DREDGE MATERIAL STABILIZATION USING THE POZZOLANIC OR SULFO-POZZOLANIC REACTION OF LIME BY-PRODUCTS TO MAKE AN ENGINEERED STRUCTURAL FILL

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ABSTRACT

Large contracts are being awarded to remove and find beneficial uses for dredge spoil. One of the challenges is to find economical and environmentally suitable means to solidify and stabilize (S/S) the solids so they can be reused for structural fill and/or cover soil. This lab study demonstrates the methodology and results of using three sustainable industrial by-products that can compete with Portland cement. They are lime kiln dust (LKD), Class F coal fly ash (FA), and spray dryer ash (SDA). SDA is the residue from spray dryer absorbers, a common type of advanced sulfur dioxide gas scrubber that uses lime. There are existing spray dryer installations in the Middle Atlantic States and new units will be coming on-line in the near future.

These industrial by-products were investigated to determine their potential for solidifying and stabilizing the dredge solids from 1) the Cox Creek confined disposal facility (CDF) for Baltimore, MD; 2) the U.S. Army Corp of Engineers (USACOE) Ft. Mifflin CDF near Philadelphia, PA; and 3) the USACOE Craney Island CDF near Portsmouth, VA; with the objective of making a structural fill material. The use of these industrial by-products may provide an opportunity to recover CO_2 credits.

Performance data for SDA, LKD, and LKD-FA blends is presented. Adequate lime alkalinity needs to be added to take advantage of the pozzolanic and sulfo-pozzolanic, cementitious reaction potential. Raising the pH levels to 9-11 for pozzolanic hydration reactivity coincide with pH levels that stabilize leachable heavy metals. Furthermore, in order to produce structural fill the moisture of the dredge spoil must be reduced as close as possible to the optimum moisture content resulting in compaction at or near maximum dry density. The addition of these by-products will add dry bulk solids and key reaction products are known to chemically reduce the free moisture through several types of hydration reactions. A “mellowing” period before compaction may help prevent swelling from Ettringite precipitation. Strength measurements with several curing times are presented.

Keywords: dredge material stabilization, lime kiln dust, coal fly ash, spray dryer ash, flue gas desulfurization by-products, solidification

1. INTRODUCTION AND BACKGROUND

Dredge material (DM) stabilization technologies are being investigated and practiced in nearly every seaport and navigable channel of water along the Atlantic Coast now that open water disposal is prohibited. Stabilization technology employing cementitious additives is studied here for fine-grained dredged materials (silts and clays), which are typically unsuitable for use as a construction material without first being amended, unlike dredged sands and gravels.

A USACOE expert states “Comprehensive regional or port-specific dredged material management plans include goals such as reducing the dredging volumes, reducing contaminated sediment (source reduction), recycling as much as possible, and disposing as little as possible. For example, Maryland’s goal is to reclaim approximately 30 percent of its annual dredged material volume. (1)

One large scale operation using stabilization technologies is Clean Earth Dredging Technologies Inc., which operates fully commercial projects in New Jersey and Pennsylvania. These projects had processed over 2 million cu. yards of amended dredged material as of 2004. The amendments or stabilization additives used included waste lime products, lime kiln dust, and coal combustion by-products. (2)

2. RESEARCH OBJECTIVES

The worldwide stage for this work is recycling DM to manufacture an engineered construction material for uses like mine land reclamation, Brownfield revitalization, and general use as a structural fill. Dredged material may be screened to remove debris greater than 0.5 to 2 inches in diameter and placed in an impoundment to statically dewater prior to treatment with additives. Upon removal from these confined disposal facilities (CDFs), the wet DM solids can be treated with alkaline and cementitious additive(s) to further reduce the moisture content of the wet solids, provide additional bearing strength, immobilize heavy metals, and buffer acid production. Alternately, freshly dredged material may be treated prior to or as an alternative to static dewatering, with bulking and/or stabilizing agents.

The overall objective of this study is to address the application of industrial by-products using this technology to produce base and embankment material. A mix design procedure for producing stabilized DM is suggested. It consists of adding a bulking agent to get near the OMC content for maximum compacted density and at the same time use bulking agents that add proper and balanced “pozzolanic chemistry to the mix,” meaning that they are added in the correct quantity and proportion to chemically react and gain strength by the pozzolanic reaction mechanism.

The corollary objective of this paper is to investigate the use of industrial by-products associated with the use of lime and coal combustion: LKD, class F fly ash, and SDA. Several types of CCPs are described in detail. Chemical reaction mechanisms when using these additives are discussed and laboratory geotechnical test results are reported.

Figure 1. Cox Creek CDF, Baltimore, MD

3. DISCUSSION

3.1 Terminology per ASTM

- **Stabilization technologies** is used here to include both solidification and stabilization (S/S).
- **Solidification** is the conversion of soils, liquids, or sludges into a solid, structurally sound material for disposal or use. Solidification typically refers to attainment of 50 psi or values similar to the strength of surrounding soil.
- **Stabilization (also fixation)** is defined as immobilization of undesirable constituents to limit their introduction into the environment. Toxic components are immobilized by treating them chemically to form insoluble compounds. The stabilization reactions described herein are specifically referring to pozzolanic and sulfo-pozzolanic reactions.

3.2 Similarity to Construction Site Soil Stabilization

Dredged material stabilization is similar to soil stabilization, which has the goal of improving soil subgrade properties for pavement or foundation design purposes, or to overcome deficiencies in available construction materials, i.e. overly wet, plastic soil. The soil stabilization process for road or construction site purposes is defined as the long-term physical and chemical alteration of soils to enhance their physical and engineering properties. (3) Available cementitious stabilization additives are mixed into soils to increase their load bearing capacity, reduce shrink-swell properties, and improve long-term durability. Industrial lime by-products as stabilization additives include the lime kiln dust (LKD), quicklime (calcium oxide or CaO), and certain Clean Coal Technology (CCT) dry ashes produced from processes that use lime or limestone to remove sulfur dioxide (SO_2) from the flue gas stream that accompanies coal combustion. Some of these dry ashes are removed with the coal fly ash, while other installations collect these ashes separately from coal fly ash.

3.3 Suitable Soil Criteria

According to civil engineers, a soil suitable for use as an engineered construction material should have a liquid limit (LL) less than 45% and a plastic index (PI) less than 20. For use as a structural fill, compacted soil should have an unconfined compressive strength (UCS) greater than ~35 psi and have a California Bearing Ratio (CBR) greater than 8.

3.4 Pozzolanic and Sulfo-pozzolanic Chemical Reaction

Drying with lime or lime by-products is accomplished in several ways. First, the addition of dry materials such as lime products and coal fly ash decreases the moisture content through a bulking effect. Second, quicklime will react with water, called hydration, to convert the quicklime (calcium oxide) to hydrated lime (calcium hydroxide). Third, the quicklime hydration reaction is exothermic, and the heat evolved can help speed evaporation of additional moisture.

Finally, hydrated lime solubilizes silicates and aluminates at high pH which initiates pozzolanic reactions and sulfo-pozzolanic reactions (when sulfates or sulfites are present). With curing and aging, these slower chemical cementitious reactions allow more bonding with water, through the formation of complex cementitious compounds such as calcium silicates, calcium aluminates, and calcium sulfo-aluminates. The chemically bonded water molecules are known as waters of hydration.

Pozzolanic Reactions:

Hydrated lime ($Ca(OH)_2$), plus a supplement of pozzolanic Class F fly ash, reacts with the DM silt and clay. Lime may be supplied in the form of LKD, quicklime, or hydrated lime. These stabilization additives provide the key components that take part in the classical pozzolanic stabilization reactions.

Description of Pozzolanic Reactions:

- Silicates:

$$SiO_2 + Ca(OH)_2 + H_2O \rightarrow CaO\text{-}SiO_2\text{-} H_2O \quad \text{(calcium silicate)}$$

- Aluminates:

$$Al_2O_3 + Ca(OH)_2 + H_2O \rightarrow CaO\text{-}Al_2O_3\text{-}H_2O \quad \text{(calcium aluminate)}$$

- Ferro Aluminates:

$$Fe_2O_3 + Al_2O_3 + Ca(OH)_2 \rightarrow CaO\text{-}Al_2O_3\text{-} Fe_2O_3\text{-}H_2O \quad \text{(calcium ferroaluminate)}$$

Comments:

1. Similar reactions occur during the hydration/curing of Portland cement.
2. Fly ash can be used to replace a portion of the Portland cement when making concrete.
3. Lime is added to modify clay soil for pavement subgrade stabilization

Description of Sulfo – pozzolanic Reaction:

- Found where calcium, sulfates (or sulfites) and aluminates exist at high pH conditions.
- Formation of Ettringite (calcium sulfo-aluminate).

$$2Ca(OH)_2 + 3CaSO_4{\cdot}H_2O + CaO{\cdot}Al_2O_3 + 30\ H_2O \rightarrow (CaO)_6 - Al_2(SO_4)_3{\cdot}32H_2O$$

Comments:

1. An example is the use of gypsum to control setting time in Portland cement concrete.
2. The high pH from lime solubilizes alumina which reacts with dissolved gypsum (calcium sulfate or $CaSO_4$-$2H_2O$).
3. The reaction consumes <u>32 moles</u> water for every 2 moles of lime and 3 moles of gypsum.
4. Calcium sulfite ($CaSO_3{\cdot}0.5H_2O$) can replace gypsum ($CaSO_4{\cdot}2H_2O$).
5. The reaction occurs with both wet and dry FGD solids.

3.5 Stabilization Additives

- **Quicklime** is produced by the calcination of calcium carbonate, or limestone. Carbon dioxide is driven out of the stone leaving reactive calcium oxide, or quicklime.
- **LKD** is a co-product produced during the manufacture of quicklime. LKD contains some active calcium oxide, usually 15-35% by weight. Because lime calcination usually uses coal for energy, LKD typically contains some coal fly ash, comprised primarily of silica and alumina oxides. LKD is sometimes used for soil or solid waste stabilization in combination with class F coal fly ash.

- **Class F coal fly ash** is produced during the combustion of Eastern bituminous coal. Class F fly ash is a popular type of pozzolanic material which is defined in ASTM C-593 as “siliceous or alumino-siliceous material that in itself possesses little or no cementitious value, but that in a finely divided form and in the presence of moisture will chemically react with alkali and alkaline earth hydroxides at ordinary temperatures to form or assist in forming compounds possessing cementitious properties.” (4)

One new class of CCP by-product may be identified as a Clean Coal Technology (CCT) by-product. These CCPs are generated from air pollution control devices that remove noxious gases, primarily sulfur dioxide (SO_2). Most often the dry scrubbing or dry flue gas desulfurization by-products result from using lime or limestone. CCT by-products can have a high degree of alkalinity, i.e. calcium carbonate equivalency (CCE), due to the presence of unreacted calcium carbonate or lime.

Experience with dry FGD products has also shown that they can perform reasonably well as low-strength structural fill materials when properly conditioned (via water addition), placed and compacted. However, testing of the material should be conducted prior to placement in a fill to ensure that delayed swelling and expansion of the material will not occur over time due to latent formation of Ettringite. (5)

CCT dry scrubber ash is exemplified here as two completely different types: circulating fluidized bed boiler (CFB) ash and spray dryer ash (SDA). However, because they contain significant amounts of lime and calcium sulfite and/or sulfate, their use will employ both the conventional pozzolanic reaction and the sulfo-pozzolanic reaction.

- **SDA** is a dry flue gas desulfurization (FGD) scrubber product. Spray dryer absorbers use lime to capture SO_2 and other acid gases, such as HCl. SDA contains a small amount of reactive lime and significant quantities of calcium sulfite and/or sulfate. Newer technologies have resulted in better lime utilization and thus lower levels of available quicklime in the ash. SDA from older dry FGD units contains coal fly ash, while newer units typically collect the fly ash separately from the FGD system.
- **CFB Ash** is also a dry FGD scrubber product. CFBs use limestone for desulfurization in a circulating fluid bed coal combustion boiler. CFB ash contains a small amount of reactive lime, along with anhydrous calcium sulfate. CFB units collect the fly ash and FGD scrubbing products in a single particulate removal device. CFB ash is already used in PA - both for DM stabilization and mixing/stabilization of coal refuse and/or abandoned mine land (AML) spoil treatment. *CFB ash was not included as part of the studies discussed in this paper.*

A geochemical analysis of LKD is shown below in *Table 1* along with quicklime, Class F coal fly ash from Eastern Bituminous coal combustion, SDA, and CFB ash.

Table 1. Geochemical Analysis of Stabilization Additives

Geo Chemical Analysis, %	High Calcium Quicklime	LKD	Class F Fly Ash (Bituminous)	SDA - Fly Ash Blend	Spray Dryer Ash (no fly ash)	CFB Ash
CaO (total)	95	60	1-12	27.8	44.4	36.5
Available CaO	91	25	Trace	4.3	1.7	12
MgO	1.5	2.5	0-5	0.7	0.3	6.1
SiO_2	1.6	7.5	20-60	20.9	1.1	13.7
Al_2O_3	0.7	2.7	5-35	10.5	0.2	4.7
Fe_2O_3	0.2	1.1	10-35	6.3	0.2	8.4
$CaSO_4$ (anhydrite)	0.1	3.1		3.91	5.61	52.36
$CaSO_3$			0-6	33.19	66.75	
$CaCO_3$	2	60	0-15	11.4	16.5	5.3
LOI			0-15			
Bulk Density, pcf	55	60	70	43	35	45

3.6 SDA - European and Future US Dry FGD Sources

According to a recent US Department of Energy (DOE) - Electric Power Research Institute (EPRI) sponsored survey and European experience, there are many demonstrated and time proven civil engineering uses for dry FGD material, i.e. SDA. As much as 91 percent of the production of dry FGD product in Europe is registered as going into various uses. Examples of utilization may add a few percent Portland cement to enable use in civil and geotechnical applications. Some is used as back-fill in coal mines. Much is used as sulfur and calcium fertilizer sources. Some is oxidized to gypsum. (6) Most dry scrubber residue does not contain fly ash since it is pre-collected before the dry scrubber. Many uses re-combine the SDA with the coal fly ash for mine fill and civil engineering uses, i.e. structural fill.

A recent DOE –EPRI sponsored survey by the Univ. of North Dakota Energy & Environmental Research Center on SDA material characterized and discussed beneficial uses. However, in the US where the utilization rate is reported at only 9.7%, most of the study's sources are electric generating units that burn low sulfur, US western coal. (7)

Future sources of SDA in the eastern US are expected to burn Eastern or Illinois Basin bituminous coal. Their SDA will come from boilers that pre-collect the Class F fly ash, as has been done for about 10 years in Europe. Thus the chemical composition of the SDA will be more comparable to the Spray Dryer Ash (no coal fly ash) material listed in *Table 1*, whereas older US sources of SDA containing fly ash are more comparable with SDA – Fly Ash Blend listed in *Table 1*. The main mineralogical components of a European, no fly ash SDA are listed in *Table 2*, as reported by the

Swedish reference (8), along with a sample from a recently started U.S. spray dryer that has not been optimized to utilize all available lime in the ash.

Table 2. Mineralogical Analysis of
Dry FGD Without Combined Fly Ash

Main Component	European Source Typical Range (%)	U.S. Source (%)
Fly ash/lime Inerts	3-10	3
$CaSO_3$	55-70	43
$CaSO_4$	5-15	19
$Ca(OH)_2$	2-10	22
$CaCO_3$	5-15	5
$CaCl_2$	1-4	2
Moisture (free H_2O)	1-3	<1

3.7 Examples of Beneficial Reuse of LKD or LKD – Fly Ash Combination for Structural Fill

- *1982 DOE* Study*: A study titled "Kiln Dust – Fly ash Systems for Highway Bases and Subbases" evaluated for the USDOT and USDOE*.

  The test data developed in this study provided evidence that, with few exceptions, lime kiln dusts are capable of being substituted for hydrated lime in lime-fly ash-aggregate road base compositions. Most LKD- fly ash combinations achieve maximum strength at 1:1 kiln dust – fly ash ratios as opposed to 1:2 for lime – fly ash combination. Kiln dust - fly ash – aggregate mixes gained strength with age and are capable of developing extremely high compressive strength, i.e.>2000 psi. Durability, volume stability, and autogenous healing characteristics of pozzolanic road base compositions were also demonstrated. (9)

- *I-70 Embankment Reconstruction*

  LKD at 3% was used to dry and condition over 1 million cu. yds. of wet borrow soil for new subgrade and embankment reconstruction during the relocation of Interstate 70 near Indianapolis, IN. Much of the embankment building process was able to be done in winter due to reductions in soil plasticity and moisture content due to the lime hydration and subsequent pozzolanic reaction, which subsequently benefited compaction at maximum density. (10)

- *Bark Camp and Other PA DEP reclamation*

  In one large scale case study in Pennsylvania supported by the PADEP, a LKD was used in conjunction with coal fly ash to stabilize/solidify (S/S) dredge spoil solids for use as structural fill in mine pit backfilling. This case study is called the Bark Camp Project, located in Clearfield County, PA and begun in 1995 by the New York / New Jersey Shore Trust (C.O.A.S.T.) and the PADEP. Over 3 years they placed over a quarter million tons of dredged sediments. Clean Earth Dredging Technologies, Inc. was a major contractor. (11) Coal fly ash was mixed with DM at the Port of Newark, NJ, and Port of New York City to raise the percent solids for transport via rail gondola cars, to abandoned mine land near Clearfield, PA. In order to further increase the solids content and facilitate compaction, additional ash material and LKD were added at the mine site. A large quantity of municipal waste incinerator ash (MWIA) from New Jersey was also used.

- Example: *PPL Inc.*

  Two large coal fired power plants in Pennsylvania condition their fly ash with 1% hydrated lime addition to make an engineered structural fill material from 100% coal ash. The small lime addition raises the ash pH above 7, which results in higher unconfined compressive strengths that capture and prevent leaching of toxic metals. (12)

- Example: *Douglassville Superfund Site*:

  In lieu of more costly on-site incineration, LKD was approved by the USEPA Region 3 for stabilization/solidification of hazardous filter cake solid waste and associated contaminated soil from an abandoned oil recycling and recovery plant**.** (13)

3.8 Examples of Beneficial Reuse of CCT By-products for Structural Fill

- *Pennsylvania AML Reclamation by PADEP*

  Large quantities of CFB ash, having a high alkaline content, i.e. calcium carbonate equivalency, are mixed with pyritic mine spoil material to be used in backfilling abandoned mine land and for reclamation of the acidic soil where waste coal gob piles were located. Because CFB ash has a high pH from the "available" lime in the ash, a large fraction of coal fly ash, and also significant sulfate content, its use would exhibit both the pozzolanic reaction and the sulfo-pozzolanic reaction. (11)

- *Platte River Power Authority*

  The coal fly ash from the Rawhide plant included some SDA from its spray dryer FGD unit. When mixed with 50% Portland cement, excellent concrete compressive strengths developed. At 35% substitution with SDA and coal fly ash this "blended" Portland cement is used to make masonry block and precast concrete cement. (14)

- *Synthetic aggregate from SDA (eastern coal)*

  Universal Aggregates operates a full scale agglomeration plant using 115,000 tons of dry SDA from the 250 MW Birchwood Power Plant in Fredericksburg, VA, to manufacture a synthetic, lightweight aggregate from. This extruded and autoclave cured material is crushed and sized to make aggregate for manufacturing masonry block. (15)

- *Tennessee Eastman Chemical, Kingston, TN*

  In lieu of removal and off-site disposal or incineration of residual industrial sludge from former wastewater treatment basins, SDA from the same chemical manufacturing plant boilers was used to stabilize and create a composite material with geotechnical properties suitable not only for site closure but also for use as a foundation for future activities. Cone Penetrometer tests correlated with strength and stiffness site monitoring of the resultant Brownfield remediation. (16)

- *Full Circle Solutions, Inc., Atlanta, GA*

  To illustrate that SDA is non-toxic, this company specializes in marketing SDA for agriculture as a fertilizer source with high availability of calcium and sulfur. See www.fcsi.biz. (17)

3.9 Leachate Control Mechanisms for DM Stabilized Structural Fill

- Use of lime products and lime containing CCPs, i.e. CFB and SDA ash is well documented as being able to control leaching/ prevent leaching of trace elements that can be toxic to the environment. Leaching is prevented by both solidification and stabilization as a result of the pozzolanic hydration reactions which create strength and durability. ASTM E-2060, titled "Use of Coal Combustion Products for Solidification/Stabilization of Inorganic Wastes", is an important reference. (18)
- Lime products alone are used to stabilize trace elements, often called heavy metals (such as lead, cadmium, barium, and zinc), which form oxyhydroxides or low solubility precipitates at high pH.
- Ettringite can form quickly but is also known as an example of a secondary hydrated or mineralization reaction which frequently occurs over extended periods of time, i.e. days or months. (19)
- Adequate unconfined compressive strengths, i.e. > 35 psi, achieved after compaction to near maximum dry density and the formation of pozzolanic and sulfo-pozzolanic mineral reaction products result in highly impermeable, clay-like soil.

3.10 Mix Design and Test Protocol

The mix design protocol for DM stabilization consists of the following steps:

Step 1 – Sampling and Sample Preparation: representative DM material and reagents are gathered and screened. Moisture content and solids content are determined.

Step 2 - Characterization: particle size distribution, % clay, silt, and sand, Atterburg Limits and soil type or classification were determined. Organic matter per AASHTO Method T267 is determined.

Steps 3 & 4 - Lime Demand and Moisture – Density Relationship: Before determining the moisture-density curve relationship and molding strength test specimens, the dosage and blend of lime – CCP additives, if any, must be determined.

The optimum lime dosage is determined by the Eads-Grim Test, ASTM D-6276, which determines the amount of lime product required to achieve a pH above 12. A high pH is needed to solubilize the alumina minerals for the formation of pozzolanic and sulfo-pozzolanic hydration products.

The moisture-density relationship, often called a Procter curve, is determined by the standard compaction procedure, ASTM D-698. The procedure determines the dry density at a range of moisture contents with the mixed additives. A curing time for reaction initialization may be allowed. The optimum moisture content (OMC) is that moisture content that exhibits the maximum or highest dry density when using a given compaction procedure. The more intensive compactive effort or load of the modified compaction procedure per ASTM D-1557 is sometimes chosen.

Step 5 – Mellowing, Strength Gain, and Moisture Sensitivity:

California Bearing Ratio *(CBR) with Swell Measurement - ASTM D-3668:*

The CBR strength test is done with a piston-like penetration force and is performed at a specific density and moisture content, i.e. the OMC after soaking for 4 days at ambient temperature. The test can be used to compare untreated and treated (stabilized) DM, with and without a curing/mellowing period before the treated material is compacted. A strain gauge measures the swelling or expansion during the soaking period. The CBR result is a relative measure (%) compared to a crushed stone base course. Moisture absorption after the 4 day soak is measured. CBRs also measure resistance to moisture damage.

Unconfined Compressive Strength (UCS) - ASTM D-5102:

The unconfined compressive strength is performed on compacted soil-lime treated mixtures and untreated DM samples. Curing conditions (time and temperature) are chosen per test objectives. If desired, these specimens can also be subjected to moisture by placing them on a porous stone surface to allow capillary soaking to occur.

3.11 Addition of Bulking Agents to Reach Optimum Moisture Content

A structural fill material must be compacted near its OMC in order to attain maximum compacted density. The solids content of DM is often so low that in order to get near the OMC additional additives are needed. An unprocessed CCP, such as dry Class F coal fly ash, is often the most economical additive. Below is a method that can be used to calculate the amount of additive that needs to be added.

Note: By convention, the solids content is calculated on a wet weight basis (WWB), i.e. dry solids divided by the wet weight of solids. Moisture content is calculated on the dry weight basis (DWB), i.e. weight loss (evaporated water) divided by the dry weight of solids.

Exhibit #1: Solidification – How to determine the addition rate of bulking agents:

- Determine starting solids content (%) (WWB), i.e. filter cake solids @ 66% solids content.
- Determine the optimum moisture content for max. dry density (OMC)
  - Moistures 2-5% above OMC are desirable for long term hydration.
- Lime & F fly ash blend are the bulking agents chosen.
  - Assume fly ash to lime ratio is at least 5:1. Typically 3-5% quicklime fines (DWB) are used.

- Determine the amounts of additional dry additives required to get the solids content to the OMC:

$$\text{OMC (\%)} = \frac{\text{(water content)} \times 100}{\text{(dry solids in waste)+ (additional dry solids needed)}}$$

Example: Pre-determined OMC is 35%.
-sludge has 34% moisture content (66% solids)
-Result: 0.31 lb of dry bulking agent(s) are required

$$35\%\ \text{OMC} = \frac{0.34\ \text{lb. water content} \times 100}{0.66\ \text{lb. dry solids} + 0.31\ \text{lb. additional solids}}$$

4. LAB TEST RESULTS

Figure 2. Cox Creek CDF Barge Unloading

4.1 Cox Creek DM Case Study

Untreated Cox Creek DM collected on April 30, 2007, July 2, 2007, and July 14, 2008 was characterized using a method similar to that used for a lime stabilized soil. The results can be seen in *Tables 3 and 4*. The untreated DM would classify as a USC Soil Group OH, otherwise considered an "organic clay of medium to high plasticity". The organic matter on the July 14 sample was 7.1%, a level that makes stabilization less efficient.

Table 3. Cox Creek DM Characterization
July 2, 2007 Sample

Particle Size % Passing	Plasticity Characteristics	Soil Composition
	Liquid Limit = 97	% Clay = 60.2
½ " = 100	Plastic Limit = 39	% Silt = 35.1
#4 mesh = 99.7	Plastic Index = 58	% Sand = 4.5
#40 mesh = 96.8		% Gravel = 0.3
#200 mesh = 95.2		USCS Soil Type: OH

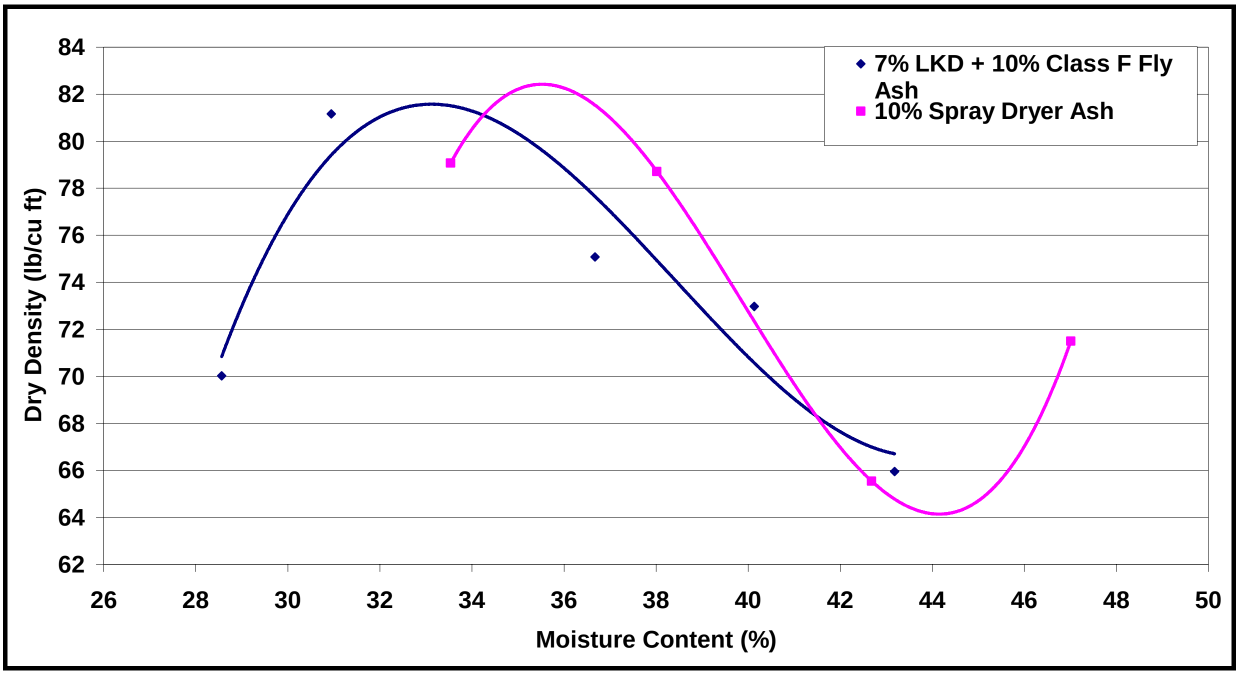

Figure 3. OMC Curves for Treated Cox Creek DM
July 2, 2007 Sample

Table 4: Cox Creek DM Characterization Results

Sample	Clay (%)	Swell (%)	Solids Content (%)	Moisture Content (%) (before soak)	Plastic Index (PI)
Apr 30, 2007					
Untreated	-	1.1	50	75	-
5% quicklime + 15% FA		-	-	-	-
10% LKD + 15% FA		-	-	-	-
July 2, 2007					
Untreated (USCS soil OH)	60	-	59	70	58
7%LKD + 10% FA		-	72	39.6 (OMC =33)	-
10%SDA		-	74	35.5 (OMC = 36)	-
July 14, 2008					
Untreated (USCS soil MH)	40	5.6	75	33	30
10% LKD		2.4	73	36.6	26
4% quicklime & 10% LKD		0.9	73	36.6	16
10% SDA		8.4	73	36.6	27

The high swelling (8.4%) with the 10% SDA addition (July 14, 2008 sample) is attributed to the Ettringite reaction and the inclusion of 32 moles of water due to hydration. Plastic indices on treated samples were measured after 24 hours, except the SDA test when it was performed after 7 days.

4.1.1 Sample Strength Gain Test Results

CBR tests were performed according to ASTM D-3668. For the April 30 sample, they were made using modified compaction of the untreated and treated material at the Frostburg State University, MD lab. The molded CBRs were brought to the Carmeuse Lime & Stone Technology Center (CLSTC) and cured for 9 days at 40°C and then soaked for 4 days as is usually done by convention. They were then tested for CBR penetration in a load cell apparatus. CBR strength results are shown in *Figure 4.*

The untreated material had a 72% moisture content (based on dry wt.) and a 58% solids content (based on wet weight). Typical soils tested at the CLSTC are normally less than 25% moisture content. It had a CBR of 1 without the 4 day soak. The penetration CBR measurement could not be performed after soaking.

CBR and UCS results are significantly negatively affected if sample moisture contents are much above their respective OMCs, which was somewhat the case here.

Two treated CBRs were made: 1) 5% quicklime (QL) and 15% fly ash and 2) 10% LKD and 15% fly ash. The additions were made on a dry weight basis.

The soaked CBR strengths were 20% and 15% respectively. The numbers are high enough to suggest the treated spoil could be used for structural fill.

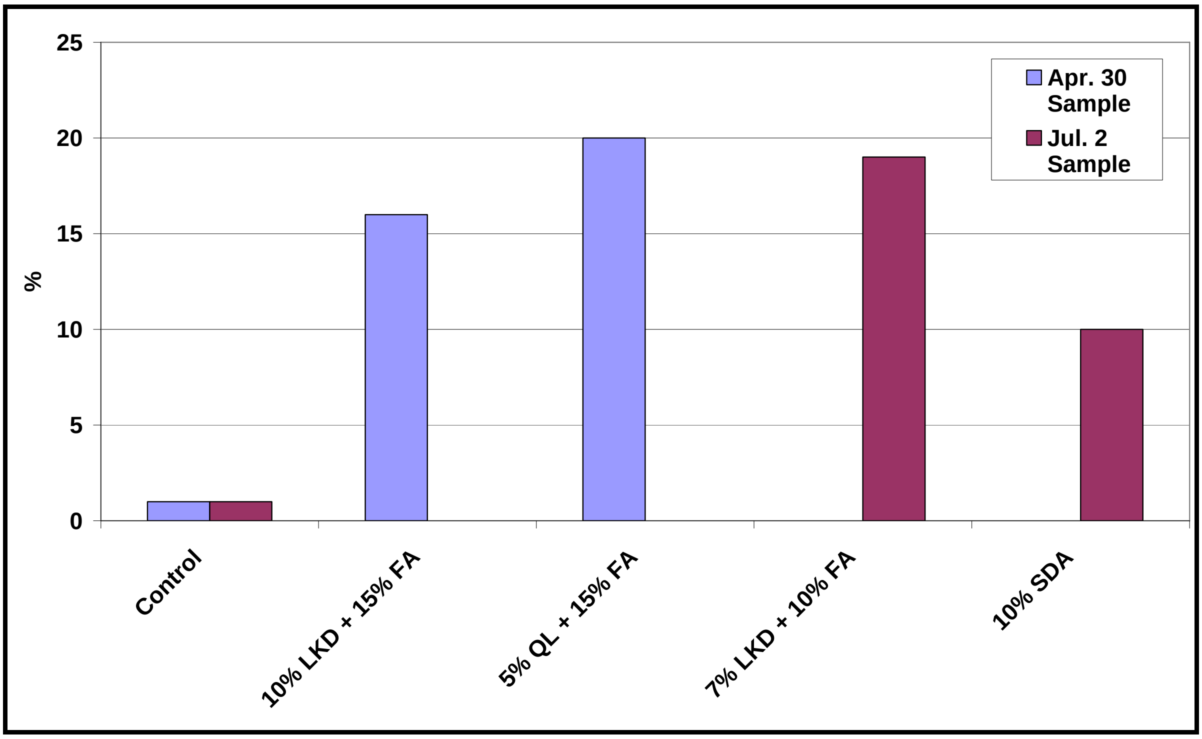

Figure 4. 7-Day CBR Results for Treated Cox Creek DM

UCSs for the samples collected in July 2007 and July 2008 are shown in *Figure 5*. UCSs were not done on the April 30, 2007 sample. In the case of the July 14 sample, at a relatively low 33% moisture content, water had to be added to get near the OMCs of 33 and 36% (untreated / treated), because the additives made the samples excessively dry. During soil stabilization at construction sites, it is common to add some water to ensure there is enough moisture to hydrate the quicklime. In the July 2 sample, the moistures of the UCS cylinders were higher than the OMC, which would make them weak at an early age.

Because the July 14 sample had a low moisture content, it was not mellowed (aged for a period of time, i.e. 7 days) before compaction (a mellowing period was allowed in the subsequent Ft. Mifflin case study).

Another significant criterion for determining adequate S/S is measured pH after curing. pH's that drop below 9 with curing are an indication that not enough lime was added to sustain the pozzolanic reaction. Without quicklime addition, the pH dropped to 8.3 for the mix of 10% LKD and pH 7.1 for the 10% SDA. The SDA used here had only 3% available lime content. The pH of the 4% QL & 8% fly ash (FA) UCS cylinder, reported in *Figure 5*, was 10.5, and the pH for the 4% QL & 10% SDA was 10.3.

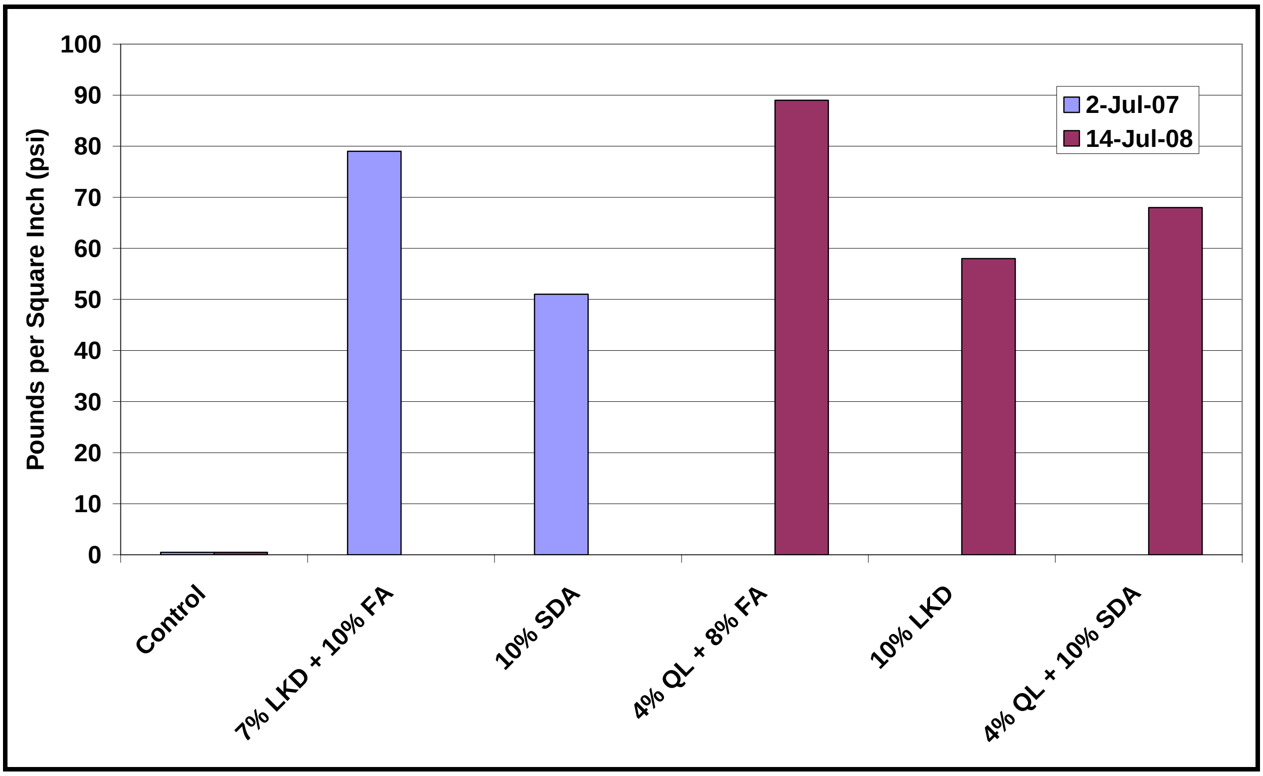

Figure 5. 7-Day UCS Results for Cox Creek DM

4.2 Fort Mifflin DM Case Study

Moisture contents are calculated by convention (and ASTM method) and are presented on a dry weight basis. The as received moisture content was about 50 percent. The solids content (%) (presented on a wet weight basis), was 67 percent. For comparison, wet subgrade soil frequently encountered in construction typically has a moisture content of 20-25 percent.

As outlined in *Table 5*, the dredge spoil particle size distribution has 54 % passing the #200 sieve. The USCS soil classification grain size distribution test found about 36% silt and 18% clay, which classifies the material as an inorganic silt. The plastic index is 29%.

Table 5. Fort Mifflin DM Characterization
Aug. 21, 2007 Sample

Particle Size % Passing	**Plasticity Characteristics**	**Soil Composition**
¾ " = 100	Liquid Limit = 62	% Clay = 18.1
½ " = 98.5	Plastic Limit = 33	% Silt = 35.9
#4 mesh = 93.5	Plastic Index = 29	% Sand = 39.4
#40 mesh = 75.9		% Gravel = 6.6
#200 mesh = 54.0	organic matter = 9.5%	USCS Soil Type: MH

The moisture – density relationship results are shown in *Figure 6*. After treatment with 7% LKD and 10% coal fly ash, the dredge spoil became less plastic. The liquid limit (LL) decreased, and the plastic limit (PL) increased, which resulted in a decrease of the plastic index (PI) to 19%.

Additional mixes were made, allowing a mellowing period before compaction so some hydration had time to occur. The resulting hydration had a further effect on reducing plasticity as shown later below.

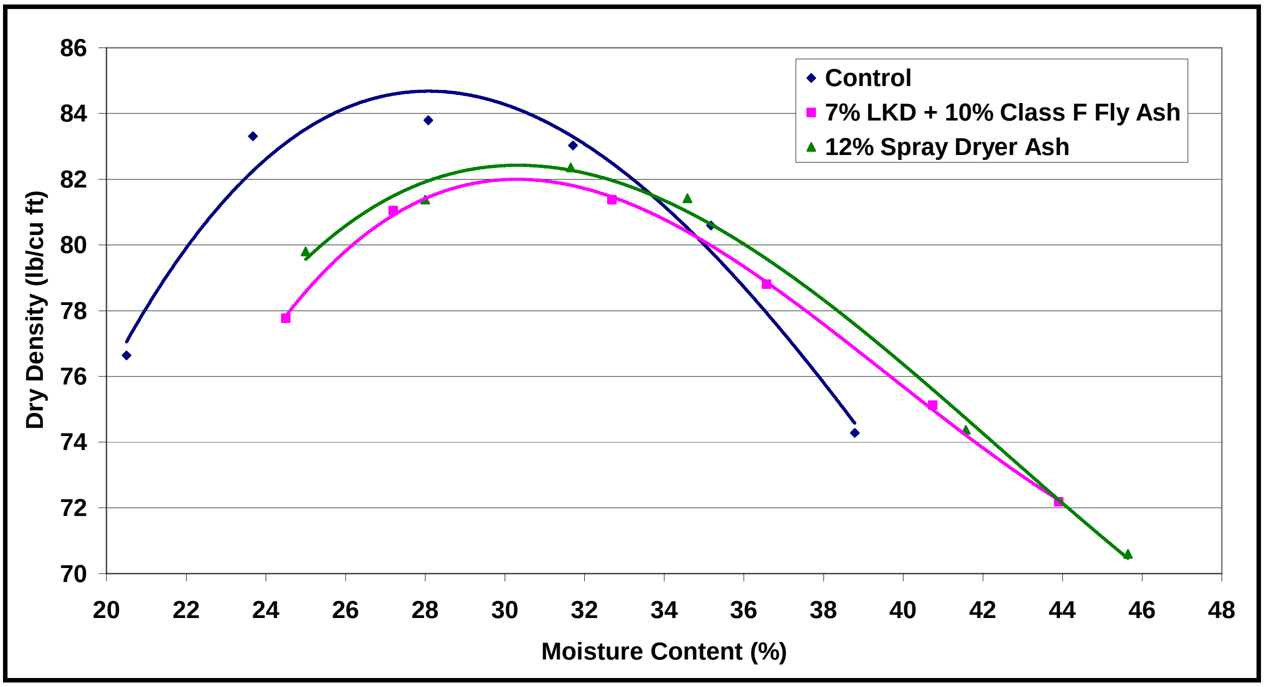

Figure 6. OMC Curves for Fort Mifflin DM
Aug. 21, 2007 Sample

4.2.1 Ft. Mifflin DM Mixes with Mellowing Period

Minimization of the additive dosage was determined by letting the treated mixture "mellow " for a period of time, i.e. a few days, to let the pozzolanic reaction get started. Also, the mellowing period allows the swelling phase (quick hydration) of the Ettringite reaction to occur before the samples were compacted. The following mixes, using a mellowing period of 7 days were made:

- 10% SDA
- 8% LKD & 8% Fly Ash
- 4% LKD and 7% SDA

These samples were kept in sealed containers during the 7 day mellowing period prior to compaction. Therefore, the moisture content was not influenced by air drying. Drying was limited to the dry bulking effect and chemical hydration. After 90 days the Atterberg Limits test was run to determine the effect of mellowing and extra curing. They were generally lower, putting them more within or closer to the "suitable soil" range. Results from the mellowing tests are shown in *Table 6*.

Table 6. Fort Mifflin DM Solids Results Following
7-Day Mellowing Period Prior to Compaction

	Untreated DM Aug 21, 2007	**10% SDA**	**8% LKD & 8% Class F Fly Ash**	**4% LKD & 7% SDA**
Liquid Limit (LL)	62	52	44	50
Plastic Limit (PL)	33	34	34	35
Plastic Index (PI)	29	18	10	15
USCS Soil Type	MH	MH	ML	MH-ML
MC (%)	50	33	33	36
SC (%)	67	75	75	74
CBR (%)	-	11	5	2
Swell (%)	0	0	0	0
Comp. Strength at 28d (tsf [psi])	0	>4.5 [> 50]	3.5 [~50]	2.5 [~35]
pH	7.4 @ 90 days			

NOTE: OMC is 28% untreated and 30.5% treated.

10% SDA:

At compaction, this mix was 32.8% moisture. Unfortunately an initial pocket penetrometer (PP) reading was not taken. At 28 days, the PP was over 4.5 tsf (tons per sq. ft.; 1 tsf = 14 psi.) The CBR was 11 after 7 days curing and 4 days soaking. This specimen did not swell, as compared to the 12% SDA mix with no mellowing. The liquid limit (LL) and resultant plastic index (PI) were lowered. It is believed this was due to the mellowing effect and the extra curing period for the hydration to progress. The LL was 52, and the PI was 18.

8% LKD & 8% fly ash:

At compaction, this mix was 33.3%moisture. The 28 day PP reading was 3.5 tsf and grew to 3.75 tsf at 90 day. The CBR was 5, and no swelling was recorded. The LL was 44, and the PI was 10.

4% LKD & 7% SDA

At compaction, this mix's moisture content was much higher at 36.3%. This adversely affected its initial PP strength, which was 2.5 tsf after 28 days. The CBR was adversely affected, with a value of 2 being recorded. The PP strength at 28 days was 2.5 tsf and increased to 2.75 at 90 days. The LL was 50, and the PI was 15.

4.3 Craney Island DM Case Study

Moisture contents are calculated by convention (and ASTM method) and are presented on a dry weight basis. The moisture content of the Craney Island DM was 130 percent, which is considerably higher than both the Cox Creek and Ft. Mifflin DMs. This wetter DM may be more representative of what might be encountered if in-scow drying and treatment were used, rather than treatment after static dewatering in a CDF. For comparison, wet subgrade soil frequently encountered in construction typically has a moisture content of 20-25 percent. The solids content (%) (presented on a wet weight basis), was calculated at ~43 percent. The untreated Craney Island DM was approximately 92% fines, with a PI of 37, a LL of 62 and was classified as "an inorganic clay of high plasticity," or USCS soil type CH.

The testing of the Craney Island DM was performed by an engineering company under contract to Carmeuse. The test methods used by this engineering company were similar, but not identical to those employed by Carmeuse's in-house soil lab. However, the methods utilized were identical to those used in previous testing performed by the engineering firm while investigating other reagents that might be suitable for treating the Craney Island DM.

The test program was comprised of two steps. The first was a "paste study" to explore the workability and compactability of treated DM mixes. The results from the paste study were used to choose design mixes that would be carried forward into a strength testing program that would produce specimens that could be tested for unconfined compressive strength (UCS) at 28 days. Lime kiln dust alone and lime kiln dust in combination with class F fly ash were used during this test program.

4.3.1 Craney Island DM Mixes

The paste study began with nine (9) different reagent addition rates/mixes. The first set utilized LKD alone at 5, 10, 15, 20, and 25% addition rates (based on dry DM solids). The second set used LKD and fly ash in four different mixes (LKD/FA) at ratios of 5/5, 5/10, 10/5 and 10/10 (also based on dry DM solids). The paste study is over a 5-day period, but it is generally recognized that to be considered feasible, the treated DM must be workable within 3 days. The paste study used both open and closed containers, to simulate both the crust on the outside of a treated pile of DM, and also the interior of a treated pile of DM. The paste study revealed that the 3-day workability criteria could only be met at reagent addition rates (LKD or LKD+FA) of 20% or greater, and then only in the open (crust) half of the test.

As a result of the paste study, it was decided to use only the mixes that had reagent addition rates equal to or greater than 20% in the mix strength testing portion of the program. An additional mix using 30% LKD alone was added to this phase of the testing. The mixes tested in the second half of the program were (LKD/FA): 10/10, 20/0, 25/0, and 30/0. Optimum moisture contents for these mixes fell in the range of 27-32%. A second set of mixes at the 20% LKD addition rates was performed at a moisture content of nearly 50%, and the resulting cylinders were broken at 7 days instead of 28 days. Unfortunately, none of the cylinders at reagent addition rates of 20% could be extruded intact from the Proctor cylinders. The UCS results are shown in *Figure 7.*

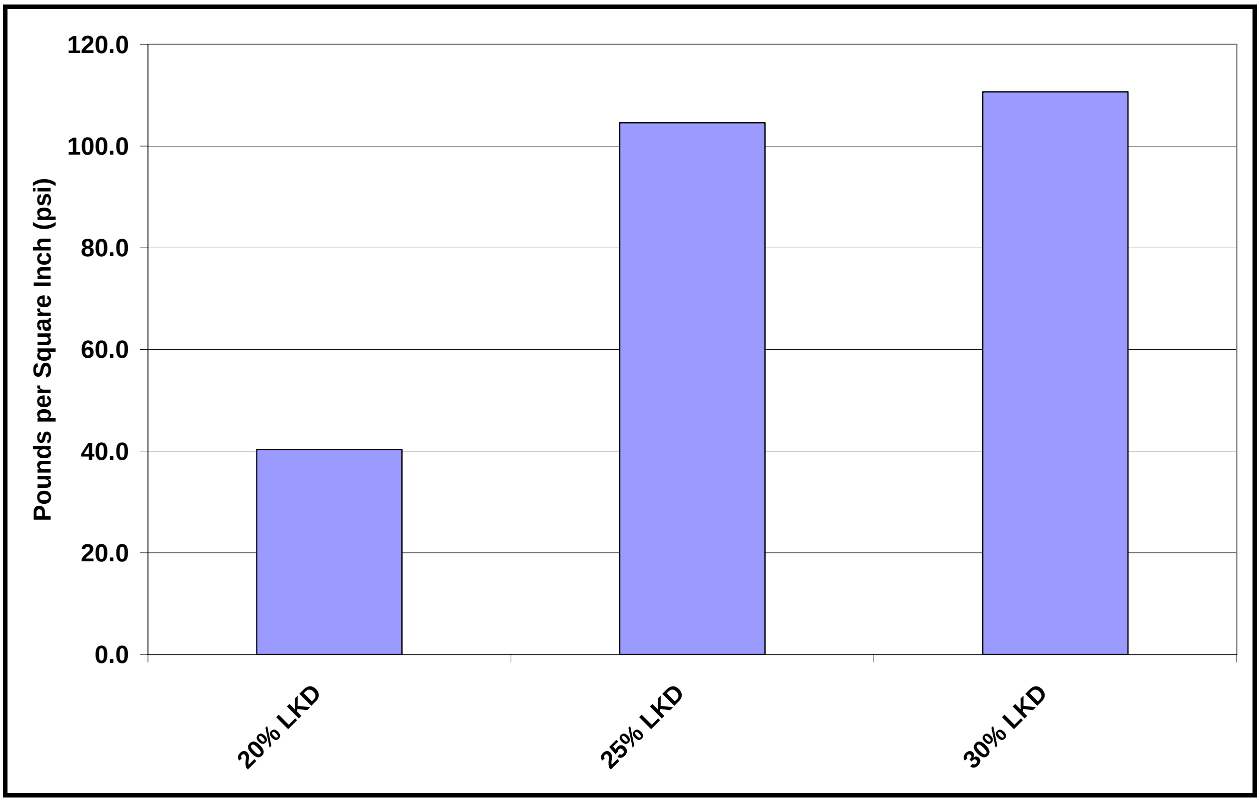

Figure 7. 28-Day UCS Results for Craney Island DM
Note: 20% LKD sample at 49% MC vs. 27-32% OMC

5. SUMMARY AND CONCLUSIONS

A mix design procedure has been explained for stabilization of dredge material, in order to make a structural fill using lime by-products (chiefly LKD) and coal combustion by-products (chiefly Class F fly ash and dry FGD Spray Dryer Ash). The same technology is used to treat soils at construction sites, to develop adequate bearing capacity. The strength-gaining chemical reactions are similar to those that occur during Portland cement hydration.

The goal was to add stabilization additives that can:

1. Add dry bulk material to raise the solids content to enable compaction for construction of a structural fill
2. At the same time add a proper and balanced pozzolanic (or sulfo-pozzolanic) chemical composition to react and gain strength and durability.

Test results are presented from analysis of three sources of dredge material. The performance of spray dryer ash was compared with blends of lime kiln dust and Class F fly ash.

Specific findings included:

- The moisture of the DM must be reduced as close as possible to the optimum moisture content for achieving compaction near maximum dry density.
- The addition of these by-products increases the solids content by “bulking” and is shown to chemically reduce free moisture through several types of hydration reactions.
    - SDA may be useful as a bulking agent when treating DM with higher moisture contents than those tested here.
- Adequate alkalinity needs to be added to take advantage of the potential strength gain that results from the pozzolanic and sulfo-pozzolanic, cementitious reactions. The pH needs to be maintained above 11 for 28 days to maintain the solubility of the reactants (lime and the alumina minerals).
- A “mellowing” period may help:
    - Improve workability of the treated DM through several different drying mechanisms.
    - Prevent swelling from Ettringite precipitation by letting these minerals form and hydrate before compaction.
- Strength and plasticity measurements were shown to meet the criteria for an engineered “suitable soil”. The influence of residual pH, curing conditions, and moisture content has a large effect on strength and compacted density results.
- Adequate unconfined compressive strengths, i.e. > 35 psi, were achieved after compaction to near maximum dry density.

- The formation of pozzolanic and sulfo-pozzolanic mineral reaction products may result in increased impermeability that will help reduce the leaching potential of toxic species within the matrix.
- "Second generation" SDA alone may not provide adequate increases in UCS to produce a material suitable for use as a structural fill. Its suitability may be tied to the amount of unreacted lime in the ash.

- Raising the pH to levels 9-11 for pozzolanic hydration reactivity coincide with pH levels that stabilize leachable heavy metals.

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