

**ASSESSMENT AND MITIGATION OF POTENTIAL ENVIRONMENTAL
IMPACTS OF PORTLAND CEMENT CONCRETE HIGHWAY GRINDINGS**

By

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To the faculty of Washington State University:

The members of the Committee appointed to examine the thesis of

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Chair

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ASSESSMENT AND MITIGATION OF POTENTIAL ENVIRONMENTAL IMPACTS OF PORTLAND CEMENT CONCRETE HIGHWAY GRINDINGS

Abstract

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Diamond Grinding of Portland Cement Concrete (PCC) pavements to improve smoothness and remove surface irregularities often caused by faulting, curling, and warping of the slabs is a highway rehabilitation technique. The grinding slurry generated during the grinding operation is typically deposited along the roadside and concern has been expressed regarding potential for negative environmental impacts. The greatest potential for negative environmental impact was believed to be the slurry pH as the Washington State Department of Transportation has documented that PCC slurry has elevated pH levels. This study was commissioned by Washington State Department of Transportation to define the impact of PCC highway grinding slurry on soil pH in disposal areas and evaluates the use of compost to neutralize slurry pH prior to or during disposal.

The results indicate that soil pH was found to be higher in slurry disposal areas in comparison with the non-impacted areas. The pH of the soil in the slurry disposal area on SR-195 ranged from 7.6-9.4 while background pH ranged from 6.3-7.5. Soil pH within the slurry disposal area on I-90 was in the range 7.1-8.2, indicating a moderate increase above the range of pH 7.1-7.2 for background samples. This indicates that slurry

application does increase soil pH in the disposal areas. Compost was shown to neutralize the slurry pH, based on the pH neutralization experiments. The observed pH reduction ranged from about 3.5- 4.5 units below the slurry pH of 12. The minimum observed pH was 8.3 with WSU compost and 8.0 for EKO compost for slurry: compost ratio of 1.3 gallons slurry: 2.2pounds compost. EKO compost had a greater effect on pH reduction than did WSU compost.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The U. S. Public road system consists of 6.3 million-centerline km of paved and unpaved surface (Slater, 1995). Portland cement concrete (PCC) surfacing constitutes about 6 % of all paved public roads. Yet, even at this relatively low level of use, more than 2000 km² are covered by PCC. The continual rehabilitation and maintenance of the system of highways is vital for the viability and integrity of the existing network. So, the national focus has shifted from constructing new highways to maintaining and repairing the existing highway network. Recent advances in concrete technology have enabled highway contractors to rehabilitate the nation's 160,000-mile (275,000 km) national highway system to extend its useful life with minimal disruption to traffic. Washington State Department of Transportation (WSDOT) maintains over 17,000 lane miles of state highway. Since 1991, approximately 15,000 lane miles have received some form of capital investment in the form of pavement rehabilitation.

1.2 Diamond Grinding of PCC Pavements

Several new techniques are being adopted to rehabilitate and resurface highways efficiently with minimum traffic interruption. Among these rehabilitation techniques are dowel retrofitting of existing concrete pavements that have undowelled slab joints to improve highway smoothness and longevity followed by diamond grinding resurfacing. Since 1980, the slab joints of most new concrete highway pavements in areas where

heavy loading is anticipated have been dowelled with 18 in. (46 cm) long smooth epoxy coated steel bars. The dowels bridge the joint sawed between the pavement slabs and help transfer traffic loads from one concrete slab to the next. The new retrofitting technique involves cutting slots across the pavement joints, inserting the bars, patching the slots with fast-track concrete mixes, and then diamond grinding the road to obtain a smooth surface. Washington State Department Of Transportation (WSDOT) is the first state DOT to undertake dowel retrofitting on a large scale to extend the service life of some of the state's 30-year-old concrete highways by 10 to 15 years ([www. cement. org/pavements](http://www.cement.org/pavements)).

Grinding of PCC pavements is done to remove surface irregularities often caused by faulting, curling, and warping of the slabs and improve smoothness. Diamond grinding as a concrete pavement restoration technique dates back to 1965, when it was first used on a 19-year-old section of the San Bernardino Freeway (I-10) in southern California to eliminate excessive faulting. Since then, diamond grinding has become a major element of PCC restoration projects.

1.3 Advantages of Diamond Grinding

Diamond grinding restores pavement-riding quality and offers numerous advantages over other rehabilitation alternatives apart from being relatively quick. It costs substantially less than an asphalt overlay, enhances surface texture and friction, consequently reducing road noise and improving safety, and for many rehabilitation projects, other characteristics of grinding also offer significant benefits (ACPA, 2000). For example, diamond grinding can be accomplished during off peak hours with short lane closures, and without having to close the adjacent lanes, which causes minimal

interference to traffic during repairs. Also, grinding of one traffic lane does not require grinding of the adjacent lane, which may have perfectly acceptable surface characteristics. The grinding operation provides a smooth riding surface that is often as good or better than new pavement. Smooth ride is achieved by removing faulting at joints and cracks, removing construction curling and moisture- gradient warping of the slabs, and other construction or environmental related roughness. It reduces accident rates in wet weather conditions by providing adequate macro texture and removing studded tires wheel-path rutting. These improvements reduce the potential for small-vehicle hydroplaning. Diamond grinding does not significantly affect fatigue life of a pavement and the material durability. Since, the diamond ground surface is nearly always dry (except during storms) it reduces any freeze thaw problems. The grinding process does not introduce any unusual conditions that would lead to poor surface durability. The hydraulic capacities of curbs and gutters on municipal streets are not affected by Diamond grinding. Conversely, bituminous overlays fill curb and gutter, reducing drainage capabilities. This is illustrated in Figure 1.1

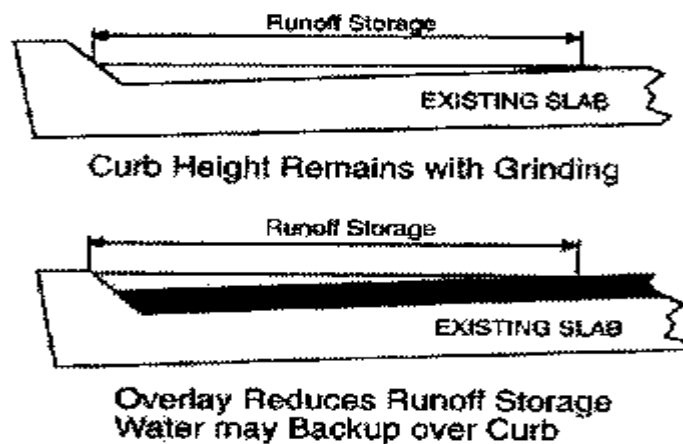


Figure 1.1 Bituminous Overlays Reduce Curb Height and Gutter Storage for Rain and Water Runoff [ACPA 2000]

Diamond grinding costs range between \$2.50/m² and \$7.00/m² (2 and \$6/yd²) although in PCC containing very hard river gravels, costs can go up to \$12/m² (\$10 /yd²). The cost depends on many factors including aggregate and PCC mix properties, average depth of removal, and smoothness specifications. It is a cost-effective technique, whether used alone or as part of an overall Concrete Pavement Restoration (CPR) program. In most cases, the diamond grinding cost is only half the cost of bituminous overlays (IGGA, 1989). Several states have compared the cost of diamond grinding with other appropriate techniques. Table 1.1 presents the cost comparisons for several comparable CPR techniques with grinding and asphalt overlay alternatives in other states.

Table 1.1 Cost Comparisons of Diamond Grinding with Other Alternatives [ACPA2000]

Location	Rehabilitation Technique	Project Size	Cost/Lane Km
North Carolina I-26	CPR with grinding	11.3 km	\$77,640
	Crack/Seal and AC Overlay	4.2 km	\$232,920
Florida I-10	CPR with grinding	106.2 km	\$38,820
	Crack/Seal and 100 mm AC Overlay	51.5 km	\$117,190
Washington I-90	Retrofit Dowel Bars with diamond grinding in truck lane	53.1 km	\$ 73,800
	Tied PCC shoulders with diamond grinding in truck lane	53.1 km	\$69,100
	110 mm AC Overlay	53.1 km	\$118,300

1.4 Diamond Grinding Equipment

Diamond grinding equipment works like a wood plane. The front wheels pass over a fault or bump. The blade assembly, set at a predetermined level across the pavement surface, produces closely spaced longitudinal saw-cut grooves. The rear wheel follows in the path left by the grinding head. The basic components of a grinding machine are shown in Figure 1.2.

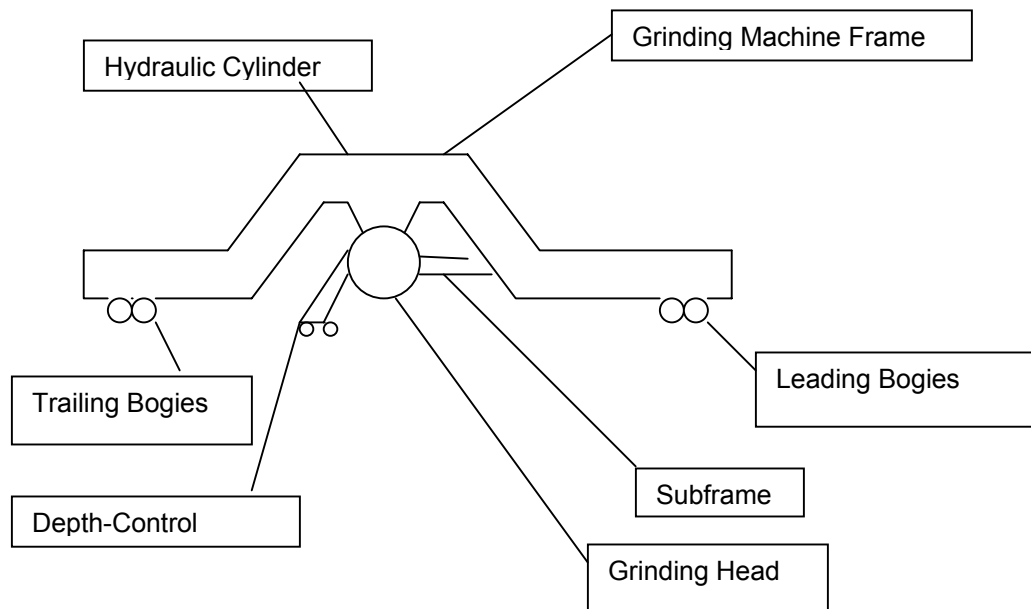


Figure 1.2 Components of a Grinding Machine [ACPA 2000]

The grinding equipment uses diamond saw blades mounted on a power driven, self-propelled machine that is specifically designed to smooth and texture PCC pavement. The grinding head that cuts the concrete is about 1m wide and consists of many diamond saw blades on a shaft. Gang mounted diamond blades are shown in Figure 1.3. Concrete pavements usually require around 18 diamond blades per 100 mm (55 blades per ft) on the grinding head. The blades should be randomly installed because they may produce an

uneven grind due to vibration. Also, the saw blade selection has an effect on grinding productivity, cost, and quality. The three factors that are important in selecting saw blades are diamond concentration, diamond size, and bond hardness.



Figure 1.3 Gang Mounted Diamond blades (left). Close up View of Diamond blades (right).

The grinding operation involves removing a thin layer (4-6 mm) at the surface of hardened Portland cement concrete using closely spaced diamond saw blades. The blade assembly cuts tiny grooves in the pavement surface, providing texture as it smoothes down surface irregularities. The grinder works in tandem with a tanker truck which supplies cooling water for the operations. The tanker truck and grinder are connected through a pair of hoses. The cooling water forms slurry with the grindings generated during grinding of the road surface. All grinding machines contain on-board wet vacuums to ensure continual removal of slurry or residue from the grinding area. The slurry pickup system leaves a damp, but relatively clean surface.

The grindings typically consist of fine stone, cement and other materials washed from the pavement. For most WSDOT operations, water constitutes about 85 to 95 % of the slurry while the solids constitute 5 to 15 %. In other states, the ratio of water to solids

is typically 50: 50. Because the aggregates are so hard, the grinding operation is more intense in Washington. This results in a higher water usage to keep the blades cool.

1.5 Problem Statement

The grinding slurry generated is typically deposited along the roadside in eastern Washington and concern has been expressed regarding potential for negative environmental impacts. The greatest potential for negative environmental impact was believed to be the slurry pH. WSDOT has documented that PCC slurry has an elevated pH level (12-13). Though diamond grinding offers several advantages as previously discussed, the slurry disposal has received considerable attention owing to its high pH. Consequently, this study was commissioned by WSDOT to identify if the slurry deposited on the roadside had any measurable impact on soil pH and to determine if compost could be used as a cost effective pH neutralization media.

1.6 Present Treatment Mechanisms for Grinding Slurry

The grinding slurry generated in the process of grinding operations has a pH in the range 12-13. The WSDOT typically uses hydrochloric acid to neutralize the pH of the slurry. The amounts of acid used last year were 0.45 to 0.95 gallons per 1000 gallons of slurry depending on the buffer capacity of the slurry and the desired final pH. WSDOT uses hydrochloric acid because it is inexpensive. Currently, compost is widely used by WSDOT in highway projects to reduce the environmental impacts of roadways due to storm water runoff where the pollutants are effectively absorbed and reduced. Also, compost is being used in significant quantities as a soil-amending agent. So, it was

decided in this study to evaluate the use of compost to neutralize alkaline pH of the grinding slurry owing to its functionality and cost effectiveness.

1.7 Research Objectives

We hypothesize that compost can be used as an effective medium to partially neutralize alkaline pH of the slurry generated during PCC grinding operations. Consequently, the primary objectives of this project were to define the impact of PCC highway grinding slurry on soil pH in disposal areas and investigate the efficacy of using compost to neutralize slurry pH prior to or during disposal. The objectives were accomplished by performing the following tasks.

- Define sampling locations where PCC slurry disposal had occurred over a range of time frames. This was done with the assistance of WSDOT personnel.
- Collect soil cores from selected locations, including cores from non-impacted areas close to the impacted areas.
- Evaluate the cores for metal concentrations (Cu, Cd, Pb, Zn, Ca, and Mg) and soil pH as a function of depth.
- Collect slurry samples from an active grinding site and analyze the samples for metals and pH. Slurry pH neutralization was evaluated by mixing slurry with locally obtained compost in varying ratios and determining pH of the mixtures.

CHAPTER 2

REVIEW OF PREVIOUS WORK

2.1 Portland Cement Concrete

PCC is widely used in transportation networks. In addition to its use for surfacing activities, PCC is the primary construction material in bridges, tunnels, over passes, and similar vital structures in our highway systems. The extensive use of Portland cement has led to the use of a large number of admixtures. These admixtures are used to improve the concrete properties with respect to workability, durability and strength. A list of common additives includes air-entraining agents (e.g., organic salts, organic acids, fatty acids and detergents), plasticizers (e.g., lignosulfates, lignosulfonic acids, sulfonated naphthalene, sulfonated melamine and zinc salts), strength accelerating agents, coloring agents, fillers (fly ash, bottom ash and furnace slag) and pumping aids.

Concerns have been aired over concrete coming into contact with water for human consumption as this account for the largest bulk of man-made material coming into contact with water in modern times (Official Journal of European Communities, 1980). The concern is centered on the cementitious materials coming into contact with water that stems from the known presence of most of the naturally occurring trace toxic metals in the raw materials used in the manufacture of cement. This concern over cementitious materials is further supported by results from a past leaching investigation involving its unhydrated form by PCA Kiln Dust Task Force (PCA Kiln Dust Task Force, 1992). PCA Kiln Dust Task Force conducted a Toxicity Characteristic Leaching Procedure (TCLP) using acetic acid on cement samples from 97 cement plants in North America. The results showed Arsenic, Beryllium, Cadmium, Chromium, Mercury,

Nickel, Lead, Antimony, Selenium, and Thorium leached in detectable concentrations. The concern over cementitious materials has resulted in the investigation by three research teams, Kanare and West (1993), Rankers and Hohberg (1991), and Germaneau et al. (1993). These teams conducted leaching investigations on hydrated cementitious materials during the 1990s. The results from these three research teams detected the presence of some trace toxic metals in the leachates sampled that seems to justify the concern being aired over the potential for concrete to leach toxic metals.

Sangha et al. (1998) investigated the long term potential of concrete to leach trace toxic metals into the environment by subjecting Portland cement concrete specimens to a laboratory leaching test that simulates environmental conditions. Also, the Portland cement used in the preparation of concrete specimens was digested using the “Lithium tetra borate ($\text{Li}_2\text{B}_4\text{O}_7$) fusion method” to determine the chemical composition of Portland cement in terms of the toxic metals being investigated (ASTM Designation E886-94, 1994). The results for the Portland cement digestions showed that arsenic (19.9 mg/kg), beryllium (1.4 mg/kg), chromium (72.7 mg/kg), lead (75.3 mg/kg), nickel (72.0 mg/kg) and vanadium (44.1 mg/kg) were detected. Antimony, cadmium, mercury and selenium were not detected. Concentrations were below 5 mg/kg for antimony and cadmium, 12 mg/kg for mercury, and 2 mg/kg for selenium. Poorly cured Portland cement concretes released detectable concentrations of vanadium; however, the leaching was restricted to the surface only.

In a study by Nelson et al. (2000) PCC (with and without plasticizer) was subjected to a complete range of tests to determine leachate characteristics and parameters for the removal/reduction/retardation (RRR factors) in a fate and transport

model. Photolysis tests and algal toxicity tests were also run on PCC leachates to further investigate the influence of pH on soluble aluminum toxicity. High levels of calcium (~700 mg/L) and significant levels of aluminum (2-5 mg/L) were found in PCC with and without plasticizer. Algal growth inhibitory effects by PCC leachates were attributed to phosphorus limitation and co-precipitation due to high levels of calcium and aluminum at alkaline pH. The report concluded that though PCC leachates contain aluminum and calcium at significant levels likely to cause algal growth inhibition, once contacted with soil or sediment, factors such as pH, competing cations, and organic complexation significantly reduce the bioavailability and subsequent toxicity of these contaminants. The results also indicated that the use of PCC with and without plasticizer should not be of concern regarding aquatic toxicity.

2.2 Studies on Grinding Slurry

Limited information exists on the impacts of grinding slurry generated during the grinding operation of PCC pavements on the environment. The International Grooving and Grinding Association performed an analysis on the grinding slurry generated from a grinding operation (IGGA, 1990). The objectives of the analysis were to determine the various components of the slurry -organics and inorganics, quantify each component and compare mass to maximum permissible limits for each component as established by the U.S. Environmental Protection Agency and the North Carolina Department of Environment, Health and Natural Resources.

The slurry samples were taken from three different work sites. Two samples were obtained from different locations on a highway grinding project in Delaware, three

samples were taken from different locations on an interstate highway grinding project in Pennsylvania and two samples were taken from different locations on a bridge deck grinding project in South Carolina. These job sites were selected because they were considered representative of most grinding work and because work was underway at the time samples were needed; the actual sample locations were selected at random and samples were obtained on different days. The slurry samples were presented to an independent testing laboratory in Charlotte, North Carolina for chemical analysis. The results of the analysis are presented in Table 2.1. The study however did not look at the pH of the slurry generated. The report concluded that the grinding slurry was non-ignitable, non-corrosive, non-toxic, and considered a non-hazardous waste under the criteria for identifying hazardous waste under 40 CFR 261.

Holmes and Narver (1997) prepared a report on sampling and analysis of concrete grinding residue associated with the grinding operation of roadway surfaces for Caltrans. Slurry samples were collected by disconnecting the hose carrying the slurry from the grinder to the tanker truck. Since decoupling the slurry hose near the grinder machine would have caused extensive splashing, the hose was disconnected at the tanker truck to allow for safe sampling. Samples were collected for inorganic analysis, organic analysis, volatile organic compound analysis, and toxicity testing. In addition to the slurry samples, fresh water used for grinding operation was also sampled to assess any potential impact of fresh water quality on the properties of the waste slurry material collected. Prior to analysis each slurry sample was separated into solid and aqueous phases (supernatant) by gravity settling.

Table 2.1 Grinding Slurry Analysis (IGGA 1990)

Sample (mg/kg)	Sample Number							Maximum Concentration Limit	
	1	2	3	4	5	6	7	EPA	NC
Arsenic	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<5.00	<0.50
Barium	0.8	1.1	0.96	2.1	2	1.65	1.8	<100	<10.00
Cadmium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<1.00	<0.10
Chromium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<5.00	<0.50
Lead	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<5.00	<0.50
Mercury	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.20	<0.02
Selenium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<1.00	<0.10
Silver	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<5.00	<0.50
Copper	3.1	1.6	1.7	2.6	3.15	2.1	1.85	NA	NA
Zinc	2.6	2.9	1.65	2.65	2.8	1.76	1.9	NA	NA
Aluminum	6570	6900	8210	7420	6840	7250	9130	NA	NA
Benzene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01
Toluene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.06	<0.01
Ethyl Benzene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.08	<0.01
Xylene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.08	<0.01
Gasoline	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<1.00	<0.10
Fuel Oil	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<1.00	<0.10
Diesel Fuel	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<1.00	<0.10
Lube Oil	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<1.00	<0.10

VOC analyses of slurry supernatant and solid samples indicated the majority of the VOCs analyzed for were not detectable except for benzene and toluene. In two of slurry supernatant samples, benzene was detected, but at levels below the Title 22 (Title 22 California Code of Regulations (CCR)) and California Drinking Water Standards. Title 22 refers to a list of heavy metals. In slurry supernatant sample, S006 the benzene concentration of 0.0011 mg/L was below the Title 22 standard (0.5 mg/L) but slightly exceeded the California Drinking Water Standard (0.001 mg/L). Toluene was detected in slurry supernatant samples at concentrations 0.00078 mg/l, 0.00057 mg/L, 0.00063 mg/L,

and 0.00071 mg/L. Toluene concentrations were all well below the California Drinking Water Standard (0.15 mg/L). No ethyl benzene, xylene, chlorinated pesticide or herbicide concentrations were detected in any of the slurry supernatant or solid samples.

The analysis of semi-volatile compounds indicated the presence of benzoic acid in all slurry supernatant samples. The benzoic acid concentrations ranged from 0.065 mg/L to 0.760 mg/L. The only other semi-volatile compound detected was phenanthrene in solid sample at a concentration of 0.43 mg/L). All slurry samples (solid and slurry supernatant) showed concentration levels for oil and grease and total petroleum hydrocarbon (TPH) above detection levels. TPH levels were between 7.9-29.0 mg/L for the slurry supernatant and 16.0-62.0 mg/Kg for solid samples. For slurry supernatant and solid samples, oil and grease concentrations ranged between 3.5-19.4 mg/L and 54.0-640.0 mg/Kg, respectively. Title 22 metals analyses indicated concentrations of barium, copper, and chromium present in all slurry supernatant and solid samples at levels below the corresponding Title 22 standards. Detectable concentrations of other metals such as antimony, arsenic, cobalt, lead, molybdenum, nickel, selenium, vanadium, and zinc were present in only a few slurry supernatant and solid samples. Cadmium was present in only one sample (slurry supernatant). Concentrations for beryllium, mercury, silver, and thallium were below detection limits in all slurry supernatant and solid samples.

Metal concentrations in a limited number of samples exceeded the California Drinking Water Standards. For the non-Title 22 metals (aluminum, magnesium, silica, iron, and calcium) analyzed in the slurry supernatant samples, concentrations of aluminum exceeded the California Drinking Water standard (1 mg/L) in samples at

concentrations of 30.2 mg/L, 2mg/L, and 3.4 mg/L. Iron concentrations in slurry supernatant samples were higher than the California Drinking Water Standard.

With respect to anionic constituents in the slurry supernatant samples, the sulfate concentrations in all samples were higher than the California Drinking Water standard. Sulfate concentrations ranged between 376 mg/L and 611 mg/L. Nitrite/Nitrate concentrations exceeded the California Drinking water Standard (10 mg/L) for slurry supernatant samples. Total cyanide concentrations in all slurry supernatant samples were significantly lower (0.02-0.03 mg/L) than the California Drinking Water standard (10 mg/L) for slurry supernatant samples S001 (17.5 mg/L), S004 (12.5 mg/L), S005 (13.0 mg/L), and S006 (14.5 mg/L). Total cyanide concentrations in all slurry supernatant samples were significantly lower (0.02-0.03 mg/L) than the California Drinking Water standard (0.2 mg/l). COD values in the slurry supernatant samples ranged between 252 mg/L and 985 mg/L. TDS concentrations varied between 1310 mg/l and 2490 mg/L S001. TSS concentrations ranged from less than 20 mg/L to 122 mg/L.

A laboratory to assess pH changes of the slurry supernatant under evaporative conditions conducted a separate experiment. The purpose of the experiment was to simulate field conditions of the off-site evaporation ponds and to determine the impact of evaporation on pH. An aliquot of each slurry sample having 10 % solid content was slowly evaporated in 24 hours at an average temperature of 36.4°C. The last reading was taken at 70°C to produce a highly concentrated solution. During the 24-hour period a total of eight pH measurements were taken. For all samples the pH values declined as the evaporation proceeded. The original pH values ranged from 9.4-11.1, while the final values revealed less alkaline conditions (pH 8.23-9.63). Also, a 96-hour Acute Toxicity

test was conducted which showed no toxicity characteristics for the slurry samples as manifested by the 100 % survival rate of the test fish (fathead minnows).

Table 2.2 Slurry Sample Analytical Results- Filtrate and Solids Inorganic Analytes (Title 22 non metals) (cited from Caltrans District 11 Task Order No.8 Final report, 1997)

Sample ID	Aluminum	Magnesium	Silica	Iron	Calcium
S001 water	ND	0.92	38.1	ND	462
S002 water	30.2	32.6	65.1	25.5	654
S003 water	ND	6.59	22.7	0.14	207
S004 water	ND	0.33	32	0.08	335
S005 water	2	15	27.1	1.72	168
S006 water	3.4	12.6	30.7	3.15	212

Table 2.3 pH Concentration Changes Under Evaporative Conditions (cited from Caltrans District 11 Task Order No.8 Final report, 1997)

Sample	* t0	t1	t2	t3	t4	t5	t6	t7
pH blank	7.08	6.08	6.39	5.98	6.91	6.93	7.1	6.7
S001	10.2	9.9	9.53	9.46	9.12	9.09	9.05	8.68
S002	10.4	10.1	9.83	9.83	9.56	9.47	9.47	9.16
S003	10.1	9.6	9.32	9.32	9.14	8.98	8.98	8.66
S004	11.1	10.5	10.2	10.24	10.18	9.97	9.97	9.63
S005	9.6	9.5	8.68	8.29	8.24	8.44	8.4	8.23
S006	9.4	9.2	8.99	8.74	8.54	8.5	8.5	8.36

* time

Diamond Surface Inc (2004) was contracted to resurface a portion of I-55 in Mississippi and slurry samples and hydrant water were collected on I-55, between exits 8 and 10, off the northbound lane just south of McComb. Three experiments were performed to neutralize the pH of the slurry with different types of acid. The acids used were sodium bisulfate (40%), sulfamic acid (20%) and hydrochloric acid. The amounts of acids used were 13.33 gallons per 1000 gallons of slurry. This is about 14 to 30 times higher than the amount used by WSDOT (Chapter 1). The samples were retested again after five days to see if the concrete slurry acted as a buffer. In addition to this, soil samples were collected at four locations. Two of the samples had concrete slurry, without acid, applied to them. The other two samples had no concrete slurry. The report concluded that concrete slurry prior to acid addition had a pH below 12.5. The acids lowered the pH of the concrete slurry. Also, it was found that the slurry did act as a buffer when the samples were retested. The results associated with the study are discussed in the Results and Discussion.

2.3 Treatment of High pH water from Hydro Demolition

The high pH water from Hydro Demolition was treated by carbon dioxide gas at one of the sites in Spokane. The pH is about 12.3. The water is pumped to the first of the two baffled, settling tanks that are gravity connected. The CO₂ tank is behind the second tank and it supplies CO₂ to the water through a hose. The water and CO₂ mix and in the outlet pH in the water is around 8. The amount of slurry-generated data could not be obtained and the only data that was obtained was the slurry was treated by CO₂ stored in 250 pound canister. This process is shown in Figure 2.1.



Figure 2.1 Treatment of High pH Water using CO₂ Gas

2.4 Why Compost?

Compost is an extremely versatile product that possesses the ability to improve the properties of soils physically, chemically, and biologically. There are several benefits of using compost on roadside applications, some of which are listed in Table 2.5. The benefit of using compost to stabilize the pH of slurry is significant. After slurry has been neutralized with compost, the disposal of slurry blended with compost on the roadside will not modify the pH of the soil greatly, as the compost has the ability to buffer or stabilize soil pH. Also, organic matter tends to bind heavy metals reducing their leachability.

Table 2.5 Benefits of Using Compost

1. Improves the soil structure, porosity, and bulk density, thus creating a better plant root environment.
2. Increases infiltration and permeability of heavy soils, reducing erosion and runoff.
3. Improves water holding capacity in sandy soils, reducing water loss and leaching.
4. Supplies a variety of macro and micronutrients.
5. Controls or suppresses certain soil-borne plant pathogens and nematodes.
6. Supplies significant quantities of organic matter.
7. Improves cation exchange capacity of soils, improving their ability to hold nutrients for plant use.
8. Supplies beneficial microorganisms to soils.
9. Improves and stabilizes soil pH.
10. Can bind and enhance degradation specific pollutants

Adapted from 'The *Field Guide to Compost Use*'. US Composting Council 1996

2.5 Compost Applications

Compost has been successfully utilized in a number of roadside applications. Some examples are erosion and sediment control, reclamation, remediation of contaminated soils by explosives, and wetlands. These examples are discussed below.

2.5.1 Erosion and Sediment Control

Research and field studies have shown that compost can often out perform conventional slope stabilization methods, such as hydroseeding, hay/straw mulching and geotextile blankets. Compost, composted mulches and compost blends are used as a soil 'blanket' or 'cover', and typically placed on up to 2:1 slopes at an application rate of 2 to 4 inches. In areas of lower flow and on less severe slopes lesser application rates are employed. The compost layer not only absorbs the energy of the rainfall that causes the movement of soil particles, but also absorbs a substantial volume of moisture, as well as reducing its flow velocity, improving moisture percolation into the soil. A bulldozer,

grading blade and pneumatic blower are typically used to place the soil 'blanket'. In a research performed for Portland Metro (W& H Pacific, 1993), yard trimmings were capable of not only controlling erosion, but also of filtering, binding and degrading contaminants from the storm water passing through the organic layer.

Research and field experience has also shown that the use of compost berms, that can be placed at the base of slopes and around construction sites, are effective in sediment control. These filters can even be used in conjunction with silt/sediment fences in areas of heavy flow. In a research by the New England Transportation Consortium (Demars et al, 2001), wood waste materials were effective as mulch for erosion control or as a filter berm at construction sites, to prevent eroded soil from leaving the site. In the Portland Metro research (W&H Pacific, 1993) it was also documented that compost filter berms (83% reduction) can be twice as effective as sediment fences (39% reduction) in reducing the total solids in runoff.

2.5.2 Reclamation

Compost has also been extensively used in reclamation of marginal and low quality soils. In the reclamation process, the sites benefit through improved soil quality, reduced erosion, enhanced plant establishment, immobilizing toxic metals and supplying microbes. In a research performed by Dr. William Sopper of Penn State University, compost and biosolids were applied to a gravelly site, possessing a low pH and organic matter content, and contaminated with zinc (The Composting Council Research and Education Foundation, March, 1997). Within fifteen months of the application, the hillside was covered by a combination of orchard grass, tall fescue and crown vetch.

Newly planted trees showed a survival rate of over 70 %. In this example, the compost not only supplied plant nutrition and moderated soil pH, but also established a nitrogen and organic matter cycle in the soil and immobilized heavy metals, by both reducing their leachability and adsorption by plants. By establishing vegetation on soils contaminated with heavy metals, water erosion can be minimized, thus reducing the transfer of pollutants. The physical structure of the compost-amended soil is also improved, increasing soil porosity and moisture infiltration, thus reducing run-off.

2.5.3 Remediation of contaminated soils by explosives

At more than 30 munitions sites across the United States, the soils are contaminated with explosives. The U.S. military has found that the use of finished (mature, cured) compost can effectively remediate munitions-contaminated soils (USEPA, 1997). To remediate a site, the soil is excavated and mixed with other feedstocks. The end product is a contaminant-free soil, containing nutrient-rich humus that can enhance landscaping and horticultural applications. The composting costs are considerably less than soil excavation and incineration, the traditional method used for the cleanups.

Compost has been successfully used to convert 15,000 tons of contaminated soil into safe soil containing humus by the Umatilla Army Depot in Hermiston, Oregon. The military saved approximately \$2.6 million by using composting instead of incineration. Clean-up goals for Umatilla were established at concentrations of less than 30 milligrams per kilogram for 2, 4, 6-trinitrotoluene (TNT) and Royal Demolition Explosives (RDX).

The project achieved nondetectable levels of explosives. Contaminant byproducts were either destroyed or permanently bound to soil or humus.

The success at Umatilla indicates that composting of explosive-contaminated soil is a cost-effective and environmentally sound clean-up method. Millions of dollars could be saved if the composting process were used rather than conventional incineration to clean up contaminated soils at these and other military operations in the United States. Other sites using composting for explosives include the U.S. Naval Submarine Base in Bangor, Washington; the Navy Surface Warfare Center in Crane, Indiana; and the Sierra Army Depot in Herlong, California.

2.5.4 Wetlands

In the last three decades organic matter in the soils of wetlands in the United States has decreased steadily. According to Dr. Donald Hey, an expert in flood plain management, more than 100 million acres of U.S. wetlands have been drained, and currently the wetlands contain only about half the amount of organic matter they contained in the 17th century (USEPA, 1997). As a result, annual floods have worsened, ground water quality has deteriorated, and wildlife diversity has declined. Compost, with its high organic matter content, can absorb up to four times its weight in water and can replace essential organic material in wetlands. With the rapid urbanization, wetlands are being destroyed in the construction of roads and other structures. Re-establishment of wetlands as a means of improving water quality is becoming a vital component. The goal of any wetlands mitigation project is to develop a wetland that functions well in terms of hydrology, soil properties and plant community composition.

Compost, because of its high organic matter content, water holding capacity, and microbial activity, is an excellent component to manufactured wetland soils. In developing an effective wetlands media using compost, it is important to understand the soluble salt and nutrient levels of the compost and their relationship to the wetland plants being established. The wetland construction mixes must be developed in such a manner so that they have similar characteristics to the surrounding soils, and for that reason, manufacturing wetland must be done on a case-by-case basis (Alexander, 1999).

2.6 Compost use by Washington State Department of Transportation

Compost has been successfully utilized by many state DOTs in a number of highway related projects. The WSDOT also completed a project that involved soil bioengineering on problematic slopes (Lewis et al., 2001). One of the objectives of this study was to provide viable alternatives known as soil bioengineering for slope and shallow rapid landside stabilization along different roadside environments. Compost was used as a part of soil bioengineering solution. The Class A composted biosolids used on one of the sites improved soil workability and enhanced plant growth.

CHAPTER 3

EXPERIMENTAL METHODS

3.1 Sample Collection

Soil samples were collected from I-90 and SR-195 where PCC slurry disposal had occurred over a range of time frames. Figure 3.1 shows a map of I-90 and SR-195 where the soil samples were collected. The details of the various resurfacing projects by WSDOT and the time they were done are presented in Table 3.1. A location on SR-195 where the soil sample was collected is shown in Figure 3.2. Samples were collected at intervals of 10 cm to approximately a depth of 30 cm. Additionally soil samples were also collected in the non-impacted areas and used as background samples. As soil samples require no preservation prior to analysis, the soil samples were simply stored at 4°C. Also, slurry samples were collected from the SR-195 (Eastern region) project, the Starbird Road project and the Bellingham project. The two composts used for the neutralization of PCC grinding slurry were WSU and EKO composts obtained from a local garden and landscaping shop (SYG Nursery). The characteristics of the two composts are presented in Table 3.1. A difference in the treatment effect is expected because the pH of the two composts differs by 0.9 units.

Table 3.1 Characteristics of WSU and EKO Composts

Composts	Parameters				
	pH	Zn (mg/Kg)	Cu (mg/Kg)	Cd (mg/Kg)	Pb (mg/Kg)
WSU	7.96	19.025	4.065	1.26	1.275
EKO	7.14	134.075	41.24	1.445	3.655

3.2 Soil pH

The pH of all soil samples were measured using the saturated paste procedure prior to acid digestion of the soil samples (USEPA Method 200.7). About 20-25 g of soil was taken in a plastic beaker and DI water was added slowly in increments. The soil was stirred frequently while adding water and addition of water was stopped until a shiny, glistening surface was obtained on the soil. The beaker was tapped a few times on the table to expel air and allowed to sit for a minute or two. Additional DI water was added if the surface no longer glistened. Soil was added if there was standing water. The consistency of soil was such that it flowed slightly. The saturated paste was allowed to stand for 35-40 minutes and centrifuged enough to obtain a clear supernatant. The pH meter was calibrated according to the manufacturer's recommendations. A pH (Fisher Accumet) electrode was then placed in the clear supernatant and the pH reading was taken.

Table 3.2 Resurfacing projects of WSDOT

Contract	SR	Project Name	Year
4107	90	Kachess River to Yakima River	1992
4235	90	Easton Hill to Yakima River	1993
4902	90	Hyak Vicinity to Ellensburg-Phase1	1997
5144	195	Bridge 195/34 to Bridge 195/38	1997



Figure 3.1 Map of I-90 and SR-195

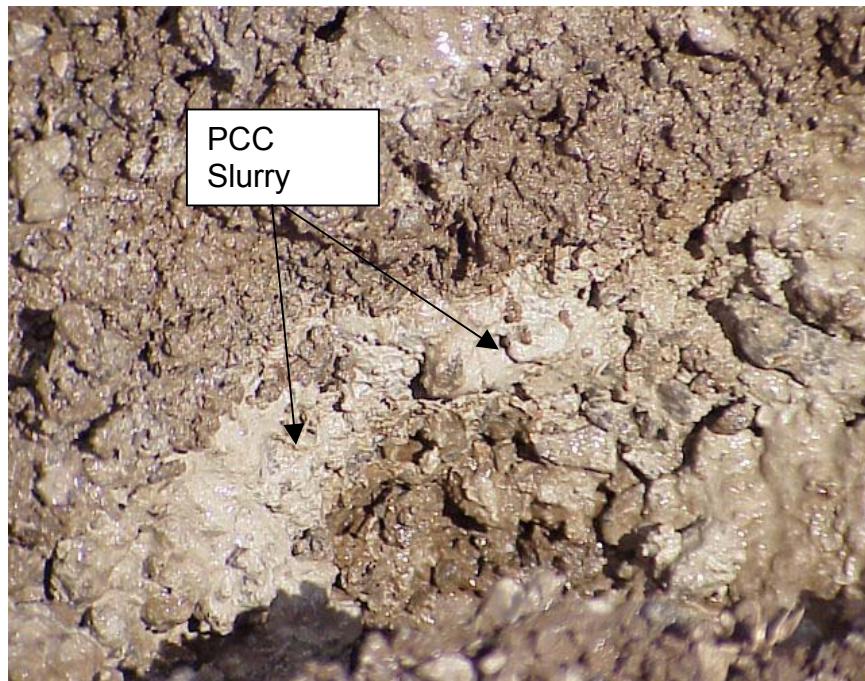


Figure 3.2 Photograph of a Sampling Location along SR-195 showing a layer of PCC slurry

3.3 Determination of Metals by Inductively Coupled Plasma Mass Spectrometry

The soil samples were analyzed for the metals by the acid digestion procedure (EPA Method 200.7). For the determination of total recoverable analytes in soil samples, the soil sample was mixed thoroughly and a portion of the sample (>20g) was transferred to a tared weighing dish. The sample was weighed and the wet weight (WW) was recorded. For samples with <35 % moisture a 20 g portion was sufficient. For samples with moisture >35% a larger aliquot (50-100g) was required. The sample was dried to a constant weight at 60°C and the dry weight (DW) of the sample was recorded. The sample was dried at 60°C to minimize the loss of mercury and other possible volatile metallic compounds, to facilitate sieving, and to ready the sample for grinding. The dried sample was sieved using a No. 5-mesh polypropylene sieve to remove large objects and ground using a mortar and pestle. From the dried, ground material an accurately weighed (1.0 ± 0.01 g) representative aliquot (W) of the sample was transferred to a 250-mL beaker for acid extraction. To the beaker 4 mL of (1+1) reagent grade HNO₃ and 10 mL of (1+4) HCl are added. The lip of the beaker was covered with a watch glass and the beaker was placed on a hot plate for reflux extraction of the analytes. The hot plate was located in a fume hood and previously adjusted to provide a reflux temperature of approximately 95°C.

The sample was heated and gently refluxed for 30 minutes. Very slight boiling occurred, however vigorous boiling was avoided to maintain an azeotropic mixture. About 3 to 4 mL of solution evaporated. The sample was allowed to cool and the extract

was transferred to a 100-mL volumetric flask. The extract was diluted with DI water and the flask was stoppered and mixed thoroughly. The sample extract solution was allowed to stand overnight and filtered prior to analysis. The acid extracts were stored at 4°C prior to analysis. Copper, cadmium, lead and zinc were quantified by inductively coupled argon plasma mass spectrometry (ICP-MS, HP 4500 Plus). Since the soil samples were believed to have high concentrations of calcium and magnesium, particularly in the slurry disposal areas, the acid extracts were analyzed by inductively coupled argon plasma optical emission spectrometry (ICP-OES, Perkin-Elmer Optima 3200RL) for those elements, as it is better suited for calcium analysis and for high concentration samples. The slurry samples, cuttings and paste material were also analyzed for metal concentrations. Prior to analysis, the slurry sample was separated into solid and aqueous phases (slurry filtrate) by filtration. The solid material retained was dried and extracted for total metals.

3.3.1 Calibration Standards

Mixed calibration standards of 25 mg/L, 50 mg/L and 100 mg/L were prepared by combining the appropriate volumes of the metal stock solutions in 1-L volumetric flasks. Charles Knaack in the WSU Center for Multiphase Environmental research lab prepared the standards. The stock solutions were separately analyzed for possible spectral interference. Calibration standards were verified for stability by using quality control standards.

3.3.2 Blanks

Three types of blanks are used in this method. A calibration blank was used to establish an analytical calibration curve. A laboratory reagent blank was used to assess possible contamination from the sample preparation procedure. A rinse blank was used to flush the instrument uptake system and nebulizer between standards, instrument performance check solutions, and samples to reduce memory interferences. Instrument Performance Check Solution is a solution of method analytes used to evaluate the performance of the instrument system. It was prepared in the same acid mixture as the calibration standards by combining method analytes at appropriate concentrations.

3.3.3 Instrument Calibration and Sample analysis

The instrument was calibrated according to the manufacturer's recommended procedure. The instrument configuration and operating conditions met with the analytical requirements of maintaining quality control data. The instrument was calibrated for the analytes to be determined using the calibration blank and calibration standards. A rinse blank was used to flush the system between solution changes for blanks, standards and samples. Sufficient rinse time of 5 seconds was allowed to remove traces of previous samples. Standards were run before the sample run and also at the end of sample run. The Method Detection Limits (MDL) for the metals analyzed for are presented in Table 3.2. MDL is the minimum concentration of an analyte that can be identified, measured, and reported with 99% confidence that the analyte concentration is greater than zero.

Table 3.3 Total Recoverable Method Detection Limits (MDL)

Analytes	MDLs
	Solids, mg/kg ⁽¹⁾
Cu	0.5
Cd	0.2
Pb	2
Zn	0.3
Ca	2
Mg	3

(1) Estimated, Calculated from aqueous MDL determinations

3.4 Alkalinity of Slurry and Cooling Water

The alkalinity of slurry filtrate and the water used for cooling the blades were also determined by the procedure (Alkalinity 2320) outlined in Standard Methods.

3.5 Chemical Oxygen Demand

The COD of the slurry sample was also determined by the Hach Dichromate Reactor Digestion Method followed by Colorimetric Measurement. The procedure involved homogenizing 100 mL of sample and pipetting 2 mL of sample into COD reaction vials and then heating the vials for 2 hours in a COD reactor. After two hours, the reactor was turned off and the vials were cooled to room temperature. The absorbance values were then recorded with the wavelength of the spectrophotometer set to 420 nm.

The sample was analyzed using COD reaction vials and the sample concentration was determined by plotting the data on the standard curve.

3.6 pH Neutralization Experiment

Grinding slurry collected from the resurfacing sites at SR-195, the Starbird Road project and the Bellingham project was blended with WSU and EKO compost over a range of slurry:compost ratios. Prior to this the pH and the metal concentrations of WSU and EKO composts were also determined. The pH of the compost was measured by the procedure used for measuring soil pH. The slurry:compost mixtures were allowed to age for at least 24 hours. During the aging period, the pH was monitored and recorded. When the compost added to slurry was increased, the slurry:compost consistency was such that it did not flow. In that case, DI water was added to a small portion of the slurry: compost mixture and the pH of the extract was measured. The neutralization experiments were started by neutralizing 5 L of slurry with 0.5 kg of compost. The amount of compost used to neutralize the slurry was then increased to 1 kg and it was used to neutralize 5 L of slurry separately to determine if the amount of compost had any effect on pH reduction. In this experiment, the pH of the slurry over time was not monitored. So, it was decided to monitor the pH of the slurry as well in the subsequent experiments. Neutralization experiment was then carried out with 100 mL of slurry with 75 g of compost. In the neutralization of 100 mL of slurry with the 75 g of compost, the pH measurements were taken for a week to study the effect of time on pH reduction of the slurry as well as the slurry:compost mixture. The Accumet pH Meter was used to monitor the pH of the slurry as well as the slurry:compost mixtures.

3.7 Total Suspended Solids

The Total Suspended Solids of the slurry was determined by the Standard Method Procedure Total Suspended Solids (2540 D).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Soil pH

The pH of the soil in the non-impacted area on SR-195 was in the range 6.3-7.5 that is typical of soils found in this region. On the other hand, the pH of the soil in the slurry disposal area ranged from 7.6-9.4 indicating that the soil in the receiving area is slightly alkaline to strongly alkaline. This can be ascribed to the alkaline pH of the grinding slurry that is deposited along the roadside. This clearly indicates that slurry application can increase the soil pH. Soil pH within the slurry disposal area on I-90 was in the range 7.1-8.2 indicating that the soil is slightly alkaline to medium alkaline while the soil in the non-impacted area ranged from 7.1-7.2 indicating slightly alkaline soil. The slurry disposal location on SR-195 where the pH was highest is 1 unit above the highest pH value on I-90. This difference is due to the time difference over which slurry disposal occurred in the past. The last resurfacing activity at the particular location on SR-195 was done in 1997 while that on I-90 was done in 1993. Soil pH increased with depth as bases are leached down the profile. Soil pH increased with depth at almost all locations on both SR-195 and I-90. This anomaly can be explained by the fact that soil pH differs significantly due to localized variations within the soil, even with different buffering mechanisms such as hydroxyaluminum ions, CO₂, carbonates and cation exchange reactions that buffer pH to varying extents. The soil pH on SR-195 and I-90 are presented in Figures 4.1 and 4.2. In the graphs shown below the numbers on the x-axis denote the milepost locations where soil samples were collected, the y-axis shows the depth at which the soil samples were collected. BG denotes the background samples.

A t-test that compares the actual difference between two means in relation to the variation in the data was performed on the data from SR-195 and I-90 using the Analysis Toolpak of Microsoft Excel. The results showed that the means of soil pH at the surface were significantly different while the means at a depth of 10 cm and 30 cm were not significantly different. The data obtained from Diamond Surface Inc. are presented in Tables 4.1, 4.2 and 4.3. The initial pH data of the slurry from Diamond Surface Inc. is presented in Table 4.1. In the data obtained from Diamond Surface Inc, the pH of the slurry prior to the addition of acids on the day 1 was in the range 11.18 -11.44. After the acids were added to the slurry, the pH measurements were made and the pH reduction with hydrochloric acid was found to be highest followed by sulfamic acid and sodium bisulfate. The pH data recorded after 15 minutes indicated that the slurry with hydrochloric acid had a pH of 6.52 while that with sulfamic acid and sodium bisulfate had a pH of 10.2 and 10.42 respectively. Hydrochloric acid was the most effective acid among the acids used by Diamond Surface Inc, to reduce the pH of the slurry. However, when the pH was recorded after 30 minutes it was found that the pH of the slurry with acid was higher when compared to the pH of the slurry with acid recorded at 15 minutes. The pH of the slurry with hydrochloric acid was 11.28 while that of slurry with sodium bisulfate and sulfamic acids were 11.11 and 10.38 respectively. The results indicated that slurry did act as a buffer when the samples were test. The pH data of the slurry tested after 5 days is presented in Table 4.2. Diamond Surface Inc. also collected soil samples with the slurry deposited on the roadside and without slurry as well. The pH of the soil samples without slurry were 7.02 and 7.11 while that of the samples with slurry (No acid) were 8.08 and 7.96. The higher soil pH in the slurry disposal area on both SR-195 and I-

90 in comparison to the soil pH in the non-impacted area (background sample) correlates with the data obtained from Diamond Surface Inc. This confirms that slurry application on the roadside does increase soil pH.

**Table 4.1 Initial pH data on 4/28/04
(Diamond Surface Inc, 2004)**

Sample	Acids		
	Sodium Bisulfate	Sulfamic	HCl
Hydrant water	6.75	6.57	6.68
Raw Slurry before acid	11.18	11.44	11.39
Slurry after acid	10.61	10.07	9.53
Slurry after 15 min	10.42	10.2	6.52
Slurry after 30 min	11.11	10.38	11.28

**Table 4.2 pH data after 5 days on 5/03/04
(Diamond Surface Inc, 2004)**

Sample	Acids		
	Sodium Bisulfate	Sulfamic	HCl
Hydrant water	7.04	6.76	6.81
Raw Slurry before acid	11.14	11.54	11.34
Slurry after acid	10.88	10.47	9.98
Slurry after 15 min	10.71	10.6	8.95
Slurry after 30 min	11.19	10.74	11.32

**Table 4.3 Soil Data
(Diamond Surface Inc, 2004)**

Soil samples with Slurry (No acid)	
Mile Marker #8	8.08
Exit 10	7.96
Soil Samples without Slurry	
Mile Marker #12	7.02
Mile Marker #13	7.11

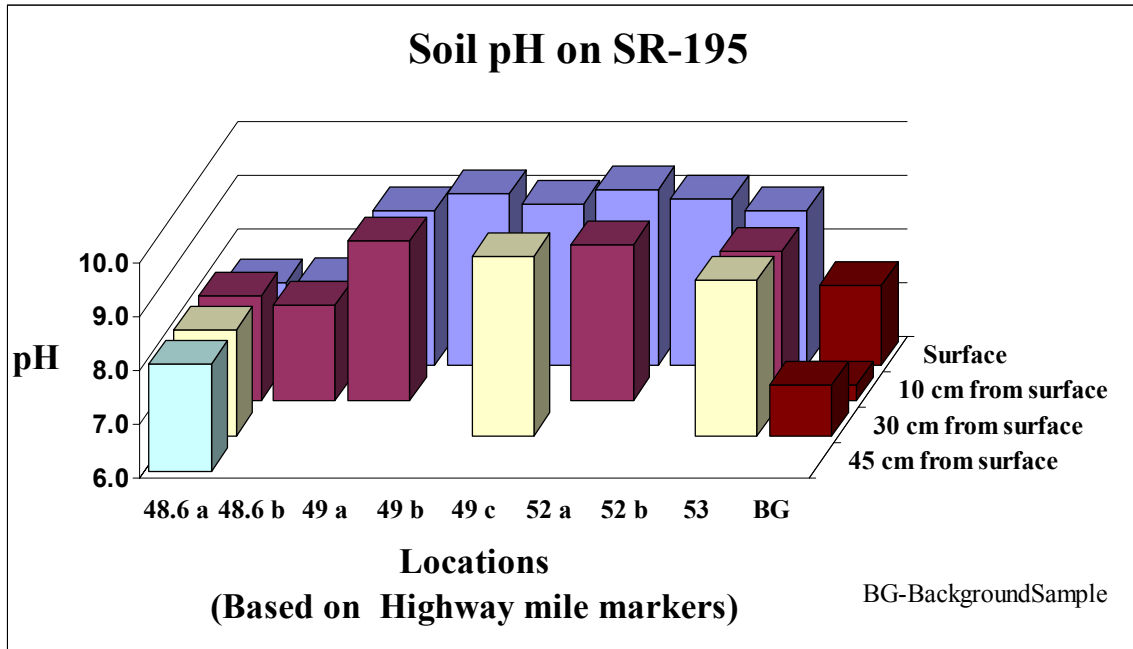


Figure 4.1 Soil pH on SR-195

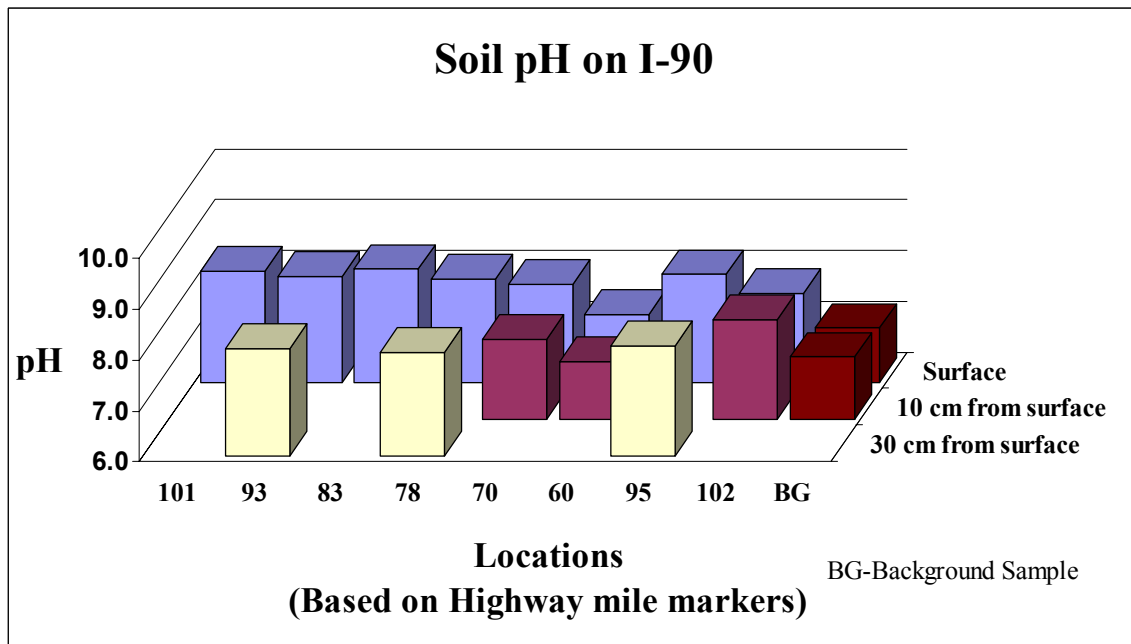


Figure 4.2 Soil pH on I-90

4.2 Metal Concentrations

In general, for those sites along I-90 where samples could be collected as a function of depth, metal concentrations decreased as the depth increased. Their limited downward movement is expected, as these metals tend to exhibit relatively high partition coefficients on soils. A similar trend was observed in the decrease of metal concentrations with depth in the samples collected along SR-195. It was not possible to collect at all depths at some locations owing to the presence of gravel and hard rocks. The surface soil concentrations of metals that were measured in soils on both I-90 and SR-195 were by no means extreme. It is well known that roadside copper, cadmium, lead and zinc concentrations depend on traffic, but high concentrations of metals at a particular location do not necessarily indicate high concentration at a location a few meters away. For instance, along SR-195 at MM 48.6 the concentrations of zinc and lead in the surface soil were 132.8 mg/kg and 32.78 mg/kg respectively, while the concentrations of zinc and lead in the surface soil at a location that was about 1 m away were 93.68 mg/kg and 77.34 mg/kg. However, the background concentrations of zinc and lead were 74.47 mg/kg and 49 mg/kg respectively. This indicates that a number of variables can be accounted for. Some of the factors are methods of soil engineering applied during the road construction, the time the road was completed and traffic started flowing, the presence of cations from deicing road salts competing with copper, cadmium, lead and zinc for exchange sites on the soil surface, storm water runoff, the presence of local industries discharging one or another of metals into the air as fume or dust, the proportion between motor vehicles using diesel oil and those that do not, the conversion of metals once they have lodged in the soil from one matrix to another one, the contents and availability of copper,

cadmium, lead and zinc that are native to the soil and the direction of prevailing wind. Therefore it is extremely difficult to quantify the concentration of metals that come from a particular source.

The metal concentrations in soils within the slurry disposal area along SR-195 were not exceptionally high when compared to the background concentrations. However, the concentration of cadmium in the background samples was below detection limit. In contrast, the cadmium contents of soil samples within the slurry disposal area revealed a range from 0.37 mg/kg-1.32 mg/kg less than the values reported earlier. The maximum lead value, which was in the surface soil at MM 52, was 97.13 mg/kg less than the maximum lead value reported by Turer et al. of about 820 mg/kg for sample from the 0-10 cm depth interval. However, the maximum lead concentration on I-90 was in the surface soil at MM 78 with a concentration of 30.4 mg/kg. The distribution of lead on highways is usually ascribed to combustion of leaded gasoline by automobiles. The presence of lead near highways has been studied by Warren and Delavault (1962) and others (Cannon and Bowles, 1962; Dunn and Bloxam, 1933; Kloke and Riebartsch, 1964; Leh, 1966; Singer and Hanson, 1969). All these studies related the distribution of lead to the density of traffic and to distances from the road. Lead with an isotopic composition typical of gasoline lead has been detected even at distances of over 100 miles from the nearest metropolitan area (Chow and Johnstone, 1965). The values of zinc in the surface soil within the slurry disposal area on SR-195 ranged from 37.25-132.8 mg/kg and the background concentration in the surface soil was 74.47 mg/kg. The concentration of zinc in surface soil within the slurry disposal area on I-90 was in the range 2.642-130.45 mg/kg, while the background concentration was 114.49 mg/kg. The background

concentrations on both I-90 and SR-195 were well within the range of values of 17-125 mg/kg as background contents of surface soils of different countries reported by Kabata-Pendias (1984).

The copper concentration in the background sample along I-90 was 56.83 mg/kg and twice higher than the copper concentration of 24 mg/kg in the background sample on SR-195. Also, the Cd concentration in background sample along I-90 was slightly higher than the concentration of samples within the slurry disposal area. The zinc, cadmium and lead concentrations in soils along I-90 are lower than the ones measured along SR-195. However, Copper concentrations were slightly higher in soils along I-90 than ones on SR-195 except for two locations where copper and lead concentrations were below detection limits. Zinc and cadmium levels were lowest at this location. No particular trend was observed in the decrease of calcium and magnesium concentrations with depth at all locations as they are influenced by factors such as pH of the soil, redox potential of the soil and the kind and amount of adsorption sites associated with the solid phase of the soil. This leads to the conclusion that slurry deposition does not affect the concentration of metals in the soil because apart from being native to the soil or derived from amendments these metals are present in the soil as a result of long-term effects of soil or climatic conditions on aerial deposits.

A t-test was performed on the means of metal data and the results are summarized below. The means of copper concentration at the surface are not significantly different while the concentrations at 10 cm and 30 cm are significantly different. With respect to Zinc, the means were significantly different at all depths. A similar trend was observed with cadmium and lead concentrations.

High concentrations of calcium and magnesium were found in soils along SR-195. However, no particular trend was found in the decrease of concentrations with depth as the concentrations were found to be higher at a certain depth than the concentration in the surface soil. This is confirmed by the fact that PCC slurry was found even at 15 cm from surface at locations within the slurry disposal area. A location where PCC slurry was found is shown in Figure 4.3. Highest concentrations of calcium were found at MM 49. It was also at this location the pH of the soil was maximum. Occurrences of high concentrations of calcium are expected because PCC has strength accelerating agents like calcium chloride, calcium acetate, and carbonates. The road deicing salts might also contribute to the very high concentration of calcium in the roadside soils.



Figure 4.3 Presence of Slurry at a location on SR-195

The background sample calcium concentration decreased with depth along SR-195. In comparison with the soils along SR-195, the soils along I-90 had relatively less calcium concentration. The highest calcium concentration along I-90 was 8,000 mg/kg almost four times less than the highest calcium concentration found along SR-195.

However, magnesium concentration in the samples were high at few locations in comparison with the calcium concentration. No particular trend was observed in the decrease of metal concentrations along the soil profile within the slurry disposal area. However, the background sample along I-90 showed a very high concentration of calcium in comparison with the soils within the slurry disposal area. The highest concentration was at 10 cm from the surface. This might be due to the number of exchange sites in the soil at that location. As stated earlier, again it is extremely difficult to quantify the exact source of calcium in soils.

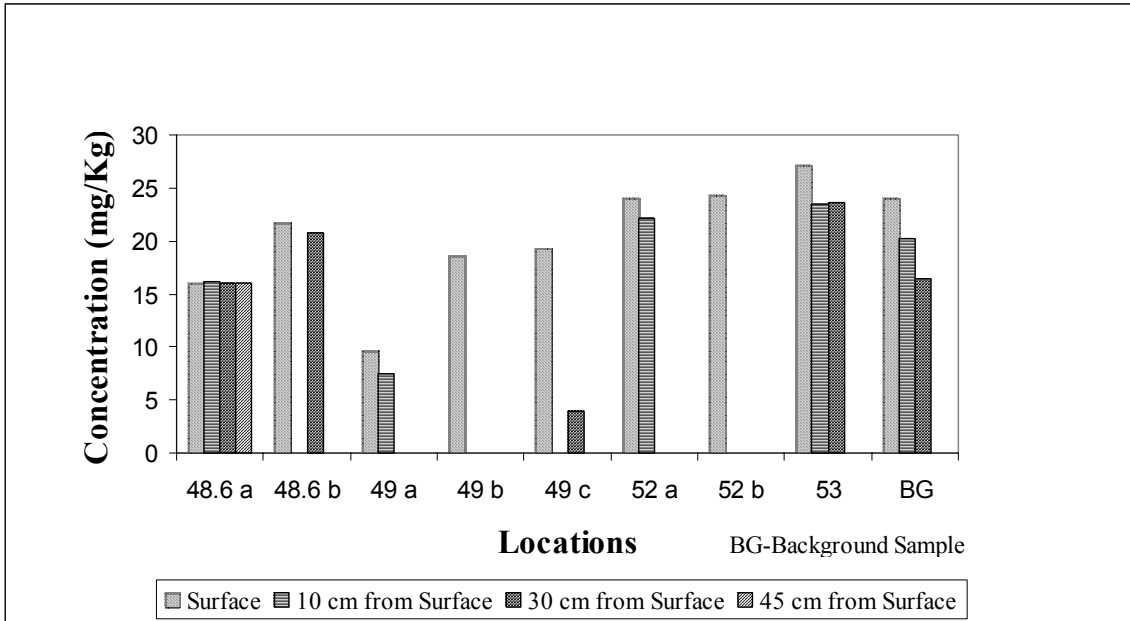


Figure 4.4 Distribution of Copper with Depth in Soil on SR-195

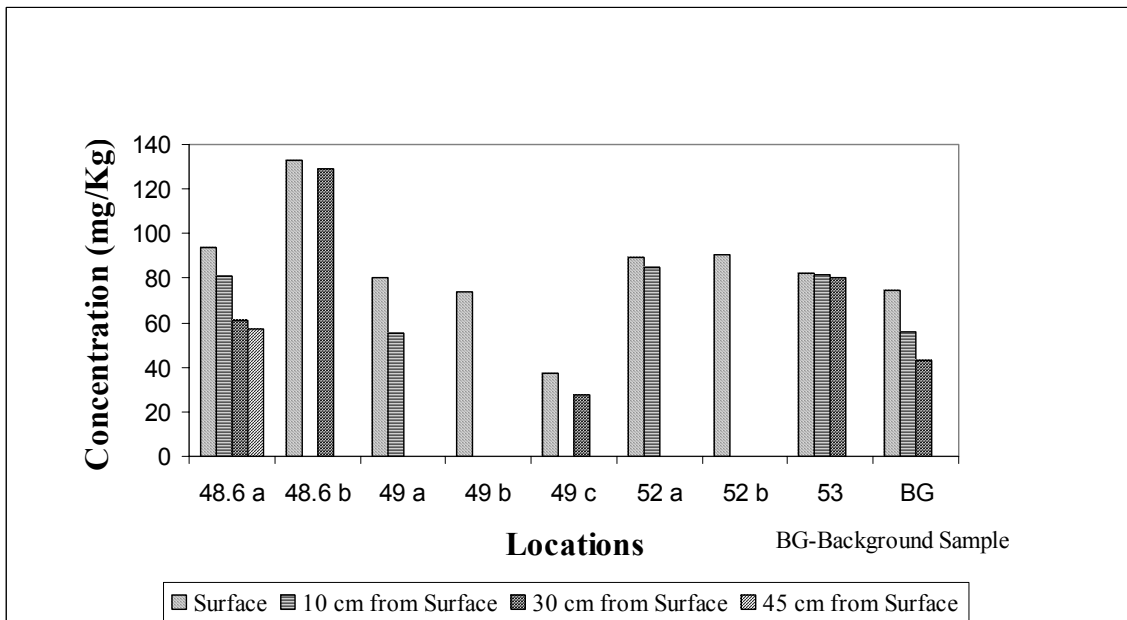


Figure 4.5 Distribution of Zinc with Depth in Soil on SR-195

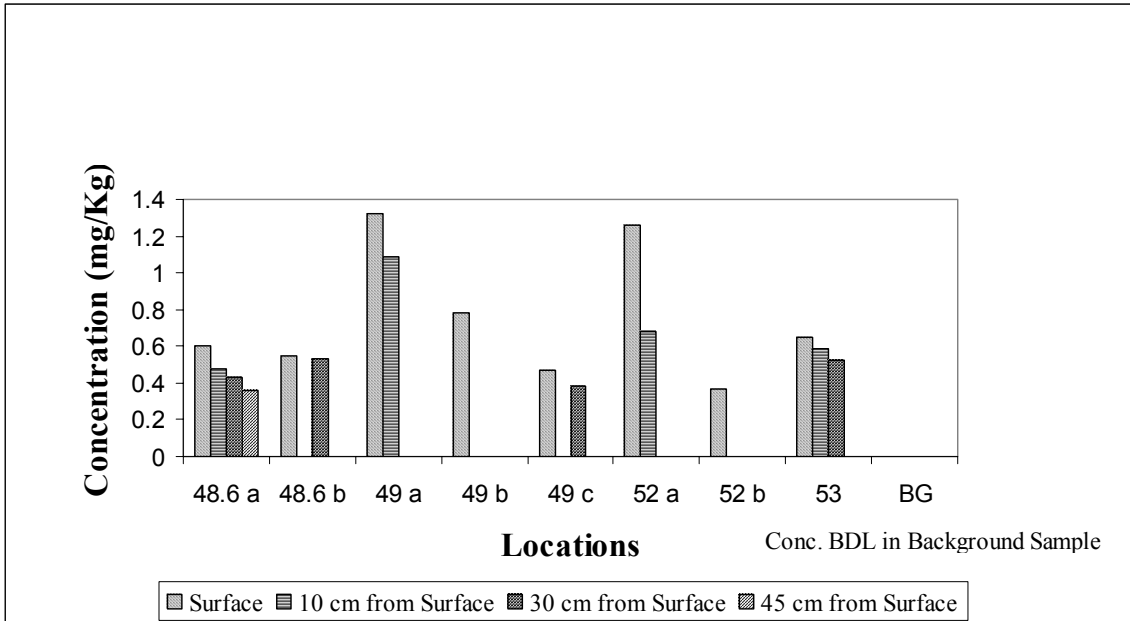


Figure 4.6 Distribution of Cadmium with Depth in Soil on SR-195

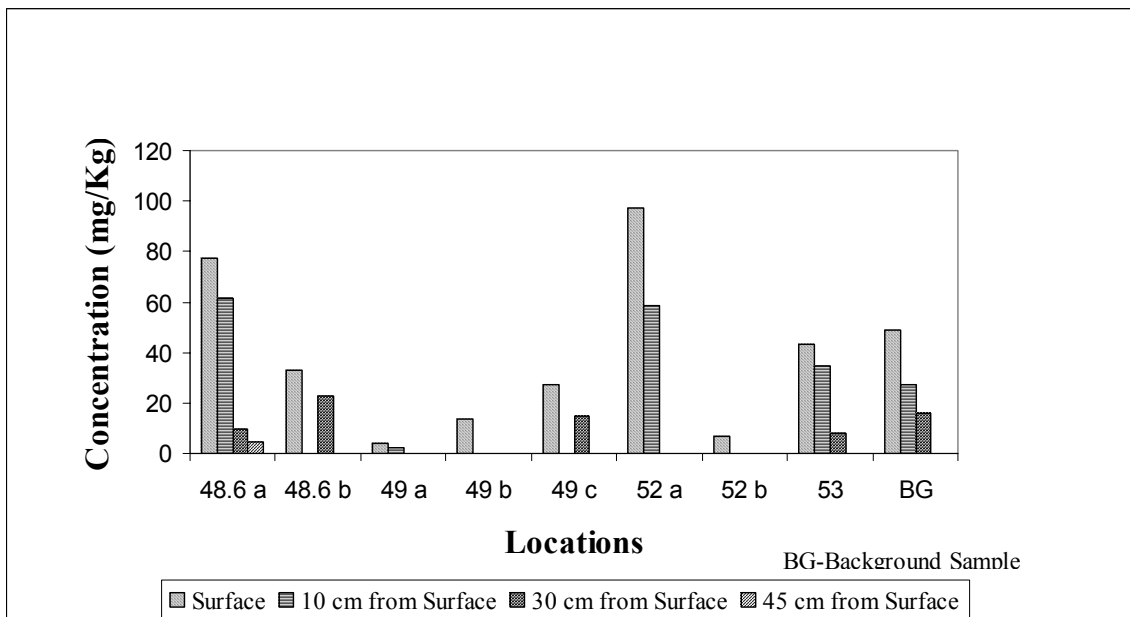


Figure 4.7 Distribution of Lead with Depth in Soil on SR-195

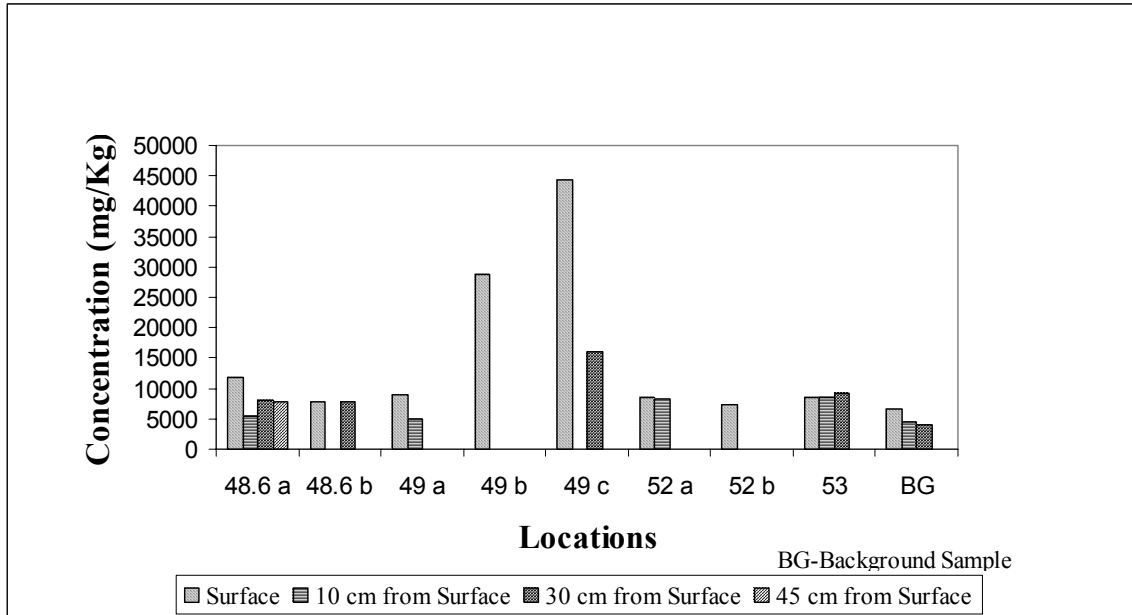


Figure 4.8 Distribution of Calcium with Depth in Soil on SR-195

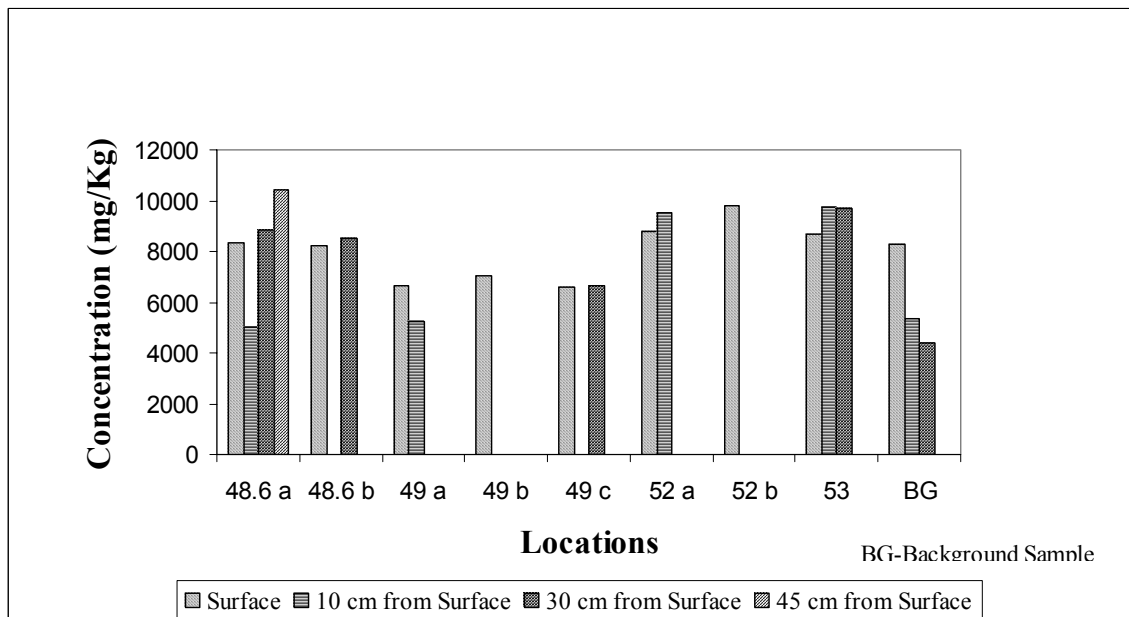


Figure 4.9 Distribution of Magnesium with Depth in Soil on SR-195

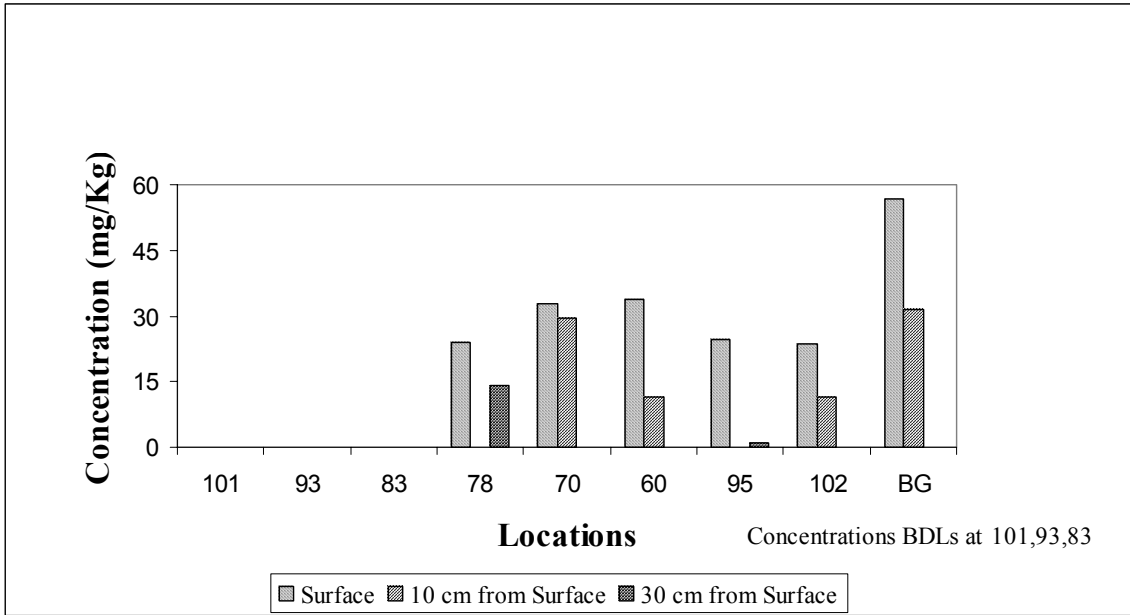


Figure 4.10 Distribution of Copper with Depth in Soil on I-90

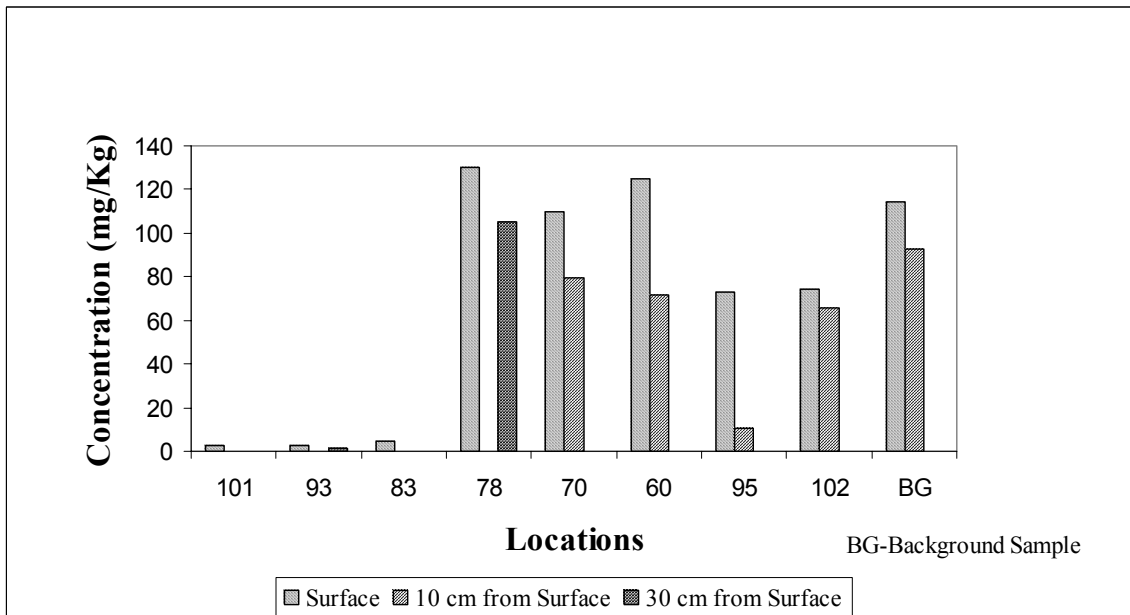


Figure 4.11 Distribution of Zinc with Depth in Soil on I-90

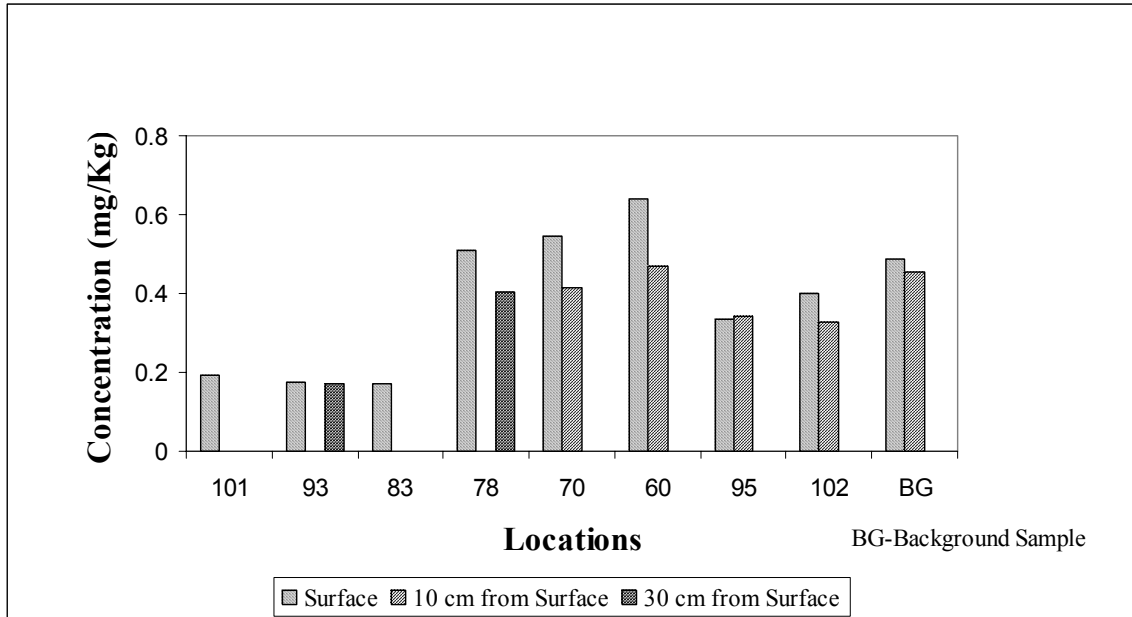


Figure 4.12 Distribution of Cadmium with Depth in Soil on I-90

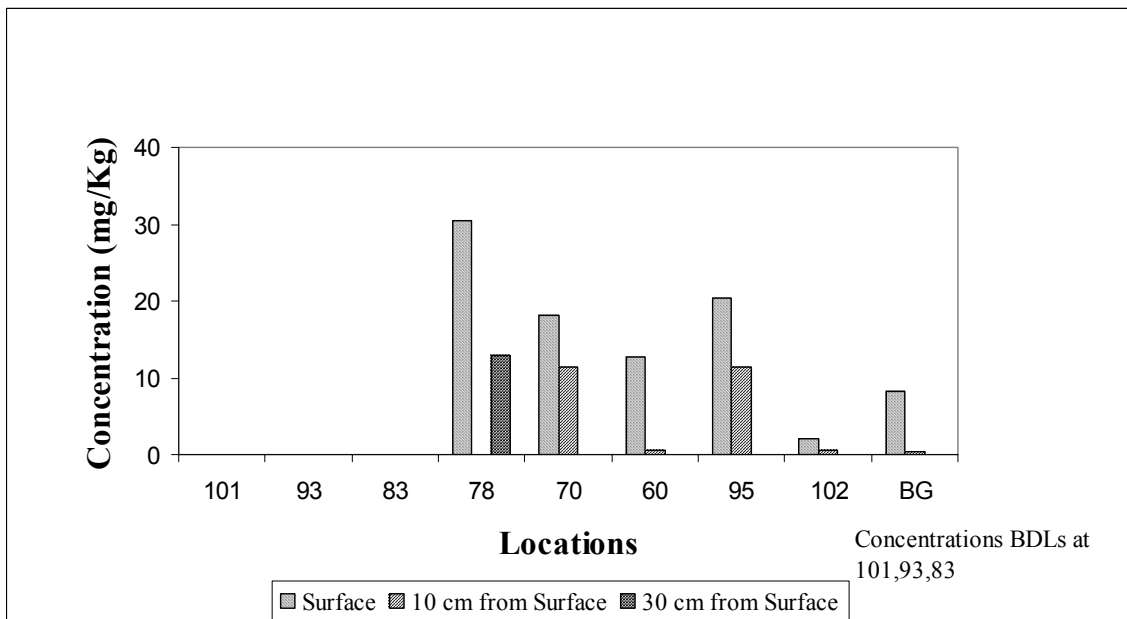


Figure 4.13 Distribution of Lead with Depth in Soil on I-90

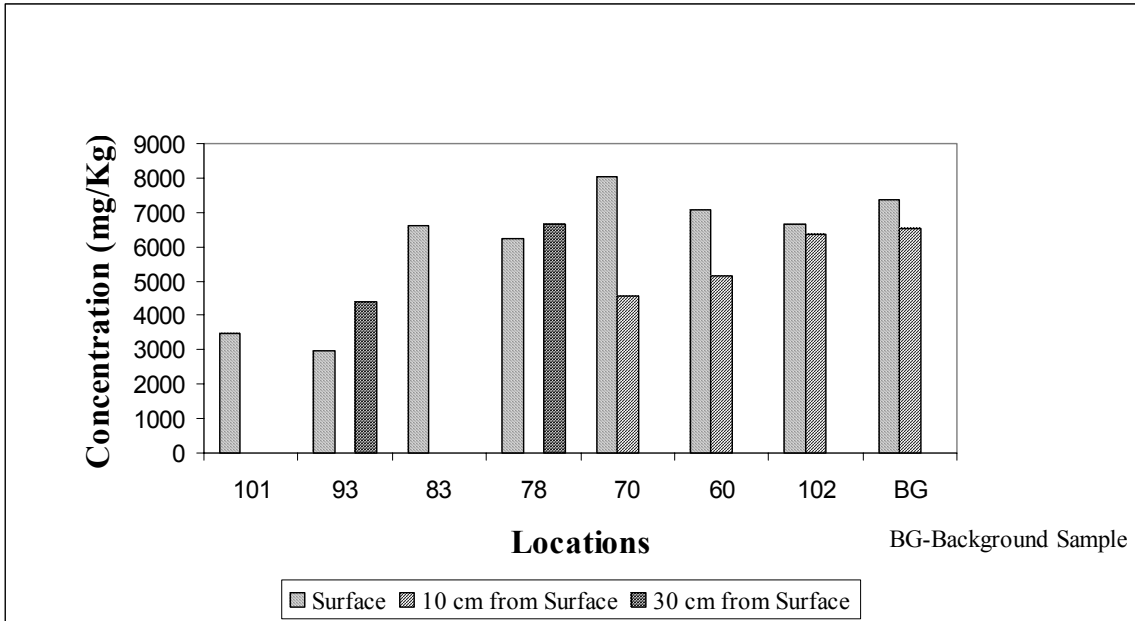


Figure 4.14 Distribution of Calcium with Depth in Soil on I-90

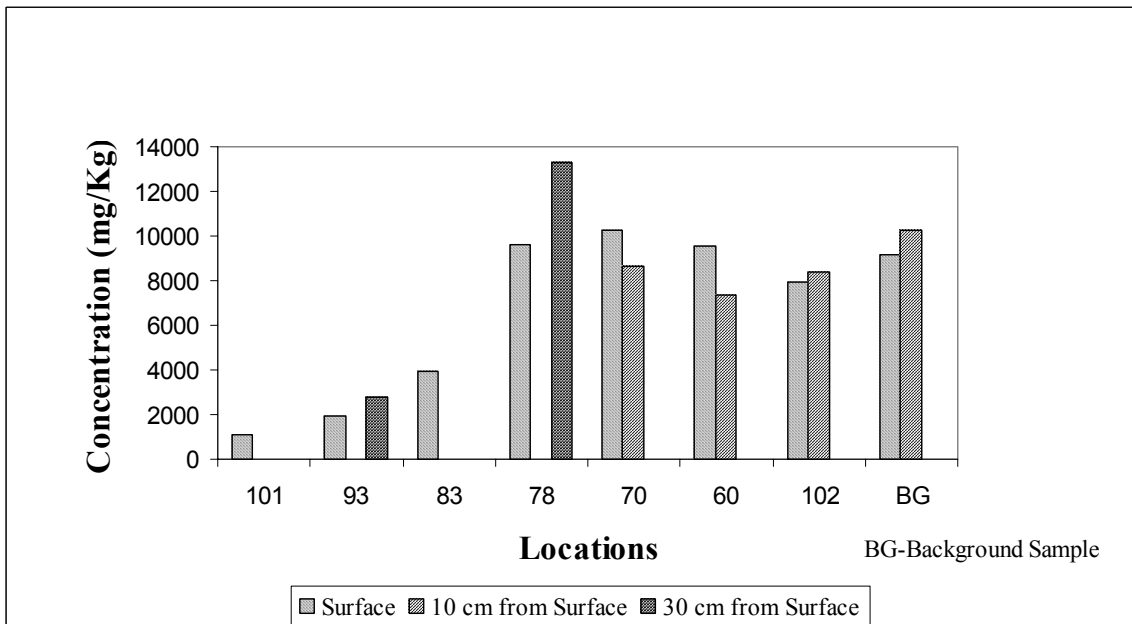


Figure 4.15 Distribution of Magnesium with Depth in Soil on I-90

4.3 pH Neutralization

The grinding slurry collected from the projects was blended with WSU and EKO compost over a range of slurry:compost ratios and pH was monitored as a function of time. Prior to the neutralization experiments, the pH of the composts used was measured. The WSU compost had a pH of 8.0 while EKO compost had a pH of 7.1. The PCC slurry used in the neutralization experiments had a pH range of 11.9-12.1. The pH reduction over time was small relative to the initial reduction. EKO compost significantly reduced the pH of the slurry in comparison with the WSU compost, likely because EKO compost was slightly more acidic than WSU compost. The pH decrease over time in the neutralization of slurry with EKO compost was not significant. A similar trend was observed with WSU compost. The pH of the slurry with WSU compost and EKO composts were 10.9 and 10.4 respectively after the compost was added to the slurry as shown in Figure 4.16. The pH of the slurry with WSU and EKO composts measured at the end of 24 hours were 10.8 and 10.3 respectively. When the amount of compost was increased to 1 kg, the pH of the slurry measured at the end of 24 hours with WSU and EKO composts were 8.3 and 8.0 respectively. This indicates that irrespective of the amount of compost added, the pH reduction was higher initially and over time the reduction was small. The slurry: compost mixture has been converted to a mass-to-mass basis in the Figures 4.16 and 4.17. The pH decrease in the slurry: compost (5 L: 1 Kg) mixture was about 2 units less than the slurry: compost (5 L: 0.5 Kg). It was decided to monitor pH of the slurry to observe if the pH of the slurry also decreased over time.

In the subsequent pH neutralization experiments the slurry pH was also measured. The neutralization of slurry was also performed using 75 g of compost for 100 mL of slurry. In this experiment, the pH measurements were taken for a week. The slurry pH was 11.9. The initial pH of the slurry: compost mixture after the slurry has been blended with WSU and EKO composts were 9.6 and 9.3 respectively. The final pH measured at the end of the week for the slurry: compost mixtures were 8.6 and 8.4 with WSU and EKO composts respectively. The slurry pH also decreased over time and the final pH measured at the end of the week was 11.8. The pH decrease in the slurry was about 0.2 units. This is shown in Figure 4.18. In all the neutralization experiments, the pH reduction was higher initially and pH reduction that followed later was not high. The pH neutralization of PCC slurry results suggests that the pH values of the slurry:compost mixtures revealed less alkaline conditions.

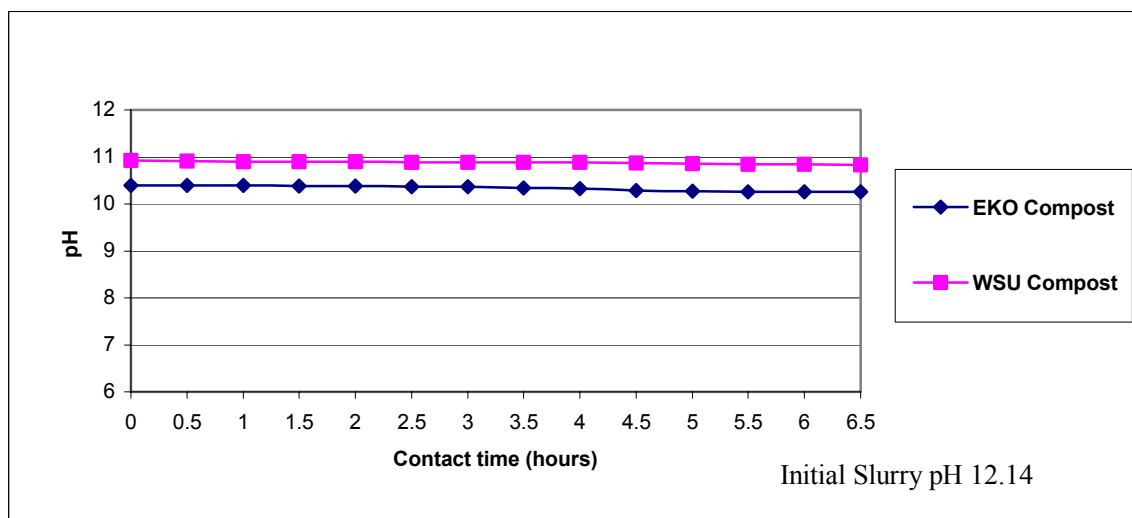


Figure 4.16 Slurry pH Neutralization at slurry:compost ratio of 10:1 w/w

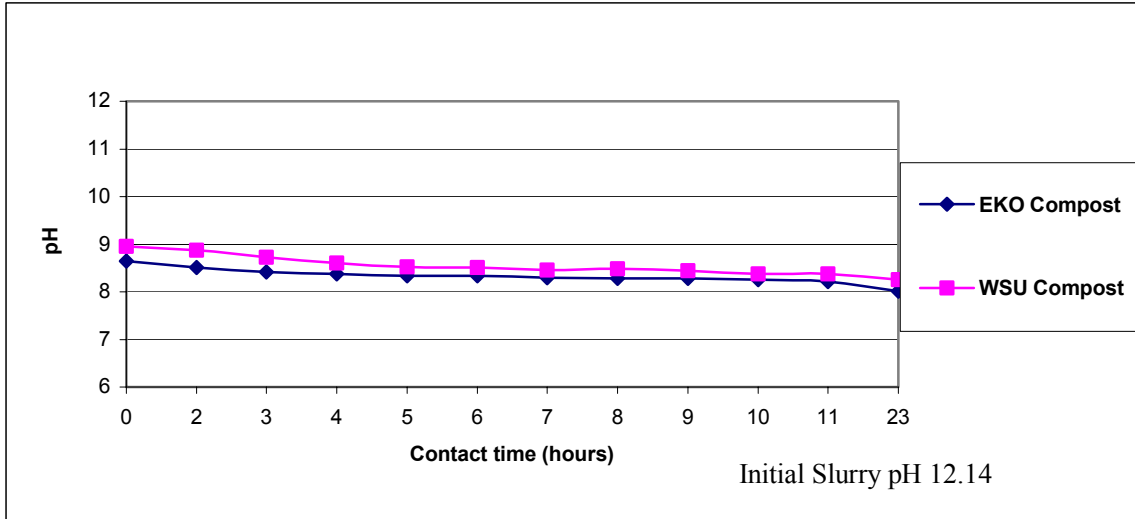


Figure 4.17 Slurry pH Neutralization at slurry:compost ratio of 5:1 w/w

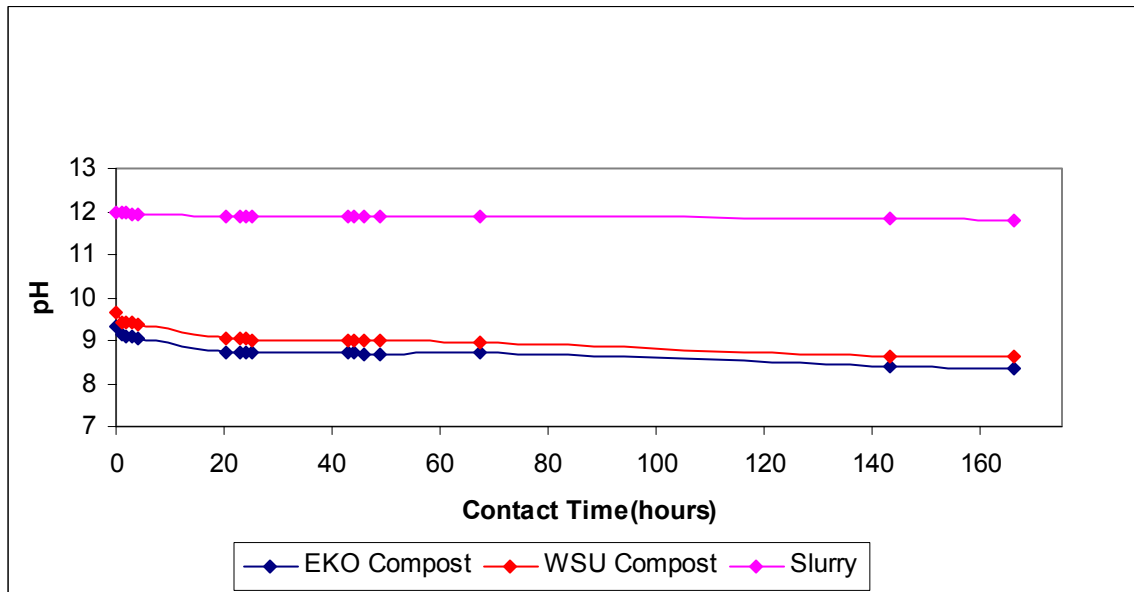


Figure 4.18 Slurry pH Neutralization at slurry:compost ratio of 1.3:1 w/w

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

Dowel retrofitting of Portland cement concrete pavements is a rehabilitation technique to improve highway smoothness and longevity. It involves cutting slots across the pavement joints, inserting the bars, patching the slots with fast-track concrete mixes, and then diamond grinding the road to obtain a smooth surface. The grinding operation produces slurry, which generally is deposited along the roadside untreated. Concern has been expressed regarding potential for negative environmental impacts due to slurry disposal. Most concern has been related to pH impacts as PCC slurry as elevated pH levels. The primary objectives of this study were to define the impact of PCC slurry on the roadside soil pH and to evaluate the effectiveness of using compost to neutralize slurry pH. The objectives were accomplished by collecting soil cores from selected locations including non-impacted areas and evaluating the soil cores for pH and metal concentrations as a function of depth. The pH of the slurry was neutralized by mixing the slurry in varying ratios with two types of compost.

5.2 Conclusions

The results indicate that soil pH was higher in slurry disposal areas in comparison with the non-impacted areas. The pH of the soil in the slurry disposal area on SR-195 ranged from 7.6-9.4 while background pH ranged from 6.3-7.5. Soil pH within the slurry disposal area on I-90 was in the range 7.1-8.2, indicating a moderate increase above the range of pH 7.1-7.2 for background samples. This indicates that slurry

application does increase soil pH in the disposal areas. With respect to the metal concentrations, the concentrations of copper, cadmium, lead and zinc decreased with depth in soil profile. However, no particular trend was observed in the variation of calcium and magnesium with depth in the soil profile. Compost was shown to neutralize the slurry pH, based on the pH neutralization experiments. The observed pH reduction ranged from about 3.5- 4.5 units below the slurry pH of 12. The minimum observed pH was 8.3 with WSU compost and 8.0 for EKO compost for slurry: compost ratio of 1.3 gallons slurry: 2.2 pounds compost. EKO compost had a greater effect on pH reduction than did WSU compost. The bulk density of the compost was estimated as 625 lbs/cu.yd. The amount of slurry generated per lane mile of grinding is 135×10^4 gallons. Based on the slurry:compost ratios of 10:1 and 5:1 the amounts of compost required to partially neutralize the slurry are presented in the Table 5.1.

Table 5.1 Amount of Compost required for partial Neutralization of Slurry

Slurry: Compost Ratio	Amount of Compost
5:1	3.6×10^4 cu.yd
	2.3×10^9 pounds
10:1	1.8×10^4 cu.yd
	1.1×10^8 pounds

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APPENDIX

Slurry Sample Analytical Results- Filtrate and Solids
Inorganic Analytes (Title 22 metals) (cited from Caltrans District 11 Task Order No.8 Final report, 1997)

Sample ID	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Lead	Mercury	Molybdenum	Nickel	Selenium	Silver	Thallium	Vanadium	Zinc
S001 water	0.006	0.01	0.1	ND	ND	0.11	ND	0.27	ND	ND	0.05	0.03	0.009	ND	ND	ND	ND
S001 solid	ND	8.4	190	ND	ND	6.8	2.4	15	6.3	ND	ND	7.9	ND	ND	ND	13.8	28.4
S002 water	0.009	0.03	4.35	ND	0.001	0.11	0.04	0.12	0.046	ND	0.04	0.11	0.004	ND	ND	0.11	0.19
S002 solid	ND	8.4	224	ND	ND	18.2	4.7	27.1	13.5	ND	ND	18.7	ND	ND	ND	21.8	46.9
S003 water	ND	ND	0.1	ND	ND	0.05	ND	0.06	ND	ND	0.02	ND	ND	ND	ND	0.03	ND
S003 solid	ND	9.7	166	ND	ND	10	1.7	22.4	9.9	ND	ND	7.7	ND	ND	ND	14.3	33.9
S004 water	ND	ND	0.08	ND	ND	0.07	ND	0.06	ND	ND	0.03		ND	ND	ND	0.04	ND
S004 solid	ND	8.7	347	ND	ND	18.5	3.2	53.8	11.8	ND	ND	32.5	ND	ND	ND	19.6	37.9
S005 water	0.004	ND	0.08	ND	ND	0.04	ND	0.002	0.002	ND	0.02	0.02	ND	ND	ND	0.04	ND
S005 solid	ND	2.3	51	ND	ND	8	1.4	3.3	3.3	ND	ND	5.3	ND	ND	ND	16.3	33.1
S006 water	ND	ND	0.1	ND	ND	0.07	ND	0.004	0.004	ND	0.04	0.02	ND	ND	ND	0.04	0.03
S006 solid	ND	2.7	66	ND	ND	9.7	2.6	5.5	5.5	ND	ND	6.8	ND	ND	ND	17.8	31.6
(mg/L) STLC*	15	5	100	0.75	1	5	80	25	5	0.2	350	20	1	5	7	24	250
(mg/kg), TTLC*	500	500	10,000	75	100	2500	8000	2500	1000	20	3500	2000	100	500	700	2400	5000
California Drinking Water Standards (mg/L)	0.006	0.05	1	0.004	0.005	0.05		1	0.5	0.002		0.1	0.05	0.1	0.002		5

* Title 22 Regulations
STLC Soluble Threshold Limit Concentration
TTLC Total Threshold Limit Concentration

Soil pH on SR-195

Mile Post	Location	LD1	LD2	Mean	pH
48.6	Surface	2.23872E-08	3.3884E-08	2.814E-08	7.55
48.6	About 10 cm from surface	1.1749E-08	9.7724E-09	1.076E-08	7.97
48.6	About 35 cm from surface	0.00000001	1.0965E-08	1.048E-08	7.98
48.6	About 45 cm from surface	8.31764E-09	1.122E-08	9.769E-09	8.01
48.6	Surface	1.44544E-08	3.9811E-08	2.713E-08	7.57
48.6	About 30 cm from surface	1.04713E-08	2.138E-08	1.593E-08	7.80
49	Surface	1.54882E-09	1.0471E-09	1.298E-09	8.89
49	About 10 cm from surface	1.12202E-09	8.7096E-10	9.965E-10	9.00
49	Surface	7.07946E-10	5.2481E-10	6.164E-10	9.21
49	Surface	1.04713E-09	8.9125E-10	9.692E-10	9.01
49	About 30 cm from surface	5.62341E-10	3.3113E-10	4.467E-10	9.35
52	Surface	5.88844E-10	4.4668E-10	5.178E-10	9.29
52	About 10 cm from surface	1.41254E-09	9.5499E-10	1.184E-09	8.93
52	Close to the edge of shoulder	6.60693E-10	9.1201E-10	7.864E-10	9.10
53	Surface	1.09648E-09	1.4791E-09	1.288E-09	8.89
53	About 10 cm from surface	1.51356E-09	1.7783E-09	1.646E-09	8.78
53	About 30 cm from surface	1.34896E-09	1.0471E-09	1.198E-09	8.92

Copper Concentration in soil on SR-195

Mile Post	Location	LD1	LD2	Mean	Concentration (mg/kg)
48.6	Surface	15.23	16.79	16.0100	16.01±0.049
48.6	About 10 cm from surface	18.74	13.56	16.1500	16.15±0.162
48.6	About 35 cm from surface	16.82	15.24	16.0300	16.03±0.05
48.6	About 45 cm from surface	18.61	13.33	15.9700	15.97±0.166
48.6	Surface	22.09	21.22	21.6550	21.655±0.027
48.6	About 30 cm from surface	21.15	20.36	20.7550	20.755±0.025
49	Surface	10.59	8.57	9.5800	9.58±0.063
49	About 10 cm from surface	6.01	9.634	7.8220	7.822±0.114
49	Surface	18.64	18.64	18.6400	18.64
49	Surface	19.83	18.69	19.2600	19.26±0.036
49	About 30 cm from surface	3.146	4.766	3.9560	3.956±0.051
52	Surface	25.86	22.3	24.0800	24.08±0.112
52	About 10 cm from surface	24.54	19.79	22.1650	22.165±0.149
52	Close to the edge of shoulder	25.3	23.27	24.2850	24.285±0.064
53	Surface	27.3	26.96	27.1300	27.13±0.011
53	About 10 cm from surface	22.24	24.83	23.5350	23.535±0.081
53	About 30 cm from surface	23.98	23.16	23.5700	23.57±0.026

Zinc Concentration in soil on SR-195

Mile Post	Location	LD1	LD2	Mean	Concentration (mg/kg)
48.6	Surface	91.27	96.09	93.6800	93.68±0.151
48.6	About 10 cm from surface	84.82	76.58	80.7	80.7±0.699
48.6	About 35 cm from surface	63.29	58.48	60.8850	60.885±0.258
48.6	About 45 cm from surface	68.3	45.99	57.1450	57.145±0.151
48.6	Surface	135.6	130	132.8000	132.8±0.176
48.6	About 30 cm from surface	117.3	140.6	128.9500	128.95±0.731
49	Surface	78.91	81.11	80.0100	80.01±0.069
49	About 10 cm from surface	50.42	60.42	55.4200	55.42±0.314
49	Surface	76.07	71.88	73.9750	73.975±0.131
49	Surface	29.49	45.01	37.2500	37.25±0.487
49	About 30 cm from surface	25.34	30.46	27.9000	27.9±0.161
52	Surface	86.3	92.57	89.4350	89.435±0.197
52	About 10 cm from surface	93.55	75.45	84.5000	84.5±0.567
52	Close to the edge of shoulder	96.12	84.36	90.2400	90.24±0.369
53	Surface	84.53	79.49	82.0100	82.01±0.158
53	About 10 cm from surface	81.16	81.49	81.3250	81.325±0.010
53	About 30 cm from surface	79.26	81.26	80.2600	80.26±0.063

Cadmium Concentration in soil on SR-195

Mile Post	Location	LD1	LD2	Mean	Concentration (mg/kg)
48.6	Surface	0.5821	0.6164	0.5993	0.5993±0.001
48.6	About 10 cm from surface	0.4908	0.4645	0.4777	0.4777±0.001
48.6	About 35 cm from surface	0.4461	0.4174	0.4318	0.4318±0.001
48.6	About 45 cm from surface	0.3572	0.3609	0.3591	0.3591±0.000
48.6	Surface	0.5387	0.5547	0.5467	0.5467±0.001
48.6	About 30 cm from surface	0.5204	0.5404	0.5304	0.5304±0.001
49	Surface	0.5492	2.088	1.3186	1.3186±0.048
49	About 10 cm from surface	0.4761	1.691	1.0836	1.0836±0.038
49	Surface	0.5635	0.9947	0.7791	0.7791±0.014
49	Surface	0.4652	0.468	0.4666	0.4666±0.000
49	About 30 cm from surface	0.3787	0.3851	0.3819	0.3819±0.000
52	Surface	0.5806	1.944	1.2623	1.2623±0.043
52	About 10 cm from surface	0.7444	0.6133	0.6789	0.6789±0.004
52	Close to the edge of shoulder	0.3901	0.3525	0.3713	0.3713±0.001
53	Surface	0.7338	0.5634	0.6486	0.6486±0.005
53	About 10 cm from surface	0.5726	0.6062	0.5894	0.5894±0.001
53	About 30 cm from surface	0.5137	0.5365	0.5251	0.5251±0.001

Lead Concentration in soil on SR-195

Mile Post	Location	LD1	LD2	Mean	Concentration (mg/kg)
48.6	Surface	82.07	72.61	77.3400	77.3400±0.297
48.6	About 10 cm from surface	86.62	36.1	61.3600	61.360±1.584
48.6	About 35 cm from surface	5.632	13.51	9.5710	9.5710±0.247
48.6	About 45 cm from surface	4.37	<0	4.3700	4.3700
48.6	Surface	31.62	33.95	32.7850	32.7850±0.073
48.6	About 30 cm from surface	21.81	23.46	22.6350	22.6350±0.052
49	Surface	4.091	<0	4.0910	4.0910
49	About 10 cm from surface	<0	2.243	2.2430	2.2430
49	Surface	14.89	12.84	13.8650	13.8650±0.064
49	Surface	29.79	25.3	27.5450	27.5450
49	About 30 cm from surface	14.52	15.3	14.9100	14.91±0.141
52	Surface	116.3	77.97	97.1350	97.1350±1.202
52	About 10 cm from surface	73.57	43.26	58.4150	58.4150±0.950
52	Close to the edge of shoulder	7.54	5.862	6.7010	6.7010±0.053
53	Surface	51.91	34.36	43.1350	43.1350±0.035
53	About 10 cm from surface	34.26	35.16	34.7100	34.7100±0.550
53	About 30 cm from surface	7.14	8.241	7.6905	7.6905±0.028

Soil pH on I-90

Mile Post	Location	LD 1	LD 2	Mean	Mean pH
101	Surface	7.94328E-09	5.2481E-09	6.596E-09	8.18
93	Surface	8.91251E-09	7.0795E-09	7.996E-09	8.10
93	About 25 cm from surface	6.30957E-09	9.7724E-09	8.041E-09	8.09
83	About 30 cm from surface	6.16595E-09	5.4954E-09	5.831E-09	8.23
78	Surface	1.07152E-08	7.9433E-09	9.329E-09	8.03
78	About 30 cm from surface	7.4131E-09	1.1749E-08	9.581E-09	8.02
70	Surface	1.44544E-08	9.1201E-09	1.179E-08	7.93
70	About 10 cm from surface	2.18776E-08	3.3113E-08	2.75E-08	7.56
60	Surface	7.24436E-08	2.884E-08	5.064E-08	7.30
60	About 10 cm from surface	9.12011E-08	5.8884E-08	7.504E-08	7.12
78	Surface	1.07152E-08	9.3325E-09	1.002E-08	8.00
78	About 10 cm from surface	7.4131E-09	5.4954E-09	6.454E-09	8.19
88	Surface	1.20226E-08	9.5499E-09	1.079E-08	7.97
88	About 15 cm from surface	8.91251E-09	7.9433E-09	8.428E-09	8.07
95	Surface	8.51138E-09	6.6069E-09	7.559E-09	8.12
95	About 30 cm from surface	7.58578E-09	6.3096E-09	6.948E-09	8.16
102	Surface	2.13796E-08	1.4454E-08	1.792E-08	7.75
102	About 10 cm from surface	1.1749E-08	1.0233E-08	1.099E-08	7.96

Copper Concentration in Soil on I-90

Mile Post	Location	LD1	LD2	Mean	Concentration (mg/Kg)
101	Surface	<0	<0	0.0000	0
93	Surface	<0	<0	0.0000	0
93	About 25 cm from surface	<0	<0	0.0000	0
83	About 30 cm from surface	0.03575	0.141	0.0884	0.0884±0.003
78	Surface	23.78	23.91	23.8450	23.845±0.004
78	About 30 cm from surface	17.9	9.993	13.9465	13.9465±0.248
70	Surface	33.85	31.54	32.6950	32.695±0.072
70	About 10 cm from surface	29.74	29.52	29.6300	29.63±0.007
60	Surface	34.04	33.71	33.8750	33.875±0.010
60	About 10 cm from surface	13.22	10.02	11.6200	11.62±0.100
78	Surface	34.04	29.68	31.8600	31.86±0.137
78	About 10 cm from surface	30.71	28.6	29.6550	29.655±0.066
88	Surface	1.125	3.173	2.1490	2.149±0.064
88	About 15 cm from surface	1.008	1.495	1.2515	1.2515±0.015
95	Surface	24.35	24.67	24.5100	24.51±0.010
95	About 30 cm from surface	1.032	0.7332	0.8826	0.8826±0.009
102	Surface	24.93	22.23	23.5800	23.58±0.085
102	About 10 cm from surface	9.742	13.02	11.3810	11.381±0.103

Zinc Concentration in Soil on I-90

Mile Post	Location	LD1	LD2	Mean	Concentration (mg/Kg)
101	Surface	2.613	2.671	2.6420	2.642±0.00
93	Surface	2.804	1.892	2.3480	2.348±0.029
93	About 25 cm from surface	1.634	1.333	1.4835	1.4835±0.009
83	About 30 cm from surface	6.979	2.743	7.5270	4.861±0.133
78	Surface	91.3	83.16	87.2300	87.23±0.255
78	About 30 cm from surface	78.48	61.82	70.1500	70.15±0.522
70	Surface	106.4	112.9	109.6500	109.65±0.204
70	About 10 cm from surface	80.03	78.42	79.2250	79.225±0.050
60	Surface	128.1	121.8	124.9500	124.95±0.198
60	About 10 cm from surface	74.96	68.29	71.6250	71.625±0.209
78	Surface	124.6	136.3	130.4500	130.45±0.367
78	About 10 cm from surface	111.3	99.34	105.3200	105.32±0.375
88	Surface	20.66	37.38	29.0200	29.02±0.524
88	About 15 cm from surface	15.7	18.93	17.3150	17.315±0.101
95	Surface	76.54	69.58	73.0600	73.06±0.218
95	About 30 cm from surface	12.94	7.839	10.3895	10.3895±0.160
102	Surface	72.3	76.41	74.3550	74.355±0.129
102	About 10 cm from surface	64.81	66.41	65.6100	65.61±0.050

Cadmium Concentration in Soil on I-90

Mile Post	Location	LD1	LD2	Mean	Concentration (mg/Kg)
101	Surface	0.1994	0.1862	0.1928	0.1928±0.000
93	Surface	0.1826	0.1636	0.1731	0.1731±0.001
93	About 25 cm from surface	0.1747	0.1663	0.1705	0.1705±0.000
83	About 30 cm from surface	0.169	0.1698	0.1694	0.1694±0.000
78	Surface	0.5228	0.4973	0.5101	0.5101±0.001
78	About 30 cm from surface	0.3927	0.412	0.4024	0.4024±0.001
70	Surface	0.5426	0.5475	0.5451	0.5451±0.000
70	About 10 cm from surface	0.3889	0.4437	0.4163	0.4163±0.002
60	Surface	0.6461	0.6313	0.6387	0.6387±0.000
60	About 10 cm from surface	0.4972	0.4423	0.4698	0.4698±0.002
78	Surface	0.735	0.7581	0.7466	0.7466±0.001
78	About 10 cm from surface	0.5392	0.5056	0.5224	0.5224±0.001
88	Surface	0.3235	0.3903	0.3569	0.3569±0.002
88	About 15 cm from surface	0.3217	0.3359	0.3288	0.3288±0.000
95	Surface	0.3427	0.3289	0.3358	0.3358±0.000
95	About 30 cm from surface	0.3422	0.3427	0.3425	0.3425±0.000
102	Surface	0.4061	0.3961	0.4011	0.4011±0.000
102	About 10 cm from surface	0.321	0.3328	0.3269	0.3269±0.000

Lead Concentration in Soil on I-90

Mile Post	Location	LD1	LD2	Mean	Concentration (mg/Kg)
101	Surface	<0	<0	0.0000	0
93	Surface	<0	<0	0.0000	0
93	About 25 cm from surface	<0	<0	0.0000	0
83	About 30 cm from surface	<0	<0	0.0000	0
78	Surface	43.4	17.4	30.4000	30.4±0.815
78	About 30 cm from surface	14.03	11.81	12.9200	12.92±0.070
70	Surface	17.19	19.12	18.1550	18.155±0.061
70	About 10 cm from surface	10.99	11.64	11.3150	11.315±0.020
60	Surface	12.77	12.82	12.7950	12.795±0.002
60	About 10 cm from surface	0.9668	0.2131	0.5900	0.58995±0.024
78	Surface	82.88	82.76	82.8200	82.82±0.004
78	About 10 cm from surface	18.94	16.81	17.8750	17.875±0.067
88	Surface	1.278	3.923	2.6005	2.6005±0.083
88	About 15 cm from surface	1.21	3.57	2.3900	2.3900±0.074
95	Surface	19.31	21.32	20.3150	20.3150±0.063
95	About 30 cm from surface	10.23	12.47	11.3500	11.35±0.070
102	Surface	2.114	1.971	2.0425	2.0425±0.004
102	About 10 cm from surface	0.4725	0.4789	0.4757	0.4757±0.000

Calcium Concentration in Soil on SR-195

Mile Post	Location	Mean Concentration (mg/Kg)
48.6	Surface	11703.5
48.6	About 10 cm from surface	5372.45
48.6	About 35 cm from surface	8002.25
48.6	About 45 cm from surface	7865.35
48.6	Surface	7758.75
48.6	About 30 cm from surface	7832.05
49	Surface	8998.9
49	About 10 cm from surface	4890.8
49	Surface	28817.5
49	Surface	44377.5
49	About 30 cm from surface	16135.5
52	Surface	8395.25
52	About 10 cm from surface	8289.2
52	Close to the edge of shoulder	7389.25
53	Surface	8417.2
53	About 10 cm from surface	8461
53	About 30 cm from surface	9144.25

Calcium Concentration in Soil on I-90

Mile Post	Location	Mean Concentration (mg/Kg)
101	Surface	3481.55
93	Surface	2982.92
93	About 25 cm from surface	4394.99
83	Surface	6613.24
78	Surface	6237.10
78	About 30 cm from surface	6672.84
70	Surface	8033.64
70	About 10 cm from surface	4546.40
60	Surface	7081.40
60	About 10 cm from surface	5165.32
102	Surface	6657.56
102	About 10 cm from surface	6380.90

**Slurry pH Neutralization
(10:1 w/w)**

Contact time	WSU	EKO
0	10.92	10.39
0.5	10.91	10.39
1	10.90	10.39
1.5	10.90	10.38
2	10.90	10.38
2.5	10.89	10.37
3	10.89	10.37
3.5	10.89	10.34
4	10.89	10.33
4.5	10.87	10.29
5	10.86	10.27
5.5	10.84	10.26
6	10.84	10.26
6.5	10.83	10.26

**Slurry pH Neutralization
(5 :1 w/w)**

Contact time	WSU	EKO
0	8.95	8.64
2	8.87	8.51
3	8.72	8.41
4	8.61	8.37
5	8.52	8.34
6	8.51	8.33
7	8.46	8.29
8	8.48	8.28
9	8.44	8.28
10	8.38	8.26
11	8.37	8.22
23	8.25	8.02

**Slurry pH Neutralization
(1.3:1 w/w)**

Contact Time	Slurry	WSU	EKO
0	11.98	9.63	9.32
1	11.98	9.44	9.12
2	11.96	9.42	9.10
3	11.95	9.42	9.09
4	11.95	9.38	9.06
20.5	11.9	9.04	8.73
23	11.9	9.03	8.73
24	11.89	9.03	8.73
25	11.89	9.02	8.72
43	11.89	9.02	8.71
44	11.89	9.01	8.70
46	11.88	8.99	8.69
49	11.88	8.98	8.69
67.5	11.87	8.97	8.70
143	11.83	8.65	8.38
166	11.81	8.63	8.36