The Use of Carbonated Cement Kiln Dust as a Soil Stabilization Amendment

Team K.V.S.C

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Project Descriptions

- To determine the effectiveness of Carbonated Cement Kiln Dust (CCKD) for use as a soil stabilization amendment
- Previous study on lime, Class C Fly Ash and CKD shows that CKD can be used as soil stabilization amendment
- Cement production accounts for approximately 5% of all human produced CO_2, and CKD is currently treated as waste by cement manufacturers

Figure 1: CKD [1]

Client & Stakeholders

Client: Alarick Reiboldt, Civil and Environmental Engineering Instructor

- The study on the uses of CCKD

Stakeholders:

- Cement Manufacturing Companies
  - The use of CCKD, reducing CKD waste
- Construction Companies
  - The use of CCKD as a soil stabilizer
- Global Community
  - The reduction of CO_2 in the atmosphere

Figure 2: The Client, professor Alarick Reiboldt [2]

Figure 3: Cement Manufacturing Company [3]

CKD & CCKD Chemical Components

- Reacting CKD with Carbon Dioxide (CO_2) to get CCKD is a critical solution
- The main component of CKD is Calcium Oxide (CaO) (64.72%)
- Calcium Carbonate ($CaCO_3$) is the result of reverse quicklime process (Figure 4 shows quicklime process)
- CCKD consists of mainly $CaCO_3$, which can be used as a soil stabilizer

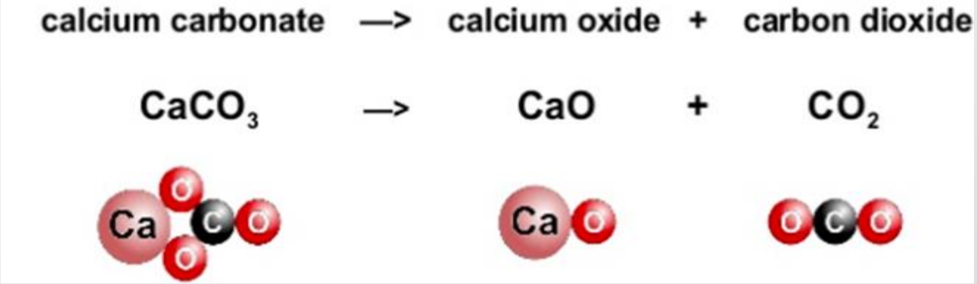

Figure 4: Quicklime Process [2]

Scope of Work

Task 1: Literature Review

Task 2: Soil Classification

- Sieve Analysis (ASTM D421)
- Atterberg Limit Tests (ASTM D4318-10e1)

Task 3: Preparing Soil Samples

Task 4: Soil Strength Tests

- Direct Shear Test (ASTM D3080)
- Triaxial Shear Test (UU - ASTM D2850-03a)

Task 5: Analysis Results

Task 6: Project Management

- Scheduling
- Meetings
- Deliverables

Figure 5: Triaxial Shear Machine

Exclusions

- Tasks that are not listed under Scope of Work section are excluded from the project
- Additional Laboratory Testings will only be considered if deem necessary and approved by the client

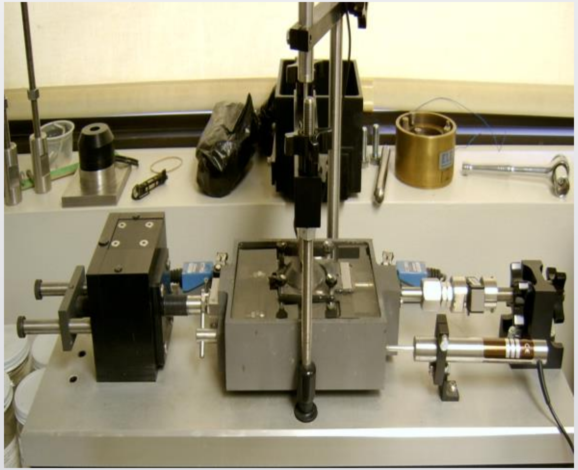

Figure 6: Direct Shear Machine

Literature Review

Review previous study on lime, Class C Fly Ash and CKD

by Dr. Solanki (University of Oklahoma in Norman, Oklahoma)

- CKD mixed 5%, 10% and 15% by weight
- 7-day curing periods for samples
- Soils used in previous study (USCS Classification): **CL-ML Sandy Silty Clay**

Soil Selection

- Looking for soils that are rich of silt materials

  (with the help of Geology Faculty)
- Sieve Analysis (ASTM D421)
- Atterberg Limit Tests (ASTM D4318-10e1)
- Soil Classification (USCS Classification)

Figure 7: Soil Obtained Site [4]

Atterberg Limits

For Soil Samples retained on, and passing through sieve #200:

- Liquid Limit: 29.41% ± 1.488%
- Plasticity Index: 5.186%

Figure 8: Casagrande Device - Liquid Limit Test

Table 3: Liquid Limit

Sample #	Liquid Limit (LL)
LL1	28.71
LL2	29.13
LL3	31.88
LL4	27.93
Average Liquid Limit	**29.41**
Standard Deviation	**1.488**

Table 4: Plastic Limit

Sample #	Plastic Limit (PL)
PL1	24.59
PL2	23.90
PL3	26.32
PL4	23.31
PL5	23.93
PL6	24.19
PL7	23.64
PL8	23.95
Average Plastic Limit	**24.23**
Standard Deviation	**0.8633**

Soil Classification

Original Soils (USCS Classification): **SM Silty Sand**

Engineered Soil Samples:

- Keeping soils retained on, and passing through sieve #200
- % Sand: ~ 38%
- % Fines: ~ 62%
- LL: ~ 29.4%
- PI: ~ 5.2%
- Over 30 kg obtained

Engineered Soil Sample (USCS Classification): **CL-ML Sandy Silty Clay**

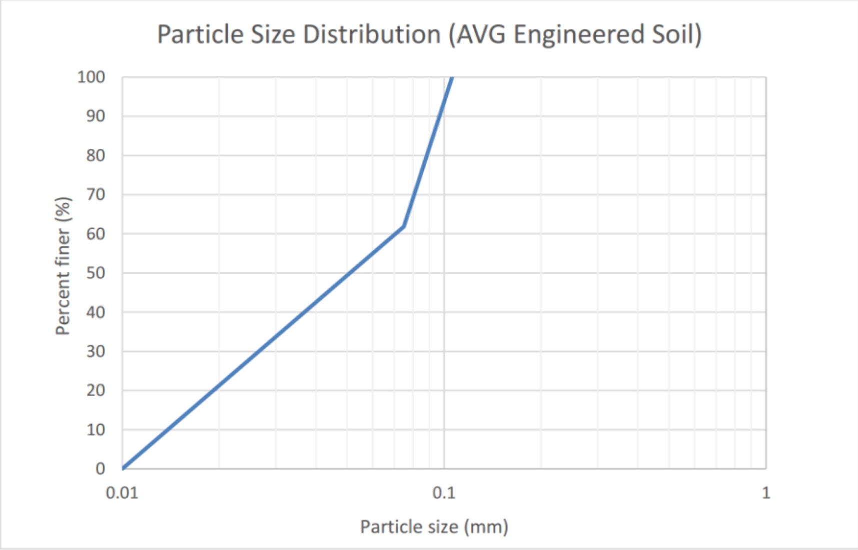

Figure 9: Engineered Soil's Average PSD Graph

Table 1: Engineered Soil's Avg % Finer

Sieve #	Average Percent Finer (%)
140	100.0
200	61.85
Pan	0

Preparing Soil Mixtures

Obtained Lime, CKD and CCKD

- Lime (3 Mixes - 3 samples each)
- CKD (3 Mixes - 3 samples each)
- CCKD (3 Mixes - 3 samples each)

Prepared soil mixtures based on CKD's chemical components

Figure 10: CCKD

Figure 11: Lime

Table 2: Soil Sample Mixtures

	% Admixture	% Soil
lime	3%	97%
	7%	93%
	10%	90%
CKD	5%	95%
	10%	90%
	15%	85%
CCKD	9%	91%
	18%	82%
	27%	73%

Figure 12:CKD

Soil Strength Tests

- Direct Shear Tests (ASTM D3080)
  - Broken Direct Shear machine (only have results for Control and Lime1 mixtures)
  - After Discussion with Client, Direct Shear Tests are parts of exclusions
- Triaxial Shear Tests (UU - ASTM D2850-03a) (30 mixtures)

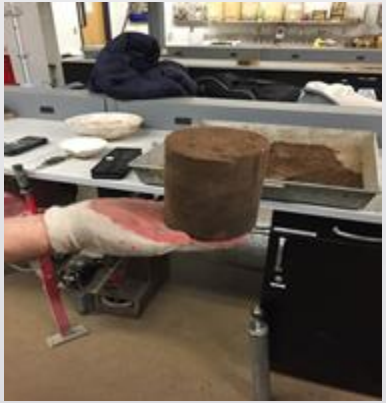

Figure 13: Preparing Soil Samples

Figure 14: Digital Tritest

Figure 15: Tri-flex 2 Master Control Panel

Results of Analysis

- Proctor Compaction Results
- Triaxial Shear (UU) Results
  - 3 Control Results (Soils without admixture)
  - 9 Lime Results (Lime 1, 2 & 3)
  - 9 CKD Results (CKD 1, 2 & 3)
  - 9 CCKD Results (CCKD 1, 2 & 3)

Figure 16: Proctor Compaction tools [7]

Proctor Compaction Results

- Soil samples will have maximum density when maximum dry unit weight and optimum moisture content are achieved
- Average Soil's Optimum Moisture Content (3 Proctor Tests): **17.43%**
- Mixtures were mixed at Soil's **Optimum Moisture Content**

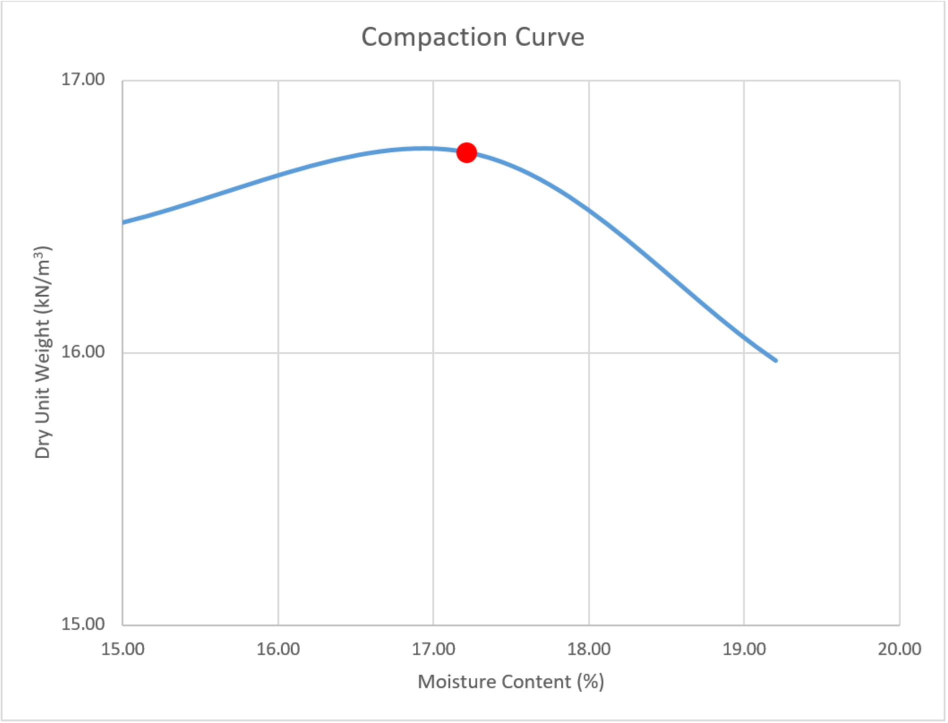

Figure 17: Dry Unit Weight vs. Moisture Content

Triaxial Shear Tests - Results

Table 3: Triaxial Shear Results (Average Shear Strength and Percent Increase in Strength compared to Control Samples)

Mix	Amount of Calcium Oxide in Mix (%)	Average Shear Strength (psi)	Standard Deviation (psi)	Percent Increase (%)
Control	0	12.29	0.8428	-
CCKD1	3.273	22.98	3.309	87.06
CCKD2	6.546	21.44	2.960	74.47
CCKD3	**9.819**	**28.06**	**4.121**	**128.4**
CKD1	3.273	17.11	12.12	39.23
CKD2	6.546	17.94	1.895	46.06
CKD3	9.819	21.01	2.584	71.01
Lime1	3.273	9.983	7.249	-18.74
Lime2	6.546	26.81	9.578	118.3
Lime3	9.819	21.49	2.143	74.93

Shear Strength versus Percent Calcium Oxide in Mixtures

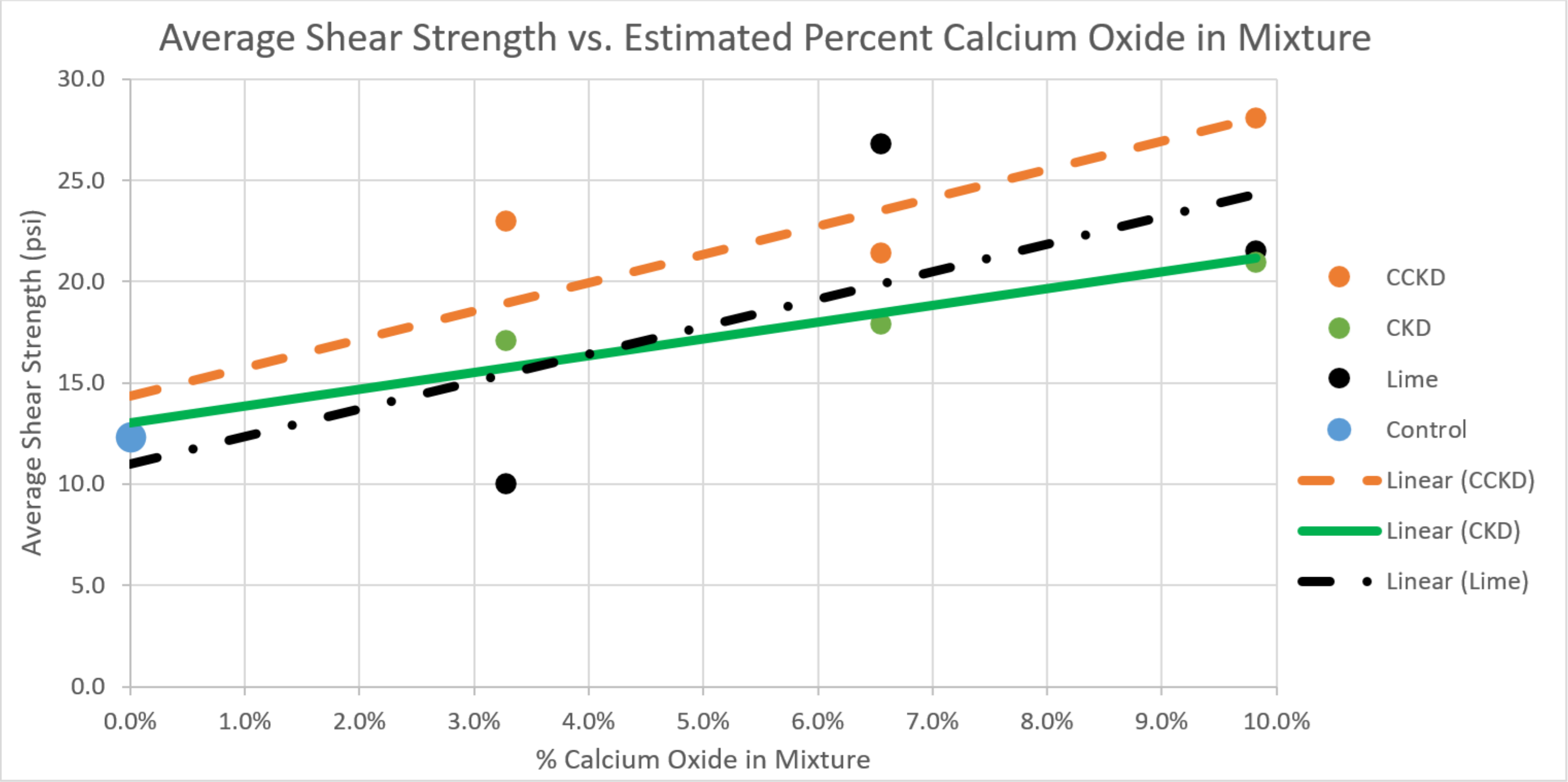

Figure 18: Average Triaxial Shear Test results for All Mixtures versus percent Calcium Oxide in Mixtures

Factors Affecting Results

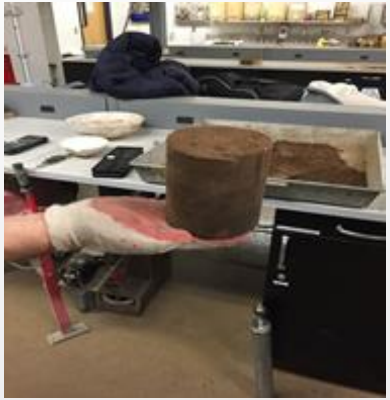

Figure 19: Mold sample

Results obtained from soil testing **highly vary** due to:

- Shape of sample (samples have to be shaved down for use)
- Contents of Lime, CKD and CCKD added when preparing mixtures
- Percent Calcium Oxide added when making samples
- Moisture loss during curing process

Project Impacts

- The reduction of CO_2 from the making of CCKD will **GREATLY** benefit the global community!!!
- The use of CCKD as a soil stabilizer will increase shear strength of soils, resisting failure and sliding along any plane inside soils (**Leaning Tower of Pisa**)
- CKD will no longer be treated as waste, reducing the amount of landfill materials
- Producing CCKD from CKD waste will save natural resources, reducing the use of new materials as soil stabilizers
- CCKD manufacturing process will create potential new jobs

Project Hours

Table 4: Project Hours

Task	SENG (hrs)	ENG (hrs)	INT (hrs)	Actual Hours	Predicted Hours
1.0 Literature Review	20	40	-	60	120
2.0 Soil Selection				170	128
2.1 Determining Soil Used	*25*	*10*	-	*35*	*48*
2.2 Obtaining Soil Samples	-	*10*	*100*	*110*	*40*
2.3 Soil Classification	-	*12.5*	*12.5*	*25*	*40*
3.0 Preparing Soil Samples	-	47	47	94	40
4.0 Soil Strength Tests				181.25	166
4.1 Proctor Compaction	-	*1.5*	*20*	*21.5*	*0*
4.2 Direct Shear Tests	-	*7*	*35*	*42*	*68*
4.3 Triaxial Shear Tests	-	*17.75*	*100*	*117.75*	*98*
5.0 Analysis Results	9.25	18.5	-	27.75	120
6.0 Project Management				111.75	228
6.1 Scheduling	*28.75*	-	-	*28.75*	*8*
6.2 Meetings	*17*	*17*	*17*	*51*	*60*
6.3 Deliverables	*16*	*16*	-	*32*	*160*
TOTAL (HRS)	**116**	**197.25**	**331.5**	**644.75**	**802.00**

Table 5: Personnel Descriptions

Code	Classification
SENG	Senior Engineer
ENG	Engineer
INT	Engineering Intern

Scheduling: Gantt Chart (Predicted)

Name	Begin d...	End date	Duration
1. Literature Review	1/16/17	1/29/17	2 weeks
2. Soil Classification	1/30/17	2/19/17	3 weeks
3. Preparing Soil Samples	2/20/17	2/26/17	1 week
4. Soil Strength Test	2/27/17	4/9/17	6 weeks
4.1 Direct Shear Test	2/27/17	3/19/17	3 weeks
4.2 Triaxial Shear Test	3/20/17	4/9/17	3 weeks
5. Analysis Results	4/10/17	4/23/17	2 weeks
6. Project Management	1/16/17	5/5/17	4 months

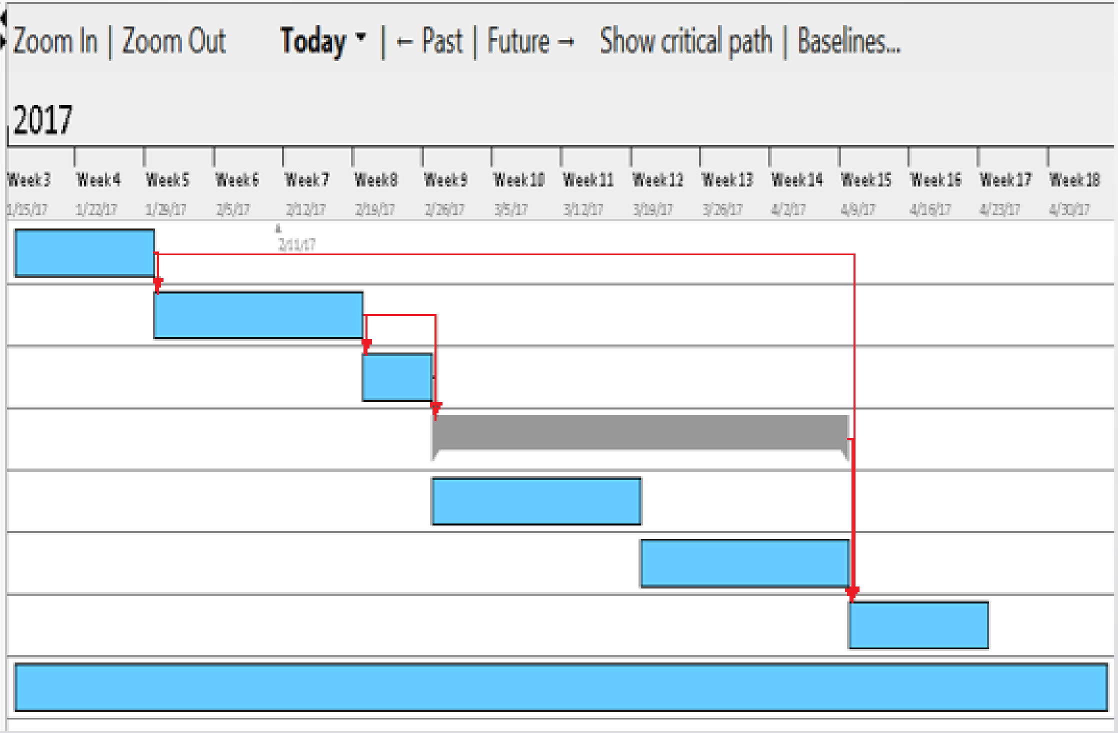

Figure 20: Predicted Gantt Chart

Scheduling: Gantt Chart (Actual)

Name	Begin date	End date	Duration
1. Literature Review	1/17/17	1/23/17	6 days
2. Soil Classification	1/24/17	2/15/17	19 days
3. Preparing Soil Samples	2/16/17	3/31/17	43 days
4. Soil Strength Test	2/24/17	3/31/17	35 days
4.1 Direct Shear Test	2/24/17	3/3/17	7 days
4.2 Triaxial Shear Test	2/24/17	3/31/17	35 days
5. Analysis Results	4/3/17	4/14/17	11 days
6. Project Management	1/17/17	5/8/17	7 days

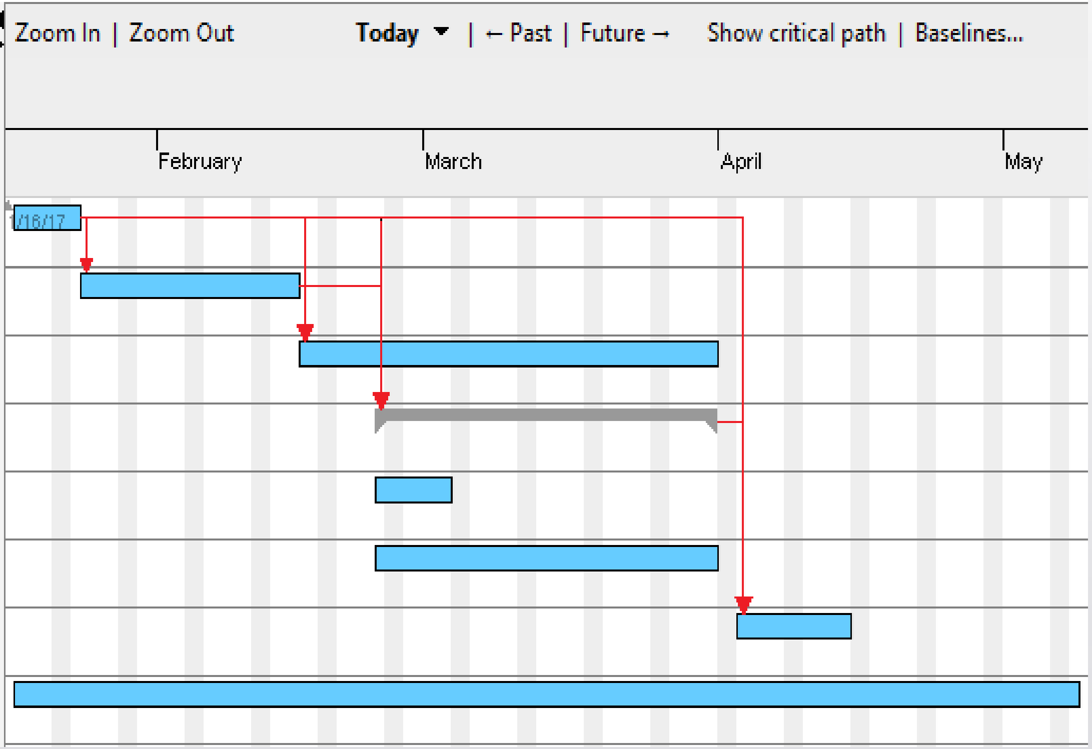

Figure 21: Actual Gantt Chart

Total Cost

Table 6: Total Cost

Engineering Services	Classification	Staffing Hours	Billing Rate	Actual Cost	Projected Cost
Personnel	SENG	116 hrs	$115/hr	$13,340	$22,540
	ENG	197.25 hrs	$58/hr	$11,441	$20,648
	INT	331.5 hrs	$45/hr	$14,918	$11,250
	Total Personnel			**$39,698**	**$54,438**
Laboratory Work	Soil Classification	6 hrs	$100/hr	$600	$4,000
	Sieving Soils	30 hrs	$100/hr	$3,000	-
	Proctor Compaction	9 hrs	$100/hr	$900	-
	Direct Shear	12 hrs	$100/hr	$1,200	$6,000
	Triaxial Shear (UU)	90 hrs	$100/hr	$9,000	$9,000
	Total Laboratory Cost			**$14,700**	**$19,000**
TOTAL COST				**$54,398**	**$73,438**

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- Naji Khoury, Assistant Professor, Civil and Environmental Engineering, Temple University
- M. Zaman, Associate Dean for Research, College of Engineering, University of Oklahoma

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Supplemental Information: CCKD vs. Control Results

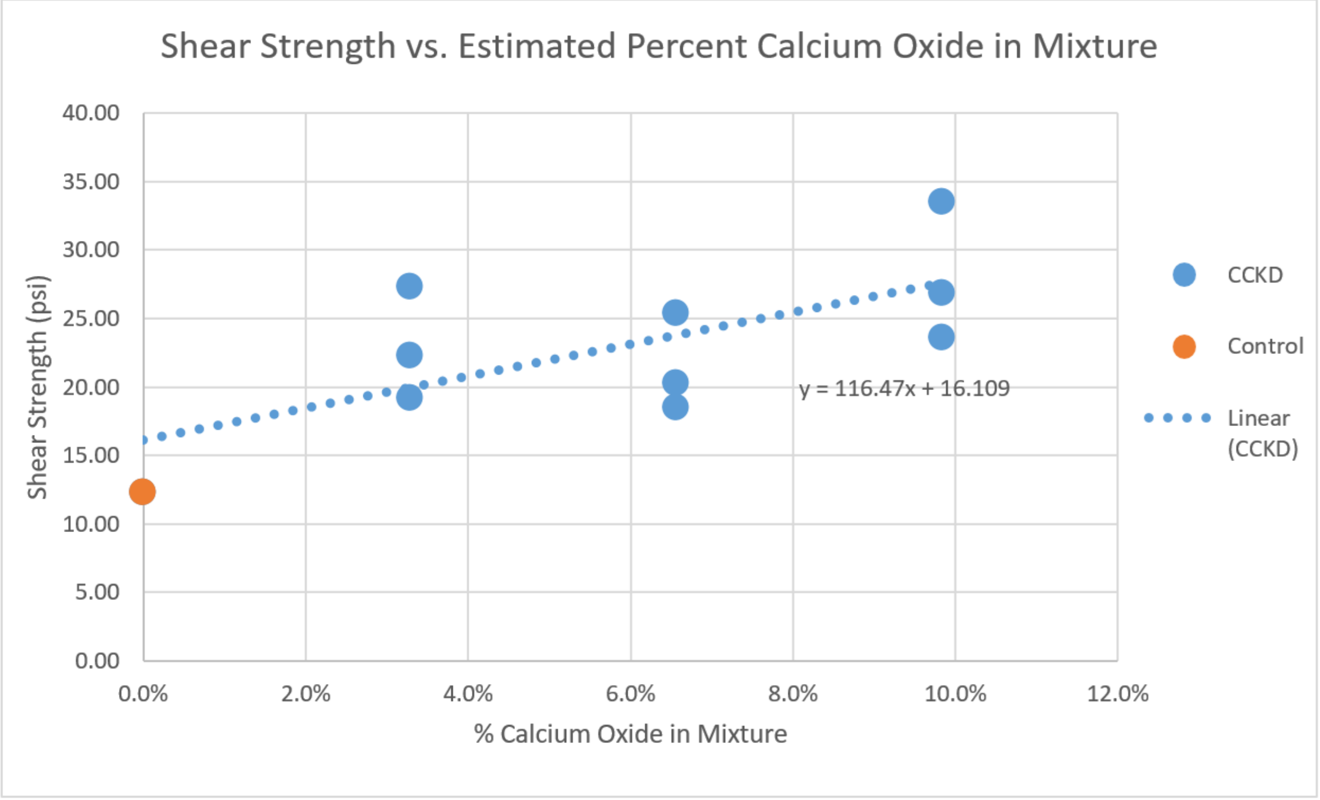

Figure 22: Average Triaxial Shear Test results for CCKD Mixtures versus percent Calcium Oxide in Mixtures

Supplemental Information: CKD vs. Control Results

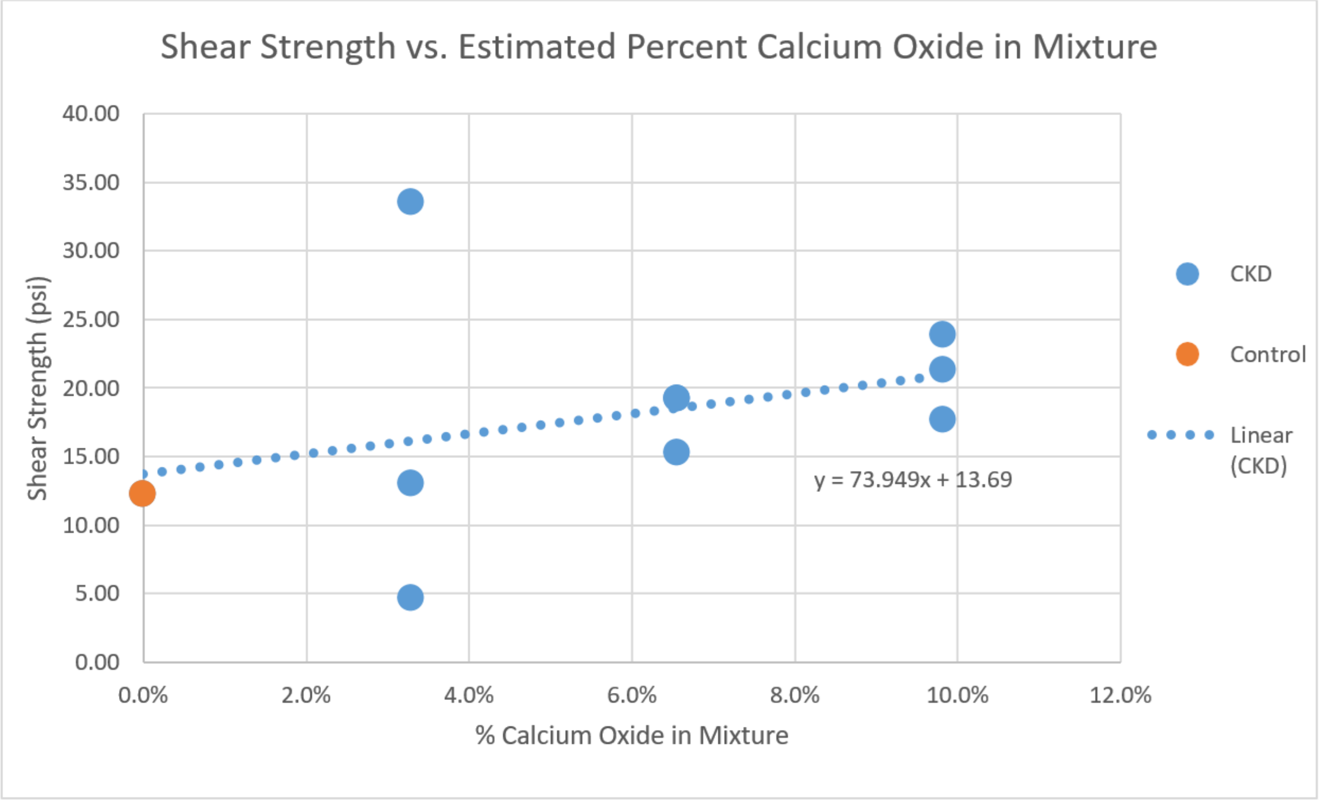

Figure 23: Average Triaxial Shear Test results for CKD Mixtures versus percent Calcium Oxide in Mixtures

Supplemental Information: Lime vs. Control Results

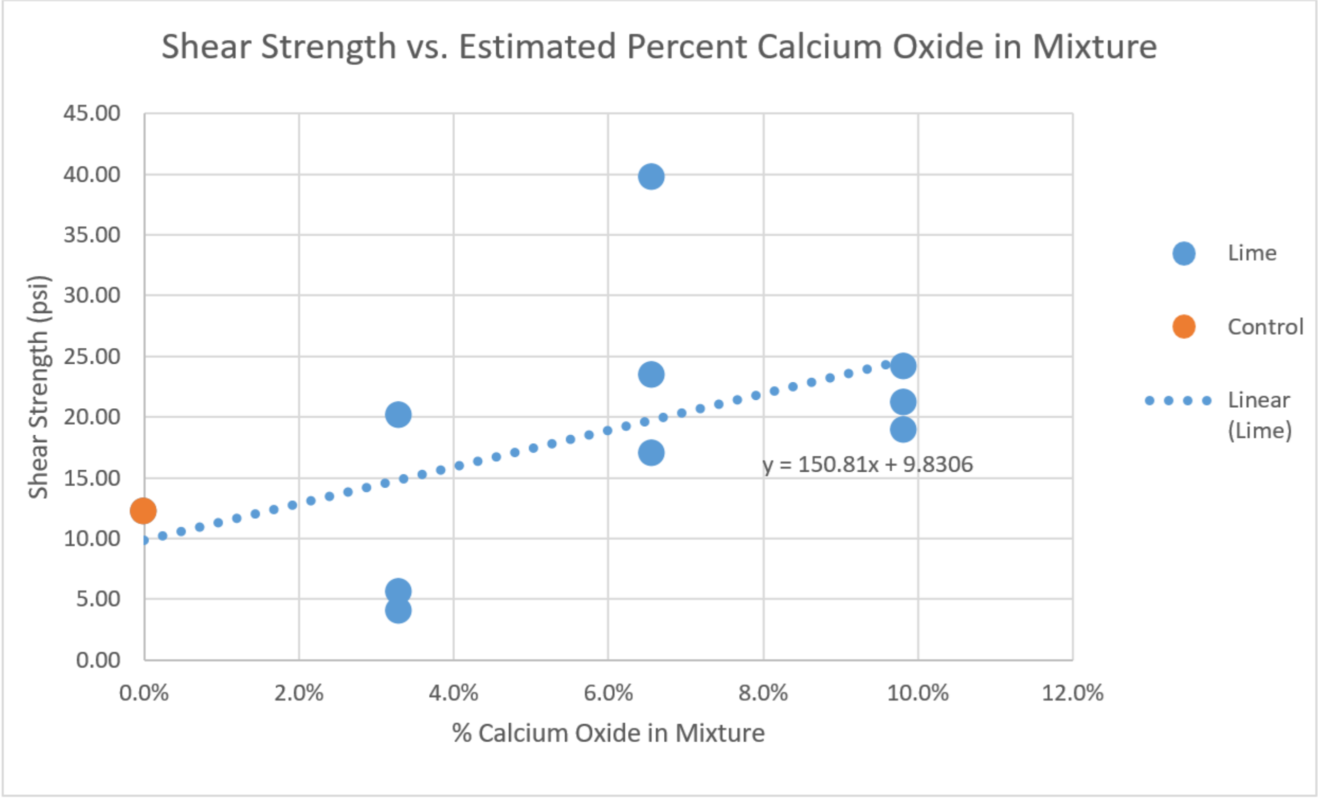

Figure 24: Average Triaxial Shear Test results for Lime Mixtures versus percent Calcium Oxide in Mixtures