APPENDIX A

LABORATORY TEST DATA

Table A1: Unconfined Compressive Strength Test Data of Untreated Soil-1 (A-6)

	Untreated Soil-1 (A-6)			
Test	**Unsoaked**		**Soaked**	
	Stress, psi	Strain, %	Stress, psi	Strain, %
1	33.44	6.59	2.67	15.02
2	32.14	5.56	2.79	14.83
3	31.19	5.56	2.36	15.02
Average	32.26	5.90	2.61	14.96

Table A2: Unconfined Compressive Strength Test Data of Untreated Soil-2 (A-4)

	Untreated Soil-2 (A-4)			
Test	**Unsoaked**		**Soaked**	
	Stress, psi	Strain, %	Stress, psi	Strain, %
1	37.37	5.31	2.47	15.01
2	34.58	4.75	3.19	15.00
3	36.06	4.36	4.10	15.01
Average	36.00	4.81	3.25	15.01

Table A3: Unconfined Compressive Strength Test Data of Untreated Soil-3 (A-7-6)

	Untreated Soil-3 (A-7-6)			
Test	**Unsoaked**		**Soaked**	
	Stress, psi	Strain, %	Stress, psi	Strain, %
1	69.56	3.66	1.45	14.86
2	54.80	4.36	1.61	14.61
3	63.12	4.37	1.24	15.01
Average	62.49	4.13	1.43	14.83

Table A4: Unconfined Compressive Strength Test Data of CKD Treated Soil-1 (A-6)

		6% CKD, 0 days curing				6% CKD, 1 days curing				6% CKD, 3 days curing				6% CKD, 7 days curing				6% CKD, 14 days curing				6% CKD, 28 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
6% CKD, Soil-1 (A-6)	1	37	6.56	2.71	4.35	50.69	4.56	17.96	6.06	60.42	3.76	28.58	4.74	105.5	4.46	30.73	2.86	-	-	40.47	2.95	-	-	54.3	2.56
	2	34.1	3.86	3.5	4.36	44.7	3.35	24.2	4.96	61.9	3.96	25.2	3.86	95.7	4.46	32.8	3.35	-	-	35.9	2.75	-	-	46	3.16
	3	42.52	5.56	5.82	7.56	49.27	5.56	13.03	4.04	62.86	4.05	32.57	3.66	123.9	4.15	27.42	3.66	-	-	40.63	2.95	-	-	51.76	2.46
	Average	37.88	5.33	4.01	5.42	48.20	4.49	18.38	5.02	61.72	3.92	28.78	4.09	108.36	4.36	30.33	3.29	N/A	N/A	39.01	2.88	N/A	N/A	50.70	2.73

8% CKD, Soil-1 (A-6)	8% CKD, 0 days curing				8% CKD, 01 days curing				8% CKD, 3 days curing				8% CKD, 7days curing				8% CKD,14 days curing				8% CKD,28 days curing			
Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	32.21	7.06	3.72	9.33	50.92	9.09	23.17	5.03	67.32	7.31	44.71	3.15	192.34	4.07	63.56	2.84	-	-	104.3	2.55	-	-	133.6	1.56
2	33.64	7.57	5.75	9.33	47.13	9.84	23.69	4.94	71.93	7.32	51.15	2.55	185.82	3.46	79.88	2.54	-	-	106.3	1.85	-	-	132.6	2.1
3	35.63	6.3	6.83	8.86	48.52	9.59	22.01	4.56	72.88	7.82	40.46	2.35	210.81	3.35	72.28	2.64	-	-	122.2	2.24	-	-	117.1	2.55
Average	33.83	6.98	5.43	9.17	48.86	9.51	22.96	4.84	70.71	7.48	45.44	2.68	196.32	3.63	71.91	2.67	N/A	N/A	110.91	2.21	N/A	N/A	127.73	2.07

		12% CKD, 0 days curing				12% CKD, 1 days curing				12% CKD, 3 days curing				12% CKD, 7 days curing				12% CKD, 14 days curing				12% CKD, 28 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
12% CKD, Soil-1 (A-6)	1	48.63	6.82	10.15	5.55	103.89	4.26	43.78	4.66	155.82	3.35	49.05	3.56	177.68	2.75	77.05	2.44	-	-	109.6	1.86	-	-	141.4	2.05
	2	51.26	5.31	9.87	6.31	107.98	3.55	40.22	4.25	145.90	2.35	41.35	2.66	183.01	2.94	76.84	2.95	-	-	109.6	1.65	-	-	144.8	1.55
	3	49.49	3.86	7.91	5.3	119.28	4.27	38.31	4.07	158.80	3.46	43.5	2.05	180.39	3.15	79.43	2.96	-	-	109.1	2.55	-	-	156.5	1.84
	Average	49.79	5.33	9.31	5.72	110.38	4.03	40.77	4.33	153.51	3.05	44.63	2.76	180.36	2.95	77.77	2.78	N/A	N/A	109.43	2.02	N/A	N/A	147.55	1.81

Table A5: Unconfined Compressive Strength Test Data of CF Treated Soil-1 (A-6)

		4% CF, 0 days curing				4% CF, 1 days curing				4% CF, 3 days curing				4% CF, 7 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
4% CF, Soil-1 (A-6)	1	51.58	5.06	1.91	15	48.14	4.77	2.26	15	56.15	3.96	1.52	13.9	68.28	4.55	3.43	15
	2	42.46	4.87	1.77	15	52.36	4.57	1.56	14.9	57.73	4.78	1.81	15	73.89	3.44	3.93	15
	3	41.53	4.56	1.74	15.02	56.86	3.56	**1.37	**4.75	53.69	3.66	1.54	14.36	82.76	4.75	5.51	15.02
	Average	45.19	4.83	1.81	15.00	52.45	4.30	1.91	14.94	55.86	4.13	1.62	14.42	74.97	4.25	4.29	15.02

** Discarded value

		12% CF, 0 days curing				12% CF% CKD, 01 day curing				12% CF, 3 days curing				12% CF, 7 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
12% CF, Soil-1 (A-6)	1	40.52	6.35	4.41	15	49.43	7.09	4.92	15	50.06	6.31	5.24	15	61.17	6.06	15.7	15
	2	32.73	7.58	3.8	10.1	44.82	6.32	5.19	15	41.22	5.58	5.87	15	75.68	5.32	18.1	15
	3	41.69	6.58	4	15	48.73	6.08	2.94	15	54.02	5.33	5.99	15	73.80	5.57	21.3	15
	Average	38.31	6.84	4.07	13.37	47.66	6.50	4.35	15.01	48.43	5.74	5.70	15.02	70.22	5.65	18.40	15.01

25% CF, Soil-1 (A-6)		25% CF, 0 days curing				25% CF, 1 days curing				25% CF, 3 days curing				25% CF, 7 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
	1	33.69	5.57	3.74	15	54.96	5.82	7.73	5.82	51.59	3.87	14.22	10.08	64.79	5.06	**8.34	4.96
	2	43.47	4.87	5.07	9.83	54.48	5.33	6.73	6.32	63.39	4.55	19.8	9.33	76.28	3.75	20.2	7.84
	3	54.34	5.07	4.13	15	49.62	5.07	4.89	4.16	57.82	4.48	11.9	9.08	76.60	3.87	19.6	9.6
	Average	43.83	5.17	4.31	13.29	53.02	5.41	6.45	5.43	57.60	4.30	15.29	9.50	72.56	4.23	19.91	7.47

** Discarded value

Table A6: Unconfined Compressive Strength Test Data of FA Treated Soil-1 (A-6)

		0 days curing				1 days curing				3 days curing				7 days curing				14 days curing				28 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
10% Fly Ash, Soil-1 (A-6)	1	43.90	7.32	3.64	10.3	62.67	6.08	5.69	4.95	67.67	5.83	9.65	3.45	95.8	3.56	10.8	3.35	-	-	23.4	1.85	-	-	42.7	1.74
	2	54.11	6.32	4.65	9.95	53.24	7.82	4.89	9.33	57.95	7.07	11.7	2.75	79.5	5.32	12	3.25	-	-	30.4	1.75	-	-	35.5	2.05
	3	49.58	7.33	3.89	6.31	68.26	6.82	5.55	5.56	65.82	5.83	11.1	3.46	80.9	3.65	10	4.06	-	-	27.4	1.65	-	-	30.2	1.74
	Average	49.19	6.99	4.06	8.86	61.39	6.91	5.38	6.61	63.81	6.24	10.81	3.22	85.40	4.18	10.94	3.55	N/A	N/A	27.05	1.75	N/A	N/A	36.15	1.84

15% Fly Ash, Soil-1 (A-6)

	0 days curing				1 days curing				3 days curing				7 days curing				14 days curing				28 days curing			
Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	61.66	3.45	4.36	15.01	86.84	2.85	4.18	15.01	93.86	2.26	5.97	10.33	124.1	2.35	4.4	5.05	-	-	4.02	4.55	-	-	3.78	3.85
2	54.95	3.05	4.56	15.01	89.75	2.65	4.91	15.02	98.37	2.75	5.25	10.34	122.2	3.05	6.23	7.82	-	-	3.13	7.31	-	-	5.7	15
3	59.90	3.14	4.07	15.01	91.00	2.64	5.23	15	86.19	2.46	5.16	5.56	126.89	2.85	3.49	2.96	-	-	4.02	5.69	-	-	sample	broken
Average	58.84	3.22	4.33	15.01	89.20	2.71	4.77	15.01	92.81	2.49	5.46	8.74	124.39	2.75	4.71	5.28	N/A	N/A	3.72	5.85	N/A	N/A	4.74	9.43

25% Fly Ash, Soil-1 (A-6)

	0 days curing				1 days curing				3 days curing				7 days curing				14 days curing				28 days curing			
Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	64.41	3.65	4.38	15.01	85.18	3.35	4.19	11.08	100.56	2.96	5.08	4.86	149.1	3.06	5.81	3.94	-	-	4.71	3.41	-	-	4.85	3.04
2	67.42	4.06	3.55	15.01	93.27	3.57	4.26	8.06	59.68	2.25	3.58	4.46	140.2	2.55	4.07	4.05	-	-	4.25	4.15	-	-	4.03	2.74
3	66.33	3.15	2.94	14.89	82.00	2.94	4.92	15.01	78.47	2.55	4.93	5.31	161.71	3.76	**2.66	7.57	-	-	2.45	3.96	-	-	Sample	broken
Average	66.06	3.62	3.62	14.97	86.82	3.29	4.46	11.38	79.57	2.59	4.53	4.88	150.35	3.12	4.94	5.19	N/A	N/A	3.80	3.84	N/A	N/A	4.44	2.89

** Discarded value

Table A7: Unconfined Compressive Strength Test Data of LKD+FA Treated Soil-1 (A-6)

2%LKD+5% FA, Soil-1 (A-6)		2% LKD & 5% FA, 0 days curing				2% LKD & 5% FA, 1 days curing				2% LKD & 5% FA,3 days curing				2% LKD & 5% FA, 7 days curing				2% LKD & 5% FA, 14 days curing				2% LKD & 5% FA, 28 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
	1.00	46.14	3.34	3.91	10.70	77.94	3.05	4.70	2.95	85.16	1.45	4.60	3.45	120.96	2.15	8.22	3.66	-	-	9.43	2.95	-	-	9.74	2.56
	2.00	56.41	3.16	4.80	7.83	75.93	2.65	5.75	6.18	92.44	1.64	4.28	3.46	119.00	2.25	8.99	2.95	-	-	11.89	2.95	-	-	Broken	
	3.00	52.49	3.36	3.83	4.76	78.84	2.65	6.46	3.65	86.84	1.66	5.94	3.97	102.60	1.46	8.88	3.46	-	-	7.06	2.85	-	-	9.58	2.85
	Average	51.68	3.29	4.18	7.76	77.57	2.78	5.64	4.26	88.14	1.58	4.94	3.62	114.19	1.95	8.70	3.35	N/A	N/A	9.46	2.92	N/A	N/A	9.66	2.70

5%LKD+15% FA, Soil-1 (A-6)

Test	5% LKD & 15% FA, 0 days curing				5% LKD & 15% FA, 01 days curing				5% LKD & 15% FA, 3 days curing				5% LKD & 15% FA,7days curing				5% LKD & 15% FA,14 days curing				5% LKD & 15% FA,28 days curing			
	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1.00	61.22	3.35	13.63	3.35	181.01	1.95	74.00	1.84	196.95	2.55	85.90	2.53	185.13	2.85	148.36	0.75	-	-	136.03	2.96	263.13	1.64	155.99	1.64
2.00	56.35	3.35	15.90	4.55	145.46	1.75	83.59	1.54	187.74	3.26	135.92	2.26	**149.66	2.18	142.87	0.76	-	-	177.23	1.66	269.71	1.66	177.87	1.75
3.00	48.96	4.35	16.43	3.15	168.93	2.55	66.59	1.95	192.95	2.75	110.21	2.34	200.15	2.45	150.22	1.25	-	-	165.15	1.15	229.52	2.04	168.94	2.05
Average	55.51	3.68	15.32	3.68	165.13	2.08	74.73	1.78	192.55	2.85	110.68	2.38	192.64	2.49	147.15	0.92	N/A	N/A	159.47	1.92	254.12	1.78	167.60	1.82

** Discarded value

3%LKD+9% FA, Soil-1 (A-6)

	3% LKD & 9% FA, 0 days curing				**3% LKD & 9% FA, 01 days curing**				**3% LKD & 9% FA,, 3 days curing**				**3% LKD & 9% FA, 7days curing**				**3% LKD & 9% FA, 14 days curing**				**3% LKD & 9% FA, 28 days curing**			
Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1.00	69.47	3.35	7.18	3.25	140.86	1.14	16.27	2.25	169.18	2.85	44.64	1.35	181.44	2.35	88.34	3.05	-	-	87.38	1.55	-	-	104.60	1.45
2.00	71.88	3.06	7.51	3.84	157.48	1.74	16.17	1.55	143.13	2.05	59.74	1.44	173.63	1.95	86.69	3.65	-	-	**72.68	1.76	-	-	102.34	2.64
3.00	70.57	3.95	7.59	3.94	145.66	1.95	**55.6	2.45	175.13	2.65	75.94	3.15	169.01	2.54	82.78	3.15	-	-	89.77	2.44	-	-	81.31	2.16
Average	70.64	3.45	7.42	3.68	148.00	1.61	16.22	1.90	162.48	2.52	60.11	1.98	174.69	2.28	85.94	3.29	N/A	N/A	88.58	1.92	N/A	N/A	96.08	2.08

** Discarded value

Table A8: Unconfined Compressive Strength Test Data of LKD & DLKD Treated Soil-1 (A-6)

	Test	6% LKD, 0 days curing				6% LKD, 01 days curing				6% LKD, 03 days curing				6% LKD, 07 days curing				6% LKD, 14 days curing				6% LKD, 28 days curing			
		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
6% LKD, Soil-1 (A-6)	1	67.04	1.95	**3.21	**3.26	90.14	1.94	14.08	1.95	73.48	1.34	**7.29	**0.26	93.52	1.64	21.57	1.34	-	-	30.05	1.04	-	-	**27.52	**0.03
	2	53.31	1.55	7.46	3.65	83.64	1.95	14.06	2.15	82.39	1.75	25.41	0.94	106.4	1.75	24.96	0.81	-	-	**21.59	**0.73	-	-	39.74	0.88
	3	59.6	2.04	6.33	3.85	69.9	1.64	10.5	1.44	96.95	2.15	20.3	0.83	85.2	1.26	32.3	1.04	-	-	40.5	1.04	-	-	34.04	1.14
	Average	59.97	1.85	6.90	3.75	81.23	1.84	12.88	1.85	84.27	1.75	22.87	0.89	95.05	1.55	26.27	1.06	N/A	N/A	35.28	1.04	N/A	N/A	36.89	1.01

** Discarded value

12% DLKD, Soil-1 (A-6)

Test	**12% DLKD, 0 days curing**				**12% DLKD, 01 days curing**				**12% DLKD, 03 days curing**				**12% DLKD, 07 days curing**				**12% DLKD, 14 days curing**		**12% DLKD, 28 days curing**	
	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Soaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	50.2	2.66	3.65	15	49.8	2.84	3.59	4.52	71.90	2.75	8.03	6.31	74.4	2.84	11.6	3.24	8.82	2.55	10.80	2.95
2	41.4	2.26	3.97	15	50.6	4.05	4.7	5.81	61.45	2.14	7.23	4.45	69.3	2.25	11.3	4.56	11.5	3.16	8.99	2.95
3	47.5	2.36	3.94	15	61.1	3.26	5.09	5.31	66.89	3.05	7.56	4.06	63.3	2.25	8.86	3.56	11.7	4.16	8.52	3.45
Average	46.37	2.43	3.85	15.01	53.84	3.38	4.46	5.21	66.75	2.65	7.61	4.94	69.00	2.45	10.59	3.79	10.68	3.29	9.44	3.12

Table A9: Unconfined Compressive Strength Test Data of CKD Treated Soil-2 (A-4)

		6% CKD, 0 days curing				6% CKD, 1 days curing				6% CKD, 3 days curing				6% CKD, 7 days curing				6% CKD, 14 days curing				6% CKD, 28 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
6% CKD, Soil-2 (A-4)	1	41.68	3.44	10.49	6.32	101.68	2.65	46.62	2.55	135.31	1.54	57.80	1.64	204.97	1.94	117.28	1.44	-	-	146.43	1.34	-	-	169.28	1.85
	2	40.21	3.46	8.95	4.87	100.54	2.45	30.33	2.25	166.97	2.35	47.32	1.46	228.20	2.55	107.25	1.85	-	-	131.99	1.85	-	-	169.13	2.15
	3	46.15	2.75	8.34	4.96	106.43	2.46	37.07	2.46	171.75	2.65	56.35	1.63	227.97	2.05	118.38	1.35	-	-	154.89	1.34	-	-	143.42	1.25
	Average	42.68	3.22	9.26	5.38	102.89	2.52	38.01	2.42	158.01	2.18	53.82	1.58	220.38	2.18	114.30	1.55	N/A	N/A	144.44	1.51	N/A	N/A	160.61	1.75

8% CKD, Soil-2 (A-4)

	8% CKD, 0 days curing				**8% CKD, 01 days curing**				**8% CKD, 3 days curing**				**8% CKD, 7days curing**				**8% CKD,14 days curing**				**8% CKD,28 days curing**			
Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	65.38	2.95	7.66	4.25	123.07	2.35	35.93	2.75	197.58	2.46	74.76	2.65	277.82	2.44	100.61	2.84	-	-	113.58	1.84	-	-	210.13	1.34
2	65.60	2.36	10.24	6.82	153.46	2.64	43.40	3.34	213.26	3.15	62.13	1.84	279.64	2.45	98.61	2.04	-	-	124.17	1.15	-	-	247.17	1.35
3	66.68	3.75	8.23	5.31	147.92	2.84	36.96	3.46	209.18	2.36	66.99	2.54	307.74	2.85	115.44	2.55	-	-	152.87	1.85	-	-	182.60	1.54
Average	65.89	3.02	8.71	5.46	141.48	2.61	38.76	3.18	206.67	2.66	67.96	2.34	288.40	2.58	104.89	2.48	N/A	N/A	130.21	1.61	N/A	N/A	213.30	1.41

4% CKD, Soil-2 (A-4)

Test	**4% CKD, 0 days curing**				**4% CKD, 1 days curing**				**4% CKD, 3 days curing**				**4% CKD, 7 days curing**				**4% CKD, 14 days curing**				**4% CKD, 28 days curing**			
	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	39.19	4.16	6.96	3.85	83.78	2.34	28.24	1.95	99.51	2.14	52.37	1.92	142.1	2.52	82.02	1.54	-	-	118.1	2.15	-	-	133.3	1.55
2	33.95	3.54	7.55	4.95	78.44	3.21	26.09	1.75	130.15	2.76	42.23	1.25	150.1	2.35	84.74	2.05	-	-	93.76	2.05	-	-	117.5	1.85
3	36.30	3.45	8.96	4.55	75.31	1.74	26.44	1.75	124.24	2.25	36.70	1.85	153.7	3.06	78.43	2.05	-	-	109.9	1.95	-	-	123.4	2.14
Average	36.48	3.72	7.82	4.45	79.18	2.43	26.92	1.82	117.97	2.38	43.77	1.68	148.64	2.64	81.73	1.88	N/A	N/A	107.26	2.05	N/A	N/A	124.74	1.85

Table A10: Unconfined Compressive Strength Test Data of CF Treated Soil-2 (A-4)

		4% CF, 0 days curing				**4% CF, 1 days curing**				**4% CF, 3 days curing**				**4% CF, 7 days curing**				**4% CF, 14 days curing**				**4% CF, 28 days curing**			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
4% CF, Soil-2 (A-4)	1	18.53	12.09	5.15	15.01	29.17	9.59	5.37	15.00	29.82	10.59	17.57	13.10	29.56	10.33	4.00	8.98	-	-	7.79	10.59	-	-	5.70	4.14
	2	19.91	10.34	5.63	15.03	28.24	13.34	4.88	14.85	28.60	9.32	13.10	11.34	27.38	8.82	11.59	15.00	-	-	23.21	15.00	-	-	8.98	7.82
	3	25.52	10.33	6.29	15.02	27.65	10.33	8.45	15.02	22.21	7.81	21.96	10.33	37.15	8.32	4.88	12.59	-	-	20.67	11.34	-	-	8.89	14.85
	Average	21.32	10.92	5.69	15.02	28.35	11.09	6.23	14.96	26.88	9.24	17.54	11.59	31.36	9.16	6.82	12.19	N/A	N/A	17.22	12.31	N/A	N/A	7.86	8.94

12% CF, Soil-2 (A-4)		**12% CF, 0 days curing**				**12% CF, 01 days curing**				**12% CF, 3 days curing**				**12% CF, 7days curing**				**12% CF,,14 days curing**				**12% CF, 28 days curing**			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
	1	38.26	6.31	3.57	15.01	47.37	6.07	5.16	15.01	52.84	6.57	7.16	15.00	52.32	5.05	5.88	15.01	-	-	5.64	15.01	-	-	5.85	14.96
	2	36.71	4.86	2.19	15.02	42.91	6.56	4.42	15.03	46.16	4.06	2.99	15.02	58.35	4.65	5.41	15.01	-	-	7.86	15.03	-	-	5.19	15.01
	3	35.60	5.82	4.29	15.00	53.50	5.55	4.29	15.03	49.63	5.81	3.88	13.60	60.03	3.45	5.13	15.02	-	-	10.13	15.02	-	-	5.48	15.03
	Average	36.86	5.66	3.35	15.01	47.93	6.06	4.63	15.02	49.54	5.48	4.68	14.54	56.90	4.38	5.47	15.01	N/A	N/A	7.88	15.02	N/A	N/A	5.51	15.00

25% CF, Soil-2 (A-4)		25% CF, 0 days curing				25% CF, 1 days curing				25% CF, 3 days curing				25% CF, 7 days curing				25% CF, 14 days curing				25% CF, 28 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
	1	43.39	5.56	7.79	15.01	37.66	3.66	12.02	10.58	43.31	6.06	14.93	9.58	51.36	5.05	14.44	6.82	-	-	6.77	9.33	-	-	5.28	5.54
	2	48.09	3.45	8.16	15.00	43.90	4.86	14.47	10.57	48.71	4.06	16.90	6.06	61.78	4.06	16.89	6.32	-	-	9.95	7.32	-	-	7.31	4.54
	3	44.73	4.66	9.14	11.59	50.42	4.96	14.06	9.59	49.22	4.76	9.30	6.32	59.40	4.16	10.16	4.36	-	-	8.12	7.83	-	-	9.71	5.56
	Average	45.40	4.56	8.36	13.87	43.99	4.49	13.52	10.25	47.08	4.96	13.71	7.32	57.51	4.42	13.83	5.83	N/A	N/A	8.28	8.16	N/A	N/A	7.43	5.21

Table A11: Unconfined Compressive Strength Test Data of FA Treated Soil-2 (A-4)

		10% FA, 0 days curing				10% FA, 1 days curing				10% FA, 3 days curing				10% FA, 7 days curing				10% FA, 14 days curing				10% FA, 28 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
10% FA, Soil-2 (A-4)	1	42.08	3.85	5.00	15.02	45.08	2.25	3.82	8.33	sample	broken	5.68	3.55	82.99	2.05	2.89	1.75	-	-	9.22	1.85	-	-	14.11	2.44
	2	40.44	3.46	6.38	8.25	54.13	2.05	4.62	5.31	55.63	2.35	5.46	4.87	73.38	2.04	4.15	3.85	-	-	4.51	2.56	-	-	15.7	1.75
	3	44.41	3.76	6.14	10.84	58.16	3.35	5.66	5.06	63.12	2.34	4.68	2.34	78.50	2.15	5.28	3.25	-	-	10.54	2.65	-	-	10.6	3.45
	Average	42.31	3.69	5.84	11.37	52.46	2.55	4.70	6.23	59.37	2.34	5.27	3.59	78.29	2.08	4.10	2.95	N/A	N/A	8.09	2.35	N/A	N/A	13.47	2.55

15% FA, Soil-2 (A-4)

	15% FA, 0 days curing				15% FA, 01 days curing				15% FA, 3 days curing				15% FA, 7days curing				15% FA,14 days curing				15% FA,28 days curing			
Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	42.94	3.36	3.96	15.01	75.59	2.04	sample	broken	72.92	2.94	8.71	3.14	84.69	1.95	22.89	2.25	-	-	25.03	2.25	-	-	41.98	1.54
2	53.48	3.14	4.20	13.59	79.97	2.15	3.92	3.96	87.82	2.35	12.81	2.55	88.38	2.25	21.90	2.05	-	-	11.69	1.55	-	-	43.04	1.95
3	53.81	2.14	5.14	15.03	71.42	2.35	5.18	15.02	81.44	2.75	10.94	2.04	88.58	2.35	20.16	2.34	-	-	26.24	2.85	-	-	43.64	2.74
Average	50.08	2.88	4.43	14.54	75.66	2.18	4.55	9.49	80.73	2.68	10.82	2.58	87.22	2.18	21.65	2.21	N/A	N/A	20.99	2.22	N/A	N/A	42.89	2.08

		25% FA, 0 days curing				25% FA, 1 days curing				25% FA, 3 days curing				25% FA, 7 days curing				25% FA,, 14 days curing				25% FA, 28 days curing			
25% FA, Soil-2 (A-4)	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
	1	46.1	2.95	2.01	15	105	3.36	2.49	14.96	94.9	2.15	4.06	2.44	88.6	2.82	7.04	2.55	-	-	41.5	2.15	-	-	67.25	1.14
	2	60.7	3.75	3.15	15	90.7	2.76	1.79	3.06	96.7	2.84	3.5	3.05	72.4	3.16	15.3	2.95	-	-	44.7	0.94	-	-	51.41	1.55
	3	52.6	2.85	3.08	14.1	76.9	2.34	2.07	3.66	84.4	1.54	2.45	2.85	74.3	2.84	20.2	2.35	-	-	46.4	1.85	-	-	67.87	2.06
	Average	53.13	3.18	2.75	14.72	90.75	2.82	2.12	7.23	92.00	2.18	3.34	2.78	78.40	2.94	14.15	2.62	N/A	N/A	44.21	1.65	N/A	N/A	62.18	1.58

Table A12: Unconfined Compressive Strength Test Data of LKD+FA Treated Soil-2 (A-4)

		2% LKD & 8% FA, 0 days curing				2% LKD & 8% FA, 1 days curing				2% LKD & 8% FA, 3 days curing				2% LKD & 8% FA, 7 days curing				2% LKD & 8% FA, 14 days curing				2% LKD & 8% FA, 28 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
2%LKD+8% FA, Soil-2 (A-4)	1	57.97	3.15	8.55	2.95	135.16	2.65	72.37	0.89	163.36	2.46	76.28	1.15	**169.67	2.75	94.05	1.54	-	-	112.41	1.85	-	-	146.42	1.24
	2	65.72	3.15	9.92	2.35	162.60	3.86	83.44	1.25	208.12	2.84	74.59	2.15	203.23	3.45	98.15	2.56	-	-	95.44	2.15	-	-	108.88	0.96
	3	87.90	2.95	11.35	3.65	178.41	2.35	80.64	1.63	190.05	2.56	70.20	1.74	209.38	2.34	84.78	2.14	-	-	118.30	1.75	-	-	122.06	1.15
	Average	70.53	3.08	9.94	2.98	158.72	2.95	78.82	1.26	187.18	2.62	73.69	1.68	206.30	2.85	92.33	2.08	N/A	N/A	108.72	1.92	N/A	N/A	125.79	1.12

** Discarded value

2%LKD+5% FA, Soil-2 (A-4)

	2% LKD & 5% FA, 0 days curing				**2% LKD & 5% FA, 01 days curing**				**2% LKD & 5% FA, 3 days curing**				**2% LKD & 5% FA, 7days curing**				**2% LKD & 5% FA,14 days curing**				**2% LKD & 5% FA,28 days curing**			
Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	87.08	2.85	-	-	118.38	2.85	55.45	1.24	152.20	2.46	82.98	0.97	160.69	3.05	84.99	2.05	-	-	107.24	1.02	-	-	88.14	2.54
2	49.64	2.64	10.43	2.96	120.05	2.55	52.98	1.64	134.51	2.16	78.77	1.55	154.35	2.53	78.59	1.45	-	-	119.64	1.24	-	-	82.69	1.45
3	77.99	2.45	10.16	2.75	141.33	3.05	11.38	1.35	149.48	2.04	72.43	1.44	166.86	2.67	92.57	1.65	-	-	103.07	1.15	-	-	97.72	1.25
Average	82.53	2.65	10.29	2.85	126.59	2.82	54.21	1.41	145.40	2.22	78.06	1.32	160.63	2.75	85.38	1.71	N/A	N/A	109.98	1.14	N/A	N/A	89.52	1.75

Table A13: Unconfined Compressive Strength Test Data of LKD & DLKD Treated Soil-2 (A-4)

	Test	4% LKD, 0 days curing				4% LKD, 01 days curing				4% LKD, 03 days curing				4% LKD, 07 days curing				4% LKD, 14 days curing		4% LKD, 28 days curing	
		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Soaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
4% LKD, Soil-2 (A-4)	1	19.92	2.34	2.32	4.75	34.06	3.54	15.41	1.35	45.12	2.76	13.12	2.53	43.25	1.85	15.67	2.35	19.06	4.15	23.94	2.15
	2	23.00	3.34	4.57	4.56	47.20	3.26	10.56	3.16	23.93	0.87	13.86	4.16	29.50	3.05	15.74	2.05	15.27	4.56	24.62	3.25
	3	15.68	1.74	1.92	4.25	27.86	3.15	13.53	3.85	59.74	3.15	12.56	2.35	37.53	3.25	16.06	1.75	15.65	5.31	25.82	2.85
	Average	19.53	2.48	2.94	4.52	36.38	3.32	13.17	2.79	42.93	2.26	13.18	3.01	36.76	2.71	15.82	2.05	16.66	4.67	24.80	2.75

17% DLKD, Soil-2 (A-4)

Test	**17% DLKD, 0 days curing**				**17% DLKD, 01 days curing**				**17% DLKD, 03 days curing**				**17% DLKD, 07 days curing**				**17% DLKD, 14 days curing**		**17% DLKD, 28 days curing**	
	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Soaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	59.88	3.45	5.90	15.03	50.97	2.95	7.43	4.15	63.78	2.46	20.16	4.46	81.36	2.64	33.04	3.76	44.08	3.84	36.02	2.85
2	59.17	3.55	3.43	7.82	47.16	3.64	8.66	4.26	**31.82	**3.95	22.27	4.36	64.66	2.16	27.49	1.96	65.17	3.35	-	-
3	54.02	3.65	5.48	7.57	42.72	3.15	9.95	6.57	64.88	3.36	19.86	4.56	67.28	2.76	39.76	3.75	43.06	2.36	78.24	3.55
Average	57.69	3.55	4.94	10.14	46.95	3.25	8.68	5.00	64.33	2.91	20.76	4.46	71.10	2.52	33.43	3.15	50.77	3.18	57.13	3.20

** Discarded value

Table A 14: Unconfined Compressive Strength Test Data of CKD Treated Soil-3 (A-7-6)

		6% CKD, 0 days curing				6% CKD, 1 days curing				6% CKD, 3 days curing				6% CKD, 7 days curing				6% CKD, 14 days curing				6% CKD, 28 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
6% CKD, Soil-3 (A-7-6)	1	71.25	3.24	12.51	3.36	218.58	2.35	36.79	1.34	214.82	2.65	105.37	1.54	203.85	1.75	129.40	2.45	-	-	180.95	1.95	-	-	152.22	1.45
	2	81.80	3.46	14.67	3.85	167.73	1.55	56.04	1.75	192.35	2.76	83.81	2.15	236.25	2.05	97.40	2.95	-	-	140.11	1.24	-	-	145.52	1.45
	3	82.69	2.85	15.88	4.15	160.08	2.25	41.17	1.75	262.59	2.55	97.23	2.45	288.85	2.26	88.35	1.25	-	-	146.01	1.75	-	-	107.39	1.94
	Average	78.58	3.18	14.35	3.79	163.91	2.05	44.67	1.61	223.26	2.66	95.47	2.05	242.98	2.02	105.05	2.22	N/A	N/A	155.69	1.65	N/A	N/A	148.87	1.61

** Discarded value

8% CKD, Soil-3 (A-7-6)

Test	8% CKD, 0 days curing				8% CKD, 01 days curing				8% CKD, 3 days curing				8% CKD, 7days curing				8% CKD,14 days curing				8% CKD,28 days curing			
	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	69.57	2.06	19.02	2.45	154.69	1.85	74.17	1.71	241.68	2.76	101.76	1.55	229.89	2.05	95.64	2.25	-	-	230.20	1.55	-	-	201.25	1.76
2	56.36	1.94	20.19	3.06	162.05	2.26	62.70	1.76	209.80	1.65	124.17	2.86	233.52	2.04	134.97	3.05	-	-	152.17	2.45	-	-	221.71	2.55
3	68.74	2.45	18.96	3.06	146.46	2.65	66.43	2.15	209.91	2.05	111.45	2.66	254.72	2.25	169.68	1.84	-	-	164.13	3.36	-	-	218.75	2.35
Average	64.89	2.15	19.39	2.86	154.40	2.26	67.77	1.87	220.46	2.15	112.46	2.36	239.38	2.11	133.43	2.38	N/A	N/A	182.17	2.45	N/A	N/A	213.90	2.22

4% CKD, Soil-3 (A-7-6)	4% CKD, 0 days curing				4% CKD, 1 days curing				4% CKD, 3 days curing				4% CKD, 7 days curing				4% CKD, 14 days curing				4% CKD, 28 days curing			
Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	114.43	4.56	16.18	4.15	137.04	4.86	52.36	1.55	171.53	3.75	69.24	1.54	151.04	2.76	79.57	4.44	-	-	86.38	2.25	-	-	140.76	2.15
2	101.34	4.85	9.32	2.95	110.60	3.87	50.36	3.45	171.94	2.85	52.39	2.45	151.04	5.31	55.51	2.45	-	-	91.64	2.95	-	-	112.90	3.05
3	90.65	3.96	13.49	4.86	137.48	3.66	61.63	3.55	185.21	2.34	61.75	2.95	195.17	2.35	109.19	1.65	-	-	115.17	3.45	-	-	97.91	2.24
Average	102.14	4.46	13.00	3.99	128.38	4.13	54.79	2.85	176.23	2.98	61.13	2.32	165.75	3.47	81.42	2.84	N/A	N/A	97.73	2.88	N/A	N/A	117.19	2.48

Table A15: Unconfined Compressive Strength Test Data of CF Treated Soil-3 (A-7-6)

		4% CF, 0 days curing				4% CF, 1 days curing				4% CF, 3 days curing				4% CF, 7 days curing				4% CF, 14 days curing				4% CF, 28 days curing			
4% CF, Soil-3 (A-7-6)	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
	1	98.12	3.96	5.48	7.58	82.92	3.96	2.66	15.01	78.66	4.44	8.75	15.01	52.97	3.06	4.46	12.86	-	-	4.69	9.07	-	-	6.15	10.09
	2	84.84	3.35	6.04	12.34	77.82	3.94	2.96	15.01	58.06	3.66	6.68	13.35	73.66	3.05	4.02	12.35	-	-	6.89	11.83	-	-	4.96	7.32
	3	121.75	4.67	4.94	12.83	86.07	3.56	4.84	15.01	78.58	3.75	7.39	15.01	74.10	3.46	4.27	7.83	-	-	4.42	14.85	-	-	6.14	7.07
	Average	101.57	4.00	5.49	10.92	82.27	3.82	3.49	15.01	71.77	3.95	7.60	14.46	66.91	3.19	4.25	11.01	N/A	N/A	5.33	11.92	N/A	N/A	5.75	8.16

15% CF, Soil-3 (A-7-6)			Test 1	Test 2	Test 3	Average
15% CF, 0 days curing	Unsoaked	Stress, psi	49.72	49.53	43.24	47.50
		Strain, %	5.57	4.66	4.56	4.93
	Soaked	Stress, psi	3.11	4.54	4.26	3.97
		Strain, %	11.84	10.33	6.57	9.58
15% CF, 01 days curing	Unsoaked	Stress, psi	60.10	49.55	39.92	49.86
		Strain, %	4.75	4.16	3.35	4.09
	Soaked	Stress, psi	5.35	6.50	8.16	6.67
		Strain, %	6.07	3.76	6.07	5.30
15% CF, 3 days curing	Unsoaked	Stress, psi	50.29	58.02	55.21	54.51
		Strain, %	4.27	5.06	5.05	4.79
	Soaked	Stress, psi	8.34	10.53	4.89	7.92
		Strain, %	3.95	4.95	3.75	4.21
15% CF, 7days curing	Unsoaked	Stress, psi	51.86	48.28	48.93	49.69
		Strain, %	3.75	2.65	5.82	4.07
	Soaked	Stress, psi	10.20	3.58	5.95	6.58
		Strain, %	4.16	8.85	3.35	5.45
15% CF,,14 days curing	Unsoaked	Stress, psi	-	-	-	N/A
		Strain, %	-	-	-	N/A
	Soaked	Stress, psi	4.77	12.33	7.95	8.35
		Strain, %	7.07	5.31	3.45	5.28
15% CF, 28 days curing	Unsoaked	Stress, psi	-	-	-	N/A
		Strain, %	-	-	-	N/A
	Soaked	Stress, psi	10.09	broken	9.75	9.92
		Strain, %	4.56	sample	4.46	4.51

25% CF, Soil-3 (A-7-6)

Test	25% CF, 0 days curing				25% CF, 1 days curing				25% CF, 3 days curing				25% CF, 7 days curing				25% CF, 14 days curing				25% CF, 28 days curing			
	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	55.47	3.45	6.55	7.31	47.34	4.05	4.26	5.06	48.05	4.76	9.83	4.16	59.47	4.85	**2.45	**9.57	-	-	15.83	4.15	-	-	14.33	3.56
2	80.43	5.31	4.75	7.58	39.29	5.06	5.26	4.45	62.87	4.45	9.69	3.45	59.41	4.16	broken	sample	-	-	6.58	4.86	-	-	12.44	4.55
3	65.77	4.75	4.25	6.81	48.43	3.55	3.35	4.66	64.02	4.47	9.10	3.56	48.49	3.04	13.30	3.25	-	-	15.30	3.65	-	-	6.44	3.25
Average	67.22	4.50	5.18	7.24	45.02	4.22	4.29	4.72	58.31	4.56	9.54	3.72	55.79	4.02	13.30	3.25	N/A	N/A	12.57	4.22	N/A	N/A	11.07	3.79

** Discarded value

Table A16: Unconfined Compressive Strength Test Data of FA Treated Soil-3 (A-7-6)

		10% FA, 0 days curing				10% FA, 1 days curing				10% FA, 3 days curing				10% FA, 7 days curing				10% FA, 14 days curing				10% FA, 28 days curing			
10% FA, Soil-3 (A-7-6)	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
	1	43.44	8.82	5.42	4.66	78.00	5.06	6.21	3.44	90.97	4.95	7.59	2.76	127.88	3.06	27.96	2.36	-	-	49.72	2.55	-	-	37.60	3.76
	2	61.08	6.07	4.46	5.04	99.47	5.05	6.27	3.35	77.55	4.86	10.44	3.05	93.54	5.55	21.79	1.94	-	-	42.96	2.45	-	-	48.65	1.84
	3	76.35	6.57	6.41	5.55	97.81	4.75	6.46	4.34	138.93	2.85	6.97	4.26	112.20	3.24	23.03	1.25	-	-	32.86	1.14	-	-	33.66	2.64
	Average	60.29	7.15	5.43	5.09	91.76	4.95	6.31	3.71	102.48	4.22	8.34	3.35	111.21	3.95	24.26	1.85	N/A	N/A	41.85	2.05	N/A	N/A	39.97	2.75

15% FA, Soil-3 (A-7-6)

	15% FA, 0 days curing				**15% FA, 01 days curing**				**15% FA, 3 days curing**				**15% FA, 7days curing**				**15% FA,14 days curing**				**15% FA,28 days curing**			
Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	52.37	4.45	5.42	6.82	100.51	3.46	27.80	2.45	108.65	4.06	54.75	2.55	118.63	1.85	69.76	3.86	-	-	59.83	3.86	-	-	85.57	2.25
2	55.00	3.75	3.62	5.57	94.03	4.25	28.04	4.37	77.18	3.45	35.13	2.75	130.77	3.26	64.54	4.45	-	-	72.59	1.95	-	-	47.12	2.75
3	48.88	6.06	3.99	5.31	71.65	3.36	33.19	5.57	87.53	3.45	54.55	4.26	124.06	3.94	69.67	2.35	-	-	63.42	4.46	-	-	93.82	2.45
Average	52.08	4.75	4.34	5.90	88.73	3.69	29.68	4.13	91.12	3.65	48.14	3.19	124.49	3.02	67.99	3.55	N/A	N/A	65.28	3.42	N/A	N/A	75.50	2.48

25% FA, Soil-3 (A-7-6)

Test	25% FA, 0 days curing				25% FA, 1 days curing				25% FA, 3 days curing				25% FA, 7 days curing				25% FA,, 14 days curing				25% FA, 28 days curing			
	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	85.57	4.96	5.12	8.08	84.04	3.36	8.77	3.34	104.34	2.76	62.85	2.25	**63.62	2.57	63.86	2.25	-	-	99.03	1.54	-	-	59.54	1.52
2	56.17	4.36	4.91	6.82	79.24	2.56	9.72	3.16	118.49	2.35	22.13	4.45	117.43	2.05	94.53	1.25	-	-	81.05	2.05	-	-	88.62	3.65
3	68.15	3.26	6.73	7.05	94.38	2.85	10.21	3.36	93.25	2.15	57.92	1.55	122.47	2.15	33.31	1.34	-	-	54.06	3.85	-	-	74.42	1.75
Average	69.96	4.19	5.59	7.32	85.89	2.92	9.57	3.29	105.36	2.42	47.63	2.75	119.95	2.26	63.90	1.61	N/A	N/A	78.05	2.48	N/A	N/A	74.19	2.31

** Discarded value

Table A17: Unconfined Compressive Strength Test Data of LKD+FA Treated Soil-3 (A-7-6)

2%LKD+8% FA, Soil-3 (A-7-6)		2% LKD & 8% FA, 0 days curing				2% LKD & 8% FA, 1 days curing				2% LKD & 8% FA, 3 days curing				2% LKD & 8% FA, 7 days curing				2% LKD & 8% FA, 14 days curing				2% LKD & 8% FA, 28 days curing			
	Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
	1	71.35	2.25	4.58	5.81	80.12	3.45	broken	sample	81.46	1.44	32.48	1.35	98.47	1.44	55.00	2.15	-	-	48.55	3.05	-	-	55.24	1.05
	2	62.74	2.44	4.67	14.60	72.05	2.26	14.20	0.90	94.50	2.25	22.30	1.84	93.76	1.75	40.70	2.24	-	-	56.08	3.55	-	-	19.35	2.75
	3	58.24	2.15	5.22	5.31	93.21	2.25	17.73	2.35	72.51	3.24	35.69	3.55	77.83	3.04	45.62	2.65	-	-	34.49	3.24	-	-	72.64	2.05
	Average	64.11	2.28	4.82	8.57	81.80	2.65	15.96	1.62	82.83	2.31	30.15	2.25	90.02	2.08	47.11	2.35	N/A	N/A	46.38	3.28	N/A	N/A	63.94	1.95

** Discarded value

2%LKD+5% FA, Soil-3 (A-7-6)

Test	2% LKD & 5% FA, 0 days curing				2% LKD & 5% FA, 01 days curing				2% LKD & 5% FA, 3 days curing				2% LKD & 5% FA, 7days curing				2% LKD & 5% FA,14 days curing				2% LKD & 5% FA,28 days curing			
	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	68.18	2.85	4.16	4.85	119.45	2.15	10.28	2.55	110.43	1.81	22.26	1.85	115.93	3.65	37.81	3.45	-	-	55.76	2.45	-	-	55.27	1.45
2	67.17	2.15	5.75	5.56	107.24	1.95	9.40	2.85	96.32	1.75	19.25	2.66	101.52	2.95	55.68	1.24	-	-	43.62	1.15	-	-	57.84	1.56
3	82.45	2.16	4.00	3.56	101.36	2.25	11.17	2.85	110.45	1.55	21.82	2.05	111.63	3.25	43.03	1.84	-	-	64.18	0.99	-	-	57.41	1.34
Average	72.60	2.39	4.64	4.66	109.35	2.12	10.28	2.75	105.74	1.70	21.11	2.19	109.69	3.28	45.51	2.18	N/A	N/A	54.52	1.53	N/A	N/A	56.84	1.45

3%LKD+9% FA, Soil-3 (A-7-6)

	3% LKD & 9% FA, 0 days curing				3% LKD & 9% FA, 01 days curing				3% LKD & 9% FA, 3 days curing				3% LKD & 9% FA, 7days curing				3% LKD & 9% FA,14 days curing				3% LKD & 9% FA,28 days curing			
Test	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	64.40	3.15	15.71	3.45	139.43	3.15	82.96	2.55	128.46	2.24	84.34	3.06	128.9	2.04	**152.55	1.65	-	-	104.31	4.05	-	-	133.78	4.96
2	66.57	3.45	11.25	2.35	134.98	3.05	76.82	2.75	120.77	2.76	101.08	3.36	broken	sample	139.10	3.36	-	-	139.27	3.86	-	-	125.81	4.76
3	72.13	3.96	8.88	1.74	137.12	2.45	63.04	3.55	115.40	2.45	82.80	3.05	116.7	1.65	121.15	2.45	-	-	143.32	3.25	-	-	132.12	4.45
Average	67.70	3.52	11.94	2.52	137.18	2.88	74.27	2.95	121.54	2.48	89.41	3.16	122.81	1.85	130.12	2.48	N/A	N/A	128.97	3.72	N/A	N/A	130.57	4.73

** Discarded value

Table A18: Unconfined Compressive Strength Test Data of LKD & DLKD Treated Soil-3 (A-7-6)

	Test	6% LKD, 0 days curing				6% LKD, 01 days curing				6% LKD, 03 days curing				6% LKD, 07 days curing				6% LKD, 14 days curing		6% LKD, 28 days curing	
		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Soaked		Soaked	
		Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
6%LKD, Soil-3 (A-7-6)	1	40.04	3.25	5.15	2.85	46.87	3.35	25.98	2.05	63.24	2.75	16.75	3.65	22.06	3.65	30.63	3.36	31.76	4.95	47.16	2.64
	2	43.32	3.06	4.95	2.05	45.32	5.83	23.71	1.65	38.63	1.85	17.27	2.75	60.99	3.66	38.12	3.05	28.40	3.76	46.51	2.34
	3	25.26	1.75	7.32	2.75	46.03	3.15	31.16	2.05	31.02	2.25	11.09	0.68	55.67	1.85	37.97	1.95	33.15	3.84	48.04	3.65
	Average	36.21	2.68	5.81	2.55	46.07	4.11	26.95	1.92	44.29	2.28	15.03	2.36	46.24	3.05	35.57	2.78	31.10	4.19	47.24	2.88

16%LKD, Soil-3 (A-7-6)

Test	16% DLKD, 0 days curing				16% DLKD, 01 days curing				16% DLKD, 03 days curing				16% DLKD, 07 days curing				16% DLKD, 14 days curing		16% DLKD, 28 days curing	
	Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Soaked		Soaked	
	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
1	59.71	3.66	1.65	5.53	73.01	2.06	10.12	1.56	68.83	5.56	10.96	2.24	116.30	3.25	31.33	4.46	32.19	3.96	45.51	1.55
2	64.12	3.06	5.46	5.56	71.03	2.25	13.95	2.75	38.74	6.57	16.26	1.75	116.29	3.15	28.11	3.25	39.20	4.26	44.64	1.94
3	57.25	2.95	broken	sample	50.06	3.36	9.48	1.74	**20.36	**2.35	13.95	2.36	113.89	3.16	24.46	3.15	43.84	6.09	45.35	3.36
Average	60.36	3.22	3.55	5.54	64.70	2.55	11.18	2.02	53.78	6.07	13.72	2.12	115.49	3.19	27.96	3.62	38.41	4.77	45.17	2.28

** Discarded value

Table A19: 96-hr Soaked California Bearing Ratio Test Data

		Test-1		Test-2		Test-3		Average		CBR	Increase (%)
		CBR-1	CBR-2	CBR-1	CBR-2	CBR-1	CBR-2	CBR-1	CBR-2		
Soil-1 (CL, A-6)	Untreated	3.9	4.43	2.4	3.13	2.4	2.8	2.9	3.5	3.5	0
	8%CKD	7.2	8	5.8	6.67	9	10	7.3	8.2	8.2	138
	3%LKD+9%FA	27.4	24.2	32.8	31.53	40	29.67	33.4	28.5	33.4	867
Soil-2 (ML, A-4)	Untreated	2	2.57	1.98	2.42	2	2.43	2.0	2.5	2.5	0
	4%CKD	51	59.33	50.7	58.33	48.1	51.33	49.9	56.3	56.3	2177
	2%LKD+5%FA	45.1	41.07	54.4	50.67	32.5	43	44.0	44.9	44.9	1716
Soil-3 (ML, A-7-6)	Untreated	10.08	8.11	4.12	4.45	6	6.31	6.7	6.3	6.7	0
	4%CKD	76.4	75.13	48.7	49.19	40.88	38.47	55.3	54.3	55.3	722
	3%LKD+9%FA	44.7	47.12	43.34	38.33	61.4	56.53	49.8	47.3	49.8	640
	15% FA	39	36.27	37.55	32.63	30.4	34.53	35.7	34.5	35.7	429

Table A20: UnSoaked California Bearing Ratio Test Data

		Test-1		Test-2		Test-3		Average		CBR	Increase (%)
		CBR-1	CBR-2	CBR-1	CBR-2	CBR-1	CBR-2	CBR-1	CBR-2		
Soil-1 (CL, A-6)	Untreated	22.7	24	16.9	18.83	10.52	15.92	16.7	19.6	19.6	0
	8%CKD	31.95	32.43	20.96	21.23	21.44	26.91	24.8	26.9	26.9	37
	3%LKD+9%FA	39.5	41.6	24.27	26.6	33.9	35	32.6	34.4	34.4	76
Soil-2 (ML, A-4)	Untreated	9.5	13.9	19.5	20	15.5	18.7	14.8	17.5	17.5	0
	4%CKD	26.4	30.5	22.3	24.3	24.3	24.4	24.3	26.4	26.4	51
	2%LKD+5%FA	41.5	42.4	38.1	35	29	27.4	36.2	34.9	36.2	106
Soil-3 (ML, A-7-6)	Untreated	22.74	23.64	23.8	22.8	28.4	23.99	25.0	23.5	25.0	0
	4%CKD	23	23.6	25.6	22	77.5	78	42.0	41.2	42.0	68
	3%LKD+9%FA	29.4	32.5	31.7	30.7	45.5	44.6	35.5	35.9	35.9	44
	15% FA	25.1	26.1	26.2	26.6	30.9	32.6	27.4	28.4	28.4	14

Table A21: Laboratory Freeze/thaw Test Data (Capillary soaking at the end of design cycle)

		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-1	**8% CKD**	1	63.56	2.84	50.85	3.36	46.57	2.95	25.24	3.76	11.30	5.07
		2	79.88	2.54	**34.34	**2.35	44.61	3.06	15.04	4.15	7.90	4.97
		3	72.28	2.64	49.33	3.16	44.80	2.55	26.13	4.36	9.93	5.57
		Average	71.91	2.67	50.09	3.26	45.32	2.85	22.14	4.09	9.71	5.20
Soil-1	**3%LKD + 9%FA**	Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
		1	88.34	3.05	**3.61	**3.90	33.93	2.56	28.02	2.15	21.74	4.05
		2	86.69	3.65	73.73	2.66	**24.43	**3.55	45.77	2.45	33.89	2.55
		3	82.78	3.15	64.77	2.55	55.64	4.01	46.40	2.54	16.21	4.36
		Average	85.94	3.29	69.25	2.60	44.78	3.28	40.06	2.38	23.94	3.66
Soil-2	**4% CKD**	Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
		1	82.02	1.54	22.74	3.15	12.08	6.06	10.44	5.33	12.43	4.73
		2	84.74	2.05	25.00	4.05	12.09	5.05	10.65	4.97	10.33	4.35
		3	78.43	2.05	25.55	3.45	14.49	5.05	8.36	4.76	11.83	4.86
		Average	81.73	1.88	24.43	3.55	12.89	5.39	9.82	5.02	11.53	4.65
Soil-2	**2%LKD + 5%FA**	Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
		1	84.99	2.05	7.34	5.31	7.25	5.31	6.77	4.76	7.16	3.56
		2	78.59	1.45	9.16	4.65	6.89	4.66	7.12	4.86	4.18	5.05
		3	92.57	1.65	11.86	4.65	7.30	5.30	7.42	4.46	5.11	3.85
		Average	85.38	1.71	9.45	4.87	7.15	5.09	7.10	4.70	5.48	4.15

		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-3	**4% CKD**	1	79.57	4.44	49.84	3.76	35.27	3.85	30.03	4.06	33.55	3.14
		2	55.51	2.45	42.79	2.76	33.00	3.56	34.26	4.35	27.87	3.66
		3	109.19	1.65	63.30	2.95	24.26	3.35	37.64	3.75	17.82	3.45
		Average	81.42	2.84	51.98	3.15	30.84	3.59	33.98	4.05	26.41	3.42
		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-3	**3%LKD + 9%FA**	1	**152.55	**1.65	78.17	3.05	46.25	3.05	50.54	3.96	24.49	3.25
		2	139.10	3.36	66.17	2.95	48.61	3.25	37.76	3.96	46.76	3.16
		3	121.15	2.45	80.78	2.76	54.26	3.15	54.57	4.46	36.99	1.45
		Average	130.12	2.48	75.04	2.92	49.71	3.15	47.63	4.12	36.08	2.62
		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-3	**15% FA**	1	69.76	3.86	19.43	4.86	**5.98	**2.45	24.59	5.57	17.72	4.45
		2	64.54	4.45	16.78	3.46	15.31	4.16	19.94	5.57	17.37	6.07
		3	69.67	2.35	12.98	4.45	16.39	5.31	**29.43	**4.17	18.26	3.95
		Average	67.99	3.55	16.40	4.26	15.85	4.73	22.26	5.10	17.79	4.82

** Discarded Value

Table A22: Laboratory Freeze/thaw Test Data (Capillary soaking during every thawing period)

		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-1	**8% CKD**	1	63.56	2.84	37.04	0.87	17.99	0.63	4.76	1.44	broken	sample
		2	79.88	2.54	51.65	4.56	16.40	1.54	5.61	2.04	broken	sample
		3	72.28	2.64	55.32	3.25	18.82	1.55	8.23	3.05	broken	sample
		Average	71.91	2.67	48.00	2.89	17.74	1.24	6.20	2.18	N/A	N/A
		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-1	**3%LKD + 9%FA**	1	88.34	3.05	80.53	2.34	29.63	3.75	14.14	4.75	broken	sample
		2	86.69	3.65	83.80	2.95	17.82	4.65	10.50	3.36	broken	sample
		3	82.78	3.15	74.13	2.35	20.23	4.46	11.57	4.65	broken	sample
		Average	85.94	3.29	79.49	2.55	22.56	4.29	12.07	4.25	N/A	N/A
		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-2	**4% CKD**	1	82.02	1.54	60.10	1.83	22.92	3.84	8.72	3.36	broken	sample
		2	84.74	2.05	74.31	3.05	24.64	4.25	14.39	5.30	broken	sample
		3	78.43	2.05	57.69	3.25	34.92	4.45	11.59	3.75	broken	sample
		Average	81.73	1.88	64.03	2.71	27.50	4.18	11.57	4.14	N/A	N/A
		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-2	**2%LKD + 5%FA**	1	84.99	2.05	9.83	2.95	10.73	5.31	4.77	6.50	broken	sample
		2	78.59	1.45	13.59	3.06	9.74	5.05	3.43	3.65	broken	sample
		3	92.57	1.65	22.04	3.55	8.04	4.05	4.97	4.35	broken	sample
		Average	85.38	1.71	15.15	3.19	9.50	4.81	4.39	4.83	N/A	N/A

		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-3	**4% CKD**	1	79.57	4.44	67.97	2.95	29.25	5.04	13.34	4.16	broken	sample
		2	55.51	2.45	60.58	4.56	27.49	3.85	19.60	5.05	4.21	6.56
		3	109.19	1.65	52.86	2.04	27.69	6.07	14.06	6.57	13.23	4.67
		Average	81.42	2.84	60.47	3.18	28.14	4.99	15.67	5.26	8.72	5.62
		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-3	**3%LKD + 9%FA**	1	**152.55	**1.65	45.34	4.16	32.37	5.30	4.28	3.05	7.52	4.46
		2	139.10	3.36	57.34	4.26	30.58	5.82	14.17	4.44	4.82	2.86
		3	121.15	2.45	70.57	1.65	32.35	3.55	14.71	5.06	2.04	1.55
		Average	130.12	2.90	57.75	3.36	31.77	4.89	11.05	4.18	4.79	2.96
		Test Number	Cycle-0		Cycle-1		Cycle-3		Cycle-7		Cycle-12	
			Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %	Stress, psi	Strain, %
Soil-3	**15% FA**	1	69.76	3.86	46.06	2.25	10.43	3.63	5.03	5.56	3.99	4.55
		2	64.54	4.45	45.84	2.86	5.93	4.06	6.54	6.32	5.00	6.82
		3	69.67	2.35	38.66	3.65	11.50	5.31	5.50	6.56	5.98	6.32
		Average	67.99	3.55	43.52	2.92	9.29	4.33	5.69	6.15	4.99	5.90

** Discarded Value

Table A23: Chemical Composition of Fly Ash

Analyte	Weight %
SiO_2	37.86
Al_2O_3	18.07
Fe_2O_3	5.77
CaO	21.51
MgO	4.36
SO_3	2.65
Na_2O	1.33
K_2O	0.87
TiO_2	1.21
P_2O_5	1.14
Mn_2O_3	0.03
SrO	0.29
Cr_2O_3	0.02
ZnO	0.02
BaO	0.68
L.O.I. (950°C)[2]	4.02
Total	99.84

APPENDIX B

CONSTRUCTION SPECIFICATIONS FROM DIFFERENT AGENCIES

APPENDIX B 1

CONSTRUCTION SPECIFICATIONS FROM MICHIGAN DEPARTMENT OF TRANSPORTATION

MICHIGAN
DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION
FOR
LIME STABILIZED SUBGRADE

a. Description. This work consists of all material including water, equipment, labor and testing for constructing a 12 inch compacted uniform layer of lime stabilized subgrade and determining the minimum amount of lime, or lime and fly ash combination required for the soil. The work shall be performed in accordance with this specification, 2003 Standard Specifications for Construction, as directed by the Engineer, and shall conform to the lines, grades, notes, and typical sections shown on the plans. **For the bidding purpose only, minimum rate of quicklime application is 5% on a dry weight basis of the soil. Fly Ash may or may not be required as determined by the Contractor Design Tests. For bidding purpose only, the estimated quantity of Fly Ash is 1,200 tons.**

b. Materials.

Lime. Lime shall be quicklime conforming to the requirements of ASTM C 977 specifications with the modification that all quicklime shall pass the 3/8 inch size sieve. A lime shall be certified by "Test Data Certification" method as per the MDOT Material Source Guide and shall represent each lot of lime delivered on the project.

Fly ash. Fly ash shall conform to ASTM C 618 for class F. Bulk fly ash may be transported dry in bulk trucks and stored in tanks or may be transported in dampened condition (15 percent moisture, maximum). The fly ash class F must be selected from current MDOT Material Source Guide Approved Manufacturer's list. A proper documentation must be supplied from the manufacturer to meet the ASTM C 618 requirements.

Water. Water for mixing and curing shall meet the requirements of subsection 911.02 of the 2003 Standard Specifications for Construction.

Soil. Soil for the lime stabilization as used in this specification is the in-place subgrade soil material. The soil shall be uniform in quality and gradation, be free of roots, sod, weeds, and stones larger than 2-1/2 inches, and shall be approved by the Engineer.

c. **Contractor Designed Lime or lime-fly ash, and Soil Mix.** The Contractor shall develop and submit, for approval, a mix design specifying percent of lime, or lime and fly ash in the soil to be stabilized. The Contractor's qualified representative or geotechnical engineer shall collect representative soil samples that are evenly distributed along the project length under the direction of the Engineer. Take one sample for every 20,000 square yard area of soil to be treated, one per major type of soil, or a minimum of 5 samples per project, whichever is greater, and submit to an AASHTO or ASTM accredited geotechnical laboratory to determine the recommended percentage of lime, or lime and fly ash for each soil sample taken. The station, offset and the depth of these soil borings shall be recorded and submitted to the Engineer. Prior to sampling, the Contractor shall submit the sampling location plan to the Engineer for review.

The AASHTO or ASTM accredited geotechnical laboratory shall perform the following tests and services for the untreated soil and lime-treated soil. Samples must be prepared with the same stabilizing material(s) that will be supplied to the job.

1. Soil Classification per AASHTO M145 and ASTM D2487 for the untreated soil and lime-treated soil.
2. Moisture and density testing per AASHTO T99 for the untreated soil and lime-treated soil.
3. California Bearing Ratio (CBR) laboratory test of uncured soil-lime mixture as per ASTM D 1883.
4. Perform Liquid, Plastic, and Plasticity Index of soil samples as per ASTM D 4318
5. Perform unconfined compressive strength test as per ASTM 5102. Prepare sample cylinders according to ASTM, Method B with the following modification: Revise Section 12 to read: Cure compacted specimens in a plastic air tight moisture proof container at 40 degrees Celsius temperature for 7 days.
6. Determine the minimum amount of lime, or lime and fly ash using each sample of untreated soil as per ASTM D 6276 that results in a soil-lime pH of 12.4, CBR of 10 for uncured soil-lime mixture, and a minimum unconfined compressive strength of 125 psi. Note: Fly Ash is not required if lime alone can meet these pH, CBR, and unconfined compressive strength requirements.
7. Submit copies of test reports from the geotechnical lab with all of the data to the Engineer for review and approval a minimum of 10 days prior to the commencement of the test strip construction.

Upon the Department's acceptance of the lime or lime-fly ash combination percentages, the contractor shall make moisture density curves for the chosen percentages of lime, or lime-and-fly ash combination and soil mix according to AASHTO T 99 for each soil sample taken above. Thoroughly mix the lime or lime-fly ash combination with the soil, and allow the mixtures to mellow for at least 24 hours before making the curves. Plot the wet and dry weight on a graph. Submit this data to the Engineer a minimum of 10 working days before the work begins. Engineer will use these curves or MDOT Typical Density Curves for compaction acceptance.

d. Equipment, Machines, and Tools. The equipment, machines, and tools used in the work shall be subject to approval and shall be maintained in satisfactory condition at all times. Other compacting equipment may be used in lieu of that specified where it could be demonstrated that the results are equivalent. Protective equipment, apparel, and barriers shall be provided to protect the eyes, respiratory system, and the skin of workers who are exposed to lime or lime dust.

1. Sheep-foot or Vibratory pad foot roller. Self propelled type with a minimum weight of 15 tons or greater as needed for compaction.

2. Steel-Wheeled Smooth Rollers. Steel-Wheeled rollers shall be the self-propelled type with a total weight of not less than 10 tons, and a minimum weight of 300 pounds per inch width of rear wheel. Wheels of the rollers shall be equipped with adjustable scrapers. The use of vibratory rollers is optional.

3. Pneumatic-Tired Rollers. Pneumatic-tired rollers shall be self-propelled and weigh when ballasted at least 8 tons but not more than 30 tons. It shall be equipped with a

minimum of 7 wheels situated on axles in such a way that the rear group of tires will not follow in the tracks of forward group of tires.

4. Mechanical Spreader. Mechanical spreader shall be cyclone, screw-type box, pressure manifold, or other approved equipment. A motor grader shall not be used to spread lime.

5. Watering Equipment. Watering equipment shall consist of tank trucks fitted with pressure distributors, or other approved equipment designed to apply controlled quantities of water uniformly over variable widths of surface without the truck adversely affecting the quality of the subgrade.

6. Tampers. Tampers shall be of an approved mechanical type, operated by either pneumatic pressure or internal combustion, and shall have sufficient weight and striking power to produce the compaction required.

7. Rotary Pulvamixer. A rotary pulvamixer shall be used for all mixing. Pulvamixer shall utilize a direct hydraulic drive and be capable of mixing the full 12 inch depth in one lift.

e. Construction.

1. General. Perform subgrade stabilization work when the air temperature is 40 degrees Fahrenheit or above and rising. Do not apply lime, or lime-fly ash combination to frosted subgrade under any circumstances. All work must be performed between April 1st and October 31st. **The depth of subgrade to be stabilized is 12 (twelve) inches**. Uniformly mix the approved proportion of the stabilizing materials through the entire 12-inch stabilized depth, and compact subgrade to the minimum 95% of required density. The Engineer will verify that a minimum of 12 inches of uniformly stabilized and compacted subgrade is achieved by digging 12-inch deep test holes at representative intervals. Adequate drainage shall be provided during the entire construction period to prevent water from collecting or standing on the area to be modified or on pulverized, mixed, or partially mixed material. Finished and completed lime stabilized subgrade shall conform to the lines, grades, and cross sections, and dimensions indicated in the plans.

2. Lime Stabilization Omission Locations: If during construction, the Engineer determines that certain locations have soils that are unsuitable for lime, or lime-and-fly ash stabilization, the Engineer may request for a modification of the lime stabilization procedure, or the use of other methods as necessary or cost effective. These soil types include, but not limited to granular soils and cohesive soils with excessive moisture content.

3. Contractor's Quality Control (QC) Plan: The contractor shall submit a QC plan, for the approval of the Engineer, a minimum of 5 days prior to starting the construction of the test strip. The QC plan shall include, but not limited to, name and description of the equipments to be used, personnel responsible for monitoring application raters, methods of determining and adjusting moisture contents.

4. Test Section. Upon the Engineer's approval of the Contractor's QC plan, a 600 linear feet test section comprising of either one or more lane width (depending upon construction staging) will be selected (with the approval of the Engineer) to implement the details of lime stabilization. The contractor shall submit a work plan for the test strip a minimum of 5 working days in advance of construction of the test strip. The work for this test section will be in accordance with this special provision. The Contractor can proceed with the stabilization of roadway subgrade if the test section meets the approval of the Engineer. At the Engineer's discretion, the test section may be accepted as part of the total required lime stabilized area.

5. Subgrade Preparation. Prior to adding the stabilizing materials, remove all deleterious materials such as topsoil, roots, organic material, and rock fragments larger than 2-1/2 inches. The subgrade treatment area shall be graded to conform to the lines, grades, and cross sections shown in the plans prior to being processed for stabilization. All the deleterious material removed as part of subgrade preparation will be the property of the Contractor and shall be considered included in the payment for lime stabilized subgrade.

6. Lime or lime-and-fly ash Application. Apply the contractor designed lime, or lime-and-fly ash combination on a dry weight basis. Submit verification testing to show that the required application rate is utilized, and provide the results to the Engineer at the end of each workday. Spread the lime, or lime-and-fly ash combination uniformly on the scarified subgrade by means of distributors or equipment approved by the Engineer. Place a canvas shroud on the distribution bar and extend to the subgrade. Do not apply lime or lime-and-fly ash when the wind conditions are such that blowing material would become objectionable to the adjacent property owners or create potential hazards to traffic. In order to enhance dust control, the Contractor may use moisture-conditioned fly ash (if the fly ash is determined necessary as per the Contractor design mix). Lime and fly ash can be spread as individual components.

7. Spreading. The spreading of stabilizing material shall be limited to an area that can be incorporated and mixed, within the same working day. While spreading lime, or lime-and-fly ash combination, minimize dusting and impact to the traffic by periodic water sprinkling at no cost to the Department.

8. Mixing.
   Initial Mixing: Immediately after the lime or lime-and-fly ash combination has been spread, thoroughly mix the lime or lime-and-fly ash into the subgrade by using an approved rotary mixer to a depth of 12 inches. Add enough water to raise the moisture content of the soil mixture to 3% to 5% above the optimum moisture content. Continue mixing until lime, or lime-and-fly ash combination has been uniformly incorporated into the subgrade to the required depth with the mixture being homogeneous and friable. Complete this initial mixing within 4 hours of spreading the lime. A waiting period after initial mixing of 1 to 24 hours or longer may be required or necessary for all lime particles to hydrate.

   Final Mixing: After the waiting period, soil shall be remixed, adding water as needed to raise the moisture content to 2 to 3% above optimum. Continue mixing until the quicklime has been uniformly incorporated into the subgrade to the required depth and with soil clods broken down to pass a 2-inch screen and at least 60% passing No. 4 sieve, exclusive of rock particles. Final mixing shall be accomplished within 5 days of initial mixing. There shall be no unhydrated lime pebbles present before compaction operations start. The Engineer may verify that any visible particles are not unhydrated lime before compaction begins.

It is the contractor's responsibility to determine the in-situ moisture content of the soil or soil-lime mixture in order to determine the quantity of water required to raise the moisture content to the required level above the optimum moisture content.

The Engineer may run the field gradation testing to determine the adequacy of mixing. In order to determine the adequacy of the mixing, two control sieves, 2-inch and No. 4, shall be used. All of soil clods during the mixing must pass 2-inch sieve and at least 60% pass a No. 4 sieve, exclusive of rock particles.

9. Compaction. Begin compaction immediately after final mixing. Add water or aerate the subgrade to bring the soil-lime mixture to optimum moisture content, plus or minus 2%. Continue final compaction until the stabilized subgrade has a density of not less than 95% of maximum density established as above for the soil-lime, or soil-lime-and-fly ash combination mixture. Rolling shall begin at the outside edge of the surface and proceed to the center, overlapping on successive trips at least one-half width of the roller, or as determined by the Engineer based upon construction staging. At all times, the speed of the roller shall not cause displacement of the mixture to occur. Areas inaccessible to the rollers shall be compacted with mechanical tampers, and shall be shaped and finished by hand methods. Final compaction shall be done with steel wheel smooth drum rollers. **The Engineer will perform the density and moisture testing for the compacted subgrade for acceptance as per this special provision and 2003 Standard Specifications for Construction.**

10. Curing and protection. Immediately after the stabilized subgrade has been compacted and finished as specified above, the surface shall be protected against rapid drying, for 7 days by periodic sprinkling and shall be kept moist for 7-day curing period, unless covered by subsequent layers of pavement section (sand subbase or aggregate base). Other suitable method of curing the compacted lime-soil mix may be approved the Engineer at his/her discretion.

11. Re-stabilization. If an approved stabilized area shows failure, tenderness or damage after curing, the Engineer shall require re-stabilization to be performed, where appropriate at no additional cost to the Department.

f. Use of Moisture Conditioned Fly Ash. The use of moisture-conditioned fly ash for lime-and-fly ash combination of soil treatment is acceptable (only Class F fly ash is permitted). Moisture conditioned fly ash shall contain no more than 15% moisture by dry weight of fly ash. When moisture-conditioned fly ash is used, the lime and fly ash shall be spread in two separate applications and the following additional construction procedures shall apply:

The lime shall be added to the subgrade and mixed in accordance with the above mixing subsection 8 of section "e". After the lime is thoroughly mixed, the subgrade shall be compacted with a steel wheel roller to achieve the surface strength and smoothness required to spread the moisture-conditioned fly ash.

Within 72 hours of mixing the lime and soil, the moisture-conditioned ash shall be uniformly spread onto the lime treated soil to provide the equivalent dry weight basis content of fly ash as determined by the contractor designed mix. The soil shall be remixed to blend the moisture-conditioned fly ash homogeneously with the lime treated soil.

g. Construction Traffic. Completed portion of lime stabilized subgrade may be opened immediately to light construction traffic at the contractor's own risk and option, provided the curing is not impaired. After 7-day curing period has elapsed, completed areas may be opened to construction traffic. Placement of subsequent pavement layers may begin the day following completion of lime stabilization, provided the lime-stabilized completed area has strengthened sufficiently to prevent marring or distorting of the surface by equipment or traffic. Lime and water may be hauled over the completed area with pneumatic-tired equipment if approved by the Engineer. Finished portions of lime-modified subgrade that are traveled on by the equipment used in construction of adjoining section shall be protected in a manner to prevent equipment from marring and damaging the completed work. The Contractor is responsible for correcting and restabilizing the damaged areas at his/her cost.

h. Field Quality Control and Assurance. Results of field quality control testing shall verify that the materials comply with this special provision and 2003 Standard Specification for Construction. When a material source is changed, the new material shall be tested for compliance. When deficiencies are found, the initial analysis shall be repeated and the material already placed shall be retested to determine the extent of unacceptable material. All in-place unacceptable material shall be replaced or repaired, as directed by the Engineer at no additional cost to the Department.

Completed **thickness** of the lime stabilized subgrade soil layer shall be within ½ inch of specified thickness of 12 inches. When the measured thickness of the lime stabilized subgrade soil is more than ½ inch deficient, such areas shall be corrected by scarifying, adding additional lime, remixing and recompacting as directed by the Engineer. Where the measured thickness of the lime stabilized subgrade layer is more than ½ inch thicker than required, it shall be considered conforming to the specified thickness requirement, provided the elevation of finished subgrade is within the tolerance as per the 2003 Standard Specification for Construction. Thickness of lime stabilized subgrade layer shall be measured for each 4000 square yards, at least one per day, or as determined by the Engineer. Measurements shall be made in 3 inch diameter or larger test holes penetrating the lime stabilized subgrade.

Lime content of uncured lime, or lime-and-fly ash and soil mixture shall be determined in accordance with ASTM D 3155. Sample for testing shall be obtained from mid-depth of the lime stabilized subgrade layer. Sampling and testing shall be conducted at the rate of one test per 4000 square yards, at least one per day, or as determined by the Engineer. Lime content shall not be less than 1% below the Contractor designed lime-soil mix design.

At least one **field density test** shall be performed for each 4,000 square yards of lime stabilized subgrade, but at least one per day.

i. Contractor Warranty and Maintenance. Perform the following work at no cost to the Department. Repeat this work as often as necessary to keep the lime stabilized subgrade intact.

1. Maintain the lime or lime-fly ash stabilized subgrade in good condition until the work is completed and accepted.

2. Maintain a smooth surface of the lime stabilized subgrade by blading.

3. Immediately repair any defects that occur.

j. Method of Measurement. Actual area of the Lime Stabilized Subgrade as ordered and completed to the 12 inch thickness and cross sections shown on the plans, and accepted, will be measured in square yards. All calculations of areas measured for payment shall be based on measurements made to the nearest 0.1 yard with area calculated to the nearest square yard. The length will be measured along the surface of the completed roadbed at its centerline. The width will be the top surface width of the completed roadbed specified on the plans, measured perpendicular to the center line of roadbed. Additional areas required for tapers, etc shall be measured by length and width along the surface area stabilized.

Lime and fly-ash actually incorporated in the work will be measured by the ton. A certified delivery tickets shall be furnished to the Engineer for lime and fly-ash used in the construction of lime stabilized subgrade.

k. Basis of Payment. The completed work as described shall be paid for at the contract unit price for the following contract items (pay items):

Contract Item (Pay Item)	**Pay Unit**
Lime Stabilized Subgrade	Square Yard
Lime	Ton
Fly ash	Ton

The ordered and accepted area of **Lime Stabilized Subgrade**, measured as noted above, will be paid for at the contract unit price bid per square yard. Said unit price bid shall be full compensation for all the sampling, design of lime or lime-fly ash soil mix, scarifying, pulverizing, mixing, shaping, water, curing, compacting, and application of lime, testing; and for all equipment, tools, labor, and incidentals needed for completion of the work.

The accepted quantity of **lime** and **fly ash** actually incorporated in the work except as noted herein, measured as provided above, will be paid for at the contract unit price per ton of lime, or fly ash, which price shall be payment in full for furnishing, transporting, storing, handling, and spreading; and for all equipment, tools, labor, and incidentals needed for completion of the work.

MICHIGAN
DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION
FOR
CHEMICALLY STABILIZED SUBGRADE

a. Description. This work consists of providing all labor, equipment, materials, testing and determining the optimum amount of chemical required to construct a 12 inch compacted uniform stabilized subgrade layer. The work must be performed in accordance with this special provision, as detailed on the plans, the standard specifications and as directed by the Engineer.

b. Materials. Lime Kiln Dust (LKD) and Cement Kiln Dust (CKD) are the only chemical stabilizers acceptable for use on this project.

CKD and LKD must conform to the requirements of ASTM D 5050. All CKD and LKD must be certified by Test Data Certification method according to the *Materials Quality Assurance Procedures Manual*. CKD must be tested under the appropriate sections of ASTM C 25 and AASHTO T 105 to determine the total alkalis (K_2O+Na_2O) and total sulfates (SO_3). Test data must be within the following limits:

Property	**Limit, % maximum**
Total alkalis (K_2O+Na_2O)	10
Total sulfates (SO_3)	15

Water for dust control, mixing and curing must be according to section 911 of the Standard Specifications for Construction.

Soil for stabilization as specified herein is the in-place subgrade soil. The soil must be visually free of deleterious materials such as topsoil, roots, organic material and rock fragments larger than 2½ inches, and must be approved by the Engineer prior to treatment.

c. Contractor Mix Design for Chemically Stabilized Soils. Develop and submit, for approval, a mix design specifying percent of chemical stabilizer (LKD or CKD) in the soil to be stabilized. The Engineer reserves the right to reject the selected chemical stabilizer and request a new mix design with a different chemical stabilizer at no cost to the Department based on the mix-design results. One chemical stabilizer from the same source must be used on this project, unless otherwise approved by the Engineer.

1. Untreated Soil Characteristics and Properties. The Contractor's qualified representative or geotechnical engineer must collect representative soil samples that are evenly distributed along the project length at the direction of the Engineer. Take one sample for every 20,000 square yard area of soil to be treated, one per major type of soil, or a minimum of 5 samples per project, whichever is greater. The station, elevation, offset and depth of these soil samples must be recorded and submitted to the Engineer. Prior to sampling, the Contractor must submit the sampling location plan to the Engineer for review and approval.

An AASHTO or ASTM accredited geotechnical laboratory must determine the following for the untreated soil samples:

A. Soil Classification according to AASHTO M 145 and ASTM D 2487.

B. Moisture and density testing according to AASHTO T 99.

C. Liquid Limit, Plastic Limit and Plasticity Index according to ASTM D 4318.

Submit copies of test reports from the geotechnical laboratory with all pertinent data to the Engineer for review and approval. The Engineer is permitted up to 10 days to review this information.

2. Mix Design Procedure.

A. Moisture and Density Testing. Perform moisture and density testing according to AASHTO T 99. Prepare four mixtures of soil treated with the CKD or LKD percentages in the soil samples initially at 3 percent, 6 percent, 9 percent and 12 percent for each soil sample. Prepare the mixtures according to ASTM D 558. Alternate percentages may be allowed as directed by the Engineer.

B. California Bearing Ratio (CBR) Laboratory Testing. Perform CBR testing for uncured treated soil mixtures according to ASTM D 1883.

C. Unconfined Compression Strength (UCS) Test Specimens. P repare four mixtures of treated soil with the CKD or LKD percentages in the soil samples initially at 3 percent, 6 percent, 9 percent and 12 percent for each soil sample. Prepare sample cylinders according to ASTM D 1633 Method A.

D. Curing. Cure compacted specimens in an air tight, moisture proof container at 70 degrees F (21 degrees C) for 7 days.

3. UCS of the Cured Specimens. Determine, calculate and r eport UCS of each specimen in accordance with ASTM D 1633 Method A.

4. Minimum Chemical Mixture Content for Soil Stabilization. Recommend the minimum chemical mixture content (LKD or CKD) that results in a CBR of 10 percent for uncured treated soil mixtures, and a minimum unconfined compressive strength of 125 psi for cured specimens. Add 1 percent to this percentage for application in the field.

A. Upon the Department's approval of the chemical percentages, the Contractor must make moisture density curves for the chosen percentages of chemical and soil mix according to AASHTO T 99 for each soil sample taken above.

B. Thoroughly mix the chemical with the soil and immediately make the mixtures for moisture and density testing.

C. Plot the wet and dr y weight on a gr aph. Submit this data to the Engineer for approval a minimum of 10 working days before the work begins. The Engineer will use these curves for compaction acceptance.

d. Equipment. The equipment used to conduct the work is subject to approval by the Engineer and must be maintained in satisfactory condition at all times. Other compaction equipment may be used in lieu of that specified where it can be demonstrated that the results are equivalent. Protective equipment, apparel and barriers must be provided to protect eyes, respiratory system and skin of the workers who are exposed to chemical stabilizer.

1. Sheepsfoot or Vibratory Pad Foot Roller. Self propelled type with a minimum weight of 15 tons or greater as needed for compaction.

2. Steel-Wheeled Smooth Drum Rollers. Steel-wheeled smooth drum rollers must be self-propelled with a total weight of at least 10 tons, and a minimum weight of 300 pounds per inch width of rear wheel. The wheels of the rollers must be equipped with adjustable scrapers. The use of vibratory rollers is optional.

3. Pneumatic-Tired Rollers. Pneumatic-tired rollers must be self-propelled and weigh when ballasted at least 8 tons but not more than 30 tons. The roller must be equipped with a minimum of 7 tires situated on two axles such that the rear tires will not follow in the tracks of the forward tires.

4. Mechanical Spreader. Mechanical spreader must be a cyclone, screw-type box, pressure manifold or other approved type. A motor grader must not be used to spread the chemical.

5. Watering Equipment. Watering equipment must consist of tank trucks fitted with pressure distributors, or other approved equipment designed to apply controlled quantities of water uniformly over variable widths of surface without the truck adversely affecting the stability of the subgrade.

6. Tampers. Tampers must be of an approved mechanical type, operated by either pneumatic pressure or internal combustion and must have sufficient weight and striking power to produce the required compaction.

7. Rotary Pulvimixer. A rotary pulvimixer must be used for all mixing and must utilize a direct hydraulic drive and be capable of mixing the full 12 inch depth in one lift.

e. Construction.

1. General. Perform subgrade stabilization work when the air temperature is 40 degrees Fahrenheit or above and rising. Do not apply chemical to frozen subgrade under any circumstances. All work must be performed between April 1st and October 31st. The depth of subgrade to be stabilized is 12 inches. Uniformly mix the approved proportion of the stabilizing material through the entire 12-inch depth to be stabilized and compact subgrade to at least 95 percent of the maximum unit weight. Adequate drainage must be provided during the entire construction period to prevent water from collecting or standing on the area to be modified, or on pulverized, mixed, or partially mixed material. Finished and completed stabilized subgrade must conform to the lines, grades, and cross sections as indicated on the plans.

2. Chemical Stabilization Omission/Modification Locations. If during construction the Engineer determines that certain locations are inappropriate for chemical stabilization, the treatment may be omitted or the Engineer may request a modified stabilization procedure.

3. If the Engineer modifies the stabilization procedure to stabilize to a depth greater than 12 inches, those modified locations will be paid for 1.5 times the unit bid price.

4. Contractor's Quality Control (QC) Plan. The Contractor must submit a QC plan, for approval by the Engineer, a minimum of 10 days prior to starting construction of the test strip. The QC plan must include, but not be limited to, name and description of the equipment to be used, personnel responsible for monitoring application rates, methods of determining and adjusting moisture content.

5. Test Section. Upon the Engineer's approval of the Contractor's QC plan, a 600 foot long test section a minimum of one lane width will be selected to implement the chemical stabilization work. The Contractor must submit a work plan for the test strip a minimum of 10 working days in advance of construction of the test strip. The work for this test section will be in accordance with this special provision. The Contractor can proceed with the stabilization of roadway subgrade if the test section meets the approval of the Engineer. At the Engineer's discretion, the test section may be accepted as part of the total required stabilized area.

6. Subgrade Preparation. Prior to adding the stabilizing materials, remove and dispose of all deleterious materials such as topsoil, roots, organic material and rock fragments larger than 2½ inches. The subgrade treatment area must be graded to conform to the lines, grades, and cross sections shown on the plans prior to being processed for stabilization.

7. Chemical Application. Apply the chemical combination as approved by the Engineer on a dry weight basis. Submit verification testing to show that the required application rate is utilized, and provide the results to the Engineer at the end of each workday. The Contractor will conduct a rate application test in the field to demonstrate the chemical is being applied at the prescribed rate. The test will incorporate a receptacle made of metal, plastic, canvas or similar material of known area and volume. The spreader will pass over the receptacle and spread the chemical at the anticipated rate. It will be weighed in the field and the actual application rate will be determined. Spread the chemical uniformly on a scarified subgrade by means of distributors or equipment approved by the Engineer. Place a canvas shroud on the distribution bar and extend to the subgrade to minimize dust. Do not apply chemical when the wind conditions are such that blowing material would become objectionable to the adjacent property owners or create potential hazards to traffic.

8. Spreading. While spreading chemical, minimize dusting and impact to traffic by periodic water sprinkling at no cost to the Department. The spreading of stabilizing material must be limited to an area that can be incorporated and mixed, within 1 hour of application.

9. Mixing. Immediately after the chemical has been spread, mix into the subgrade soil using a rotary pulvimixer to a depth determined by the Engineer. Add enough water to raise the moisture content of the soil mixture within the range of 1 percent below to 2 percent above the optimum moisture content. Continue mixing until the chemical has been uniformly incorporated into the subgrade to the required depth with the mixture being homogenous and friable.

It is the Contractor's responsibility to determine the in situ moisture content of the soil or soil-chemical mixture in order to determine the quantity of water required to raise the moisture content to the required level above the optimum moisture content.

The Engineer may run the field gradation testing to determine the adequacy of mixing. In order to determine the adequacy of the mixing, two control sieves, 1 inch and No. 4, will be used. All soil clods must pass the 1 inch sieve and at least 60 percent must pass the No. 4 sieve, exclusive of rock particles. Mixing must continue until the required gradation is achieved.

10. Compaction. After mixing, shape the subgrade. Start compaction within 1 hour after the final mixing. Add water or aerate the subgrade to bring the soil-chemical mixture to optimum moisture content, plus or minus 2 percent. Continue final compaction until the stabilized subgrade has a density of at least 95 percent of maximum unit weight established as above for the soil-chemical mixture. Rolling must begin at the outside edge of the surface and proceed to the center, overlapping on successive trips at least one half width of the roller, or as determined by the Engineer. At all times, the speed of the roller must not cause displacement of the mixture to occur. Areas inaccessible to the rollers must be compacted with mechanical tampers and must be shaped and finished by hand methods. Final compaction must be done with steel wheel smooth drum rollers. The Engineer will perform the density, moisture and DCP testing for the compacted subgrade for acceptance as per this special provision.

Complete the mixing, compacting, shaping and fine grading within 3 hours from start to finish.

11. Curing and Protection. Immediately following the final grading, cure the compacted subgrade for a minimum of 24 hours before placement of the overlying course. The surface must be protected from rapid drying during this period by periodic sprinkling unless covered by subsequent layers of pavement section. Other suitable methods of curing the compacted stabilized subgrade may be approved by the Engineer. The Engineer may modify the amount of time required for curing based on site conditions. Protect the stabilized subgrade from disturbance. Do not operate construction equipment on the treated soil during the curing period. Do not allow the treated soil to freeze during the cure period.

12. Re-stabilization. If an approved stabilized area shows failure, rutting or damage after curing, re-stabilization must be performed at no additional cost to the Department.

g. Construction Traffic. The completed portions of stabilized subgrade may be opened immediately to light construction traffic at the Contractor's own risk and option, provided the curing is not impaired. After the curing period has elapsed, completed areas may be opened to construction traffic. Placement of subsequent pavement section layers may begin the day following completion of subgrade stabilization provided the stabilized area has strengthened sufficiently to prevent marring or distorting of the surface by equipment or traffic. Chemical and water may be hauled over the completed area with pneumatic-tired equipment if approved by the Engineer. Finished portions of stabilized subgrade that are traveled on by the equipment used during construction of adjoining sections must be protected in a manner to prevent marring and damaging the completed work. The Contractor is responsible for correcting and re-stabilizing the damaged areas at no cost to the Department.

h. Field Quality Control and Acceptance Testing. Results of field quality control must verify that the materials comply with this special provision and the standard specifications. All in-place unacceptable material must be replaced or repaired, as directed by the Engineer at no additional cost to the Department.

The Engineer will use a Dynamic Cone Penetrometer (DCP) at representative intervals to verify that a minimum of 12 inches of uniformly stabilized and compacted subgrade has been achieved.

The thickness of the stabilized subgrade layer must be within ½ inch of the specified thickness of 12 inches. When the measured thickness of the stabilized subgrade soil is more than ½ inch deficient, such areas must be corrected by scarifying, adding additional chemical, remixing and re-compacting as directed by the Engineer with no additional cost to the Department. Where the measured thickness of the stabilized subgrade layer is more than 12 inches, it is acceptable, provided the elevation of finished subgrade is within the tolerance according to the standard specifications.

Stabilized thickness and field stabilized subgrade stiffness must be evaluated in accordance with ASTM D 6951. Stabilized subgrade thickness and stiffness is measured by plotting cumulative penetration blows versus depth. A change of slope on this graph will indicate the stabilized thickness. Average CBR for the stabilized layer is calculated in accordance with ASTM D 6951. A minimum average CBR of 10 percent in the stabilized zone is required for acceptance. Areas where the average CBR is less than 10 percent must be corrected by scarifying, adding additional chemical, remixing and re-compacting as directed by the Engineer. When the average CBR is less than 10 percent, the Engineer will verify the chemical application rate to determine whether the Contractor is following the specification and mix design appropriately. If the Engineer determines that the Contractor has not followed the mix design and the specification, all corrections must be completed with no additional cost to the Department.

At least one field density test must be performed for each 4000 square yards of stabilized subgrade or at least one per day.

i. Contractor Warranty and Maintenance. Perform the following work at no cost to the Department. Repeat this work as often as necessary to keep the stabilized subgrade intact.

1. Maintain the stabilized subgrade in good condition until the work is completed and accepted.

2. Maintain a smooth drainable stabilized subgrade surface.

3. Immediately repair any defects that occur.

j. Measurement and Payment. The completed work, as described, will be measured and paid for at the contract unit price using the following pay items:

Pay Item	**Pay Unit**
Chemically Stabilized Subgrade	Square Yard
Chemical Stabilizer	Ton

The area of stabilized subgrade completed to the 12 inch thickness and cross sections shown on the plans, and accepted, will be measured in square yards. All calculations of area measured for payment must be based on measurements made to the nearest 0.1 yard with area calculated to the nearest square yard. The length will be measured along the surface of the completed roadbed at centerline. The width will be the top surface width of the completed roadbed specified on the plans, measured perpendicular to the center line of roadbed. Additional areas required for tapers, etc. must be measured by length and width along the surface area stabilized.

Chemically Stabilized Subgrade, measured as noted above, will be paid for at the contract unit price bid per square yard and includes full compensation for all sampling, mix design, scarifying, pulverizing, mixing, shaping, water, curing, compacting, application of stabilizer, and testing; and for all equipment, tools, labor, and incidentals needed for completion of the work as described herein.

Chemical Stabilizer measured as noted above will be paid for at the contract unit price bid per ton and includes full compensation for furnishing, transporting, storing, handling, and spreading; and for all equipment, tools, labor, and incidentals needed for completion of the work as described herein. Only chemical stabilizer actually incorporated into the work will be included in the pay item. Additional compensation will not be made for excess waste or otherwise unused chemical stabilizer.

APPENDIX B 2

CONSTRUCTION SPECIFICATIONS FROM OHIO DEPARTMENT OF TRANSPORTATION

STATE OF OHIO
DEPARTMENT OF TRANSPORTATION

SUPPLEMENT 1120
MIXTURE DESIGN FOR CHEMICALLY STABILIZED SOILS

July 18, 2014

1120.01 Description. This work consists of sampling and testing soils mixed with cement, lime, or lime kiln dust to determine the optimum mix design. This supplement can be used in design to compare alternative mixes, and in construction to determine the optimum spreading percentage rate.

1120.02 Testing Laboratory. Use an accredited Geotechnical Testing Laboratory with a qualified staff experienced in testing and designing chemical stabilization and capable of performing the tests listed in the tables below. The staff must be under the supervision of a Professional Engineer with at least five years of geotechnical engineering experience. The Geotechnical Testing Laboratory must be currently accredited by either of the following:

AASHTO Materials Reference Laboratory (AMRL)
National Institute of Standards and Technology
100 Bureau Drive, Stop 8619
Building 202, Room 211
Gaithersburg, Maryland 20899-8619
(301)-975-5450 www.amrl.net

American Association of Laboratory Accreditation (A2LA)
5301 Buckeystown Pike, Suite 350
Frederick, Maryland 21704
(301)-644-3248 www.A2LA.org

The Geotechnical Testing Laboratory minimum accreditations required are a general laboratory inspection and the following AASHTO or ASTM designation tests:

TABLE 1120.02-1

Test Method	AASHTO Designation	ASTM Designation
Dry Preparation of Soil Samples	T 87	D 421
Particle Size Analysis of Soils	T 88	D 422
Determining the Liquid Limit of Soils	T 89	D 4318
Determining the Plastic Limit and Plasticity Index of Soils	T 90	D 4318
Moisture-Density Relations of Soils (Standard Proctor)	T 99	D 698
Specific Gravity of Soils	T 100	D 854
Unconfined Compressive Strength of Cohesive Soil	T 208	D 2166
Laboratory Determination of Moisture Content of Soils	T 265	D 2216

Ensure the Geotechnical Testing Laboratory is also proficient in the following tests:

ABLE 1120.02-2

Test Method	AASHTO Designation	ASTM Designation	Other Test Method
Family of Curves – One Point Method	T 272	–	–
Classification of Soils (as modified by the Department Specifications for Geotechnical Explorations)	M 145	–	–
Organic Content by Loss on Ignition	T 267	D 2974	–
Determining Sulfate Content in Soils – Colorimetric Method	–	–	TEX-145-E [1]
Moisture-Density Relations of Soil-Cement Mixtures	–	D 558	–
Wetting and Drying Compacted Soil-Cement Mixtures	–	D 559	–
Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory	–	D 1632	–
Compressive Strength of Molded Soil-Cement Cylinders	–	D 1633	–
Laboratory Preparation of Soil-Lime Mixtures Using a Mechanical Mixer	–	D 3551	–
One Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures	–	D 3877	–
Unconfined Compressive Strength of Compacted Soil-Lime Mixtures	–	D 5102	–
Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization	–	D 6276	–

[1] Texas Department of Transportation (Feb. 2005) ftp.dot.state.tx.us/pub/txdot-info/cst/TMS/100-E_series/pdfs/soi145.pdf

1120.03 Sampling and Testing of Untreated Soil. Collect one soil sample for every 5000 square yards (4000 m^2) of treated subgrade area or 2000 cubic yards (1500 m^3) of treated embankment, but not less than a total of four soil samples for a project. Each sample consists of 75 pounds (35 kg) of soil (about a five gallon bucket). Record the station, offset, geographic coordinates (Latitude and Longitude as decimal degree to six decimal places), and elevation of each sample location.

When this supplement is used during construction for stabilizing embankment (Item 205), collect samples from locations and elevations that represent the soils that will be chemically treated. When this supplement is used during construction for stabilizing subgrade (Item 206), collect samples of in-place soil at the proposed subgrade elevation. However, if the chemical stabilization will be performed on embankment fill, collect the soil samples from the source or sources of the embankment material that will be stabilized. Collect each sample from a different location. For in-place soil samples, collect the samples from locations distributed across the treated area. Obtain the Department's approval before collecting samples from outside the treated area.

When this supplement is used during the design phase, the geotechnical consultant shall submit a plan to modify the above sampling procedure to quantify the effects of chemical mixtures on the soil that will be stabilized.

Visually inspect each soil sample for the presence of gypsum ($CaSO_4 \cdot 2H_2O$). Gypsum crystals are soft (easily scratched by a knife; they will not scratch a copper penny), translucent (milky) to transparent, and do not have perfect cleavage (do not split into thin sheets). Photos of gypsum crystals are shown in Figures 1120-1 to 1120-4. If gypsum is present, immediately notify the Department.

Perform the following tests on each soil sample. Perform each test according to the test method shown and as modified by the Department Specifications for Geotechnical Exploration (Section 603.3). If more than one test method is shown for a test, use any of the given test methods to perform the test. If the sulfate content is greater than 3,000 parts per million (ppm), immediately notify the Department.

TABLE 1120.03-1 TESTS FOR UNTREATED SOIL

Test	**AASHTO Designation**	**ASTM Designation**	**Other Test Method**
Moisture content	T 265	D 2216	–
Particle-size analysis	T 88	D 422	–
Liquid limit	T 89	D 4318	–
Plastic limit and plasticity index	T 90	D 4318	–
Family of curves – one point method	T 272	–	–
Organic content by loss on ignition	T 267	D 2974	–
Sulfate content in soils – colorimetric method	–	–	TEX-145-E [1]

[1] Texas Department of Transportation (Feb. 2005) ftp.dot.state.tx.us/pub/txdot-info/cst/TMS/100-E_series/pdfs/soi145.pdf

Classify the soil sample according to the ODOT soil classification method described in the Department Specifications for Geotechnical Exploration (Section 603). Determine the optimum moisture content and maximum dry density of the soil using the one-point Proctor test and the Ohio typical moisture-density curves according to Supplement 1015.

Submit the soil classification and test results for each sample to the Department for review before continuing with the mixture design test procedure. Also submit to the Department for review and acceptance a recommendation as to how the soil samples will be combined or grouped for the remaining mixture design test procedures. Obtain written acceptance from the Department before continuing with the mixture design test procedure. Allow seven days for the review. During construction, submit the information to the Project Engineer, who will forward the submittal to the District Geotechnical Engineer, the Office of Geotechnical Engineering, and the Office of Construction Administration. During design, submit the information to the District Geotechnical Engineer.

1120.04 Mixture Design Test Procedure. Use the following procedure to prepare four mixtures from each soil sample that will be tested. From each mixture, prepare three specimens for testing. This results in a total of 12 test specimens for each soil sample.

Each mixture consists of soil mixed with varying amounts of the stabilization chemical, except for the first mixture which consists of the untreated soil. The percentage of stabilization chemical in each mixture is shown in the table below. Calculate the quantity of stabilization chemical to add to the mixture by multiplying the given percentage by the dry weight of the soil.

TABLE 1120.04-1 PERCENTAGE OF CHEMICAL FOR TRIAL MIXES

	Cement	Lime	Lime Kiln Dust
Mix 1 (Untreated soil)	–	–	–
Mix 2	3%	MLP	4%
Mix 3	5%	MLP + 2%	6%
Mix 4	7%	MLP + 4%	8%

MLP – Minimum Lime Percentage (1120.04.A)

Carefully store the cement, lime, or lime kiln dust until used so that it does not react with moisture or excess carbon dioxide. When this supplement is used during construction, use cement, lime, or lime kiln dust from the same source that will supply the chemical for soil stabilization.

A. Minimum Lime Percentage. If using lime for chemical stabilization, determine the minimum percentage of lime required for soil stabilization using ASTM D 6276 (also known as the "Eades-Grim" test). Determine the lowest percentage of lime that produces a pH of 12.4. Report this value as the Minimum Lime Percentage. ASTM D 6276 addresses special cases where the highest measured laboratory pH is less than 12.4. Notify the Department if the measured pH is less than 12.3 or if the Minimum Lime Percentage is greater than 8 percent.

Not all laboratory pH-measuring devices are capable of accurate calibration to determine pH levels above 12.0. Ensure the pH meter can accurately measure pH up to 14 and can be calibrated with a pH 12 buffer solution.

B. Optimum Moisture Content and Maximum Dry Density. Determine the optimum moisture content and maximum dry density of treated soil mixtures using the one-point Proctor test and the Ohio typical moisture-density curves according to Supplement 1015 (the optimum moisture content and maximum dry density of the untreated soil were determined in 1120.03 above.) Prepare the mixtures according to ASTM D 3551 if using lime, and according to ASTM D 558 if using cement or lime kiln dust.

Thoroughly mix the soil, stabilization chemical, and water until the chemical appears to be consistently blended throughout the soil. Use a laboratory or commercial-grade mixer, such as a Hobart mixer. Do not mix by hand.

If using lime for stabilization, seal the mixture in an airtight, moisture-proof bag or container, and store it at room temperature for 20 to 24 hours. This is called the "mellowing" period. Remove the soil-lime mixture from the sealed container and lightly remix it for one to two minutes before performing the one-point Proctor test. Cement and lime kiln dust do not require a "mellowing" period.

C. Unconfined Compressive Strength Specimens. Prepare three specimens for unconfined compressive strength (UCS) testing from each mixture shown in Table 1120.04-1. If using lime for stabilization, use ASTM D 5102, Procedure B. If using cement or lime kiln dust, use ASTM D 1633, Method A. Compact the specimens at the moisture content shown in Table 1120.04-2.

TABLE 1120.04-2 MOISTURE CONTENT FOR PREPARING UCS SPECIMENS

	Cement	Lime	Lime Kiln Dust
Mix 1 (Untreated soil)	OMC (*u*)	OMC (*u*)	OMC (*u*)
Mix 2	OMC (*2*)	OMC (*2*) + 2%	OMC (*2*) + 1%
Mix 3	OMC (*3*)	OMC (*3*) + 2%	OMC (*3*) + 1%
Mix 4	OMC (*4*)	OMC (*4*) + 2%	OMC (*4*) + 1%

OMC (*u*) – Optimum moisture content of untreated soil (determined in 1120.03)
OMC (*n*) – Optimum moisture content of Mix *n* (determined in 1120.04.B)

D. Curing. Immediately wrap each specimen with plastic wrap and store each specimen in a separate airtight, moisture-proof bag. If using lime for stabilization, store the specimens at 104 ºF (40 ºC). If using cement or lime kiln dust for stabilization, store the specimens at 70 ºF (21 ºC). Allow the specimens from the treated soil mixtures (mixes 2, 3, and 4) to cure undisturbed for seven days. Do not cure the untreated soil specimens for more than 24 hours before performing the strength tests on them.

E. Moisture Conditioning. After curing, moisture condition the specimens from the treated soil mixtures by capillary soaking before performing the unconfined compressive strength tests. Do the following:

1. Remove the specimens from the airtight bag and remove the plastic wrap.
2. Use a caliper or pi-tape to measure the height and diameter of the specimens. Record at least three height and diameter measurements each. Calculate the average height and diameter.
3. Wrap the specimens with a damp, absorptive fabric.

4. In a shallow tray, place each wrapped specimen on a porous stone.
5. Add water to the tray until the water level is near the top of the stone and in contact with the absorptive fabric, but not in direct contact with the specimen.
6. Allow the specimens to capillary soak for 24 hours (± 1 hour).
7. Remove and unwrap the specimens and proceed with expansion testing.

Do not moisture condition the untreated soil specimens.

F. Expansion Testing. After moisture conditioning the specimens from the treated soil mixtures, but before performing the strength tests, measure the height and diameter again. Record and average at least three height and diameter measurements for each specimen. Calculate the volume change from before to after moisture conditioning. Report this change as a percentage. Notify the Department if the volume change exceeds 1.5 percent. Further expansion testing may be required using ASTM D 3877. If further expansion testing is required, the Department will pay for it as Extra Work. Do not perform the expansion testing on the untreated soil specimens.

G. Unconfined Compressive Strength Testing. Determine the unconfined compressive strength of each specimen according to the following:

1. For untreated soil, use AASHTO T 208 or ASTM D 2166.
2. For lime, use ASTM D 5102, Procedure B.
3. For cement or lime kiln dust, use ASTM D 1633, Method A.

Calculate the average unconfined compressive strength for each mixture.

1120.05 Recommended Spreading Percentage Rate. Estimate the recommended spreading percentage rate using the following procedure.

A. Generate a graph that shows the average unconfined compressive strength for each mixture versus the percent of stabilization chemical in the mixture (include the strength for the untreated soil at zero percent). Include the results from all tested soil samples.

B. Determine the minimum percentage of chemical that results in an average 8-day unconfined compressive strength that meets the minimum strengths shown in the following table. Interpolate the minimum percentage between points on the graph. If the average strength for the mixture with the greatest percentage of stabilization chemical does not meet the minimum strengths, contact the Department.

TABLE 1120.05-1 MINIMUM UNCONFINED COMPRESSIVE STRENGTH

	UCS after 8 days	Increase over UCS of Mix 1 (untreated soil)
Cement	100 psi (0.7 MPa)	+50 psi (+0.35 MPa)
Lime	100 psi (0.7 MPa)	+50 psi (+0.35 MPa)
Lime Kiln Dust	100 psi (0.7 MPa)	+50 psi (+0.35 MPa)

C. Round the minimum percentage up to the nearest 0.5 percent.

D. Add 0.5 percent to the percentage.

E. The minimum recommended spreading rate shall be 4.0 percent.

The Department may adjust the recommended spreading percentage rate due to site specific conditions.

1120.06 Mixture Design Report. Submit a mixture design report to the Department for review that includes the following information:

A. For each soil sample, report the following:

1. Soil classification
2. Moisture content
3. Particle-size analysis
4. Liquid limit
5. Plastic limit and plasticity index
6. Sulfate content (ppm)
7. Sample location, i.e., station, offset, geographic coordinates, and elevation

B. For each specimen, report the following:

1. Height and diameter measurements and averages from before and after moisture conditioning
2. Calculated percent volume change (swell)
3. Unconfined compressive strength

C. For each mixture, report the following:

1. Percent of chemical in the mixture
2. Optimum moisture content
3. Maximum dry density
4. Average volume change (swell)
5. Average unconfined compressive strength

D. The graph of average strength versus the percent of stabilization chemical in the mixture.

E. The recommended spreading percentage rate for the stabilization chemical.

During construction, submit the report to the Project Engineer for review. Allow seven days for the review. The Project Engineer will forward the submittal to the District Geotechnical Engineer, the Office of Geotechnical Engineering, and the Office of Construction Administration. The Department will determine the spreading percentage rate based on the mixture design report and site specific conditions.

During design, submit the report to the District Geotechnical Engineer.

1120.07 Field Verification of the Mix Design. During construction, sample the treated soil after mixing but before compaction. Take three samples from random locations for every 15,000 cubic yards (11,500 cubic meters) of treated soil for Item 205 and for every 40,000 square yards (33,500 square meters) for Item 206. Prepare three test specimens in the field from each sample according to 1120.04.C above, except compact the specimens at the in-place moisture content. Immediately wrap each specimen with plastic wrap and store each specimen in a separate airtight, moisture-proof bag before transporting the specimens to the lab. Perform the procedures described in 1120.04.D through 1120.04.G.

Submit the measurements and test results for each set of field verification samples to the Project Engineer as they are completed. The Project Engineer will forward the submittal to the District Geotechnical Engineer, the Office of Geotechnical Engineering, and the Office of Construction Administration.

PHOTOS OF GYPSUM CRYSTALS

FIGURE 1120-1 Gypsum crystals

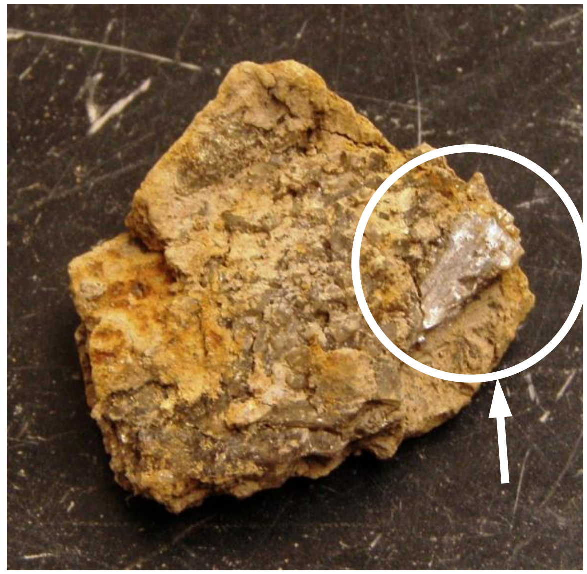


FIGURE 1120-2 Gypsum crystal in clay

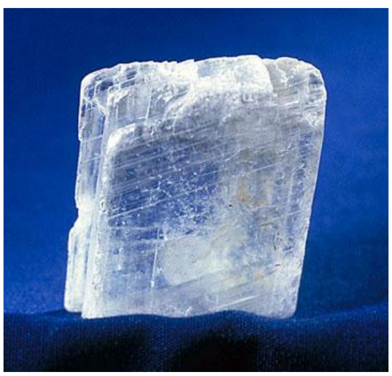


FIGURE 1120-3
Specimen quality gypsum crystal

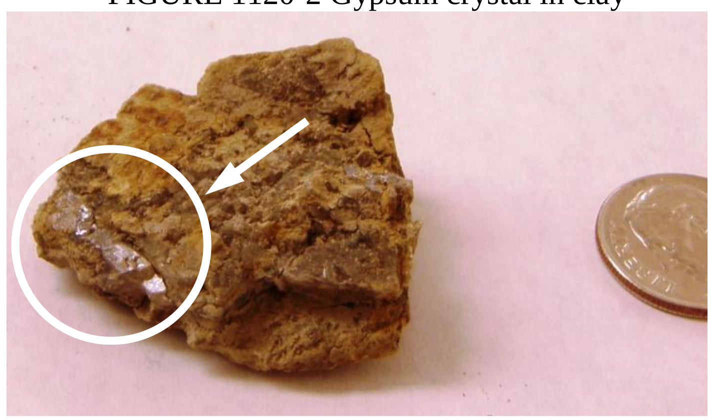


FIGURE 1120-4 Gypsum crystal in clay

FIGURE 1120-5 Gypsum crystals in clay

For more information about identifying minerals, see FHWA (1991) *Rock and Mineral Identification for Engineers*, Publication No. FHWA-HI-91-025, U.S. Department of Transportation.

204	Cubic Yard (Cubic Meter)	Granular Embankment
204	Cubic Yard (Cubic Meter)	Granular Material Type ___
204	Square Yard (Square Meter)	Geotextile Fabric

ITEM 205 CHEMICALLY STABILIZED EMBANKMENT

205.01 Description
205.02 Materials
205.03 Submittals
205.04 Construction
205.05 Mixture Design for Chemically Stabilized Soils
205.06 Method of Measurement
205.07 Basis of Payment

205.01 Description. This work consists of constructing a chemically stabilized embankment by mixing cement, lime, or lime kiln dust into the embankment soil using the method for the specified chemical.

The Contract Documents include an estimated quantity for the specified chemical.

205.02 Materials. Furnish materials conforming to:

Portland cement 701.04
Lime (quick lime) 712.04.B
Lime kiln dust.. 712.04.C

Furnish water conforming to 499.02. Furnish suitable natural soil, from on or off the project site, conforming to 703.16 and 203.03.

205.03 Submittals. Submit, for the Engineer's acceptance, a report that lists the type of equipment to be used, speed of the intended equipment usage, rate of application of the chemical, and calculations that demonstrate how the required percentage of chemical will be applied. Submit the report to the Engineer for acceptance at least 2 workdays before the stabilization work begins.

If the pay item for Mixture Design for Chemically Stabilized Soils is included in the Contract Documents, prepare and submit reports according to Supplement 1120.

205.04 Construction. Perform chemically stabilized embankment work when the air temperature is 40 °F (5 °C) or above and when the soil is not frozen.

Do not perform this work during wet or unsuitable weather.

Drain and maintain the work according to 203.04.A.

A. Spreading. If the pay item for Mixture Design for Chemically Stabilized Soils is not included in the Contract Documents, use the following spreading percentage rate for the specified chemical. The percentage is based on a dry density for soil of 110 pounds per cubic foot (1760 kg/m³):

TABLE 205.04-1

Chemical	Spreading Rate
Cement	6 %
Lime	5 %
Lime Kiln Dust	7 %

Spread the chemical uniformly on the surface using a mechanical spreader at the approved rate and at a constant slow rate of speed.

Use a distribution bar with a maximum height of 3 feet (1 meter) above the ground surface. Use a canvas shroud that surrounds the distribution bar and extends to the ground surface.

Minimize dusting when spreading the chemical. Control dust according to 107.17. Do not spread chemical when wind conditions create blowing dust that exceeds the limits in 107.19.

Do not spread the chemical on standing water.

B. Mixing. Immediately after spreading the chemical, mix the soil and chemical by using a power driven rotary type mixer. If necessary, add water to bring the mixed material to at least optimum moisture content for cement and lime kiln dust, and to at least 3 percent above optimum moisture content for lime. Continue mixing until the chemical is thoroughly incorporated into the soil, all soil clods are reduced to a maximum size of 2 inches (50 mm), and the mixture is a uniform color.

For areas not under pavements or paved shoulders, the Contractor may use a spring tooth or disk harrow in place of the power-driven rotary type mixer by modifying the above procedure as follows:

1. Open the soil with a spring tooth or disc harrow before spreading.

2. Spread the chemical.

3. Use a minimum disc harrow coverage of ten passes in one direction and ten passes in the perpendicular direction to thoroughly incorporate the chemical into the soil. Continue mixing until all soil clods are reduced to a maximum size of 1 inch (25 mm) and the mixture is a uniform color.

C. Compacting. Construct and compact chemically stabilized embankment according to 203.07, except use 98 percent of the maximum dry density for acceptance.

Determine the maximum dry density for acceptance using the Ohio Typical Moisture Density Curves, the moisture density curves from the Contractor's mixture design submittal, or the maximum dry density obtained by test section method.

205.05 Mixture Design for Chemically Stabilized Soils. When included in the plans, perform a mixture design for chemically stabilized soils according to Supplement 1120.

205.06 Method of Measurement. The Department will measure chemically stabilized embankment by the number of cubic yards (cubic meters) used in the complete and accepted work, as determined by Item 203.

The Department will measure cement, lime, and lime kiln dust by the number of tons (metric tons) incorporated in the complete and accepted work.

205.07 Basis of Payment. The Department will pay lump sum for all work, labor, and equipment described in 205.05. The Department will pay two-thirds of the lump sum amount bid when the sampling and testing is complete and the report is accepted by the Department. The Department will pay one-third of the lump sum amount bid when the chemically stabilized embankment is completed and accepted by the Department, and the field verification test results are all submitted.

The Department will pay for accepted quantities at the contract prices as follows:

Item	Unit	Description
205	Cubic Yard (Cubic Meter)	Cement Stabilized Embankment
205	Cubic Yard (Cubic Meter)	Lime Stabilized Embankment
205	Cubic Yard (Cubic Meter)	Lime Kiln Dust Stabilized Embankment
205	Ton (Metric Ton)	Cement
205	Ton (Metric Ton)	Lime
205	Ton (Metric Ton)	Lime Kiln Dust
205	Lump Sum	Mixture Design for Chemically Stabilized Soils

ITEM 206 CHEMICALLY STABILIZED SUBGRADE

206.01 Description. This work consists of constructing a chemically stabilized subgrade by mixing cement, lime, or lime kiln dust into the subgrade soil using the method for the specified chemical. The Contract Documents include an estimated quantity for the specified chemical.

206.02 Materials. Furnish materials conforming to:

Portland cement 701.04
Lime (quick lime) 712.04.B

APPENDIX B 3

DESIGN PROCEDURES FOR SOIL MODIFICATION OR STABILIZATION

INDIANA DEPARTMENT OF TRANSPORTATION

Design Procedures for Soil Modification or Stabilization

Production Division
Office of Geotechnical Engineering
120 South Shortridge Road
Indianapolis, Indiana 46219

January 2008

Table of Contents

DESIGN PROCEDURES FOR SOIL MODIFICATION OR STABILIZATION

1.0 General

It is the policy of the Indiana Department of Transportation to minimize the disruption of traffic patterns and the delay caused today's motorists whenever possible during the construction or reconstruction of the State's roads and bridges. INDOT Engineers are often faced with the problem of constructing roadbeds on or with soils, which do not possess sufficient strength to support wheel loads imposed upon them either in construction or during the service life of the pavement. It is, at times, necessary to treat these soils to provide a stable subgrade or a working platform for the construction of the pavement. The result of these treatments are that less time and energy is required in the production, handling, and placement of road and bridge fills and subgrades and therefore, less time to complete the construction process thus reducing the disruption and delays to traffic.

These treatments are generally classified into two processes, soil modification or soil stabilization. The purpose of subgrade modification is to create a working platform for construction equipment. No credit is accounted for in this modification in the pavement design process. The purpose of subgrade stabilization is to enhance the strength of the subgrade. This increased strength is then taken into account in the pavement design process. Stabilization requires more thorough design methodology during construction than modification. The methods of subgrade modification or stabilization include physical processes such as soil densification, blends with granular material, use of reinforcements (Geogrids), undercutting and replacement, and chemical processes such as mixing with cement, fly ash, lime, lime by-products, and blends of any one of these materials. Soil properties such as strength, compressibility, hydraulic conductivity, workability, swelling potential, and volume change tendencies may be altered by various soil modification or stabilization methods.

Subgrade modification shall be considered for all the reconstruction and new alignment projects. When used, modification or stabilization shall be required for the full roadbed width including shoulders or curbs. Subgrade stabilization shall be considered for all subgrade soils with CBR of less than 2.

INDOT standard specifications provide the contractor options on construction practices to achieve subgrade modification that includes chemical modification, replacement with aggregates, geosynthetic reinforcement in conjunction with the aggregates, and density and moisture controls. Geotechnical designers have to evaluate the needs of the subgrade and include where necessary, specific treatment above and beyond the standard specifications.

Various soil modification or stabilization guidelines are discussed below. It is necessary for designers to take into consideration the local economic factors as well as environmental conditions and project location in order to make prudent decisions for design.

It is important to note that modification and stabilization terms are not interchangeable.

2.0 Modification or Stabilization of Soils

2.01 Mechanical Modification or Stabilization

This is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction efforts, or undercutting the existing soils and replacing them with granular material.

A common remedial procedure for wet and soft subgrade is to cover it with granular material or to partially remove and replace the wet subgrade with a granular material to a pre-determined depth below the grade lines. The compacted granular layer distributes the wheel loads over a wider area and serves as a working platform. (1)

To provide a firm-working platform with granular material, the following conditions shall be met.

1. The thickness of the granular material must be sufficient to develop acceptable pressure distribution over the wet soils.

2. The backfill material must be able to withstand the wheel load without rutting.

3. The compaction of the backfill material should be in accordance with the Standard Specifications.

Based on the experience, usually 12 to 24 in. (300 to 600mm) of granular material should be adequate for subgrade modification or stabilization. However, deeper undercut and replacement may be required in certain areas

The undercut and backfill option is widely used for construction traffic mobility and a working platform. This option could be used either on the entire project or as a spot treatment. The equipment needed for construction is normally available on highway construction projects.

2.02 Geosynthetic Stabilization

Geogrid has been used to reinforce road sections. The inclusion of geogrid in subgrades changes the performance of the roadway in many ways (6). Tensile reinforcement, confinement, lateral spreading reduction, separation, construction uniformity and reduction in strain have been identified as primary reinforcement mechanisms. Empirical design and post-construction evaluation have lumped the above described benefits into better pavement performance during the design life. Geogrid with reduced aggregate thickness option is designed for urban area and recommendations are follows;

Excavate subgrade 9 in. (230 mm) and construct the subgrade with compacted aggregate No. 53 over a layer of geogrid, Type I. This geogrid reinforced coarse aggregate should provide stable working platform corresponding to 97 percent of CBR. Deeper subgrade problem due to high moisture or organic soils requires additional recommendations.

Geogrid shall be in accordance with 918.05(a) and be placed directly over exposed soils to be modified or stabilized and overlapped according with the following table.

SPT blow Counts per foot (N)	Overlap
> 5	12 in. (300 mm)
3 to 5	18 in. (450 mm)
less than 3	24 in. (600 mm)

2.03 Chemical Modification or Stabilization

The transformation of soil index properties by adding chemicals such as cement, fly ash, lime, or a combination of these, often alters the physical and chemical properties of the soil including the cementation of the soil particles. There are the two primary mechanisms by which chemicals alter the soil into a stable subgrade:

1. Increase in particle size by cementation, internal friction among the agglomerates, greater shear strength, reduction in the plasticity index, and reduced shrink/swell potential.

2. Absorption and chemical binding of moisture that will facilitate compaction.

3.0 Design Procedures

3.01 Criteria for Chemical Selection

When the chemical stabilization or modification of subgrade soils is considered as the most economical or feasible alternate, the following criteria should be considered for chemical selection based on index properties of the soils. (2)

1. Chemical Selection for Stabilization.

    a. Lime: If PI > 10 and clay content (2μ) > 10%.

    b. Cement: If PI ≤ 10 and < 20% passing No. 200.

    Note: Lime shall be quicklime only.

2. Chemical Selection for Modification

    a. Lime: PI ≥ 5 and > 35 % Passing No. 200

    b. Fly ash and lime fly ash blends: 5 < PI < 20 and > 35 % passing No. 200

    c. Cement and/ or Fly ash: PI < 5 and ≤ 35 % Passing No. 200

    Fly ash shall be class C only.
    Lime Kiln Dust (LKD) shall not be used in blends.
    Appropriate tests showing the improvements are essential for the exceptions listed above.

3.02 Suggested Chemical Quantities For Modification Or Stabilization

a. Lime or Lime By-Products: 4% to7 %

b. Cement: 4% to 6%

c. Fly ash Class C: 10% to 16%

% for each combination of lime-fly ash or cement-fly ash shall be established based on laboratory results.

3.03 Strength requirements for stabilization and modification

The reaction of a soil with quick lime, or cement is important for stabilization or modification and design methodology. The methodology shall be based on an increase in the unconfined compression strength test data. To determine the reactivity of the soils for lime stabilization, a pair of specimens measuring 2 in. (50 mm) diameter by 4 in. (100 mm) height (prepared by mixing at least 5% quick lime by dry weight of the natural soil) are prepared at the optimum moisture content and maximum dry density (AASHTO T 99). Cure the specimens for 48 hours at 120^{o} F (50^{o} C) in the laboratory and test as per AASHTO T 208. The strength gain of lime-soil mixture must be at least **50 psi** (350 kPa) greater than the natural soils. A strength gain of **100 psi** (700 kPa) for a soil-cement mixture over the natural soil shall be considered adequate for cement stabilization with 4% cement by dry weight of the soils and tested as described above

In the case of soil modification, enhanced subgrade support is not accounted for in pavement design. However, an approved chemical (LKD, cement, and fly ash class C) or a combination of the chemicals shall attain an increase in strength of **30 psi** over the natural soils when specimens are prepared and tested in the same manner as stabilization.

4.0 Laboratory Test Requirements

Soil Sampling and Suitability: An approved Geotechnical Engineer should visit the project during the construction and collect a bag sample of each type of soil in sufficient quantity for performing the specified tests. The geotechnical engineer should review the project geotechnical report and other pertinent documents such as soil maps, etc., prior to the field visit. The geotechnical consultant shall submit the test results and recommendations, along with the current material safety data sheet or mineralogy to the engineer for approval.

When the geotechnical engineer determines the necessity of chemical-soil stabilization during the design phase, they should design a subgrade treatment utilizing the chemical for the stabilization in the geotechnical report in accordance with INDOT guidelines. Following tests should be performed and the soils properties should be checked prior to any modification or stabilization.

a. Grain size and Hydrometer test results in accordance with AASHTO T 89, 90, and M145,

b. Atterberg limits,

c. Max. Dry unit weight of 92 pcf (Min.) in accordance with AASHTO T 99,

d. Loss of ignition (LOI) not more than 3% by dry weight of soil in accordance with AASHTO T 267,

e. Carbonates not more than 3 % by dry weight of the soils, if required,

f. As received moisture content in accordance with AASHTO T 265.

4.01 Lime or Lime By-Products Required for Modification or Stabilization.

Lime reacts with medium, moderately fine and fine-grained soils to produce decreased plasticity, increased workability, reduced swelling, and increased strength. The major soil properties and characteristics that influence the soils ability to react with lime to produce cementitious materials are pH, organic content, natural drainage, and clay mineralogy. As a general guide, treated soils should increase in particle size with cementation, reduction in plasticity, increased in internal friction among the agglomerates, increased shear strength, and increased workability due to the textural change from plastic clay to friable, sand like material.

The following procedures shall be utilized to determine the amount of lime required to stabilize the subgrade. Hydrated or quick lime and lime by-products should be used in the range of 4 ± 0.5% and 5 ± 1% by weight of soil for modification respectively. The following procedures shall be used to determine the optimum lime content.

Perform mechanical and physical tests on the soils.

Determine the separate pH of soil and lime samples.

Determine optimum lime content using Eades and Grim pH test.

- A sufficient amount of lime shall be added to soils to produce a pH of 12.4 or equal to the pH of lime itself. An attached graph is plotted showing the pH as lime content increases. The Optimum lime content shall be determined corresponding to the maximum pH of lime-soil mixture. (See Figure 4.0 A).

- Representative samples of air-dried, minus No. 40 soil is equal to 20 g of oven-dried soil are weighed to the nearest 0.1 g and poured into 150-ml (or larger) plastic bottles with screw on tops.

- It is advisable to set up five bottles with lime percentages of 3, 4, 5, 6, and 7. This will insure, in most cases, that the percentage of lime required can be determined in one hour. Weigh the lime to the nearest 0.01 g and add it to the soil. Shake the bottle to mix the soil and dry lime.

- Add 100 ml of CO_2-free distilled water to the bottles.

- Shake the soil-lime mixture and water until there is no evidence of dry material on the bottom. Shake for a minimum of 30 seconds.

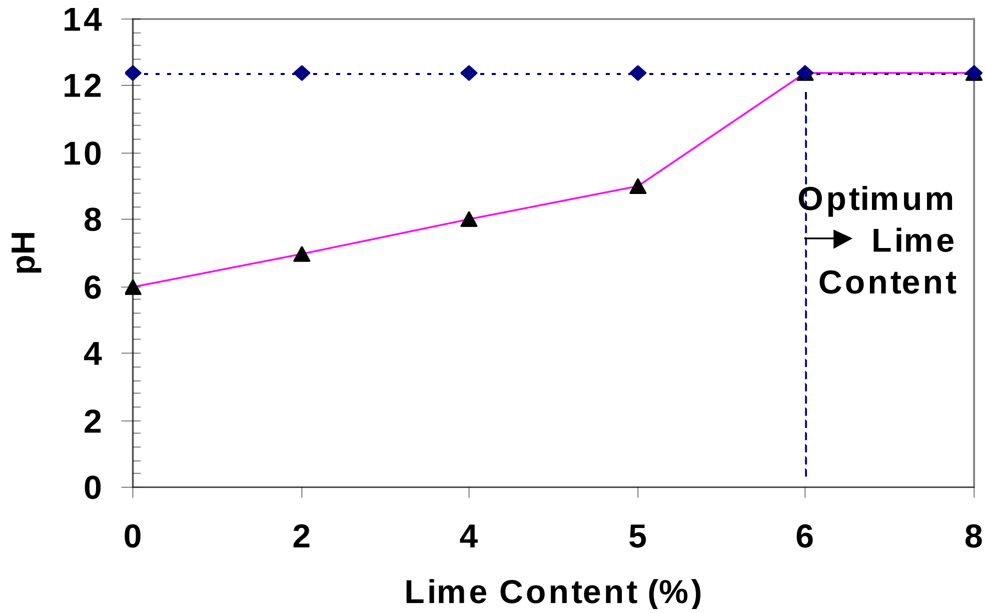
- Shake the bottles for 30 seconds every 10 minutes.

- After one hour, transfer part of the slurry to a plastic beaker and measure the pH. The pH meter must be equipped with a Hyalk electrode and standardized with a buffer solution having a pH of 12.00.

- Record the pH for each of the lime-soil mixtures. If the pH readings go to 12.40, then the lowest percent lime that gives a pH of 12.40 is the percentage required to stabilize the soil. If the pH does not go beyond 12.30 and 2 percentages of lime give the same readings, the lowest percent which gives a pH of 12.30 is the amount required to stabilize the soil. If the highest pH is 12.30 and only 1 percent lime gives a pH of 12.30, additional test bottles should be started with larger percentages of lime.

d. Atterberg limits should be performed on the soil-lime mixtures corresponding to optimum lime content as determined above.

e. Compaction shall be performed in accordance with AASHTO T 99 on the optimum lime and soil mixture to evaluate the drop in maximum dry density in relation to time (depending on the delay between the lime-soil mixing and compaction.)



pH vs. Lime Content

Figure 4.0 A

In the case of stabilization, the Unconfined Compression Test (AASHTO T 208) and California Bearing Ratio (AASHTO T 193, soaked) or resilient modulus (AASSHTO T 307) tests at 95% compaction shall be performed in addition to the above tests corresponding to optimum lime-soil mixture of various predominant soils types.

4.02 Cement Required for Stabilization or Modification

The criteria for cement percentage required for stabilization shall be as follows. The following methodology shall be used for quality control and soil-cement stabilization.

1. Perform the mechanical and physical property tests of the soils.

2. Select the Cement Content based on the following:

AASHTO Classification	Usual Cement Ranges for Stabilization (% by dry weight of soil)
A-1-a	3 – 5
A-1-b	5 – 8
A-2	5 – 9
A-3	7 – 10

Suggested Cement Contents
Figure 4.0B

3. Perform the Standard Proctor on soil-cement mixtures for the change in maximum dry unit weight in accordance with AASTO T 134.

4. Perform the unconfined compression and CBR tests on the pair of specimens molded at 95% of the standard Proctor in case of stabilization. A gain of 100 psi of cement stabilization is adequate enough for stabilization and % cement shall be adjusted.

Although, there is no test requirement for the optimum cement content when using cement to modify the subgrade. An amount of cement 4% ± 0.50% by dry weight of the soil should be used for the modification of the subgrade.

4.03 Fly Ash Required for Modification

1. The in-situ soils should meet the criteria for modification.

2. Standard Proctor testing should be performed in accordance with AASHTO T 99 to determine the maximum dry density and optimum moisture content of the soil.

3. A sufficient amount of fly ash (beginning from 10% by dry weight of soil) should be mixed with the soil in increments of at least 5%. The moisture content of the mix shall be in the range of optimum moisture content + 2%. Each blend of the fly ash soil mixture should be compacted as per the standard Proctor to determine the maximum dry density.

4. The compaction of the mixes shall be completed within 2 hours.

5. The percentage of fly ash, which provides the maximum dry density, should be considered the **optimum amount of fly ash** for that soil.

6. The compressive strength of the **optimum fly ash mix** should be determined 2, 4, and 8 hours after compaction.

7. A pair of specimens of the **optimum fly ash** mix should be molded of standard Proctor and soaked for 4 days. The swelling should be observed daily. A percentage swell of more than 3 not be allowed in soils modification.

4.04 Combination of Cement Fly Ash and Lime Mixture

To enhance the effectiveness of lime, cement or fly ash modification or stabilization combinations, the subsequent guidelines shall be used. An increase of **50 to 100 psi** over the natural soil is required for the stabilization and an increase of **30 psi** over the natural soils is required for modification.

1. Lime and Fly ash: The ratio between lime and fly ash mixture should be in the range of 1:1 to 1:9 respectively.

2. Cement and Fly ash: The ratio of cement and fly ash should be in the range of 1:3 to 1:4 respectively.

3. Lime, cement, and fly ash ratio should be 1:2:4 respectively.

5.0 Construction Considerations

Modification of soils to speed construction by drying out wet subgrades with lime, cement and fly ash is not as critical as completely stabilizing the soil to be used as a part of the pavement structure. With the growth of chemical modification throughout Indiana, a variety of applications are being suggested due to such factors as soil types, percentage of modification/stabilization required, environmental restraints, and availability of chemicals. Furthermore, when chemically stabilized subgrades are used to reduce the overall thickness of the roadway then the stabilized layer must be built under tight construction specifications; whereas the requirements for the construction of a working platform are more lenient. Following are a few recommendations for modification or stabilization of subgrade soils.

1. Perform recommended tests on each soil to see if the soil will react with chemicals then determine the amount of chemical necessary to produce the desired results.

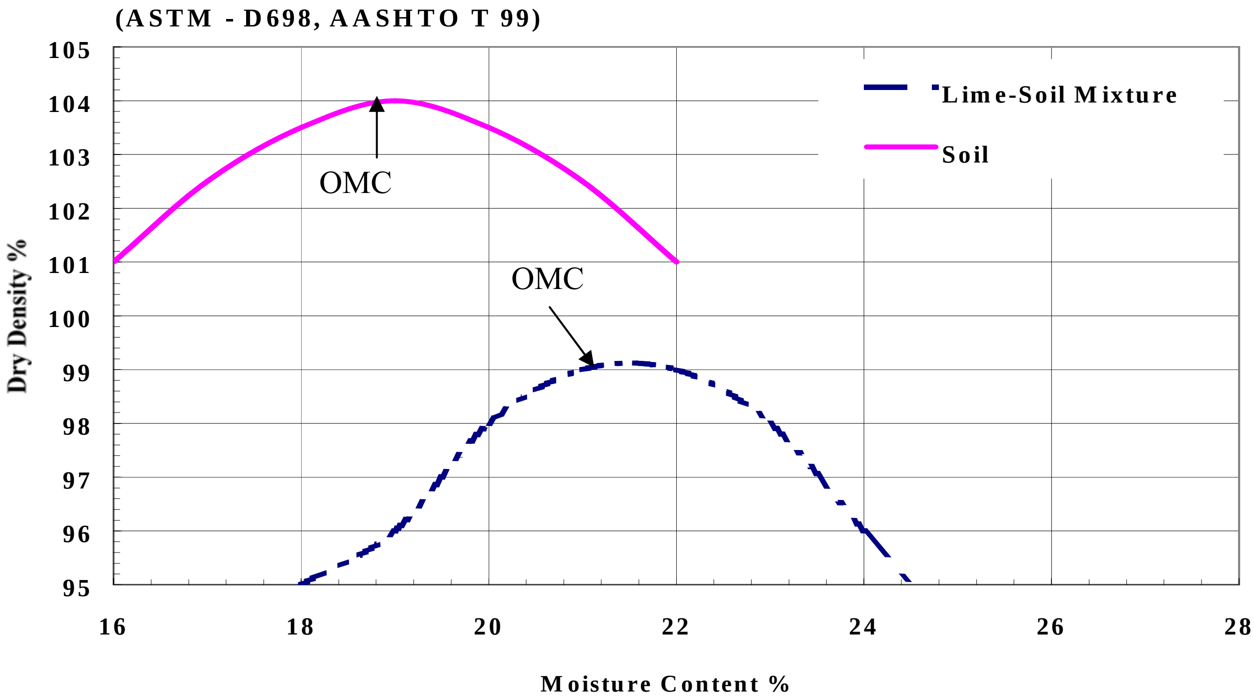
2. More chemicals may not always give the best results.

3. Sulfate, when mixed with calcium will expand. Soils having over 10% sulfate content shall not be mixed with chemicals.

4. Chemicals used shall meet the INDOT Standard Specifications.

5. One increment of chemical is recommended to produce a working platform. Proofrolling is required before placing the base or subbase. Pavement shall not be installed before curing is completed.

6. The density of cement treated soils may likely be different than that of untreated soils. Standard Proctor tests should be performed in the laboratory to estimate the appropriate target density.



Moisture Density Relationship
Figure 5.0 A

7. The grade should be set low to account for the swell in the lime. A swell factor of 10% is an approximate estimate.

8. Uniform distribution of chemical, throughout the soil is very important.

9. Curing takes 7 days of 50^{o} F or above weather for stabilization. No heavy construction equipment should be allowed on the stabilized grade during the curing period.

10. The maximum dry density of the soil-lime mixture is lower than in untreated soils. Maximum dry density reduction of 3-5 Pcf approximately, is common for a given compactive effort. It is, therefore, important that the laboratory for field control purposes provide appropriate density. (See Figure 5.0A).

11. The modified or stabilized roadbed must be covered with pavement before suspending work for the winter and construction traffic shall be limited

12. Cement or fly ash treated soils exhibit shrinkage cracks due to soil type, curing, chemical contents, etc. Therefore, it is recommended to provide surface sealing on stabilized subgrade after the curing period.

13. Moisture content of modified or stabilized subgrade should be maintained above the optimum moisture content of modified subgrade during the curing.

14. Lime raises the pH of the soil. Phenolphthalein, a color sensitive indicator solution can be sprayed on the soil to determine the presence of lime. If lime is present, a reddish-pink color develops. (See Figure 5.0B).

Lime Modified Subgrade Uniformity Determination by Phenolphthalein
Figure 5.0B

15. Because lime can cause chemical burns, safety gear, such as gloves, eye protection, and dust masks shall be used during construction and inspection.

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1. Thomson, M.R., "Final Report Subgrade Stability" - Civil Engineering Studies, Transportation Engineering Series No. 18, Illinois Cooperative Highway and Transportation Series No. 169, University of Illinois at Urbana - Champaign, 1977.
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APPENDIX B 4

MIXTURE DESIGN AND TESTING PROCEDURES FOR LIME STABILIZED SOILS

NATIONAL LIME ASSOCIATION

National Lime Association

LIME

The Versatile Chemical

Technical Brief

Mixture Design and Testing Procedures for Lime Stabilized Soil

Steps for Mixture Design and Testing for Lime Stabilized Soil

Evaluate soil to gain a general understanding of its suitability for lime stabilization.

Determine minimum amount of lime required for stabilization.

Evaluate lime-stabilized soil strength for long term durability within its exposure environment, with special attention to cyclic freezing and thawing and periods of extended soaking.

If soils to be stabilized are expansive, evaluate using capillary soaking and expansion measurements.

The use of lime to dry, modify, and stabilize soil is a well established construction technique, documented in studies dating back to the 1950s and 1960s [see Ref. 1]. A variety of mixture proportioning procedures have evolved, as various agencies have developed criteria and procedures to fit their specific design needs and objectives, often reflecting local conditions and experience [1].*

The procedures outlined in this publication are intended for soil that is to be stabilized with lime, not merely dried or modified. These procedures are intended to help ensure the long term strength and durability of a lime stabilized soil and are not typically required when soil drying and modification is the desired goal. Other laboratory tests, such as measuring decrease in soil moisture content or reduction in plasticity index (PI), are more appropriate when soil drying/modification is the intended result.

In 1999, the National Lime Association commissioned Dr. Dallas Little to evaluate various procedures and develop a definitive lime stabilization mixture design and testing procedure (MDTP) that specifying agencies, design engineers, and laboratory personnel could use with confidence for soil conditions and environmental exposures throughout the United States. The resulting series of reports summarize the literature on lime stabilization [2, 3]; describe mix proportioning and testing procedures for lime stabilized soil [4]; and present a field validation of the protocol [5].

Lime-Treated Soil – Drying, Modification, and Stabilization

Lime has a number of effects when added into soil [6, 7], which can be generally categorized as soil drying, soil modification, and soil stabilization:

- Soil drying is a rapid decrease in soil moisture content due to the chemical reaction between water and quicklime and the addition of dry material into a moist soil. [8]
- Modification effects include: reduction in soil plasticity, increase in optimum moisture content, decrease in maximum dry density, improved compactability, reduction of the soil's capacity to swell and shrink, and improved strength and stability after compaction. These effects generally take place within a short time period after the lime is introduced – typically 1 to 48 hours – and are more pronounced in soils with sizable clay content, but may or may not be permanent.
- Lime stabilization occurs in soils containing a suitable amount of clay and the proper mineralogy to produce long-term strength; and permanent reduction in shrinking, swelling, and soil plasticity

** Construction techniques are not addressed in this publication--see Ref. 6.*

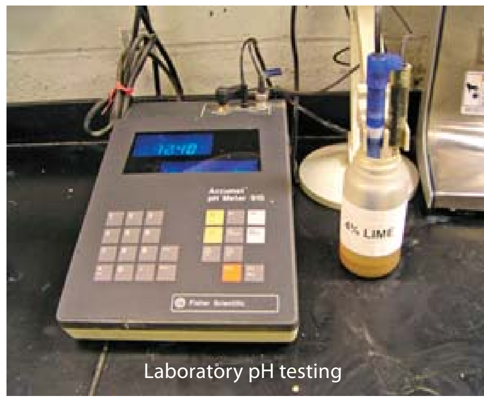
with adequate durability to resist the detrimental effects of cyclic freezing and thawing and prolonged soaking. Lime stabilization occurs over a longer time period of "curing." The effects of lime stabilization are typically measured after 28 days or longer, but can be accelerated by increasing the soil temperature during the curing period. A soil that is lime stabilized also experiences the effects of soil drying and modification.

Lime Stabilization Mix Design and Testing Procedures

The procedures outlined in this document are to evaluate if a soil can be stabilized with lime and, if so, determine the minimum amount of lime required for long-term strength, durability and the other desired properties of the stabilized soil. This is achieved by:

- Initially evaluating the soil to gain a general understanding of its suitability for lime stabilization.
- Determining the minimum amount of lime required for stabilization.
- Evaluating the lime-stabilized soil strength for long term durability within its exposure environment, with special attention to cyclic freezing and thawing and periods of extended soaking.
- If the soils to be stabilized are expansive, evaluate using capillary soaking and expansion measurements.

Steps for Mixture Design and Testing for Lime Stabilized Soil



Laboratory pH testing

Step 1 – Initial Soil Evaluation

Purpose: Evaluate key soil characteristics as an initial step to determine if it is suitable for lime stabilization.

Procedure: Use ASTM C136 [10] procedures to determine the amount of soil passing the 75 micron (75-μm) screen and ASTM D 4318 (wet method) [11] to determine the soil plasticity index (PI).

Criteria: Generally, soil with at least 25% passing a 75 micron screen and having a PI of 10 or greater are candidates for lime stabilization. Some soils with lower PI can be successfully stabilized with lime, provided the pH and strength criteria described in this document can be satisfied.

Additional Considerations: Soil with organics content above 1-2% by weight as determined by ASTM D 2974 [12] may be incapable of achieving the desired unconfined compressive strength for lime stabilized soil (Step 6) [13]. Soils containing soluble sulfates greater than 0.3% can be successfully stabilized with lime, but may require special precautions (see NLA's "Technical Memorandum – Guidelines for Stabilization of Soils Containing Sulfates" Ref. 14 for more information).

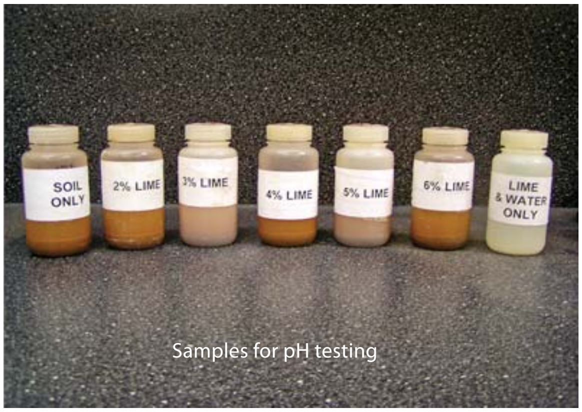
Step 2 – Determine the Approximate Lime Demand

Purpose: Determine the minimum amount of lime required for stabilization.

Procedure: Use ASTM D 6276 [15] procedures. This is also known as the "Eades-Grim" test.

Criteria: The lowest percentage of lime in soil that produces a laboratory pH of 12.4 [flat section of the pH vs. lime percentage curve produced by the test] is the minimum lime percentage for stabilizing the soil.

Additional Considerations: ASTM D 6276 has additional provisions for cases in which the measured laboratory pH is 12.3 or less. Note that lime can react with moisture and carbon dioxide. Careful storage is required to maintain lime's integrity and produce reliable results.



Samples for pH testing

Step 3 – Determine Optimum Moisture Content and Maximum Dry Density of the Lime-Treated Soil

Purpose: Determine optimum moisture content (OMC) and maximum dry density (MDD) of the soil after lime has been added. This is necessary because adding lime will change the soil's OMC and MDD.


Lab mixing of soil & lime

Procedure: Make a mixture of soil, lime, and water at the minimum percentage of lime as determined from Step 2 (Eades-Grim test), using a water content of OMC + 2-3%. Seal the mixture in an airtight, moisture proof bag stored at room temperature for 1-24 hours. Determine the OMC and MDD of the mixture using ASTM D 698 procedures (standard compaction effort) [16].

Criteria: Determine the OMC and MDD for Step 4.

Additional Considerations: When using quicklime, the mixture should be stored for 20-24 hours to ensure hydration.

Step 4 – Fabricate Unconfined Compressive Strength (UCS) Specimens

Purpose: Fabricate test specimens for UCS testing (Step 6).

Procedure: Using ASTM D 5102 [17] procedure B, fabricate a minimum of two test specimens of lime, soil and water using the amount (percentage) of lime determined from Step 2 at the OMC (± 1%) as determined from Step 3. The soil-lime-water mixture should be stored in an airtight, waterproof bag for 1-24 hours prior to fabricating the test specimens.

Desired Result: A minimum of two specimens for UCS testing.


Making Proctor specimen

Additional Considerations: When using quicklime, the mixture should be stored for 20-24 hours to ensure hydration. Additional specimens may be fabricated if additional testing is desired. In some cases it may be advisable to make test specimens at higher lime content(s) than that determined from ASTM D 6276 testing (Step 2). These additional specimens can be used to determine the UCS of lime-soil-water mixtures at higher lime contents. For instance, if ASTM D 6276 testing (Step 2) indicates that 4% lime is needed, additional UCS testing could be done at 5% and 6% lime to ensure that the UCS criteria (Step 6) is also achieved.

Step 5 – Cure and Condition the Unconfined Compressive Strength (UCS) Specimens

Purpose: Approximate, in an accelerated manner, field curing and moisture conditions.


Soaking specimens

Procedure: Immediately following the fabrication of the test specimens, wrap the specimens in plastic wrap and seal in an airtight, moisture proof bag. Cure the specimens for 7 days at 40°C. Subject the specimens to a 24 hour capillary soak prior to testing.

The capillary soaking process should be done by removing the specimens from the airtight bag, then removing the plastic wrapping. The specimens are wrapped with wet absorptive fabric and placed on a porous stone. The water level should reach the top of the stone and be in contact with the fabric wrap throughout the capillary soak process, but the soil specimen should not come directly into contact with the water.

Desired Result: A minimum of two cured and moisture conditioned specimens for UCS testing.

Step 6 – Determine the Unconfined Compressive Strength (UCS) of the Cured and Moisture Conditioned Specimens


Unconfined compressive strength test (ASTM D5102)

Purpose: To determine the UCS of the lime-stabilized soil to ensure adequate field performance in a cyclic freezing and thawing and an extended soaking environment.

Procedure: Use ASTM D 5102 procedure B to determine the UCS of the cured and moisture conditioned specimens. The UCS is the average of the test results for a least two specimens.

Criteria: The minimum desired UCS depends on the intended use of the soil, the amount of cover material over the stabilized soil, exposure to soaking conditions, and the expected number of freezing and thawing cycles during the first winter of exposure. Suggested minimum UCS are shown in the following table.

Soil-Lime Mixture Unconfined Compressive Strength Recommendations [18]				
Anticipated Use	UCS Recommendations for Various Anticipated Service Conditions			
	Extended Soaking for 8 Days (psi)	Cyclic Freeze-Thaw[a]		
		3 Cycles (psi)	7 Cycles (psi)	10 Cycles (psi)
Subbase				
Rigid Pavement/ Floor Slabs/ Foundations	50	50	90	120
Flexible Pavement (> 10 in.)[b]	60	60	100	130
Flexible Pavement (8 in -10 in.)[b]	70	70	100	140
Flexible Pavement (5 in. – 8 in.)[b]	90	90	130	160
Base				
	130	130	170	200

Notes:

a – Number of freeze-thaw cycles expected in soil-lime layer during the 1st winter of exposure.

b – Total pavement thickness overlying the subbase.

Step 7 – Determine the Change in Expansion Characteristics [only for expansive soils]

Purpose: To evaluate the expansiveness of lime stabilized soils.

Procedure: Note the vertical and circumferential dimensions of the samples fabricated in Step 5 prior to performing the capillary soak. After soaking, perform new measurements using a caliper for the vertical dimension and a pi-tape for the circumference. Calculate the volume change between the initial (dry) condition and the soaked condition.

Criteria: Three-dimensional expansion of between 1 and 2% is commonly regarded as acceptable.

Additional Considerations: If the expansion exceeds the design parameter, fabricate additional samples increasing the lime content by 1 and 2% and repeat the test. If additional expansion, shrinkage, and uplift pressure data is desired, perform ASTM D3877 [19]. This step is applicable only to expansive soils.

Other Considerations

The procedures outlined in this document can be used to determine whether a soil can be stabilized with lime and, if so, to quantify the minimum amount of lime required to produce long-term strength, durability, and the other desired properties of a lime-stabilized soil. Typical construction specifications require 0.5 - 1.0 percent more lime than suggested by laboratory procedures, to account for differences between lab and field techniques (for example, field gradation vs. controlled lab pulverization) and field variability.

Other characteristics and properties of the soil, both untreated and lime-treated, may be important for engineering design, construction, and quality control. These characteristics and properties may include, for example: moisture content, moisture reduction, gradation, soil classification, Atterberg limits, organic content, soluble sulfate content, strength characteristics and indices such as CBR, modulus of resilience (Mr), modulus of subgrade reaction (k), R-value, shear strength, and bearing strength. The effect of lime to improve many of these soil properties and characteristics is often substantial, but beyond the scope of this document. They should however, be evaluated as required on a project by project basis.

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16. ASTM D698 "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort" Note that some jurisdictions require modified compaction, D1557. (www.astm.org)

17. ASTM D5102 "Standard Test Method for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures" (www.astm.org)

18. Excerpted from Reference 2, Table 3, page 36 (after Thompson, 1970).

19. ASTM D3877 "Standard Test Methods for One-Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures" (www.astm.org).

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