FINAL REPORT

System Chemistry To Control Potential Environmental and Safety Hazards of Recycled Concrete Aggregate with Lead-Based Paint

SERDP Project SI-1549

January 2010

Stephen D. Cosper
Construction Engineering Research Laboratory (CERL)/U.S. Army Engineer Research and Development Center

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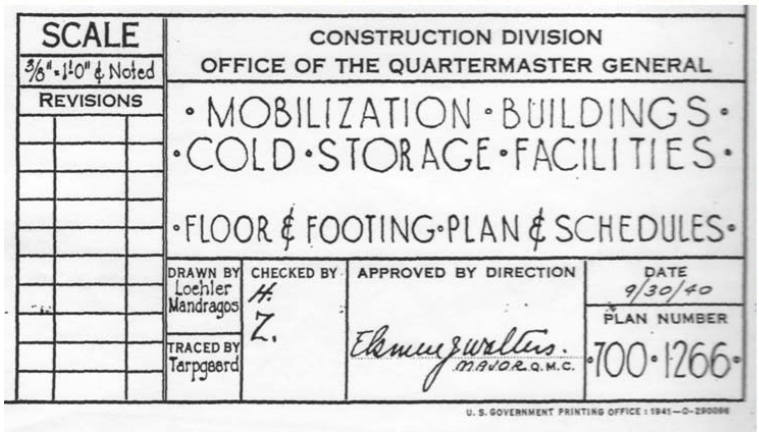

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14. ABSTRACT

The lead (Pb) content of concrete is often a concern to project managers and environmental regulators. Waste reduction policies give an incentive to limit landfilling of demolition debris, but many material recycling scenarios involve some environmental exposure to crushed concrete. This work observed a demolition project to investigate relative Pb concentrations and solubility of Pb in runoff water. Painted walls were sampled before demolition; mass of concrete was calculated; and a projected Pb concentration for total demolition debris was calculated. An extraction experiment was designed to mimic the environmental performance of using crushed concrete as a paving material for parking lots. This experiment showed that, for expected levels of Pb, very little of the heavy metal moved. Levels of Pb in runoff water remained below drinking water standards. Also, after exposure to a simulated 2 years of rainfall, the concrete retained very high alkalinity, which limits the action of acidic rain.

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Abstract: The lead (Pb) content of concrete is often a concern to project managers and environmental regulators. Waste reduction policies give an incentive to limit landfilling of demolition debris, but many material recycling scenarios involve some environmental exposure to crushed concrete. This work observed a demolition project to investigate relative Pb concentrations and solubility of Pb in runoff water. Painted walls were sampled before demolition; mass of concrete was calculated; and a projected Pb concentration for total demolition debris was calculated. An extraction experiment was designed to mimic the environmental performance of using crushed concrete as a paving material for parking lots. This experiment showed that, for expected levels of Pb, very little of the heavy metal moved. Levels of Pb in runoff water remained below drinking water standards. Also, after exposure to a simulated 2 years of rainfall, the concrete retained very high alkalinity, which limits the action of acidic rain.

Executive Summary

The original SERDP Exploratory Development (SEED) statement of need, to which this project responds, sought methods for removal of lead-based paint (LBP) from buildings, before demolition. In fact, this is not typical industry practice. This study performed tests to determine whether the lead (Pb) content of crushed concrete could cause an environmental hazard that would require paint removal before recycling/reuse or landfilling of the concrete waste.

A demolition project at Fort Jackson, SC was selected as a case study to investigate relative concentrations and solubility of Pb in concrete demolition waste. Painted walls were sampled before demolition; the mass of concrete was calculated; and a projected Pb concentration for total demolition debris was calculated. This important baseline first step was taken to address the possibility that it may be possible to show mathematically that the expected Pb concentration value was so low as to cause no environmental concern. This calculated value was about one order of magnitude less than post-crushing field sampling revealed. This was likely due to incomplete initial paint sampling, and an overly conservative assumption of paint thickness.

Next, a column extraction experiment was designed to mimic the environmental performance of using crushed concrete as a paving material for parking lots. This application was tested to address the concern that acidic rainfall might mobilize Pb in the paint residue. This experiment showed that for expected (and much higher) levels of Pb, very little of the heavy metal moved out of the column. The Pb concentration of the simulated rainfall runoff remained below drinking water standards. This experiment also showed that, after exposing the crushed concrete with LBP to a simulated 2 years of rainfall, the concrete retained very high alkalinity thereby limiting the action of acid rain to dissolve and mobilize Pb in the column.

Because the simulated rainfall extraction did not lower the pH of the concrete, a test was designed to determine the concrete's ultimate buffering capacity by measuring the pH after the additions of known quantities of nitric acid. Data from this experiment generated curves that allowed the estimation of the amount of acidic rainfall required to drop the pH of the

concrete matrix to neutral (i.e., pH of 7). Calculations show that this would take many years' of rainfall to cause this pH drop.

These steps were taken to determine the environmental impact of a recycling application of crushed concrete with measurable Pb content. This study recommends follow-on work to identify variation in buffering capacity of concrete of different ages and from different regions; and to determine how this variation affects LBP immobilization.

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Preface

This study was conducted for the Strategic Environmental Research and Development Program (SERDP) Office as a SERDP Exploratory Development (SEED) Project titled, "System Chemistry to Control Potential Environmental and Safety Hazards of Recycled Concrete Aggregate with Lead-Based Paint." The technical monitor was Dr. John Hall, Sustainable Infrastructure Program Manager, SERDP Program Office.

The work was managed and executed by the Environmental Processes Branch (CN-E) of the Environmental Division (CN), Construction Engineering Research Laboratory (CERL). The CERL principal investigator was Stephen Cosper. Appreciation is owed to Mr. Bradley Smith and Dr. Jeffrey Marqusee, former and present SERDP Executive Directors, and to Dr. John Hall, for their technical assistance; and to the HydroGeoLogic, Inc. staff for their administrative assistance. Special thanks are offered to several people who were instrumental in accomplishing this work. Gary Bordson and John Scott, of the Illinois Sustainable Technology Center (ISTC), devised specific laboratory methods to develop the data the author sought. Susan Drozdz (CERL) advised on LBP regulation and formulated sample LBP for use in the laboratory. Richard Lampo (CERL) helped conceive this project and prepare the proposal. Ed McDowell (Fort Jackson DLE) facilitated material sampling at Fort Jackson and described uses for crushed concrete. Thomas Napier (CERL) performed quantity take-offs of the study building and helped formulate the overall project. Giselle Rodriguez (CERL) assisted with sampling. Howard Weinick (Concurrent Technologies Corporation [CTC]) performed and provided sampling data on Pb content of paint on the study building at Fort Jackson. Deborah Curtin is Chief, CEERD-CN-E, and John Bandy is Chief, CEERD-CN. The associated Technical Director was Martin Savoie, CEERD-CV-T. The Director of ERDC-CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Gary E. Johnston, and the Director of ERDC is Dr. Jeffery P. Houston.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	Liters
inches	0.0254	meters
mils	0.0254	millimeters
pounds (mass)	0.45359237	kilograms
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
tons (2000 pounds, mass)	.9071847	tons (metric. 1,000 kg)
tons (2000 pounds, mass)	907.1847	kilograms
tons (2000 pounds, mass) per square foot	9,764.856	kilograms per square meter

1 Introduction

1.1 Background

Within the Army, hundreds of Korean War-era barracks (at approximately 90,000 sq ft each) and associated concrete-masonry buildings, which contain lead-based paint (LBP), are being replaced with modern barracks complexes. Although these older barracks represent some of the most common current demolition projects, the problem of LBP in concrete-masonry buildings is not unique to the Army. Throughout the U.S. Department of Defense (DOD), many such constructed before the 1970s contain LBP.

Some Army installations report that construction and demolition debris (C&D) constitutes 80 percent of their solid waste stream. Of this amount, about 63 percent is estimated to be concrete materials (Cosper 2004). The past few years have seen a growing trend to reduce C&D waste by reusing or recycling of the materials made available by the demolition of excess buildings. The presence of LBP in this waste, however, can present a real barrier to the reuse for some of these building materials. If the standard leaching test (i.e., the toxicity characteristic leaching procedure [TCLP]) results on the material are 5 mg/kg or more, the material is classified as a Resource Conservation and Recovery Act (RCRA) "hazardous waste upon disposal." Dealing with such hazardous waste is problematic. Tipping fees for hazardous waste such as LBP-containing C&D debris are usually many times that of nonhazardous C&D wastes. Also, the large volume represented by C&D concrete waste can significantly reduce the life of the landfill, a further cause for concern. Furthermore, if landfilled, an otherwise recoverable and useful resource may be needlessly buried.

The Strategic Environmental Research and Development Program (SERDP) solicited proposals for the development of environmentally friendly methods and techniques used in the deconstruction (demolition) of masonry buildings and other permanent (concrete) structures on military installations that are contaminated with lead-based paints (LBP). The SERDP Exploratory Development (SEED) Statement of Need (SON)* indicated that LBP-containing concrete waste is commonly landfilled as a haz-

* SISEED-07-01, *Environmentally Friendly Deconstruction Techniques for Buildings and Other Permanent Structures Containing Lead-Based Paint* (2005).

ardous waste. Actually, this is not typical practice since the chemistry of the concrete will usually buffer the TCLP test so it would not be classified as a hazardous waste. Acidification of soil does change the chemistry and mobility of heavy metals. However, the degree of mobility varies by specie, e.g., cobalt, zinc, cadmium, nickel are more mobile in an acid environment. Lead is particularly immobile and tends to accumulate in organic materials (Kennedy 1992).

Moreover, the mass of the concrete in the demolition waste is much larger that the mass of the LBP since the Pb concentration in the bulk demolition material is usually very low. Nevertheless, there are concerns about the disposal of LBP-containing concrete aggregate in a landfill or reuse such as in a road base. A guidance put out by the Wisconsin Department of Natural Resources, for example, advises the use of caution when reusing concrete containing LBP (WDNR 2004). Still, recent preliminary tests indicate that Pb will not leach from concrete road gravel even when directly exposed to the elements. There is a need to determine all of the elements of the Pb-concrete chemical system and the interactions that may affect the migration of the Pb into the environment.

1.2 Objectives

The objective of this work was to determine the mobility of residual Pb content in crushed demolition concrete in the environment when exposed to rainfall.

1.3 Approach

This study was accomplished in four steps:

1. The Pb concentration in recycled concrete aggregate (RCA) was estimated based on paint sampling and construction quantity take-offs, pre-demolition.
2. These figures were compared to RCA samples taken, post-demolition and crushing.
3. A laboratory experiment was designed to model Pb leaching from RCA as commonly applied to the landscape.
4. The ultimate acid rain buffering capacity of RCA was determined.

1.4 Scope

This study involved the characterization, demolition, crushing, and reuse of concrete from one building at Fort Jackson, SC. This work did not assume that the composition of this building was typical of Army buildings. Any further work should analyze concrete from different regions and of varying ages, and the behavior of LBP on masonry.

This work focused on an in-depth examination of the properties of concrete; it did not address other, similar, demolition materials, such as masonry since concrete is a much larger portion of the demolition waste stream than masonry, and it has a much higher potential for reuse.

This study did not address phosphate-based buffering chemistry because this is currently done commercially.

1.5 Mode of technology transfer

This report will be made accessible through the World Wide Web (WWW) at URL:

http://www.cecer.army.mil

2 Project Model

The Army has been making efforts to reuse and recycle waste from Army demolition and construction projects for many years. In 2006 and 2007, the Army Construction Engineering Laboratory (CERL) worked with the Army Environmental Center (AEC, now the Army Environmental Command) and Concurrent Technologies Corporation (CTC) to document some C&D waste diversion measures at Fort Jackson in Columbia, SC. In one case, the Fort Jackson Directorate of Logistics and Engineering (DLE) planned to demolish a large concrete cold storage building (CSB) (a heavy, reinforced building of 19,750 sq ft), and to then crush the resultant debris for reuse on the installation, mainly as basic paving material. The native, clayey soil is prone to erosion and is difficult for vehicles to traverse when wet; there is a recurring need for paving. The main product produced was "3 in. minus" for paving.* Experience shows this to be a common, economical, realistic way to reuse concrete, especially on a government installation. This process eliminates the costs to haul and dispose of the waste materials off-site, and precludes the purchase of virgin materials.

Most old concrete buildings will have at least some LBP present that becomes incorporated into the RCA matrix upon recycling. In industry, the presence of Pb is usually ignored, for it is generally understood that the Pb concentration is very low when diluted by the huge mass of concrete. In some cases, where the RCA will be employed in a sensitive area, or when the overall project has a high profile, Pb contamination is more closely scrutinized. (The concern is that Pb from the paint will dissolve in acidic rainfall and migrate into the environment.) This study was undertaken to test whether this actually happens, through a variety methods.

Because the disposition of the CSB is representative, this SEED project used the following experience as a case study:

- The total Pb concentration of the RCA was predicted through paint sampling data.
- The total Pb concentration of the RCA was measure directly.

* The term "3 in. minus" is a common industry term referring to material with a maximum diameter of 3 in. Other similar products produced from the concrete include "3 in." for railroad ballast; and "6 in. plus" for erosion control projects.

- In the laboratory, representative columns of RCA weree subjected to synthetic rainwater to quantify leaching.
- The buffering capacity of the RCA was measured.

Figures 1 through 10 show the events described, above. Figure 1 shows the title block from one of the original contraction drawings for the CSB. Until the vast acceleration of activity leading up to World War II, the Army Quartermaster was in charge of military design and construction. That responsibility then shifted to U.S. Army Corps of Engineers (USACE). Figures 2 and 3 show the CSB before demolition. Figure 4 shows an image from a short movie of the building demolition, taken by AEC staff. Figures 5 and 6 show large pieces of concrete and reinforcing steel that result from demolition. Figure 6 shows a closeup of a typical painted surface. As the concrete goes through the crushed, some paint is knocked off the surface and ends up the fines. Figure 7 shows the portable concrete crushing plant that Fort Jackson DLE contracted to crush the material from the CSB, and other debris. Figure 8 shows Mr. Ed McDowell of the Fort Jackson DLE next to the stockpile of RCA from the CSB. Figure 9 and 10 show the RCA deployed as paving material for a parking lot. The depth of RCA is roughly 6 in. Note that the clay soil surface would tend to limit contaminate migration. Excess rainwater would tend to flow horizontally, rather than percolate into the soil. This study will show if any Pb from the RCA will migrate with the runoff.

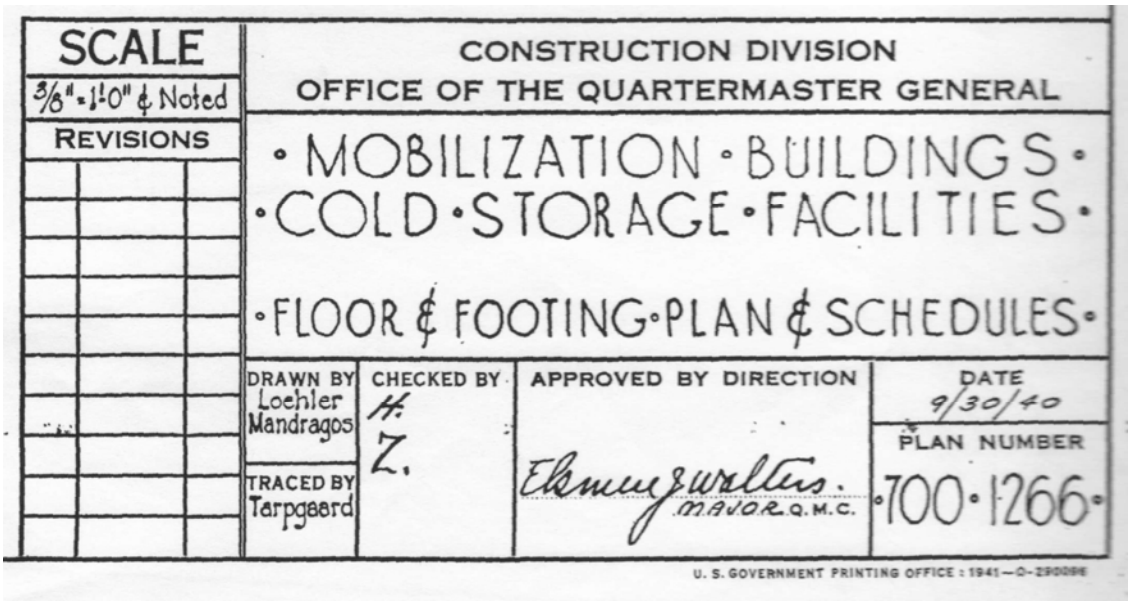

Figure 1. CSB drawing title block.

Figure 2. Exterior, Fort Jackson CSB.

Figure 3. Interior of the Fort Jackson CSB, before demolition.

Figure 4. Mechanical demolition of the Fort Jackson CSB.

Figure 5. Concrete demolition debris from the CSB stockpiled at Fort Jackson.

Figure 6. Closeup of concrete debris with adhered paint.

Figure 7. Concrete crushing operation at Fort Jackson

Figure 8. Crushed concrete stockpile.

Figure 9. Crushed concrete as paving material at Fort Jackson.

Figure 10. Closeup of paving material.

3 Pre-Demolition Prediction of Pb Concentration

3.1 General

The first method used to estimate impact of RCA with LBP on the environment is to: (1) calculate the mass of Pb in the building, (2) calculate the mass of concrete, and (3) then divide the mass of Pb by the mass of concrete to get the concentration. This simple method would be useful to project planners since it can be done to predict Pb concentrations, and to anticipate potential problems well before demolition work begins.

3.2 Pre-demolition paint sampling

Total Pb analysis is a straightforward analytical procedure, routinely conducted by commercial environmental laboratories. CTC, working in conjunction with CERL and AEC, sampled the painted wall surfaces of the CSB before demolition (Table 1 and Figure 11). The paint was scraped off of the concrete wall surfaces by hand. The samples were analyzed by Severn Trent Laboratories in Tampa, FL using EPA Method 6010B for total Pb concentration, inductively coupled plasma – atomic emission spectrometry. This method has since been updated to 6010C (USEPA 2007).

Table 1. Pre-demolition paint sampling.

Description	Total Pb Concentration (mg/kg)
Exterior wall, white paint	62,000
Exterior door	36,000
Exterior door	340
Exterior wall, white paint	68,000
Exterior wall, white paint	46,000
Exterior wall, brown paint	50,000
Interior wall, white paint	4.7
Exterior wall, white paint	68,000
Interior wall, green/gray paint	2,800
Interior wall, mint green paint	1,800
Exterior wall, white paint	49,000
Exterior wall, brown paint	15,00
Exterior wall, white paint	54,000
Average interior concentration	1,535
Average exterior concentration	48,149

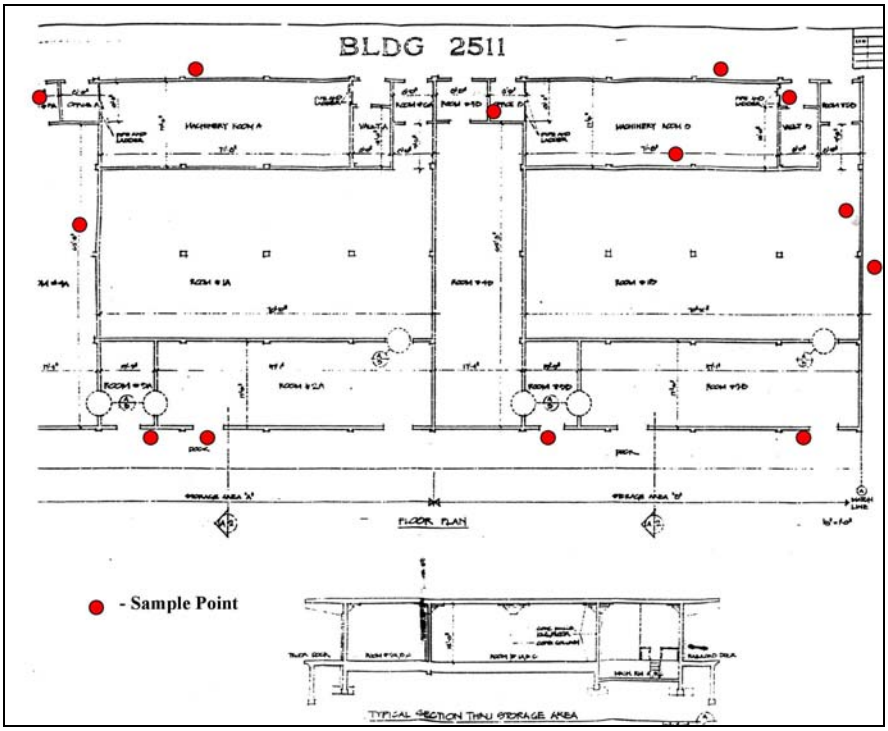

Figure 11. CSB floor plan with sampling points.

3.3 Calculation of concrete mass

CERL researchers calculated the quantity of concrete and reinforcing steel in the CSB at Fort Jackson. This was done through inspection of the building (pre-demolition), and study of construction drawings. This data were combined in a detailed reverse quantity take-off, i.e., calculating the inventory of construction materials in an existing building. Tables A-17–A-25 (pp 54–58) list the detailed calculations. Table 2 lists a summary of these calculations. The total mass of concrete in the CSB was 3700 metric tons.

The next step was to calculate the painted surface area, and then to use that figure to calculate the amount of LBP in the building. Details of this calculation, based on construction drawings, are listed in Table A-26 (p 58), and are summarized in Table 3.

Table 2. Summary of concrete volume calculations.

Bldg Section	Concrete Volume (cu ft)
Footings	3,182
Pedestals	104
Piers	496
Beams	1,322
Foundation walls	8,595
Floor deck	14,059
Interior walls	5,566
Exterior walls	5,505
Roof structure	15,614
Total volume	54,443
Total weight (pounds) at 150 pounds/cu ft	8,166,429
Mass (g)	3.7+9
Mass (metric tons)	3.7E+3

Table 3. Summary of surface area calculation.

Area	Area (sq ft)	Area (m^2)
Painted interior surface	49,117	4,565
Painted exterior surface	12,732	1,183
Total painted surface	61,849	5,748

3.4 Results

By combining all the information above, one can perform a series of conversions to arrive at a Pb concentration figure, as an average throughout the entire building (Table 4):

- Take a representative sampling from painted surfaces, pre-demolition (Table 1).
- Calculate mass of concrete in the building (Table 2).
- Calculate painted surface area.
- Convert painted area to mass of paint, using a known conversion factor. In this case, a conservative paint thickness of 10 mils was assumed, based on age of the building, and likely paint applications. Unfortunately, paint thickness was not recorded at the time of initial sampling. Ten mils paint thickness is equivalent to 380 g/m^2.
- Find the mass of Pb by multiplying the mass of paint by sampled Pb concentration.
- Divide the mass of Pb by the mass of concrete to arrive at concentration of Pb in concrete, i.e., expected concentration of Pb in concrete demolition debris.

Table 4. Prediction of Pb concentration based on pre-demolition sampling.

Area	Interior	Exterior	Whole Bldg
Painted area (m^2)	4,565	1,183	5,748
Mass paint per surface area, assuming 10 mils (g/m^2)	380	380	380
Mass paint (g)	1,733,559	449,244	2,182,803
Average Pb conc in paint (mg/kg)	1,535	48,149	
Mass Pb in paint (g)	2,661	21,631	24,292
Mass concrete (g)			3.70E+09
Concentration Pb in concrete (mg/kg)			6.57

This process requires a number of steps, but is worthwhile to perform, before demolition begins, to ensure that the ending Pb concentration will be reasonable for the anticipated end application of crushed concrete. In this case, the calculated Pb concentration in concrete demolition debris from the Fort Jackson CSB was expected to be 6.57 mg/kg.

4 Material Characterization

4.1 General

Three tests were done to characterize the crushed concrete at Fort Jackson. CERL researchers took about 20 samples of the crushed concrete product from around the stockpile at Fort Jackson (Figure 8). Each sample of a few kilograms was placed in a plastic "zip-lock" bag.

4.2 Total Pb in crushed concrete

Fourteen crushed concrete were submitted to the Waste Management and Research Center (WMRC) at the University of Illinois for total Pb analysis.* The remaining sample material was held in reserve for other analyses.

Data were obtained by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) using bismuth as an internal standard. Portions of each sample were digested before analysis, using a total microwave digestion procedure in which nitric acid, hydrogen peroxide, and hydrofluoric acid were used. This modified microwave digestion procedure is equivalent to EPA Method 3052. This very aggressive method ensures that *total* Pb is extracted from the concrete matrix.

Table 5 lists the results of the total Pb analysis. The average value is 78.5 mg/kg, with a standard deviation of 28.6. While the Pb concentration on painted walls can vary widely, it was expected that the Pb concentration throughout the crushed concrete stockpile would be relatively homogeneous due to dilution and mixing through the demolition and crushing process.

There are two values for sample FJ-14 because the analysis was done on two aliquots from a large composite sample.

These numbers are roughly 10 times higher than the predicted pre-demolition values, above. This is likely due to inadequate initial paint sampling, and a low assumption for paint thickness.

* Note that this group is now known as the Illinois Sustainable Technology Center (ISTC), http://istc.illinois.edu

Table 5. Total Pb in RCA, analytical results.

Sample ID	Total Pb Concentration (mg/kg)
FJ-1	53
FJ-2	84
FJ-3	110
FJ-4	85
FJ-5	67
FJ-6	88
FJ-7	120
FJ-8	110
FJ-9	120
FJ-10	39
FJ-11	51
FJ-12	63
FJ-13	44
FJ-14	47
FJ-14 (duplicate)	96

Quality control measures associated with this analysis included digestion blanks, digestion duplicates, analytical duplicates, matrix spikes, analytical spikes, and a Coal Fly Ash standard reference material traceable to the National Institute of Standards and Technology. The duplicates yielded relative percent differences ranging from of 1 to 12 percent. The spikes yielded recoveries that ranged from 89 to 112 percent, and the standard reference material (SRM) recovered at 92 and at 95 percent. Based on results of the quality control parameters, it is estimated that the reported results for Pb have a maximum uncertainty of no more than $\pm$ 15 percent.

4.3 SPLP leaching of crushed concrete

Three sub-samples were subjected to the synthetic precipitation leaching procedure (SPLP), conducted per EPA Method 1312 (USEPA 1994b). The pH of the extraction fluid used was 4.2 $\pm$0.05.

A major limitation of using Method 1310 and 1311 (TCLP and related, respectively) for this purpose is the fact that the sanitary landfill co-disposal scenario does not apply to contaminated soils (USEPA 1989). If these methods are used to assess sites for cleanup purposes, the acetic acid leaching fluid could selectively dissolve toxicants (specifically Pb) and incorrectly classify the solid as hazardous (via the toxicity characteristic) when, in fact, no mobilization (leaching) would be expected to occur in the environment. The dilute nitric acid/sulfuric acid mixture used simulates

the nature of the precipitation occurring in the region where the soil sample originated.

Method 1312 is designed to simulate acid rain leaching of a waste (not associated with a landfill situation); and to determine the mobility of both organic and inorganic analytes present in liquids, soils, and wastes. It is commonly used for leaching studies of mine wastes (Hageman 2007). For samples containing greater than 0.5 percent solids, the liquid phase, if any, is separated from the solid phase and stored for later analysis; the particle size of the solid phase is reduced, if necessary. The solid phase is extracted with an amount of extraction fluid equal to 20 times the weight of the solid phase. The extraction fluid employed is a function of the region of the country where the sample site is located if the sample is a soil. If the sample is a waste or wastewater, the extraction fluid employed is a pH 4.2 solution. Following extraction, the liquid extract is separated from the solid phase by filtration through a 0.6 to 0.8 μm glass fiber filter.

The only deviation from this method noted was that 1000 ml of extraction fluid was used instead of 2000 ml due to size limitations of the mechanical tumbler.

Table 6 lists the Pb concentration and pH results for the SPLP extracts. The relatively large standard deviation observed with the Pb results is most likely due to the heterogeneity of the sample. The sample duplicate completed in the Pb analysis produced a relative percent difference of 1 percent and the analytical spike sample produced a recovery of 96 percent. Based on the quality control associated with the analysis, the uncertainty of the results is ±5 percent.

Table 6. Synthetic precipitation leaching procedure data for RCA with LBP.

Sample #	pH of Leachate	Pb Concentration of Leachate (mg/L)
1	11.83	0.0011
2	11.65	0.0094
3	11.71	0.00070
Average	11.72	0.0037
Std Dev	—	0.0049

5 Column Leaching Experiment

5.1 General

The next most complex method for estimating the impact of Pb in concrete was to conduct a leaching experiment, which was designed to mimic the application of crushed concrete for parking lots at Fort Jackson. CERL researchers and ISTC staff developed a column leaching procedure in which the main variable was the concentration of Pb in the crushed concrete column. The depth of concrete, pH of extraction fluid, and volume of extraction fluid were all held constant. Since the objective of the experiment was to duplicate, as closely as possible, the physical situation at Fort Jackson, rainfall quantity and pH for Columbia, SC first had to be determined.

5.2 Columbia rain data

A review of data from National Oceanic and Atmospheric Administration (NOAA) shows that Columbia, SC has a consistent monthly rainfall total of 4 in. Figure 12 shows an NOAA map of annual average rainfall depth across the United States. Table 7 lists average precipitation data for Columbia, SC between the years of 1955 and 1999 (NCDC 2003). Table A-16 (p 53) lists precipitation data in more detail.

The USGS participates in the National Atmospheric Deposition Program (NADP), which monitors wet atmospheric deposition at approximately 300 locations throughout the United States (USGS 2009). One of the monitoring stations is in the Santee National Wildlife Refuge; approximately 60 mi southeast of Fort Jackson. A review of the pH data from this station showed that pH oscillates between 4 and 5 (Figure 13). Table 8, which lists pH statistics for this site for the year 2006 (USGS 2007), shows an average pH of 4.60, and a minimum pH of 4.15.

After reviewing this rainfall pH data, it was decided to used extraction fluid at pH 4.2, to remain consistent with the SPLP work described above. While 4.2 is slightly lower than the apparent average for this area, this is a more conservative approach for the purpose of this experiment, because it is more likely to dissolve Pb from the concrete matrix.

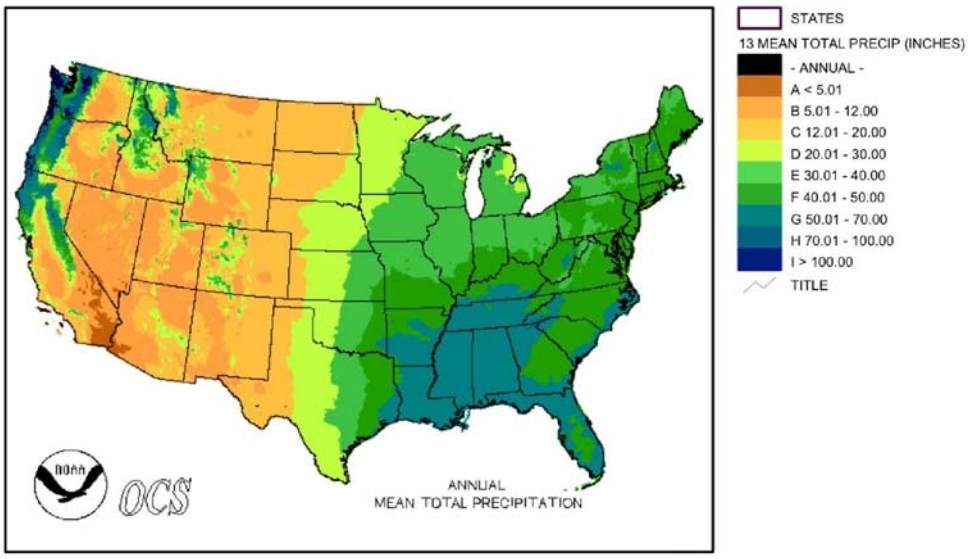

Figure 12. U.S. rainfall map.

Table 7. Summary precipitation data, 1955 to 1999, Columbia, SC.

Item Description	Monthly Avg.	Annual
Precipitation total (in)	4.0	47.5
Average storm duration (hr)	—	9.8
Number of storm events	5.3	63.1
Average storm depth (in)	—	0.7
Average intensity (in/hr)	—	0.1
Maximum hourly rainfall rate (in/hr)	—	0.6
Maximum storm depth (in)	—	1.6
Duration of item max storm (hr)	—	17.5
Number of wet days	6.0	71.7

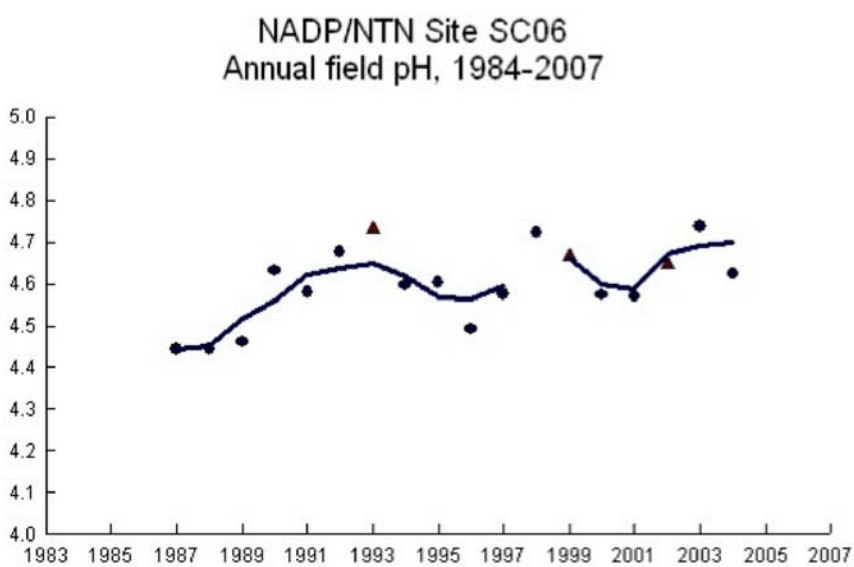

Figure 13. Annual rainfall pH averages, near Fort Jackson, SC.

Table 8. Precipitation pH statistics for 2006, near Fort Jackson, SC.

Time Period	pH
Winter	4.70
Spring	4.61
Summer	4.52
Fall	4.84
Weekly minimum	4.15
Weekly maximum	5.19
Weekly arithmetic mean	4.60

5.3 LBP for spike

New LBP was used to spike the crushed concrete in the experimental columns. In previous work, CERL researchers created approximately one quart of LBP, following an old Federal Specification, TT-P-104B Paint (White Lead and Oil, Exterior, Ready Mixed, White and Light Tints). This specification (was revoked in 1972) or one very similar was used in military construction throughout the decades, from which, demolition debris is now generated. Table 9 lists the ingredients.

ISTC also measured the Pb content of the spike LBP directly. To achieve sample homogeneity, the paint container was tumbled end-over-end for 30 minutes and stirred for 5 minutes with a glass-stirring rod. A nitric acid microwave (Milestone, Model Ethos, Monroe, CT) digestion procedure, equivalent to EPA Method 3051, was followed to dissolve paint samples into solution for lead analysis. The paint sample was digested in triplicate. Paint digestion samples were analyzed with an Atomic Absorption Spectrometer (Varian, Model SpectrAA 55B, Walnut Creek, CA) at a wavelength of 217 nm. Lead concentrations of the SPLP extracts and the concrete column extracts were measured with an Inductively Coupled Plasma Mass Spectrometer (VG Elemental, PQ ExCell, Franklin, MA). Measurement of pH was done with an pH electrode and meter (Beckman, Model Φ32, Fullerton, CA). The sample duplicate produced a relative percent difference of 2 percent and the analytical spike sample recovered of 92 percent. Based on the associated quality control data, the uncertainty in the paint sample results is ±10 percent.

The average concentration of Pb in the paint to be used in the lab leaching experiments is 46 percent (Table 10). Percent wet weight was reported because wet paint was to be added to the material in the leaching columns. The weight of wet paint was recorded, and was used to calculate the overall concentration of Pb in the columns.

Table 9. Old Federal LBP recipe.

Ingredient	gal	lb	wet weight %
Basic carbonate white lead	0.26	14.20	72%
Refined linseed oil	0.21	1.63	8%
Raw linseed oil	0.21	1.63	8%
Bodied linseed oil	0.10	0.81	4%
Mineral spirits (volatile)	0.22	1.43	7%
Total nonvolatile	0.78	18.27	93%
Total paint	1.00	19.70	

Table 10. Analytical total Pb content of LBP to be used in leaching experiment.

Sample #	Pb Concentration (Wet Weight %)
1	46
2	48
3	44
Average	46
Std Dev	1.9

5.4 Column setup

A series of columns were set up to represent water leaching through crushed concrete applied as a parking lot. Material to a depth of 6-in. was placed in soil core tubes of $1^7/_8$-in. diameter. Approximately 500 g of material provided 6 in. of depth. As listed in Table 7, the long term, average rainfall at the site is 4 in. per month. In this setup, about 180 ml introduced to the column is equivalent to 1 month of rainfall.

The goal of this experiment was to subject columns of crushed concrete to 2 years of simulated rainfall, and to note the changes in pH of the extraction fluid and concentration of Pb over time. One aliquot or fraction was collected for each month. The experiment sought to answer these questions:

- Does the pH of the rainwater/surface water decrease over time? How fast? How much rainfall/time must pass before the rain (pH = 4.2) neutralizes the alkalinity of the crushed concrete?
- How much Pb leaves the concrete matrix? How does the concentration of Pb in the concrete affect the Pb in the effluent?

A total of 13 columns were prepared (Table 11). Two of these contained glass beads of about 5 mm diameter, with the purpose of eliminating the

buffering capacity of the concrete. The glass beads were washed in an acid solution, then rinsed before loading into the column to eliminate any contamination or coatings. Four columns contain the crushed concrete from the CSB only. No LBP was added, but they did contain some Pb from the original building (Table 5, p 16).

Seven columns contained crushed concrete plus added LBP (see section 5.3) in amounts ranging from100 mg to 100 g. The desire mass of LBP was weighed out onto aluminum foil, then rinsed onto a tray containing crushed concrete, using acetone (Figure 17). This was mixed, allowed to dry, then loaded into the column. This gives a range in Pb concentration from 80 to 110,000 mg/kg.

The values in Table 11 are:

- Col ID = description
- Mass material = mass of crushed concrete (or glass beads) added to the column
- Mass Pb in matrix = mass of concrete multiplied by 79 mg/kg Pb (Table 5, p 16)
- Mass LBP added = mass of LBP mixed in with the crushed concrete
- Mass Pb in column = mass of Pb contributed from residue in the concrete, and from the LBP
- Pb conc. in column = total Pb mass over mass of concrete.

Concrete spike columns were mixed with a known mass paint and treated in the same manner as sample columns. Extraction fluid identical in composition to the SPLP extraction was passed through the concrete spike column at a rate of 5 ml/min. Effluent fractions were collected from the column and analyzed for Pb and pH. Initially, all of the effluent was collected in beakers (Figure 18). For most of the columns, only the first 50 ml of effluent for each “month” was collected in Falcon tubes (Figure 19), with the remaining 130 ml collected in a waste beaker and discarded.

Pb concentrations of the concrete column extracts were measured with an Inductively Coupled Plasma Mass Spectrometer (VG Elemental, PQ Ex-Cell, Franklin, MA) (Figure 20). Measurement of pH was done with a pH electrode and meter (Beckman, Model Φ32, Fullerton, CA).

Figures 14 through 20 show this column extraction set up.

Table 11. Column descriptions.

Col ID	Mass material (g)	Mass Pb in Matrix (g)	Mass LBP Added (g)	Mass Pb in Column (g)	Pb Concentrate in Column (mg/kg)
Glass blank	500	0.000	0	0.000	0
Glass spike	500	0.000	1	0.460	920
Concrete blank 1	500	0.040	0	0.040	79
Concentrate blank 2	420	0.033	0	0.033	79
Concentrate blank 3	580	0.046	0	0.046	79
Concentrate blank 4	440	0.035	0	0.035	79
Concentrate spike 1	420	0.033	20	9.233	21,984
Concentrate spike 2	440	0.035	0.1	0.081	184
Concentrate spike 3	400	0.032	1	0.492	1,229
Concentrate spike 4	440	0.035	1	0.495	1,124
Concentrate spike 5	460	0.036	4	1.876	4,079
Concentrate spike 6	420	0.033	20	9.233	21,984
Concentrate spike 7	420	0.033	100	46.033	109,603

Figure 14. Packing leaching column with a base of glass wool to retain solids.

Figure 15. Loading leaching column with crushed concrete.

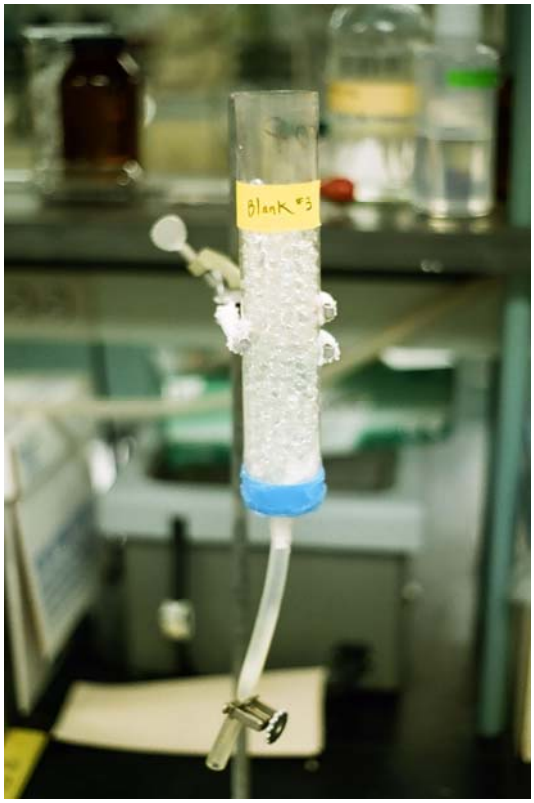

Figure 16. Glass beads in column, used as control for leaching experiment.

Figure 17. Applying LBP spike to a sample of RCA.

Figure 18. Bench with mounted columns and beakers for aliquot collection.

Figure 19. Bench with Falcon tubes for aliquot collection.

Figure 20. Inductively coupled plasma mass spectrometer with autosampler, used for total Pb analysis of column leachate.

5.5 Results

Tables A-1 through A-13 (pp 40–29) list the main Pb and pH results for spike column extracts. Sample duplicates produced relative percent differences ranging from 0 to 5 percent and analytical spike samples had recoveries that ranged from 95 to 109 percent. Based on the associated quality control data, the uncertainty of the Pb results is ±10 percent.

Table 12 lists the results from the column leaching trials. It shows the mass of Pb leached out of each column, over the course of the "2-year" equivalent trial; and the percent of mass leached out. The relative percentage of Pb leaving each of the crushed concrete columns is fairly consistent. A small amount of Pb leached from the glass beads (8µg). This may be due to Pb contamination in the glass. The table also shows the change in Pb concentration in the columns. Finally, Table 12 lists the pH of the leachate at the beginning and end of each column trial, after adding a total of 4.3 L of synthetic rain at pH 4.2. For all of the columns containing crushed concrete, the leachate pH started and stayed near 11. The glass blank contained no added LBP. The leachate pH decreased from 6.8 to 5.0; is would likely have eventually approached 4.2. The glass spike contained 1 g of LBP. The starting leachate pH was 10.2, indicating that the carbonate in the paint has some capacity to neutralize incoming acidity.

Table 12. Data summary from column leaching.

Col ID	Starting Pb Concentration In Column (Mg/Kg)	Concentration Reduction (Mg/Kg)	Mass Pb Leached Out (Mg)	% Mass Pb Leached Out	Starting Leachate Ph	Ending Leachate Ph
Glass blank	0	0.02	0.0082	—	6.82	5.04
Glass spike	920	12.58	6.2895	1.367%	10.15	4.52
Concrete blank 1	79	0.01	0.0061	0.015%	11.41	9.20
Concrete blank 2	79	0.00	0.0008	0.002%	11.58	11.65
Concrete blank 3	79	0.06	0.0371	0.081%	11.30	11.34
Concrete blank 4	79	0.04	0.0155	0.044%	11.09	11.24
Concrete spike 1	21,984	0.88	0.3679	0.004%	10.86	11.11
Concrete spike 2	184	0.05	0.0223	0.028%	11.37	11.31
Concrete spike 3	1,229	0.89	0.3577	0.073%	11.53	11.19
Concrete spike 4	1,124	1.39	0.6096	0.123%	11.38	11.14
Concrete spike 5	4,079	2.64	1.2134	0.065%	11.60	11.27
Concrete spike 6	21,984	3.32	1.3954	0.015%	11.50	11.20
Concrete spike 7	109,603	33.96	14.2630	0.031%	10.75	10.78

6 Concrete Buffering Capacity

6.1 General

Soil samples must be mixed with some amount of distilled water (or other solution) so that the pH can be measured with a standard electronic pH meter. A soil-to-water ratio (mass) of 1:1 or 1:2 are most commonly used because this most closely reflects natural soil conditions (Tan 1996).

In agricultural soil science, the most common concern regarding soil pH occurs when the soil is too acidic for optimum plant growth, such that lime must be added to increase pH to near neutral. This "lime requirement" is presented in terms of pounds of lime to add per acre to achieve the desired pH rise. In the case of the crushed concrete, by contrast, the initial pH of any extract is very high. Consequently, it is desirable to measure the amount of acid necessary to *lower* pH to a "normal" soil range—essentially the inverse of a lime requirement. The procedure is to measure the pH of a known mass of sample, add a known quantity of acid, measure the pH, and then repeat the procedure using different quantities of acid. The resultant set of values can be manipulated into a graph of acid addition (H+) vs. pH. This allows the prediction of the amount of time, number of rainfall events, or total acidic rainfall accumulation that would be required to reduce the pH of the RCA matrix.

6.2 Method

Buffering capacity data associated with that listed in Table 13 was generated by adding ~10 grams of concrete material to deionized water (Labconco, 18 MΩ) and an initial pH measurement was taken (Figure 21). Then a known volume of 10 percent (v/v) nitric acid was added to the mixture and pH measurements were taken immediately and 24 hrs later. The buffering capacity results (Table 14) were obtained by adding a known volume of 5 percent nitric acid to 10 grams of concrete in deionized water and pH measurements were taken again immediately and 24 hrs later.

Data inTable 15 were obtained by adding 1.0 ml of 10 percent nitric acid stepwise to 100 g of concrete in deionized water, and by measuring pH at each interval. After an addition of 25 ml was reached, the sample was allowed to stand overnight for 24 hrs and the procedure was repeated until a total of 10 ml 10 percent nitric was added in addition to the 25 ml earlier.

Table 13. Buffering capacity data for 10 g concrete sample with 10 percent nitric acid.

Sample #	pH Initial	ml 10% Nitric Acid	pH After Acid	pH After 24 hrs
1	10.49	0.00	10.59	10.81
2	10.69	0.25	6.18	10.76
3	10.62	0.50	5.82	9.93
4	10.61	1.0	5.08	8.86
5	10.69	2.0	3.27	7.99
6	10.82	5.0	2.49	4.01
7	10.76	10	1.09	2.88

Table 14. Buffering capacity data for 10 g concrete sample with 5 percent nitric acid.

Sample #	ml 5% Nitric Acid	pH After Acid	pH After 24 hrs
1	0.00	11.12	11.40
2	0.20	10.27	11.37
3	0.40	9.26	11.27
4	0.60	6.82	11.25
5	0.80	5.55	10.74
6	1.0	5.98	11.00
7	2.0	4.29	11.09
8	3.0	5.26	10.55
9	4.0	4.05	10.60
10	5.0	3.48	10.09
11	6.0	2.44	6.65
12	7.0	3.19	6.31
13	8.0	2.62	5.05
14	9.0	2.71	5.69
15	10	2.74	6.14
16	12	2.19	4.12
17	14	1.64	3.39
18	16	1.50	3.37
19	18	1.30	2.59
20	20	1.95	3.47

Table 15. Buffering capacity of 100 g concrete samples with 10 percent nitric acid.

ml 10% Nitric Acid	pH After Acid
0.0	11.04
1.0	8.03
2.0	6.24
3.0	6.00
4.0	5.74
5.0	5.79
6.0	5.28
7.0	5.63
8.0	5.12
9.0	5.70
10	4.82
11	4.58
12	4.02
13	4.00
14	3.84
15	3.85
16	3.83
17	3.50
18	3.48
19	3.48
20	3.14
21	2.97
22	2.85
23	2.74
24	2.90
25	2.71
Wait 24 Hrs	
0.0	4.38
1.0	3.71
2.0	3.47
3.0	2.92
4.0	2.78
5.0	2.65
6.0	2.53
7.0	2.32
8.0	2.30
9.0	2.11
10	1.98

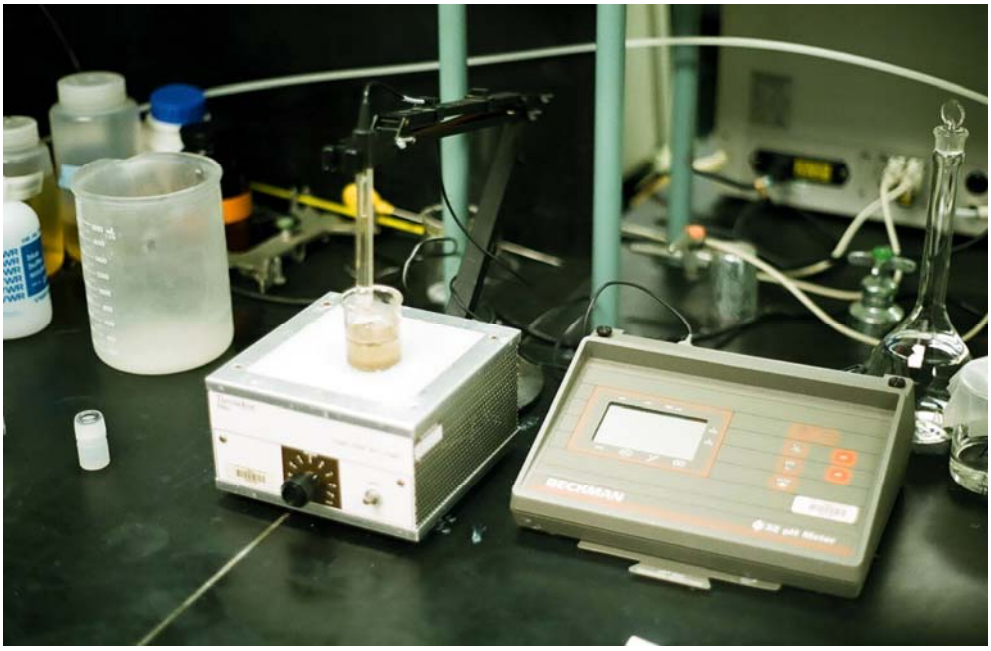

Figure 21. Measuring pH.

6.3 Results

The acid buffering capacity of the crushed concrete under study must be determined to be able to predict how much acidic rainfall must impact a parking lot deployment of this material before this buffering capacity is diminished. The common factor one can employ to measure acidity (i.e., to account for acid solution strength) is moles of hydrogen ions, whether in nitric acid in the lab, or in natural rainfall. Therefore, the acid quantity data presented in previous section was converted to charts showing moles of H^+ (per mass of concrete) vs. pH achieved.

Figure 22 uses the data in Table 13 as a first, coarse demonstration of this technique. For the data in Figure 23, a lower strength nitric acid was used, with smaller intervals. The curves are comparable because the x-axis data (acidity added) was normalized to moles of H^+ per gram of concrete sample. In both cases, a 10 g sample of crushed concrete was placed in a beaker with distilled water, and a known quantity of acid; then pH is recorded. Then a new 10 g sample was prepared, with more acid, etc., so the acid was not cumulative within the same beaker. The shape of both sets of curves was similar: an initial sharp drop in pH with initial acid addition; then lesser decreases with additional acid. The difference between immediate pH reading, and 24 hrs later was similar in both trials. It is likely that 24-hr contact time allows the acid to permeate deeper into the RCA particles and react with more of the Portland cement matrix.

A 100-g sample was prepared for the trial shown in Figure 24, and 35 ml of acid solution was added, 1 ml at a time, sequentially. After 25 ml were added, the sample was allowed to rest 24 hrs before continuing. The jump in pH after 24 hrs is similar to that seen in Figures 22 and 23. Table 16 lists the amount of H^+ required to drop the pH to 7 and 4. The numbers for the first and second figures are similar, both for the immediate pH readings, and after 24 hrs. However, the values from the third figure are about half of that in the previous two, possibly due to cumulative effect and longer contact time, which was more effective in lowering pH. This last (more conservative) set of values will be used for further analysis.

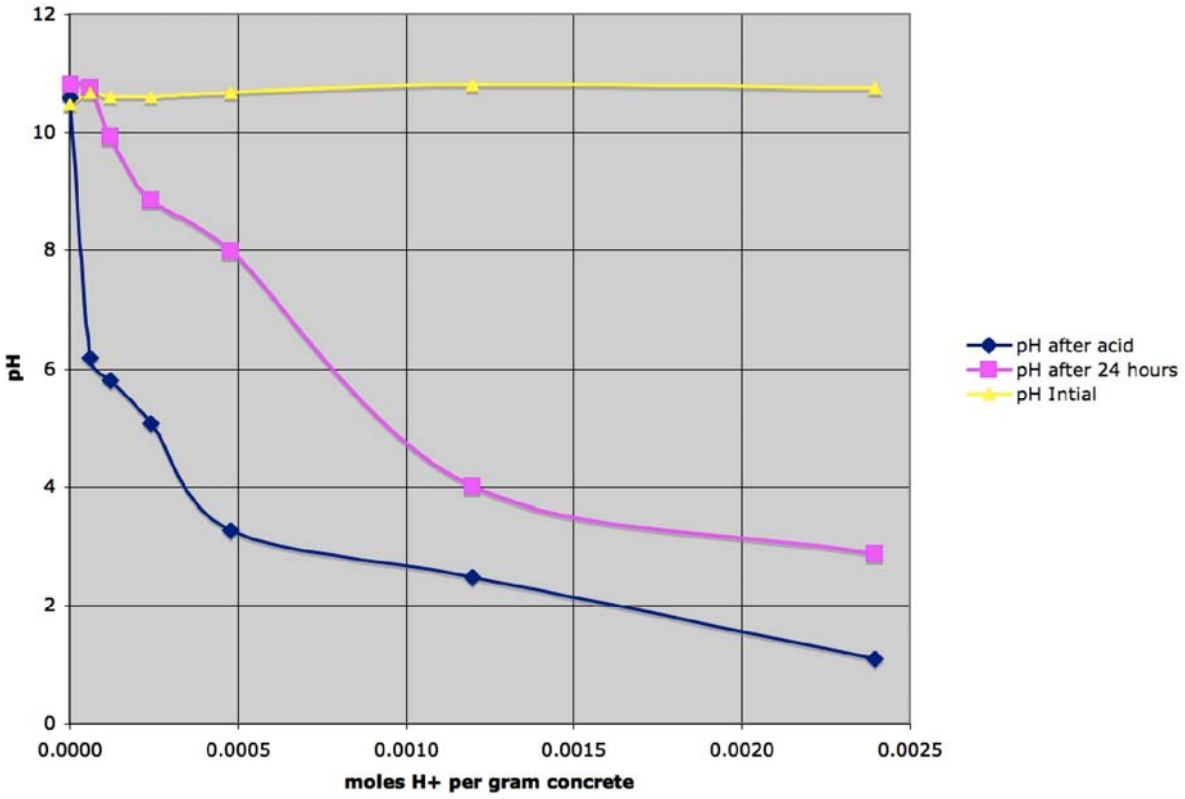

Figure 22. Ten percent nitric acid added to concrete vs. pH, and 24 hrs later.

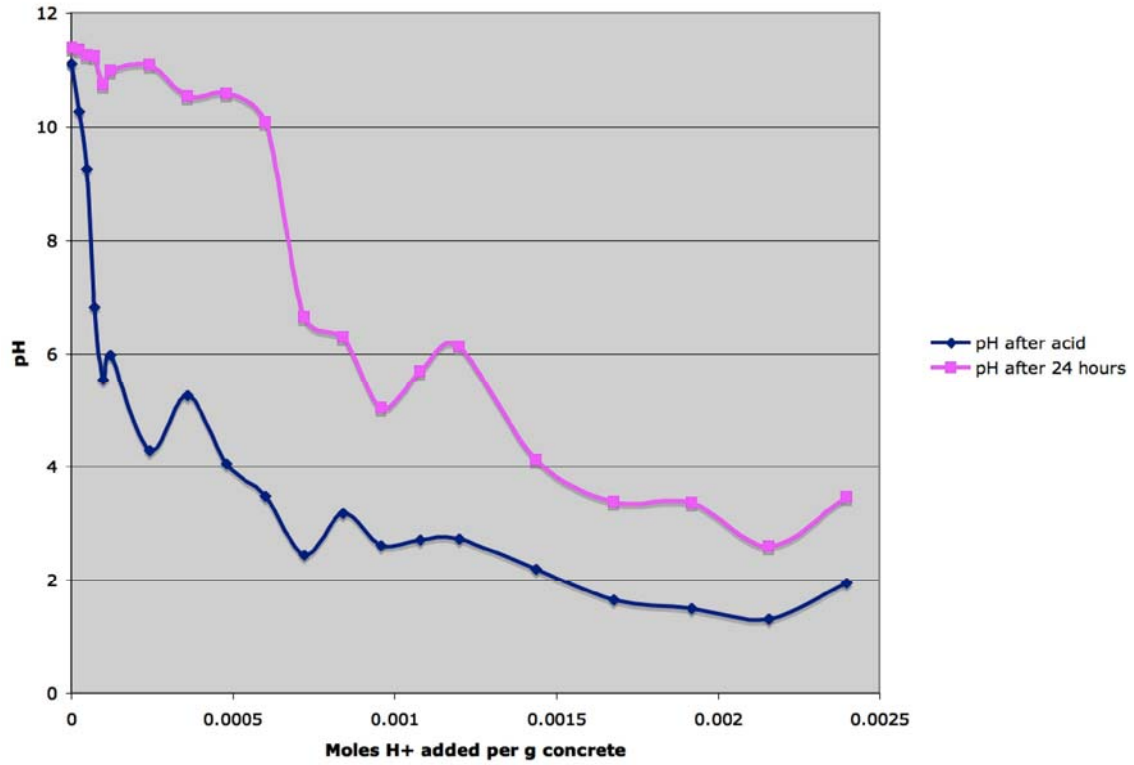

Figure 23. Five percent nitric acid added to concrete vs. pH, and 24 hrs later.

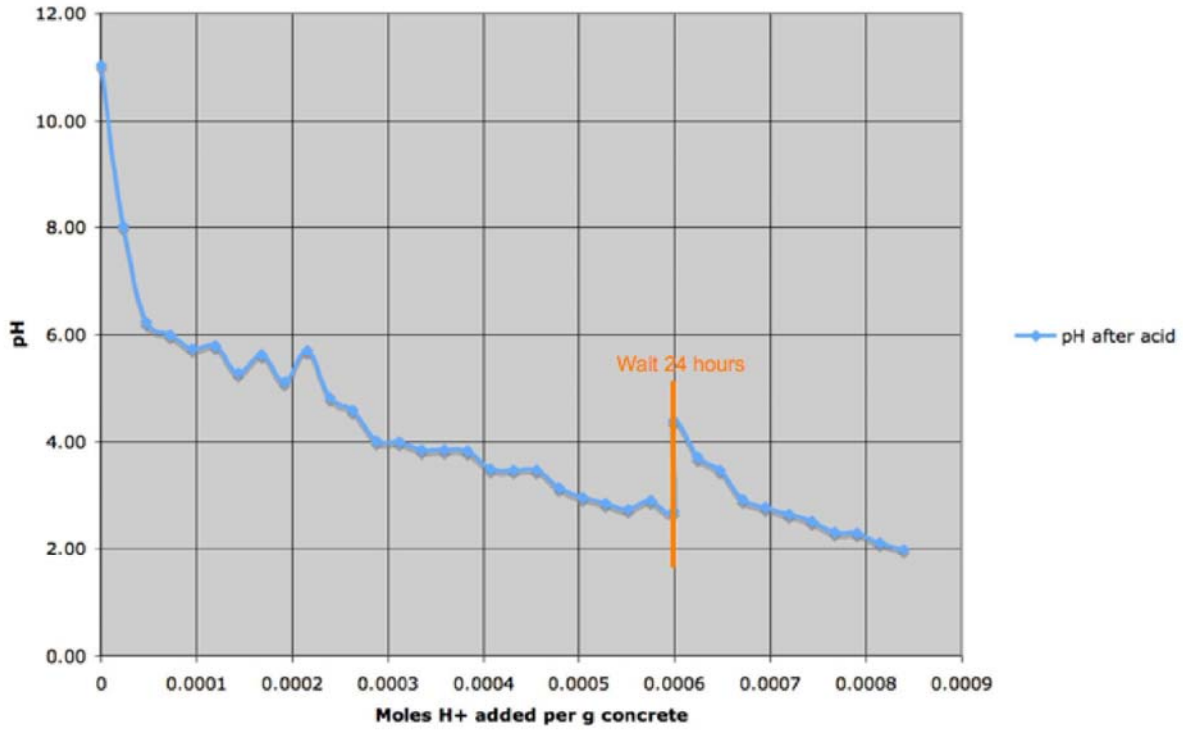

Figure 24. Sequential acid addition vs. pH.

Table 16. addition of H+ to pH 7 and 4.

Chart	H^+ Addition to pH7 (mole/g)	H^+ Addition to pH4 (mole/g)	H^+ Addition to pH7, 24 hrs (mole/g)	H^+ Addition to pH4, 24 hrs (mole/g)
1	0.00005	0.00034	0.00065	0.0011
2	0.00007	0.00048	0.0007	0.00145
3	0.000035	0.00028	0.00035*	0.00062
* This value is an estimate because the 24 break occurred after pH had decreased past 7.				

6.4 Calculations

The data in Table 16 show the amount of acid that must be added to crushed concrete to lower the pH to neutral or below. Basic Pb carbonate ($Pb(OH)_2$ $2PbCO_3$), the most common white Pb pigment is considered insoluble in water and alcohol; and slightly soluble in acid. Therefore, if the pH of the LBP-containing RCA matrix remains at neutral or above, Pb should not be dissolved in acid rain. To that end, the follow calculations will show, based on all the preceding experimental data, how much incident rainfall would be required to lower the pH to 7:

1. Start with value from Table 16, 0.00035 moles H^+ per gram of crushed concrete to reduce matrix pH to 7, after 24 hrs.
2. Multiply by 500 g (the approximate mass in the column experiment) to get 0.175 moles H^+ to raise pH in the column to 7.
3. The experimental equivalent on 1 month's rainfall at the subject location is 180 ml (average of 4 in./month). The pH of the extraction fluid, and a reasonable approximation of the natural rain is 4.2. This is equivalent to 6.31 x 10^{-5} mol H^+/L. Multiply by 0.180 L/month to get 1.14 x 10^{-5} mol H^+/month incident on the sample due to natural rainfall.
4. Divide 0.175 moles H^+ (step 2) by 1.14 x 10^{-5} mol H^+/month. This gives 15,400 months (1,284 years) of rainfall required to deliver enough acidity to lower the pH of the crushed concrete to 7.

Of course, there is much variability in performing calculations like this; a sensitivity analysis could be done to see how much various assumptions influence the results. However, the relative magnitudes involved indicate that it is very difficult to acidify the concrete.

6.5 Results

6.5.1 Drinking water

The Federal drinking water action level for Pb is 0.015 mg/L. A municipal water utility must take action if 10 percent of tap water samples exceed

this limit. Both Pb and Cu are regulated by a Treatment Technique that requires controlling the corrosiveness of drinking water supplied by utilities. The goal is zero Pb. The SPLP values in Table 6 are well below this for drinking water.

The extract from all of the concrete blank columns from the leaching experiment was at or below the Maximum Contaminant Level (MCL). Recall that "blank" means that no LBP was added, but there was some lead content there from demolition (Table 5, p 16). The leachate from all the columns spiked with LBP exceed (sometimes greatly exceeding) the MCL, except for the second, which only had a Pb concentration of 184 mg/kg. The Pb concentration in all the other spike columns was *much* higher than one would ever see in concrete demolition debris.

6.5.2 Soil

One study compared hundreds of soil samples from across the United States (Wixon 1993). Table 17 lists total Pb results for open areas in a few cities; median values are shown, but the range was very great, likely due to localized contamination from LBP near buildings, up to tens of thousands of mg/kg in older urban centers. The total Pb values in Table 5 (p 16) show that the crushed concrete samples are similar in Pb content to urban soils.

The USEPA Biosolids Rule (Clean Water Act [CWA], part 503) (USEPA 1994a) limits the total Pb concentration for sewage sludge applied to land to 840 mg/kg; and 300 mg/kg for "exceptional quality biosolids." The total Pb figures in Table 5 (p 16) are below 300 mg/kg.

Table 17. Urban Pb in soil.

Location	Total Pb Concentration, Median Value (mg/kg)
Baltimore, MD	100
New Orleans, LA	212
Natchitoches, LA	14
Minneapolis, MN	290
Rochester, MN	30

7 Conclusions and Recommendations

This study found that the total Pb values for the RCA samples used in this study (Table 5 [p 16]) were found to be similar in Pb content to urban soils (less than 300 mg/kg). Also, the SPLP values in the synthetic precipitation leaching procedure data for RCA with LBP (Table 6) were well below the MCL for drinking water established by the Federal drinking water action level for Pb, and the extract from all of the concrete blank columns from the leaching experiment was at or below the MCL. Based on these findings, this study concludes that the Pb concentration in runoff from RCA with reasonable, real world amount of LBP, is extremely low.

Given the low concentrations of Pb in the RCA samples tested relative to regulatory limits (see p 35) and the buffering capacity of concrete (described in detail in Chapter 6, p 28), this study concludes that the environmental risk from Pb-containing crushed concrete applied to land is negligible. Moreover, the uses for crushed concrete as road base or fill conveys little risk of environmental or human exposure; in such cases, the RCA would be placed underneath thick layers of soil or paving materials, thus limiting environmental and human exposure.

On any given demolition project, it is recommended that some sampling and calculations be performed to ensure that unusually high LBP-to-concrete ratio are appropriately addressed. It is also recommended that future work to expand and improve on this study include:

- Identification of the variation in buffering capacity of concrete of different ages and from different regions, to determine whether this variation is great enough to significantly affect rainwater Pb leaching described in this report
- Correlation of SPLP and TCLP results
- Development of a computer tool to ease prediction of Pb concentration in RCA, pre-demolition
- Modeling the leaching properties of other common uses of RCA
- Determination of state-by-state testing requirements for RCA use, and any perceived limitations.

Acronyms and Abbreviations

Term	Spellout
AEC	Army Environmental Command
ANSI	American National Standards Institute
C&D	construction and demolition
CEERD	U.S. Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
CSB	cold storage building
CTC	Concurrent Technologies Corporation
CWA	Clean Water Act
DC	District of Columbia
DLE	Directorate of Logistics and Engineering
DOD	U.S. Department of Defense
E/W	east/west
EPA	U.S. Environmental Protection Agency
ERDC	Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ID	Identification
ISTC	Illinois Sustainable Technology Center
LBP	lead-based paint
MCL	Maximum Contaminant Level
N/S	North/south
NADP	National Atmospheric Deposition Program
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NSN	National Supply Number
NW	Northwest
OMB	Office of Management and Budget
QA	Quality Assurance
RCA	recycled concrete aggregate
RCRA	Resource Conservation and Recovery Act
SEED	SERDP Exploratory Development
SERDP	Strategic Environmental Research and Development Program
SON	Statement of Need
SPLP	synthetic precipitation leaching procedure
SRM	standard reference material
TCLP	Toxicity Characteristic Leaching Procedure
TR	Technical Report

Term	Spellout
URL	Universal Resource Locator
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WDNR	Wisconsin Department of Natural Resources
WMRC	Waste Management and Research Center
WWW	World Wide Web

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Appendix A: Experimental Data

Concrete column extraction data

Table A-1. Glass blank extraction data.

Fraction #	Pb Extracted (mg/L)	pH
1	0.0192	6.82
2	0.0021	9.31
3	0.0009	9.26
4	0.0015	8.71
5	0.0015	8.45
6	0.0026	6.97
7	0.0019	7.9
8	0.0053	7.5
9	0.0005	8.45
10	0.0009	8.22
11	0.0008	6.81
12	0.0005	6.77
13	0.0005	7.25
14	0.0007	7.31
15	0.0005	7.45
16	0.0012	7.31
17	0.0005	7.21
18	0.0007	7.1
19	0.0003	7.18
20	0.0007	6.38
21	0.0005	6.27
22	0.0006	5.78
23	0.0009	6.89
24	0.0010	5.04

Table A-2. Glass spike.

Fraction #	Pb Extracted (mg/L)	pH
1	0.006	10.15
2	1.066	9.71
3	1.626	8.93
4	1.220	8.86
5	1.328	8.07
6	1.198	7.2
7	1.221	6.69
8	1.302	6.09
9	1.120	6.39
10	1.125	6.47
11	1.357	6.36
12	1.843	6.11
13	1.192	5.88
14	1.067	5.43
15	0.949	5.85
16	0.464	5.18
17	9.969	5.98
18	1.683	6.23
19	1.386	5.81
20	1.076	5.05
21	0.811	4.78
22	0.725	4.78
23	0.688	4.52
24	0.520	4.52

Table A-3. Concrete blank 1.

Fraction #	Pb Extracted (mg/L)	pH
1	0.0004	11.41
2	0.0013	11.82
3	0.0004	11.27
4	0.0017	11.47
5	0.0022	10.66
6	0.0022	11.71
7	0.0012	11.65
8	0.0008	11.06
9	0.0012	11.05
10	< 0.0002	9.26
11	0.0021	11.61
12	0.0047	11.33
13	0.0010	11.36
14	0.0009	11.16
15	0.0062	11.52
16	0.0047	10.08
17	0.0007	11.04
18	0.0021	9.2

Table A-4. Concrete blank 2.

Fraction #	Pb Extracted (mg/L)	pH
1	< 0.0002	11.58
2	< 0.0002	11.54
3	< 0.0002	11.63
4	< 0.0002	11.6
5	< 0.0002	11.64
6	< 0.0002	11.6
7	< 0.0002	11.57
8	< 0.0002	11.61
9	< 0.0002	11.64
10	< 0.0002	11.64
11	0.0007	11.61
12	< 0.0002	11.62
13	< 0.0002	11.68
14	< 0.0002	11.67
15	< 0.0002	11.68
16	< 0.0002	11.61
17	< 0.0002	11.66
18	< 0.0002	11.63
19	< 0.0002	11.67
20	< 0.0002	11.65

Table A-5. Concrete blank 3

Fraction #	Pb Extracted (mg/L)	pH
1	0.0482	11.3
2	0.0082	11.47
3	0.0110	11.58
4	0.0040	11.55
5	0.0113	11.4
6	0.0103	11.52
7	0.0037	11.32
8	0.0147	11.49
9	0.0039	11.28
10	0.0057	11.35
11	0.0093	11.46
12	0.0036	11.27
13	0.0027	11.44
14	0.0043	11.3
15	0.0058	11.22
16	0.0042	11.31
17	0.0131	11.34
18	0.0146	11.41
19	0.0054	11.31
20	0.0050	11.32
21	0.0047	11.37
22	0.0030	11.39
23	0.0055	11.42
24	0.0062	11.38
25	0.0207	11.22
26	0.0401	11.18
27	0.0297	11.21
28	0.0114	11.21
29	0.0066	11.07
30	0.0057	11.26
31	0.0089	11.22
33	0.0066	10.54
35	0.0045	11.16
37	0.0060	11.16
39	0.0049	11.3
41	0.0048	11.38
43	0.0027	11.31
45	0.0042	11.48
47	0.0014	11.25
49	0.0051	11.34

Table A-6. Concrete blank 4.

Fraction #	Pb Extracted (mg/L)	pH
1	0.0012	11.09
2	0.0011	11.44
3	0.0022	11.51
4	0.0012	11.54
5	0.0011	11.35
6	0.0015	11.38
7	0.0019	11.21
8	0.0050	11.32
9	0.0024	11.23
10	0.0021	11.21
11	0.0023	11.32
12	0.0034	11.3
13	0.0012	11.1
14	0.0022	11.07
15	0.0016	11.01
16	0.0022	11.21
17	0.0041	11.15
18	0.0020	11.12
19	0.0056	11.21
20	0.0053	11.3
21	0.0026	11.36
22	0.0071	11.4
23	0.0125	11.22
24	0.0037	11.18
25	0.0049	11.22
26	0.0052	11.24
27	0.0061	11.08
28	0.0046	11.21
29	0.0042	11.32
30	0.0025	11.11
31	0.0051	8.43
33	0.0040	8.42
35	0.0055	11.24
37	0.0054	11.4
39	0.0032	11.29
41	0.0038	11.18
43	0.0032	11.44
45	0.0020	11.26
47	0.0018	11.34
49	0.0029	11.24

Table A-7. Concrete spike 1.

Fraction #	Pb Extracted (mg/L)	pH
1	0.034	10.86
2	0.027	11.36
3	0.024	11.28
4	0.039	11.34
5	0.052	11.28
6	0.063	11.3
7	0.063	11.33
8	0.062	11.35
9	0.057	11.2
10	0.065	11.21
11	0.076	11.03
13	0.053	11.06
15	0.060	10.79
17	0.042	10.98
19	0.036	8.26
21	0.036	8.62
23	0.035	9.48
25	0.039	8.96
27	0.040	8.19
29	0.039	10.33
31	0.113	9.72
33	0.137	8.53
35	0.152	8.1
37	0.116	9.44
39	0.120	8.34
41	0.134	9.81
43	0.098	8.61
45	0.263	11.39
47	0.143	11.25
49	0.106	11.11

Table A-8. Concrete spike 2.

Fraction #	Pb Extracted (mg/L)	pH
1	0.0438	11.37
2	0.0025	11.29
3	0.0018	11.3
4	0.0005	10.95
5	0.0007	11.09
6	0.0014	11.07
7	0.0012	11.08
8	0.0029	11.09
9	0.0015	11.14
10	0.0022	11.15
11	0.0022	11.13
12	0.0006	11.11
13	0.0013	11.17
14	0.0108	11.2
15	0.0015	11.12
16	0.0468	11.18
17	0.0012	11.36
18	0.0009	11.31

Table A-9. Concrete spike 3.

Fraction #	Pb Extracted (mg/L)	pH
1	0.069	11.53
3	0.139	11.22
5	0.095	11.23
7	0.104	11.25
9	0.098	11.17
11	0.082	11.22
13	0.075	11.14
15	0.076	11.21
17	0.061	11.29
19	0.088	11.22
21	0.043	11.19
22	0.044	11.18
23	0.043	11.15
24	0.039	11.19

Table A-10. Concrete spike 4.

Fraction #	Pb Extracted (mg/L)	pH
1	0.054	11.38
2	0.092	11.34
3	0.138	11.11
4	0.137	11.22
5	0.130	11.24
6	0.122	11.25
7	0.123	11.25
8	0.122	11.3
9	0.118	11.31
10	0.117	11.31
11	0.119	11.15
12	0.114	11.2
13	0.115	11.24
14	0.108	11.29
15	0.106	11.32
16	1.036	11.31
17	0.079	11.26
18	0.083	11.22
19	0.088	11.31
20	0.102	11.23
21	0.082	11.21
22	0.071	11.19
23	0.067	11.16
24	0.062	11.14

Table A-11. Concrete spike 5.

Fraction #	Pb Extracted (mg/L)	pH
1	0.049	11.6
2	0.173	11.42
3	0.107	11.143
4	0.080	11.3
5	0.097	11.35
6	0.109	11.37
7	0.149	11.35
8	0.384	11.3
9	0.231	11.36
10	0.291	11.29
11	0.400	11.31
12	0.260	11.31
13	0.315	11.25
14	0.272	11.226
15	0.317	11.28
16	0.282	11.28
17	0.248	11.3
18	0.233	11.24
19	1.107	11.28
20	0.282	11.29
21	0.242	11.31
22	0.344	11.25
23	0.350	11.26
24	0.420	11.27

Table A-12. Concrete spike 6.

Fraction #	Pb Extracted (mg/L)	pH
1	0.18	11.5
2	0.19	11.17
3	0.21	11.21
4	0.21	11.22
5	0.20	11.2
6	0.19	11.23
7	0.19	10.99
8	0.19	11.12
9	0.20	11.11
10	0.19	11.16
11	0.19	11.14
12	0.18	11.13
13	0.15	11.17
14	0.16	11.2
15	0.24	11.3
16	0.20	11.02
17	0.20	11.12
18	0.19	11.1
19	0.18	11.07
20	2.79	11.38
21	0.39	11.33
22	0.13	11.25
23	0.66	11.23
24	0.13	11.2

Table A-13. Concrete spike 7.

Fraction #	Pb Extracted (mg/L)	pH
1	0.24	10.75
2	1.53	10.61
3	1.85	10.64
4	1.93	10.72
5	2.12	10.75
6	2.55	10.56
7	2.74	10.67
8	2.92	10.71
9	3.27	10.72
10	3.29	10.69
11	2.82	10.71
12	2.78	10.68
13	6.67	10.78
14	4.26	10.71
15	3.69	10.71
16	6.54	10.83
17	4.76	10.64
18	4.32	10.73
19	3.77	10.73
20	3.54	10.69
21	5.96	11.01
22	3.04	10.55
23	2.51	10.83
24	2.13	10.78

Rainfall data for Columbia, SC

Tables A-14 and A-15 list precipitation data for the two NOAA weather stations closest to Fort Jackson (NCDC 2004). (The airport is about 11 mi from Fort Jackson, and about 5 mi from the university.)

Table A-14. Monthly precipitation at Columbia Metro Airport, 1971-2000.

Month	Mean Monthly (in)	Record Daily (in)	Record Monthly (in)	# Days with More than 0.5 in	# Days with More than 1.0 in
Jan	4.66	2.79	9.26	3.3	1.3
Feb	3.84	3.69	8.1	2.7	1.2
Mar	4.59	3.24	10.89	3	1.3
Apr	2.98	3.03	6.85	2.3	0.8
May	3.17	4.68	7.88	2.3	0.8
Jun	4.99	5.4	14.81	3.1	1.4
Jul	5.54	5.79	17.46	3.6	1.9
Aug	5.41	5.03	11.75	3.3	1.9
Sep	3.94	5.17	7.86	2.3	1.4
Oct	2.89	4.09	11.66	2	0.9
Nov	2.88	2.6	6.26	2.1	1
Dec	3.38	3.18	8.54	2.1	0.9
Annual	48.27	—	—	32.1	14.8
Avg Monthly	4.02				

Table A-15. Monthly precipitation at University of South Carolina, Columbia, SC, 1971-2000.

Month	Mean Monthly (in)	Record Daily (in)	Record Monthly (in)	# Days with More than 0.5 in	# Days with More than 1.0 in
Jan	4.57	3.11	9.46	3.4	1.2
Feb	3.75	3.33	8.01	2.6	1.2
Mar	4.56	3.72	10.01	3.1	1.5
Apr	2.96	2.81	7.31	2.1	0.8
May	3.21	4.19	7.42	2	0.8
Jun	5.19	4.22	12.6	3.2	1.6
Jul	5.2	5.75	14.93	3.3	1.5
Aug	4.51	4.53	10.39	2.7	1.3
Sep	3.83	5.9	8.77	2.4	1.3
Oct	2.89	4.02	11.88	1.6	0.9
Nov	3.11	2.88	7.45	2.4	0.8
Dec	3.36	2.91	9.82	2.4	0.8
Annual	47.14	-	-	31.2	13.7
Avg Monthly	3.93				

Table A-16 lists almost 50 years of precipitation data for the Columbia, SC airport (NCDC 2003).

Table A-16. Columbia, SC precipitation data, 1955 to 1999.

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Precip total (in)	4.3	3.9	4.6	3.2	3.4	4.4	5.5	5.4	3.9	3.0	2.6	3.3	47.5
Avg storm duration (hr)	13.7	12.3	11.7	10.3	8.6	6.8	6.0	6.4	9.5	10.6	9.6	12.4	9.8
Number of storm events	5.6	5.1	5.9	4.4	5.3	6.1	7.4	6.8	4.4	3.4	3.8	5.0	63.1
Avg storm depth (in)	0.7	0.7	0.8	0.7	0.6	0.6	0.7	0.8	0.8	0.7	0.6	0.6	0.7
Variance of the avg storm depth (in^2)	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.3	0.3	0.1	0.1	0.0
Avg intensity (in/hr)	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Max, hourly rainfall rate (in/hr)	0.4	0.4	0.5	0.5	0.7	0.9	1.0	1.1	0.8	0.5	0.4	0.3	0.6
Max storm depth (in)	1.7	1.6	1.8	1.5	1.5	1.7	1.8	2.1	2.0	1.5	1.1	1.4	1.6
Duration of item 8 (hr)	24.0	22.5	21.2	17.7	14.8	13.3	12.9	13.9	18.3	16.0	13.9	21.5	17.5
Longest dry period (day)	9.3	10.3	9.9	11.9	13.2	10.4	9.8	10.3	12.9	16.3	14.5	10.8	11.6
Max storm duration (hr)	26.0	24.7	22.7	19.2	17.6	15.6	15.5	16.7	20.6	18.3	16.2	23.3	19.7
Depth of item 11 (in)	1.6	1.4	1.5	1.4	1.3	1.4	1.5	1.8	1.7	1.4	1.0	1.3	1.5
Number of wet days	7.0	6.2	7.2	5.1	5.8	6.6	7.7	7.2	4.9	4.0	4.3	5.7	71.7

CSB concrete calculations

Tables A-17 to A-26 in this section show the calculations that went into determining the mass of concrete in the Fort Jackson CSB.

Table A-17. Concrete footings volume calculation.

Footings												
1,6,25,30	4.25	ft x	3.16	ft x	1.5	ft thick =	20.15	cu ft x	12	footings =	241	cu ft
2,3,4,5	3.67	ft x	3.67	ft x	1.5	ft thick =	20.20	cu ft x	12	footings =	242	cu ft
7,13,18,19	5.50	ft x	4.50	ft x	2.0	ft thick =	49.50	cu ft x	12	footings =	594	cu ft
8,9,10,11	4.50	ft x	4.50	ft x	2.0	ft thick =	40.50	cu ft x	12	footings =	486	cu ft
12,24	5.83	ft x	4.83	ft x	2.0	ft thick =	56.32	cu ft x	6	footings =	337	cu ft
14,22,23	4.67	ft x	4.67	ft x	2.0	ft thick =	43.62	cu ft x	9	footings =	392	cu ft
15,16,17	4.33	ft x	4.33	ft x	2.0	ft thick =	37.50	cu ft x	9	footings =	337	cu ft
20,21	4.83	ft x	4.83	ft x	2.0	ft thick =	46.66	cu ft x	6	footings =	279	cu ft
26	4.00	ft x	4.00	ft x	1.5	ft thick =	24.00	cu ft x	3	footings =	72	cu ft
27,28,29	3.83	ft x	3.83	ft x	1.5	ft thick =	22.00	cu ft x	9	footings =	198	cu ft
								Total Footings			*3,182*	*cu ft*
*Assume the footings are designed at 6000 pounds/sq ft soil bearing.												

Table A-18. Concrete pedestal volume calculation.

Pedestals												
1,6,25,30, 7,13,18,19,12,24	2.46	ft x	1.33	ft x	0.5	ft thick =	1.64	cu ft x	30	ped =	49	cu ft
2, 3, 4, 5, 8, 9, 10, 11, 14, 22, 23, 20, 21, 26, 27, 28, 29	1.33	ft x	1.33	ft x	0.5	ft thick =	0.88	cu ft x	51	ped =	45	cu ft
15,16,17	1.50	ft x	1.50	ft x	0.5	ft thick =	1.13	cu ft x	9	ped =	10	cu ft
								Total Pedestals			104	cu ft

Table A-19. Concrete piers calculation.

Piers												
1, 6, 25, 30, 7, 13, 18, 19, 8, 9, 10, 11, 12, 24	1.17	ft x	1.33	ft x	3.0	ft high =	4.67	cu ft x	42	pier =	196	cu ft
2, 3, 4, 5, 8, 9, 14, 22, 23, 20, 21, 26, 27, 28, 29	1.33	ft x	1.33	ft x	3.0	ft high =	5.31	cu ft x	45	pier =	238	cu ft
15, 16, 17	1.50	ft x	1.50	ft x	3.0	ft high =	6.75	cu ft x	9	pier =	60.	cu ft
								Total Piers			495	cu ft

Table A-20. Concrete beams calculation.

Beams												
B1-2-2-1	0.83	ft x	2.50	ft x	72.0	ft long =	149.40	cu ft x	3	bays =	448	cu ft
B4-5-6	0.83	ft x	2.50	ft x	56.5	ft long =	117.24	cu ft x	3	bays =	351	cu ft
B10	0.83	ft x	2.50	ft x	18.0	ft long =	37.35	cu ft x	3	bays =	112	cu ft
B11	0.83	ft x	2.50	ft x	18.0	ft long =	37.35	cu ft x	3	bays =	112	cu ft
B8 & B13	0.67	ft x	1.33	ft x	19.8	ft long =	17.60	cu ft x	3	bays =	52	cu ft
B7 & B12	0.83	ft x	2.50	ft x	37.2	ft long =	77.13	cu ft x	3	bays =	231	cu ft
B9	0.50	ft x	1.17	ft x	7.8	ft long =	4.58	cu ft x	3	bays =	13	cu ft
								Total Beams			*1,321*	*cu ft*

Table A-21. Foundation walls.

Foundation Walls												
N/S walls	180.00	ft x	6.83	ft high x	0.67	ft thick =	823.70	cu ft x	3	bays =	2,471	cu ft
End & party walls	72.33	ft x	6.83	ft high x	0.67	ft thick =	330.99	cu ft x	4	walls =	1,323	cu ft
Floor level change	126.00	ft x	5.25	ft high x	0.67	ft thick =	443.21	cu ft x	3	bays =	1,329	cu ft
Load'g dock walls	180.00	ft x	6.83	ft high x	0.67	ft thick =	823.70	cu ft x	3	bays =	2,471	cu ft
Add for bumper	180.00	ft x					0.50	cu ft/ft x	3	bays =	270	cu ft
Ld. dk. end walls	6.83	ft x	6.83	ft high x	0.67	ft thick =	31.25	cu ft x	4	walls =	125	cu ft
Ld. dk. Lat. Walls	5.50	ft x	6.83	ft high x	0.67	ft thick =	25.17	cu ft x	24	walls =	604	cu ft
								Total Foundation Walls			*8,594*	*cu ft*

Table A-22. Floor slab volume calculation.

Floor slab:	72.33	ft x	90.00	ft x	0.42	ft thick =	2,734.07	cu ft x	3	bays =	8,202	cu ft
Add at refrig. fl	70.83	ft x	54.00	ft x	0.42	ft thick =	1,606.42	cu ft x	3	bays =	4,819	cu ft
Loading dock deck:	180.00	ft x	5.83	ft x	0.42	ft thick =	440.75	cu ft x	3	bays =	1,322	cu ft
											14,343	cu ft
Back out for walls:												
Interior walls	235.25	ft x	0.67	ft thick x	0.42	ft. slab thickness =					-66	cu ft
Add at refrig slab	216.00	ft x	0.67	ft thick x	0.42	ft. slab thickness =					-60	cu ft
Exterior walls	252.33	ft x	0.67	ft thick x	0.42	ft. slab thickness =					-71	cu ft
Add at refrig slab	162.00	ft x	0.67	ft thick x	0.42	ft. slab thickness =					-45	cu ft
Add at party walls	144.66	ft x	0.67	ft thick x	0.42	ft. slab thickness =					-40	cu ft
								Total Floor Deck			*14,059*	*cu ft*

Table A-23. Interior walls.

Interior Walls												
NW corner	25.92	ft										
N/S walls, W to E	72.33	ft										
	17.50	ft										
	12.00	ft										
	17.50	ft										
E/W walls, N to S	8.83	ft										
	81.17	ft										
	235.25	ft x	12.00	ft high x	0.5	ft thick =	1,411.50	cu ft x	3	bays =	4,234	cu ft
Party walls	72.33	ft x	12.00	ft high x	0.67	ft thick =	581.53	cu ft x	2	walls =	1,163	cu ft
Pilasters	1.17	ft wide x	12.00	ft high x	0.5	ft thick =	7.02	cu ft x	24	pilast'r =	168	cu ft
								Total Interior Walls			*5,566*	*cu ft*
NOTE: Columns incorporated into the wall are taken-off with the walls												

Table A-24. Exterior walls volume calculation.

Exterior Walls												
N/S walls	180.00	ft x	12.00	ft high x	0.67	ft thick =	1,447.20	cu ft x	3	bays =	4,341	cu ft
End walls	72.33	ft x	12.00	ft high x	0.67	ft thick =	581.53	cu ft x	2	walls =	1,163	cu ft
Pilasters	1.00	ft wide x	12.00	ft high x	0.33	ft thick =	3.96	cu ft x	24	pilast'r =	95	cu ft
								Total Exterior Walls			*5,504*	*cu ft*
NOTE: Columns incorporated into the wall are taken-off with the walls												

Table A-25. Roof volume calculation.

Roof												
Beams @ party walls	1.00	ft x	2.50	ft x	72.3	ft long =	180.83	cu ft x	2	beams =	361	cu ft
Columns	1.17	ft x	1.17	ft x	11.3	ft high =	15.51	cu ft x	9	col =	139	cu ft
Capitals	4.00	ft x	4.00	ft x	1.8	ft high x	0.33	volume =	9.24	cu ft ea x		
									60	col =	554	cu ft
Drop panels	6.33	ft x	6.33	ft x	0.3	ft thick =	11.62	cu ft x	60	col =	697	cu ft
Roof deck	90.00	ft x	88.00	ft x	0.6	ft thick =	4,593.60	cu ft x	3	bays =	13,780	cu ft
Parapet	144.33	ft x	0.83	ft high x	0.7	ft thick =					80.26	cu ft
								Total Roof Structure			*15,613*	*Cu ft*
NOTE: Only free-standing columns (15,16,17)are counted												

Table A-26. Surface area calculation.

Interior Walls													
NW corner	25.92	ft											
N/S walls, W to E	72.33	ft											
	17.50	ft											
	12.00	ft											
	17.50	ft											
E/W walls, N to S	8.83	ft											
	81.17	ft											
	235.25	ft x	12.00	ft high x		2	sides		3	bays =	16,938	sq ft	int
Party walls	72.33	ft x	12.00	ft high x		2	sides		2	walls =	3,472	sq ft	int
Pilasters	1.17	ft wide x	12.00	ft high x		2	sides		24	pilast'r =	674	sq ft	int

Interior Walls													
								Total Interior Walls			*21,084*	*sq ft*	*int*
Exterior walls:													
N/S walls	180.00	ft x	12.00	ft high x					3	bays =	6,480	sq ft	ext
											6,480	sq ft	int
End walls	72.33	ft x	12.00	ft high x					2	walls =	1,736	sq ft	ext
											1,736	sq ft	int
Pilasters	1.00	ft wide x	12.00	ft high x					24	pilast'r =	288	sq ft	ext
											288	sq ft	int
Interior ceiling	72.33	ft x	90.00	ft x	3	bays					19,529	sq ft	int
Loading dock ceiling	7.83	ft x	90.00	ft x	3	bays	2.00	sides			4,228	sq ft	ext
										Total int	49,117	sq ft	
										Total ext	12,732	sq ft	
										Total surface	*61,849*	*sq ft*	