Cyclic and Monotonic Response of Class F Ponded Fly Ash

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Outline

• Objective
• Motivation
• Material Properties
• Specimen Preparation
• Monotonic Load Response
• Cyclic Load Response
• Summary
Objective: Determine Cyclic and Monotonic Response of Class F Ponded Fly Ash For Liquefaction Potential Assessment

1. Investigate Response Under Monotonic Loading For Static Liquefaction Potential of Pluviated Ash Specimen.

2. Investigate Response Under Cyclic Loading For Dynamic Liquefaction Potential and Develop A Response Curve.
Motivation

1. Unlike Naturally Occurring Material, We Don’t Have Significant Case History Data Available For Fly Ash Material

2. Fly Ash Particles Are Is Silt Size But Behaves More Like Fine Sand
   - Has Relatively High Permeability
   - Particles Are More Compressible
   - Particles Have Internal Voids
**Static Liquefaction**

- Occurs in strain softening materials under undrained conditions
- Material **fails** if static shear demand is larger than capacity
- Occurs in loose cohesionless material

**Dynamic (Cyclic) Liquefaction**

- Occurs due to shear stress **reversals**
- Requires sufficient undrained cyclic loadings causing loss of effective confining stress
- Results in **large deformations**
Basic Properties:
- Specific Gravity : 2.15
- Fines : 53%
- Coarse : 47%
- Minimum density* : 45.2 pcf
- Maximum density* : 61.2 pcf
- pH : 7.08
- CaO : 1995 mg/kg

*Realizable dry density following EPRI (2012) suggested method

Uniformity (CU) : 7.17
Curvature (CC) : 0.59

Source: Bachus (2019)
Specimen Preparation

Reconstruction Objectives:

- Use Water Pluviation to Simulate In-Situ Deposition
- Target Relative Density* 60-65%
- Target Dry Density 54.8-55.6 pcf
- Saturated

* Relative Density, $D_r$ (%) = \( \frac{\gamma_{d_{\text{specimen}}} - \gamma_{d_{\text{min}}}}{\gamma_{d_{\text{max}}} - \gamma_{d_{\text{min}}}} \times 100 \)

Reference: Bachus (2019)
Split mold is lined with membrane and filled with water

Premeasured amount of fly ash placed in flask

Pluviation from flask to split mold

Vibration applied to flask to prevent clogging

End of pluviation
Triaxial Specimen Preparation By Pluviation

Specimen after removal of flask
Vacuum application to specimen
Specimen after removing split-mold
Specimen in triaxial chamber for consolidation
Testing at the end of consolidation
Specimen Uniformity

- Specimen formed in “rings”
- Divided in cylindrical 1” segments along length
- Measured density, moisture contents and gradation

Particle Size Distribution

- Segment 5 - Top
- Segment 4
- Segment 3
- Segment 2
- Segment 1
- Segment 0 - Bottom
- Source

Specimen Preparation
Video: Wet Pluviation

https://youtu.be/VHNxFIvXyul
## Test Schedule

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>Relative Density, $D_r$ (%)</th>
<th>Dry Density (pcf)</th>
<th>Moisture Content (%)</th>
<th>B-value</th>
<th>Type</th>
<th>Test Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2-P8</td>
<td>60%</td>
<td>54.7</td>
<td>80%</td>
<td>0.96</td>
<td>Cyclic Triaxial</td>
<td>CSR 0.10</td>
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<tr>
<td>S3-P9</td>
<td>55%</td>
<td>54</td>
<td>79%</td>
<td>0.99</td>
<td>Cyclic Triaxial</td>
<td>CSR 0.15</td>
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<td>S1-P10</td>
<td>61%</td>
<td>55</td>
<td>79%</td>
<td>0.98</td>
<td>Cyclic Triaxial</td>
<td>CSR 0.25</td>
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<td>S2-P11</td>
<td>61%</td>
<td>55</td>
<td>85%</td>
<td>0.96</td>
<td>Cyclic Triaxial</td>
<td>CSR 0.30</td>
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<tr>
<td>S3-P12</td>
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<td>54.5</td>
<td>81%</td>
<td>0.96</td>
<td>Cyclic Triaxial</td>
<td>CSR 0.35</td>
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<tr>
<td>S2-P14</td>
<td>60%</td>
<td>54.8</td>
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<td>S1-P15</td>
<td>57%</td>
<td>54.4</td>
<td>83%</td>
<td>0.99</td>
<td>Cyclic Triaxial</td>
<td>CSR 0.35</td>
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<tr>
<td>S3-P17</td>
<td>64%</td>
<td>55.4</td>
<td>81%</td>
<td>0.99</td>
<td>Cyclic Triaxial</td>
<td>CSR 0.20</td>
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<tr>
<td>S3-P20</td>
<td>59%</td>
<td>54.7</td>
<td>76%</td>
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<td>Cyclic Triaxial</td>
<td>CSR 0.15</td>
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<td>S2-P21</td>
<td>60%</td>
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<td>73%</td>
<td>0.98</td>
<td>Cyclic Triaxial</td>
<td>CSR 0.35</td>
</tr>
<tr>
<td>S2-P25</td>
<td>57%</td>
<td>54.3</td>
<td>77%</td>
<td>0.95</td>
<td>Undrained Triaxial</td>
<td>$\sigma'_c = 9$ psi</td>
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<tr>
<td>S3-P27</td>
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<td>53.9</td>
<td>83%</td>
<td>0.98</td>
<td>Undrained Triaxial</td>
<td>$\sigma'_c = 18$ psi</td>
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<tr>
<td>S1-P28</td>
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<td>54.5</td>
<td>69%</td>
<td>0.95</td>
<td>Undrained Triaxial</td>
<td>$\sigma'_c = 19$ psi</td>
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<td>S2-P29</td>
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<td>54.6</td>
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<td>Undrained Triaxial</td>
<td>$\sigma'_c = 39$ psi</td>
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<tr>
<td>S3-P30</td>
<td>58%</td>
<td>54.5</td>
<td>67%</td>
<td>0.96</td>
<td>Undrained Triaxial</td>
<td>$\sigma'_c = 48$ psi</td>
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### Specification

<table>
<thead>
<tr>
<th>Type</th>
<th>Number of Test/Specimens</th>
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<tbody>
<tr>
<td>Cyclic Triaxial Test (ASTM D5311-13)</td>
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<tr>
<td>Consolidated Undrained Triaxial Test (ASTM D4767-11)</td>
<td>5</td>
</tr>
</tbody>
</table>

### Specimen Preparation
Consolidated Undrained Triaxial Test Protocol (ASTM D4767)

1. Prepare pluviated specimen
2. Saturate specimen to B > 0.95 by backpressure
3. Consolidate specimen to preset effective stress
4. Shear specimen at a constant rate
   - $\varepsilon_{a,\text{max}} < 15 \%$
   - $\frac{\delta \varepsilon_a}{\delta t} 0.5\%/\text{min}$
5. Measurements (40 Hz recording speed)
   - Axial displacement ($\Delta L$)
   - Deviator stress ($\sigma_d$)
   - Pore pressure ($u$)
   - Cell pressure ($\sigma_c$)
6. Retrieve entire specimen
   - Density
   - Void ratio
   - Moisture content
Triaxial Test Setup

- Load Cell
- Cell Pressure
- Pore Pressure
MC = Max excess pore pressure
PT = Lowest p' (phase transformation)
MO = max q/p' (Envelope)
ET = End of test

Consolidated Undrained Triaxial Test
 Consolidated Undrained Triaxial Test

MC = Max excess pore pressure
PT = Lowest p' (phase transformation)
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ET = End of test
MC = Max excess pore pressure
PT = Lowest p' (phase transformation)
MO = max q/p' (Envelope)
ET = End of test

Consolidated Undrained Triaxial Test
Cyclic Triaxial Test Protocol (ASTM D5311)
1. Prepare pluviated specimen
2. Saturate specimen to B > 0.95 by backpressure
3. Consolidate specimen to 20 psi
4. Apply uniform load waveform until:
   - Double amplitude axial strain, $\epsilon_{da} < 20 \%$,
   - Single amplitude axial strain, $\epsilon_{sa} < 20 \%$,
   - Number of load cycles, $N_{cycles} \leq 500$, or
   - Deteriorated load waveform
5. Assessment:
   - Initial Liquefaction $\Delta u = \sigma'_c$
   - No liquefaction $N_{cycles} > 500$
6. Measurements (40 Hz recording speed)
   - Axial displacement ($\Delta L$)
   - Deviator stress ($\sigma_d$)
   - Pore pressure ($u$)
   - Cell pressure ($\sigma_c$)
7. Retrieve entire specimen:
   - Density
   - Void ratio
   - Moisture content
Cyclic Triaxial Test
Cyclic Triaxial Test
Cyclic Triaxial Test

Stiffness

Initial Stiffness

Reduced Stiffness
Cyclic Triaxial Test
LIQUEFACTION TEST OF PONDED FLY ASH AT OHIO STATE

Cyclic Stress Ratio (CSR) vs. Cycles to Liquefaction ($N_{\text{liq}}$)

- No Liquefaction
- Cyclic Triaxial Test
Liquefaction Test of Ponded Fly Ash done at Ohio State

Cyclic Stress Ratio (CSR) vs. Cycles to Liquefaction ($N_{\text{liq}}$)

- Toyoura sand
- $D_r = 50 \%$, $\sigma_m = 100 \text{ kPa}$
- $D_r = 50 \%$, $\sigma_m = 300 \text{ kPa}$
- $D_r = 20 \%$, $\sigma_m = 100 \text{ kPa}$
- $D_r = 20 \%$, $\sigma_m = 300 \text{ kPa}$

Ref: Mandokhail et al., (2017)
Cyclic Triaxial Test

Compressive strain range for peak $R_u$
Summary

• Water-pluviation Technique Produces Uniform Ash Specimen.
• The Phase Transformation, Maximum Stress Obliquity, And Maximum Pore Pressure Ratio All Occur At Distinct Stress Ratios For Monotonic Loading
• Phase Transformation and Maximum Pore Pressure Are Not Coincident
• Near The Onset Of Cyclic Liquefaction, Peak Pore Water Pressure Is Associated With Deviatomic Acceleration.
• A Power Function Usable For Modeling Relation Between Cyclic Stress Ratio And Number Of Cyclic To Liquefaction.
• Maximum Pore Pressure In Monotonic and Cyclic Loadings Occurs At Similar Strains
Thank You!