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EVALUATION OF STABILIZATION/SOLIDIFICATION FOR TREATMENT OF CONTAMINATED SOILS FROM WALDICK AEROSPACE DEVICES, INC. SITE, NEW JERSEY

by

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13. ABSTRACT *(Maximum 200 words)*

The Waldick Aerospace Devices (WAD) site is located in Wall Township, Monmouth County, New Jersey. The 1.72-acre (6,960-m^2) site was the location for manufacturing and electroplating of quick-release pins for the aerospace industry. The contaminants of interest are chromium, cadmium, volatile organics, and petroleum hydrocarbons. Samples were collected at depths up to 15 ft (4.6 m) and revealed concentrations of petroleum hydrocarbons, chromium, cadmium, and volatile organics as high as 120,000, 4,390, 37,000, and 6,848 mg/ℓ, respectively.

The objectives of the evaluation of stabilization/solidification (S/S) technologies on WAD soils were to determine the effects of S/S and determine if physical and chemical handling properties of WAD soils were improved. The physical and chemical properties were evaluated through the Unconfined Compressive Strength (UCS) test and Toxicity Characteristic Leaching Procedure (TCLP),

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respectively. Reduction in contaminant mobility was evaluated by comparison of TCLP runs on untreated soils and treated soils.

To evaluate the effect of volatile organic components in the soils, a portion of the soils was subjected to heat as a pretreatment to S/S. The purpose of the heat treatment was to volatilize organic compounds and provide a comparison of S/S between heated and nonheated soils.

An initial screening test was used to determine the proportions of binder and water to add to the soils for preparation of specimens for detailed evaluation. The cone index test incorporated the use of an airfield penetrometer to measure resistance to penetration of the treated soils after 48 hr of cure.

Initially, a binder-to-soil ratio (BSR) of 0.05 was selected for contaminant release testing for the heated and nonheated soils. The TCLP analyses of the specimens revealed no decrease in contaminant mobility. No apparent differences in contaminant mobility between the heated and nonheated soils were noted. As a result, additional extraction tests were run using a cement BSR of 0.25 and lime/fly ash BSR of 0.15/0.15.

Small quantities of binder materials added to the soils were shown to produce UCS values above the 50-psi (345-kPa) criteria. Water was added to the process to aid in mixing of the binders with the soils. The stabilized/solidified soil set within 24 hr, with on visible free liquids. Although UCS values at a 0.25 cement BSR were higher than UCS values of the 0.15/0.15 lime/fly ash BSR, contaminant mobility within the lime/fly ash-treated soil was less than mobility within the cement-treated soil. Both cement and lime/fly ash were shown to be effective treatments for the reduction of mobility of chromium and cadmium in the WAD soils.

PREFACE

This report was prepared for the US Army Engineer District, Kansas City, by the US Army Engineer Waterways Experiment Station (WES) under Intra-Army Order No. KC-89-103.

The study was conducted by Ms. Elizabeth Fleming and Dr. M. John Cullinane, Jr., of the Water Supply and Waste Treatment Group (WSWTG), Environmental Engineering Division (EED), Environmental Laboratory (EL), WES. Waste extractions and chemical analyses were performed by O'Brien and Gere Engineers, Inc. Cement, lime, fly ash, and kiln dust analyses were performed by the Materials and Concrete Analysis Group, Concrete Technology Division, Structures Laboratory, WES.

The work was performed under the direct supervision of Mr. Norman R. Francingues, Chief, WSWTG, and under the general supervision of Dr. Raymond L. Montgomery, Chief, EED, and Dr. John Harrison, Chief, EL.

COL Larry B. Fulton, EN, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
gallons (US liquid)	3.785412	cubic decimeters
inches	2.54	centimeters
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
square inches	6.4516	square centimeters
tons (2,000 pounds, mass)	907.1847	kilograms

EVALUATION OF STABILIZATION/SOLIDIFICATION FOR TREATMENT OF CONTAMINATED SOILS FROM WALDICK AEROSPACE DEVICES, INC., SITE, NEW JERSEY

PART I: INTRODUCTION

Background

1. The Waldick Aerospace site is an inactive industrial facility located at 2121 Highway 35 in the Sea Girt section of Wall Township, Monmouth County, New Jersey (Figure 1). The 1.72-acre* site is bordered to the east by Route 35, to the south by commercial property, and to the west and north by undeveloped woodland. In 1979, the property was leased to Waldick Aerospace Devices, Inc. (WAD). WAD manufactured and electroplated quick-release pins for the aerospace industry for 5 to 6 years.

2. A 1982 inspection by the New Jersey Department of Environmental Protection, the Monmouth County Division of Criminal Justice, and the Monmouth County Board of Health revealed that a series of degreasing, dip, rinse, and plating tanks, along with a polishing machine, were discharging wastewater through polyvinyl chloride pipes directly onto the ground around the main building. The runoff from this effluent sometimes flowed across the front lawn and onto the adjacent property. Soils at the rear (western side) of the plant, in an area approximately 30 by 70 ft, appeared to be saturated with oil. Strong organic vapors were noted, and 30 to 40 drums were scattered throughout this area. A 2,000-gal storage tank was also located above the ground behind the plant. These conditions are believed to have existed for at least the first 3 years of operations.

3. Primary contaminants of interest are cadmium, chromium, volatile organics, and petroleum hydrocarbons. Contamination at depths up to 16 ft has been identified. Table 1 lists the major soil contaminants found at the Waldick site.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

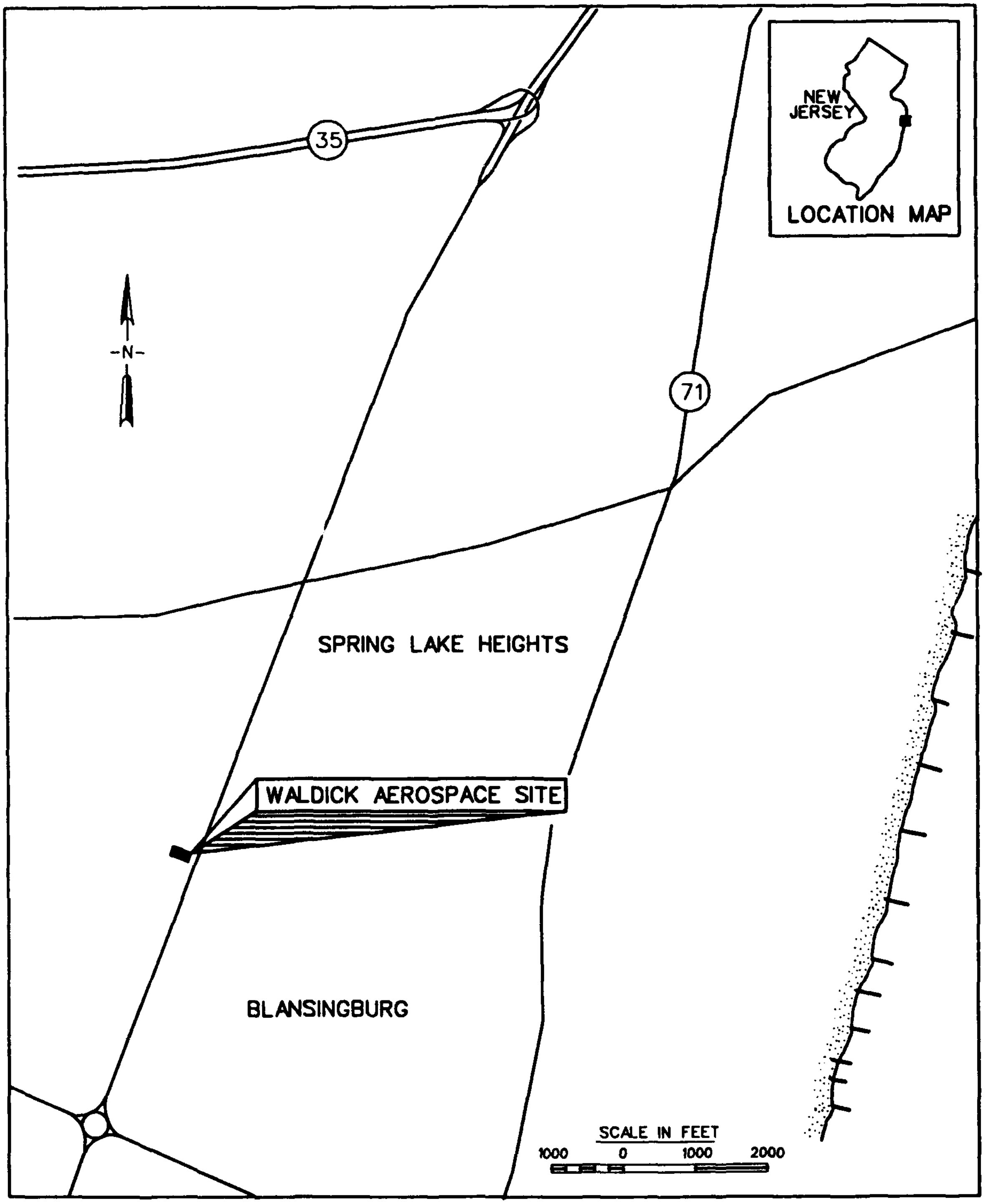


Figure 1. Location of Waldick Aerospace Devices site

Table 1

Major Contaminants at Waldick Aerospace Devices Site

Parameter, mg/ℓ	Depth ft	Sampling Date Jun 85	Sampling Date Nov 85	OBG*
Between Main Building and Auto Supply Store				
Organics				
Tetrachloroethene	1	>6,400.0	76.0	210
	3	0.630		
	6			160
	15			ND**
Trichloroethene	1	47.0	21.0	
Trans-1,2-dichloroethene	1		0.250	
Chlorobenzene	1	0.140		
Ethylbenzene	1	0.140		
1,1-Dichloroethene	1		0.120	
Toluene	1		0.080	
Chloroform	1		0.040	
1,1,1-Trichloroethane	1	>0.021		
	3		>0.006	
Bis (2-ethylhexyl) phthalate	1	400.0		
Petroleum hydrocarbons	1			120,000
	6			2,600
	15			890
Inorganics				
Cadmium	1	16,200.0	2,270.0	37,000
	3	288.0		
	6			325
	15			600
Chromium (total)	1	3,160.0	4,390.0	1,200
	3	66.0		
	6			85
	15			97
Aluminum	1		11,800.0	
Zinc	1		3,840.0	
Lead	1	625.0		
Nickel	1	140.0	100.0	
Cyanide	1		84.0	

(Continued)

* Based on the highest value in the area reported by O'Brien and Gere Engineers, Inc.

** Not detected.

Table 1 (Concluded)

Parameter, mg/ℓ	Depth ft	Sampling Date Jun 85	Nov 85	OBG
		Front Lawn of Main Building		
Organics				
Tetrachloroethene	1	4.9		
	2	1.0		
1,1,1-Trichloroethane	2	>0.009		
Toluene	2	>0.009		
Trichloroethene	3.5	>0.005		
Inorganics				
Cadmium	1	520.0		987
	2	1,420.0		
	3.5	139.0		
		Rear of Main Building		
Organics				
1,1,1-Trichloroethane	1	>0.005		
	2	10.0		
	3		5.2	
Tetrachloroethane	2	4.6		
	3		0.580	
Toleune	3		0.040	
Bis (2-ethylhexyl) phthalate	3		2.2	
Petroleum hydrocarbons	1			3300
	6			3500
	15			ND
Inorganics				
Cadmium	1			3
	6			ND
	15			ND

Stabilization/Solidification

4. Stabilization/solidification (S/S) is a process that involves the mixing of a contaminated soil with a binder material to enhance the physical and chemical properties of the soil and to chemically bind any free liquid (US Environmental Protection Agency (USEPA) 1986b). Typically, the binder is a cement, pozzolan, or thermoplastic. Proprietary additives may also be added. In most cases, the S/S process is changed to accommodate specific contaminants and soil matrices. Since it is not possible to discuss completely all possible modifications to a S/S process, discussions of most S/S processes have to be related directly to generic process types. The performance observed for a specific S/S system may vary widely from its generic type, but the general characteristics of a process and its products are usually similar. Comprehensive general discussions of waste S/S processes are given in Malone and Jones (1979), Malone, Jones, and Larson (1980), and USEPA (1986b).

5. Waste S/S systems that have potential application include:

   a. Portland cement processes.

   b. Lime/fly ash pozzolanic processes.

   c. Pozzolan processes.

6. Portland cement processes use Portland cement to produce a type of soil/concrete composite. Contaminant migration is reduced by microencapsulation of the contaminants in the concrete matrix. The addition of soluble silicates to Portland cement processes may accelerate hardening. As with lime/fly ash and other pozzolanic systems, metals are also converted to less soluble forms.

7. Lime/fly ash and other pozzolanic processes use a finely divided, noncrystalline silica in fly ash and the calcium in lime to produce low-strength cementation. The waste containment is produced by entrapping the waste in the pozzolan concrete matrix (microencapsulation). Metals are also converted to less soluble forms that further inhibit leaching.

Study Objectives and Scope

8. The objectives of this study were to:

   a. Determine the effects of S/S techniques on contaminated soils from the Waldick Aerospace Devices site.

b. Evaluate the physical and chemical properties of the stabilized/solidified soils to determine if S/S techniques will substantially reduce the amount of contaminants in the leachate and improve the physical handling properties of the soil.

9. Three binder systems (cement, kiln dust, and lime/fly ash) were used to stabilize/solidify the soil. The stabilized/solidified soil was cured, and the physical and contaminant properties of the stabilized/solidified soil were determined. The Unconfined Compressive Strength (UCS) test was used to measure the physical strength, and the Toxicity Characteristic Leaching Procedure (TCLP) was used to measure the leachability of the contaminants from the stabilized/solidified soil.

Organization of Report

10. This report is divided into four parts:

a. Part I presents background information, explains the need for this study, and introduces the concept of S/S.

b. Part II describes the methods used for sampling, treatment, and testing of the contaminated soils.

c. Part III describes the results of physical and contaminant mobility testing of the S/S soil.

d. Part IV presents conclusions based on the results of the implemented testing program.

PART II: MATERIALS AND METHODS

General Approach to the Investigation

11. This investigation was conducted in the four phases, summarized below.

a. Phase I: Sample Collection. Samples of contaminated soil were collected and shipped to WES by personnel of O'Brien and Gere Engineers, Inc. (under contract to the Kansas City District).

b. Phase II: Preparation of Test Specimens. Test specimens of stabilized/solidified soil were prepared. Before stabilization/solidification was initiated, half of the test specimens were subjected to heat treatment. The purpose of this treatment was to volatize polycyclic aromatic hydrocarbons. Preparation of the test specimens included an initial screening test to determine the appropriate water-binder-soil ratios for detailed evaluation.

c. Phase III: Physical and Contaminant Release Testing. Physical characteristics were evaluated using the UCS test. Based on the results of the physical testing, binder-to-waste ratios were selected to evaluate the contaminant release properties using the TCLP.

d. Phase IV: Data Analysis. Data from the US Army Engineer Waterways Experiment Station (WES) and O'Brien and Gere Engineers, Inc., were consolidated and evaluated.

Sample Collection

12. The materials of interest were contaminated soils obtained from the Waldick Aerospace Devices site, Monmouth County, New Jersey. Contaminants of interest include cadmium, chromium, volatile organics, and petroleum hydrocarbons. Based upon the points of known high contaminant concentration, a composite sample was collected by personnel of O'Brien and Gere on 11 July 1989. Samples were collected from 0 to 2 ft in depth in a 4-ft by 10-ft excavation. Sixty gallons of sample material was collected and shipped to WES. Upon receipt at WES, the samples were placed in cold storage until implementation of the S/S evaluation protocol.

Preparation of Test Specimens

Pretreatment

13. Contaminants of interest at the Waldick site include petroleum and volatile organic materials. In addition to their potential environmental impacts, these organic compounds are known to have potentially adverse impacts on S/S processes. As a result, consideration is being given to implementing a low-temperature heat treatment process as an element of remedial action at the Waldick site. To evaluate the impact of the volatile organics and heating on the S/S process, a portion of the soil sample was subjected to pretreatment by heating for 15 min at 100° C before the S/S process was initiated. The purpose of the heat treatment was to drive off volatile organics and to provide a comparison of the effect of the S/S process on heated and nonheated samples. Because heat treatment was performed for 15 min, no significant reduction of moisture was noted.

14. To ensure that soils collected for S/S studies were in fact contaminated, and for comparison before and after applying S/S technologies, the TCLP was performed on the untreated soils. Table 2 presents the results of this analysis.

15. Soils collected from the Waldick site are classified as silty sands and mixed gravels and sands with Unified Soil Classification System classifications of SP, SW, and GW. The moisture contents of the untreated soils are presented in Table 3.

General description of the S/S process

16. Three solidification processes were used to stabilize/solidify the contaminated soil. These are differentiated by the type of binder material used: Portland cement, kiln dust, and lime/fly ash. Compositional and chemical analyses of the binders used in this study are presented in Tables 4 and 5, respectively.

17. The S/S process involves the addition of water and binder material to the soil followed by mixing and a curing period. A schematic flowchart of S/S processing is shown as Figure 2.

Initial screening test

18. The objective of the initial screening test was twofold: to determine the appropriate water-to-soil ratio (WSR) for each S/S process and to narrow the range of binder-to-soil ratios (BSR) used for detailed evaluation.

Table 2

Results of TCLP Analysis on Unstabilized Soils

Parameter	Detection Limit mg/ℓ	Nonheat-Treated Sample, mg/ℓ			Heat-Treated Sample, mg/ℓ		
		A	B	C	A	B	C
Arsenic	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	0.5	1.70	1.50	1.50	1.80	1.60	1.70
Cadmium	0.01	43.00	55.00	41.00	39.00	38.00	41.00
Chromium	0.05	0.90	0.87	0.92	1.00	0.96	1.00
Lead	0.05	0.05	0.05	<0.05	<0.05	<0.05	<0.05
Mercury	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Selenium	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Silver	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 3

Moisture Contents of Unstabilized Soils

Sample	Heat-Treated (% moisture)			Nonheat-Treated (% moisture)		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
A	12.40	12.28	11.93	13.29	13.55	14.09
B	12.12	11.08	12.43	13.88	13.48	13.81
C	12.40	12.83	12.60	14.09	13.69	14.15
		Average	12.23		Average	13.78

Although the soil was a moist, fine material, it was necessary to add water to hydrate the contaminated soil for S/S to be effective. The WSRs were chosen on the basis of previous experience by the testing personnel. The matrix of test specimens prepared during the initial screening test is shown in Table 6.

19. Determination of the appropriate WSRs and BSRs was based on the results of the cone index (CI) test performed on the initial screening test specimens after they had cured for 48 hr. The CI measures the resistance of a material to the penetration of a 30-deg right circular cone. The method specified in Technical Manual 5-530 was followed (Headquarters, Department of the Army 1971). The CI value is reported as force per unit surface area

Table 4

Compositional Analyses of Binder Materials

Compositional Analysis	Cement Type I %	Lime %	Fly Ash Class F %	Kiln Dust %
SiO_2	20.47	0.40	49.67	6.94
Al_2O_3	5.40	0.57	29.15	4.23
Fe_2O_3	3.58	0.16	7.11	1.47
CaO	64.77	72.27	1.26	62.93
MgO	0.87	0.65	1.43	0.44
SO_3	2.73	0.02	0.23	7.01
Insoluble residue	0.17	0.24	70.70*	3.09
Moisture loss	0.43	0.41	0.12**	0.05
Loss on ignition	0.96	24.04	4.07	14.08
TiO_2	0.28	0.01	0.20	0.11
Mn_2O_3	0.06	0.00	0.00	0.00
P_2O_5	0.28	0.02	1.00	0.05
Total alkali				
Na_2O	0.12	0.01	0.23	0.25
K_2O	0.28	0.00	2.33	0.40
Na	0.05	0.004	0.10	0.10
K	0.11	0.00	0.97	0.17
Total as Na_2O	0.30	0.01	1.76	0.51
Acid-soluble alkali				
Na_2O	0.12	0.01	0.06	0.25
K_2O	0.28	0.00	0.50	0.40
Na	0.05	0.004	0.03	0.10
K	0.11	0.00	0.21	0.17
Water-soluble alkali				
Na_2O	0.018	0.0033	0.050	0.021
K_2O	0.139	0.0220	0.105	0.050
Na	0.0075	0.0013	0.0210	0.0088
K	0.0577	0.0091	0.0440	0.0208

* Insoluble residue includes SiO_2.
** Free water.

Table 5

Chemical Analyses of Binder Materials

Chemical Analysis	Cement Type I mg/kg	Kiln Dust mg/kg	Lime mg/kg	Fly Ash Class F mg/kg
Si	95,700	1,900	232,200	32,400
S (total)	10,800	700	1,700	31,200
Ti	1,400	50	1,000	600
P	900	60	3,200	200
Sb	<1.77	<1.63	<1.77	13.3
As	13.1	14.7	6.74	172
Be	2.13	4.24	<1.77	28.9
Cd	0.284	2.28	0.639	1.01
Cr	61.3	30.0	14.6	139
Cu	14.9	12.7	<0.355	196
Pb	2.13	15.6	<0.355	57.7
Hg	<0.100	<0.100	<0.100	<0.100
Ni	25.9	33.6	6.39	190
Se	<17.7	<16.3	<17.7	<19.5
Ag	<3.54	<3.26	<3.55	<3.90
Tl	<10.6	<9.78	<10.6	13.6
Zn	41.8	107	17.7	211
Al	23,100	13,500	238	150,000
Ba	178	119	<3.55	1,350
Ca	454,000	440,000	500,000	12,000
Cd	10.6	<9.78	10.6	77.2
Fe	25,400	14,800	1,070	50,700
Mg	5,460	3,040	2,700	6,040
Mn	503	64.2	48.6	156
Na	1,270	2,110	110	2,740
Sn	195	73.0	74.5	118
V	55.6	34.6	11.7	351

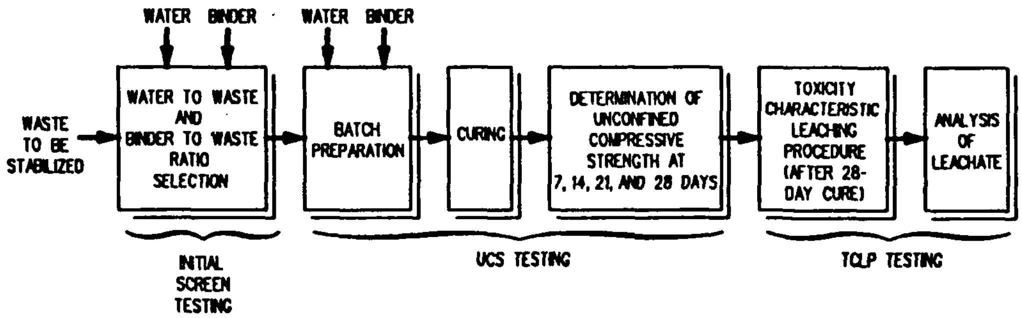


Figure 2. Schematic flowchart of stabilization/solidification processing

Table 6

Matrix of Specimens Prepared for Initial Waste/Binder Screening

		Number of Specimens at Indicated Water-to-Soil Ratio			
		Heat-Treated WSR		Nonheat-Treated WSR	
Binder-to-Soil Ratio		0.2	0.7	0.2	0.7
Cement-soil					
0.1		1	1	1	1
0.7		1	1	1	1
1.4		1	1	1	1
2.8		1	1	1	1
Kiln dust-soil					
0.1		1	1	1	1
0.7		1	1	1	1
1.4		1	1	1	1
2.8		1	1	1	1
Lime-soil	Fly ash-soil				
0.1	0.1	1	1	1	1
0.1	0.7	1	1	1	1
0.7	0.1	1	1	1	1
0.7	0.7	1	1	1	1

(pounds per square inch) of the cone base required to push the cone through a test material at a rate of 72 in./min. Two cones are available for this test: the standard WES cone having an area of 0.5 sq in. and the airfield penetrometer having a base area of 0.2 sq in. Because of the calibrations on each penetrometer, the standard WES cone was used on material with a CI less than 100 psi, and the airfield penetrometer was used on materials with CI greater than 100 psi. The maximum CI value that can be measured by the airfield penetrometer is 750 psi; therefore, materials having CI values greater than 750 psi are reported simply as >750 psi.

20. The results of the initial screening test define the appropriate WSR and BSR and produce data that aid in the selection of the binder/contaminated soil ratios for detailed evaluation. The test specimens generated during the initial screening test were not used for further evaluation.

Specimens for detailed evaluation

21. The two samples of contaminated soil (nonheat-treated and heat-treated) were stabilized using the three binders: cement, kiln dust, and lime/fly ash. The BSRs are tabulated below.

	Cement	Kiln Dust	Lime/Fly Ash
Nonheat-treated	0.05, 0.10, 0.15, 0.20, 0.25	0.05, 0.10, 0.15, 0.20, 0.25	0.05/0.05, 0.05/0.10, 0.05/0.15, 0.10/0.05, 0.10/0.10, 0.10/0.15, 0.15/0.05, 0.15/0.10, 0.15/0.15
Heat-treated	0.05, 0.10, 0.15, 0.20, 0.25	0.05, 0.10, 0.15, 0.20, 0.25	0.05/0.05, 0.05/0.10, 0.05/0.15. 0.10/0.05, 0.10/0.10, 0.10/0.15, 0.15/0.05, 0.15/0.10, 0.15/0.15

22. Solidified specimens were prepared by mixing water and binder with contaminated soil in a Hobart K455S mixer. The water/binder/contaminated soil slurry was poured into 2- by 2- by 2-in. brass molds. To aid in removing UCS specimens from the molds, a light coating of grease was applied to the molds. Specimens used for the TCLP were prepared in ungreased molds. Immediately after the binder/water/contaminated soil mixtures were placed in the molds, they were vibrated on a Sentron model VP61D1 vibration table to remove voids. At the higher binder-to-soil ratios, the binder/water/contaminated soil mixture was very viscous, and vibration was an ineffective method for removing voids. These specimens were tamped according to ASTM method C 109-86 (American Society for Testing and Materials 1986) using a Model CT-25A tamper.

23. The molded, stabilized/solidified materials were cured in the molds at 23° C and 98-percent relative humidity for a minimum of 24 hr. Specimens were removed from the molds when they developed sufficient strength to be free standing, and were cured under the same temperature and relative humidity conditions until further testing.

Physical and Contaminant Release Testing

Unconfined compressive strength

24. The UCS was used to define and characterize the effects of the S/S process on the physical characteristics of the soil. The UCS was determined using ASTM method C 109-86 (ASTM 1986). The only deviation from this method was vibration or tamping of the specimens, as discussed in paragraph 22.

25. UCS testing was performed on cubes after they had cured for 7, 14, 21, and 28 days. One cube for each batch of binder/contaminated soil mixture was tested at these curing periods. The surface area of each cube was determined by using a Flower Max-cal caliper, and each cube was crushed with a Tinius Olsen Super L compression apparatus. The UCS was reported as pounds per square inch required to fracture the cube.

Selection of binder ratio

26. The success of a S/S process can be evaluated in a number of ways. For the purposes of this testing program, the UCS test was chosen as the parameter on which to base this determination (USEPA 1987). One cube from each S/S batch was subjected to the UCS test at the completion of the 28-day cure period, as previously discussed. The BSR specimen that exhibited UCS values closest to but greater than 50 psi was selected to assess the effects of S/S on the contaminant release characteristics of the treated soil. A UCS of 50 psi was chosen based on information found in the Office of Solid Waste and Emergency Response Policy Directive 9487.00-24 (USEPA 1986d). Based on this criterion, one binder-to-soil ratio was selected from each S/S process for TCLP extraction and analysis.

Contaminant mobility testing

27. Toxicity Characteristic Leaching Procedure. The TCLP extracts were analyzed for metals according to the methods and within the time constraints summarized in the Federal Register (USEPA 1986a) and specified in SW-846 (USEPA 1986c). The contaminants of interest and the appropriate analytical methods are listed in Table 7. Analyses for volatile and semivolatile compounds were not performed since it was assumed that these organic compounds would be removed in unit processes implemented prior to S/S.

28. Quality assurance/quality control. The quality assurance/quality control (QA/QC) for this project was divided between WES and O'Brien and Gere Engineers, Inc. The WES was responsible for preparing the stabilized/solidified soil specimens. O'Brien and Gere Engineers was responsible for

Table 7

Chemical Analysis Methods

Contaminant of Interest	USEPA Analytical Method
Arsenic	7060
Barium	6010
Cadmium	6010
Chromium	6010
Lead	6010
Mercury	7470/7471
Selenium	7740
Silver	6010

laboratory QA/QC related to the conduct of the TCLP extractions and chemical analysis of the resulting extracts.

PART III: DISCUSSION OF RESULTS

Heat-Treated Soils

Initial screening test results

29. The results of the initial screening test for all binders are presented in Table 8. Table 9 summarizes the matrix of test specimens prepared for detailed evaluation. Each time a stabilization process was applied, a batch of material was generated. As shown, 15 batches of solidified soil were prepared for the cement and kiln dust processes, and 27 batches were prepared for the kiln dust and lime/fly ash processes. Five BSRs were run in triplicate for cement and kiln dust, and nine BSRs were run in triplicate for lime/fly ash. The WSR was 0.15 for all formulations.

30. Cement binder. In the initial screening test, water ratios of 0.2 and 0.7 were tested based upon the moisture content of the heat-treated soil shown in Table 3 and in order to have a wide range of water contents to evaluate. At the 0.1 BSR, both the 0.2 and 0.7 WSRs produced very moist, low-strength mixtures. At the 0.7, 1.4, and 2.8 BSRs, more than sufficient strength was developed to meet the 50-psi criterion. Based upon the results of the initial screening test and the experience of WES personnel, a 0.15 WSR was chosen for detailed evaluation. The WSR of 0.2 in the initial screening test was reduced to 0.15 for the detailed evaluation because the 0.2 WSR produced too much moisture. The BSRs chosen for detailed evaluation were 0.05, 0.10, 0.15, 0.20, and 0.25.

31. Kiln dust binder. The results of the initial screening test using kiln dust as the binder were similar to the cement results, as shown in Table 8. At 0.7 WSR/0.1 BSR, a 1/4-in. liquid layer was retained on the top of the sample. The 0.2 WSR/0.1 BSR developed a CI value of 70. At the higher BSRs, sufficient strength was produced, indicating that a decrease in the WSR could lead to a decrease in the BSR required to meet the 50-psi criterion for detailed evaluation. Based on the results of the initial screening tests and the experience of WES personnel, a WSR of 0.15 and BSRs of 0.05, 0.10, 0.15, 0.20, and 0.25 were chosen for detailed evaluation.

32. Lime/fly ash binder. The results of the lime/fly ash initial screening test were similar to the cement and kiln dust results (Table 8). The 0.7 WSR did not attain sufficient strength at any of the BSR combinations. The 0.2 WSR gained substantial strength at the 0.7 lime/0.1 fly ash and

Table 8

Initial Screening Test Results for Waldick Soil Sample

Binder-Soil Ratio		48-hr Cone Index Value, psi			
		Heat-treated Water-Soil Ratio		Nonheat-Treated Water-Soil Ratio	
		0.2	0.7	0.2	0.7
Cement-soil					
0.1		128	12	147	11
0.7		>750	>750	>750	>750
1.4		>750	>750	>750	>750
2.8		>750	>750	>750	>750
Kiln dust-soil					
0.1		70	0	50	0
0.7		>750	15	>750	13
1.4		>750	620	>750	450
2.8		>750	>750	>750	>750
Lime-soil	**Fly ash-soil**				
0.1	0.1	10	0	10	0
0.1	0.7	400	0	617	0
0.7	0.1	>750	5	>750	[illegible]
0.7	0.7	>750	20	>750	15

0.7 lime/0.7 fly ash ratios. Reducing the WSR from 0.7 to 0.2 produced significant strength gains. The 0.1 lime/0.7 fly ash ratio did not gain as much strength as the 0.7 lime/0.1 fly ash ratio with CI values of 400 and 750+ psi, respectively. The ratios selected for detailed evaluation were 0.15 WSR and BSRs of 0.05 lime/0.05 fly ash, 0.05 lime/0.10 fly ash, 0.05 lime/0.15 fly ash, 0.10 lime/0.10 fly ash, 0.10 lime/0.15 fly ash, 0.15 lime/0.05 fly ash, 0.15 lime/0.10 fly ash, and 0.15 lime/0.15 fly ash. Because the same ratios for cement, kiln dust, and lime/fly ash were evaluated, comparison of the immobilization properties of the binders was simplified.

UCS results

33. The results of the UCS tests (at 7, 14, 21, and 28 days) are summarized in Appendix A, shown in Figures 3-5, and discussed below.

34. Cement binder. With each BSR increase of 0.05, the strength of the material increased considerably. The 0.05 BSR developed a UCS of 100 psi after 28 days of cure. At the next two increases of 0.05 (0.10 and 0.15), the UCS tripled, with UCS values of 250 and 791, respectively, after 28 days of

Table 9

Summary of S/S Program for Heat-Treated Soils

Binder-to-Soil Description Code		BSR	Batch Designation Run 1	Run 2	Run 3
		Binder: Portland Cement (C)			
A		0.05	C.1.A	C.2.A	C.3.A
B		0.10	C.1.B	C.2.B	C.3.B
C		0.15	C.1.C	C.2.C	C.3.C
D		0.20	C.1.D	C.2.D	C.3.D
E		0.25	C.1.E	C.2.E	C.3.E
		Binder: Kiln Dust (KD)			
F		0.05	KD.1.F	KD.2.F	KD.3.F
G		0.10	KD.1.G	KD.2.G	KD.3.G
H		0.15	KD.1.H	KD.2.H	KD.3.H
I		0.20	KD.1.I	KD.2.I	KD.3.I
J		0.25	KD.1.J	KD.2.J	KD.3.J
		Binder: Lime/Fly Ash (L/F) Mixture			
	Lime-Soil Ratio	Fly Ash-Soil Ratio			
K	0.05	0.05	L/F.1.K	L/F.2.K	L/F.3.K
L	0.05	0.10	L/F.1.L	L/F.2.L	L/F.3.L
M	0.05	0.15	L/F.1.M	L/F.2.M	L/F.3.M
N	0.10	0.05	L/F.1.N	L/F.2.N	L/F.3.N
O	0.10	0.10	L/F.1.O	L/F.2.O	L/F.3.O
P	0.10	0.15	L/F.1.P	L/F.2.P	L/F.3.P
Q	0.15	0.05	L/F.1.Q	L/F.2.Q	L/F.3.Q
R	0.15	0.10	L/F.1.R	L/F.2.R	L/F.3.R
S	0.15	0.15	L/F.1.S	L/F.2.S	L/F.3.S

cure (Figure 3). The UCS also increased with cure time. At the 0.10 BSR, 7 days of cure provided a UCS of 161 psi. This value increased after 14, 21, and 28 days to 234, 247, and 250 psi, respectively. The 14-day UCS was one third the 7-day UCS. The 21- and 28-day cure times did not display

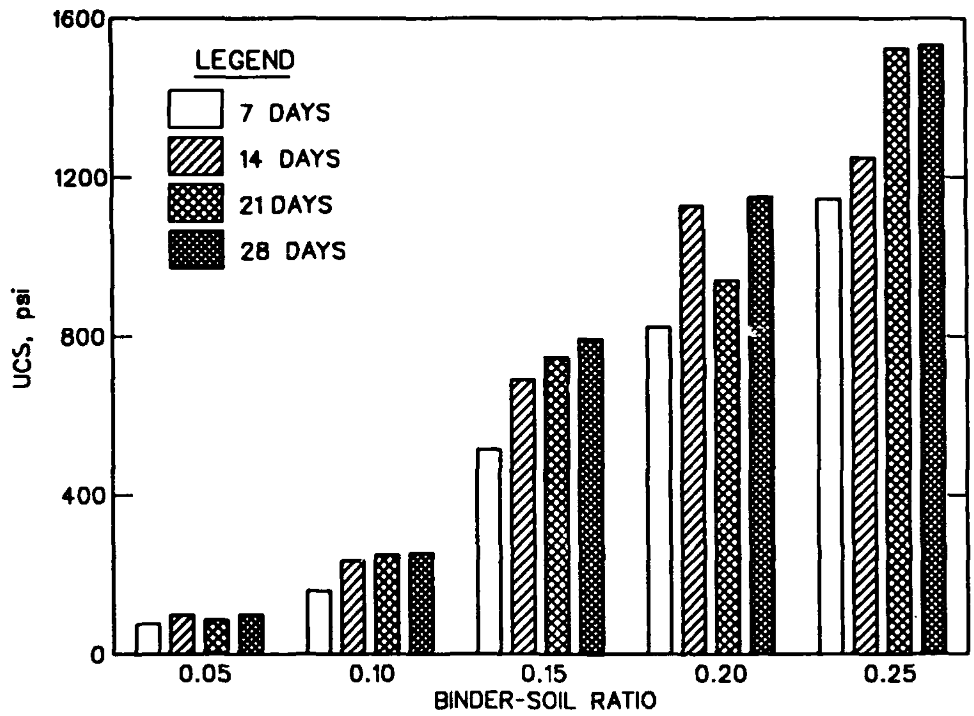


Figure 3. UCS results for heat-treated soils using cement as binder

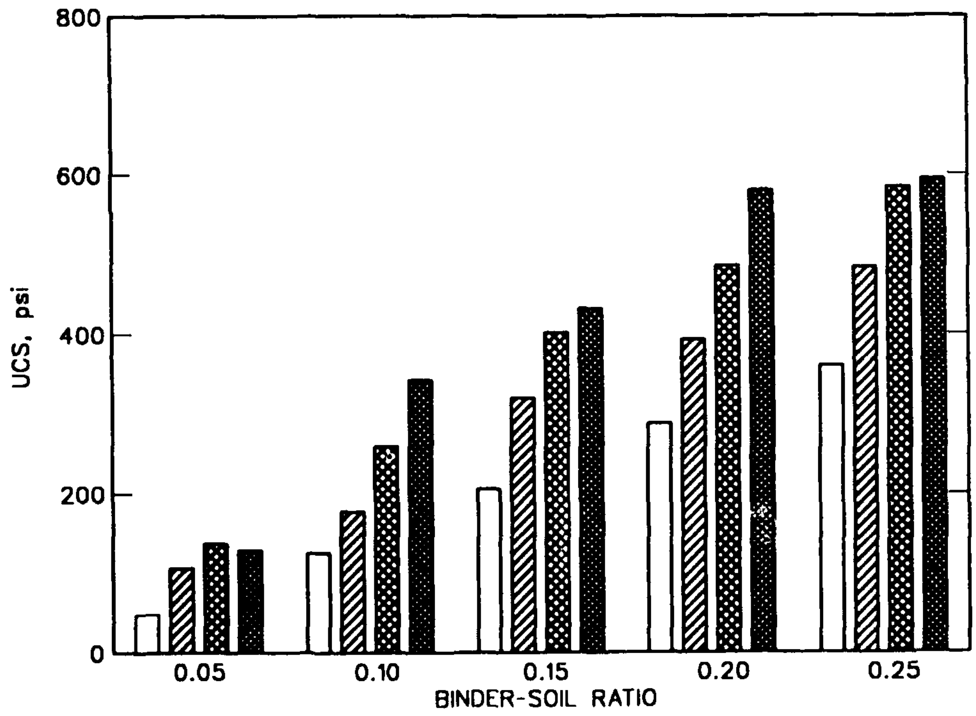


Figure 4. UCS results for heat-treated soils using kiln dust as binder

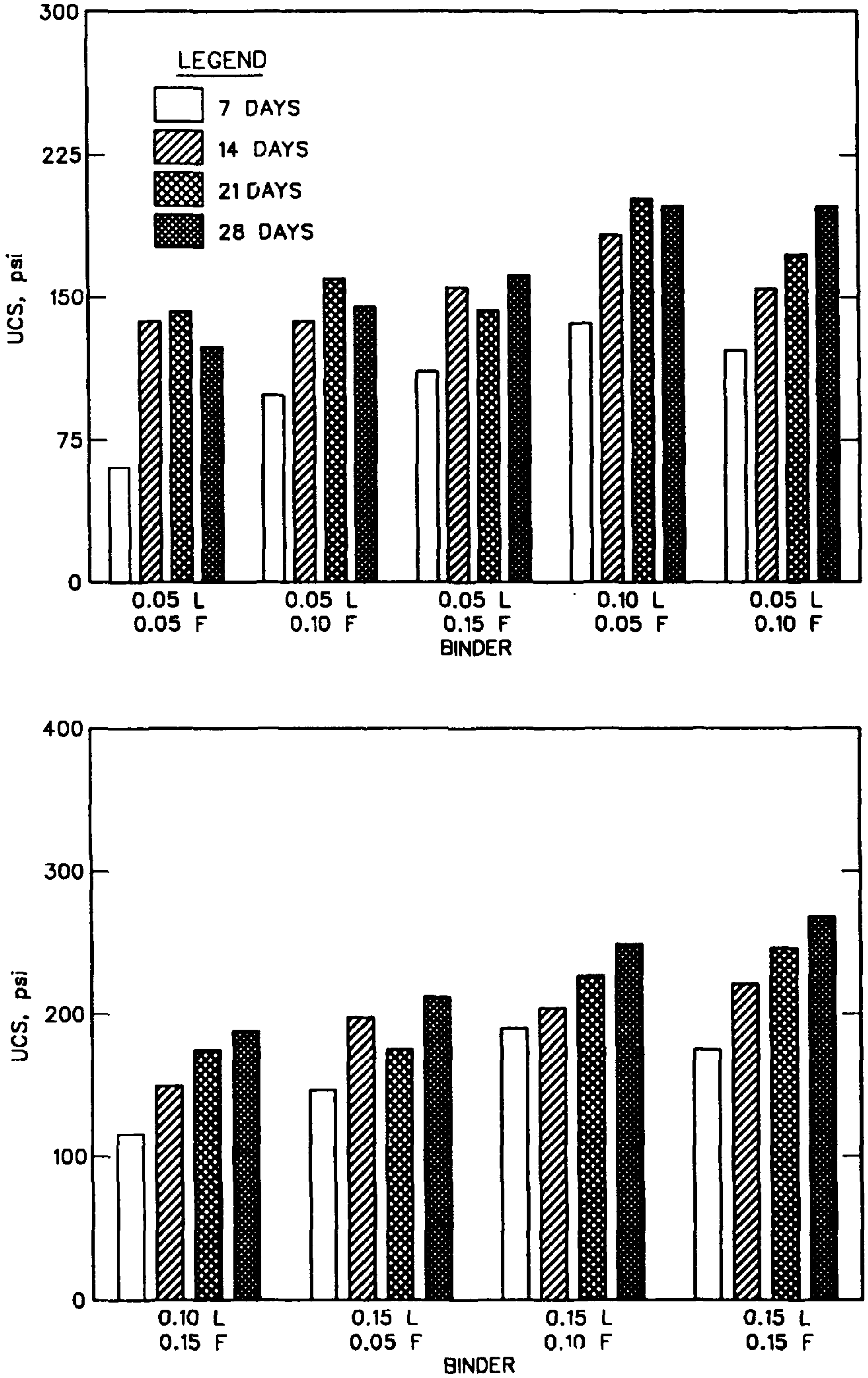


Figure 5. UCS results for heat-treated soils using lime/fly ash (L/F) as binder

considerable increases above the 14-day UCS, indicating that near-maximum UCS was attained after only 14 days of cure.

35. Kiln dust binder. Similarly to the cement binder, the UCS of the kiln dust increased as the curing time increased. The 0.05 and 0.10 BSRs developed UCS values of 130 and 342 psi, respectively, after 28 days of cure (Figure 4). The UCS increase over time was not as significant at the higher BSRs. At BSRs of 0.15, 0.20, and 0.25, the 28-day UCS values were 432, 581, and 595 psi, respectively, after 28 days of cure. At BSRs of 0.05 and 0.10, the UCS for kiln dust was higher than that of cement at similar ratios. In contrast, the UCS values of kiln dust at BSRs of 0.15, 0.20, and 0.25 were much lower than cement at these BSRs.

36. Lime/fly ash binder. Like the cement and kiln dust ratios, the UCS increased with cure time. After 28 days of cure, the UCS increased approximately 20 psi for each 0.05 increase in the BSR (Figure 5). The highest BSR, 0.15 lime/0.15 fly ash, with a UCS of 267 psi after 28 days of cure, did not gain as much strength as the highest cement and kiln dust BSRs, with UCS values of 1,532 and 595 psi, respectively, after 28 days of cure.

Initial extraction test results

37. As shown in Appendix A, all the binders at the BSRs investigated developed UCS well above the 50-psi selection criterion. The results of initial characterization by O'Brien and Gere Engineers, Inc., are presented in Appendix B. The materials designated for TCLP analysis were chosen by selecting the batch with the minimum BSR. The BSR for extractions included 0.05 cement, 0.05 kiln dust, 0.05 lime/0.05 fly ash.

38. The results of the TCLP for the heat-treated stabilized/solidified contaminated soils are given in Table 10. Results are presented for the eight compounds identified as contaminants of interest. The results reflected no significant reduction in the apparent leachability of the contaminants.

Nonheat-Treated Soils

Initial screening test results

39. The results of the initial screening test for all binders are presented in Table 8. Table 11 summarizes the matrix of test specimens prepared for detailed evaluation. Each time a stabilization process was applied, a batch of material was generated. The same formulations were prepared for the heat-treated and nonheat-treated soils. Five BSRs for cement and kiln dust

Table 10

TCLP Analysis for Heat-Treated Soils

Parameter	Concentration, mg/ℓ								
	C.1.A*	C.2.A	C.3.A	KD.1.F	KD.2.F	KD.3.F	L/F.1.K	L/F.2.K	L/F.3.K
Arsenic	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Barium	1.35	1.80	1.40	1.00	1.10	1.10	1.30	1.10	1.20
Cadmium	36.00	48.50	45.00	37.00	39.00	40.00	34.00	33.00	36.00
Chromium	2.25	2.70	2.40	3.40	3.60	3.50	3.20	3.30	3.30
Lead	0.125	0.145	0.13	0.36	0.27	0.27	0.20	0.16	0.23
Mercury	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Selenium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silver	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

* Batch designations are identified in Table 9.

Table 11

Summary of S/S Program for Nonheat-Treated Soils

Binder-to-Soil Description Code		BSR	Batch Designation Run 1	Run 2	Run 3
		Binder: Portland Cement (C)			
A		0.05	C.1.A	C.2.A	C.3.A
B		0.10	C.1.B	C.2.B	C.3.B
C		0.15	C.1.C	C.2.C	C.3.C
D		0.20	C.1.D	C.2.D	C.3.D
E		0.25	C.1.E	C.2.E	C.3.E
		Binder: Kiln Dust (KD)			
F		0.05	KD.1.F	KD.2.F	KD.3.F
G		0.10	KD.1.G	KD.2.G	KD.3.G
H		0.15	KD.1.H	KD.2.H	KD.3.H
I		0.20	KD.1.I	KD.2.I	KD.3.I
J		0.25	KD.1.J	KD.2.J	KD.3.J
		Binder: Lime/Fly Ash (L/F) Mixture			
	Lime-Soil Ratio	Fly Ash-Soil Ratio			
K	0.05	0.05	L/F.1.K	L/F.2.K	L/F.3.K
L	0.05	0.10	L/F.1.L	L/F.2.L	L/F.3.L
M	0.05	0.15	L/F.1.M	L/F.2.M	L/F.3.M
N	0.10	0.05	L/F.1.N	L/F.2.N	L/F.3.N
O	0.10	0.10	L/F.1.O	L/F.2.O	L/F.3.O
P	0.10	0.15	L/F.1.P	L/F.2.P	L/F.3.P
Q	0.15	0.05	L/F.1.Q	L/F.2.Q	L/F.3.Q
R	0.15	0.10	L/F.1.R	L/F.2.R	L/F.3.R
S	0.15	0.15	L/F.1.S	L/F.2.S	L/F.3.S

and nine BSRs for lime/fly ash were prepared in triplicate. A WSR of 0.15 was selected.

40. Cement binder. The results of the initial screening test for the nonheat-treated soils were very similar to those for the heat-treated soils. Both the 0.2 and 0.7 WSRs produced very wet mixtures at the 0.1 BSR. Based on the experience of WES personnel, a 0.15 WSR was selected for detailed evaluation. Similar to the heat-treated soils, the decrease in WSR decreased the amount of binder necessary for S/S. Therefore, BSRs of 0.05, 0.10, 0.15, 0.20, and 0.25 were also chosen for further evaluation of the nonheat-treated soils.

41. Kiln dust binder. The results of the initial screening test on the nonheat-treated soils were similar to those for the heat-treated soils. Similar to the cement mixtures, the 0.2 and 0.7 WSRs provided mixtures that contained too much moisture. A 0.15 WSR was chosen for further evaluation. The BSRs chosen for further evaluation were 0.05, 0.10, 0.15, 0.20, and 0.25. These ratios were chosen because the 0.2 WSR/0.7 BSR reached a strength of >750 psi. Reducing the WSR to 0.15 would allow reduction of the BSR to 0.05, 0.10, 0.15, 0.20, and 0.25, while obtaining the same strength.

42. Lime/fly ash binder. The 0.7 WSR did not produce significant strengths at any of the BSRs. The 0.2 WSR, 0.1/0.1 BSR specimens had very low strength. An increase in fly ash to 0.7 increased the strength substantially, to 617 psi. An increase in lime to 0.7 produced more strength (750 psi) than the fly ash, indicating that lime had more effect on the CI value. Based on the results of the initial screening test and the experience of WES personnel, a WSR of 0.15 and BSRs of 0.05 lime/0.05 fly ash, 0.05 lime/0.10 fly ash, 0.05 lime/0.15 fly ash, 0.10 lime/0.05 fly ash, 0.10 lime/0.10 fly ash, 0.10 lime/0.15 fly ash, 0.15 lime/0.05 fly ash, 0.15 lime/0.10 fly ash, and 0.15 lime/0.15 fly ash were selected for further evaluation. The same values were evaluated for the heat-treated soil.

UCS results

43. The results of the UCS tests for nonheat-treated soils are summarized in Appendix C, shown in Figures 6-8, and discussed below.

44. Cement binder. Each of the BSRs exceeded the minimum 50-psi UCS requirement. As the cure time increased, the UCS increased in most cases. The 28-day UCS for 0.20 and 0.25 BSRs decreased (from the 21-day values of 1,112 and 1,008 psi) to 711 and 862 psi, respectively. This behavior could be due to a change in equipment operators. As the BSR increased, the UCS

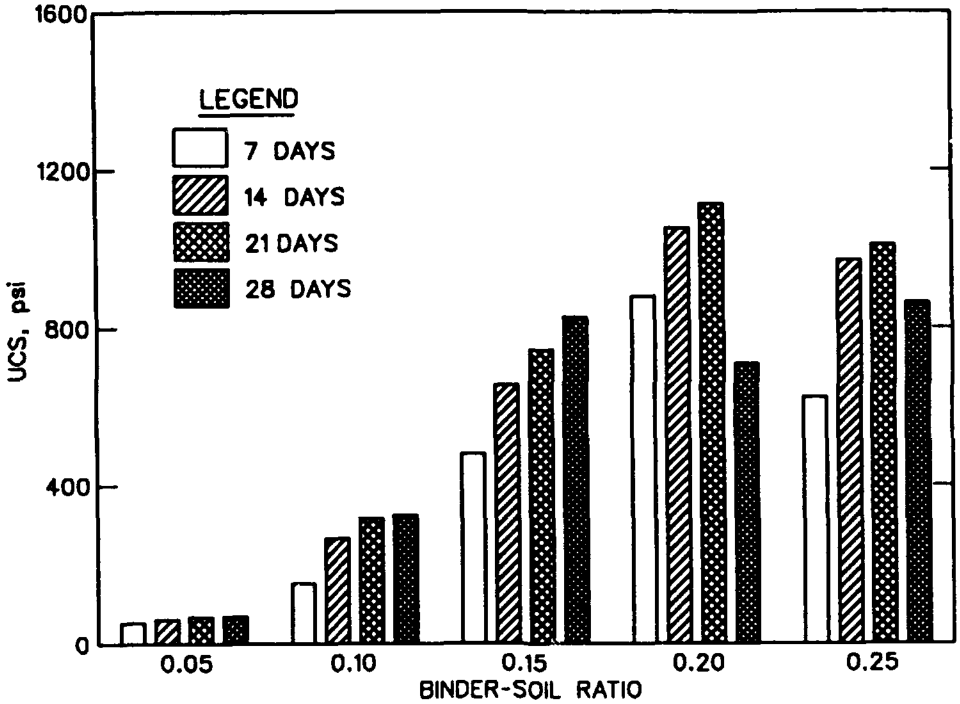


Figure 6. UCS results for nonheat-treated soils using cement as binder

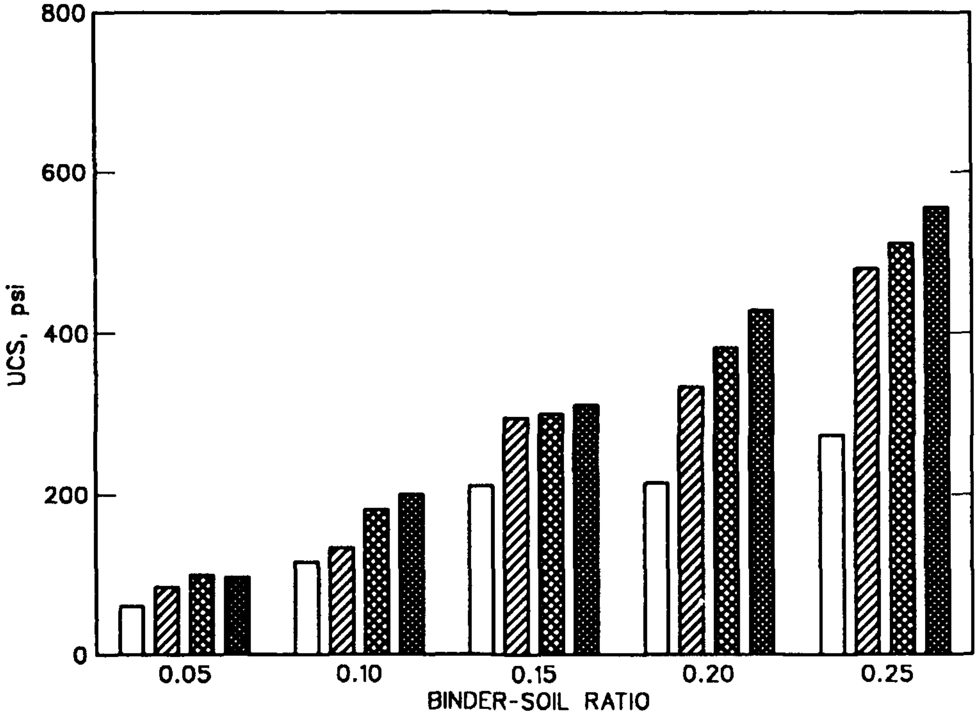
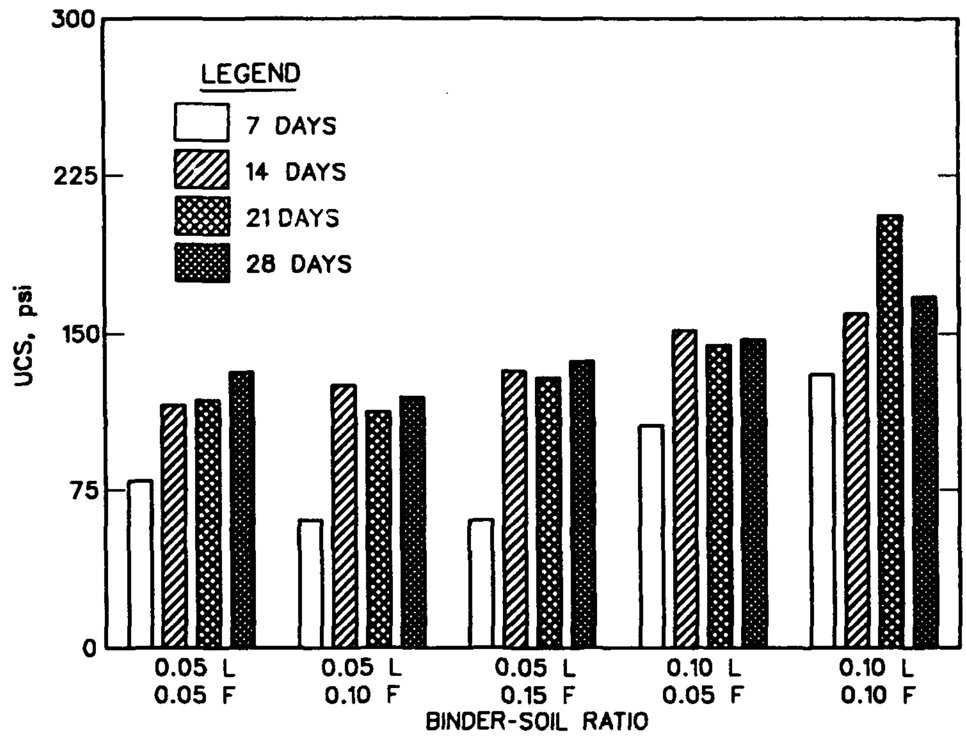


Figure 7. UCS results for nonheat-treated soils using kiln dust as binder



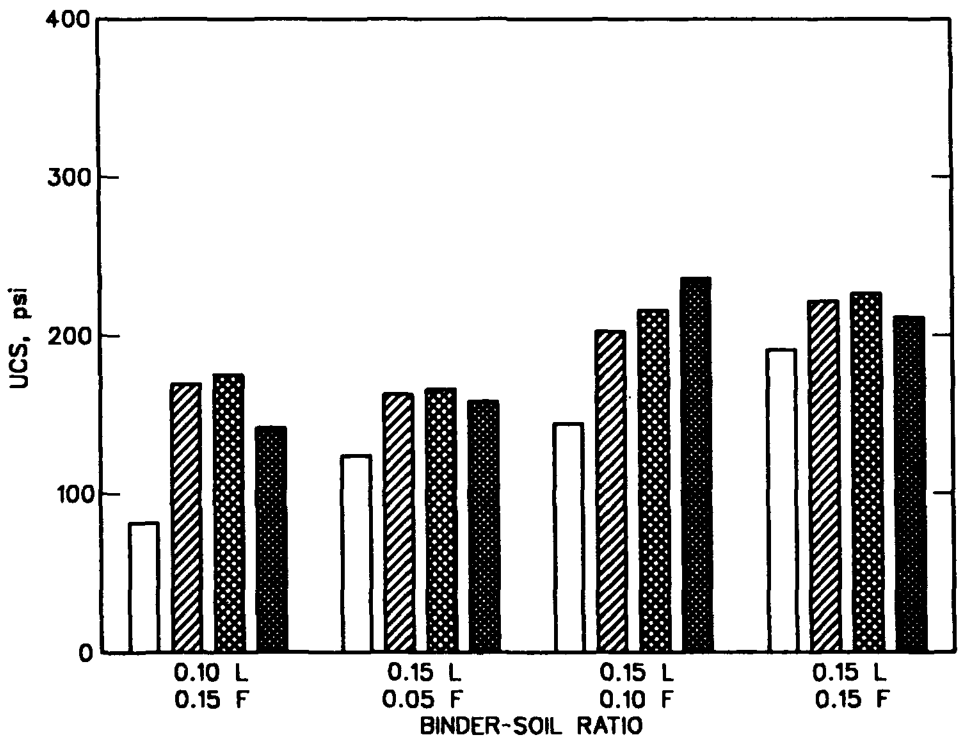


Figure 8. UCS results for nonheat-treated soils using lime/ fly ash (L/F) as binder

increased. The 0.05 BSR specimen developed a strength of 68 psi. Increasing the BSR to 0.10 increased the UCS to 322 psi. The 0.15 BSR tripled the UCS of the 0.10 BSR. At a BSR of 0.2, the UCS was 711 psi. The average UCS increased to 862 psi at the 0.25 BSR.

45. Kiln dust binder. All BSRs tested exceeded the minimum 50-psi requirement. With each 0.05 increase in BSR, the UCS increased approximately 100 psi. The 0.25 BSR produced a 28-day UCS of 555 psi, which was lower than the 0.25 cement BSR of 862 psi after 28 days of cure.

46. Lime/fly ash binder. After 14 days of cure, the UCS remained approximately the same through 28 days of cure. The lowest UCS after 28 days of cure was at the 0.05 lime/0.10 fly ash BSR. This value (133 psi) was lower than the 0.05 lime/0.05 fly ash BSR. The UCS values did not increase significantly as the BSRs were increased.

Initial extraction test results

47. As shown in Appendix B, all the binders at the BSRs investigated developed UCS well above the 50-psi selection criterion. The materials designated for TCLP analysis were chosen by selecting the specimens with the minimum BSR. The BSRs selected for TCLP extraction included 0.05 BSR for cement, 0.05 BSR for kiln dust, and 0.05 lime/0.05 fly ash for lime/fly ash. The results of the TCLP on these ratios are presented in Table 12. As in the case of the heat-treated soils, the selected BSRs did not significantly reduce contaminant mobility.

Additional extraction test results

48. Based on the initial analysis of the heat-treated specimens, it appeared that the BSRs selected for detailed evaluation were too low to effectively immobilize the contaminants of interest. The decision was made to evaluate contaminant mobility using specimens prepared with higher BSRs. It was further determined that there was no significant difference between the results on the heat-treated and nonheat-treated soils. Therefore, as a cost-saving measure, further testing of the higher BSR specimens was limited to the nonheat-treated specimens. Results of the TCLP for the 0.25 cement and 0.15 lime/0.15 fly ash samples are given in Table 13. Results are presented for the eight compounds identified as contaminants of interest.

49. The results presented in Table 13 reflect substantial reduction in the apparent leachability of cadmium and chromium based upon the initial characterization. Based on an average TCLP concentration of samples A, B, and C

Table 12

Initial TCLP Analysis for Nonheat-Treated Soils

	Concentration, mg/ℓ								
Parameter	C.1.A*	C.2.A	C.3.A	KD.1.F	KD.2.F	KD.3.F	L/F.1.K	L/F.2.K	L/F.3.K
Arsenic	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Barium	1.35	1.80	1.40	1.00	1.10	1.10	1.30	1.10	1.20
Cadmium	36.00	48.50	45.00	37.00	39.00	40.00	34.00	33.00	36.00
Chromium	2.25	2.70	2.40	3.40	3.60	3.50	3.20	3.30	3.30
Lead	0.125	0.145	0.130	0.36	0.27	0.27	0.20	0.16	0.23
Mercury	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Selenium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silver	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

* Batch designations are identified in Table 9.

Table 13

Final TCLP Analysis for Nonheat-Treated Soils

Parameter	Concentration, mg/ℓ C.1.E	C.2.E	C.3.E	LF.1.S	LF.2.S	LF.3.S
Arsenic	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Barium	1.00	0.80	0.90	1.10	1.10	1.10
Cadmium	2.50	0.68	<0.01	<0.01	<0.01	<0.01
Chromium	0.53	0.57	0.45	0.25	0.24	0.26
Lead	0.09	0.07	0.07	0.09	0.07	0.08
Mercury	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Selenium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silver	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

before stabilization/solidification and an average of the values after cement treatment, the cadmium leachability decreased from 46 mg/ℓ to 1.0 mg/ℓ for the cement-treated material. Note that there was relatively wide variation (values ranged from <0.01 to 2.5 mg/ℓ) in the results of the cadmium analysis for the triplicate samples. This variation cannot be readily explained. The lime/fly ash binder decreased the leachability of cadmium to below detection limits. Similar results were obtained for chromium. Although UCS values for the cement were higher than the lime/fly ash values, the leachability was reduced more by the lime/fly ash. The kiln dust binder was not tested.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

50. A laboratory study was conducted to investigate the effects of three S/S processes on a contaminated soil. Both UCS and TCLP tests were performed on the stabilized/solidified specimens. Based on the results of these tests, the following conclusions were made.

- a. Small quantities of binding agents produce materials with UCS well above the 50-psi criterion.
- b. Water must be added to the contaminated soil in order for the binders to develop strength.
- c. The binders can be easily mixed with the contaminated soil.
- d. The stabilized/solidified soils set within 24 hr, and no free liquid was observed after this 24-hr period.
- e. The S/S processing of the soil was effective in reducing the mobility of the contaminants in the soil.
- f. A WSR of 0.15 and cement BSR of 0.25 was effective in reducing contaminant mobility of cadmium and chromium.
- g. A WSR of 0.15 and lime/fly ash BSR of 0.15/0.15 was effective in reducing the contaminant mobility of cadmium and chromium.

Recommendations

51. Based on the results of this study, the following recommendations are made.

- a. Either Type I Portland cement or lime/fly ash should be considered as effective S/S agents for the contaminated soils found at the Waldick site and evaluated during pilot-scale testing.
- b. Pilot-scale testing should be initiated with the trial mix formulations presented in the tabulation below.

Binder	Binder-to-Soil Ratio	Water-to-Soil Ratio	Binder Weight, lb	Water Weight, lb
Cement*	0.25	0.15	500	300
Lime/fly ash*	0.15/0.15	0.15	300/300	300
Cement**	0.25	0.30	500	600
Lime/fly ash**	0.15/0.15	0.30	300/300	600

* Calculations are based on 1 ton of soil and 13-percent moisture content in the untreated soil (water content of soils in the treatability study).

** Calculations are based on 1 ton of soil and 2-percent moisture content in the untreated soil (water content expected after thermal treatment in the field).

c. During pilot-scale testing of the cement binder, two additional BSRs, 0.35 and 0.45, should be evaluated. The WSR should be adjusted to enhance field operations and improve compatibility with the method be used to transport the stabilized/solidified soil from the treatment area to the final disposal site.

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APPENDIX A: UNCONFINED COMPRESSIVE STRENGTH DATA FOR HEAT-TREATED SOILS

Table A1

UCS Results for Heat-Treated Soils

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Cement				
0.05	A	7	71	
	B	7	87	
	C	7	83	80
0.05	A	14	103	
	B	14	98	
	C	14	94	98
0.05	A	21	90	
	B	21	91	
	C	21	90	90
0.05	A	28	91	
	B	28	105	
	C	28	104	100
0.10	A	7	159	
	B	7	163	
	C	7	160	160
0.10	A	14	250	
	B	14	234	
	C	14	217	233
0.10	A	21	249	
	B	21	246	
	C	21	247	247
0.10	A	28	264	
	B	28	277	
	C	28	210	250
0.15	A	7	537	
	B	7	504	
	C	7	505	515
0.15	A	14	671	
	B	14	642	
	C	14	755	689
0.15	A	21	734	
	B	21	705	
	C	21	800	746
0.15	A	28	750	
	B	28	794	
	C	28	830	791

(Continued)

(Sheet 1 of 7)

Table A1 (Continued)

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Cement (Cont.)				
0.20	A	7	811	
	B	7	805	
	C	7	842	819
0.20	A	14	1,083	
	B	14	1,192	
	C	14	1,096	1,123
0.20	A	21	757	
	B	21	1,151	
	C	21	912	940
0.20	A	28	1,300	
	B	28	1,146	
	C	28	999	1,148
0.25	A	7	1,034	
	B	7	1,133	
	C	7	1,257	1,141
0.25	A	14	1,010	
	B	14	1,343	
	C	14	1,388	1,247
0.25	A	21	1,478	
	B	21	1,593	
	C	21	1,494	1,521
0.25	A	28	1,459	
	B	28	1,631	
	C	28	1,506	1,532
Kiln dust				
0.05	A	7	52	
	B	7	47	
	C	7	51	50
0.05	A	14	121	
	B	14	110	
	C	14	93	108
0.05	A	21	126	
	B	21	147	
	C	21	135	136
0.05	A	28	128	
	B	28	147	
	C	28	115	130

(Continued)

(Sheet 2 of 7)

Table A1 (Continued)

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Kiln dust (Cont.)				
0.10	A	7	121	
	B	7	126	
	C	7	127	124
0.10	A	14	159	
	B	14	199	
	C	14	171	176
0.10	A	21	208	
	B	21	330	
	C	21	235	257
0.10	A	28	270	
	B	28	377	
	C	28	378	341
0.15	A	7	206	
	B	7	206	
	C	7	204	205
0.15	A	14	315	
	B	14	316	
	C	14	327	319
0.15	A	21	387	
	B	21	413	
	C	21	410	403
0.15	A	28	454	
	B	28	446	
	C	28	396	432
0.20	A	7	281	
	B	7	277	
	C	7	303	287
0.20	A	14	390	
	B	14	405	
	C	14	385	393
0.20	A	21	458	
	B	21	475	
	C	21	524	485
0.20	A	28	557	
	B	28	598	
	C	28	587	580

(Continued)

(Sheet 3 of 7)

Table A1 (Continued)

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Kiln dust (Cont.)				
0.25	A	7	344	
	B	7	388	
	C	7	345	359
0.25	A	14	464	
	B	14	455	
	C	14	533	484
0.25	A	21	590	
	B	21	564	
	C	21	601	585
0.25	A	28	478	
	B	28	636	
	C	28	672	595
Lime/fly ash				
0.05 0.05	A	7	83	
	B	7	44	
	C	7	54	60
0.05 0.05	A	14	140	
	B	14	140	
	C	14	133	137
0.05 0.05	A	21	134	
	B	21	150	
	C	21	143	142
0.05 0.05	A	28	131	
	B	28	126	
	C	28	115	124
0.05 0.10	A	7	91	
	B	7	83	
	C	7	120	98
0.05 0.10	A	14	130	
	B	14	134	
	C	14	148	17
0.05 0.10	A	21	161	
	B	21	169	
	C	21	148	159
0.05 0.10	A	28	154	
	B	28	131	
	C	28	149	144

(Continued)

(Sheet 4 of 7)

Table A1 (Continued)

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Lime/fly ash (Cont.)				
0.05 0.15	A	7	111	
	B	7	117	
	C	7	106	111
0.05 0.15	A	14	135	
	B	14	164	
	C	14	165	154
0.05 0.15	A	21	123	
	B	21	175	
	C	21	130	142
0.05 0.15	A	28	160	
	B	28	171	
	C	28	152	161
0.10 0.05	A	7	161	
	B	7	120	
	C	7	126	135
0.10 0.05	A	14	201	
	B	14	188	
	C	14	156	181
0.10 0.05	A	21	210	
	B	21	179	
	C	21	213	200
0.10 0.05	A	28	223	
	B	28	178	
	C	28	191	197
0.10 0.10	A	7	108	
	B	7	108	
	C	7	146	120
0.10 0.10	A	14	154	
	B	14	160	
	C	14	147	153
0.10 0.10	A	21	179	
	B	21	169	
	C	21	167	171
0.10 0.10	A	28	205	
	B	28	190	
	C	28	196	197
0.10 0.15	A	7	130	
	B	7	107	
	C	7	102	113

(Continued)

(Sheet 5 of 7)

Table A1 (Continued)

Binder-to-Soil Ratio		Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Lime/fly ash (Cont.)					
0.10	0.15	A	14	128	
		B	14	168	
		C	14	147	147
0.10	0.15	A	21	163	
		B	21	202	
		C	21	158	174
0.10	0.15	A	28	182	
		B	28	213	
		C	28	165	186
0.15	0.05	A	7	137	
		B	7	163	
		C	7	136	145
0.15	0.05	A	14	190	
		B	14	204	
		C	14	197	197
0.15	0.05	A	21	202	
		B	21	157	
		C	21	170	176
0.15	0.05	A	28	199	
		B	28	217	
		C	28	220	212
0.15	0.10	A	7	221	
		B	7	212	
		C	7	135	189
0.15	0.10	A	14	188	
		B	14	237	
		C	14	183	202
0.15	0.10	A	21	255	
		B	21	225	
		C	21	199	226
0.15	0.10	A	28	270	
		B	28	257	
		C	28	216	247
0.15	0.15	A	7	114	
		B	7	208	
		C	7	200	174

(Continued)

(Sheet 6 of 7)

Table A1 (Concluded)

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Lime/fly ash (Cont.)				
0.15 0.15	A	14	235	
	B	14	212	
	C	14	212	219
0.15 0.15	A	21	219	
	B	21	249	
	C	21	268	245
0.15 0.15	A	28	273	
	B	28	277	
	C	28	250	266

(Sheet 7 of 7)

APPENDIX B: LABORATORY RESULTS FROM O'BRIEN AND GERE ENGINEERS, INC.

LABORATORIES, INC.

Laboratory Report

CLIENT U.S. ARMY CORPS OF ENGINEERS JOB NO. 3068.014.517

DESCRIPTION Waldick Aerospace - Soils

DATE COLLECTED 7-19-89 DATE REC'D. 7-26-89 DATE ANALYZED

Description	# 1 Drum Unheated	#2 Drum Heated			
Sample #	I8250	I8251			
Total Metals:					
SILVER	< 1.2				
ARSENIC	2.1	-			
BARIUM	25.				
CADMIUM	1200.	-			
CHROMIUM	510.				
MERCURY	< 0.5	-			
LEAD	28.				
SELENIUM	< 0.6	-			
Other Analysis:					
PERCENT TOTAL SOLIDS	86	88			

UNITS: mg/kg dry weight

Methodology: Federal Register — 40 CFR, Part 136, October 26, 1984

Units: mg/l (ppm) unless otherwise noted

Comments:

Authorized: [signature]

Date: August 21, 1989

OBG Laboratories, Inc., an O'Brien & Gere Limited Company
Box 4942 / 1304 Buckley Rd. / Syracuse, NY 13221 / (315) 457-1494

OBG LABORATORIES, INC.

Laboratory Report

CLIENT: U.S. ARMY CORPS OF ENGINEERS JOB NO: 3068.014.517

DESCRIPTION: Waldick Aerospace - TCLP Extracted Soils

DATE COLLECTED: 7-19-89 DATE REC'D: 7-26-89 DATE ANALYZED:

Description	Homogenized A	Homogenized B	Homogenized C	Heat Treat A	Heat Treat B	Heat Treat C
Sample #	18252	18253	18254	18255	18256	18257
TCLP Metals:						
SILVER	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ARSENIC	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
BARIUM	1.7	1.5	1.5	1.8	1.6	1.7
CADMIUM	43.	55.	41.	39.	38.	41.
CHROMIUM	0.90	0.87	0.92	1.0	0.96	1.0
MERCURY	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
LEAD	0.05	<0.05	<0.05	<0.05	<0.05	<0.05
SELENIUM	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Other Analysis:						
PERCENT TOTAL SOLIDS	86.	86.	86.	87.	89.	88.

UNITS: mg/l

Methodology: Federal Register — 40 CFR, Part 136, October 26, 1984

Units: mg/l (ppm) unless otherwise noted

Comments:

Authorized: Michael D. Pettinelli

Date: August 21, 1989

OBG Laboratories, Inc., an O'Brien & Gere Limited Company
Box 4942 / 1304 Buckley Rd / Syracuse, NY / 13221 / (315) 457-1494

LABORATORIES, INC.

Laboratory Report

CLIENT: U.S. ARMY CORPS OF ENGINEERS JOB NO. 3068.014.517

DESCRIPTION: Waldick Aerospace - Soils

DATE COLLECTED: 7-19-89 DATE REC'D.: 7-26-89 DATE ANALYZED: 8-29-89

Description	#1 Drum Unheated	#2 Drum Heated			
Sample #	I8250	I8251			
Petroleum Hydrocarbons by IR Spectrophotometry:					
TOTAL HYDROCARBONS	200.	190.			

UNITS: mg/kg dry weight

Methodology: Federal Register — 40 CFR, Part 136, October 26, 1984

Units: mg/l (ppm) unless otherwise noted

Comments:

Authorized: [signature]

Date: August 29, 1989

OBG Laboratories, Inc., an O'Brien & Gere Limited Company
Box 4942 / 1304 Buckley Rd. / Syracuse, NY 13221 / (315) 457-1494

OBG LABORATORIES, INC.

Report

CLIENT U.S. ARMY CORPS OF ENGINEERS — JOB NO 3068.014.517

DESCRIPTION Waldick Aerospace - TCLP Extracted Solid Samples

DATE COLLECTED - DATE REC'D See Below DATE ANALYZED

Description / Date Received	A UWHCA 28055U 8-23-89	A UWHCA 28056U 8-23-89	B UWHCB 280511U 8-23-89	B UWHCB 280512U 8-23-89	C UWHCC 28051U 8-23-89	C UWHCC 28052U 8-23-89	UWUCA 28055U 8-30-89	UWUCA 28056U 8-30-89	UWUCB 280511U 8-30-89	UWUCB 280512U 8-30-89	UWUCC 28051U 8-30-89	UWUCC 28052U 8-30-89
Sample #	19585	19586	19587	19588	19589	19590	19860	19861	19862	19863	19864	19865
TCLP Metals:												
SILVER	<0.02*	<0.02*	<0.02*	<0.02*	<0.02*	<0.02*	<0.02*	<0.02*	<0.02*	<0.02*	<0.02*	<0.02*
ARSENIC	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*
BARIUM	1.6	1.5	1.4	1.4	1.4	1.4	1.3	1.4	1.5	2.1	1.4	1.4
CADMIUM	37.	37.	35.	35.	35.	36.	36.	36.	49.	48.	45.	45.
CHROMIUM	2.5	2.4	2.3	2.4	2.3	2.1	2.2	2.3	2.7	2.7	2.5	2.3
MERCURY	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
LEAD	0.11	0.09	0.09	0.10	0.11	0.10	0.12	0.13	0.13	0.16	0.13	0.13
SELENIUM	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*

UNITS: mg/l

Methodology: Federal Register — 40 CFR, Part 136, October 26, 1984

Units: mg/l (ppm) unless otherwise noted

Comments: *The detection limit has been raised due to the presence of matrix interferences (calcium).

Authorized: [signature]

Date: September 21, 1989

OBG Laboratories, Inc. an O'Brien & Gere Limited Company
Box 4942 / 1304 Buckley Rd / Syracuse, NY / 13221 / (315) 457-1494

LABORATORIES, INC.

Report

CLIENT: U.S. ARMY CORPS OF ENGINEERS JOB NO: 3068.014.517

DESCRIPTION: Woldrick Aerospace TCLP Extracted Soil Samples

DATE COLLECTED: Unknown DATE REC'D: See Below DATE ANALYZED:

Description	A UWUKDA280-55U 9-6-89	A UWUKDA280-56U 9-6-89	B UWUKDB280-511U 9-6-89	B UWUKDB280-512U 9-6-89	C UWUKDC280-51U 9-6-89	C UWUKDC280-52U 9-6-89	A UWHKDA280-55U 9-7-89	A UWHKDA280-56U 9-7-89	B UWHKDB280-511U 9-7-89	B UWHKDB280-512U 9-7-89	C UWHKDC280-51U 9-7-89	C UWHKDC280-52U 9-7-89
Sample #	J0204	J0205	J0206	J0207	J0208	J0209	J0210	J0211	J0212	J0213	J0214	J0215
TCLP Metals:												
SILVER	<0.02*	-	<0.02*	-	<0.02*	-	<0.02*	-	<0.02*	-	<0.02*	-
ARSENIC	<0.005	-	<0.005	-	<0.005	-	<0.005	-	<0.005	-	<0.005	-
BARIUM	1.0	-	1.1	-	1.1	-	1.0		1.1	-	0.9	-
CADMIUM	37.	-	39.	-	40.	-	35.	-	36.	-	35.	-
CHROMIUM	3.4	-	3.6	-	3.5	-	3.8	-	3.8	-	3.9	-
MERCURY	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
LEAD	0.36	-	0.27	-	0.27	-	0.21	-	0.20	-	0.25	-
SELENIUM	<0.05*	-	<0.05*	-	<0.05*	-	<0.05*	-	<0.05*	-	<0.05*	-

Methodology: Federal Register - 40 CFR, Part 136, October 26, 1984

Units: mg/l (ppm) unless otherwise noted

Comments: * The detection limit has been raised due to the presence of matrix interferences.

Authorized: [signature]

Date: October 4, 1989

OBG Laboratories Inc., an O'Brien & Gere Limited Company
Box 4942 / 1304 Buckley Rd. / Syracuse, NY / 13221 / (315) 457-1494

LABORATORIES, INC.

Laboratory Report

CLIENT U.S. ARMY CORPS OF ENGINEERS **JOB NO** 3068,014,517

DESCRIPTION Waldick Aerospa e - TCLP Extracted Solid Samples

DATE COLLECTED - **DATE REC'D** 9-12-89 **DATE ANALYZED**

Description	A UWHLFA280-5055U Heated	A UWHLFA280-5056U Heated	B UWHLFB280-50511U Heated	B UWHLFB280-50512U Heated	C UWHLFC280-5051U Heated	C UWHLFC280-5052U Heated	A UWULFA280-5055U Unheated	A UWULFA280-5056U Unheated	B UWULFB280-50511U Unheated	B UWULFB280-50512U Unheated	C UWULFC280-5051U Unheated	C UWULFC280-5052U Unheated
Sample #	J0353	J0354	J0355	J0356	J0357	J0358	J0359	J0360	J0361	J0362	J0363	J0364
TCLP Metals:												
SILVER	<0.02*	-	<0.02*	-	<0.02*	-	<0.02*	-	<0.02*	-	<0.02*	-
ARSENIC	<0.05*	-	<0.05*	-	<0.05*	-	<0.05*	-	<0.05*	-	<0.05*	-
BARIUM	1.3	-	1.1	-	1.2	-	1.2	-	1.3	-	1.3	-
CADMIUM	34.	-	33.	-	36.	-	37.	-	35.	-	39.	-
CHROMIUM	3.2	-	3.3	-	3.3	-	2.9	-	3.2	-	3.4	-
MERCURY	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
LEAD	0.20	-	0.16	-	0.23	-	0.15	-	0.17	-	0.19	-
SELENIUM	<0.05*	-	<0.05*	-	<0.05*	-	<0.05*	-	<0.05*	-	<0.05*	-

UNITS: mg/l

Methodology: Federal Register — 40 CFR, Part 136, October 26, 1984

Units: mg/l (ppm) unless otherwise noted

Comments: * The detection limit has been raised due to the presence of matrix interferences.

OBG Laboratories, Inc., an O'Brien & Gere Limited Company
Box 4942 / 1304 Buckley Rd / Syracuse, NY / 13221 / (315) 457-1494

Authorized:

Date: October 4, 1989

LABORATORIES, INC.

Laboratory Report

CLIENT: U.S. ARMY CORPS OF ENGINEERS JOB NO. 3068.014.517

DESCRIPTION: Waldick Aerospace - TCLP Extracted Solid Samples

DATE COLLECTED: - DATE REC'D. 9-21-89 DATE ANALYZED:

Description	A Unheated 0.25 Cement	B Unheated 0.25 Cement	C Unheated 0.25 Cement	A Unheated .15 Lime .15 Fly Ash	B Unheated .15 Lime .15 Fly Ash	C Unheated 0.15 Lime .15 Fly Ash
Sample #	J0867	J0868	J0869	J0873	J0874	J0875
TCLP Metals:						
SILVER	<0.02*	<0.02*	<0.02*	<0.02*	<0.02*	<0.02*
ARSENIC	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*
BARIUM	1.0	0.8	0.9	1.1	1.1	1.1
CADMIUM	2.5	0.68	<0.01	<0.01	<0.01	<0.01
CHROMIUM	0.53	0.57	0.45	0.25	0.24	0.26
MERCURY	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
LEAD	0.09	0.07	0.07	0.09	0.07	0.08
SELENIUM	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*

UNITS: mg/l

Methodology: Federal Register — 40 CFR, Part 136, October 26, 1984

Units: mg/l (ppm) unless otherwise noted

Comments: * The detection limit has been raised due to the presence of matrix interferences.

5

Authorized: Michael N. Petrilli

Date: October 5, 1989

OBG Laboratories, Inc., an O'Brien & Gere Limited Company
Box 4942 / 1304 Buckley Rd / Syracuse, NY / 13221 / (315) 457-1494

APPENDIX C: UNCONFINED COMPRESSIVE STRENGTH DATA FOR NONHEAT-TREATED SOILS

Table C1

UCS Results for Nonheat-Treated Soils

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Cement				
0.05	A	7	51	
	B	7	48	
	C	7	65	54
0.05	A	14	59	
	B	14	63	
	C	15	67	63
0.05	A	21	62	
	B	21	71	
	C	21	72	68
0.05	A	28	70	
	B	28	70	
	C	28	64	68
0.10	A	7	168	
	B	7	145	
	C	7	137	150
0.10	A	14	270	
	B	14	243	
	C	14	276	263
0.10	A	21	329	
	B	21	310	
	C	21	296	311
0.10	A	28	340	
	B	28	318	
	C	28	309	322
0.15	A	7	484	
	B	7	470	
	C	7	479	477
0.15	A	14	572	
	B	14	688	
	C	14	711	657
0.15	A	21	720	
	B	21	729	
	C	21	773	740
0.15	A	28	824	
	B	28	837	
	C	28	816	825

(Continued)

(Sheet 1 of 7)

Table C1 (Continued)

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Cement (Cont.)				
0.20	A	7	916	
	B	7	850	
	C	7	866	877
0.20	A	14	1,085	
	B	14	1,006	
	C	14	1,058	1,049
0.20	A	21	1,147	
	B	21	1,077	
	C	21	*	1,112
0.20	A	28	718	
	B	28	786	
	C	28	630	711
0.25	A	7	640	
	B	7	615	
	C	7	605	620
0.25	A	14	761	
	B	14	697	
	C	14	1,459	972
0.25	A	21	758	
	B	21	788	
	C	21	1,477	1,007
0.25	A	28	620	
	B	28	612	
	C	28	1,354	862
Kiln dust				
0.05	A	7	73	
	B	7	53	
	C	7	56	60
0.05	A	14	89	
	B	14	82	
	C	14	77	82
0.05	A	21	99	
	B	21	91	
	C	21	106	98
0.05	A	28	97	
	B	28	100	
	C	28	90	95

(Continued)

* Denotes reading not available.

(Sheet 2 of 7)

Table C1 (Continued)

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Kiln dust (Cont.)				
0.10	A	7	112	
	B	7	121	
	C	7	109	114
0.10	A	14	142	
	B	14	119	
	C	14	134	131
0.10	A	21	178	
	B	21	172	
	C	21	174	174
0.10	A	28	191	
	B	28	195	
	C	28	200	195
0.15	A	7	212	
	B	7	230	
	C	7	177	206
0.15	A	14	296	
	B	14	335	
	C	14	254	295
0.15	A	21	320	
	B	21	287	
	C	21	293	300
0.15	A	28	350	
	B	28	308	
	C	28	275	311
0.20	A	7	216	
	B	7	218	
	C	7	201	211
0.20	A	14	353	
	B	14	351	
	C	14	299	334
0.20	A	21	382	
	B	21	350	
	C	21	414	427
0.20	A	28	424	
	B	28	416	
	C	28	442	382

(Continued)

(Sheet 3 of 7)

Table C1 (Continued)

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Kiln dust (Cont.)				
0.25	A	7	294	
	B	7	264	
	C	7	261	273
0.25	A	14	459	
	B	14	449	
	C	14	529	479
0.25	A	21	483	
	B	21	474	
	C	21	574	510
0.25	A	28	525	
	B	28	551	
	C	28	590	555
Lime/fly ash				
0.05 0.05	A	7	124	
	B	7	58	
	C	7	57	79
0.05 0.05	A	14	123	
	B	14	103	
	C	14	125	117
0.05 0.05	A	21	125	
	B	21	130	
	C	21	101	118
0.05 0.05	A	28	122	
	B	28	144	
	C	28	132	132
0.05 0.10	A	7	53	
	B	7	62	
	C	7	67	60
0.05 0.10	A	14	135	
	B	14	124	
	C	14	123	127
0.05 0.10	A	21	113	
	B	21	98	
	C	21	131	114
0.05 0.10	A	28	133	
	B	28	119	
	C	28	111	121

(Continued)

(Sheet 4 of 7)

Table C1 (Continued)

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Lime/fly ash (Cont.)				
0.05 0.15	A	7	88	
	B	7	49	
	C	7	46	61
0.05 0.15	A	14	137	
	B	14	137	
	C	14	128	134
0.05 0.15	A	21	129	
	B	21	140	
	C	21	124	131
0.05 0.15	A	28	145	
	B	28	142	
	C	28	133	140
0.10 0.05	A	7	115	
	B	7	132	
	C	7	73	106
0.10 0.05	A	14	157	
	B	14	145	
	C	14	155	152
0.10 0.05	A	21	170	
	B	21	128	
	C	21	140	146
0.10 0.05	A	28	153	
	B	28	132	
	C	28	163	149
0.10 0.10	A	7	133	
	B	7	122	
	C	7	141	132
0.10 0.10	A	14	166	
	B	14	152	
	C	14	161	159
0.10 0.10	A	21	275	
	B	21	161	
	C	21	182	206
0.10 0.10	A	28	159	
	B	28	173	
	C	28	176	169

(Continued)

(Sheet 5 of 7)

Table C1 (Continued)

Binder-to-Soil Ratio		Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Lime/fly ash (Cont.)					
0.10	0.15	A	7	72	
		B	7	89	
		C	7	80	80
0.10	0.15	A	14	170	
		B	14	160	
		C	14	175	168
0.10	0.15	A	21	196	
		B	21	147	
		C	21	178	173
0.10	0.15	A	28	144	
		B	28	135	
		C	28	140	139
0.15	0.05	A	7	139	
		B	7	121	
		C	7	105	121
0.15	0.05	A	14	152	
		B	14	184	
		C	14	148	161
0.15	0.05	A	21	176	
		B	21	155	
		C	21	165	165
0.15	0.05	A	28	152	
		B	28	157	
		C	28	163	157
0.15	0.10	A	7	130	
		B	7	148	
		C	7	147	141
0.15	0.10	A	14	214	
		B	14	216	
		C	14	176	202
0.15	0.10	A	21	228	
		B	21	216	
		C	21	205	216
0.15	0.10	A	28	221	
		B	28	222	
		C	28	262	235

(Continued)

(Sheet 6 of 7)

Table C1 (Continued)

Binder-to-Soil Ratio	Subsample ID	Cure Time days	UCS psi	Average UCS, psi
Lime/fly ash (Cont.)				
0.15 0.15	A	7	171	
	B	7	209	
	C	7	*	190
0.15 0.15	A	14	210	
	B	14	234	
	C	14	216	220
0.15 0.15	A	21	224	
	B	21	224	
	C	21	228	225
0.15 0.15	A	28	229	
	B	28	221	
	C	28	181	210

* Denotes reading not available.

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