorganic silts.

The coefficients of secondary compression C_α from the two oedometer tests were also found to be small (0.0005 and 0.0002). Therefore, settlement due to secondary consolidation would not be of great concern for structures founded on reclaimed fly ash ground.

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