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An experimental investigation on liquefaction potential and post-liquefaction shear strength of impounded fly ash

Behrad Zand [a,*], Wei Tu [b], Pedro J. Amaya [a], William E. Wolfe [c], Tarunjit S. Butalia [c]

[a] American Electric Power Service Corporation, 1 Riverside Plaza, Columbus, OH 43215-2373, USA
[b] Black & Veatch Corporation, 8400 Ward Parkway, Kansas City, MO 64114, USA
[c] Department of Civil and Environmental Engineering and Geodetic Science, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210, USA

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ABSTRACT

Liquefaction resistance and post-liquefaction shear strength of impounded Class F fly ash are investigated using laboratory experiments. The study was aimed to evaluate liquefaction potential of a 45 ha impoundment proposed as a base for a utility monofill. The evaluation included cyclic triaxial tests performed on reconstituted fly ash specimens with various densities at different confining stresses and cyclic stress ratios representative of the impounded material and the seismic environment. The results are presented in the form of design charts. Post-liquefaction strengths were measured by reconsolidating the specimens at the initial effective confining stress and performing consolidated undrained triaxial tests. The measured cyclic strength was compared with the seismically induced stresses in the profile using a one-dimensional wave propagation method. The cyclic loadings imposed on the ash by the design earthquakes were found to be lower than the measured cyclic strength of the material. The post liquefaction shear strengths showed some scatter; however, they were typically higher than the initial shear strengths before exposure of the material to cyclic load.

1. Introduction

American coal ash association survey [1] estimates the total fly ash production in the US to be 65 million tons (71 million US tons) in 2005, of which only 41% was reused and the rest was left to be disposed in storage ponds or landfills. This fact combined with increasing landfill costs highlights the need for innovative methods to exploit full capacity of existing fly ash landfills/impoundments. A 45 ha fly ash impoundment (Fig. 1), owned by American electric power (AEP) was proposed as the base for a utility monofill. The liquefaction potential of fly ash during an earthquake was a concern of the design team. Although a broad literature exists on the cyclic resistance of sands and clayey soils [2–8] little research has been done on fly ash. In order to address this concern an experimental program combined with ground response analyses was conducted to evaluate the liquefaction potential of the impoundment and the post-liquefaction shear strength of the material. The cyclic strength of the material was evaluated using standard cyclic triaxial tests [9], and the initial and post-liquefaction shear strengths were evaluated in undrained shear (CU) tests [10]. The cyclic loadings induced during a design earthquake motion, estimated from one-dimensional ground response analyses, were compared to the measured cyclic strengths. The cyclic strength of the impounded fly ash was found to be higher than the induced loadings.

2. Testing program and specimen preparation

2.1. Material properties

Class F fly ash produced at AEP's Mitchell power plant was collected from the impoundment at a depth of ~3 m. No other types of coal combustion products have been mixed with fly ash in this facility. A gradation curve is presented in Fig. 2, showing that the dominant particle size is in the silt size range. A specific gravity of 2.27 was measured by AEP. The in situ density of the material was determined by AEP to range from 1600 to 1680 kg/m^3. In situ moisture content under the ground water table was measured to be about 30% by collecting and oven drying bag samples. The in situ dry density of the material is estimated to range from 92% to 96% of the standard Proctor optimum dry density [11]. Presented in Table 1 is the chemical composition of fly ash.

* Corresponding author. Tel.: +1 614 716 2873; fax: +1 614 716 2963.
E-mail addresses: bzand@aep.com (B. Zand), tuw@bv.com (W. Tu), pjamaya@aep.com (P.J. Amaya), wolfe.10@osu.edu (W.E. Wolfe), butalia.1@osu.edu (T.S. Butalia).

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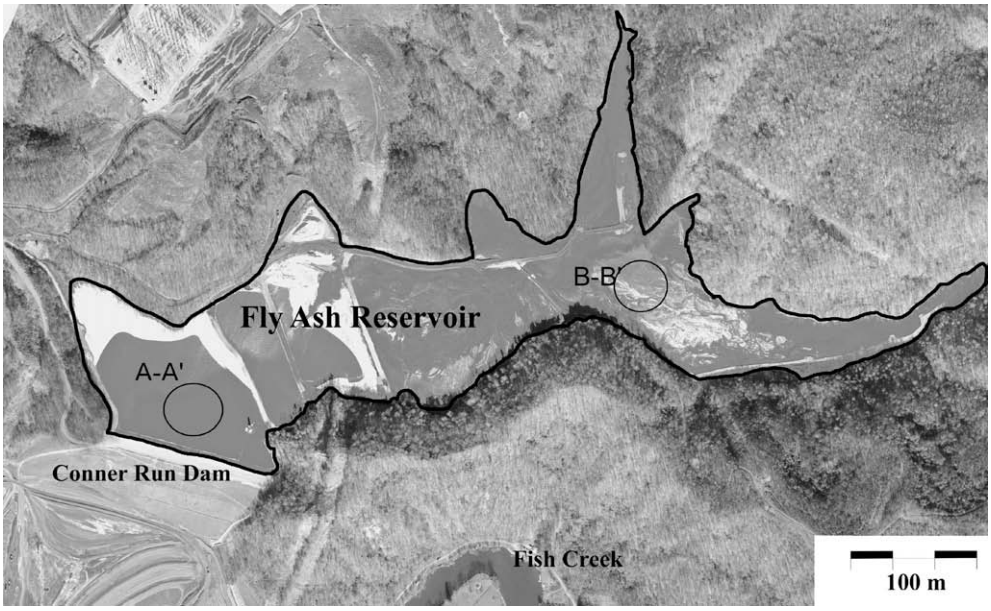

Fig. 1. Mitchell fly ash impoundment in West Virginia.

2.2. Specimen preparation

Fly ash specimens were made in Harvard miniature molds (3.35 cm diameter, 7.11 cm length) using wet tamping to achieve target densities of 86%, 95%, and 104% of the optimum standard Procter dry density (86%, 95%, and 104% relative compactions). Specimens were compacted in five equal lifts using a 110 N (25 lb) hand tamper. Fig. 3 shows a comparison between the standard Proctor and the Harvard miniature calibration curves. Saturation of the specimens was achieved by the application of a small vacuum pressure (<60 kPa) followed by a back pressure of 105–310 kPa. The time needed to saturate the specimens varied from one day to two weeks. All the specimens tested registered B-values larger than 97%.

2.3. Cyclic triaxial test

The cyclic triaxial tests were conducted following the standard ASTM D5311 method for load control cyclic triaxial test [9]. Each saturated specimen was consolidated by applying an effective confining stress σ_c of 68, 135, or 340 kPa, representing typical depths of 3.5, 7, or 20 m, respectively. Specimens were allowed to drain until full dissipation of excess pore water pressure was achieved. Then, each specimen was subjected to a uniform cyclic stress of amplitude σ_d *(zero–peak)* in the axial direction. The ratio of σ_d/σ_c, called shear–stress ratio herein, resembles the amplitude of a shear wave that is normalized by an overburden pressure equivalent to σ_c. Cyclic shear–stress ratios ranged from 7.5% to 40% of the effective confining stress.

Due to the high permeability of the material (on the order of 10^{-4} cm/s) the consolidation occurred rapidly. The cyclic test was conducted under undrained condition and constant cell pressure. The loading frequency was selected to be 0.5 Hz except for one case where a frequency of 1 Hz was used. A 450 N load cell was utilized in load control mode while axial deformations were measured by a

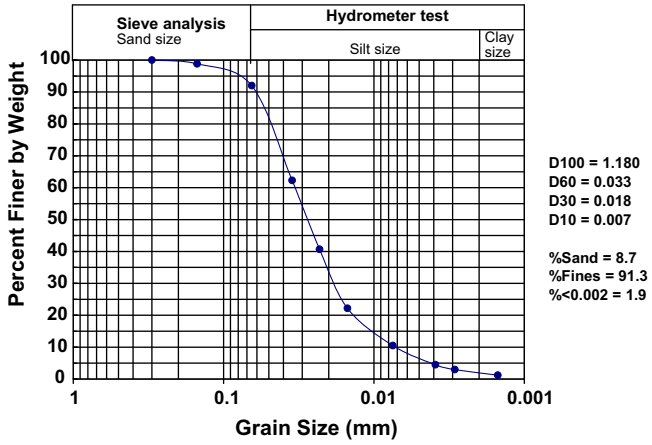

Fig. 2. Grain size distribution of fly ash.

Table 1
Fly ash chemical composition.

Constituent	Results%
Silica, SiO_2	54.9
Aluminum oxide, Al_2O_3	17.3
Iron oxide, Fe_2O_3	5.6
Copper oxide, CuO	<0.1
Nickel oxide, NiO	<0.1
Zinc oxide, ZnO	<0.1
Manganese oxide, MnO_2	<0.1
Chromium oxide, Cr_2O_3	<0.1
Molybdenum oxide, MoO_3	<0.1
Lead oxide, PbO	<0.1
Tin oxide, SnO_2	<0.1
Barium oxide, BaO	<0.1
Strontium oxide, SrO	<0.1
Calcium oxide, CaO	3.1
Magnesium oxide, MgO	2.0
Sodium oxide, MgO	0.2
Potassium oxide, K_2O	2.4
Phosphorus pentoxide, P_2O_5	0.1
Sulfur trioxide, SO_3	0.3
Titanium oxide, TiO_2	0.9
Vanadium oxide, V_2O_5	<0.1
Tungsten oxide, WO_3	<0.1
Total carbon, C	0.8
Moisture, H_2O@105 °C	5.7
Net ignition loss ()/gain(−)	5.6