In-Situ Solidification and Stabilization of Coal Combustion Residuals: Bench-Scale Study Results

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Soil and Groundwater Problems Solved

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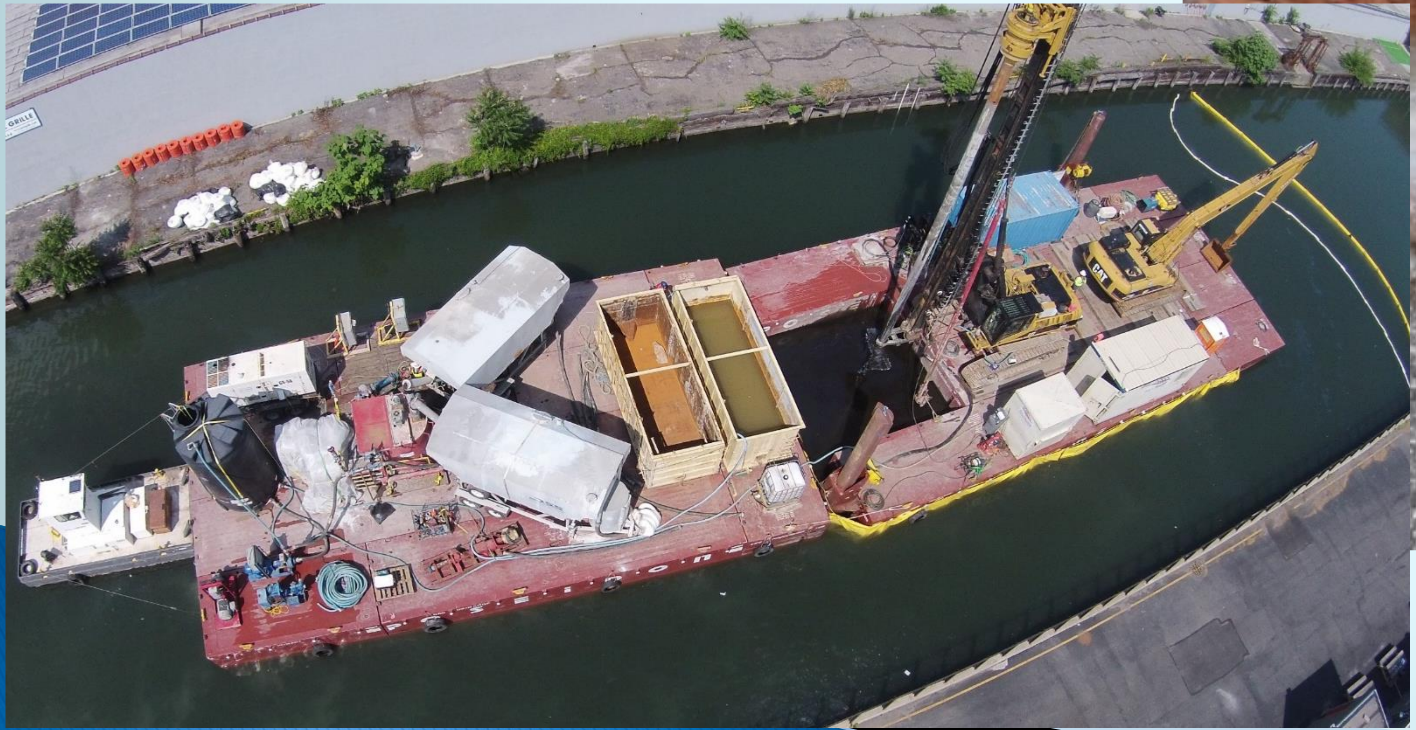
Presentation Overview

- ISS/Soil Mixing History
- Bench Scale Study
- ISS as a Closure Tool
- Closing Remarks
- Discussion



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In-Situ Solidification and Stabilization

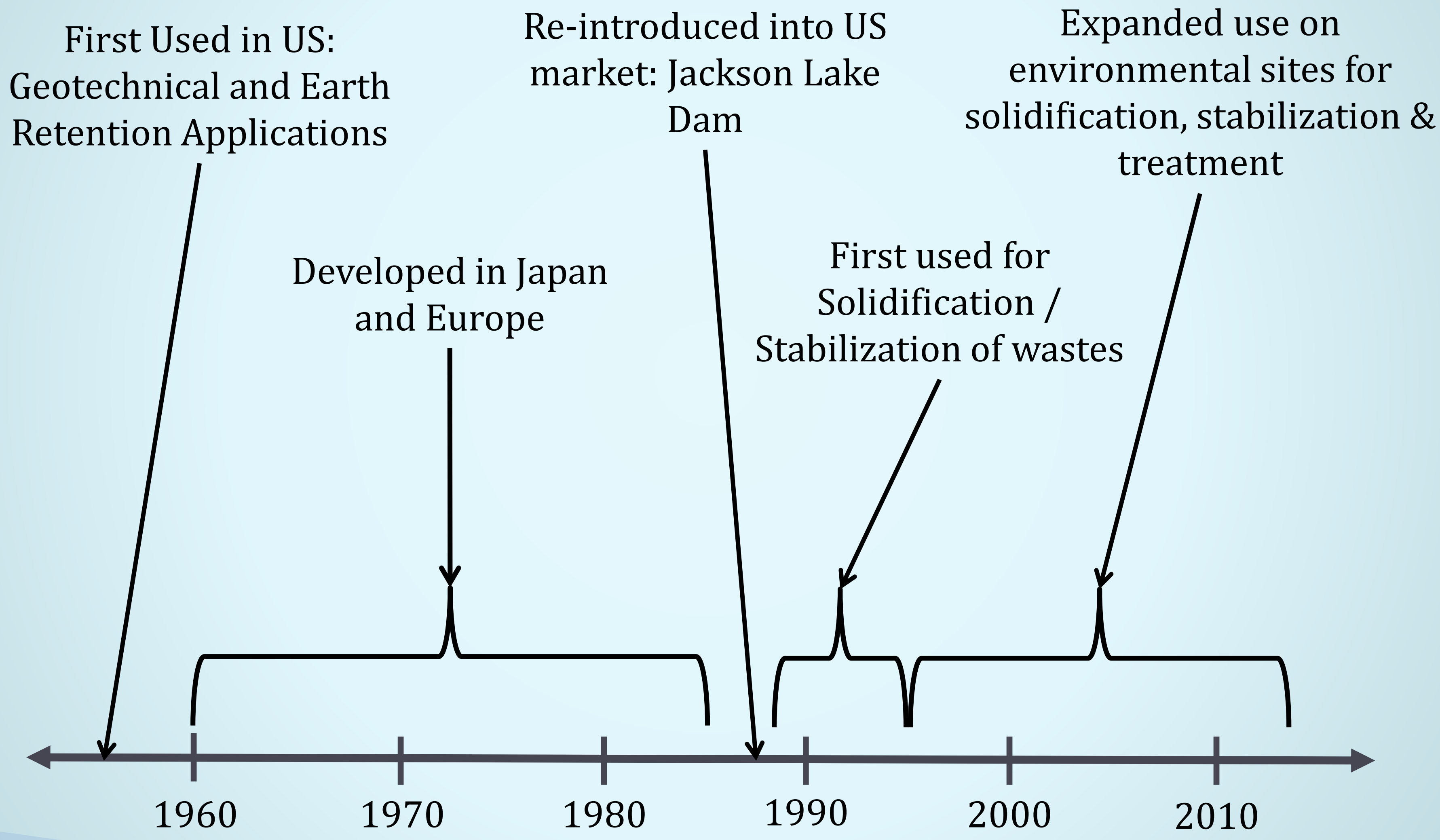
Geotechnical improvement

Contaminant containment

In situ treatment

Contaminant S/S

History



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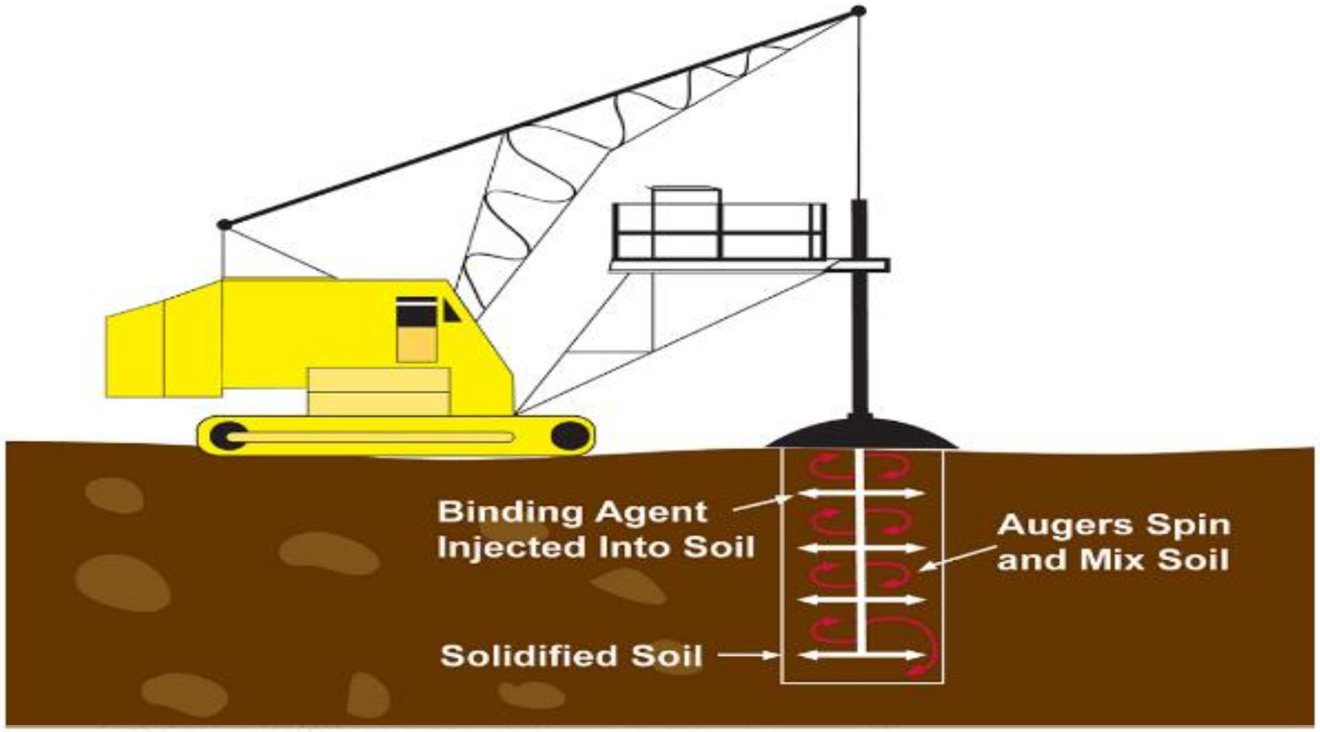
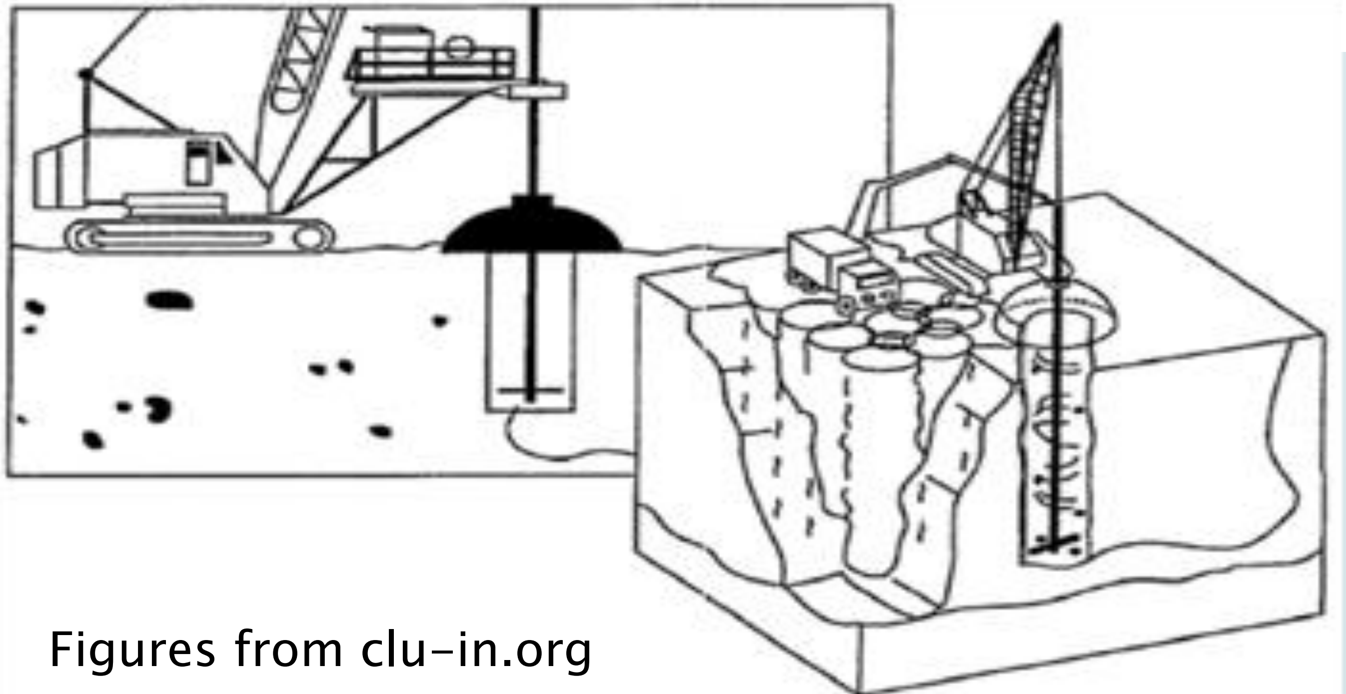
Theory

- Commonly used to reference processes by which reagents are injected and mixed with the soil

- Processes vary:
  - *In situ* vs. *ex situ*
  - Dry vs. wet
  - Single auger vs. multi auger
  - Auger vs. bucket vs. rotary tool

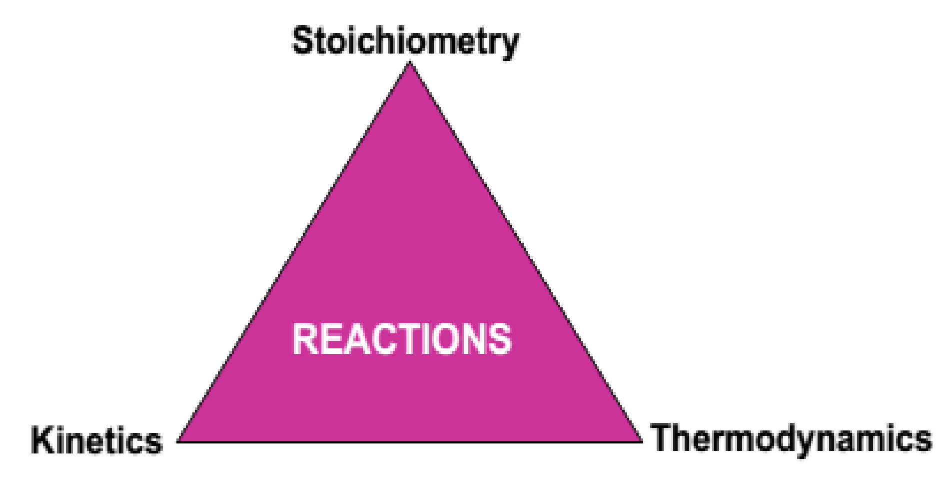


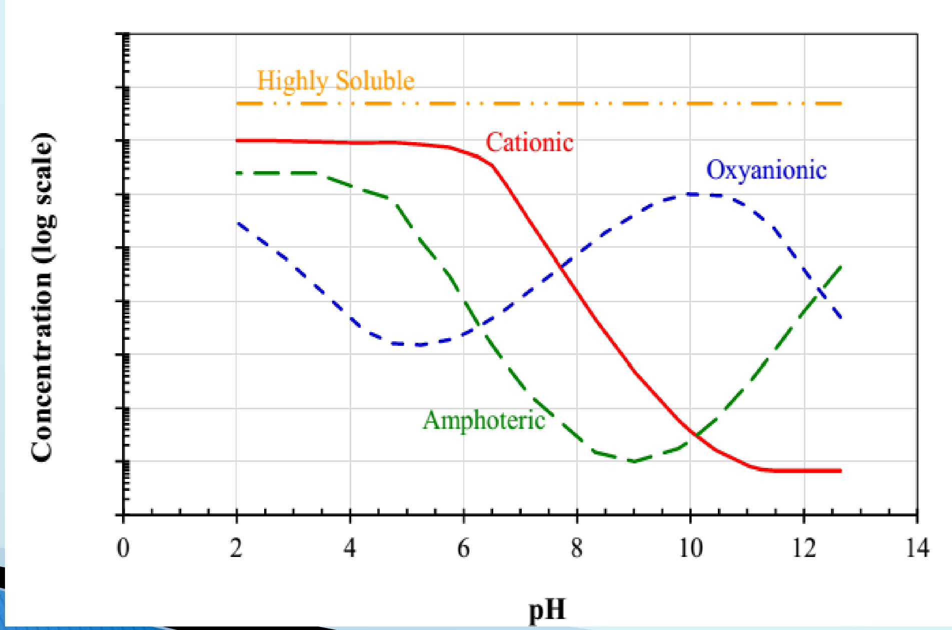


Figures from clu-in.org

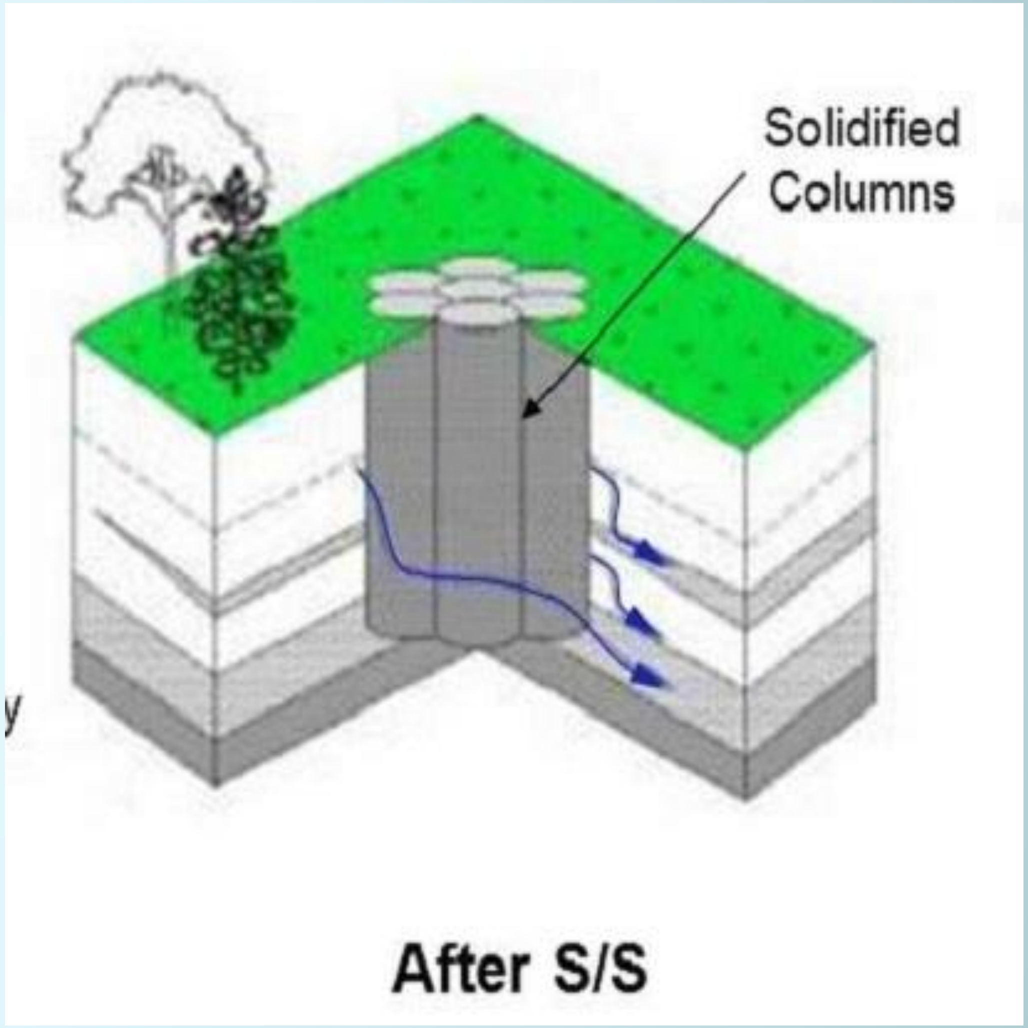
Theory

- Stabilization: fixation, oxidation, reduction





- Solidification: encapsulation, fixation



Figures from Interstate Technology & Research Council, July 2011

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Bench Scale Study Overview

- Sample Collection and Composition
- Geotechnical Index Property Testing
- Mix Design Development and Grout Testing
- Test Results
- Observations & Conclusions

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Sample Collection and Composition

- Samples were from a former coal fired power station in the eastern US
- Power station burned bituminous coal and collected fly ash using electrostatic precipitators
- Fly Ash was wet sluiced to ponds
- Samples collected via a hydraulic excavator in 3 ponds
- Samples containerized in sealed 5-gallon buckets
- Nine samples collected from each pond and composited
  - B, C and D Ponds. D consisted of both a “dry” and “wet” composite

Geotechnical Index Property Testing

- Index testing performed to develop a baseline physical properties
  - Sieve analysis (with hydrometer)
  - Moisture content
  - Atterberg limits
  - Loss on ignition
  - Classification
  - Material pH
  - Material density – Single Point Proctor at the as-received moisture content

Geotechnical Index Property Testing

Sample ID	Natural Moisture Content (%)	Organic Content (%)	pH	Grain-Size Distribution				One-Point Unit Weight (pcf)
				% Gravel	% Sand	% Fines	% Clay (< 0.002 mm)	
Pond B	12	5.7	5.2	1.6	33.8	64.6	5.9	102.2
Pond C	18	4.6	7.2	0.0	43.6	56.4	1.7	86.6
Pond D - dry	2	4.0	6.4	0.0	6.3	93.7	8.1	106.3
Pond D - wet	41	–	–	–	–	–	–	–

Sample ID	USCS Group Symbol	Classification		Atterberg Limits
		USCS[6]	USDA[11]	
Pond B	ML	Black, sandy silt, trace gravel	Silt Loam	Non-Plastic
Pond C	ML	Black, sandy silt	Sandy Loam	Non-Plastic
Pond D	ML	Black, silt, little sand	Silt Loam	Non-Plastic

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Mix Design Development and Grout Testing

- Mix Designs
  - Reagent – Portland Cement only – Lafarge Type I/II
  - Dosages – 3, 5, 7 and 9% by weight of CCR
  - Water: Cement Ratios
    - 0.8 min
    - Adjust water to allow mix to be "workable"
    - Highest observed 12.5:1

- Grout Testing
  - Viscosity – generally 28 seconds
  - pH – 13.5
  - Density – 66-86 pcf
  - Temperature – 66-71 deg F
- Samples Storage
  - Stored in humid environment
  - Temperature 60-60 deg F
- Testing
  - Unconfined Compressive Strength
  - Hydraulic Conductivity

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Sieve
Materials

Segregate large material

Weigh
material

Proportion reagents

Mix grout

Add grout

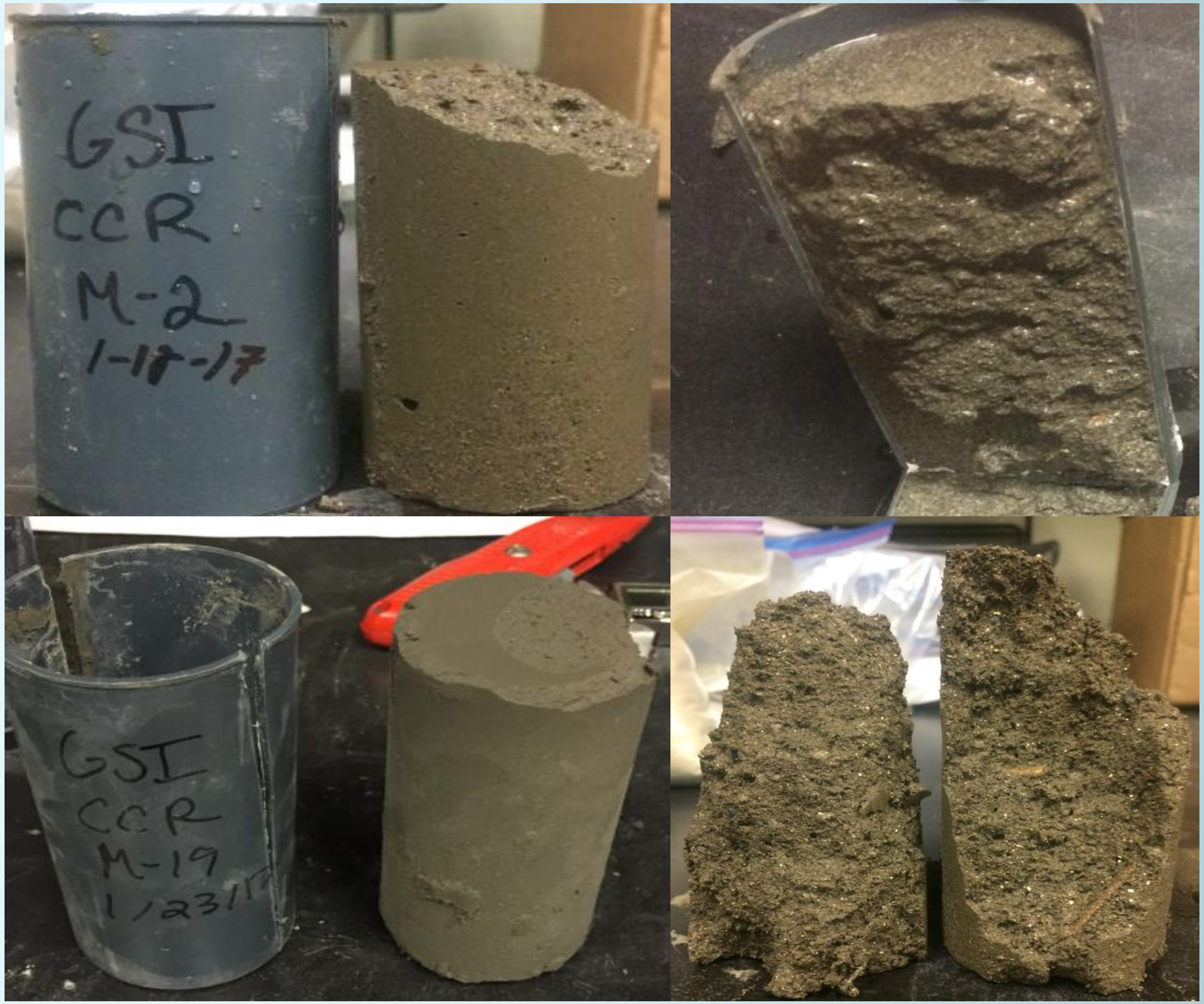
Mix CCR &
grout

Add grout to achieve workable
material

Cast cylinders

Mix Design Development and Grout Testing

- Sample Specimens & Storage
  - 2-inch by 4-inch
  - 3-inch by 6-inch
  - Stored in humid environment
  - Temperature 60-60 deg F
- Testing
  - Unconfined Compressive Strength
    - 7, 14 and 28 days of cure
  - Hydraulic Conductivity
    - After 28 Days only



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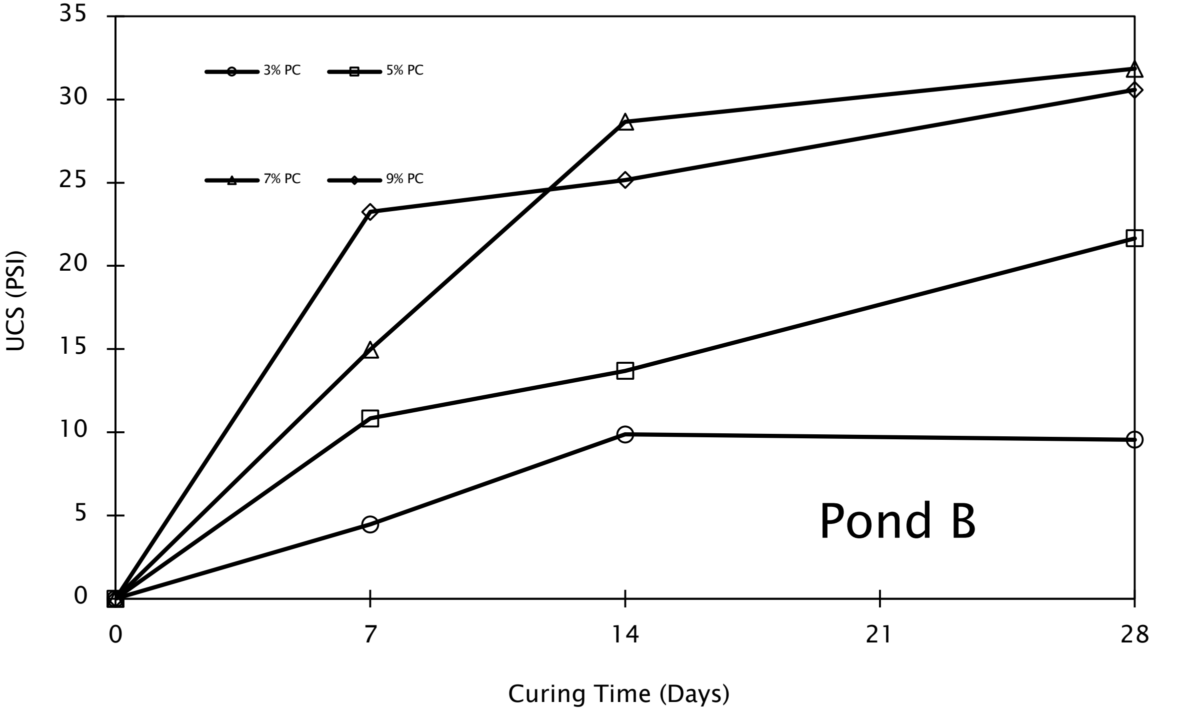
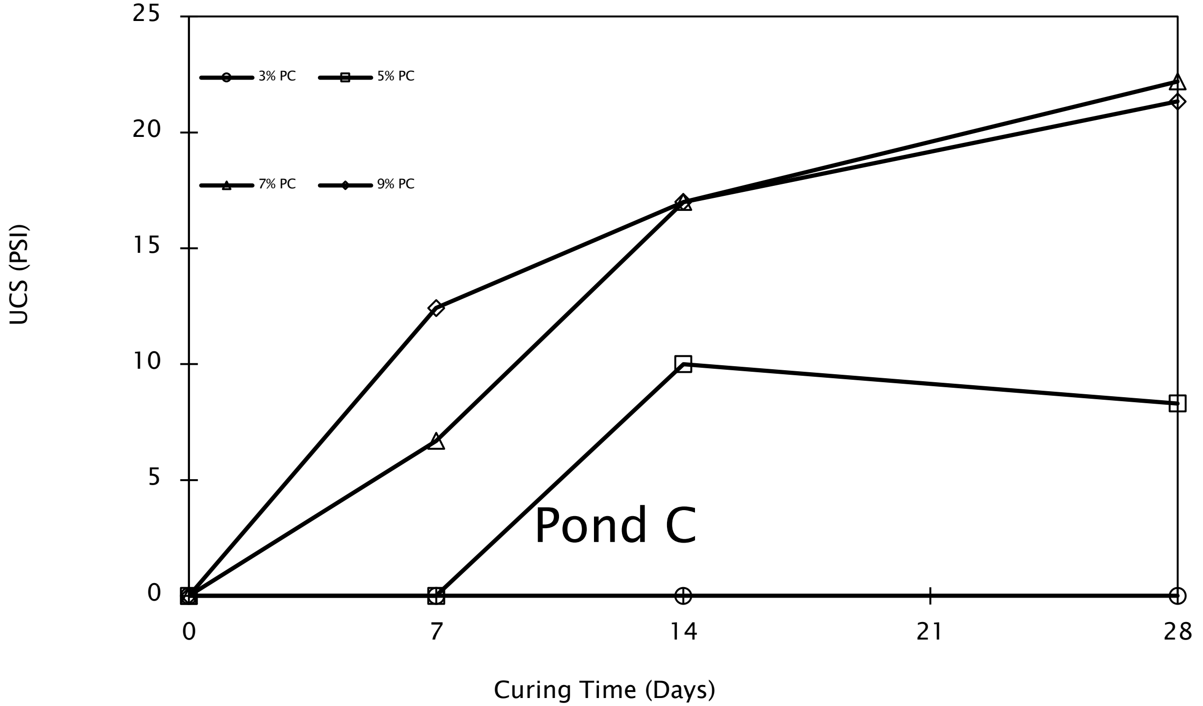
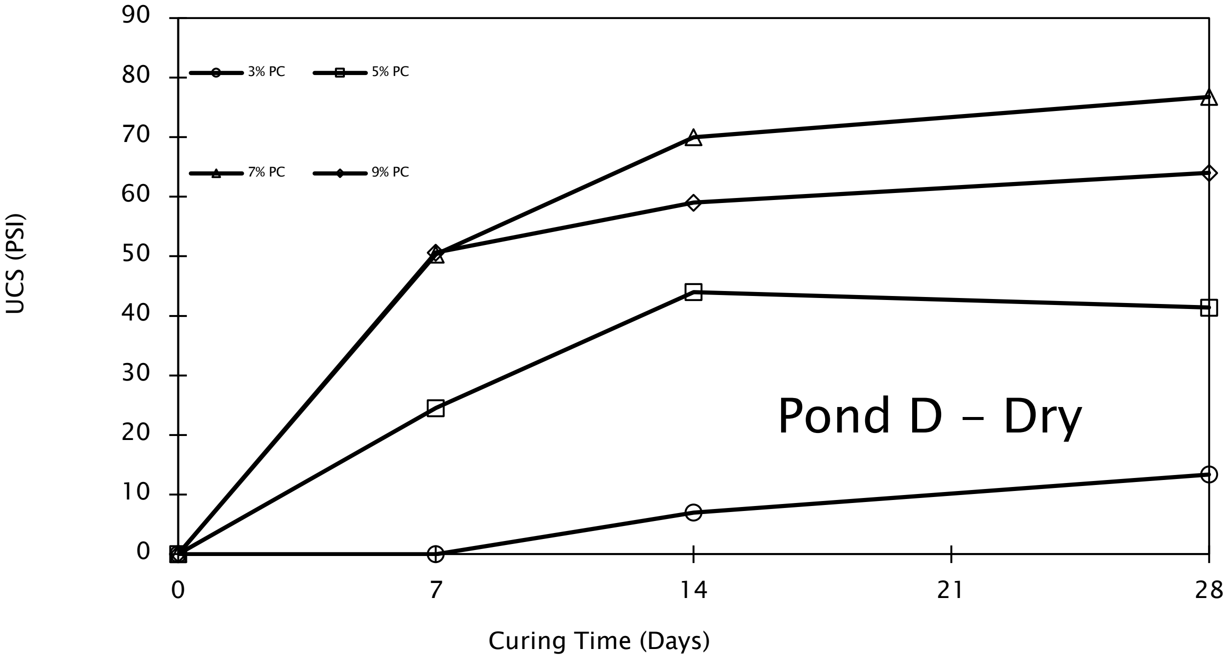
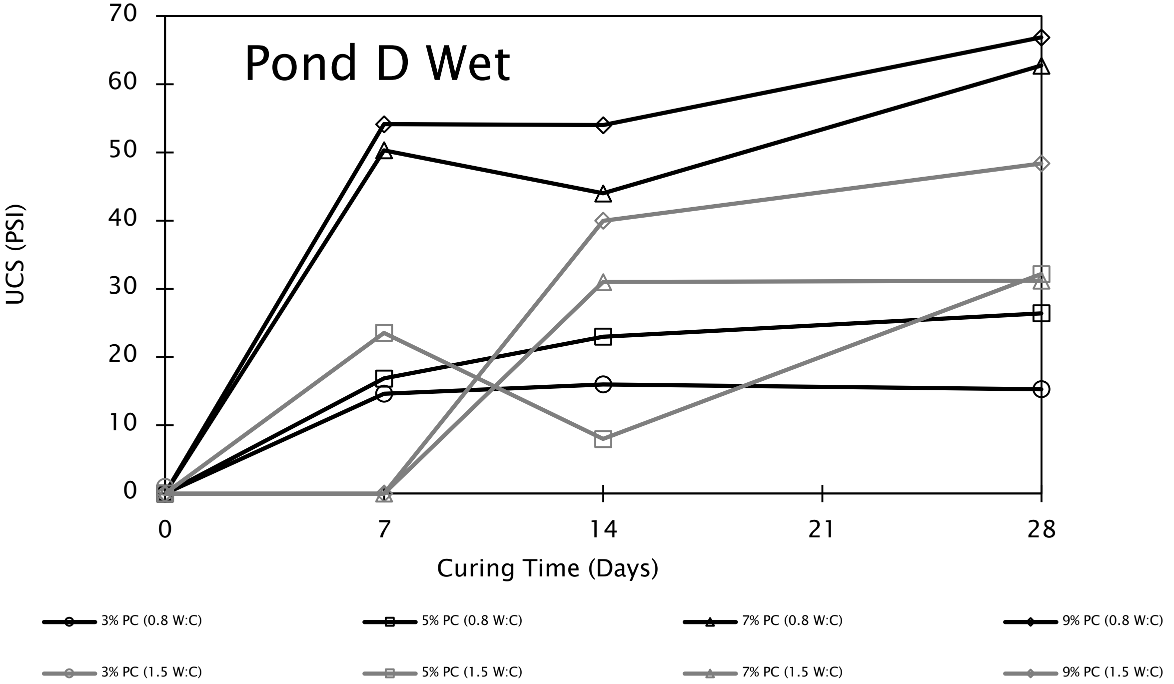
Sample ID	Mix Date	Material	Mix Density (pcf)	PC (%)	W:C	W:S	W:CM	Fly Ash (%)	7 day UCS[15] (psi)	14 day UCS[15] (psi)	28 day UCS[15] (psi)	28 Day Permeability[14] (cm/s)
Mix 1	1/18/2017	Pond B	104.5	3%	11.0	0.47	0.71	64.6	4.5	9.9	9.6	--
Mix 2			101.5	5%	7.0	0.49	0.73		11	14	22	4.3×10^{-5}
Mix 3			102.4	7%	5.0	0.48	0.71		15	29	31.8	3.0×10^{-5}
Mix 4			99.3	9%	4.0	0.48	0.79		23	25	31	--
Mix 5	1/19/2017	Pond C	90.0	3%	12.0	0.58	1.01	56.4	*	*	*	--
Mix 6			90.6	5%	7.5	0.59	1.00		*	10	8.3	--
Mix 7			90.9	7%	5.5	0.59	0.98		6.7	17	22	9.4×10^{-5}
Mix 8			91.8	9%	4.5	0.59	0.98		12	17	21	9.4×10^{-5}
Mix 9	1/20/2017	Pond D (wet)	104.8	3%	0.8	0.43	0.45	93.7	15	16	15	--
Mix 10			104.2	5%	0.8	0.44	0.46		17	23	26	--
Mix 11			103.6	7%	0.8	0.44	0.47		50.3	44	62.7	2.0×10^{-6}
Mix 12			104.5	9%	0.8	0.45	0.48		54.1	54	66.9	--
Mix 13	1/20/2017	Pond D (dry)	99.0	3%	12.5	0.39	0.42	93.7	*	7	13	--
Mix 14			100.0	5%	7.5	0.38	0.41		25	44	41.4	--
Mix 15			99.3	7%	5.5	0.39	0.41		50.3	70	76.8	--
Mix 16			100.6	9%	4.5	0.40	0.42		50.6	59	64.0	--
Mix 17	1/23/2017	Pond D (wet)	103.3	3%	1.5	0.45	0.48	93.7	*	6	11	--
Mix 18			101.5	5%	1.5	0.48	0.51		24	8	32.2	--
Mix 19			102.7	7%	1.5	0.49	0.52		*	31	31	5.2×10^{-6}
Mix 20			101.5	9%	1.5	0.53	0.56		*	40	48.4	--

Notes:
*Samples were too soft or damaged during extraction and were unable to be tested.
%: percent; cm/s: centimeters per second; ID: identification; PC: Portland cement; pcf: pounds per cubic foot; psi: pounds per square inch; W:C = water to Cement Ratio; W:S: water to solids ratio; W:CM; water to cementitious materials
UCS: unconfined compressive strength


Pond B
UCS (PSI)
Curing Time (Days)
3% PC
5% PC
7% PC
9% PC
0
5
10
15
20
25
30
35
0
7
14
21
28


Pond C
UCS (PSI)
Curing Time (Days)
3% PC
5% PC
7% PC
9% PC
0
5
10
15
20
25
0
7
14
21
28


Pond D - Dry
UCS (PSI)
Curing Time (Days)
3% PC
5% PC
7% PC
9% PC
0
10
20
30
40
50
60
70
80
90
0
7
14
21
28


Pond D Wet
UCS (PSI)
Curing Time (Days)
0
10
20
30
40
50
60
70
0
7
14
21
28
3% PC (0.8 W:C)
5% PC (0.8 W:C)
7% PC (0.8 W:C)
9% PC (0.8 W:C)
3% PC (1.5 W:C)
5% PC (1.5 W:C)
7% PC (1.5 W:C)
9% PC (1.5 W:C)

Observations & Conclusions

- Some evidence of spalling at 7-day cure duration on “dryer” initial fly ash
- Difficulties with extracting molds
- Little to no bleed or swell observed
- A significant percentage of strength gain occurred prior to 7 days and 14 days of cure time, respectively.
- 13 of the 20 mixes gained 50% or more of their 28-day strength by 7 days of cure time and 5 of those samples obtained 75% of their 28-day strength.
- 14 of the 20 samples surpassed 75% of their 28-day strength at 14 days and three samples were stronger at 14 days than at 28 days.
- These observations do not follow the expected strength gain of cement stabilized materials; however, it does appear that fly ash mixes (Pond D materials) tended to behave more like a cement stabilized material than the bottom ash most likely due to the greater fines content.
- Sulfate resistant cement and/or slag cement should be evaluated further to assess possible sulfate attack retarding the strength gain.

Observations & Conclusions

- Clearly, moisture content plays a significant role.
- For Ponds B and C, there was no significant hydraulic conductivity reduction with an increase in Portland cement addition.
- For Pond D, it did appear that the higher W:C ratio of the grout did lead to a higher hydraulic conductivity as expected. The high content of coarse grained particles likely led to the higher than expected hydraulic conductivity.
- There is a correlation between lower W:CM ratios resulting in increased UCS strength especially with Portland cement dosages greater than 3%. This data also may indicate that the coarser fraction bottom ash does not add strength as an aggregate would in concrete.
- There is a strong relationship between fly ash content (material finer than the No. 200 sieve) and both UCS and hydraulic conductivity. The mixes from Pond D produced much lower hydraulic conductivity, in an order of magnitude range, as well as consistently higher UCS results. The UCS and hydraulic conductivity results appear to indicate the old, weathered fly ash from Pond D retains its pozzolanic properties.
- An estimation of expected Portland cement dosage required to achieve a desired UCS may be based on the fly ash content of a CCR material.

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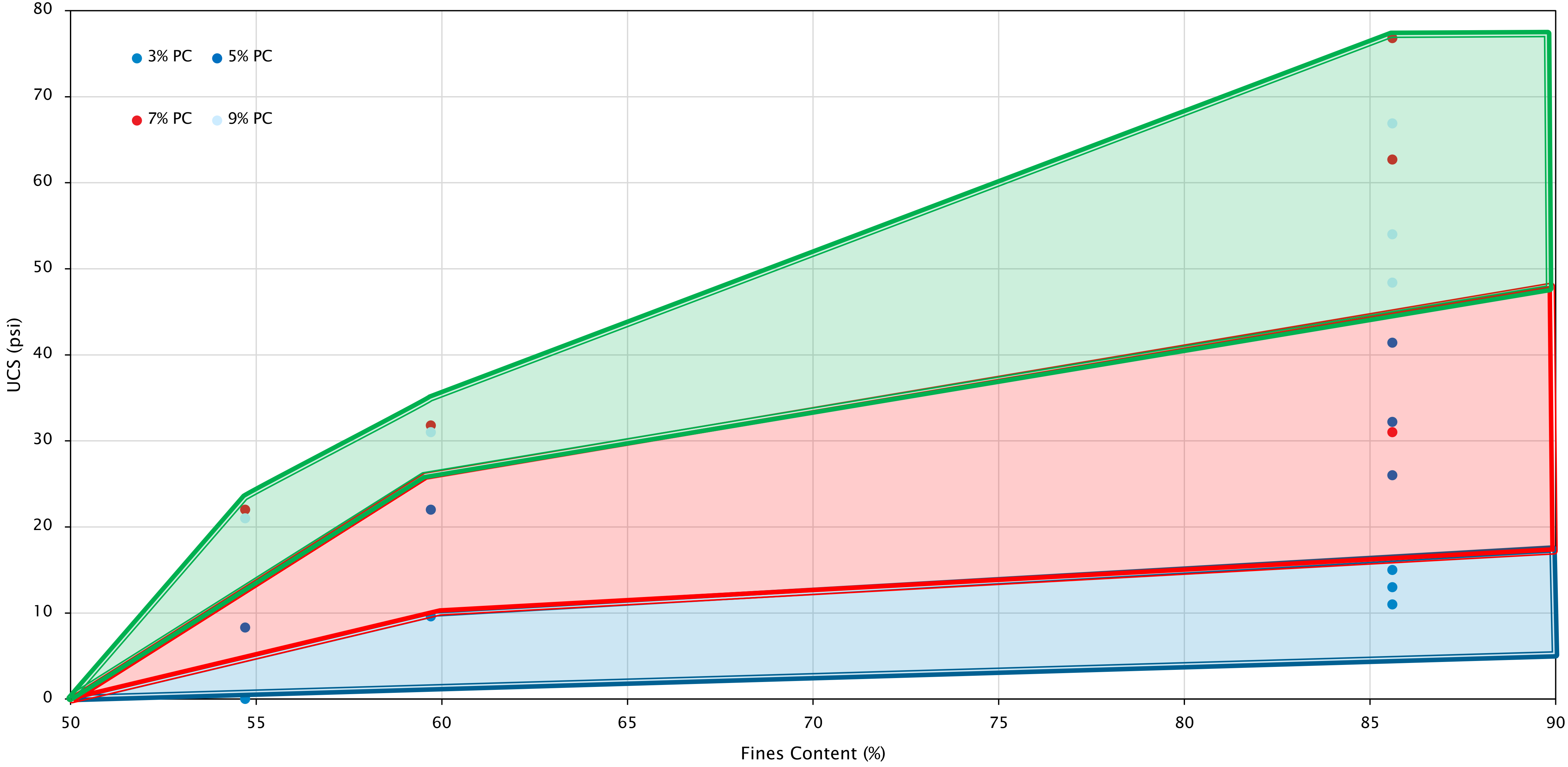
Observations & Conclusions



ISS of CCR Impoundments

ISS as a Closure Tool

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Infrastructure Needs for ISS

Essential

- Area for equipment and materials staging
- Access roads (for heavy equipment) to impoundment area
- Potable water
- Electricity (for mix plant)

Helpful

- Proximity to Portland cement suppliers
- Barge Access with off-loading facilities

Full-Depth ISS

1 Acre Pond with Tangential Columns

- Tangential columns
- 5% Portland cement addition
- 10-foot diameter augers
- ~500 columns per acre
- Typical impoundment would require multiple rigs over multiple years
- May require embankment stabilization before ISS can be implemented
- Post-ISS surface restoration compatible with future use required

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Localized ISS

- Target wet areas
- Focus on areas with anticipated redevelopment or other potential reuse
- Columns may be tangential or overlapping

- Access roads to areas within impoundment
- Reduces need for long-term dewatering and fluids management to maintain access

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Containment

- Overlapping columns
- 7% Portland cement addition
- 4-foot diameter augers
- Columns could extend up to 100 feet below grade
- Columns would key into underlying confining layer
- ISS cap or traditional cap can be installed in addition to containment

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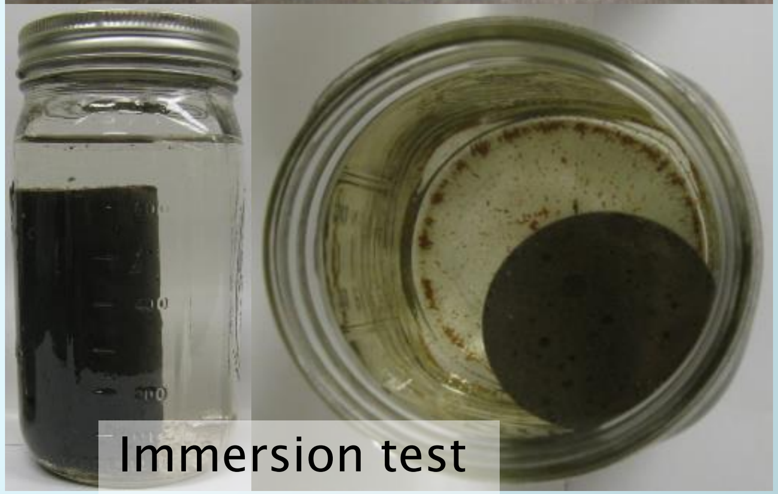
Closing

- ISS of CCR is Feasible and cost effective under the right conditions and applications
- All CCR materials are <u>Different</u>
- Bench scale studies
  - Account for bench scale to full scale performance differences
    - Target <u>2X desired strength</u>
    - Target <u>half an order of magnitude lower k</u>
  - Consider full scale construction approach
  - Consider compatibility & durability
  - <u>Perform individual bench scale on each material type, by area within the pond and by depth or observed change in physical index properties</u>



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Discussion

Contact Us!

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