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SEISMIC REMEDIATION OF THE CLEMSON UPPER AND LOWER DIVERSION DAMS; DEEP SOIL MIX CONSTRUCTION

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Bids

Clemson Total Bid Summary			Production Soil Cement Bid Summary	
Government Estimate	$7,768,587		Winning Bid	$107/yard^3
Winning & Low Bid	$7,744,657		Low Bid	$70/yard^3
High Bid	$12,592,400		High Bid	$199/yard^3
Average	$9,248,526		Average	$126/yard^3

Winning Bid: **RAITO Inc.** of Crofton, Maryland

Bids

Additional Soil Cement Bid Summary	
Winning & Low Bid	$220/yard^3
High Bid	$819/yard^3
Average	$556/yard^3

Construction – Soil Mix Equipment

- Large track mounted rig
- Six in-line, 3-foot-diameter, ~50-foot-long soil mix augers
- Four electrical motors drive the augers at either 20 or 40 rpms

Construction – Soil Mix Equipment

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- Auger mixing blades over the bottom 10 ft of the shafts
- Overlap adjacent mixing columns by 1 ft
- Average wall width of 2.76 feet
- Adjacent augers vertically offset by 1 ft

Construction – Soil Mix Equipment

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Construction – Soil Mix Equipment

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Batch and Pumping Plant

Construction – Soil Mix Equipment

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Tanker truck off-loading cement

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Construction – Soil Mix Equipment

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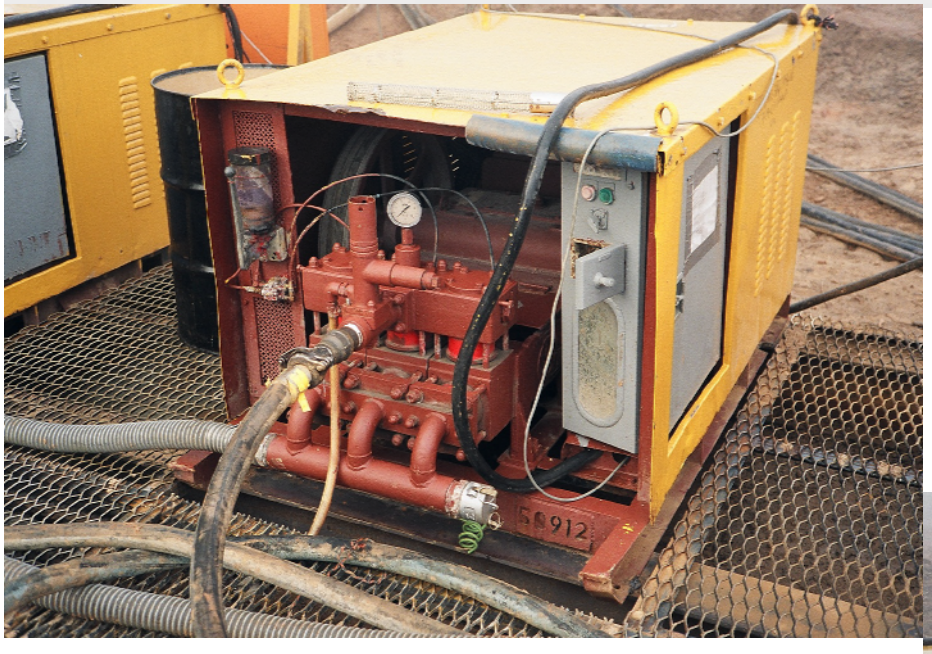

Pump

Flow Meters

Construction – Soil Mix Equipment

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Construction – QA/QC

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Monitored Parameters:

- Depth
- Time
- Flow Rate

→ Injected Cement / Foot

- Cable Load
- Electrical Motor Load

→ Resistance

- Verticality

Typical Installation Record

Installation Records

Project Name: Clemson

Element # : UDSW40196 Rig # : 1 7 / 28 / 2004

Mixing System Design Data	Depth (ft)	Slurry Injection Volume (gal/ft)		Speed (ft/min)	
		Down	Up	Down	Up
1st Layer	8.5	1.0	0.0	40.0	40.0
2nd Layer	50.0	17.6	0.0	3.5	5.5
3rd Layer	-----	-----	-----	-----	-----
4th Layer	-----	-----	-----	-----	-----

Depth	Time	Speed	Rotation	Slurry Injection Volume (gal)						Energy Index	
(ft)	(mm:ss)	(ft/min)	(rpm)	Column1	Column2	Column3	Column4	Column5	Column6		
0.0	0:00										
3.0	0:25	7.2	19	9.8	7.1	7.2	8.4	7.4	7.5	39	
6.0	1:58	1.5	19	21.3	22.7	20.7	21.8	22.3	22.6	222	
8.5	3:50	0.6	17	78.0	73.1	73.5	74.3	71.1	74.3	805	
9.0	0:24	1.2	19	17.6	18.3	18.3	18.1	18.5	18.3	377	
12.0	1:27	2.0	19	54.6	54.4	54.3	54.4	54.5	54.3	198	
15.0	1:27	2.0	19	52.0	52.3	52.2	52.1	52.2	52.3	194	
18.0	1:13	2.4	19	58.6	58.3	57.3	58.4	58.0	58.1	144	
21.0	1:08	2.6	19	64.6	64.4	63.2	64.5	64.5	64.4	76	
24.0	0:56	3.2	38	53.5	53.4	55.2	53.3	53.4	53.4	40	
27.0	1:37	1.8	40	57.1	58.6	58.7	58.6	58.1	57.3	110	
30.0	1:04	2.8	40	59.6	54.3	56.0	53.7	56.6	57.4	35	
33.0	1:05	2.7	40	56.5	56.6	57.3	54.9	57.1	56.9	36	
36.0	3:00	1.0	39	56.9	59.8	61.0	60.6	60.6	62.3	275	
39.0	1:30	2.0	21	81.3	75.5	81.2	79.5	81.2	82.0	84	
42.0	0:57	3.1	19	53.7	53.8	53.9	53.8	53.9	53.8	96	
45.0	2:14	1.3	19	62.7	63.5	63.6	63.1	64.1	63.8	348	
47.0	3:58	0.5	19	111.4	110.4	112.3	40.6	39.6	40.2	1069	***
47.1	1:31	0.0	19	33.9	34.2	34.2	32.4	32.8	30.9	1337	
45.0	0:31	4.0	19	0.5	0.5	0.5	0.5	0.5	0.5		**

Construction-QA/QC

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Construction – Planned QA/QC

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QA/QC – Wet Grab Soil-Cement Samples

Frequency:

- Two sets of samples per wall
- Not less than one set per work shift per rig

Set: Consists of 4 samples each at top, middle, bottom depths

Procedure:

- Screen samples on 1-inch sieve
- Cut particles retained to just pass the 1-inch sieve and then to be remixed with sample
- Collect enough soil-cement per sample to make four full cylinders (6-inch diameter by 12-inch height)

Unconfined tests: @ 7 days, 28 days(2), and 56 days; (12 @ 28)

Construction – Planned QA/QC

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QA/QC - Core Samples

Where:

- Two locations per test section (Test section was a single wall)
- Two locations within any production wall where wet grab samples do not meet strength criteria

When: Only after strength from unconfined tests on wet grab cylinders indicate that soil-cement strength is unsuitable

Type of core: Continuous, double tube or triple tube, minimum 3-inch diameter

Supplemental coring: If recovery less than 85 % in any run

Testing: Unconfined compression on six samples per boring

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Test Sections

Two test sections per dam.

Establish **base procedures** for installation of production walls.

If **f'sc < criteria**, then:

• use **smaller S**, wall spacing, that will meet criterion

or

• Contractor may **modify procedures** (e.g. higher cement ratio) during production to increase f'sc.

Construction – Planned QA/QC

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QA/QC – Soil-Cement Strength Criteria

Average 28-day compressive strength for each wall:

- **Average f'sc** (28 day) =/> 77.4 psi x (S / Wa)

  Average of all samples (12) from six wet grab locations or all samples (12) from two core borings (when wet grab samples fail)

- **One sample** per wall may have **f'sc < 2/3 criterion**

Construction – QA/QC

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Construction-
Excavation of Berm

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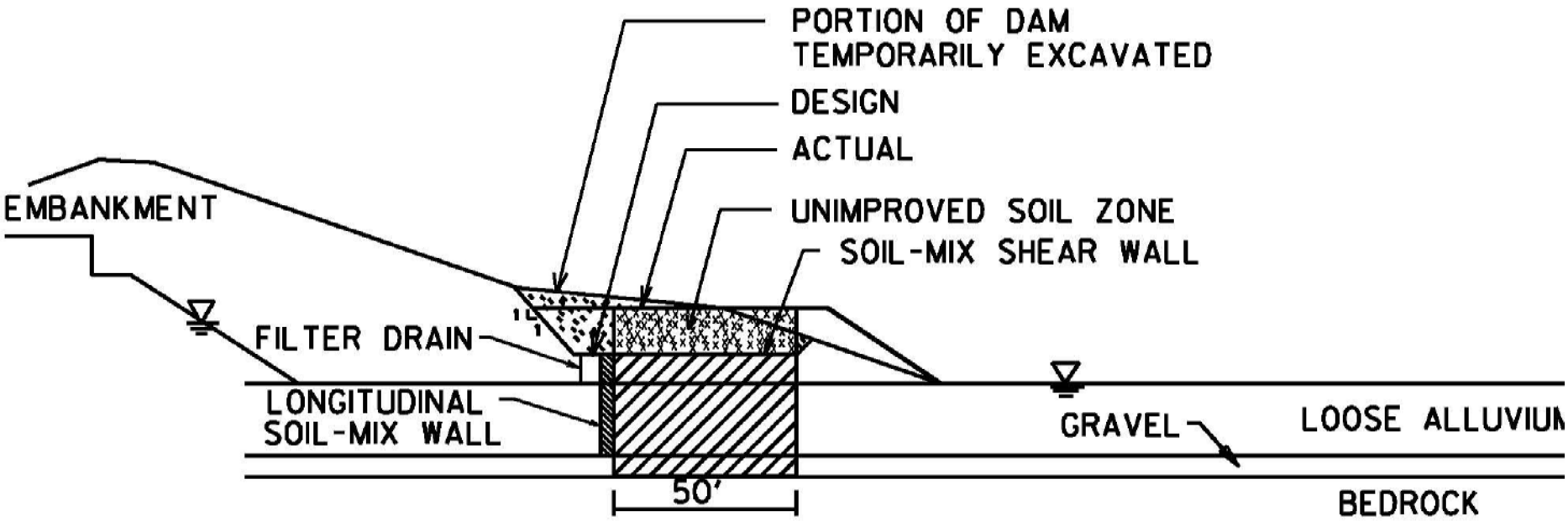

Design vs Actual – Schematic Section

Construction- Excavation of Berm

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Construction-QA/QC

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Sampler plugged with soil from unimproved zone

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Construction – QA/QC

Attempts at Wet-Grab Sampling (Unsuccessful)

Construction – QA/QC

Coring Rig for Soil-Cement Sampling

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Core in core box; note plastic sheath and burlap

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Logging of core and selecting test specimens

Construction – Actual QA/QC

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QA/QC – Soil-Cement Strength Criteria

Average 28-day compressive strength for each wall:

- **Average f'sc** (28 day) =/> 77.4 psi x (S / Wa)

Average of all samples (12) from six wet grab locations or all samples (12) from two core borings (when wet grab samples fail)

- **One sample** per wall may have **f'sc < 2/3 criterion**
- ***Criteria evolved to single core boring for a day's production; minimum six samples per core; one sample may have f'sc < 2/3 average; additional core borings as required***

Construction-
Excavation of Berm

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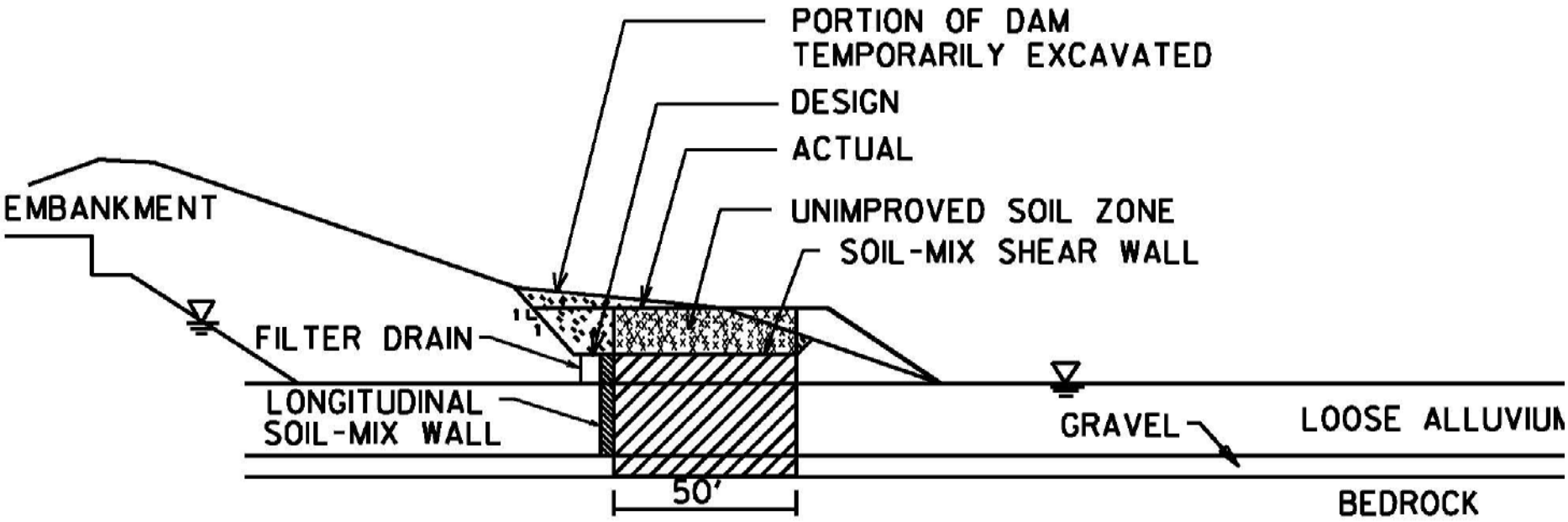

Design vs Actual – Schematic Section

Construction-
Drain Construction

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Trench box and dewatering pump station

Construction-
Drain Construction

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Installation of discharge line; note slot in longitudinal wall

Construction-
Drain Construction

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Cleanouts on drain line

Construction – Soil-Cement Production Mixes

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Cement Injection Rates:

- **840 lb/yd^3** (500 kg/m^3) at start
- **670 lb/yd^3** (400 kg/m^3) at end

Water-Cement Ratio: **0.6 to 0.7**

Construction – Penetration “Refusal” Criteria

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- Advancement Rate < 0.2 foot/minute
- Cable load < one ton
- Duration > one minute

Construction- Problems and Remedies

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Problems:

- Zones where f'sc of soil cement did not meet criteria, probably due to organic content and/or low pH, in ~13% of walls
- Difficult to judge and achieve **penetration** into dense strata, in ~20% of walls

Remedy:

- **Additional elements** or walls

Construction – Lessons

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- **Expect zones of significant deviation** of f'sc (allow some random deviations, correct deviation trends or patterns)
- **Cover as large a range of soils** as possible in design mix testing
- Test soil samples for **pH** and **organic content**
- Use **coring** and not wet grab sampling for QA
- Use **recovery** and core **RQD** or continuity as part of the QA criteria

Construction – Lessons

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- Include a defined number of **additional soil borings** and **core borings** as part of the construction program
- Define **required remedial actions** if f'sc is low or if penetration is not achieved
- Require use of **computerized data collection and injection control** for QC

Summary – Design & Construction

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The use of soil mix shear walls to provide reinforcing of the loose soil against seismic deformations and liquefaction shear slides at the Clemson Dams was feasible and cost effective

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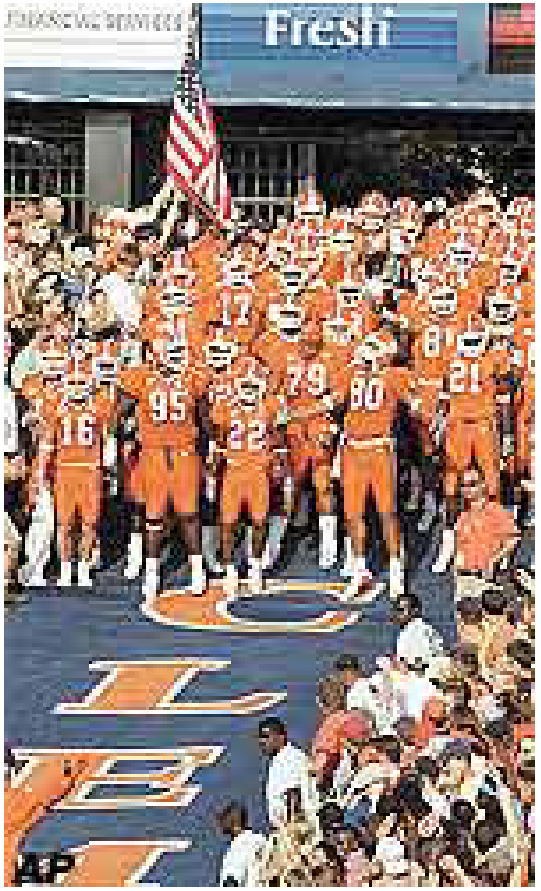
Clemson Diversion Dams



Clemson University can continue to safely perform Football Rituals in Death Valley.