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Photo by Matthew Sleep

ADA Accessible Trail Improvement with Naturally Occurring, Sustainable Materials

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Oregon TECH

ADA ACCESSIBLE TRAIL IMPROVEMENT WITH NATURALLY OCCURRING, SUSTAINABLE MATERIALS

Final Report

NITC-RR-1131

by

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16. Abstract

The Americans with Disabilities Act (ADA) provides specific guidelines and requirements that must be met in terms of accessibility. However, in the case of unpaved trails, the requirements are less defined. An ADA trail must be firm, stable and slip resistant. Some compacted aggregate material may meet this definition, but degrade over time and can no longer be ADA compliant. The benefits of using unpaved surfaces for ADA trails include fit to the natural environment, cost, sustainability and environmental benefits such as increased permeability. If an unpaved surface can be improved with the use of an additive, more could be used as ADA accessible trails. Naturally occurring, volcanic ash from the eruption of Mt. Mazama is a natural pozzolan. This study examined using this natural pozzolan, in addition to other materials, as a naturally occurring binder. This binder was applied to existing and newly created compacted aggregate trails in the laboratory and the field to determine the benefit as a stabilizer. ADA accessibility tools such as the rotational penetrometer were used to determine if the surface is improved to a firm and stable surface. By determining a low-cost, sustainable solution for improvement of ADA accessible trails, more people will have access and connectivity will increase in our community. This study outlines the long-term benefits of using naturally occurring, volcanic ash as a binder applied topically to unpaved trails and discusses the expected increases to firmness and stability.

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EXECUTIVE SUMMARY

An extensive lab and field program has been conducted to determine if topically applied binder of portland cement and volcanic ash can increase the firmness and stability of unpaved trails to meet ADA requirements. Mortar cubes (175) were created to determine the long-term effect of replacing portland cement with volcanic ash, a previously researched natural pozzolan, on unconfined compressive strength. Volcanic ash provides a beneficial long-term gain in strength when used with portland cement. Mix infiltration tests (185) were conducted using compacted gravel samples, and varying proportions of water, portland cement and volcanic ash. Samples with 60% water appear to bind more material than 50% or 70% water. There is no clear correlation between gravel gradational properties and infiltration of portland cement, volcanic ash and water slurries. A lab-scale trail testing device was constructed with adjustable confinement to determine the method of topical slurry application. It was determined that confinement and compaction have little effect on firmness and stability. Twelve separate trail lots were constructed in the field on the Oregon Institute of Technology campus. These lots were all treated with different proportioned mixes of portland cement, volcanic ash and water. In addition, three commercially available gravel stabilizers were used. It was observed that over 70 days of monitoring, the lots treated with portland cement and volcanic ash continued to show improvement at a higher rate than the commercial stabilizer. The commercial stabilizers had higher improvements to stability, but a negative impact on firmness.

1.0 INTRODUCTION

This report is a continuation of work started with NITC-RR-1075, The Use of Mt. Mazama Volcanic Ash as Natural Pozzolans for Sustainable Soil and Unpaved Road Improvement by Sleep and Masley (2018). In that report, it was concluded that volcanic ash from the eruption of Mt. Mazama, which is prevalent across the Pacific Northwest and, in particular, Southern Oregon, could be used as a natural pozzolan and replacement for portland cement. It was also shown in the Sleep and Masley report that any replacement of portland cement with processed, volcanic ash reduced both embodied energy and carbon dioxide emissions.

With the knowledge that Mt. Mazama volcanic ash is a sustainable, naturally occurring pozzolan, an innovative use of the material has been researched as part of this report. The ADA Accessibility Guidelines (ADAAG) Section 4.5 and Architectural Barriers Act (ABA) Standards (2015) requires that for accessibility, ground and floor surfaces be firm and stable (DOJ, 2015). The Department of Defense (DOD), General Services Administration (GSA) and the U.S. Postal Service (USPS) have adopted the ABA Standards. In addition, many states such as California have adopted these standards for trails. Trails as defined by the ABA include, “a pedestrian route developed primarily for outdoor recreational purposes. Pedestrian routes that are developed primarily to connect accessible elements, spaces, and buildings within a site are not a trail." The ABA guidelines apply to all new and modified trails for outdoor areas developed by the federal government. Many states and municipalities have adopted these standards. According to the United States Access Board, "The Board intends to develop guidelines for non-federal outdoor sites covered by the Americans with Disabilities Act (ADA) and areas developed with federal grants and loans covered by the ABA through a subsequent rulemaking (acess-board.gov)." Thus, more recreational areas and trails will be subject to these requirements in the future. Four conditions for exceptions are included in these standards:

1. Compliance is not practicable due to terrain. The phrase "not practicable" means not reasonably doable.
2. Compliance cannot be accomplished with the prevailing construction practices.
3. Compliance would fundamentally alter the function or purpose of the facility or the setting.
4. Compliance is limited or precluded by any of the following laws, or by decisions or opinions issued or agreements executed pursuant to any of the following laws:
    a. Endangered Species Act (16 U.S.C. §§ 1531 et seq.)
    b. National Environmental Policy Act (42 U.S.C. §§ 4321 et seq.)
    c. National Historic Preservation Act (16 U.S.C. §§ 470 et seq.)
    d. Wilderness Act (16 U.S.C. §§ 1131 et seq.)
    e. Other federal, state or local law, the purpose of which is to preserve threatened or endangered species; the environment; or archaeological, cultural, historical, or other significant natural features

These guidelines have gradually been adopted as standard practice. The ABA (2015) standards include both scoping requirements and technical requirements. Trail requirements were first introduced to the ABA standards in 2010.

In addition to technical requirements such as width and slope, the trail surface must be described as firm and stable. A description of this is provided in Section 2.1. This report details an extensive laboratory and field program to determine if unpaved trail surfaces can be improved with the use of Mt. Mazama volcanic ash applied topically to unpaved surfaces.

To accomplish this goal, four separate programs were implemented. First, 175 mortar cubes were created to determine the effects of replacing portland cement with volcanic ash on unconfined compressive strength. In addition to portland cement, other naturally occurring sources of calcium oxide were used. In addition to creating strong cemented materials, it was recognized that the ability of topically applied materials to penetrate and bind the most amount of material would be beneficial. During the second portion of lab testing, innovative pour tests were completed. In all, 185 gravel pour samples were created. During the third portion of lab testing, artificial trails were created in the lab. Two devices were constructed. These devices allowed for a full size (width) trail to be created in the lab. The walls of the trail device were movable to determine the effects of confinement. Forty-three separate combinations of gravel and binders were created and placed in the lab-scale trail testing device. The firmness and stability of these treated surfaces were examined with the Beneficial Designs rotational penetrometer (BDRP). Based on the results of these three separate lab tests, 12 separate lots were created in the field on the Oregon Institute of Technology campus. These 12 lots along an existing trail were all treated with different topically applied binding materials. The firmness and stability of these lots were also tested with the BDRP. Monitoring of the field implemented trail lots has been occurring for approximately 180 days.

2.0 BACKGROUND

A literature review on the natural pozzolan process and soil stabilization is presented in Sleep and Masley (2018).

2.1 ADA ACCESSIBLE TRAILS

Several organizations have produced dimension guidance for outdoor trails, including running slopes, cross slopes, trail widths, flat resting areas, and distances between those resting areas. Every design guide states that clear tread widths should 36in (915mm), unless required to reduce down to 32in (815mm) due to external factors. If a width smaller than 32in (815mm) is required, the trail must be as wide as possible. Tennessee and California departments do not mention going smaller than the exception, but they do not expressly forbid it, either (Richards, 2007; California, 2009). It appears that these dimensional guidelines originate from the Americans with Disabilities Act, Section 403.5.1, which clarifies that the reduced width of 32in (815mm) cannot exceed 24in (610mm) in length.

Slopes and cross slopes are also similar between different guidelines. Guidance for cross slope of trails dictates a maximum of 5%. Some places allow for a more drastic cross slope for the purposes of drainage, but for limited distances (Richards, 2007). The U.S. Department of Agriculture states that cross slope can be variable, but should not exceed the aforementioned 5%, unless the surface of the trail is paved or constructed with boards. In this instance, as the surface is more controllable, the slope should not exceed 2% (Zeller, 2012). This stipulation is corroborated by the U.S. Forest Service Forest Service Trail Accessibility Guidelines (FSTAG) (U.S. Forest Service, 2013).

Running slopes are preferred at 5% or lower, with steeper slopes being allowed for increasingly shorter distances. Steeper slopes require flat stretches of trail with a minimum length of 60in (1.52m). Slopes of 10% are restricted to lengths of 30ft (9.1m), and 12% is restricted to 10ft (3m). FSTAG and others allow for a slope between 5% and 8% for an extent of 200ft (61m) (U.S. Forest Service, 2013).

Moore Inacofano Goltsmann, Inc (MIG) have included, in their guidelines, specifications for multiuse trails. These trails are wider and intended for bicyclists and equestrians in addition to normal hikers, while maintaining the requirement that a surface must be firm and stable. Recommended trail widths increase to a range of 8ft to 10ft (2.5m to 3m) with a corridor of 12ft to 14ft (3.6m to 4.2m). This corridor is spacing that should be cleared of vegetation (MIG, 2006).

Every design guideline declared the trail surface must be firm and stable, but did not provide exact guidance as to what that meant. The U.S. Department of Justice released the Americans with Disabilities Act (ADA) in 1990 with the intention of removing and preventing discrimination or exclusion of American citizens with disabilities. This was updated in 2010. Under the ADA, it is stated that “floor and ground surfaces shall be stable, firm, and slip resistant.” The only guidance for these terms is that stable surfaces must return to their original state after a load is applied and then removed, and firm surfaces must resist deformation. For standard urban materials and design practices, these criteria are typically met with ease. However, there are no numerical guidelines to aid in the design of compliant outdoor surfaces, or surfaces that require impact attenuation.

ASTM F1951 was designed in order to allow for direct guidance and a clear answer as to whether a surface qualifies as firm and stable for playground surfaces. Playground surfaces, due to the nature of having children falling on them, must allow for some deformation to reduce or prevent injuries while still allowing all children to enjoy the playground. A surface that is too flexible would prohibit the use by children with conditions that impair movement, but a surface that is not flexible could lead to severe injuries should a child fall. The procedure of ASTM F1951 is to create a stretch of the intended playground surface and then compare the resistance and effort required to push a wheelchair across the surface to that of pushing a wheelchair up a 1:14 (7%) slope. It should be noted that this slope is steeper than the running slope recommended in ADA of 1:20 (5%).

Testing according to ASTM F1951 is not portable due to the necessity of the 1:14 ramp. To allow for field testing, Beneficial Designs created their rotational penetrometer (BDRP). The BDRP is a device designed to determine the firmness and stability by simulating a weighted wheelchair wheel and measure deformation from static loading onto the surface and then after the wheel has been moved across the surface a set number of times. Firmness testing is defined as the deformation of the surface by vertical loading of the BDRP tire after removing any potential sources of friction or resistance in the device system and resetting the measurement reference to the surface of interest. Stability testing occurs after firmness testing. Without resetting the BDRP, the loading wheel is rotated 90 degrees counter clockwise and then clockwise. This is repeated until the wheel has made a total of four motions, and then readings are taken. Readings are taken from a component on the BDRP that measures the vertical travel of the attached wheel. Firmness and stability values are calculated by removing the highest and lowest recorded values for a surface and averaging the rest. Five readings are taken per material due to the size of the frame, which is the lowest recommended by Beneficial Designs. These instructions are outlined in the BDRP 100 Series Manual and illustrated by Figure 1, and (Beneficial Designs, 2014).

For a surface to be declared “firm,” the deflections measured by the BDRP must be under 0.3in (7.62mm). If the deflection is above 0.3in (7.62mm), but below 0.5in (12.7mm), the surface is declared “moderately firm.” A firmness value above 0.5in (12.7mm) and the surface is determined to be “not firm.” The same is true for stability, as well, with the boundaries being 0.5in (12.7mm) and 1.0in (25.4mm) in place of the 0.3in and 0.5in values, respectively. Surfaces are declared as neither firm nor stable if the combined firmness and stability readings are above 1.5in (38.1mm) (Axelson and Hurley, 2017).

Table 1. Recommended firmness and stability measurements for ADA accessible surfaces using the BDRP (after Axelson and Hurley, 2017)

Firmness	
	Penetration Depth (mm)
Firm	< 0.3
Moderately Firm	0.3 to 0.5
Not Firm	> 0.5
Stability	
	Penetration Depth (mm)
Stable	< 12.7
Moderately Stable	12.7 to 25.4
Not Stable	> 25.4

Figure 1 - BDRP indenter being lowered onto the surface to measure readings

2.2 OYSTER SHELLS AS SUPPLMENTARY CEMENTITIOUS MATERIALS

As part of this study, a locally available, natural material was used to supply necessary calcium to the mix design. This material was crushed and processed oyster shells. As a primary goal of this work was a focus on sustainable design, a material such as oyster shells, can provide the necessary calcium for a cementitious reaction in a sustainable manner. On their own, oyster shells do not contain cementitious materials and must be combined with an additional pozzolan, such as volcanic ash, to create cement (Papadakis and Tsimas 2002).

A study was conducted by Liang and Wang (2013) and the use of oyster shells and fly ash to create a cementitious material that could be used to increase the strength of compacted soil. They concluded and oyster shells and fly ash do not create a significant pozzolanic reaction when mixed with soil. A limitation of their study includes that the oyster shells were crushed, but not processed. In a natural form, oyster shells contain calcium in the form of $CaCO_3$. Therefore, the shells must be heated to removed CO_2 and create CaO necessary for pozzolanic reactivity.

Seo et al. (2019) investigated the use of calcined and crushed oyster shells for cement mortars. Prior to use, the oyster shells were processed with heat to remove CO_2 and increase the CaO content of the material. The study indicated that replacements of up to 3% calcined oysters shells had a significant positive effect on compressive strength of mortar cubes. Therefore this study proceeded using calcined oyster shells.

3.0 METHODOLOGY

3.1 MATERIAL COLLECTED

The materials used in this study were described in Sleep and Masley (2018). In that study, volcanic ash from the eruption from Mt. Mazama in Southern Oregon was collected and studied for use as a natural pozzolan in portland cement concrete. These collected materials are described here again with updated properties investigated as part of this study.

According to the USGS (2002), Mt. Mazama erupted approximately 7,700 years ago. The eruption caused the volcano to collapse, forming what is now known as Crater Lake. Similar to the Mt. St. Helens eruption in 1980, the eruption of Mt. Mazama blanketed the Pacific Northwest with volcanic ash and pumice. Sleep and Masely located deposits of volcanic ash located near the Oregon Institute of Technology campus. These deposits were characterized as “ash fall” deposits. Ash fall deposits are desirable for use as a natural pozzolan compared to welded ash or pumice, as less processing is necessary prior to use in portland cement concrete.

Figure 2 shows the location where material was collected as part of this study. This is the same location as Sleep and Masley . Volcanic ash from the eruption of Mt. Mazama is found at the ground surface in this location and is unwelded. Therefore, collection requires minimal effort. As shown in Figure 2, Walker (1951) mapped airfall deposits of volcanic ash in this location.

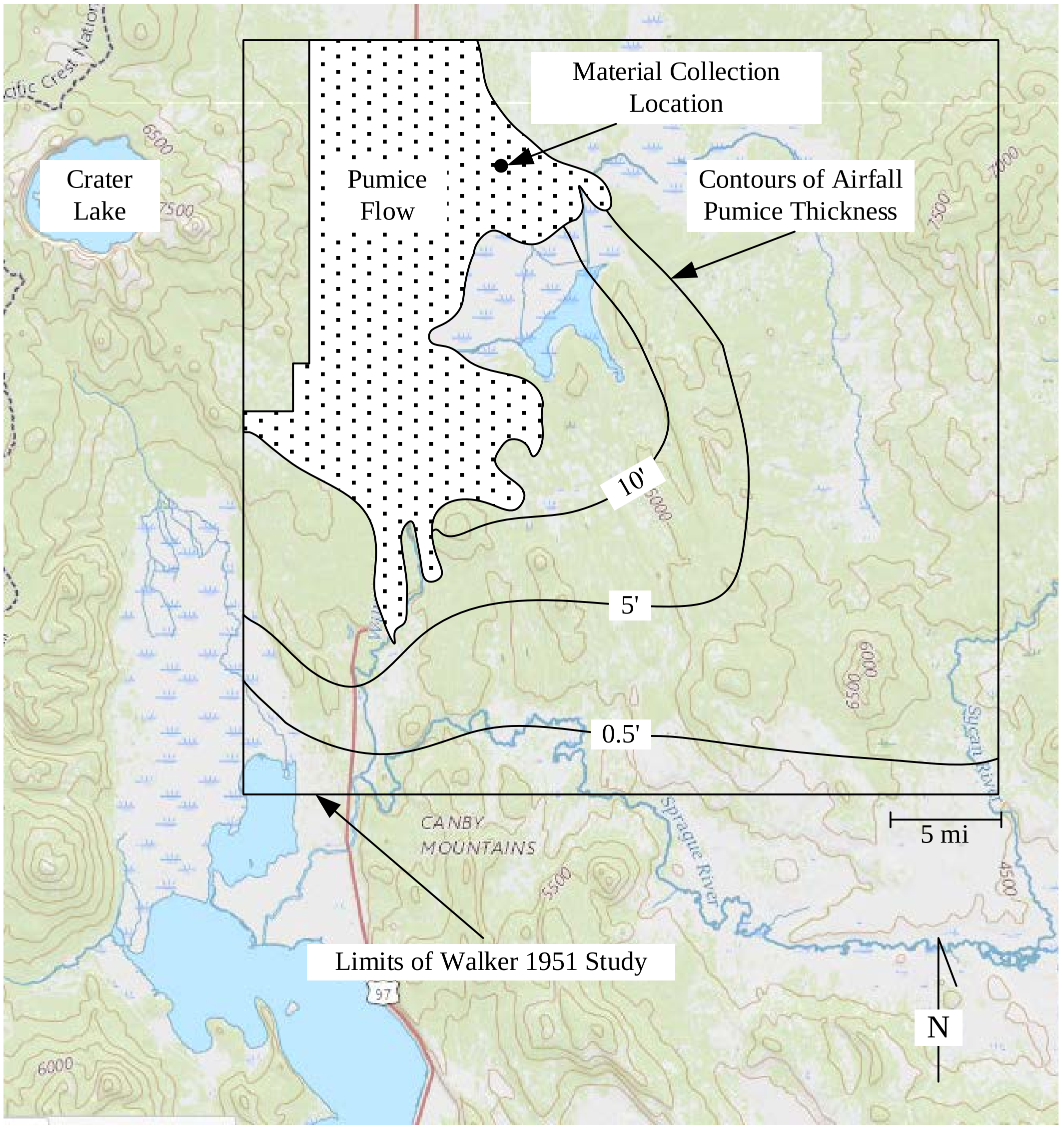

Figure 2 – Location of volcanic ash collection, limits from Walker, 1951

The Sleep and Masley study showed that the volcanic ash from this location met few of the physical and chemical requirements of a Class N pozzolan, as shown in Table 2 and Table 3. Several samples of the volcanic ash were sent to a materials testing laboratory to determine the chemical composition. The results of those tests are shown in Table 4. The volcanic ash meets all chemical requirements of Class N, F or C pozzolans.

The physical requirements for a natural pozzolan investigated as part of this study include the fineness and strength activity index. Water requirements, autoclave expansion and density variation were not studied. As noted in the Sleep and Masley study, the volcanic ash material did not meet fineness or strength activity index requirements in an unprocessed, natural state. The fineness of the material is determined by the amount of material retained on a wash No. 325 sieve (ASTM C430-17). Sleep and Masley recommended a program to determine how to process the volcanic ash into a fine material. In the Sleep and Masley study, the material was crushed with a mortar and pestle and then passed through the No. 200 sieve prior to being used as a natural pozzolan. This method produced adequate results in terms of strength activity index. For this study, a method was needed to produce larger quantities of processed volcanic ash. To accomplish this, a gas-powered rock crusher typically used for the gold mining industry was used. This crusher spins carbide chains at high speed to create sub No. 200 size material. The unit, shown in Figure 3, was able to process 25 gallons (300 lbs) of volcanic ash material in less than one hour.

To meet fineness requirements, a maximum of 34% of the material can be retained on a wash No. 325 sieve. Prior to processing, samples of volcanic ash averaged 83% retained on the wash No. 325 sieve. As shown in Table 5, after processing the material, the average retained on the wash No. 325 sieve is 42%. While this is slightly higher than the required 34% according to the ASTM, the process shows that achieving a finer material with minimal effort is possible. As with the Sleep and Masley study, the material was then passed through the No. 200 sieve before being used as a pozzolan.

Figure 3 – Rock crusher used to process volcanic ash as part of this study (kandmkruchers.com)

Table 2. Chemical requirements for ASTM C-618 pozzolan classifications

Chemical Requirements			
	Class		
Component	N	F	C
SiO_2 + Al_2O_3 + Fe_2O_3 min, %	70.0	70.0	50.0
SO_3, max %	4.0	5.0	5.0
Moisture content, max %	3.0	3.0	3.0
Loss on ignition, max %	10.0	6.0	6.0

Table 3. Physical requirements for ASTM C-618 pozzolan classifications

Physical Requirements			
	Class		
Requirement	N	F	C
Fineness (retained on No. 325 sieve), max %	34	34	34
Strength activity index seven days, % of control	75	75	75
Strength activity index 28 days, % of control	75	75	75
Water requirement max % of control	115	105	105
Autoclave expansion or contraction, max %	0.8	0.8	0.8
Max density variation from average, %	5	5	5

Table 4. Chemical analysis of volcanic ash collected for this study

Compound (%)	**Sample_AA_#1**	**Sample_AA_#2**	**Sample_BB_#1**	**Sample_BB_#2**	**Sample_CC_#1**	**Sample_CC_#2**
SiO_2	68.0	67.7	65.5	65.2	64.2	64.2
Al_2O_3	18.1	18.0	19.2	19.2	19.0	19.1
Fe_2O_3	4.0	4.0	4.5	4.5	4.7	4.8
CaO	2.8	2.9	3.5	3.4	4.0	4.0
MgO	1.2	1.2	1.5	1.4	1.8	1.8
SO_3	0.0	0.0	0.0	0.0	0.0	-0.1
Na_2O	3.3	3.3	3.1	3.1	3.2	3.2
K_2O	2.3	2.3	2.0	2.0	1.7	1.7
TiO_2	0.6	0.6	0.6	0.6	0.7	0.7
P_2O_5	0.1	0.1	0.1	0.1	0.1	0.1
Mn_2O_3	0.1	0.1	0.1	0.1	0.1	0.1
Loss On Ignition	2.1	2.1	1.9	2.0	2.0	2.2
Total Alkali	4.8	4.8	4.4	4.4	4.3	4.3

Table 5. Wash No. 325 results after passing volcanic ash through the rock crusher

Sample	**Original Dry Weight (g)**	**Retained Weight on the Sieve (g)**	**Weight Lost through Sieve (g)**	**Percentage Retained**
1	1.01	0.44	0.57	44%
2	1.00	0.44	0.56	44%
3	1.01	0.4	0.61	40%

3.2 MORTAR CUBES

One stated goal of this research program is to determine the effects of replacing portland cement with a naturally occurring pozzolan on cured strength of a concrete. To accomplish this goal, a modified form of ASTM C311 was performed. ASTM C311 is the standard test method for sampling and testing natural pozzolans for use in portland cement concrete. One procedure in this standard is the strength activity index. To calculate this index requires the construction of ASTM Type 1 cubes out of mortar, water and graded sand, according to ASTM C150 specifications. The sand is a controlled mixture of grain sizes between standard U.S. sieve size #30 and #50. According to ASTM C311, 500g of cement mortar is to be used with 275 ml of water and 1375g of the graded sand to create six 5cm cubes. Then 100g of mortar is to be replaced with the additive of interest, in this case Mt. Mazama volcanic ash, and mixed with remaining 400g of mortar, water, and sand to create six modified cubes of the same dimensions. Cubes were created with Mt. Mazama volcanic ash and tested for unconfined compressive strength.

Due to identified long-term strength of cement mixes with natural pozzolans (Bondar et al., 2011), the ASTMC311 was modified to include testing at 7, 28, 42, 56, 70, and 84 days. Natural pozzolans are siliceous materials that poses no cementitious properties on their own, but will in the presence of calcium hydroxide form cementitious compounds (Mehta, 1987). The reaction of a natural pozzolan is described in Sleep and Masley (2018). As discussed in that report, the main compounds that react in a pozzolanic reaction are the calcium hydroxide (Ca(OH)2) from the hydration reaction and a silicic acid from the pozzolan. The silica glass (SiO2) in a natural pozzolan such as volcanic ash reacts with water to form a silicic acid. This reaction is demonstrated in Equation 1.

$$\mathrm{SiO_2 + H_2O \rightarrow H_2SiO_3} \qquad \text{Equation 1.}$$

One of the more common acids produced is orthosilicic acid (H4SiO4). The product of these reactions is a calcium silica hydrate (CSH), one possible reaction with these compounds is shown in Equation 2.

$$\mathrm{Ca(OH)_2 + H_4SiO_4 \rightarrow CaH_2SiO_4 * 2H_2O} \qquad \text{Equation 2.}$$

In addition to portland cement supplying calcium hydroxide, it was investigated whether other sources of calcium hydroxide could be used to create cementitious products. For this study, crushed oyster shells and lime were used to supply calcium hydroxide.

Mortar cubes (175) were created to study the effects of replacing portland cement with various amounts of volcanic ash, lime and oyster shells. Due to the long-term strength gains common with pozzolans, unconfined compressive strength of the mortar cubes was tested at 7, 21, 28, 42, 56, 70 and 84 days. Six separate mix types were created, as shown in Table 6 and Table 7. Additional admixtures, such as plasticizers, were not used in the creation of mortar cubes. For each test sample (25), seven specimens were created to test at 7, 21, 28, 42, 56, 70 and 84 days for a total of 175 specimens.

Table 6. Mortar cubes created and tested for unconfined strength as part of this study (after Sleep and Matzen, 2020)

Mix Designation	Mortar Mix	Alterations to Mortar Mix
SC	ASTM C109 Using 500g of portland cement	Replacement of portland cement with 100, 150, 200 and 300g of Mt. Mazama volcanic ash
LC	ASTM C109 Using equivalent volume of Type S lime	Replacement of Type S lime with 100, 150 and 200g of Mt. Mazama volcanic ash
OC	ASTM C109 Using equivalent volume of crushed oyster shells	Replacement of oyster shells with 100, 150 and 200g of Mt. Mazama volcanic ash
LPC	ASTM C109 Using 100g of portland cement and equivalent volume of type S lime	Replacement of portland cement and type S lime with 100, 150 and 200g of Mt. Mazama volcanic ash
OPC	ASTM C109 Using 100g of portland cement and equivalent volume of crush oyster shells	Replacement of portland cement and oyster shells with 100, 150 and 200g of Mt. Mazama volcanic ash
RC	ASTM C109 Using equivalent volume of crushed oyster shells heated to 920 degrees Celsius	Replacement of oyster shells with 100, 150 and 200g of Mt. Mazama volcanic ash

Table 7. Mortar cube mix designs for compressive strength

		Mix Design		
Test Sample	**Cement type**	**Portland Cement (g)**	**Alternative cement weight (g)**	**Volcanic Ash (g)**
SC-0	Portland cement	500.0	0.0	0.0
SC-1	Portland cement	400.0	0.0	100.0
SC-2	Portland cement	350.0	0.0	150.0
SC-3	Portland cement	300.0	0.0	200.0
SC-4	Portland cement	200.0	0.0	300.0
LC-0	Lime	0.0	263.6	0.0
LC-1	Lime	0.0	210.9	100.0
LC-2	Lime	0.0	184.6	150.0
LC-3	Lime	0.0	158.2	200.0
OC-0	Powdered oyster shell	0.0	234.4	0.0
OC-1	Powdered oyster shell	0.0	187.5	100.0
OC-2	Powdered oyster shell	0.0	164.1	150.0
OC-3	Powdered oyster shell	0.0	140.7	200.0
LPC-0	Lime and portland cement	100.0	210.8	0.0
LPC-1	Lime and portland cement	80.0	168.6	100.0
LPC-2	Lime and portland cement	70.0	147.6	150.0
LPC-3	Lime and portland cement	60.0	126.5	200.0
OPC-0	Powdered oyster shell and portland cement	100.0	187.6	0.0
OPC-1	Powdered oyster shell and portland cement	80.0	150.1	100.0
OPC-2	Powdered oyster shell and portland cement	70.0	131.3	150.0
OPC-3	Powdered oyster shell and portland cement	60.0	112.6	200.0
RC-0	Cooked powdered oyster shell	0.0	213.4	0.0
RC-1	Cooked powdered oyster shell	0.0	170.8	100.0
RC-2	Cooked powdered oyster shell	0.0	149.4	150.0
RC-3	Cooked powdered oyster shell	0.0	128.1	200.0

As described in Sleep and Masley , it was necessary to process the volcanic ash prior to use in portland cement concrete mixes to realize the full potential of the natural pozzolan. The crushing procedure was previously described in this report in the 3.1 Material collected section. This extensive testing program created six separate mix designs to study the effects of replacing portland cement with a natural pozzolan and/or an additional source of calcium hydroxide to form cementitious products.

As shown in Table 4, the volcanic ash used in this study is comprised of primarily silica dioxide. This is very similar in chemical composition to the volcanic ash from the eruption of Mt. St. Helens (Taylor and Lichte, 1980). Volcanic ash is chemically similar to the magma of its source. Basaltic, andesitic and rhyolitic magmas have silica dioxide range from 45% to 75%, respectively (Langmann, 2013). Understanding the pozzolanic process, other sources of CaO were investigated, in addition to portland cement, to see if a cementitious material could be formed without its presence in the design. As shown in Sleep and Masley , any replacement of portland cement with a naturally occurring material has a significant decrease in embodied energy and carbon dioxide emissions. In this study, Type S lime and oyster shells were investigated to supply CaO. Type S lime mortar was chosen as it is a known source of cementitious calcium, which should allow for more integration of the different components of the volcanic ash in the final cementitious product (Sleep and Matzen, 2020).

Oyster shells were chosen for the same reason as lime mortar, but with the additional intention of determining a more widely available source of calcium. The lime mortar came in a powdered form, but the oyster shells were acquired as a combination of large flakes to whole shells typically used for poultry egg production. They were processed with the same rock crusher as the volcanic ash. Oyster shells are primarily composed of $CaCO_3$, which is not usable as a hydraulic calcium-base cement. To recover a usable hydraulic cement, the powdered shells were placed in a furnace at temperatures between 900°C and 1,000°C to burn off CO_2 and create CaO. Both were mixed with varying degrees of portland cement, and tested on their own, to determine if they could serve as either an additional supplement in the mix, or a replacement for the portland cement altogether (Sleep and Matzen, 2020).

ASTM C311 was modified to determine the unconfined compressive strength of mortar cubes created with continued replacements of portland cement with volcanic ash as well as other sources of CaO. In addition to altering the amounts of materials tested, the timeframe for testing was extended due to the long-term strength gains typically found with natural pozzolans. ASTM Type 1 mortar cubes were created out of water, portland cement volcanic ash, and graded sand. The sand is a controlled mixture of grain sizes. This is used to reduce variability in strength to only that observed by replacement of portland cement. Following ASTM C311, 500g of portland cement is used with 275 ml of water and 1375g of graded sand. This allows for the creation of six 5cm square mortar cubes. For these cubes, 100g[M1] of the 500g of the portland cement is replaced with the pozzolan of interest. In addition to replacing 100g of the portland cement, mortar cubes were created as shown in Table 7.

ASTM C311 states that mortar cubes created in this method should meet 75% of the control mortar cube strength at 28 days of curing. Variability in strengths measured in Sleep and Masley 2018 made careful determination of this requirement difficult. Here, samples SC-0 and SC-1 show that the volcanic ash, when processed and passed through the No. 200 sieve, has approximately 68% of the strength of the control specimen. These mortar cubes were created with great care and cured in a controlled environment. Prior to testing for the unconfined strength, sample faces were inspected and any unsmooth or broken surfaces were not used for testing. These results, shown in Table 8, therefore are high confidence. It was shown, however, that the long-term strength gain, common with pozzolans, does surpass the 75% unconfined strength requirement with 84 days of curing.

In this respect, the pozzolan does not meet strength activity requirements to be classified as a Class N pozzolan. However, as indicated by this testing, the volcanic as does function as a natural pozzolan as indicated by long-term strength gains. This testing can be used to determine strength as a function of time for replacements of portland cement with volcanic ash. Engineers can determine if the strength necessary at times shorter than 84 days of curing would be adequate. It is possible to increase early strength of concrete mixes with a variety of admixtures.

It has also been shown by researchers (Toutanji et al. 2004, Arel 2016), that silica fume can increase the early strength of concrete mixtures. These researchers have also shown very large increases in short term strength (less than 14 days) when the fineness of the silica fume is increased. Additional admixtures, such as silica fume, or an increase in the fineness of the volcanic ash, would both increase the short term strength of the mix.

Table 8. Unconfined strength of mortar cubes following the ASTM C311 procedure replacing portland cement with processed volcanic ash

Cure Time (days)								
		7	21	28	42	56	70	84
Sample	Percentage of Control Strength (SC-0)							
SC-0		100%	100%	100%	100%	100%	100%	100%
SC-1		67%	67%	68%	71%	74%	75%	76%

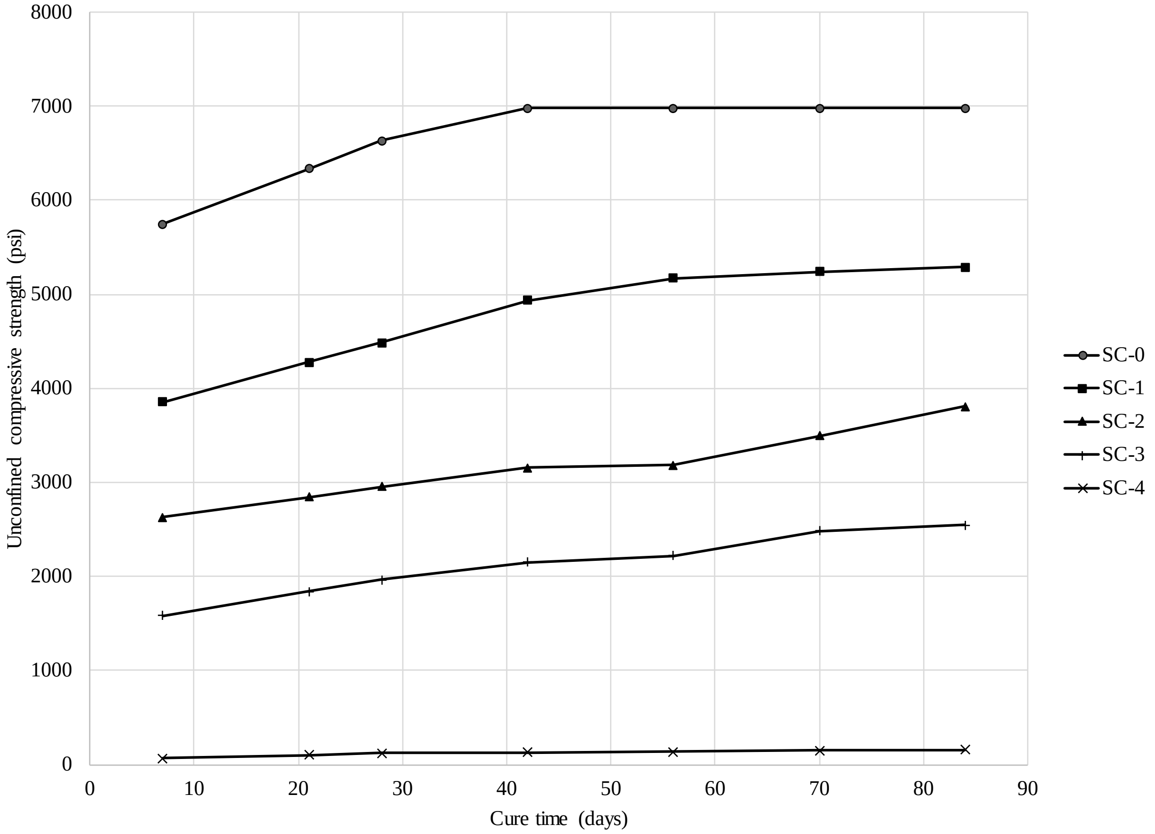

Figure 4 – Unconfined compressive strength with time (SC Samples)

As shown in Figure 4, mortar cubes created with volcanic ash showed appreciable gains in strength between 28 and 84 days of curing. The control, SC-0, displayed no increase in strength between 42 and 84 days of curing. However, samples with volcanic ash showed significant gains in strength between 42 and 84 days. The volcanic ash samples, SC-1 to SC-4, were measured to have 6%, 16%, 17% and 17% unconfined compressive strength increases between 42 and 84 days of curing.

Results of the unconfined compressive strength samples LC, OC, LPC, OPC and RC, as described in Table 7, are included in the appendix. Any mortar cubes created with less than 300g of portland cement were deemed too weak to support further testing. Unconfined compressive strength of all samples was an order of magnitude or weaker than the control sample, SC-0. However, a few useful observations can be made while reviewing the data. Figure 5 shows the unconfined compressive strength of all mortar cubes created except SC samples. Each individual mix is displayed in the appendix. The samples LC, OC, LPC, OPC and RC all show appreciable gains in unconfined compressive strength between 42 and 84 days. Observing the correlation coefficients between unconfined compressive strength and age of sample (Table 9) shows a positive correlation between 7 and 84 days and 42 and 84 days. This confirms the long-term pozzolanic strength gain of processed Mt. Mazama volcanic ash.

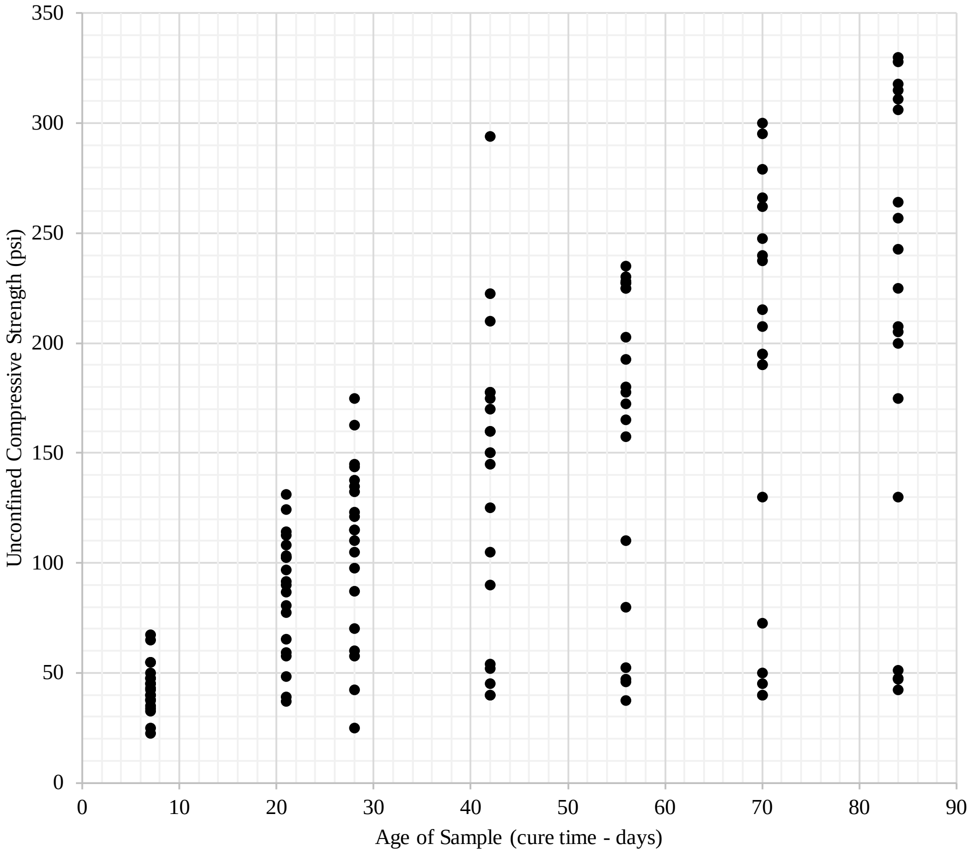

Figure 5 – Unconfined compressive strength of all mortar cubes (excluding control SC group)

Table 9. Correlation coefficients of all mortar cube data from 7-84 days and from 42-84 days (excluding control SC group)

Sample Age	Correlation Coefficient
7-84 Days	0.64
42-84 Days	0.34

3.3 MIX INFILTRATION

This test was devised to determine how various gravel materials reacted to different cementitious mixes. The objective of this testing was twofold: to determine if topical treatment would infiltrate deep enough into the chosen gravel material and how well the cementitious mix binds the gravel material together. Infiltration depth is important as a deeper infiltration would allow for reinforcement and stabilization of the gravel subsurface. Material binding, the other purpose of this test, shows how much of the available subsurface has been reinforced.

Approximately 2400g of gravel material is either gathered or created for the gravel trail of interest. This material is compacted into a plastic cylinder with a 4in (10 cm) diameter and 8in (20 cm) depth that has been lined with two mold liners for ease of sample removal. Compaction is done over three layers, with each being compacted 25 times with a steel tamping rod. Molds are weighed with liners before material is added to them, and that weight is removed from the weight of the sample after compaction to determine the weight of the aggregate. The weight of applied cementitious slurries are calculated to be 5% of the aggregate's weight in the sample.

Cementitious mix materials include water, portland cement and Mt. Mazama volcanic ash. Additional admixtures, such as plasticizers, were not used in this study. Mixes are designated by their percentage water content over the ratio of volcanic ash to portland cement. For example, a mix that is 60% water, 24% volcanic ash, and 16% Portland cement would be labeled 60/150. Dry components are weighed first and mixed before water is weighed and slowly added to reduce powder clumping when stirring the mix. Mixes are applied to the surface of the aggregate sample in an even coating. Samples are then sealed to retain moisture and allowed to cure for one week before they are opened and extracted.

Samples are weighed in the mold before careful extraction. Extracted samples are laid on their side next to a measuring device, typically a tape measure. Any unbound aggregate is removed from the testing and discarded. Unbound aggregate is classified as aggregate that does not remain attached when the sample is removed and any aggregate that falls off during handling of the sample. After the sample has been extracted and laid on its side, the distance along the sample from the deepest point from the surface is recorded before the sample is weighed. Some samples, primarily with higher water contents, had solid discs of cured cementitious material at the bottom of the mold. These were classified as having a full infiltration depth if they had bound components throughout the sample, proving the cementitious mix fully infiltrated the material.

Eleven aggregate gradations and combinations were used to determine relationships between grain size distribution characteristics and infiltration test results. Each gradation had three samples created for a volcanic ash to portland cement ratio of 1.5 and percentage water contents of 50%, 60%, and 70%. For comparison with firmness and stability testing performed in the field, samples were created using aggregate mixes created using the grain size distribution curve of the accessible geotrail located to the east of Oregon Institute of Technology's Klamath Falls campus. Geotrail samples were treated with cementitious mixes of 1.25, 1.5, and 1.75 ash to cement ratios, 50%, 60%, 70% percentage water contents, as well as three commercial aggregate stabilizers. Table 10, located below, provides more detailed descriptions of each aggregate used, as well as a list of cementitious mixes they were treated with.

Table 10. Infiltration test materials with descriptions and applied cementitious mixes

Material	Justification/Reasoning	Cementitious Mixes Applied
M1.0.0 M1.1.0 M1.1.1	M1 materials were chosen to determine effect of topical application on angular gravels. Subsets were chosen to represent potential trail gradations.	50/150, 60/150, 70/150
M2.0.0 M2.0.1	M2 materials were chosen to look at the effects of two layered materials. Subsets were chosen to represent potential trail gradations.	50/150, 60/150, 70/150
M3.0.0 M3.0.1	M3 materials were based on the specifications of Montana trails. M3.0.1 is a direct interpretation of specification while M3.0.0 includes other sizes to incorporate a higher number of finer aggregates.	50/150, 60/150, 70/150
M5.0.1	M5.0.1 was based on the subgrade for M3.0.1 to determine its effectiveness on its own.	50/150, 60/150, 70/150
Geotrail	Made to mimic the existing gravel used in the trail of interest on the east end of OIT campus.	50/150, 60/150, 70/150
M6.0.0	Recreation of C1 with different sizes to illustrate differences in results based on gravel characteristics.	50/150, 60/150, 70/150
C1	Initial available coarse gravel. Mostly used for proof-of-concept and process refinement testing as well as possible trail aggregate.	67/100, 67/900, 60/100, 60/150, 60/233, 60/400, 60/900 all with volcanic ash passing the #4 sieve. 60/100, 60/150, 60/233, 60/400, 60/900 all with volcanic ash roughly crushed. 60/100, 60/150, 60/233, 60/400, 60/900 all with volcanic ash passing the #200 sieve.

The first samples created made use of available coarse aggregate to verify the validity of this test. Through controlled trial and error, it was determined that a finer volcanic ash yielded higher amounts of bound material as well as further infiltration into the sample, as well as an ideal water percentage of 60% for the cementitious mixes, and a volcanic ash to portland cement ratio of 1.5. (Figure 6, Figure 7).

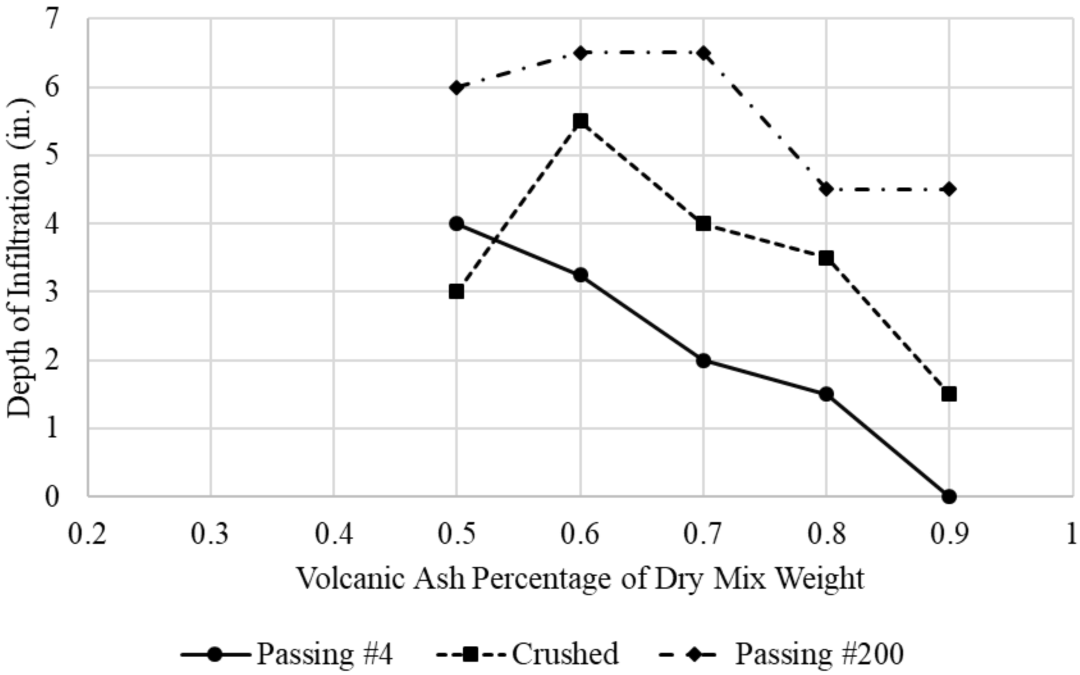

Figure 6 - Depth of infiltration with different levels of volcanic ash processing during initial infiltration testing

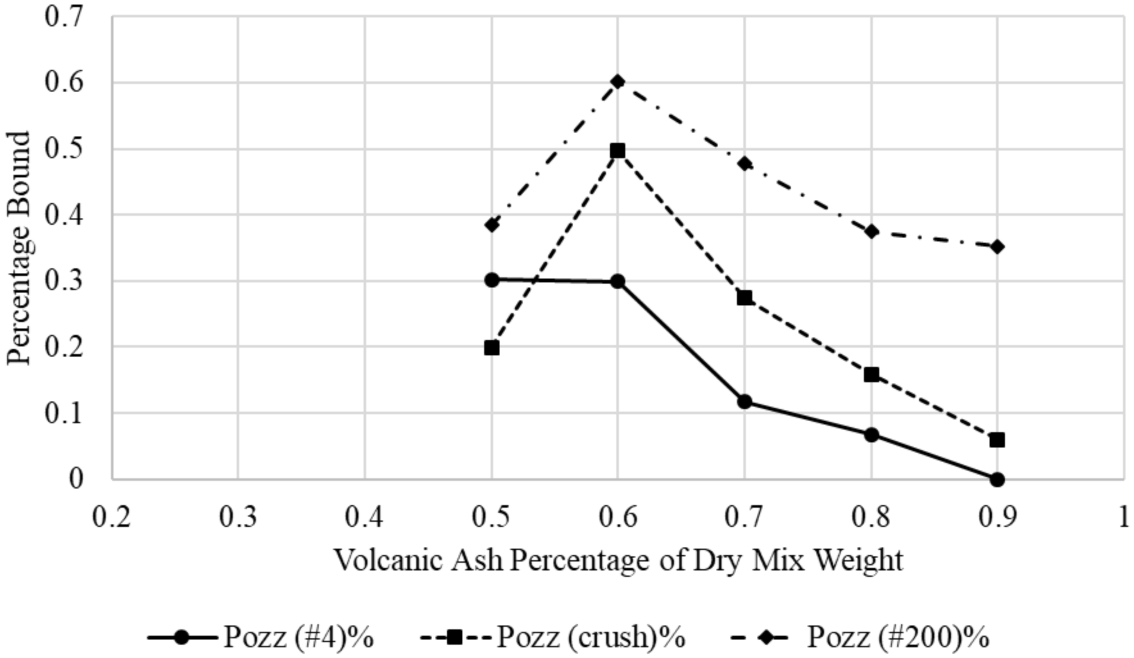

Figure 7 - Percentage of material bound with different levels of volcanic ash processing during initial infiltration testing

When looking at data for samples that were not fully infiltrated, there is a positive correlation between the amount of bound material in a treated sample and the infiltration of the cementitious mix applied (Figure 8). There is not a strong correlation between aggregate characteristics and infiltration testing results.

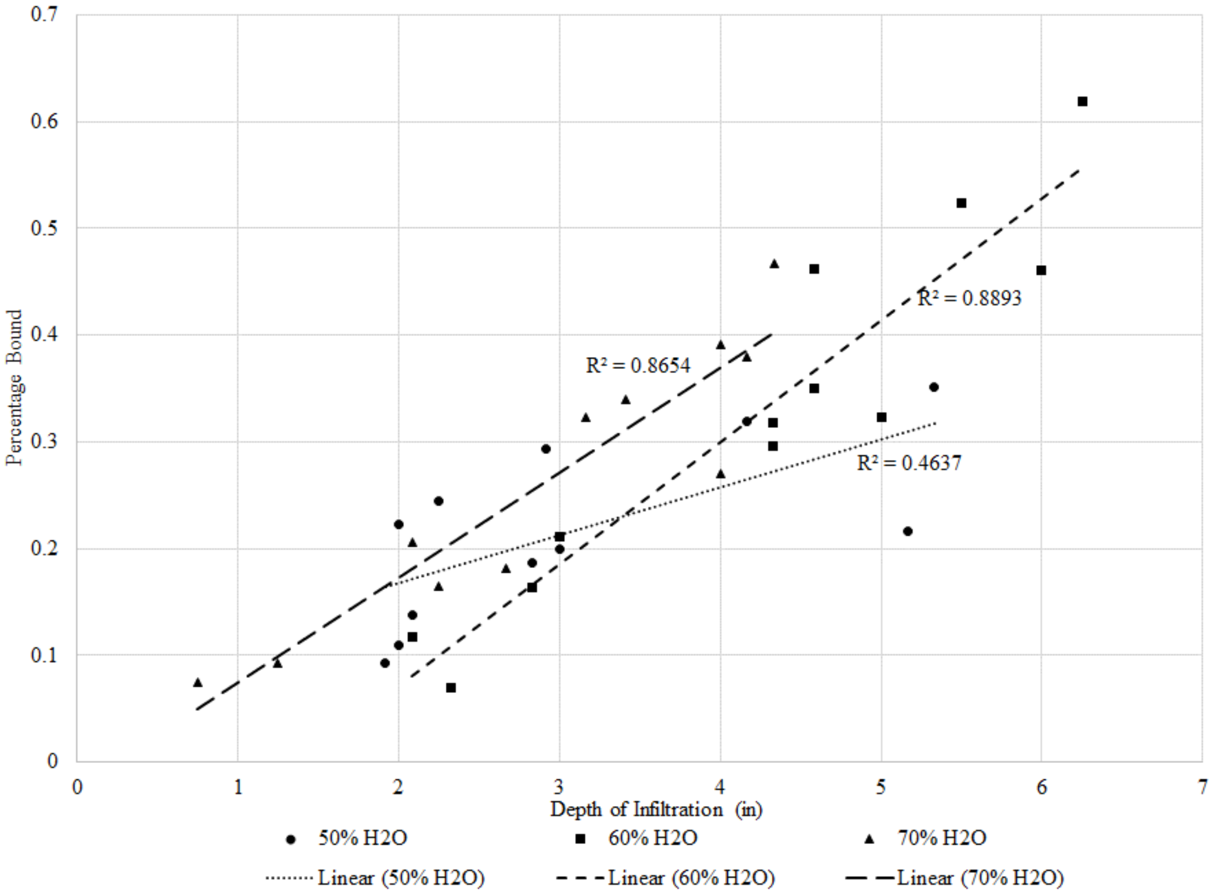

Figure 8 - Depth of infiltration compared against percentage of bound material for a 1.5 volcanic ash ratio, separated by mixture water content

Testing conducted on the aggregate mix used for the construction of the OIT Accessible Geotrail included different ratios of volcanic ash to portland cement. These tests showed a positive trend between the amount of bound material and the percentage of water present in the applied cementitious mix for each ratio of volcanic ash to portland cement applied (Figure 9 and Figure 10). It also shows a parabolic relationship between the ratio of volcanic ash and portland cement in the mix, with the 1.5 ratio as the trough of the parabola, with 1.25 and 1.75 volcanic ash ratios yielding higher binding and deeper infiltration. Infiltration depth for all three volcanic ash ratios does not have an increasing relationship with an increasing amount of water in the cementitious mix. Instead, both the 1.25 and 1.75 ratios peak at 60% of the mix being water while the 1.5 ratio has a negative relationship.

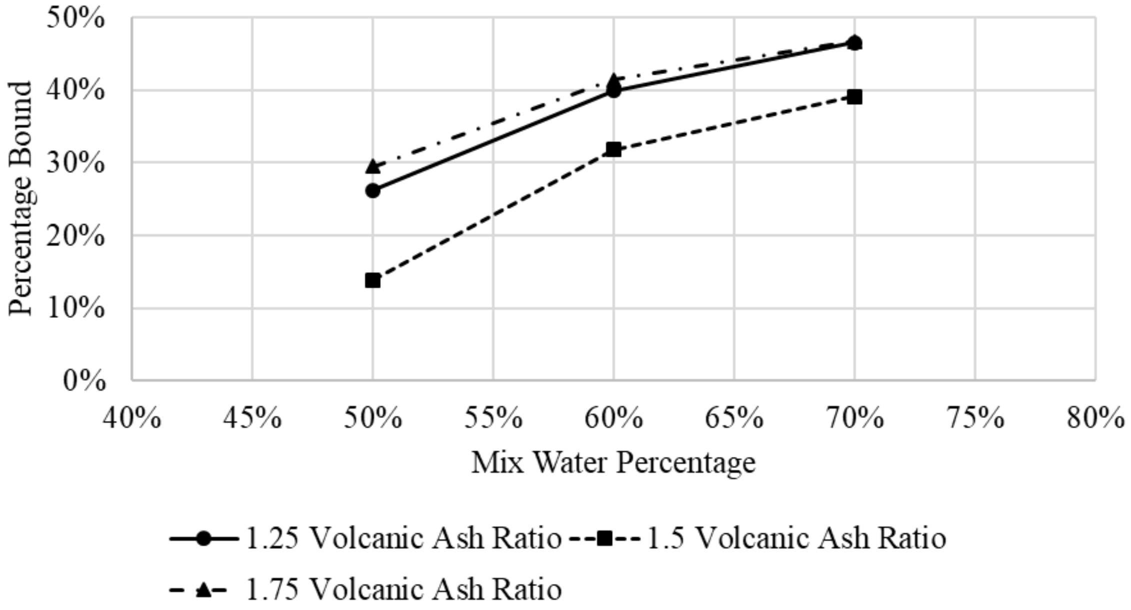

Figure 9 - Percentage of bound material for recreated geotrail infiltration tests

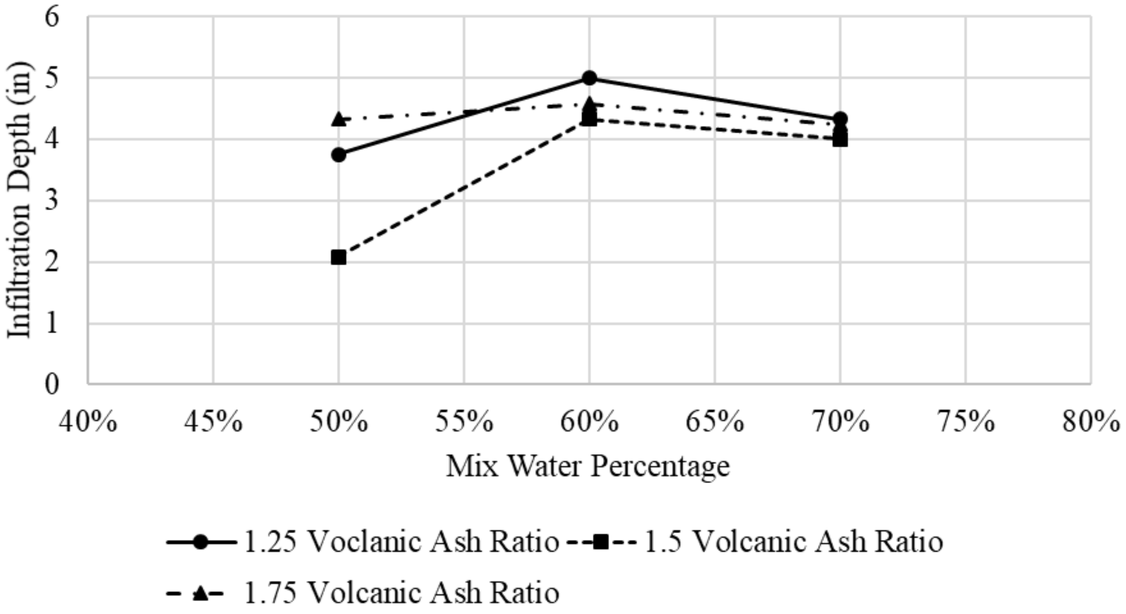

Figure 10 - Infiltration depth for recreated geotrail infiltration tests

Geotrail aggregate was also treated with three commercial stabilizers to verify their claims of being topically applicable before applying them to sections of the OIT geotrail. The stabilizers used were G3 soil stabilizer, Klingstone Amber, and SoilTac liquid topical. SoilTac liquid topical stabilizer was diluted in increasing increments of 10% water content due to a mention of a recommended dilution for application determined by the aggregate being stabilized, but no guidance. Infiltration depth and bound material results can be seen in Table 11 for the G3 and Klingstone stabilizers, as well as the results for the other geotrail infiltration tests, excluding the SoilTac samples. The results for the SoilTac stabilizer are shown in Figure 11 on opposing axes to illustrate changes due to dilution. A mixture of 30% SoilTac stabilizer and 70% water by weight was chosen for firmness and stability applications due to that mixture demonstrating a high material binding potential, as well as not fully infiltrating the sample.

Table 11. Results of cementitious mixes on recreated geotrail samples during infiltration testing

Name	Depth of Infiltration (in.)	Percentage Bound
50/125	3.75	26.3%
50/150	2.08	13.8%
50/175	4.33	29.5%
60/125	5.00	39.9%
60/150	4.33	31.8%
60/175	4.58	41.4%
70/125	4.33	46.5%
70/150	4.00	39.2%
70/175	4.25	46.7%
G3 Soil Stabilizer	7.00	9.9%
Klingstone Amber	6.00	47.3%

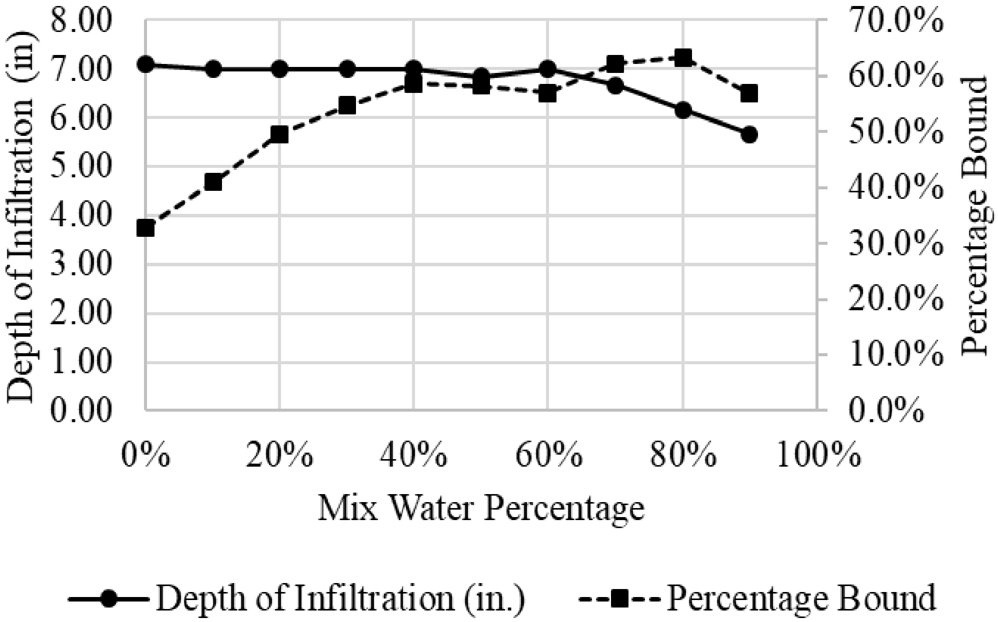

Figure 11 - Results for SoilTac stabilizer infiltration tests plotted opposite each other

3.4 LAB-SCALE TRAIL TESTING

Firmness and stability testing were conducted in order to determine the efficacy of the cementitious mixes as stabilizers with regard to accessibility. Frames were constructed to facilitate this testing in the controlled environment of the lab in order to first prove the mixes provided an improvement in firmness or stability. Conducting the tests in controlled frames allowed for control of the created surface without the need for creating large segments and control of the environment in which treated trail segments cure. This testing was completed to determine the following:

1. Effect of compaction on firmness and stability
2. Effect of confinement on firmness and stability
3. Determination of appropriate method of mix placement

3.4.1 Lab-Scale Device

Two frames were constructed for testing chosen trail materials in a controlled environment (Figure 12). The frames were constructed from dimensioned lumber, a top section comprised of 2x12 pine and a lower section comprised of 2x4 pine, and a sheet of steel secured between the two wooden sections. Structural support for the frame is provided by the lower portion, comprised of 2x4 dimensioned lumber. Supports were created with a connected series of beams matching the outer dimensioning of the top section with extra bracing provided in the center to prevent deformation of the steel sheet. For the top section, a rectangular frame was constructed with interior dimensions of 72in (182cm) length and 36in (91cm) width with the use of 2x12 nominal dimensioned lumber. The steel sheet is fastened first to the support section, and then the top section. Short lengths of lumber were affixed to the sides to increase structural stability of the upper section of the frame, and provide more connection between the upper and lower sections.

Figure 12 – Lab-scale trail testing device (red outline showing pin locations to move the walls to investigate confinement effects)

Affixed to the lower section through the steel sheet were two vertical lengths of 2x12 lumber on slide rails. The walls were positioned perpendicular to the length of the frame inside the upper section with a distance of 36in (91cm) between the side facing the other sliding wall. Each inner wall was designed with the ability and clearance to slide away from the central area a total of 15cm. Long braces were affixed to the sliding walls of the first testing frame along the bottom with two holes provided for lock-pins to hold the wall at 1in (25mm) intervals, totaling seven positions for each wall. Vertical walls created a square area that is 36in (91cm) to a side in the center of the frame where trail material is placed for testing. The walls attached to sliders allow for the expansion of the central area to a rectangular are that is 36in (91cm) by 72in (121cm). This can be used to simulate either the removal of supports, or to accommodate more trail material.

Due to the lack of upper bracing, the walls canted outward when a vibratory compactor was used to compact the chosen trail material. To prevent this from happening with the second frame, upper supports were added with holes following a similar lock-pin spacing. Lock-pins used are 1cm diameter. Sections in each of the long walls are cut so as to be removable to allow for easier clearing of trail material after testing. Marks are placed on the removable portions to measure the depth of trail material located in the frame. Each frame was fixed with casters at the corners of the central 91cm square area to allow for movement of the frame while preventing excess deformation due to the loading of trail material.

Trail material is placed in the frame, tested for base firmness and stability, and then treated with a cementitious mix. Originally, a sprayer was the intended method of application, with the intention of allowing the use of portable personal dispensing units. Due to sediment in the mixes, the sprayers were only partially successful, causing many applications to be applied by evenly pouring over the surface. Surface testing was conducted with the BDRP. Two gradations of gravel were used in the lab scale device. Gravel C1 and the geotrail material were both used in the lab device. Gradation C1 was chosen as a coarse gradation. The geotrail material was chosen because it is the material used in the field applications discussed in other sections of this report. Both material gradations are shown in Figure 13. For the lab-scale testing, gravel was placed to a depth of 6.5 inches.

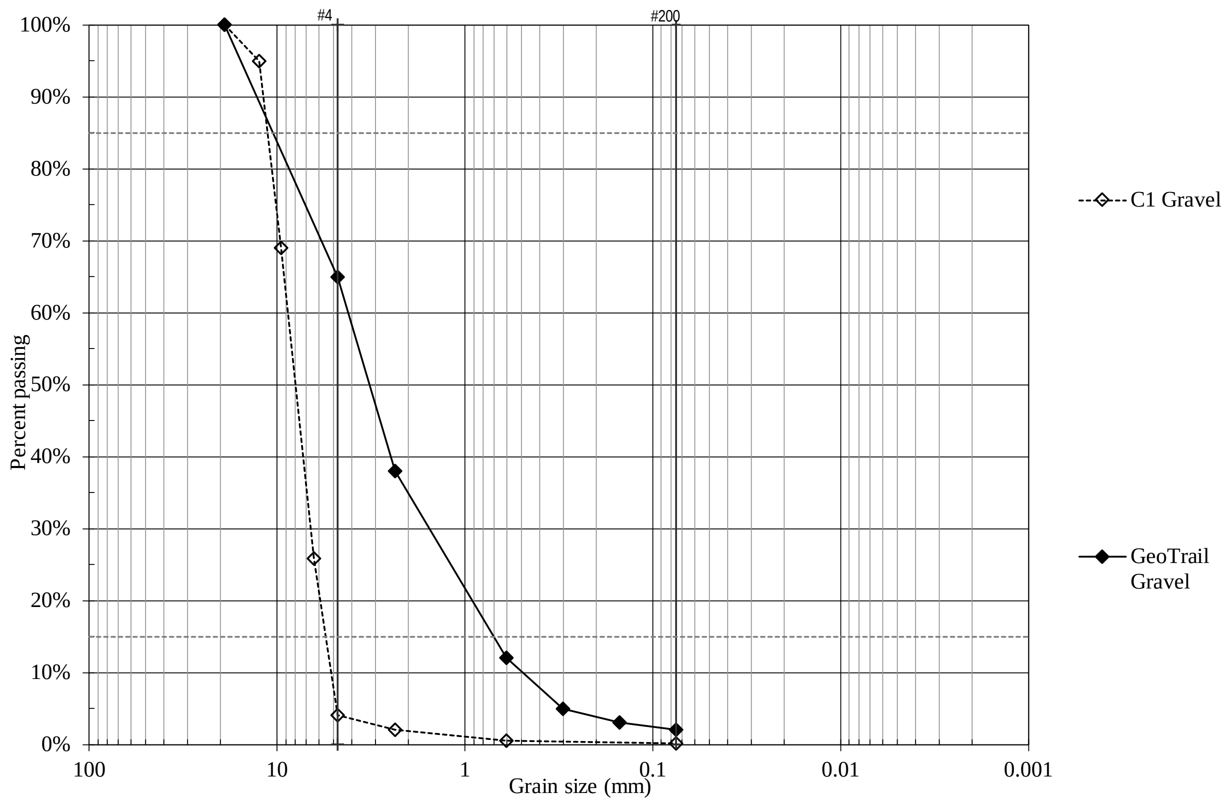

Figure 13 – Two gradations of gravel used in the lab-scale testing device

3.4.2 Effects of Compaction and Confinement

The first experiment conducted with the lab-scale testing device was with an untreated gravel (C1 from Figure 13). The material was placed to a depth of 6.5 inches in the device. One device was created with uncompacted material, and the other was compacted with a vibratory plate compactor. For the compacted and uncompacted test specimens, the firmness and stability measurements were taken with the BDRP. The walls were then moved from pin positions 0–-6, and BDRP measurements were taken again.

As shown in Figure 14 and Figure 15, moving the walls only affected the compacted gravel. It is interesting to note that the gravel becomes more stable as the confining walls are moved outward. Wall position and movement appears to have no significant, or constant, effect on the uncompacted material. Wall movement, or confinement, does not appear to have a significant influence on firmness and stability of the trails tested in the lab-scale device.

Table 12 shows the change in firmness and stability measured by the BDRP between the compacted and uncompacted specimens. These small changes indicate that compaction of this specimen does not greatly improve firmness or stability. In addition, the three commercial stabilizers tested and described later in this report recommend no compaction prior to placement of the stabilizer.

Table 12. Change in firmness and stability (percentage increase) between compacted and uncompacted specimens C1 in the lab-scale trail testing device

Pin Position	Firmness	Stability	Firmness and Stability
0	20%	5%	7%
1	13%	8%	9%
2	16%	4%	6%
3	13%	5%	6%
4	4%	4%	3%
5	18%	9%	11%

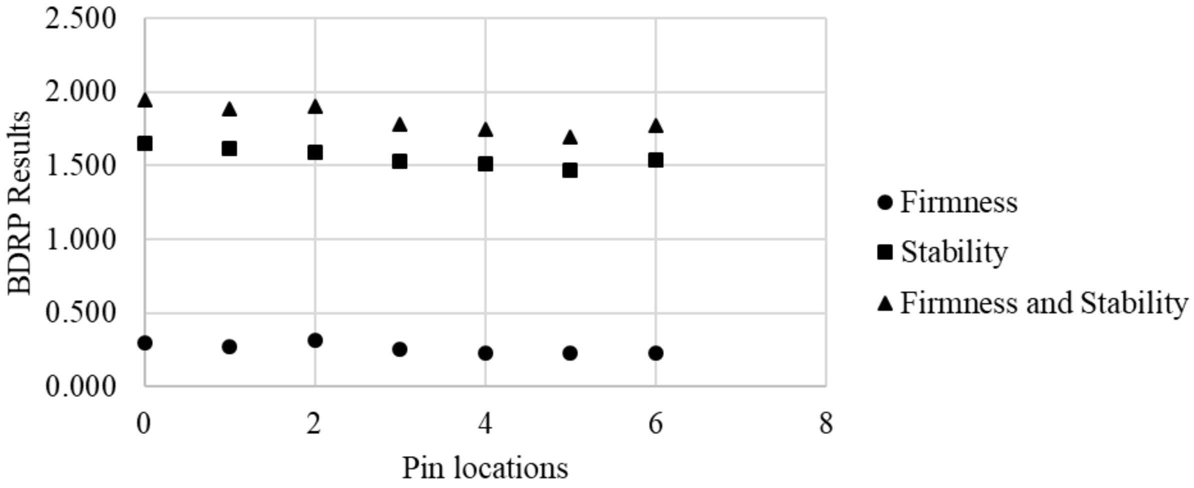

Figure 14 - Firmness and stability for gravel in lab-scale firmness and stability testing that was compacted by a vibratory compactor (material C1)

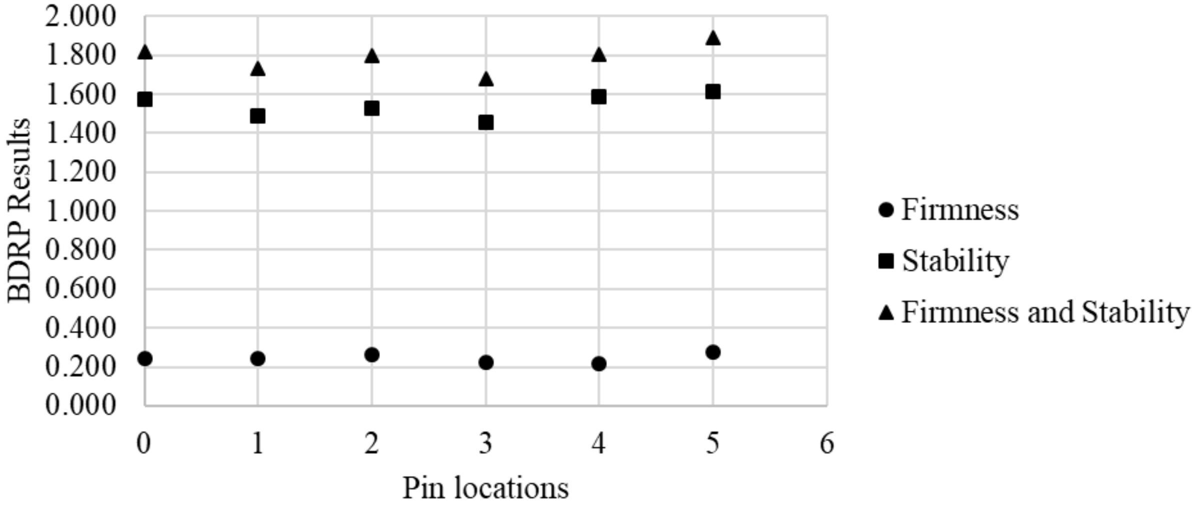

Figure 15 - Firmness and stability for gravel in lab-scale firmness and stability testing that was not compacted by a vibratory compactor (material C1)

3.4.3 Treatment of Lab-Scale Surfaces

Six separate trial mixes were applied to the lab-scale trail device. Treatment via cementitious mix proved highly successful in increasing the firmness and stability of the treated surface while in the frames. As the frames were designed to determine the effectiveness of topical cementitious treatment, variations in mix design were not investigated during these tests. Mix components, as well as surface materials used, are presented in Table 13. These mixes were applied and left to cure for seven days.

Table 13. Lab-scale firmness and stability testing samples and cementitious mixes by weight

Sample #	Material	Mix Water wt (kg)	Mix Ash wt (kg)	Mix Cement wt (kg)	Total Mix Wt (kg)
1	C1-gravel	5.40	2.18	1.45	9.03
2	Geotrail	2.09	0.82	0.54	3.45
3	C1-gravel	7.26	2.90	1.94	12.10
4	C1-gravel	3.40	1.36	0.91	5.67
5	C1-gravel	3.40	1.36	0.91	5.67
6	C1-gravel	3.40	1.36	0.91	5.67

Surface firmness was not greatly improved by treatment, improving by an average of 16.7% (Table 14). On average, surface stability was increased by an average of 49.4%, with a peak increase of 79.1%. A positive correlation has been shown between the amount of mix used and the effectiveness of the treatment (Figure 16). It should be noted that the greatest improvement in surface stability was not caused by the largest amount of cementitious mix. This could be due to the variability in effectiveness demonstrated by the three samples treated with similar mixes.

Table 14. Effects of topically applied cementitious mixes during lab-scale firmness and stability testing

Sample #	Change in Firmness	Change in Stability	Change in Firmness and Stability	% Change in Firmness	% Change in Stability	% Change in Firmness and Stability
1	0.043	1.243	1.286	17.6%	79.1%	70.9%
2	0.020	0.574	0.593	6.5%	38.3%	32.9%
3	0.129	1.050	1.179	39.4%	71.1%	65.3%
4	0.056	0.350	0.406	20.9%	23.5%	23.1%
5	0.050	0.705	0.755	14.6%	46.4%	40.6%
6	0.004	0.550	0.554	1.5%	38.0%	32.2%
Average	0.050	0.746	0.796	16.7%	49.4%	44.2%

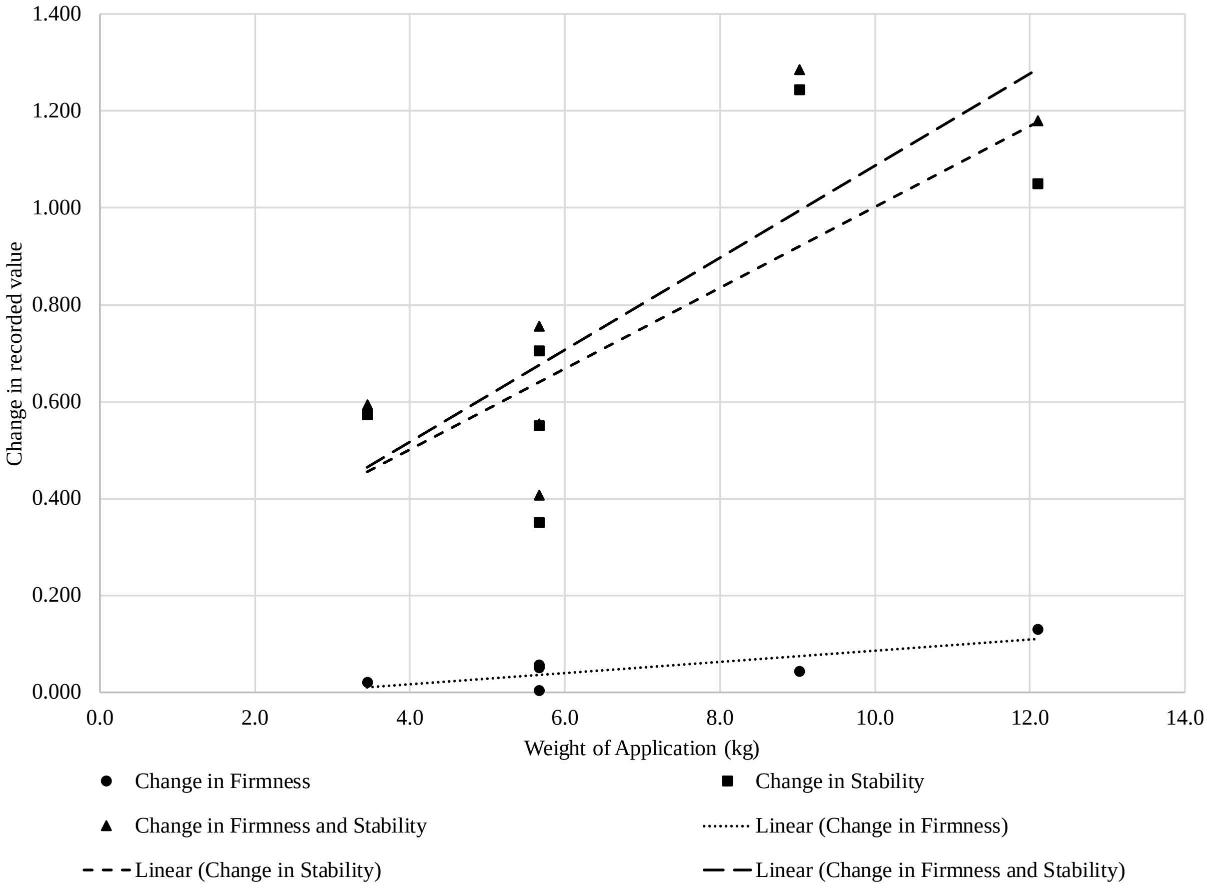

Figure 16 - Weight of cementitious mix applied plotted against the change in firmness and stability after treatment during lab-scale firmness and stability testing

3.5 FIELD-SCALE TESTING

Once treatment was determined to be effective, it was applied to the accessible geotrail located on the Oregon Institute of Technology Klamath Falls campus. Treatments were applied with intention of determining the effectiveness of stabilizing mixes, featured in the infiltration testing, in a practical application. Field applications allow the cementitious mixes more time to establish stabilization, as well as expose them to environmental conditions experienced by the chosen trail. The geotrail site, used for application of trail mixtures, is shown in Figure 17. This trail was constructed to meet ADA accessibility requirements in terms of width and slope.

Figure 17 – Application of materials at the field site

Markers were placed along the geotrail creating six sections that are 91cm wide by 3m in length. Six more were created along the trail that maintained the 91cm width, but the length was reduced to 150cm when it was determined that space did not have a noticeable impact on the firmness or stability. Sections can be seen with the cementitious mixes applied, length of the section, and date of application in Table 15. The cementitious mix applied was either 50%, 60% or 70% water with volcanic ash to portland cement ratios of 1.25, 1.50 and 1.75. For example, 70/175 in Table 15 would indicate 70% water, and 1.75 volcanic ash to portland cement ratio. Data sheets best describing the commercial binders are shown in the appendix Section 7.4 Marked sections were cordoned off for seven days after application to allow for curing. Preliminary firmness and stability readings were taken for each lot directly before being treated. Treatments were applied as volcanic ash was processed, or in the case of the SoilTac dilution, as data was made available to provide guidance.

Table 15. Information regarding the 12 sections used during field-scale firmness and stability testing

Section Designation	Cementitious Mix Applied	Length (m)	Date of Application
Lot 1	70/175	3	8/13/2019
Lot 2	50/175	3	8/13/2019
Lot 3	50/150	3	8/13/2019
Lot 4	Klingstone Amber	3	8/14/2019
Lot 5	G3 Soil Stabilizer	3	8/14/2019
Lot 6	SoilTac 30% Dilution	3	9/5/2019
Lot 7	50/125	1.5	8/22/2019
Lot 8	60/125	1.5	8/27/2019
Lot 9	60/150	1.5	8/27/2019
Lot 10	60/175	1.5	8/27/2019
Lot 11	70/125	1.5	9/3/2019
Lot 12	70/150	1.5	9/3/2019

Sprayers were attempted for application of lots 1, 2, and 3 on July 2, 2019. Applications were not even and did not cover a third of the designated surface. Furthermore, it did not appear to greatly affect the firmness or stability of the full surface due to inadequate coverage. A more thorough application was done using a vessel designed to disperse water containing particulate over a wide area. The second application was applied to lots 1, 2, and 3 with the judgement that the existence of the prior application would not greatly affect results moving forward. Each cementitious mix, except for the commercial stabilizers, was weighed and mixed in a controlled environment, transported to the site, then agitated before application to ensure they were fully mixed. For the mix, 6[M2].35kg was determined for use as it maintains the same mix ratio per weight as used in the infiltration tests (5% by weight of gravel), under the assumption that the geotrail was only 2.5cm of aggregate on top of packed soil. This assumption was created based on numerous site visits displaying a thin layer of loose gravel on top of packed soil. As field testing was carried out, it was revealed that what appeared to be packed soil was merely the fines of the trail having settled from use. Investigation confirmed prior grain size distributions were still accurate, even with this discovery.

Firmness and stability tests were conducted with the BDRP, similar to the lab-scale tests. Values were recorded on a weekly basis for 70 days after application, with readings being recorded the day of application before the mix was applied. Values were calculated for each trail section according to the process declared in the BDRP manual.

As demonstrated in the lab-scale testing, treatment improved the firmness and stability of the geotrail surface. Firmness does not appear to have improved noticeably, but when the change in firmness at weekly intervals compared proportionally with the pre-treatment firmness, it shows that surface firmness was improved by up to 27%. A solitary reading for lot 8 shows an improvement of almost 40%. For all sections except lots 8-10, sections treated with cementitious mixes that were 60% water, firmness appears to be affected more than stability, though not significantly. The reverse is true for section 1-3, 7, 11, and 12, where stability seems to be more affected by treatment than firmness, although still not significantly more. Section 4-6, which had commercial stabilizers applied to them, saw clear improvements to stability over firmness (Figure 18, Figure 19, Figure 20, Figure 21).

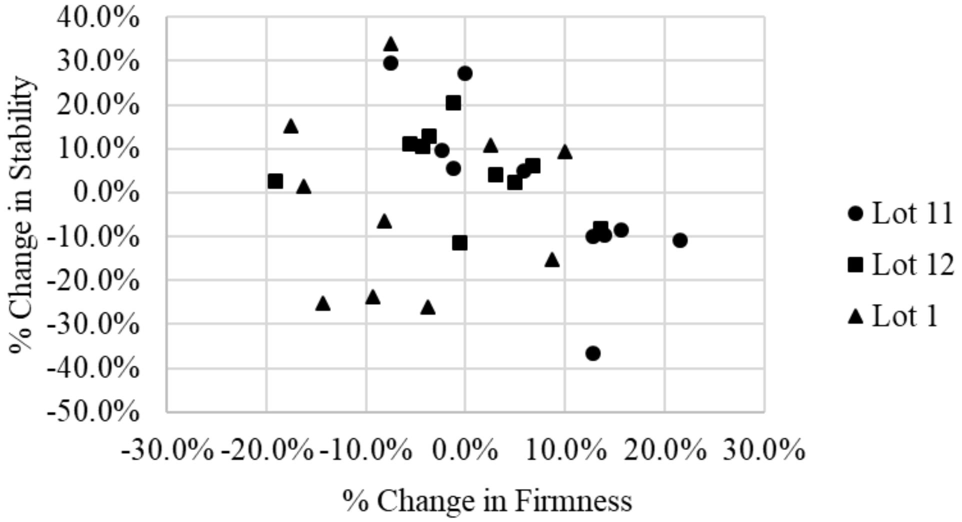

Figure 18 - Proportional change in surface characteristics for lots 11, 12, and 1 over 10 weeks of field-scale testing – 70% water mixes

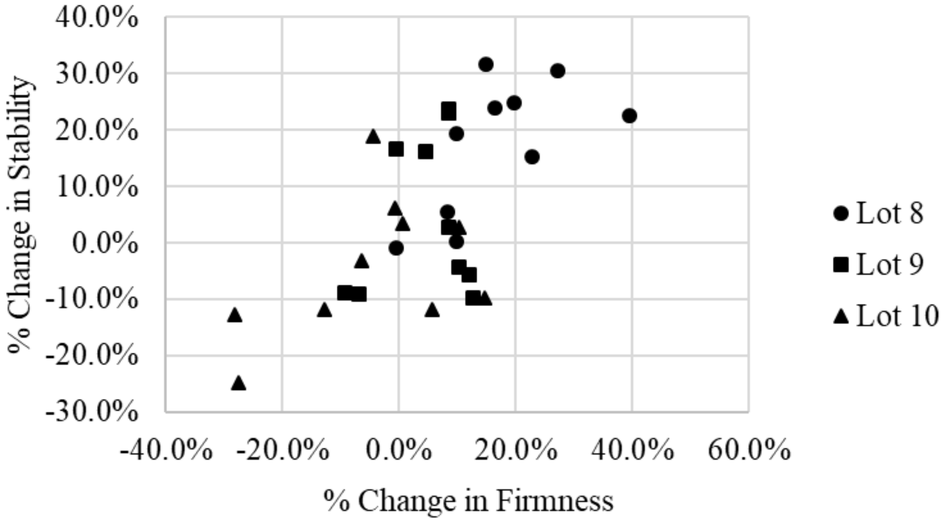

Figure 19 - Proportional change in surface characteristics for lots 8, 9, and 10 over 10 weeks of field-scale testing – 60% water mixes

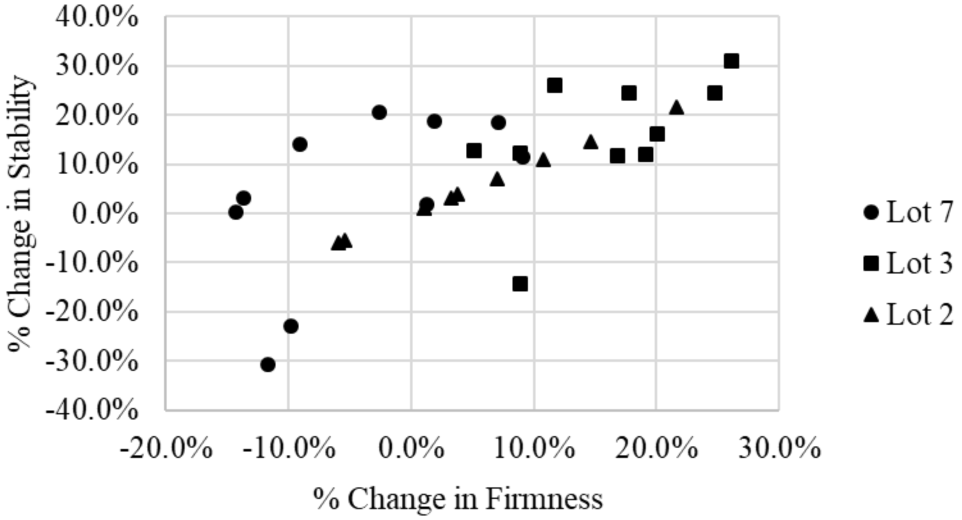

Figure 20 - Proportional change in surface characteristics for lots 7, 3, and 2 over 10 weeks of field-scale testing – 50% water mixes

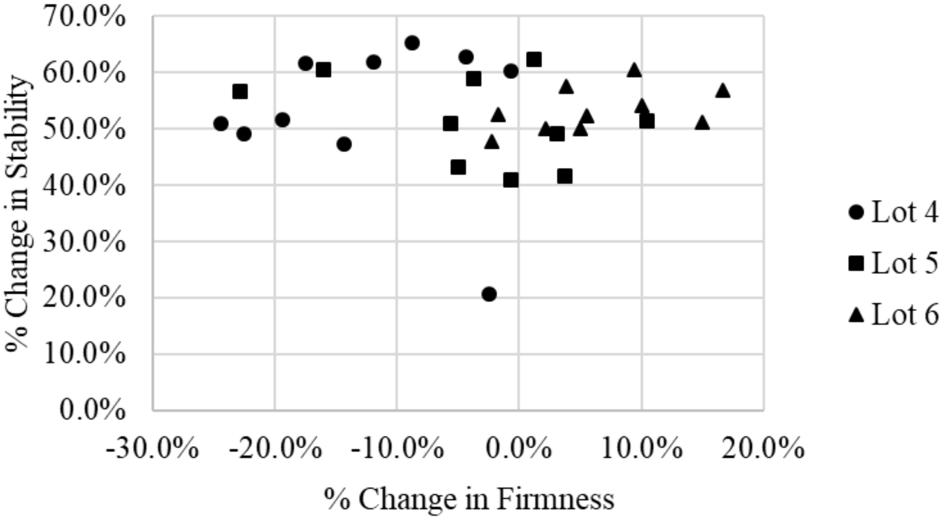

Figure 21 - Proportional change in surface characteristics for lots 4, 5, and 6 over 10 weeks of field-scale testing – commercial stabilizers

Every section treated with a non-commercial, cementitious mix saw both negative and positive changes to firmness and stability. Changes were considered mostly in relation to the pre-treated recorded characteristic for each section, and displayed as a percentage. Beneficial changes represent an increase in the surface firmness or stability, which would yield a lower reading with the BDRP. Non-beneficial changes were added to readings that showed no change from the base characteristic, as the goal of treatment is to improve the firmness and stability of the surface.

Commercial stabilizers provided no negative changes to stability, though negative changes to the surface firmness were recorded. Section 4, treated with Klingstone Amber polyurethane stabilizer, yielded no positive changes to surface firmness (Table 16) while increasing stability by an average of 53%. This increase in stability is standard among the commercial stabilizers (Table 17).

Table 16. Count of firmness and stability results that showed beneficial change or non-beneficial change during field-scale firmness and stability testing

Count of Changes to Surface Characteristics				
Lot#	Firmness		Stability	
	Non-Beneficial	Beneficial	Non-Beneficial	Beneficial
1	7	3	5	5
2	2	8	2	8
3	0	10	1	9
4	10	0	0	10
5	6	4	0	10
6	2	8	0	10
7	6	4	2	8
8	1	9	1	9
9	3	7	5	5
10	6	4	6	4
11	4	6	5	5
12	6	4	2	8
Total	53	67	29	91

Table 17. Relative change in surface firmness and stability, averaged over 10 weeks

Average Percent Increase after 70 Days			
Lot#	Mix designation	Firmness	Stability
1	70/175	-5.6%	-2.6%
2	50/175	5.2%	5.2%
3	50/150	15.9%	15.6%
4	Klingstone	-12.6%	53.1%
5	G3	-3.5%	51.5%
6	SoilTac	6.4%	53.3%
7	50/125	-4.2%	3.6%
8	60/125	16.8%	17.3%
9	60/150	4.9%	4.4%
10	60/175	-4.9%	-4.3%
11	70/125	7.2%	0.1%
12	70/150	-0.6%	5.1%

Current data suggests a trend toward lower water content mixtures, and lower ratios of volcanic ash to portland cement, yield higher quantity (Table 16) and quality (Table 17) changes to surface firmness and stability. Standing apart from this trend are lots 7, with regards to firmness, and lot 11, with regards to stability. Lot 7 was treated with a low water content and low volcanic ash ratio mixture, yet yielded non-beneficial changes to surface firmness.

Variability in firmness and stability records were calculated for each set of measurements taken. Variability was calculated by finding the two standard deviations for the recorded data and dividing it by the calculated value for that set of data. This was done with the intent of determining whether treatment of the surface would bring the recorded values into a tighter grouping, meaning the calculated firmness and stability values would be more representative of the overall surface. Lower values for variability represent lower standard deviations, therefore the spread is reduced.

Every section demonstrated an increase in variability of firmness and stability except for lots 8 and 9. Lot 8 has a significant reduction in variability, though this is probably due to the unusually high variably of the surface before receiving treatment. Other pre-treatment variability for firmness readings are between 17% and 30%, while the variability for lot 8 is 102% (Table 18). For stability, the range of variability is much larger, spanning from 15% to 74% (Table 19). Variability for both firmness and stability readings does not follow a predictable trend, and any effect of the treatment of the surface on variability would be negative. The improvement to variability in lot 9 is likely caused by the unpredictability of the variability for the data sets.

Table 18. Variation in surface firmness during field-scale firmness and stability testing per week

Firmness Variation with Time												
Days since treatment	**Lot 1**	**Lot 2**	**Lot 3**	**Lot 4**	**Lot 5**	**Lot 6**	**Lot 7**	**Lot 8**	**Lot 9**	**Lot 10**	**Lot 11**	**Lot 12**
0	17.0%	25.0%	23.0%	51.0%	29.0%	42.0%	28.0%	102.0%	17.0%	27.0%	26.0%	30.0%
7	16.0%	16.0%	46.0%	48.0%	53.0%	10.0%	47.0%	43.0%	45.0%	28.0%	26.0%	34.0%
14	31.0%	34.0%	20.0%	30.0%	38.0%	18.2%	16.0%	35.0%	21.0%	28.0%	10.5%	8.9%
21	28.0%	20.0%	29.0%	58.0%	33.0%	34.3%	18.0%	34.3%	20.7%	41.8%	38.0%	27.0%
28	21.0%	32.0%	12.0%	21.0%	47.0%	18.8%	29.4%	27.2%	15.3%	38.0%	22.3%	35.9%
35	59.0%	40.0%	7.0%	44.4%	47.9%	22.2%	20.6%	72.3%	25.9%	38.1%	24.4%	36.5%
42	9.0%	20.0%	26.0%	33.0%	22.6%	44.2%	20.9%	15.7%	72.4%	21.6%	53.2%	32.1%
49	25.4%	57.1%	28.2%	48.5%	35.6%	19.1%	34.7%	36.1%	18.7%	56.3%	25.7%	7.8%
56	23.5%	27.1%	26.8%	39.4%	44.0%	15.0%	46.8%	23.3%	36.4%	20.6%	32.0%	52.7%
63	36.0%	11.7%	30.1%	22.0%	35.6%	55.2%	18.8%	21.5%	31.4%	25.2%	29.6%	33.3%
70	62.6%	28.9%	27.0%	7.8%	34.4%	49.7%	34.0%	20.4%	21.4%	34.5%	20.0%	36.0%

Table 19. Variation in surface stability during field-scale firmness and stability testing per week

Stability Variation with Time												
Days since treatment	**Lot 1**	**Lot 2**	**Lot 3**	**Lot 4**	**Lot 5**	**Lot 6**	**Lot 7**	**Lot 8**	**Lot 9**	**Lot 10**	**Lot 11**	**Lot 12**
0	38.0%	15.0%	25.0%	21.0%	18.0%	20.0%	28.0%	42.0%	74.0%	27.0%	36.0%	74.0%
7	15.0%	29.0%	24.0%	49.0%	34.0%	21.0%	34.0%	90.0%	49.0%	68.0%	105.0%	93.0%
14	24.0%	60.0%	77.0%	26.0%	32.0%	29.4%	24.0%	71.0%	116.0%	46.0%	95.2%	58.9%
21	66.0%	82.0%	96.0%	85.0%	58.0%	36.5%	46.0%	112.4%	72.8%	57.2%	57.7%	120.9%
28	47.0%	99.0%	178.0%	92.0%	59.0%	33.3%	31.6%	75.4%	100.5%	69.6%	60.8%	84.7%
35	37.0%	68.0%	44.0%	63.6%	42.5%	31.3%	20.6%	85.8%	83.1%	35.4%	27.8%	54.5%
42	62.0%	145.0%	34.0%	98.5%	36.3%	40.1%	31.8%	53.3%	82.5%	43.2%	52.2%	85.4%
49	34.9%	78.2%	96.9%	33.1%	82.4%	39.1%	47.6%	91.2%	41.1%	56.9%	18.0%	91.2%
56	58.3%	38.3%	132.1%	45.2%	59.0%	14.8%	65.3%	60.3%	75.4%	51.0%	28.4%	91.2%
63	67.9%	32.4%	52.7%	18.2%	63.1%	43.0%	31.8%	24.4%	51.9%	48.1%	38.1%	63.8%
70	32.7%	93.5%	86.0%	91.2%	23.3%	34.7%	27.5%	53.9%	41.7%	34.9%	30.7%	40.1%

Surface firmness and stability show change with time. Firmness shows a constant positive trend, even though some are shown to have a non-beneficial change (Figure 22, Figure 23, Figure 24, Figure 25). Stability does not demonstrate any predictable or constant trend (Figure 26, Figure 27, Figure 28, Figure 29). Graphs pertaining to firmness and stability have been arranged so that similar mixes based on water content are displayed together to reduce clutter. It is also possible that the smaller non-beneficial changes are within error margins for an increase to that characteristic, as both characteristics do not display predictable behavior. However, more data is required before the full extent of the effectiveness can be determined.

Both firmness and stability were recorded for lots 1-12 for 70 days. Table 20 shows whether positive or negative changes in stability and firmness, on average, were recorded over the 70 days. As shown, all treated lots experienced an average increase in firmness over seven days. Interestingly, the change in firmness of the commercially treated lots were much less than the portland cement and volcanic ash treated lots. In terms of stability, positive and negative changes with time were experienced for the portland cement and volcanic ash treated lots. However, negative, or decreases, in stability with time were shown in the commercially treated lots. This indicates that the long-term gains in strength shown with the portland cement and volcanic ash mixes in the mortar cubes could be contributing to increases in firmness and stability with time. The commercially treated surfaces appear to be degrading in stability with time in contrast to the portland cement and volcanic ash treated surfaces.

Table 20. Averaged change in stability and firmness over 70 days for all treated lots

Lot #	Stability	Correlation Coefficient	Firmness	Correlation Coefficient
1	+	0.0003	+	0.0002
2	+	0.003	+	0.0004
3	+	0.001	+	0.0005
4	-	-0.001	+	0.00007
5	-	-0.0017	+	0.0002
6	-	-0.0008	+	0.00004
7	+	0.0025	+	0.0007
8	+	0.0022	+	0.0005
9	-	-0.0003	+	0.0004
10	+	0.0011	+	0.0009
11	-	-0.0002	+	0.0003
12	-	-0.0018	+	0.0004

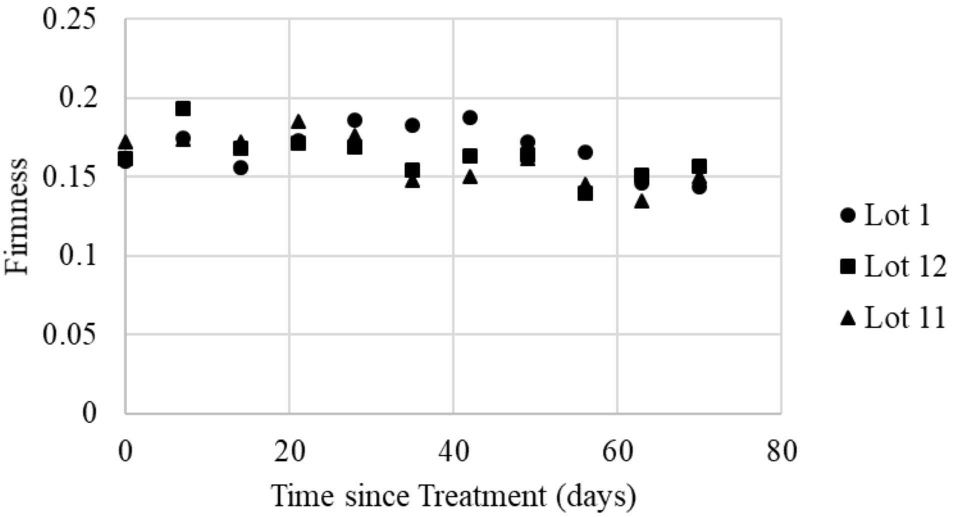

Figure 22 - Firmness of lots 1, 12, and 11 with time during field-scale firmness and stability testing

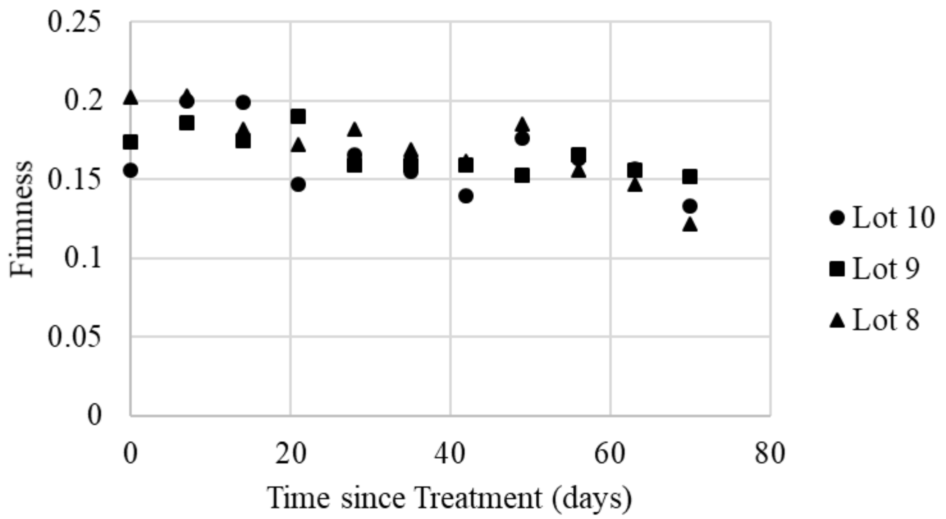

Figure 23 - Firmness of lots 10, 9, and 8 with time during field-scale firmness and stability testing

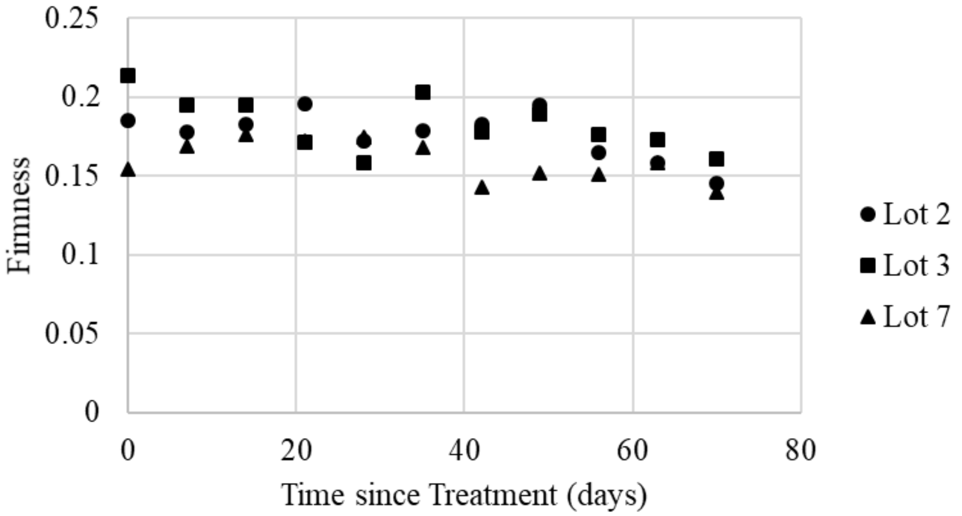

Figure 24 - Firmness of lots 2, 3, and 7 with time during field-scale firmness and stability testing

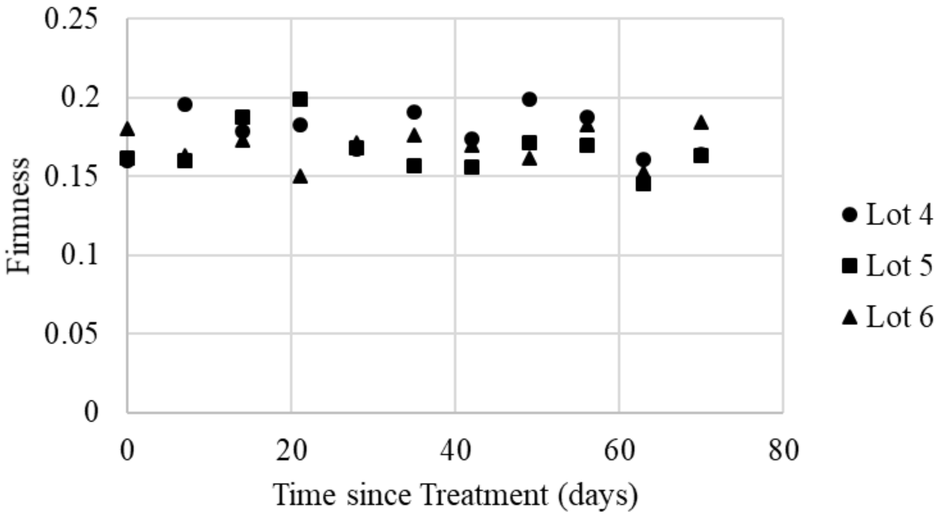

Figure 25 - Firmness of lots 4, 5, and 6 with time during field-scale firmness and stability testing

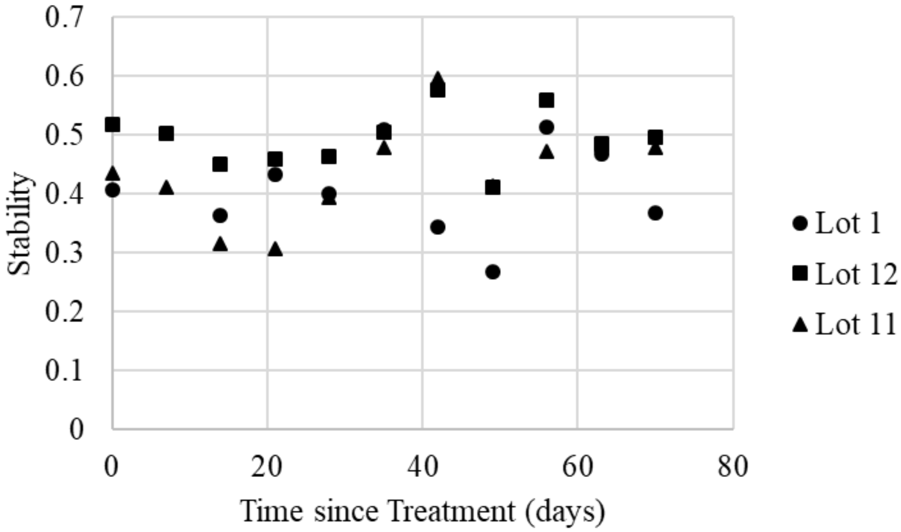

Figure 26 - Stability of lots 1, 12, and 11 with time during field-scale firmness and stability testing

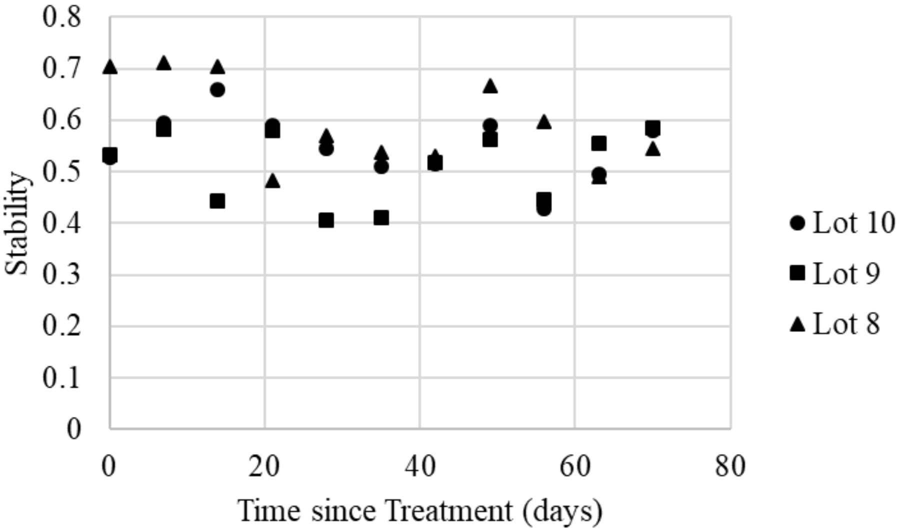

Figure 27 - Stability of lots 10, 9, and 8 with time during field-scale firmness and stability testing

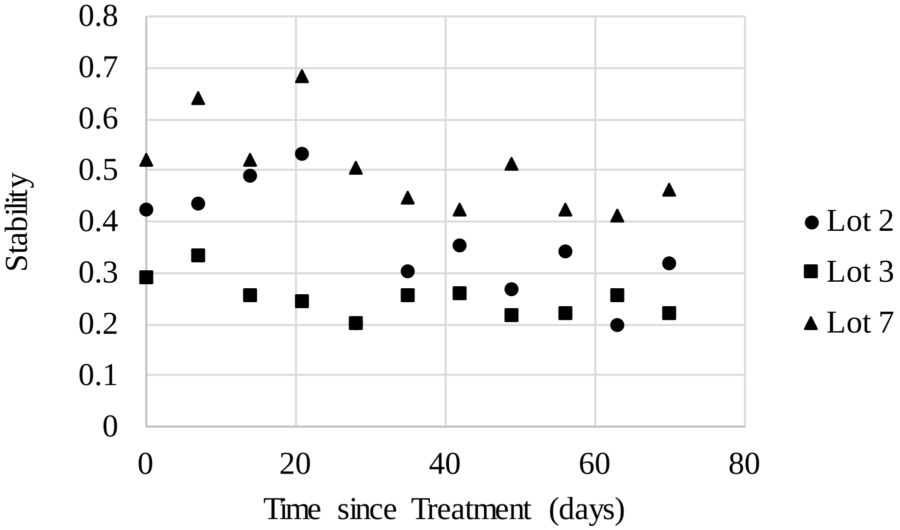

Figure 28 - Stability of lots 2, 3, and 7 with time during field-scale firmness and stability testing

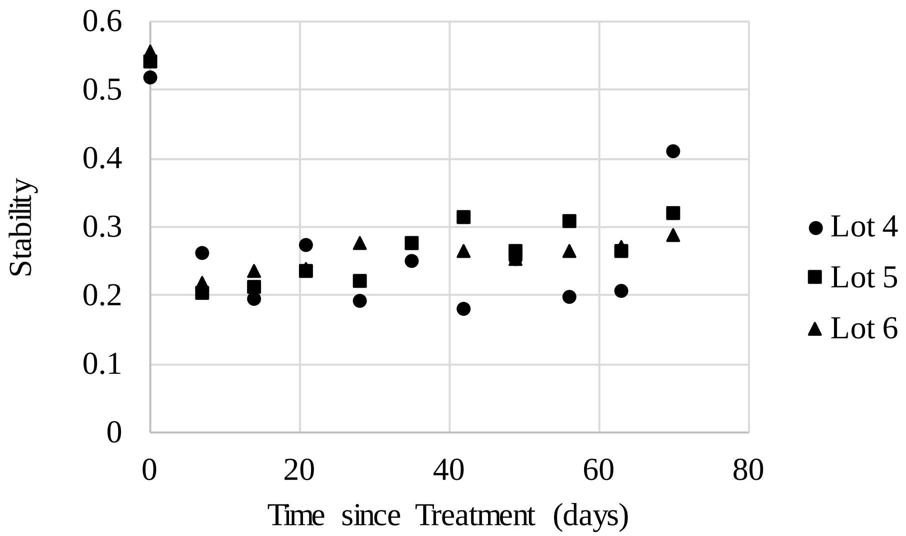

Figure 29 - Stability of lots 4, 5, and 6 with time during field-scale firmness and stability testing.

4.0 DATA INTERPRETATION AND CORRELATIONS

As discussed previously, this study has included an extensive gathering of data related to the use of a natural pozzolan for binding unpaved surfaces. Unpaved surfaces can be used as ADA accessible trails if the surface is firm and stable. Because there is an infinite combination of gravel surfaces, with different gradations and pozzolanic and cementitious materials, the data collected has been reviewed for trends and correlations. These trends and correlations can be used to transform the materials studied here to other materials and locations.

4.1.1 Compressive Strength and Ratio of Volcanic Ash to Portland Cement

For this work, over 175 mortar cubes were created with different percentages of volcanic ash and portland cement along with water and graded sand following ASTM C109. An attempt was made to understand the relationship between increasing the replacement percentage of portland cement with volcanic ash. These data relationships are shown in Figure 30, Figure 31, Figure 32, Figure 33, Figure 34, Figure 35, Figure 36 and Figure 37. A table of results is shown in Table 21. A second-order polynomial can be used to describe the relationship between strength and ash to portland ratio for sample ages from 7 to 84 days with high reliability. These presented equations can aid engineers and designers when attempting to determine the effects on strength of reducing portland cement and substituting processed, volcanic ash used in this study.

Table 21. Compressive strength of mortar cubes with increasing ratios of volcanic ash to portland cement (strength in psi)

Ratio of Volcanic Ash to Portland Cement	Age (days)						
	7	21	28	42	56	70	84
0%	5744	6335	6631	6980	6980	6980	6980
25%	3856	4274	4483	4933	5168	5241	5289
43%	2629	2844	2952	3155	3183	3496	3808
67%	1583	1839	1967	2148	2218	2481	2543
150%	65	103	123	130	138	148	158

Few studies were found that used processed, volcanic ash with similar chemical composition to that of Mt. Mazama volcanic ash to replace portland cement. One such study, by Hossain and Lachemi (2006), used a similar volcanic ash from Papua New Guinea (Table 22). Chemically, the material is nearly the same as Mt. Mazama volcanic ash however fineness of the material is appreciably higher for the Papua New Guinea volcanic ash. As with our study, Hossain and Lachemi prepared mortar cubes with increasing replacement of portland cement with volcanic ash. The strength of their cubes was compared to a control sample that had the same water to cement ratio as this study. As can be observed in Figure 36, the strength loss in samples with up to approximately 25% replacement with volcanic ash had nearly the same loss in strength between the two studies. As percentages of replacement increase beyond 25%, the two studies diverge with higher strength reported in this study. It is hypothesized that this may be due to the decrease in fineness of the materials used in this study. When fineness is decreased, pozzolanic reactivity is delayed. However this does not fully explain the large overall higher strengths observed in this study.

Table 22. Comparison of chemical composition and fineness between Mt. Mazama volcanic ash and that studied by Hossain and Lachemi (2006)

Compound	Mt. Mazama Ash (%)	Hossain and Lachemi 2006 (%)	Difference(%)
SiO_2	65.81	59.32	6.49
Al_2O_3	18.75	17.54	1.21
Fe_2O_3	4.40	7.06	2.66
CaO	3.42	6.10	2.68
MgO	1.45	2.55	1.10
SO_3	-0.01	0.71	0.72
Na_2O	3.20	3.80	0.60
K_2O	1.98	2.03	0.05
Retained on No. 325 Sieve (%)	44	12	32

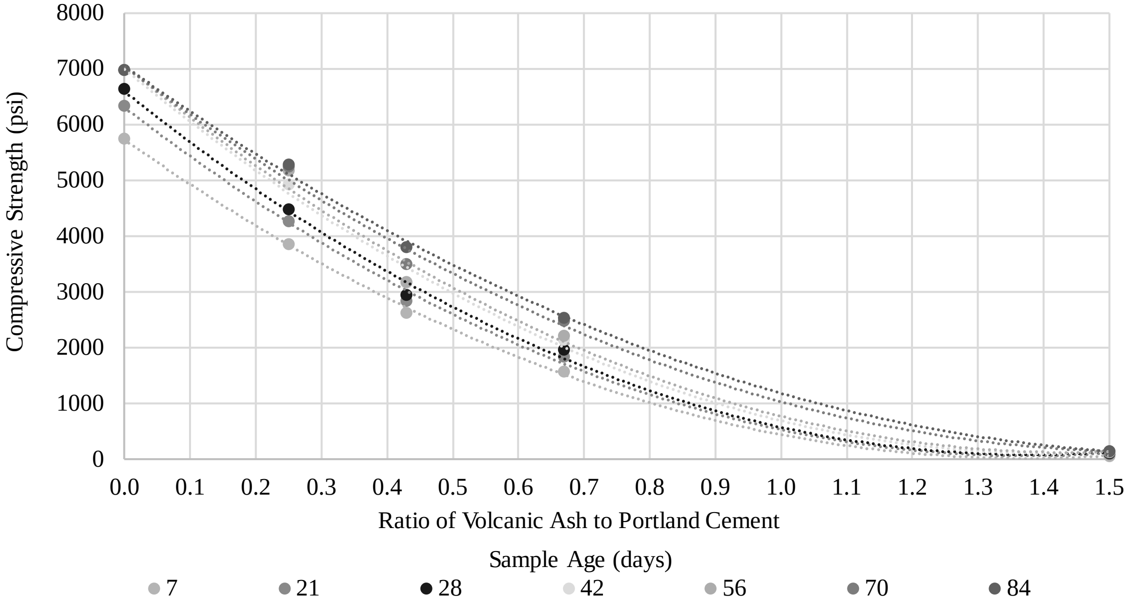

Figure 30 - The comparison between the compressive strength for each testing time period compared to the ratio of volcanic ash to portland cement

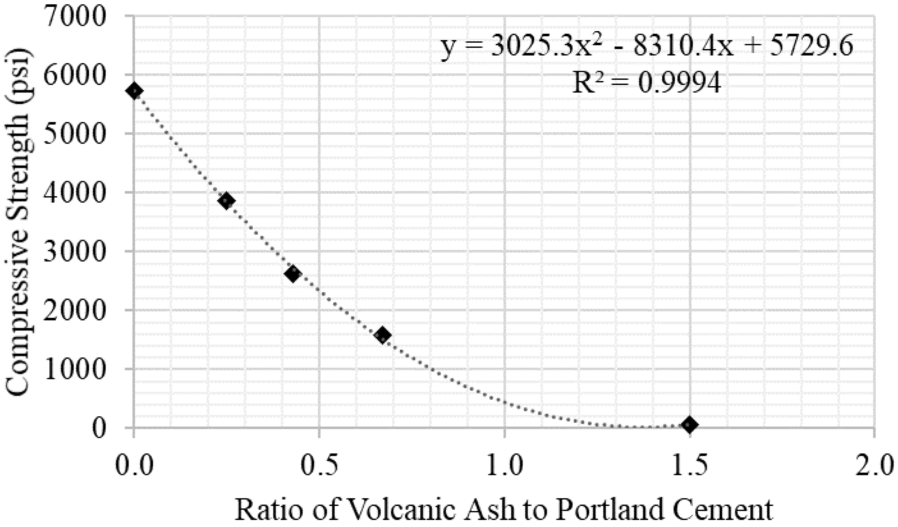

Figure 31 – Compressive strength and ratio of volcanic ash to portland cement (seven-day cure time)

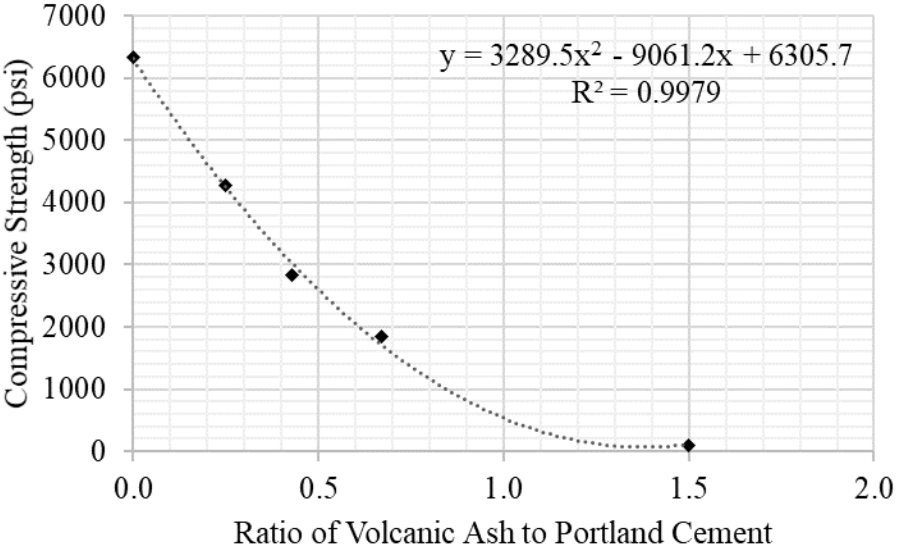

Figure 32 – Compressive strength and ratio of volcanic ash to portland cement (21-day cure time)

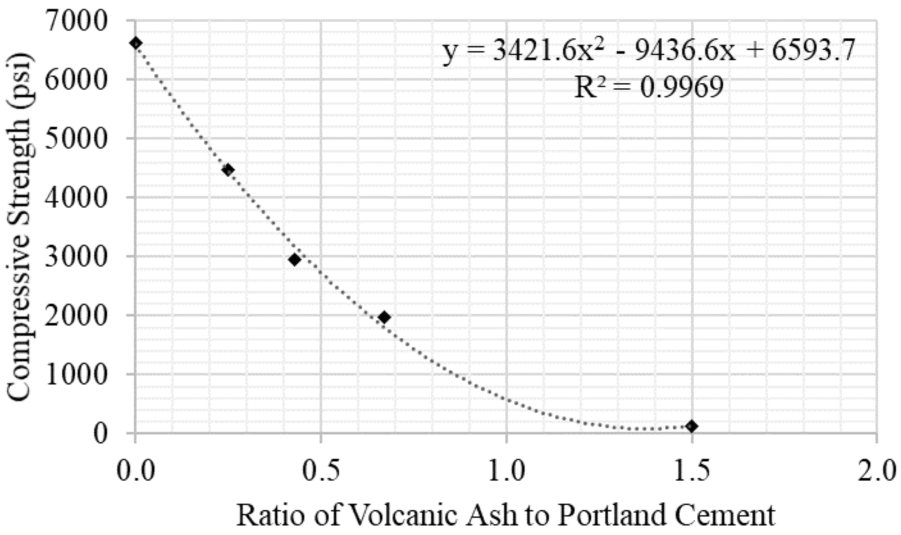

Figure 33 – Compressive strength and ratio of volcanic ash to portland cement (28-day cure time)

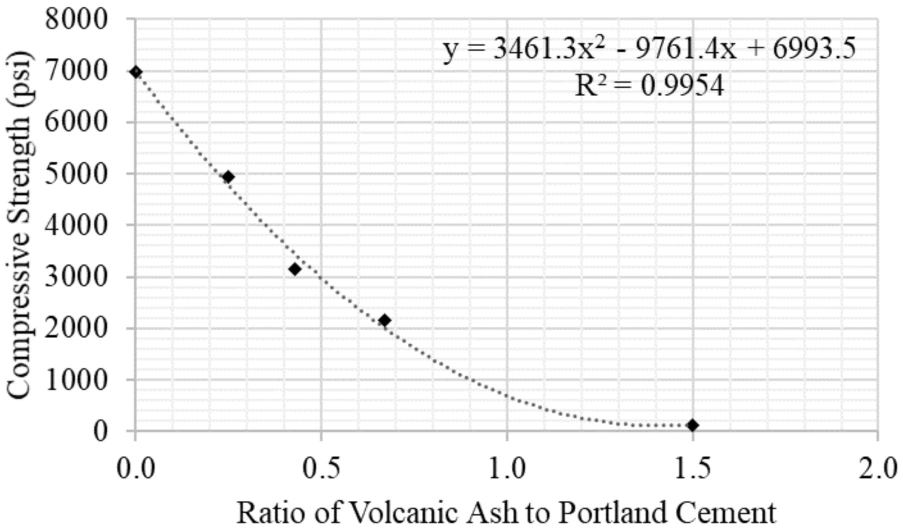

Figure 34 – Compressive strength and ratio of volcanic ash to portland cement (42day cure time)

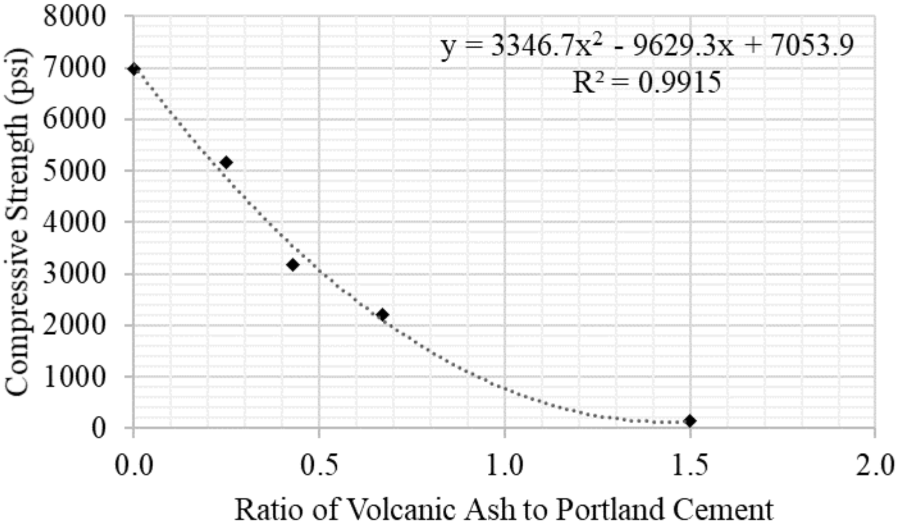

Figure 35 – Compressive strength and ratio of volcanic ash to portland cement (56-day cure time)

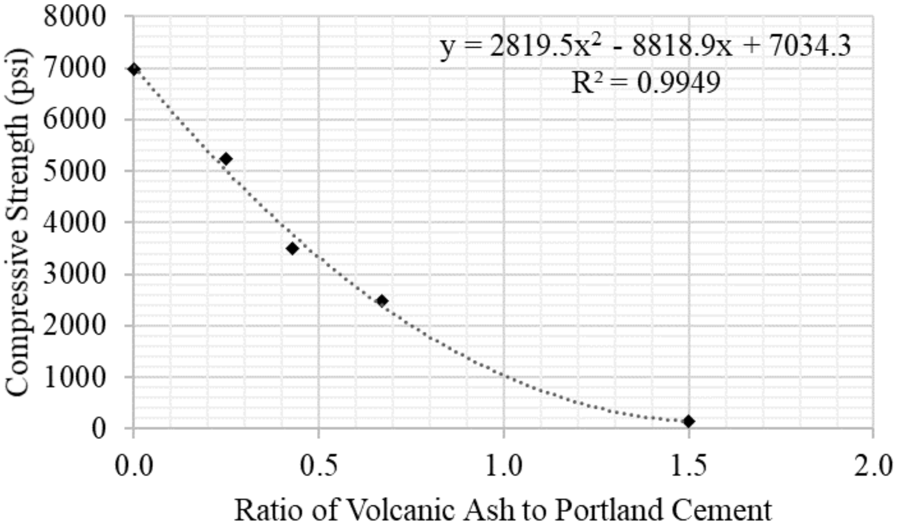

Figure 36 – Compressive strength and ratio of volcanic ash to portland cement (70-day cure time)

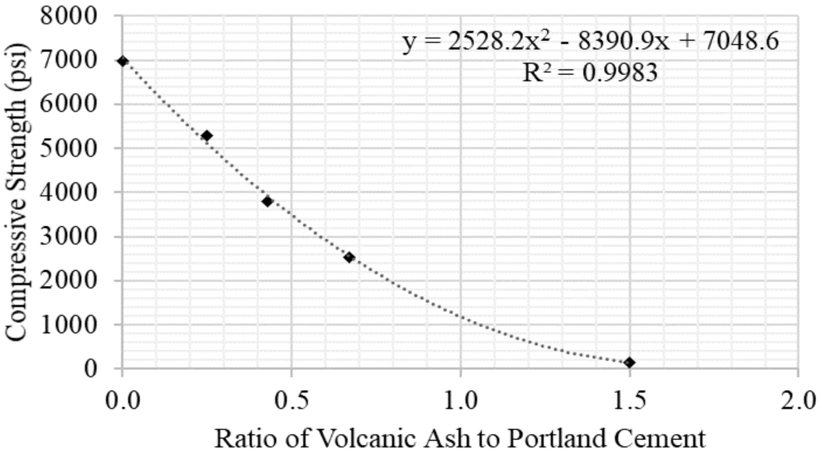

Figure 37 – Compressive strength and ratio of volcanic ash to portland cement (84-day cure time)

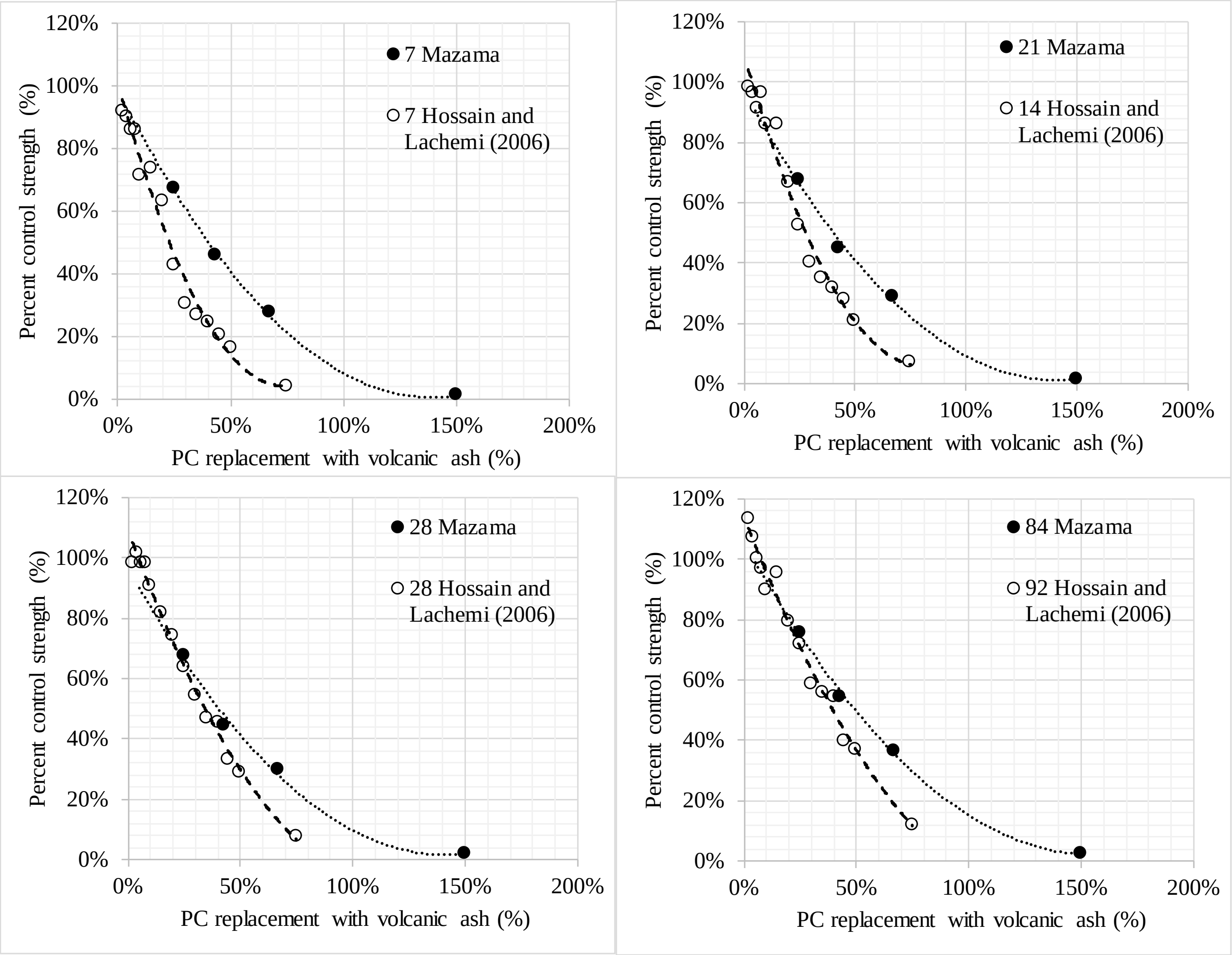

Figure 38 – Comparison of unconfined compressive strength for mortar cubes made with increasing replacement of portland cement with volcanic ash – 1, 2, 4, and 7 week curing times

4.1.2 Firmness and Stability

The BDRP takes measurements of firmness and stability as discussed in a previous section of the report. Prior to this research, it was anticipated that a strong, positive correlation would exist between the firmness and stability of an unpaved trail surface. For this study, 190 separate locations were taken of firmness and stability using the BDRP. At each location, there are seven measurements taken resulting in 1,330 separate measurements of firmness and 1,330 measurements of stability. As shown in Figure 39, while the trend is positive, the variability between firmness and stability is large. It is not accurate to assume that increases or decreases to firmness and stability occur concurrently. When separated into treated surfaces and untreated surfaces, Figure 40 and Figure 41, it appears that untreated surfaces are modeled better with a linear relationship than treated surfaces. This may indicate that treatment affects stability or firmness independently. Figure 41 appears to show a gap in measured data between stability measurements of 1.0 to 1.4. This data 'gap' is a result of testing untreated surfaces with relatively small (<1/4") and relatively large (>3/4") material. When the material is not bound with an admixture, the stability and firmness of the material is largely influence by the size of the material as individual pieces of loose aggregate are moved by the wheel of the BDRP.

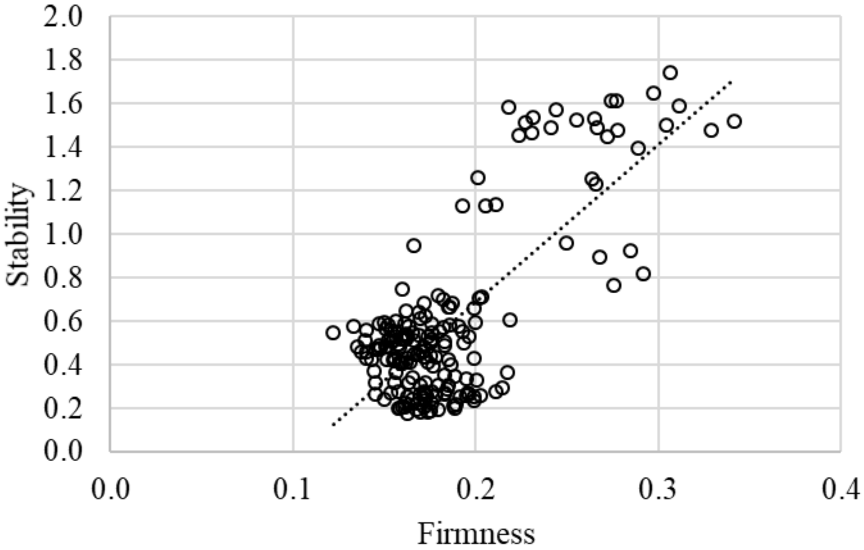

Figure 39 – Measured values of firmness and stability with the BDRP as part of this study

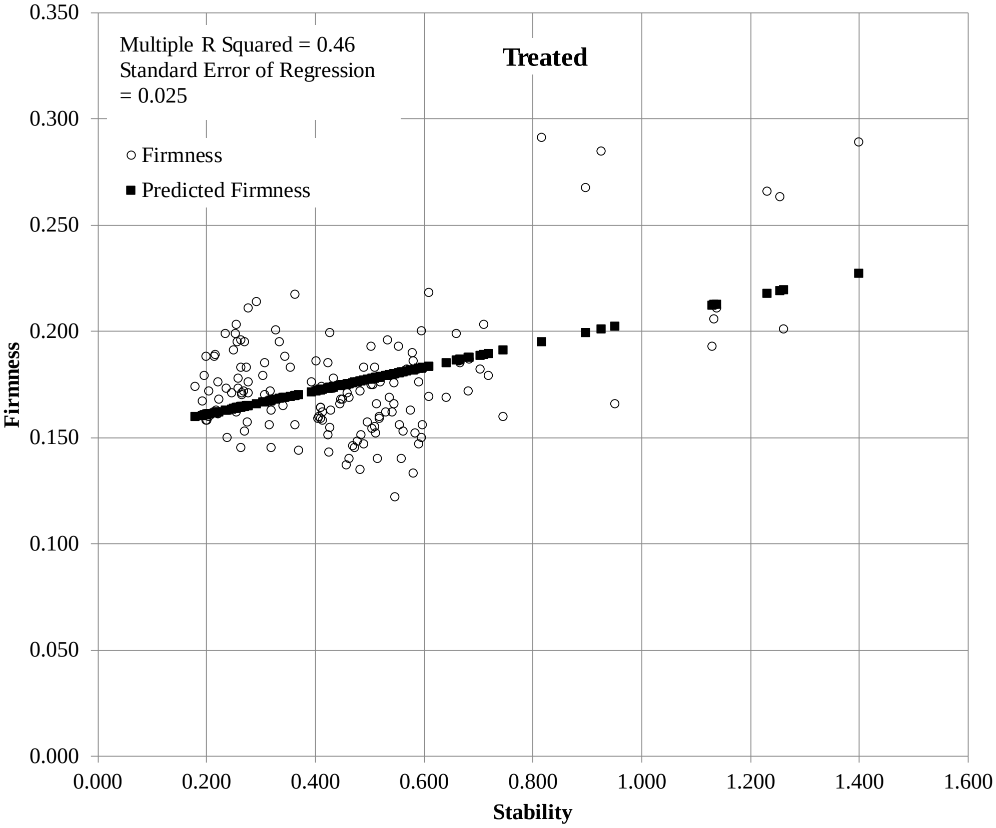

Figure 40 – Linear regression of firmness and stability for all treated surfaces

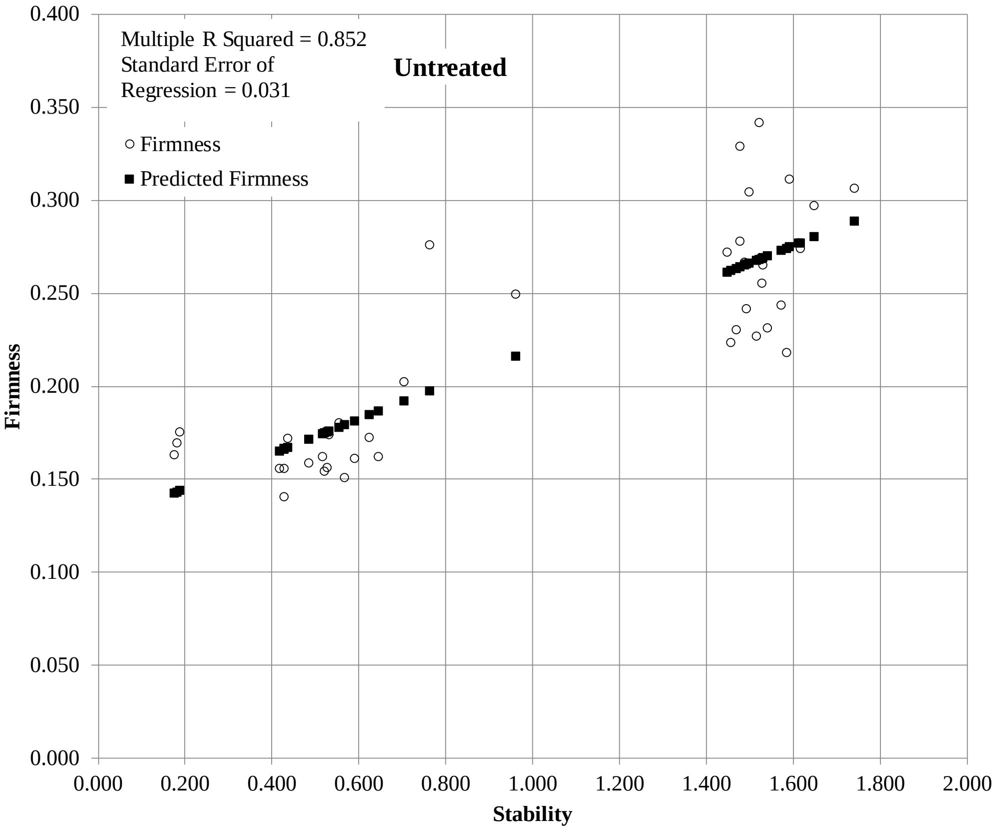

Figure 41 - Linear regression of firmness and stability for all untreated surfaces

4.1.3 Correlations between Pour Tests and Gravel Gradations

The pour tests used for this study attempted to determine proportions of water, portland cement and volcanic ash that could bind and penetrate gravel. The goal is to bind and penetrate unpaved trail surfaces (gravel) to the largest extent possible to increase firmness and stability. As with the compressive strength of mortar cubes from his study, there is an infinite combination of gradations, water, portland cement and volcanic ash that could be studied. With hopes that the information contained in this report can be translated to different locations with different gravel properties, a comprehensive review of the pour test data was conducted.

It is hypothesized that infiltration depth and percentage bound material are a function of slurry viscosity and permeability of the gravel material. Permeability is mostly controlled by the D_{10} size of a gravel as indicated in Duncan (2008). In addition to D_{10}, the influence of D_{30}, D_{60}, C_u and C_c of the gravel were investigated. As shown in Figure 42 and Figure 43, little relationship exists between these gravel gradational properties and penetration depth or bound material for three different water ratios. A similar lack of relationship between D_{30}, D_{60}, C_u and C_c of the gravel exist and were investigated. Therefore, extending this information to gravels of other gradations does not seem plausible with these basic gradational descriptors.

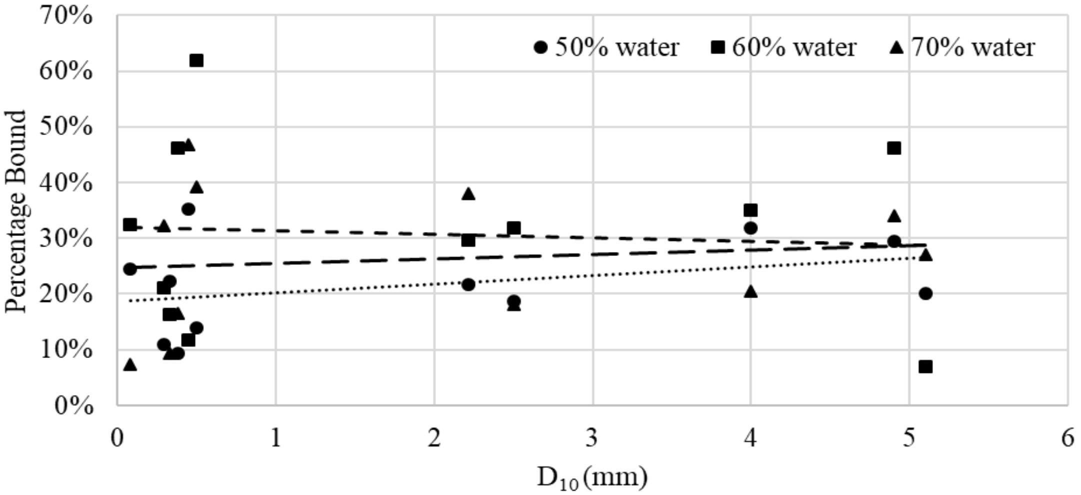

Figure 42 – Results of pour tests for percentage bound material correlated to D_{10} of the gravel (ash/cement ratio 1.5)

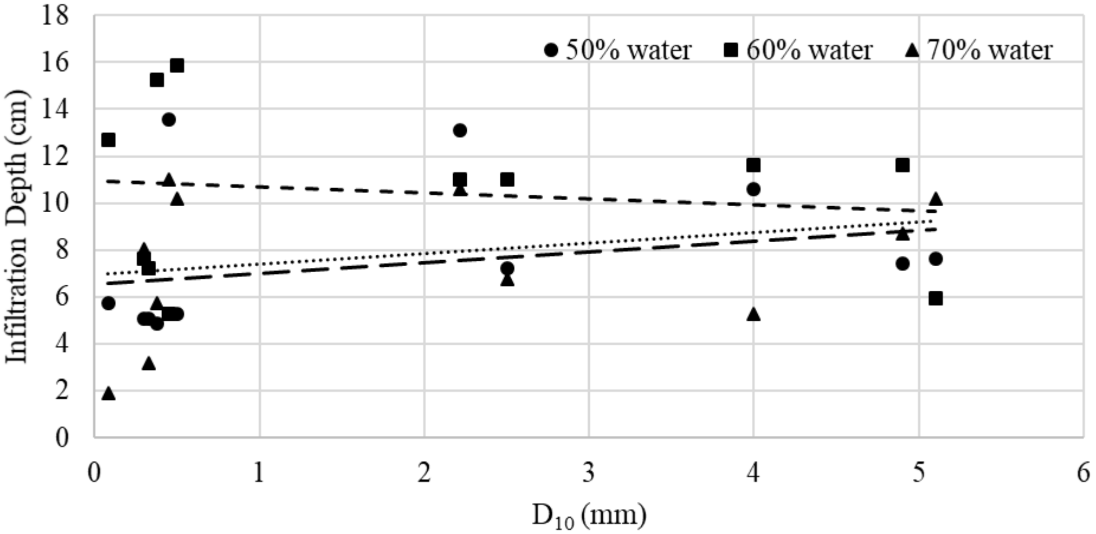

Figure 43 – Results of pour tests for infiltration depth correlated to D_{10} of the gravel (ash/cement ratio 1.5)

4.1.4 All Correlations of Data Collected

Table 23 includes the variables introduced, used, and discovered throughout the course of this project when compared through linear regression to each other. Limits were placed on the degree that a correlation would be sought, keeping the line of best fit equation to under a third order polynomial, for example. Cells with "Limited" as the entry mean there is not enough data shared by the two variables to reach a valid conclusion, generally only one or two data points. "No Comparison" means that one variable has no effect on the other; these only exist between the gravel characteristics and the mortar cube testing results. In the center of the table is a large section of "Controlled" entries. These mean that the variable was an independent variable that was controlled during testing, therefore there is no correlation among each other. The purpose of this table was to record and clearly show what variables had correlations with each other.

Table 23. Data collected and linear regression interpretation for this project

Correlation Between Variables	Cement Compressive Strength	Infiltration Depth	Percentage Bound	D10	D30	D60	Coefficient of Uniformity	Coefficient of Curvature	Mixture Water Percentage	Volcanic Ash Ratio	Firmness	Stability	Combined Firmness and Stability	Change in Firmness	Change in Stability	Combined Change	% Sample Strength	% Control Strength	Cure Time
Cement Compressive Strength	\	0.5, 2nd Order	<0.99, 2nd Order	Limited	Limited	Limited	Limited	Limited	Limited	<0 .98, 2nd Order	Limited	Limited	Limited	Limited	Limited	Limited	1, linear	>0.96, Linear	>0.97, 2nd Order
Infiltration Depth	0.5, 2nd Order	\	0.46, Linear	>0.10, Linear	>0.30, Linear	>0.15, Linear	>0.41, Linear	>0.30, Linear	<0.2, 2nd Order	<0.1, 2nd Order	0.41, 2nd Order	0.10, 2nd Order	0.14, 2nd Order	>0.1, Log	>0.1, Log	>0.3, Log	>0.88, 2nd Order	0.5, 2nd Order	Limited
Percentage Bound	<0.99, 2nd Order	0.46, Linear	\	<0.13, Linear	<0.13, Linear	<0.4, Linear	<0.23, Linear	<0.35, Linear	<0.14, 2nd Order	<0.1, 2nd Order	0.41, 2nd Order	0.10, 2nd Order	0.14, 2nd Order	>0.1, Log	>0.1, Log	>0.1, Log	0.94, 2nd Order	0.99, 2nd Order	Limited
D10	Limited	>0.10, Linear	<0.13, Linear	\	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	.53, Expon.	.74, Expon.	.73, Expon.	Limited	Limited	Limited	No Comparison	No Comparison	No Comparison
D30	Limited	>0.30, Linear	<0.13, Linear	Controlled	\	Controlled	Controlled	Controlled	Controlled	Controlled	.51, Expon.	.76, 2nd Order	.74, 2nd Order	Limited	Limited	Limited	No Comparison	No Comparison	No Comparison
D60	Limited	>0.15, Linear	<0.4, Linear	Controlled	Controlled	\	Controlled	Controlled	Controlled	Controlled	.44, 2nd Order	.76, 2nd Order	.74, 2nd Order	Limited	Limited	Limited	No Comparison	No Comparison	No Comparison
Coefficient of Uniformity	Limited	>0.41, Linear	<0.23, Linear	Controlled	Controlled	Controlled	\	Controlled	Controlled	Controlled	.52, Expon.	.76, 2nd Order	.75, Expon.	Limited	Limited	Limited	No Comparison	No Comparison	No Comparison
Coefficient of Curvature	Limited	>0.30, Linear	<0.35, Linear	Controlled	Controlled	Controlled	Controlled	\	Controlled	Controlled	.53, Expon.	.76, 2nd Order	.74, Expon.	Limited	Limited	Limited	No Comparison	No Comparison	No Comparison
Mixture Water Percentage	Limited	<0.2, 2nd Order	<0.14, 2nd Order	Controlled	Controlled	Controlled	Controlled	Controlled	\	Controlled	Limited	Limited	Limited	Limited	Limited	Limited	No Comparison	No Comparison	No Comparison
Volcanic Ash Ratio	<0 .98, 2nd Order	<0.1, 2nd Order	<0.1, 2nd Order	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	\	Limited	Limited	Limited	Limited	Limited	Limited	No Comparison	No Comparison	No Comparison
Firmness	Limited	0.41, 2nd Order	0.41, 2nd Order	.53, Expon.	.51, Expon.	.44, 2nd Order	.52, Expon.	.53, Expon.	Limited	Limited	\	0.88, 3rd Order	0.90, 3rd Order	0.63, 2nd Order	0.57, 2nd Order	0.65, 2nd Order	Limited	Limited	Limited
Stability	Limited	0.10, 2nd Order	0.10, 2nd Order	.74, Expon.	.76, 2nd Order	.76, 2nd Order	.76, 2nd Order	.76, 2nd Order	Limited	Limited	0.88, 3rd Order	\	>0.99, Linear	<0.3, 2nd Order	>0.98, 2nd order	>0.98, 2nd order	Limited	Limited	Limited
Combined Firmness and Stability	Limited	0.14, 2nd Order	0.14, 2nd Order	.73, Expon.	.74, 2nd Order	.74, 2nd Order	.75, Expon.	.74, Expon.	Limited	Limited	0.90, 3rd Order	>0.99, Linear	\	<0.3, 2nd Order	>0.97, 2nd Order	>0.98, 2nd order	Limited	Limited	Limited
Change in Firmness	Limited	>0.1, Log	>0.1, Log	Limited	Limited	Limited	Limited	Limited	Limited	Limited	0.63, 2nd Order	<0.3, 2nd Order	<0.3, 2nd Order	\	0.20, 2nd order	<0.3, 2nd Order	Limited	Limited	Limited
Change in Stability	Limited	>0.1, Log	>0.1, Log	Limited	Limited	Limited	Limited	Limited	Limited	Limited	0.57, 2nd Order	>0.98, 2nd order	>0.97, 2nd Order	0.20, 2nd order	\	>0.98, linear	Limited	Limited	Limited
Combined Change	Limited	>0.3, Log	>0.1, Log	Limited	Limited	Limited	Limited	Limited	Limited	Limited	0.65, 2nd Order	>0.98, 2nd order	>0.98, 2nd order	<0.3, 2nd Order	>0.98, linear	\	Limited	Limited	Limited
% Sample Strength	1, Linear	>0.88, 2nd Order	0.94, 2nd Order	No Comparison	No Comparison	No Comparison	No Comparison	No Comparison	No Comparison	No Comparison	Limited	Limited	Limited	Limited	Limited	Limited	\	>0.96, Linear	>0.97, 2nd Order
% Control Strength	>0.96, Linear	0.5, 2nd Order	0.99, 2nd Order	No Comparison	No Comparison	No Comparison	No Comparison	No Comparison	No Comparison	No Comparison	Limited	Limited	Limited	Limited	Limited	Limited	>0.96, Linear	\	<0.66, Linear
Cure Time	>0.97, 2nd Order	Limited	Limited	No Comparison	No Comparison	No Comparison	No Comparison	No Comparison	No Comparison	No Comparison	Limited	Limited	Limited	Limited	Limited	Limited	>0.97, 2nd Order	<0.66, Linear	\

5.0 CONCLUSIONS

An extensive laboratory and field study has been conducted to determine the effectiveness of using volcanic ash to increase the firmness and stability of unpaved trail surfaces. Volcanic ash was obtained from Klamath County, OR, and processed with a commercial rock crusher. This increased the fineness of the material to a level suitable for use as a natural pozzolan.

Mortar cubes were created with volcanic ash, portland cement, processed oyster shells and lime. It was shown that volcanic ash can create weakly cemented products without portland cement. Mortar cubes created with volcanic ash showed appreciable gains in strength between 28 and 84 days of curing. The control, SC-0, displayed no increase in strength between 42 and 84 days of curing. However, samples with volcanic ash showed significant gains in strength between 42 and 84 days. There is considerable decrease in compressive strength when portland cement is replaced with volcanic ash. This decrease is predictable based on the correlations shown in Figure 30.

A large number of mix infiltration tests were completed to determine the best possible mixtures that could bind the largest amount of particles. Both the depth of penetration and percentage of bound material was measured for different mixtures. For these two measurements, a correlation was attempted to be found between common gravel gradation descriptors. Despite creating and testing 185 separate samples, no clear correlation between gravel gradational characteristics and bound material is found for portland cement and volcanic ash mixtures of different amounts of water and varying ash to cement ratios. There is a positive correlation between the bound material and depth of infiltration. Depth of infiltration increases as the amount of water in the mixture increases.

A lab-scale testing device was constructed with adjustable confinement to refine the process of applying the topical mix. These lab-scale tests showed that compaction of the gravel sample increased firmness and stability a minor amount. In addition, confinement does not appear to have a significant impact on firmness and stability. Using the lab-scale testing device, it was determined that the topical application could not be sprayed and must be poured onto the surface.

Field-scale testing has been conducted with 12 lots of applied treatment. All treated lots experienced an average increase in firmness over 70 days. The change in firmness of the commercially treated lots were much less than the portland cement and volcanic ash treated lots. In terms of stability, positive and negative changes with time were experienced for the portland cement and volcanic ash treated lots. However, negative, or decreases, in stability with time were shown in the commercially treated lots. This indicates that the long-term gains in strength shown with the portland cement and volcanic ash mixes in the mortar cubes could be contributing to increases in firmness and stability with time. The commercially treated surfaces appear to be degrading in stability with time in contrast to the portland cement and volcanic ash treated surfaces.

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7.0 APPENDIX

7.1 MORTAR CUBE INFORMATION

Table 24. Unconfined compressive strength of mortar cubes

	Cure Time (days)							
	0	7	21	28	42	56	70	84
Sample	Unconfined Compressive Strength (psi)							
SC-0	0	5744	6335	6631	6980	6980	6980	6980
SC-1	0	3856	4274	4483	4933	5168	5241	5289
SC-2	0	2629	2844	2952	3155	3183	3496	3808
SC-3	0	1583	1839	1967	2148	2218	2481	2543
SC-4	0	65	103	123	130	138	148	158
LC-0	0	25	48	60	40	53	50	48
LC-1	0	55	108	135	175	228	195	243
LC-2	0	48	113	145	223	225	300	318
LC-3	0	45	97	123	145	173	208	200
OC-0	0	38	59	70	45	80	73	130
OC-1	0	43	131	175	178	235	240	306
OC-2	0	48	124	163	170	228	295	311
OC-3	0	35	103	138	210	178	262	330
LPC-0	0	68	39	25	40	46	45	43
LPC-1	0	45	92	115	150	180	195	264
LPC-2	0	43	103	133	294	225	266	315
LPC-3	0	40	87	110	160	193	215	225
OPC-0	0	23	66	87	52	38	40	51
OPC-1	0	38	78	98	105	165	190	208
OPC-2	0	40	90	115	150	203	238	257
OPC-3	0	33	81	105	160	230	248	328
RC-0	0	34	37	43	54	47	40	47
RC-1	0	50	58	58	90	110	130	175
RC-2	0	65	103	121	125	158	190	205
RC-3	0	55	114	144	178	228	279	350

Table 25. Percentage of unconfined compressive strength (control = SC-0)

	Cure Time (days)							
	0	7	21	28	42	56	70	84
	Percentage of Control Strength (SC-0)							
SC-0	0%	100%	100%	100%	100%	100%	100%	100%
SC-1	0%	67%	67%	68%	71%	74%	75%	76%
SC-2	0%	46%	45%	45%	45%	46%	50%	55%
SC-3	0%	28%	29%	30%	31%	32%	36%	36%
SC-4	0%	1%	2%	2%	2%	2%	2%	2%
LC-0	0%	0%	1%	1%	1%	1%	1%	1%
LC-1	0%	1%	2%	2%	3%	3%	3%	3%
LC-2	0%	1%	2%	2%	3%	3%	4%	5%
LC-3	0%	1%	2%	2%	2%	2%	3%	3%
OC-0	0%	1%	1%	1%	1%	1%	1%	2%
OC-1	0%	1%	2%	3%	3%	3%	3%	4%
OC-2	0%	1%	2%	2%	2%	3%	4%	4%
OC-3	0%	1%	2%	2%	3%	3%	4%	5%
LPC-0	0%	1%	1%	0%	1%	1%	1%	1%
LPC-1	0%	1%	1%	2%	2%	3%	3%	4%
LPC-2	0%	1%	2%	2%	4%	3%	4%	5%
LPC-3	0%	1%	1%	2%	2%	3%	3%	3%
OPC-0	0%	0%	1%	1%	1%	1%	1%	1%
OPC-1	0%	1%	1%	1%	2%	2%	3%	3%
OPC-2	0%	1%	1%	2%	2%	3%	3%	4%
OPC-3	0%	1%	1%	2%	2%	3%	4%	5%
RC-0	0%	1%	1%	1%	1%	1%	1%	1%
RC-1	0%	1%	1%	1%	1%	2%	2%	3%
RC-2	0%	1%	2%	2%	2%	2%	3%	3%
RC-3	0%	1%	2%	2%	3%	3%	4%	5%

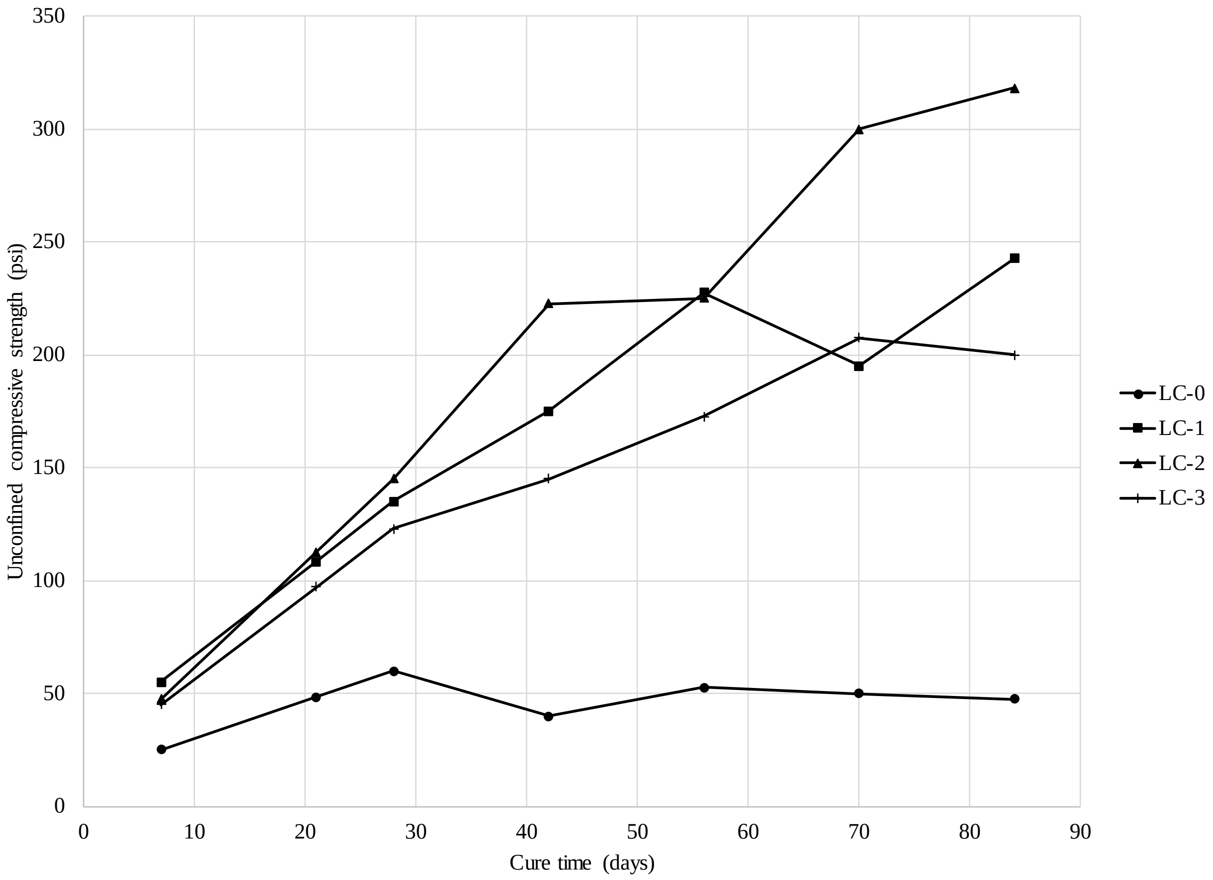


Figure 44 – Unconfined compressive strength with time (LC Samples)

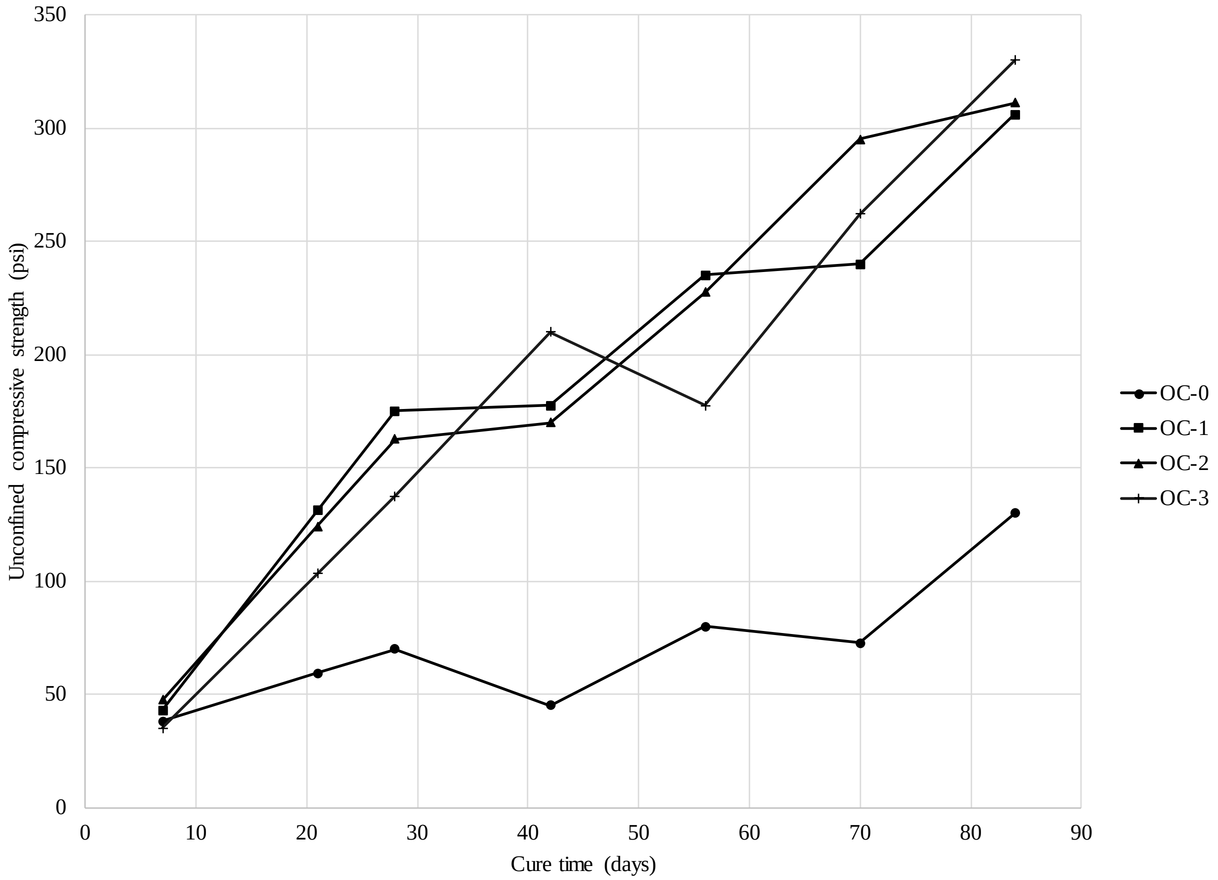


Figure 45 – Unconfined compressive strength with time (OC Samples)

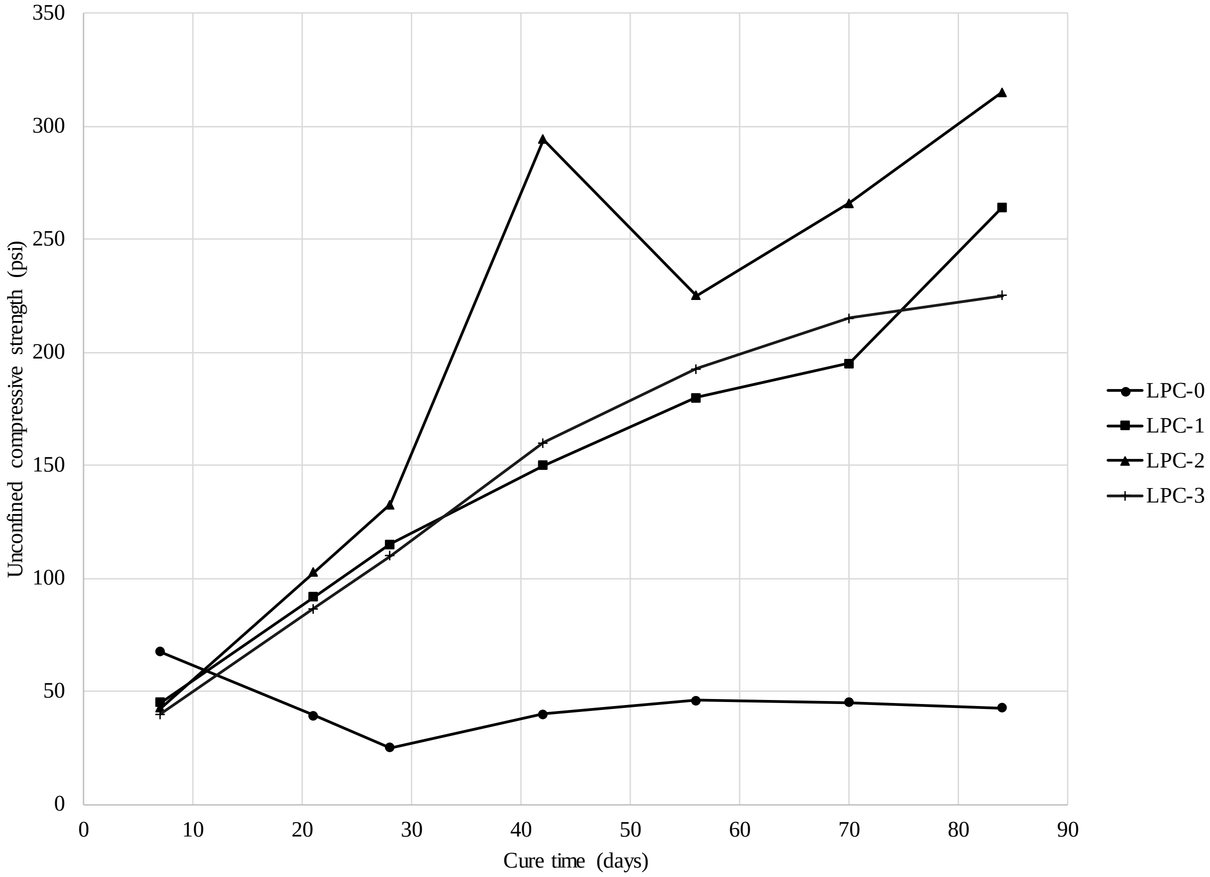


Figure 46 – Unconfined compressive strength with time (LPC Samples)

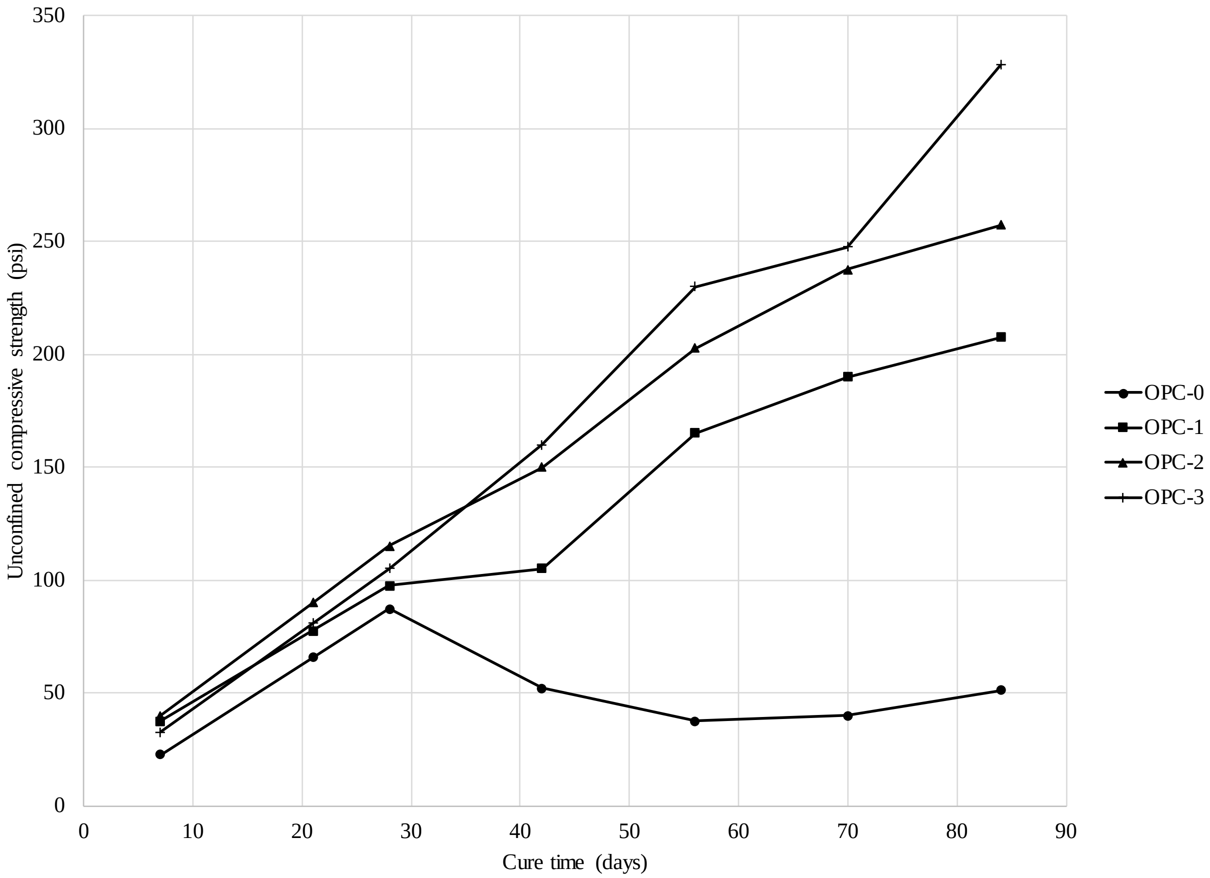


Figure 47 – Unconfined compressive strength with time (OPC Samples)

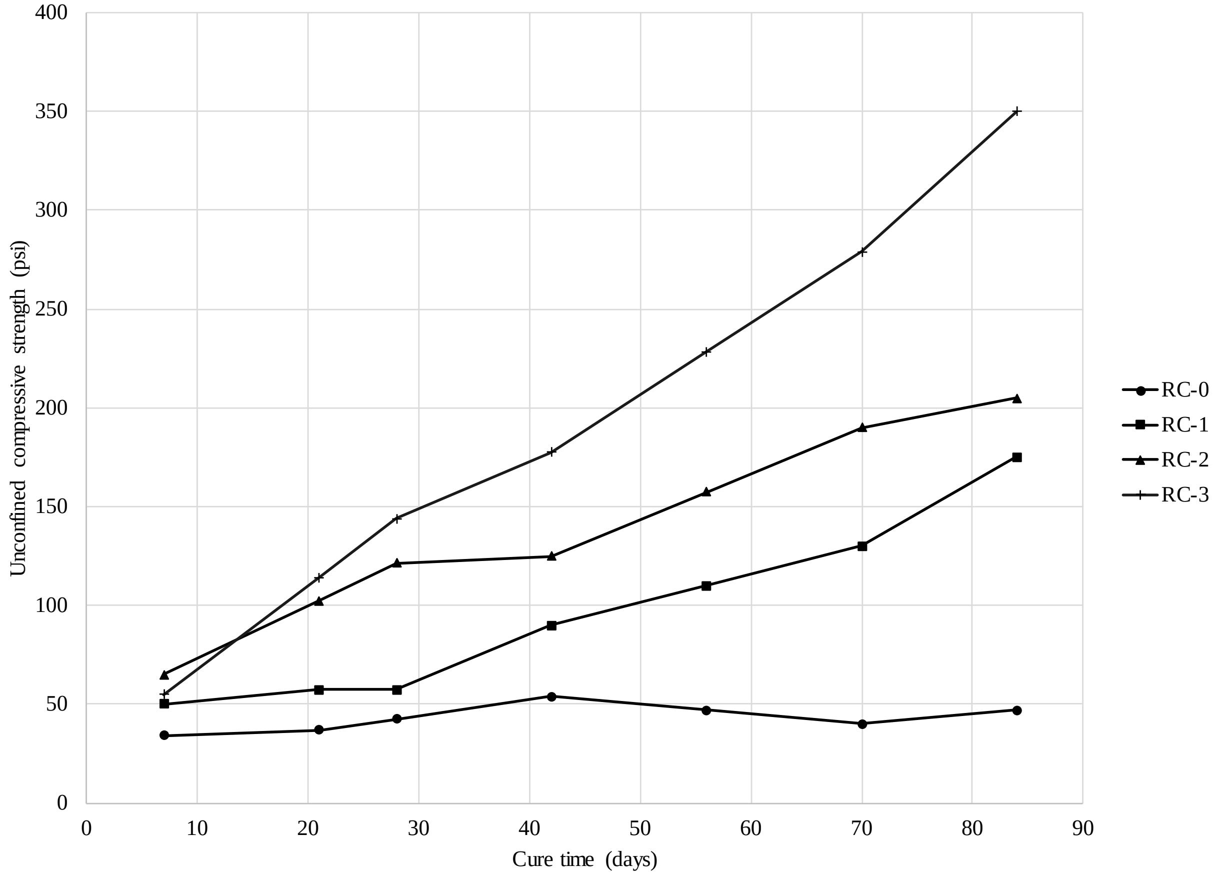


Figure 48 – Unconfined compressive strength with time (RC Samples)

7.2 POUR TEST INFORMATION

Table 26. Gravel materials and slurries applied for pour testing

Material	Justification/Reasoning	Cementitious Mixes Applied (% water/pozzolan ratio)
M1.0.0 **M1.1.0** **M1.1.1**	M1 materials were chosen to determine effect of topical application on angular gravels. Subsets were chosen to represent potential trail gradations.	50/150, 60/150, 70/150
M2.0.0 **M2.0.1**	M2 materials were chosen to look at the effects of two layered materials. Subsets were chosen to represent potential trail gradations.	50/150, 60/150, 70/150
M3.0.0 **M3.0.1**	M3 materials were based on the specifications of Montana trails . M3.0.1 is a direct interpretation of specification while M3.0.0 includes other sizes to incorporate a higher number of finer aggregate.	50/150, 60/150, 70/150
M5.0.1	M5.0.1 was based on the subgrade for M3.0.1 to determine its effectiveness on its own.	50/150, 60/150, 70/150
GeoTrail	Made to mimic the existing gravel used in the trail of interest on the East end of OIT campus.	50/150, 60/150, 70/150
M6.0.0	Recreation of C1 with different sizes to illustrate differences in results based on gravel characteristics.	50/150, 60/150, 70/150
C1	Initial available coarse gravel. Mostly used for proof-of concept and process refinement testing as well as possible trail aggregate.	67/100, 67/900, 60/100, 60/150, 60/233, 60/400, 60/900 all with volcanic ash passing the #4 sieve. 60/100, 60/150, 60/233, 60/400, 60/900 all with volcanic ash roughly crushed. 60/100, 60/150, 60/233, 60/400, 60/900 all with volcanic ash passing the #200 sieve.

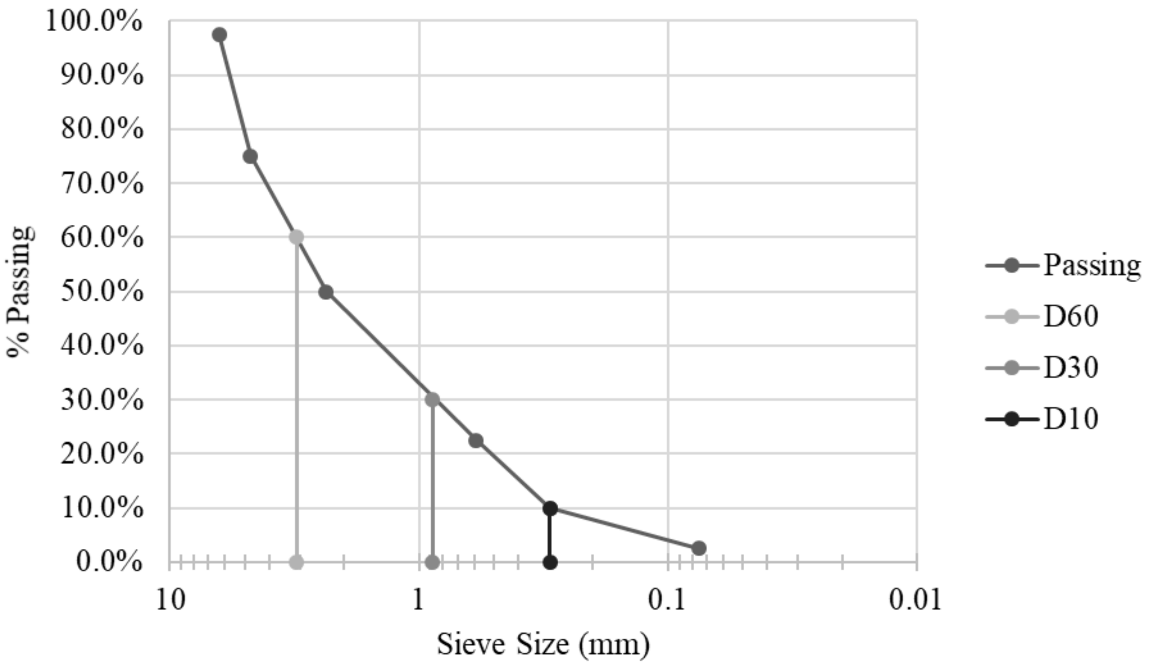


Figure 49 – Gradation of material M1.0.0

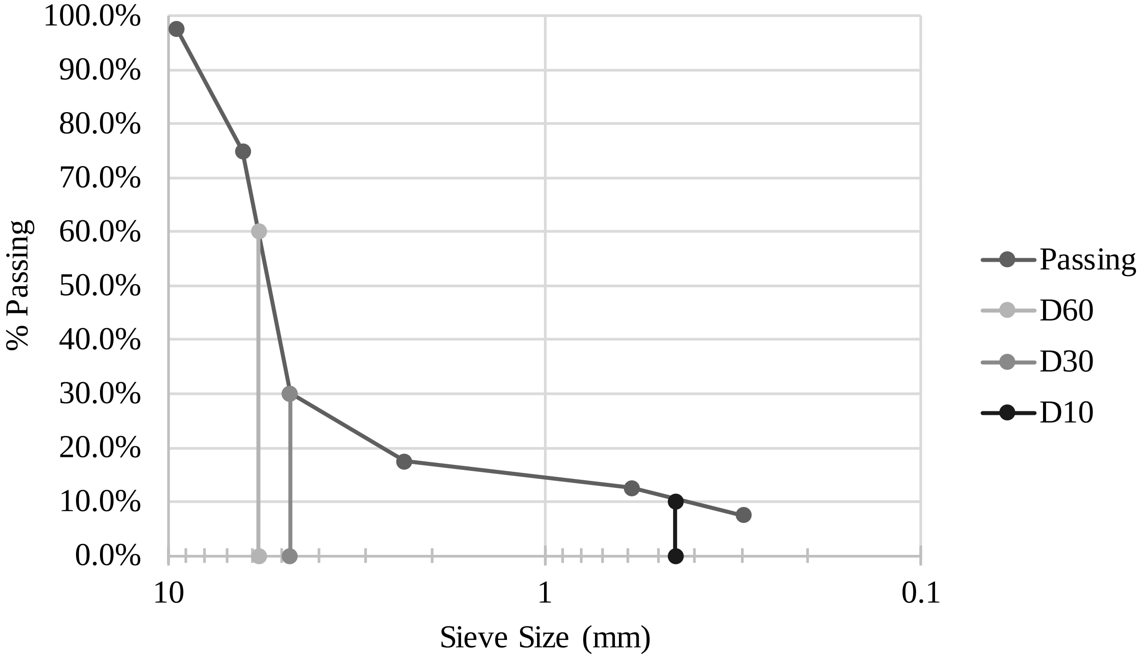


Figure 50 – Gradation of material M1.1.0

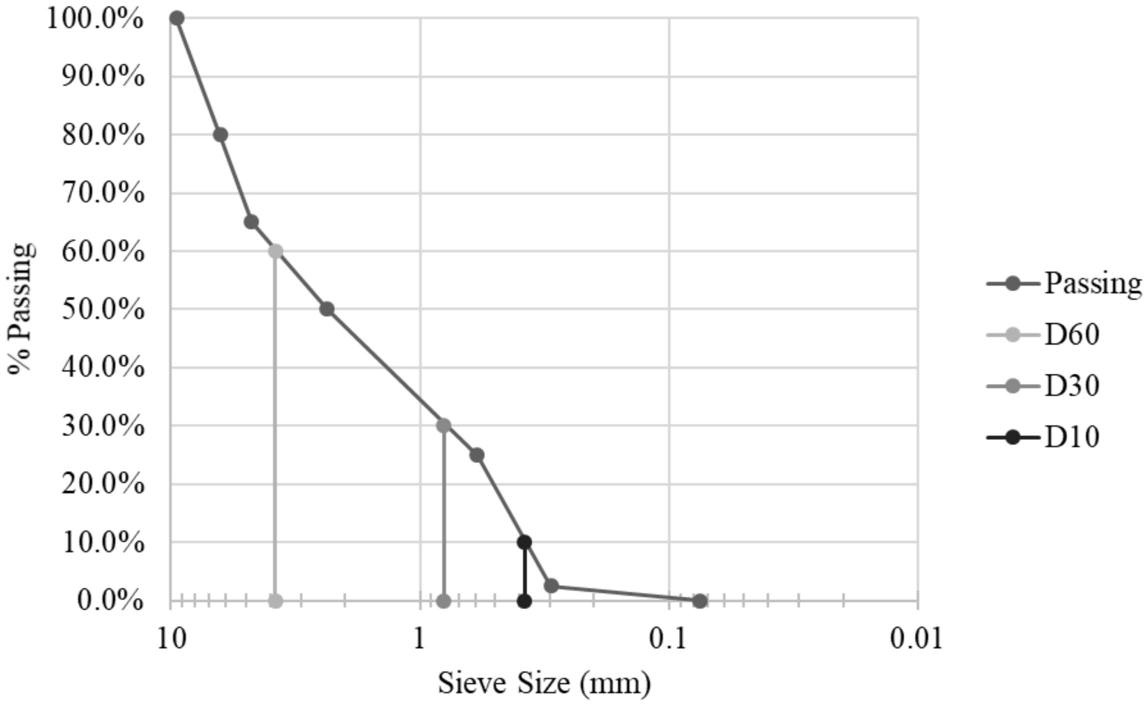


Figure 51 – Gradation of material M1.1.1

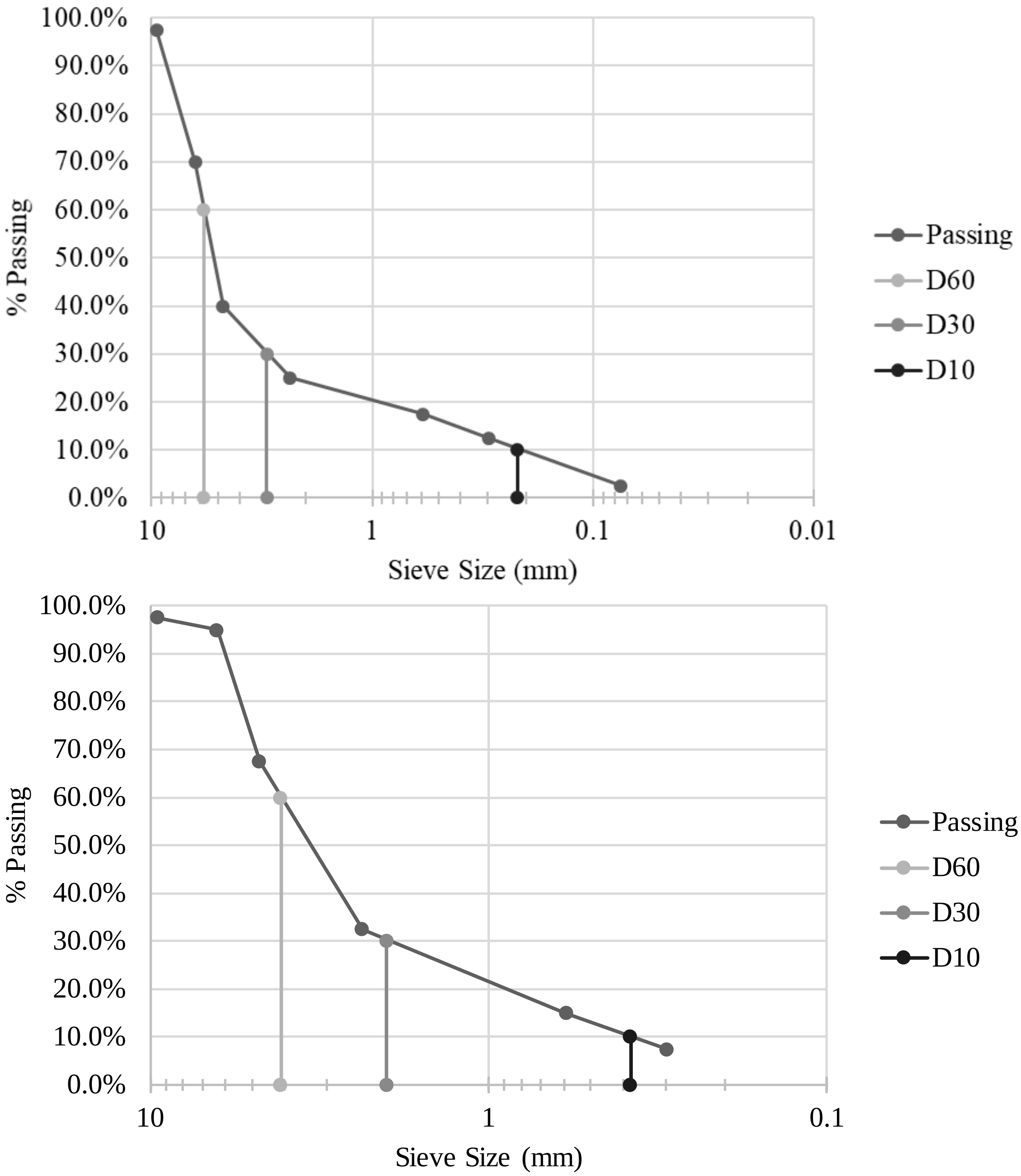


Figure 52 – Gradation of material M2.0.0 – upper (6.6cm) and lower (13.4cm) layers

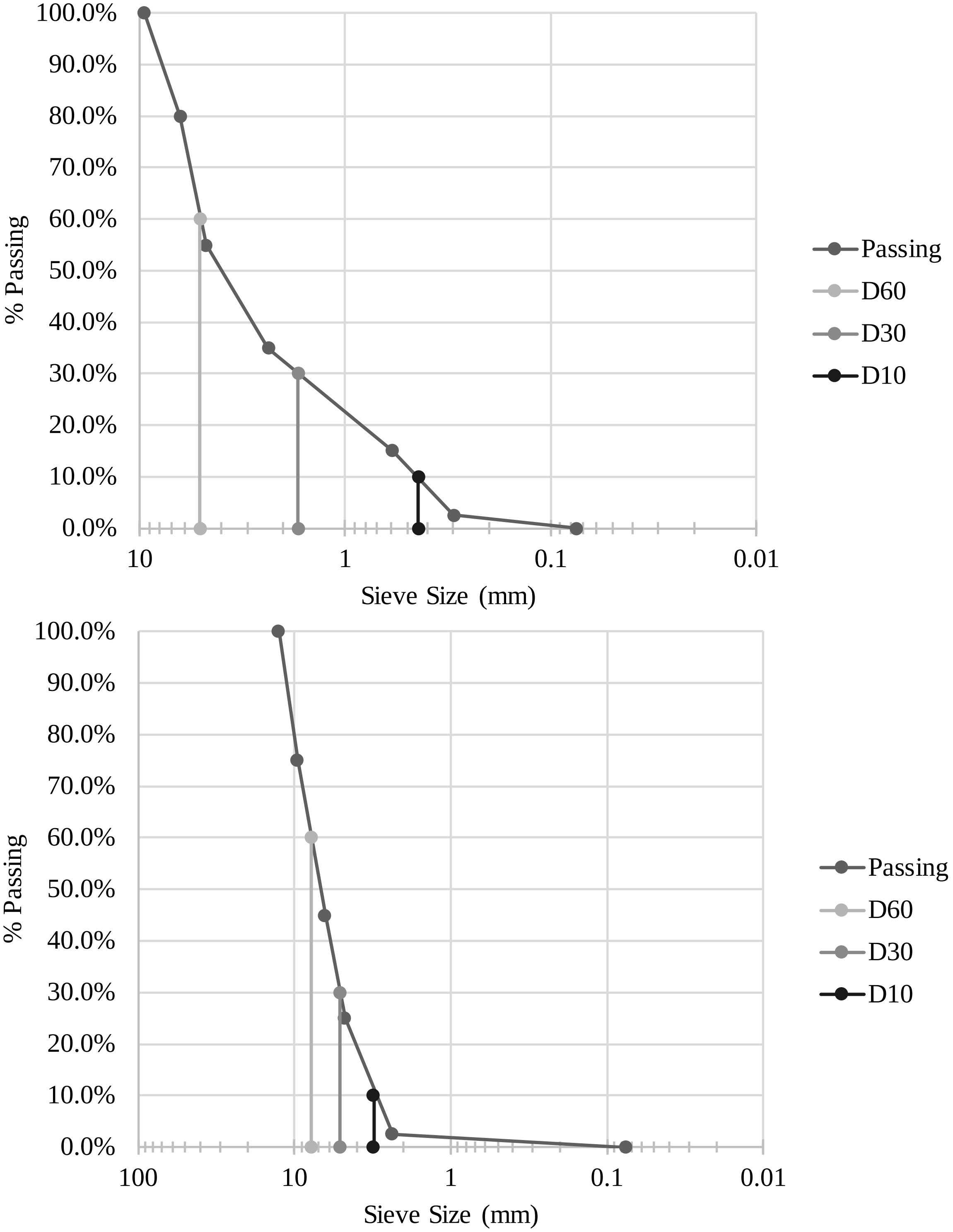


Figure 53 – Gradation of material 2.0.1 upper (6.6 cm) and lower (13.4 cm) layers

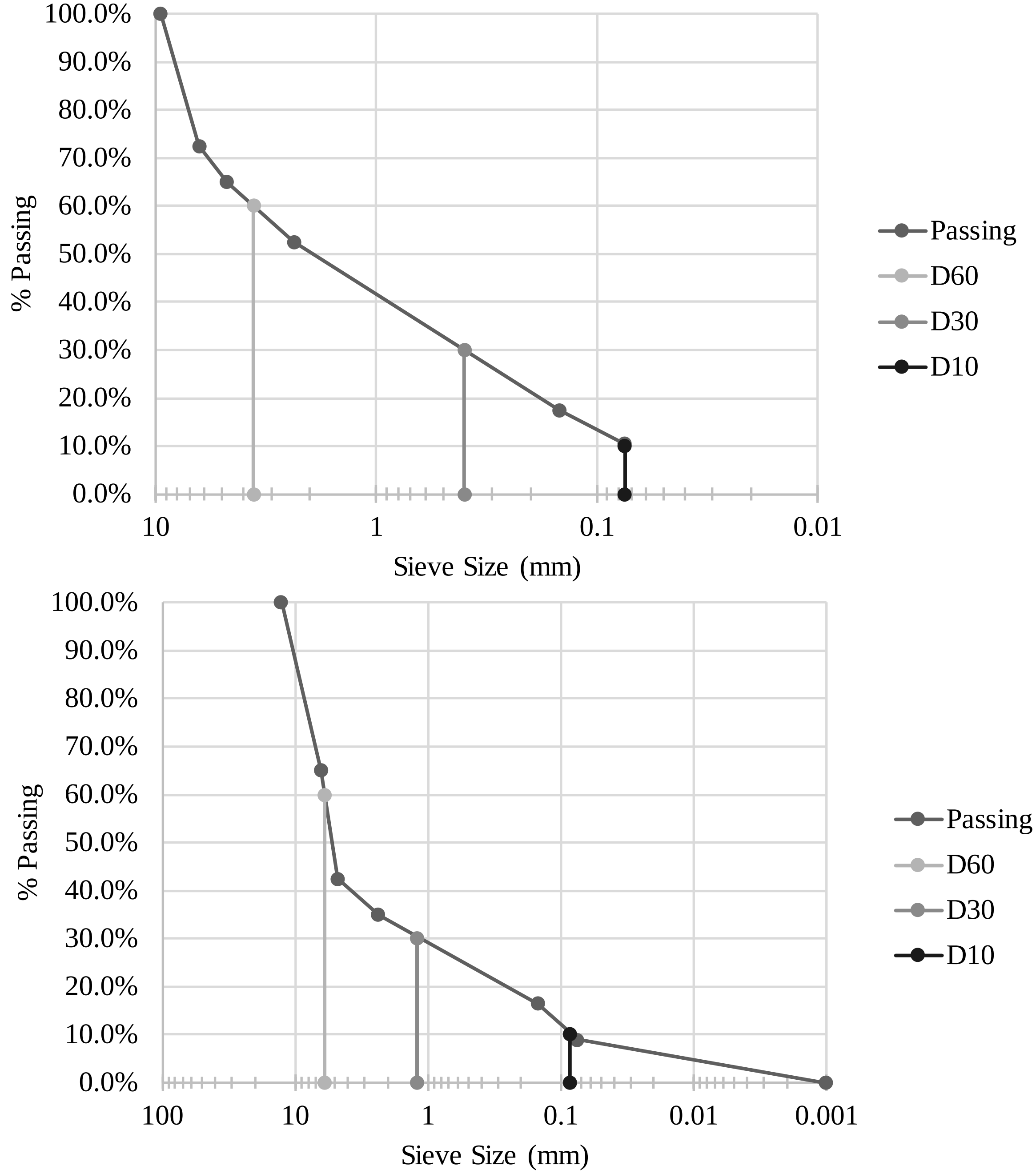


Figure 54 – Gradation of material M 3.0.0 upper (6.6 cm) and lower (13.4 cm) layers

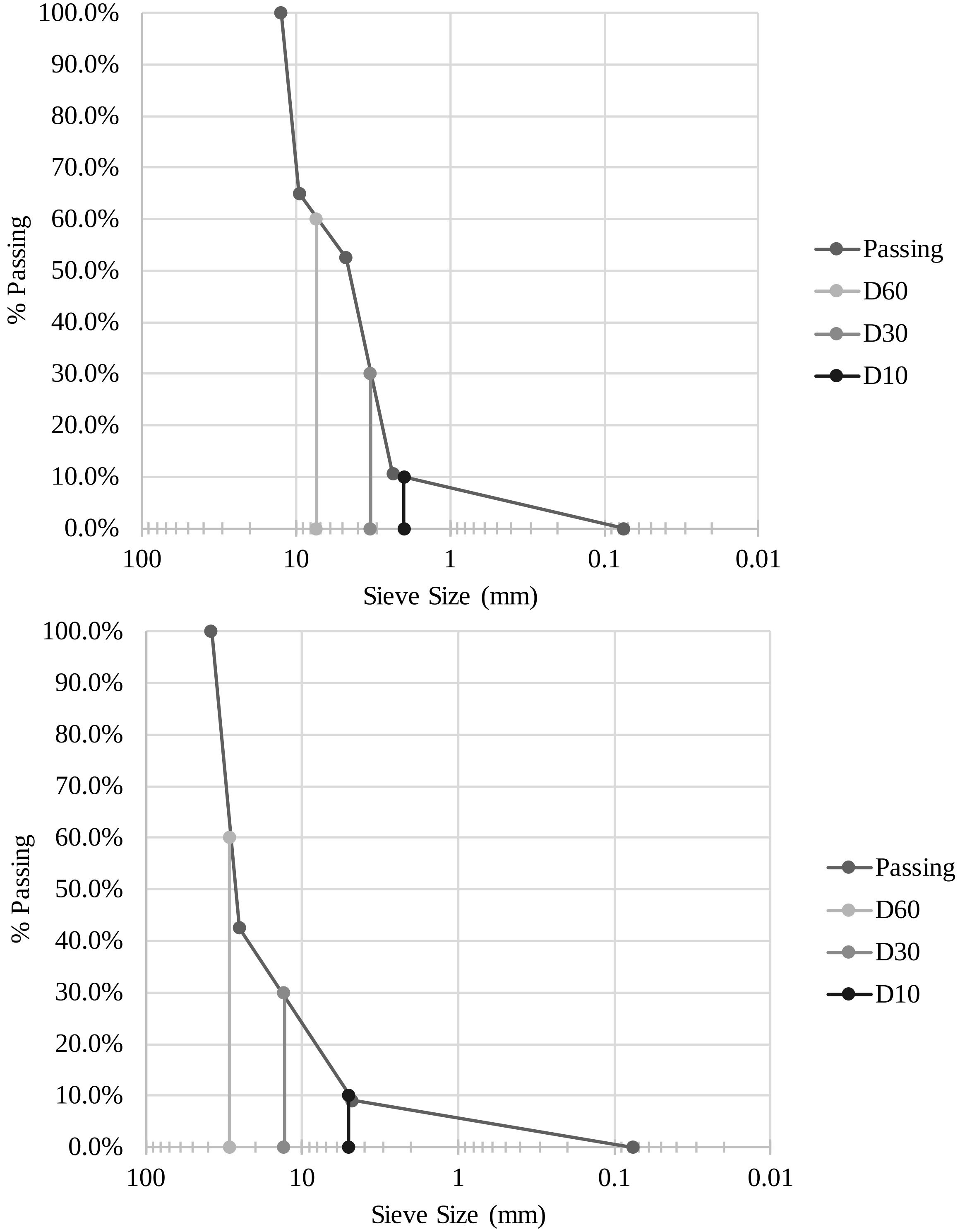


Figure 55 – Gradation of material M 3.0.1 upper (6.6 cm) and lower (13.4 cm) layers

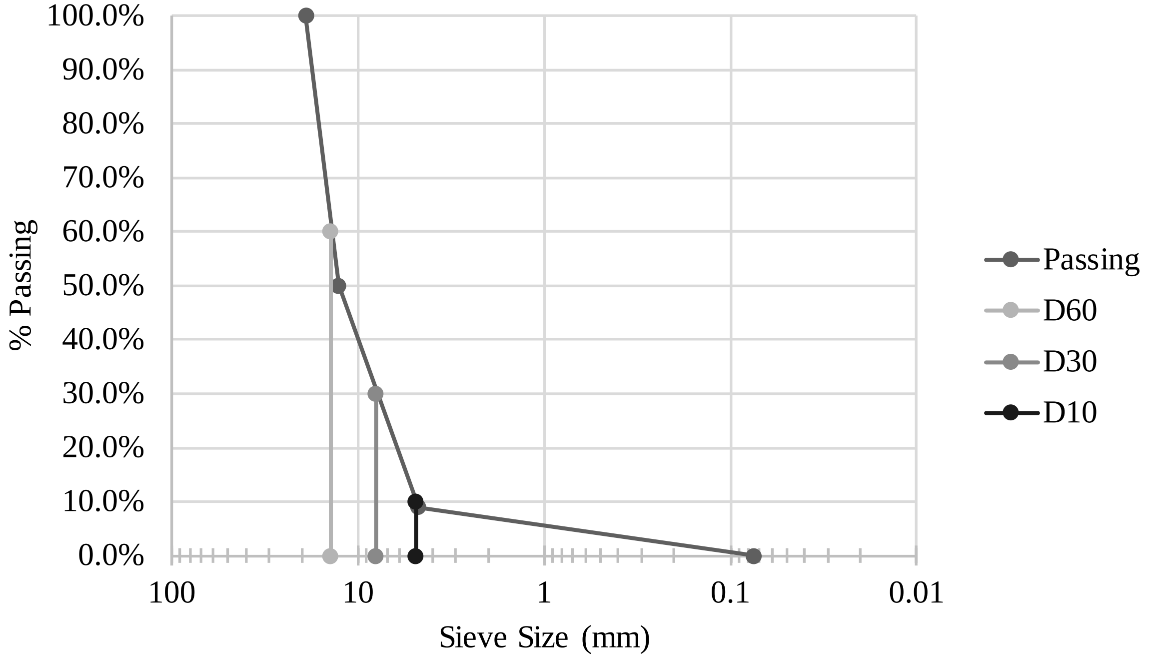


Figure 56 – Gradation of material M 5.0.1

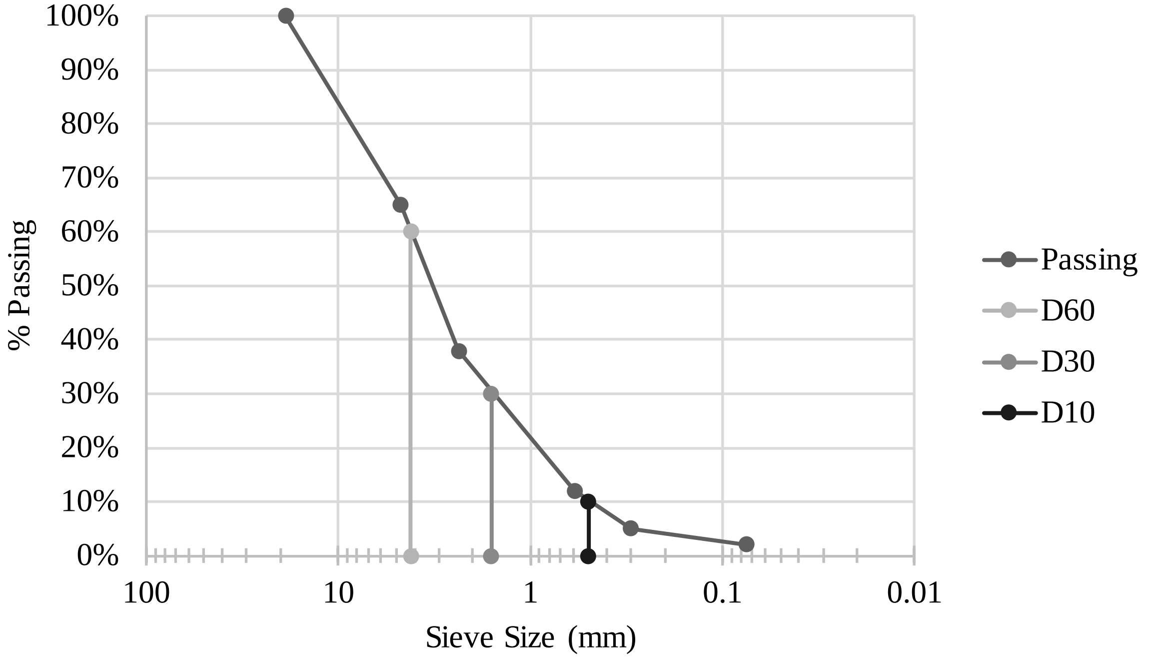


Figure 57 – Gradation of Geotrail material

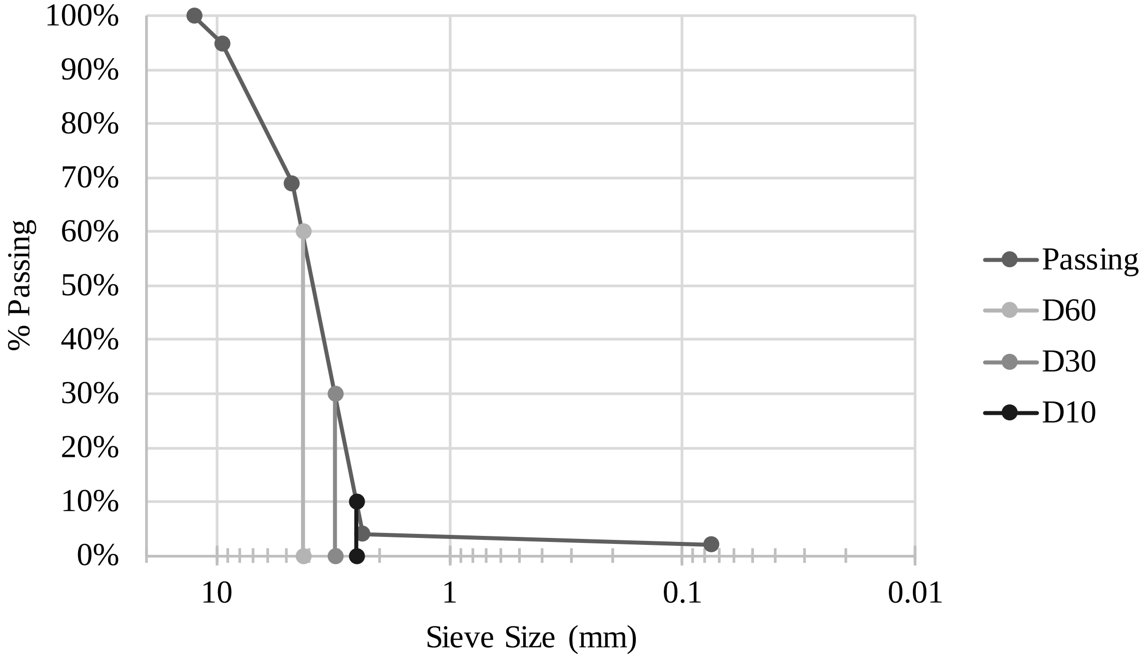


Figure 58 – Gradation of material M 6.0.0

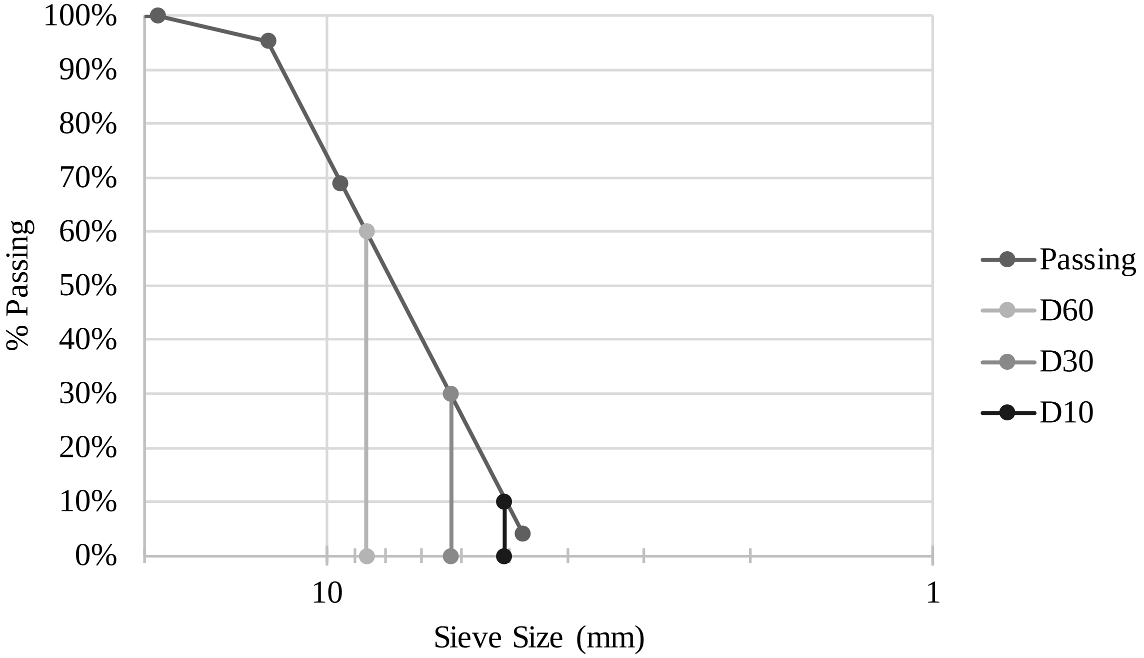


Figure 59 – Gradation of material C1

Table 27. Pour test results

Material M 1.0.0									
Sample #	**Mold**	**%H2O**	**%Pozz**	**%PC**	**Pozz. Ratio**	**Total Weight (g)**	**Top weight (g)**	**Depth (in.)**	**%Cemented**
1	145	0.6	0.24	0.16	150%	2760.24	370.2	2.25	14%
2	145	0.6	0.24	0.16	150%	2668.33	266.93	2.25	11%
3	140	0.6	0.24	0.16	150%	2667.02	267.02	1.75	11%
1	138.87	0.7	0.18	0.12	150%	2651.83	823.54	4	33%
2	139.04	0.7	0.18	0.12	150%	2654.14	784.96	2.75	31%
3	143.7	0.7	0.18	0.12	150%	2658.67	826.66	2.75	33%
1	144.25	0.5	0.3	0.2	150%	2656.95	276.85	1.75	11%
2	144	0.5	0.3	0.2	150%	2655.83	253.91	1.75	10%
3	138.68	0.5	0.3	0.2	150%	2654.45	294.05	2.5	12%
1	156.03	0	G3	G3	G3	2676.66	798.67	6.5	32%
2	156.56	0	G3	G3	G3	2677.16	1253.67	6.5	50%
3	161.55	0	G3	G3	G3	2682.62	741.31	6.5	29%
1	155.9	0	SoilTac	SoilTac	SoilTac	2737.79	485.86	6.5	19%
2	156.46	0	SoilTac	SoilTac	SoilTac	2675.83	583.85	6.5	23%
3	161.41	0	SoilTac	SoilTac	SoilTac	2684.32	715.97	6.5	28%
Material M 1.1.0									
Sample #	**Mold**	**%H2O**	**%Pozz**	**%PC**	**Pozz. Ratio**	**Total Weight (g)**	**Top weight (g)**	**Depth (in.)**	**%Cemented**
1	145	0.6	0.24	0.16	150%	2656.65	1015.37	5	40%
2	145	0.6	0.24	0.16	150%	2657.85	1220.5	7	49%
3	145	0.6	0.24	0.16	150%	2652.22	1234.36	6	49%
1	160.93	0.5	0.3	0.2	150%	2677.61	938.28	6	37%
2	156.66	0.5	0.3	0.2	150%	2671.84	901.87	5.75	36%
3	161.61	0.5	0.3	0.2	150%	2677.64	812.57	4.25	32%
1	155.5	0.7	0.18	0.12	150%	2672.45	1406.75	5	56%
2	161.26	0.7	0.18	0.12	150%	2680.33	991.28	3.75	39%
3	156.07	0.7	0.18	0.12	150%	2673.58	1135.35	4.25	45%
Material M 1.1.1									
Sample #	**Mold**	**%H2O**	**%Pozz**	**%PC**	**Pozz. Ratio**	**Total Weight (g)**	**Top weight (g)**	**Depth (in.)**	**%Cemented**
1	145	0.6	0.24	0.16	150%	2658.51	422.36	3.5	17%
2	145	0.6	0.24	0.16	150%	2658.39	417.79	2.75	17%
3	140	0.6	0.24	0.16	150%	2651.51	388.67	2.25	15%
1	140	0.5	0.3	0.2	150%	2650.26	214.83	1.75	9%
2	145	0.5	0.3	0.2	150%	2658.08	257.47	2	10%
3	140	0.5	0.3	0.2	150%	2650.62	228.36	2	9%
1	145	0.7	0.18	0.12	150%	2657.97	342.19	2	14%
2	145	0.7	0.18	0.12	150%	2656.86	382.58	2	15%
3	145	0.7	0.18	0.12	150%	2657.41	512.47	2.75	20%
Material M 2.0.0									
Sample #	**Mold**	**%H2O**	**%Pozz**	**%PC**	**Pozz. Ratio**	**Total Weight (g)**	**Top weight (g)**	**Depth (in.)**	**%Cemented**
1	145	0.60	0.24	0.16	150%	2656.82	686.01	5	27%
2	140	0.60	0.24	0.16	150%	2653.37	959.76	4	38%
3	140	0.60	0.24	0.16	150%	2652.96	582.92	4	23%
1	161.08	0.50	0.30	0.20	150%	2696.53	522.75	2	21%
2	156.3	0.50	0.30	0.20	150%	2693.35	576.37	2	23%
3	156.11	0.50	0.30	0.20	150%	2691.82	594.33	2	23%
1	156.57	0.70	0.18	0.12	150%	2695.28	0	0	0%
2	161.2	0.70	0.18	0.12	150%	2697.11	339.13	1.75	13%
3	161.74	0.70	0.18	0.12	150%	2699.28	371.47	2	15%
Material M 2.0.1									
Sample #	**Mold**	**%H2O**	**%Pozz**	**%PC**	**Pozz. Ratio**	**Total Weight (g)**	**Top weight (g)**	**Depth (in.)**	**%Cemented**
1	145	0.60	0.24	0.16	150%	2659.21	753.77	5.5	30%
2	140	0.60	0.24	0.16	150%	2653	797.61	4	32%
3	145	0.60	0.24	0.16	150%	2657.71	888.15	5.5	35%
1	140	0.50	0.30	0.20	150%	2655.53	495.7	4.5	20%
2	145	0.50	0.30	0.20	150%	2656.74	597.7	6.5	24%
3	145	0.50	0.30	0.20	150%	2660.97	540.9	4.5	21%
1	145	0.70	0.18	0.12	150%	2658.52	833.88	4	33%
2	140	0.70	0.18	0.12	150%	2653.32	1053.41	4	42%
3	140	0.70	0.18	0.12	150%	2653.12	979.83	4.5	39%

Table 28. Pour test results continued

Material M 3.0.0									
Sample #	**Mold**	**%H2O**	**%Pozz**	**%PC**	**Pozz. Ratio**	**Total Weight (g)**	**Top weight (g)**	**Depth (in.)**	**%Cemented**
1	145	0.60	0.24	0.16	150%	2658.9	766.11	4.5	30%
2	140	0.60	0.24	0.16	150%	2654.4	1052.38	4.75	42%
3	145	0.60	0.24	0.16	150%	2658.96	823.13	4.5	33%
1	160.9	0.50	0.30	0.20	150%	2675.52	606.47	2.25	24%
2	156.5	0.50	0.30	0.20	150%	2676.54	610.76	2	24%
3	156	0.50	0.30	0.20	150%	2669.8	624.81	2.5	25%
1	155.54	0.70	0.18	0.12	150%	2674.66	167.46	0.75	7%
2	161.36	0.70	0.18	0.12	150%	2680.24	204.36	0.75	8%
3	161.11	0.70	0.18	0.12	150%	2676.23	190.26	0.75	8%
Material M 3.0.1									
Sample #	**Mold**	**%H2O**	**%Pozz**	**%PC**	**Pozz. Ratio**	**Total Weight (g)**	**Top weight (g)**	**Depth (in.)**	**%Cemented**
1	140	0.60	0.24	0.16	150%	2653.36	1262.88	5	50%
2	140	0.60	0.24	0.16	150%	2653.58	1156.16	4	46%
3	140	0.60	0.24	0.16	150%	2653.84	1069.54	4.75	43%
1	145	0.50	0.30	0.20	150%	2660.54	817.62	4.5	33%
2	145	0.50	0.30	0.20	150%	2731.4	950.83	4	37%
3	140	0.50	0.30	0.20	150%	2664.24	667.57	4	26%
1	156.28	0.70	0.18	0.12	150%	2674.85	553	2	22%
2	156.2	0.70	0.18	0.12	150%	2674.85	558.16	2.5	22%
3	155.74	0.70	0.18	0.12	150%	2676.95	442.72	1.75	18%
Material M 5.0.1									
Sample #	**Mold**	**%H2O**	**%Pozz**	**%PC**	**Pozz. Ratio**	**Total Weight (g)**	**Top weight (g)**	**Depth (in.)**	**%Cemented**
1	140	0.60	0.24	0.16	150%	2615.11	1638.59	7	66%
2	140	0.60	0.24	0.16	150%	2650.02	1448.45	6.25	58%
3	145	0.60	0.24	0.16	150%	2660.35	1554.89	5.5	62%
1	140	0.50	0.30	0.20	150%	2650.7	470.04	1.75	19%
2	140	0.50	0.30	0.20	150%	2656.58	872.64	3.5	35%
3	145	0.50	0.30	0.20	150%	2655.85	873.1	3.5	35%
1	140	0.70	0.18	0.12	150%	2656.89	367.02	1.75	15%
2	145	0.70	0.18	0.12	150%	2660.38	1157.48	4	46%
3	145	0.70	0.18	0.12	150%	2659.6	1038.9	4.5	41%
Material M 6.0.0									
Sample #	**Mold**	**%H2O**	**%Pozz**	**%PC**	**Pozz. Ratio**	**Total Weight (g)**	**Top weight (g)**	**Depth (in.)**	**%Cemented**
1	139.3	0.60	0.24	0.16	150%	2392.15	257.84	3	11%
2	139.3	0.60	0.24	0.16	150%	2368.05	91.85	2	4%
3	139.3	0.60	0.24	0.16	150%	2524.77	122.86	2	5%
1	140	0.50	0.30	0.20	150%	2628.56	463.75	3.75	19%
2	140	0.50	0.30	0.20	150%	2654.9	449.51	2.75	18%
3	145	0.50	0.30	0.20	150%	2661.55	489.97	2	19%
1	145	0.70	0.18	0.12	150%	2659.61	439.78	2	17%
2	145	0.70	0.18	0.12	150%	2661.04	490.06	3	19%
3	145	0.70	0.18	0.12	150%	2659.26	438.14	3	17%

Table 29. Pour test results continued

Material C1									
Sample #	**Mold**	**%H2O**	**%Pozz**	**%PC**	**Pozz. Ratio**	**Total Weight (g)**	**Top weight (g)**	**Depth (in.)**	**%Cemented**
OC1	140	0.6	24oc%	0.16	150%oc	2356.87	0	0	0%
OC2	145	0.6	24oc%	0.16	150%oc	2416.9	0	0	0%
OC3	145	0.6	24oc%	0.16	150%oc	2409.93	96.9	1.25	4%
Poz4-1	110	0.6	20#4%	0.2	100%#4	2178.6	657.1	4	32%
Poz4-2	110	0.6	24#4%	0.16	150%#4	2306.9	689.6	3.25	31%
Poz4-3	110	0.6	28#4%	0.12	233%#4	2270.5	266.1	2	12%
Poz4-4	110	0.6	32#4%	0.08	400%#4	2258.6	152.8	1.5	7%
Poz4-5	110	0.6	36#4%	0.04	900%#4	2312.6	0	0	0%
PozCrush-1	110	0.6	20crush%	0.2	100%crush	2454.79	488.34	3	21%
PozCrush-2	110	0.6	24crush%	0.16	150%crush	2127.1	1056.64	5.5	52%
PozCrush-3	110	0.6	28crush%	0.12	233%crush	2361.19	646.45	4	29%
PozCrush-4	110	0.6	32crush%	0.08	400%crush	2247.6	356.44	3.5	17%
PozCrush-5	110	0.6	36crush%	0.04	900%crush	2279.44	137.16	1.5	6%
Poz200-1	110	0.6	20-200%	0.2	100%-200	2251.9	865.66	6	40%
Poz200-2	110	0.6	24-200%	0.16	150%-200	2261.3	1358.95	6.5	63%
Poz200-3	110	0.6	28-200%	0.12	233%-200	2167.03	1034	6.5	50%
Poz200-4	110	0.6	32-200%	0.08	400%-200	2281.12	855.54	4.5	39%
Poz200-5	110	0.6	36-200%	0.04	900%-200	2212.37	780.52	4.5	37%
PozCrush6	110	0.67	20crush%	0.2	100%crush	2305.9	198.6	1.5	9%
PozCrush7	110	0.67	36crush%	0.04	900%crush	1921.8	0	0	0%
Lined 1	161.25	0.6	24 lined%	0.16	150% lined	2194.72	0	0	0%
Lined 2	160.79	0.6	24 lined%	0.16	150% lined	2217.04	922.21	4.75	45%
Lined 3	156.6	0.6	24 lined%	0.16	150% lined	2312.2	663.57	4.75	31%

Table 30. Pour test results continued

Material GeoTrail									
Sample #	Mold	%H2O	%Pozz	%PC	Pozz. Ratio	Total Weight (g)	Top weight (g)	Depth (in.)	%Cemented
1	145	0.6	0.24	0.16	150%	2706.53	735.32	4	29%
2	140	0.6	0.24	0.16	150%	2560.49	787.75	4.5	33%
3	145	0.6	0.24	0.16	150%	2559.1	827.66	4.5	34%
1	161.38	0.5	0.3	0.2	150%	2674.95	364.16	2	14%
2	156.04	0.5	0.3	0.2	150%	2670.18	301.88	1.75	12%
3	160.74	0.5	0.3	0.2	150%	2674.71	377.6	2.5	15%
1	156.39	0.7	0.18	0.12	150%	2670.85	941.44	3.5	37%
2	161.16	0.7	0.18	0.12	150%	2674.12	987.1	4.5	39%
3	155.87	0.7	0.18	0.12	150%	2669.52	1025.1	4	41%
1	156.39	0.5	0.2778	0.2222	125%	2672.02	644.76	3	26%
2	161.04	0.5	0.2778	0.2222	125%	2672.78	638.16	2.75	25%
3	161.6	0.5	0.2778	0.2222	125%	2676.99	698.42	5.5	28%
1	156.38	0.6	0.2222	0.1778	125%	2669.82	1053.69	5	42%
2	161.3	0.6	0.2222	0.1778	125%	2675.64	964.82	5	38%
3	156.15	0.6	0.2222	0.1778	125%	2674.26	992.56	5	39%
1	161.77	0.7	0.1667	0.1333	125%	2676.08	1271.44	4.75	51%
2	161.17	0.7	0.1667	0.1333	125%	2676.8	1121.58	4	45%
3	156.46	0.7	0.1667	0.1333	125%	2671.9	1117.08	4.25	44%
1	156.05	0.5	0.3182	0.1818	175%	2670	846.26	6.25	34%
2	156.62	0.5	0.3182	0.1818	175%	2670.76	769.69	3.25	31%
3	160.94	0.5	0.3182	0.1818	175%	2673.06	608.88	3.5	24%
1	156.53	0.6	0.2545	0.1455	175%	2673.94	1025.13	4.75	41%
2	161.12	0.6	0.2545	0.1455	175%	2674.31	1069	4.5	43%
3	161.35	0.6	0.2545	0.1455	175%	2672.9	1029.47	4.5	41%
1	156.23	0.7	0.1909	0.1091	175%	2667.68	1205.22	4.25	48%
2	161.96	0.7	0.1909	0.1091	175%	2675.16	1163.89	4.5	46%
3	155.98	0.7	0.1909	0.1091	175%	2671.6	1151.42	4	46%
1	156.58	0.5	10Lime%	0.4	25%Lime	2649.35	260.41	1	10%
2	161.11	0.5	10Lime%	0.4	25%Lime	2654.5	232.16	1	9%
3	156.45	0.5	10Lime%	0.4	25%Lime	2650.32	246.03	1	10%
1	156.45	0.5	5.03POySh	0.3497	43%POySh	2643.02	213.45	1	9%
2	161.06	0.5	5.03POySh	0.3497	43%POySh	2648.7	203.79	1	8%
3	155.76	0.5	5.03POySh	0.3497	43%POySh	2645.93	177.38	1	7%
1	161.45	0.5	0.06POySh	0.2994	67%POySh	2663.11	226.82	0.75	9%
2	161.68	0.5	0.06POySh	0.2994	67%POySh	2658.61	310.39	1	12%
3	161.61	0.5	0.06POySh	0.2994	67%POySh	2655.54	277.91	0.75	11%
1	156.65	0	G3	G3	G3	2677.77	312.42	7	12%
2	155.88	0	G3	G3	G3	2676.56	275.97	7	11%
3	161.6	0	G3	G3	G3	2681.63	158.7	7	6%
1	161.83	0	SoilTac	SoilTac	SoilTac	2677.05	776.63	7	31%
2	162.01	0	SoilTac	SoilTac	SoilTac	2679.83	793.89	7.25	32%
3	156.92	0	SoilTac	SoilTac	SoilTac	2677.49	909.56	7	36%
1	156.47	0	Klingstone	Klingstone	Klingstone	2662.56	1219.83	6	49%
2	161.19	0	Klingstone	Klingstone	Klingstone	2668.89	1132.05	5.5	45%
3	161.4	0	Klingstone	Klingstone	Klingstone	2667.89	1207.79	6.5	48%
1	177.61	0.1	SoilTac	SoilTac	SoilTac	2678.39	1029.11	7	41%
2	173.38	0.1	SoilTac	SoilTac	SoilTac	2699.13	1077.8	7	43%
3	173.35	0.1	SoilTac	SoilTac	SoilTac	2670.7	970.15	7	39%
1	178.92	0.2	SoilTac	SoilTac	SoilTac	2686.41	1270.5	7	51%
2	178.33	0.2	SoilTac	SoilTac	SoilTac	2680.33	1227.6	7	49%
3	178.59	0.2	SoilTac	SoilTac	SoilTac	2680.85	1225.3	7	49%
1	178.74	0.3	SoilTac	SoilTac	SoilTac	2681.81	1319.16	7	53%
2	173.47	0.3	SoilTac	SoilTac	SoilTac	2677.12	1450.37	7	58%
3	175.89	0.3	SoilTac	SoilTac	SoilTac	2678.18	1334.72	7	53%
1	171.09	0.4	SoilTac	SoilTac	SoilTac	2672.33	1464.59	7	59%
2	171.28	0.4	SoilTac	SoilTac	SoilTac	2672.22	1456.78	7	58%
3	170.65	0.4	SoilTac	SoilTac	SoilTac	2663.87	1472.14	7	59%
1	171.29	0.5	SoilTac	SoilTac	SoilTac	2663.13	1477.72	7	59%
2	176.44	0.5	SoilTac	SoilTac	SoilTac	2671.43	1523.23	6.5	61%
3	175.9	0.5	SoilTac	SoilTac	SoilTac	2671.33	1352.46	7	54%
1	176.06	0.6	SoilTac	SoilTac	SoilTac	2667.21	1240.53	7	50%
2	175.88	0.6	SoilTac	SoilTac	SoilTac	2665.71	1366.52	7	55%
3	170.7	0.6	SoilTac	SoilTac	SoilTac	2655.1	1645.31	7	66%
1	176.42	0.7	SoilTac	SoilTac	SoilTac	2656.7	1697.02	6.75	68%
2	170.58	0.7	SoilTac	SoilTac	SoilTac	2651.23	1608.44	6.5	65%
3	176.8	0.7	SoilTac	SoilTac	SoilTac	2656.79	1326.19	6.75	53%
1	170.53	0.8	SoilTac	SoilTac	SoilTac	2639	1499.92	6	61%
2	171	0.8	SoilTac	SoilTac	SoilTac	2641.39	1570.85	6	64%
3	170.81	0.8	SoilTac	SoilTac	SoilTac	2639.21	1617.35	6.5	66%
1	171.58	0.9	SoilTac	SoilTac	SoilTac	2634.72	1389.71	5.75	56%
2	171.7	0.9	SoilTac	SoilTac	SoilTac	2631.63	1403.01	5.25	57%
3	170.86	0.9	SoilTac	SoilTac	SoilTac	2626.05	1396.61	6	57%

7.3 LAB-SCALE TRAIL TEST

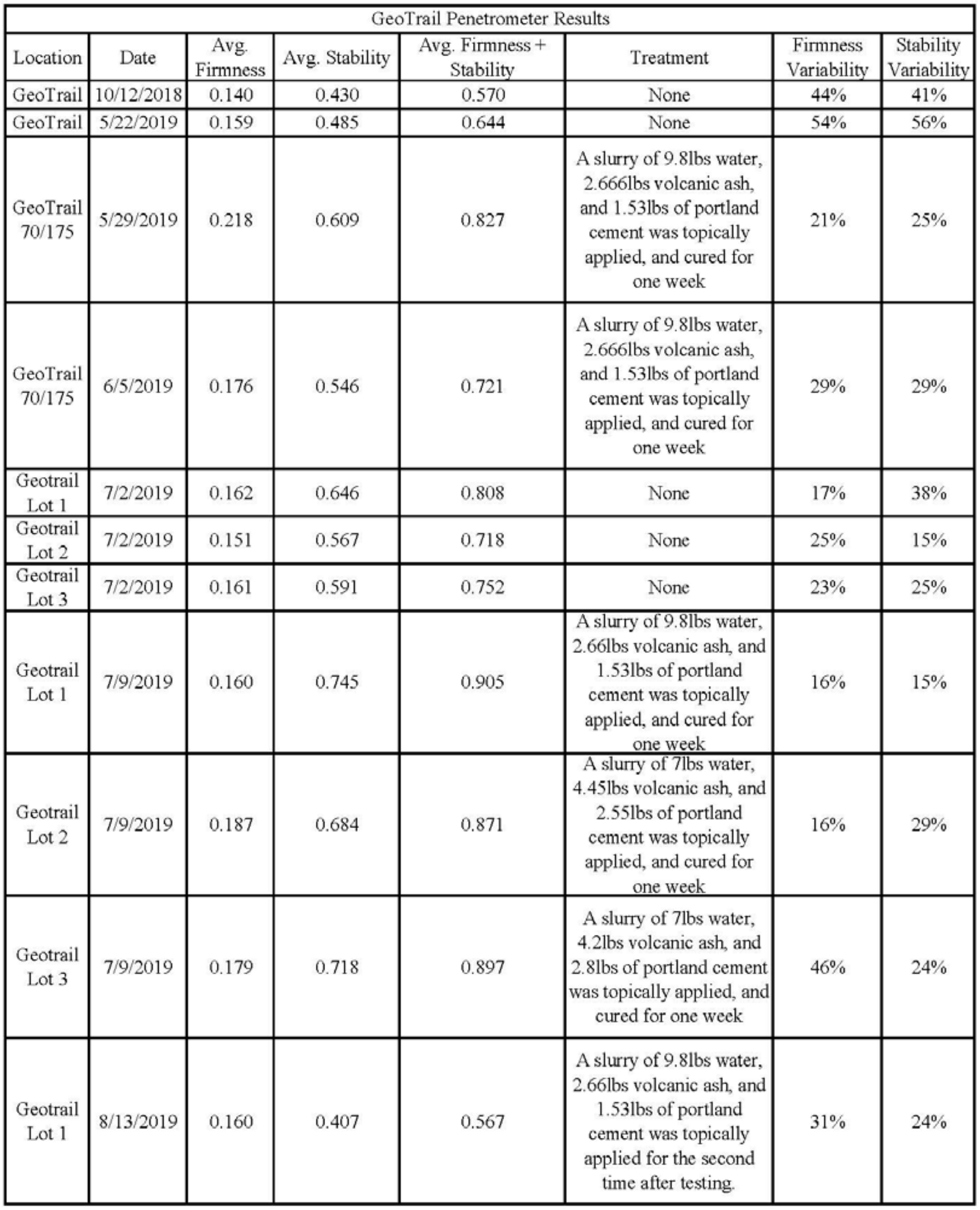
Trail Frame Results								
Surface	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Frame	Firmness Variability	Stability Variability
C1 Gravel	8/20/2018	0.297	1.649	1.946	Compacted with gas-powered vibratory compactor before testing.	1	43%	14%
C1 Gravel	8/20/2018	0.274	1.616	1.890	Compacted with gas-powered vibratory compactor before testing, pins moved to 1 from 0	1	42%	19%
C1 Gravel	8/29/2018	0.311	1.592	1.903	Compacted with gas-powered vibratory compactor before testing, pins moved to 2 from 1	1	51%	9%
C1 Gravel	8/29/2018	0.255	1.527	1.782	Compacted with gas-powered vibratory compactor before testing, pins moved to 3 from 2	1	89%	25%
C1 Gravel	8/29/2018	0.227	1.516	1.743	Compacted with gas-powered vibratory compactor before testing, pins moved to 4 from 3	1	39%	29%
C1 Gravel	8/29/2018	0.230	1.468	1.698	Compacted with gas-powered vibratory compactor before testing, pins moved to 5 from 4	1	40%	24%
C1 Gravel	8/29/2018	0.231	1.540	1.771	Compacted with gas-powered vibratory compactor before testing, pins moved to 6 from 5	1	5%	28%
C1-gravel	9/12/2018	0.244	1.571	1.815	None	1	22%	24%
C1-gravel	9/12/2018	0.241	1.491	1.733	Pins moved to 1 from 0	1	22%	10%
C1-gravel	9/12/2018	0.265	1.531	1.796	Pins moved to 2 from 1	1	19%	8%
C1-gravel	9/13/2018	0.223	1.456	1.680	Pins moved to 3 from 2	1	54%	14%
C1-gravel	9/13/2018	0.218	1.584	1.802	Pins moved to 4 from 3	1	33%	18%
C1-gravel	9/13/2018	0.277	1.611	1.888	Pins moved to 5 from 4	1	45%	16%
C1-gravel	10/23/2018	0.201	0.328	0.529	A slurry of 11.9lbs water, 3.2lbs volcanic ash, and 4.8lbs of portland cement was topically applied and left to cure for one week.	1	22%	29%
C1-gravel	10/25/2018	0.217	0.363	0.580	A slurry of 11.9lbs water, 3.2lbs volcanic ash, and 4.8lbs of portland cement was topically applied and left to cure for one week, pins moved to 1 from 0	1	32%	42%
C1-gravel	10/25/2018	0.155	0.426	0.581	A slurry of 11.9lbs water, 3.2lbs volcanic ash, and 4.8lbs of portland cement was topically applied and left to cure for one week, scuffed by foot for ~5 minutes	1	42%	73%
C1-gravel	10/30/2018	0.193	0.554	0.746	A slurry of 11.9lbs water, 3.2lbs volcanic ash, and 4.8lbs of portland cement was topically applied and left to cure for one week, scuffed by foot for ~5 minutes	1	39%	17%

Trail Frame Results

Surface	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Frame	Firmness Variability	Stability Variability
C1-gravel (subsurface)	10/31/2018	0.186	0.665	0.851	A slurry of 11.9lbs water, 3.2lbs volcanic ash, and 4.8lbs of portland cement was topically applied and left to cure for one week, scuffed surface removed	1	49%	69%
GeoTrail	10/26/2018	0.304	1.499	1.804	None	2	50%	37%
M5.0.1	11/2/2018	0.278	1.477	1.755	None	2	48%	110%
Geotrail 60/150	11/9/2018	0.285	0.926	1.210	A slurry of 4.6lbs water, 1.2lbs volcanic ash, and 1.8lbs of portland cement was topically applied.	2	12%	40%
GeoTrail mixed	11/13/2018	0.306	1.741	2.047	None	2	35%	32%
M5.0.1	11/26/2018	0.249	0.962	1.211	None	1	64%	53%
C1	1/11/2019	0.211	0.277	0.488	A slurry of 16.68lbs water, 6.67lbs volcanic ash, and 4.45lbs of portland cement was topically applied, then allowed to cure two weeks indoors and then two weeks in natural freezing conditions	1	55%	62%
C1	1/14/2019	0.137	0.457	0.594	A slurry of 16.68lbs water, 6.67lbs volcanic ash, and 4.45lbs of portland cement was topically applied, then allowed to cure two weeks indoors and then two weeks in natural freezing conditions, scuffed by foot for ~5 minutes	1	87%	86%
C1	1/14/2019	0.169	0.610	0.779	A slurry of 18.53lbs water, 7.41lbs volcanic ash, and 4.94lbs of portland cement was topically applied, then allowed to cure four weeks in natural freezing conditions	1	85%	60%
C1	1/14/2019	0.166	0.951	1.117	A slurry of 18.53lbs water, 7.41lbs volcanic ash, and 4.94lbs of portland cement was topically applied, then allowed to cure four weeks in natural freezing conditions, scuffed by foot for ~5 minutes	1	37%	54%
C1	2/22/2019	0.329	1.478	1.806	None	2	58%	14%
C1	3/1/2019	0.199	0.428	0.627	A slurry of 16lbs water, 6.4lbs volcanic ash, and 4.27lbs of portland cement was topically applied, and cured for one week	2	63%	48%
C1	3/1/2019	0.206	1.134	1.339	A slurry of 16lbs water, 6.4lbs volcanic ash, and 4.27lbs of portland cement was topically applied, and cured for one week, scuffed by foot for ~5 minutes	2	47%	19%
C1	3/14/2019	0.193	1.130	1.323	A slurry of 16lbs water, 6.4lbs volcanic ash, and 4.27lbs of portland cement was topically applied, and cured for one week, scuffed by foot for ~5 minutes, device rotated 90 degrees	2	19%	23%
C1	3/15/2019	0.267	1.488	1.754	None	1	19%	13%

Trail Frame Results								
Surface	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Frame	Firmness Variability	Stability Variability
C1	3/22/2019	0.211	1.137	1.348	A slurry of 7.5lbs water, 3lbs volcanic ash, and 2lbs of portland cement was topically applied, and cured for one week	1	18%	24%
C1	3/22/2019	0.289	1.399	1.688	A slurry of 7.5lbs water, 3lbs volcanic ash, and 2lbs of portland cement was topically applied, and cured for one week, scuffed by foot for ~5 minutes	1	28%	13%
C1	3/25/2019	0.201	1.261	1.462	A slurry of 7.5lbs water, 3lbs volcanic ash, and 2lbs of portland cement was topically applied, and cured for one week, scuffed by foot for ~10 minutes	2	49%	12%
C1	5/8/2019	0.341	1.521	1.862	None	1	95%	26%
C1	5/17/2019	0.291	0.816	1.107	A slurry of 7.5lbs water, 3lbs volcanic ash, and 2lbs of portland cement was topically applied, and cured for one week	1	20%	19%
C1	5/17/2019	0.266	1.231	1.497	A slurry of 7.5lbs water, 3lbs volcanic ash, and 2lbs of portland cement was topically applied, and cured for one week, scuffed by foot for ~5 minutes	1	32%	98%
C1	5/8/2019	0.272	1.448	1.719	None	2	60%	63%
C1	5/17/2019	0.268	0.897	1.165	A slurry of 7.5lbs water, 3lbs volcanic ash, and 2lbs of portland cement was topically applied, and cured for one week	2	45%	32%
C1	5/17/2019	0.263	1.255	1.518	A slurry of 7.5lbs water, 3lbs volcanic ash, and 2lbs of portland cement was topically applied, and cured for one week, scuffed by foot for ~5 minutes	2	25%	14%

7.4 FIELD-SCALE DATA

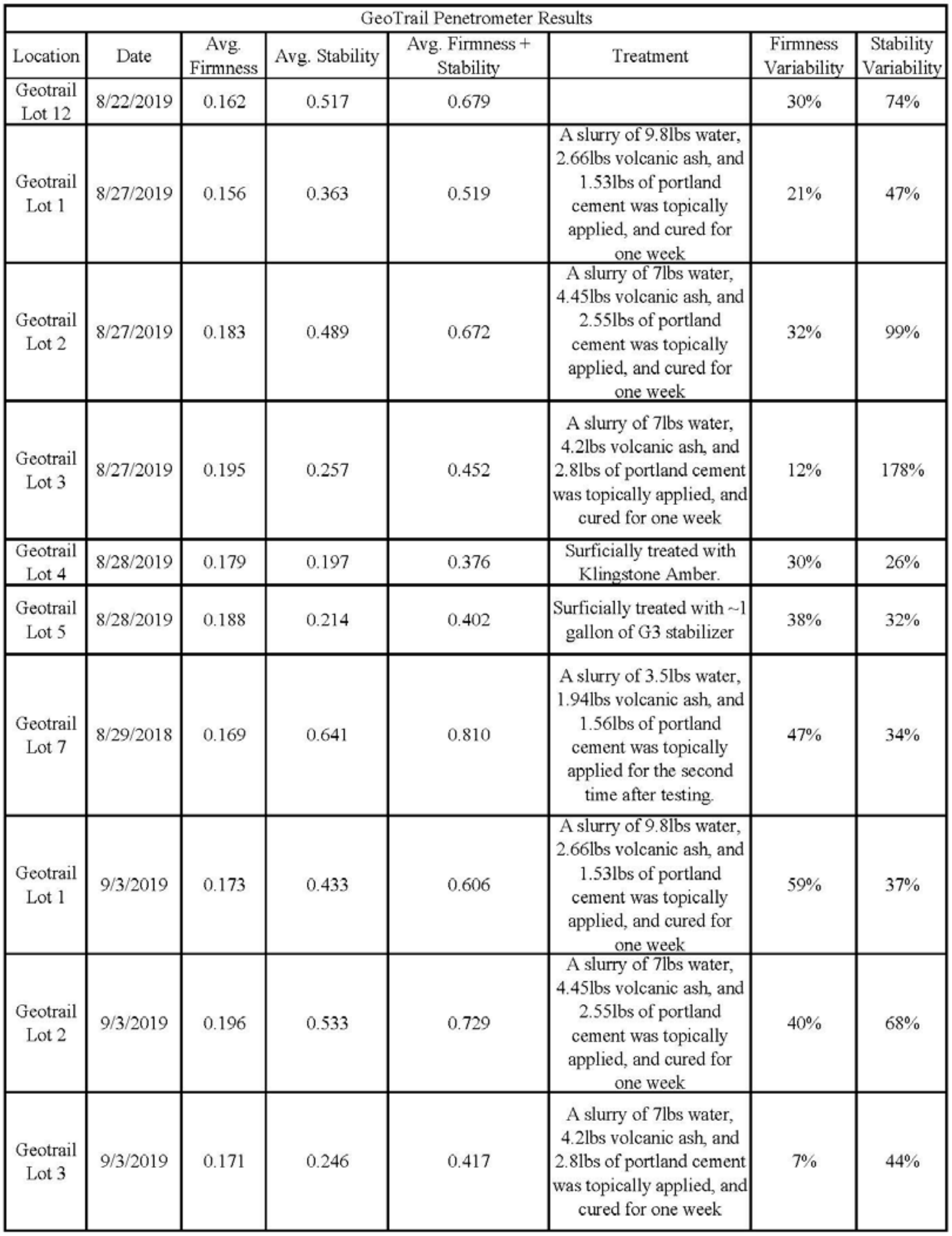


GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
GeoTrail	10/12/2018	0.140	0.430	0.570	None	44%	41%
GeoTrail	5/22/2019	0.159	0.485	0.644	None	54%	56%
GeoTrail 70/175	5/29/2019	0.218	0.609	0.827	A slurry of 9.8lbs water, 2.666lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	21%	25%
GeoTrail 70/175	6/5/2019	0.176	0.546	0.721	A slurry of 9.8lbs water, 2.666lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	29%	29%
Geotrail Lot 1	7/2/2019	0.162	0.646	0.808	None	17%	38%
Geotrail Lot 2	7/2/2019	0.151	0.567	0.718	None	25%	15%
Geotrail Lot 3	7/2/2019	0.161	0.591	0.752	None	23%	25%
Geotrail Lot 1	7/9/2019	0.160	0.745	0.905	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	16%	15%
Geotrail Lot 2	7/9/2019	0.187	0.684	0.871	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	16%	29%
Geotrail Lot 3	7/9/2019	0.179	0.718	0.897	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	46%	24%
Geotrail Lot 1	8/13/2019	0.160	0.407	0.567	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied for the second time after testing.	31%	24%

GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 2	8/13/2019	0.185	0.423	0.608	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied for the second time after testing.	31%	60%
Geotrail Lot 3	8/13/2019	0.214	0.293	0.507	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied for the second time after testing.	20%	77%
Geotrail Lot 4	8/14/2019	0.160	0.518	0.678	Surficially treated with Klingstone Amber.	51%	21%
Geotrail Lot 5	8/14/2019	0.162	0.542	0.704	Surficially treated with ~1 gallon of G3 stabilizer	29%	18%
Geotrail Lot 6	8/14/2019	0.180	0.555	0.735		42%	20%
Geotrail Lot 1	8/20/2019	0.175	0.503	0.678	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	28%	66%
Geotrail Lot 2	8/20/2019	0.178	0.434	0.612	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	20%	82%
Geotrail Lot 3	8/20/2019	0.195	0.335	0.530	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	29%	96%
Geotrail Lot 4	8/21/2019	0.196	0.263	0.459	Surficially treated with Klingstone Amber.	48%	49%
Geotrail Lot 5	8/21/2019	0.160	0.204	0.364	Surficially treated with ~1 gallon of G3 stabilizer	53%	34%
Geotrail Lot 7	8/22/2019	0.154	0.522	0.676		28%	28%
Geotrail Lot 8	8/22/2019	0.202	0.705	0.907		102%	42%
Geotrail Lot 9	8/22/2019	0.174	0.532	0.706		17%	74%
Geotrail Lot 10	8/22/2019	0.156	0.528	0.684		27%	27%
Geotrail Lot 11	8/22/2019	0.172	0.436	0.608		26%	36%



GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 12	8/22/2019	0.162	0.517	0.679		30%	74%
Geotrail Lot 1	8/27/2019	0.156	0.363	0.519	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	21%	47%
Geotrail Lot 2	8/27/2019	0.183	0.489	0.672	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	32%	99%
Geotrail Lot 3	8/27/2019	0.195	0.257	0.452	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	12%	178%
Geotrail Lot 4	8/28/2019	0.179	0.197	0.376	Surficially treated with Klingstone Amber.	30%	26%
Geotrail Lot 5	8/28/2019	0.188	0.214	0.402	Surficially treated with ~1 gallon of G3 stabilizer	38%	32%
Geotrail Lot 7	8/29/2018	0.169	0.641	0.810	A slurry of 3.5lbs water, 1.94lbs volcanic ash, and 1.56lbs of portland cement was topically applied for the second time after testing.	47%	34%
Geotrail Lot 1	9/3/2019	0.173	0.433	0.606	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	59%	37%
Geotrail Lot 2	9/3/2019	0.196	0.533	0.729	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	40%	68%
Geotrail Lot 3	9/3/2019	0.171	0.246	0.417	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	7%	44%

GeoTrail Penetrometer Results

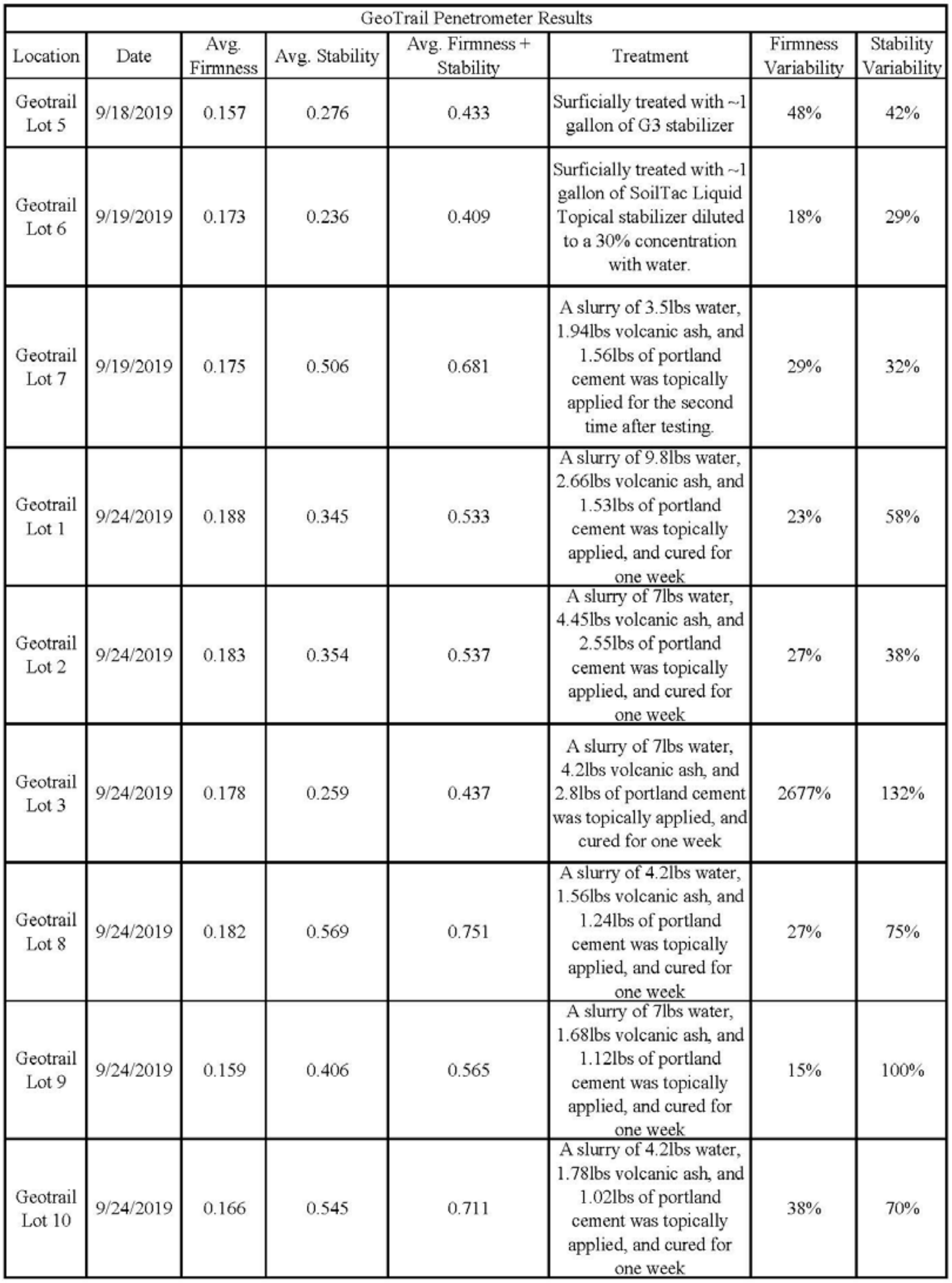
Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 8	9/3/2019	0.203	0.711	0.914	A slurry of 4.2lbs water, 1.56lbs volcanic ash, and 1.24lbs of portland cement was topically applied, and cured for one week	43%	90%
Geotrail Lot 9	9/3/2019	0.186	0.581	0.767	A slurry of 7lbs water, 1.68lbs volcanic ash, and 1.12lbs of portland cement was topically applied, and cured for one week	45%	49%
Geotrail Lot 10	9/3/2019	0.200	0.595	0.795	A slurry of 4.2lbs water, 1.78lbs volcanic ash, and 1.02lbs of portland cement was topically applied, and cured for one week	28%	68%
Geotrail Lot 4	9/4/2019	0.183	0.273	0.456	Surficially treated with Klingstone Amber.	58%	85%
Geotrail Lot 5	9/4/2019	0.199	0.235	0.434	Surficially treated with ~1 gallon of G3 stabilizer	33%	58%
Geotrail Lot 7	9/5/2019	0.176	0.520	0.696	A slurry of 3.5lbs water, 1.94lbs volcanic ash, and 1.56lbs of portland cement was topically applied for the second time after testing.	16%	24%
Geotrail Lot 1	9/10/2019	0.186	0.401	0.587	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	9%	62%
Geotrail Lot 2	9/10/2019	0.172	0.204	0.376	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	20%	145%
Geotrail Lot 3	9/10/2019	0.158	0.202	0.360	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	26%	34%

GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 8	9/10/2019	0.182	0.703	0.885	A slurry of 4.2lbs water, 1.56lbs volcanic ash, and 1.24lbs of portland cement was topically applied, and cured for one week	35%	71%
Geotrail Lot 9	9/10/2019	0.175	0.444	0.619	A slurry of 7lbs water, 1.68lbs volcanic ash, and 1.12lbs of portland cement was topically applied, and cured for one week	21%	116%
Geotrail Lot 10	9/10/2019	0.199	0.659	0.858	A slurry of 4.2lbs water, 1.78lbs volcanic ash, and 1.02lbs of portland cement was topically applied, and cured for one week	28%	46%
Geotrail Lot 11	9/10/2019	0.174	0.412	0.586	A slurry of 4.9lbs water, 1.17lbs volcanic ash, and 0.93lbs of portland cement was topically applied, and cured for one week	26%	105%
Geotrail Lot 12	9/10/2019	0.193	0.503	0.696	A slurry of 4.9lbs water, 1.26lbs volcanic ash, and 0.84lbs of portland cement was topically applied, and cured for one week	34%	93%
Geotrail Lot 4	9/11/2019	0.167	0.193	0.360	Surficially treated with Klingstone Amber.	21%	92%
Geotrail Lot 5	9/11/2019	0.168	0.223	0.391	Surficially treated with ~1 gallon of G3 stabilizer	47%	59%
Geotrail Lot 6	9/12/2019	0.163	0.219	0.382	Surficially treated with ~1 gallon of SoilTac Liquid Topical stabilizer diluted to a 30% concentration with water.	10%	21%
Geotrail Lot 7	9/12/2019	0.172	0.682	0.854	A slurry of 3.5lbs water, 1.94lbs volcanic ash, and 1.56lbs of portland cement was topically applied for the second time after testing.	18%	46%

GeoTrail Penetrometer Results

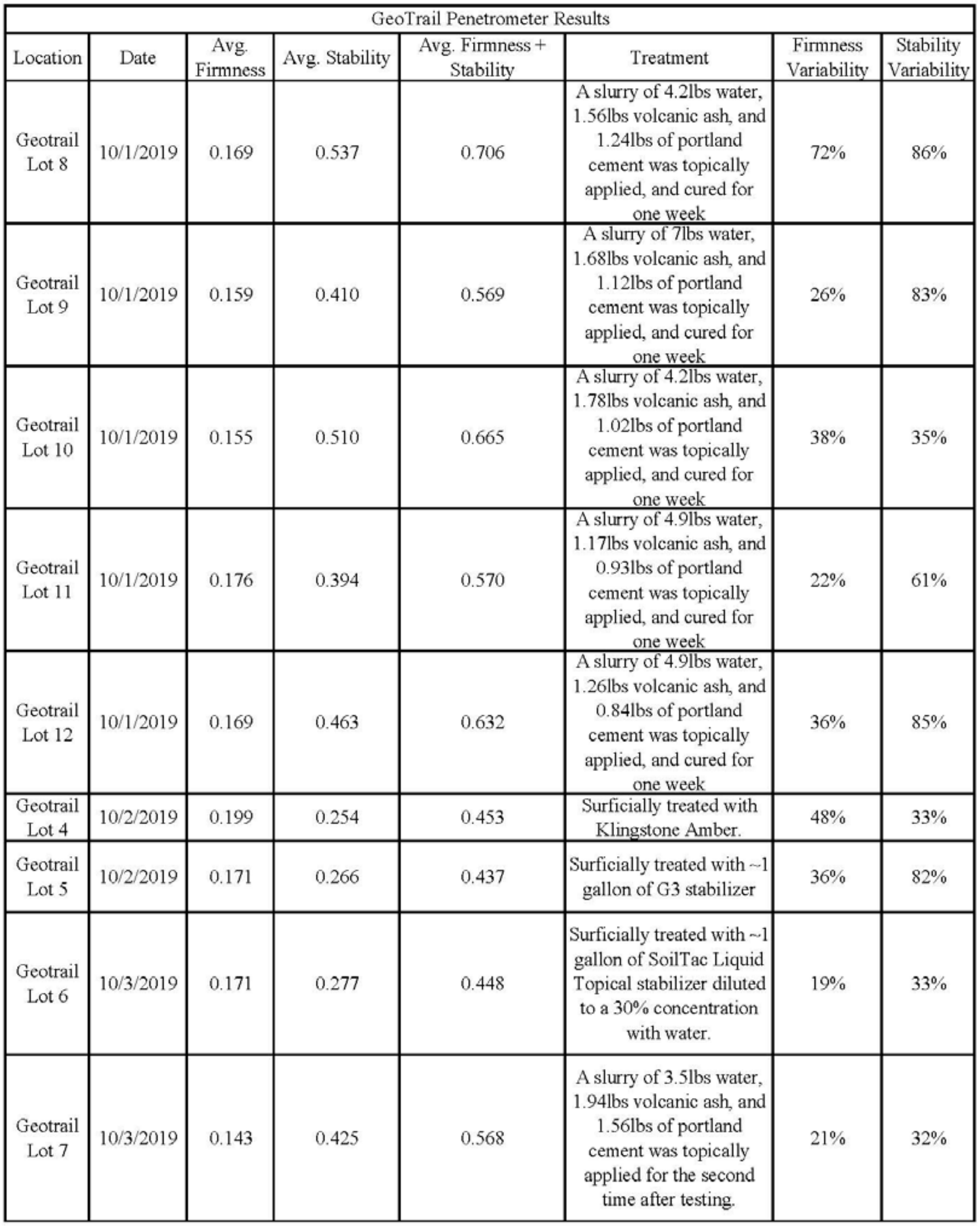
Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 1	9/17/2019	0.183	0.509	0.692	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	9%	62%
Geotrail Lot 2	9/17/2019	0.179	0.304	0.483	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	20%	145%
Geotrail Lot 3	9/17/2019	0.203	0.256	0.459	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	26%	34%
Geotrail Lot 8	9/17/2019	0.172	0.482	0.654	A slurry of 4.2lbs water, 1.56lbs volcanic ash, and 1.24lbs of portland cement was topically applied, and cured for one week	35%	71%
Geotrail Lot 9	9/17/2019	0.190	0.579	0.769	A slurry of 7lbs water, 1.68lbs volcanic ash, and 1.12lbs of portland cement was topically applied, and cured for one week	21%	116%
Geotrail Lot 10	9/17/2019	0.147	0.590	0.737	A slurry of 4.2lbs water, 1.78lbs volcanic ash, and 1.02lbs of portland cement was topically applied, and cured for one week	28%	46%
Geotrail Lot 11	9/17/2019	0.172	0.317	0.489	A slurry of 4.9lbs water, 1.17lbs volcanic ash, and 0.93lbs of portland cement was topically applied, and cured for one week	26%	105%
Geotrail Lot 12	9/17/2019	0.168	0.450	0.618	A slurry of 4.9lbs water, 1.26lbs volcanic ash, and 0.84lbs of portland cement was topically applied, and cured for one week	34%	93%
Geotrail Lot 4	9/18/2019	0.191	0.251	0.442	Surficially treated with Klingstone Amber.	44%	64%



GeoTrail Penetrometer Results							
Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 5	9/18/2019	0.157	0.276	0.433	Surficially treated with ~1 gallon of G3 stabilizer	48%	42%
Geotrail Lot 6	9/19/2019	0.173	0.236	0.409	Surficially treated with ~1 gallon of SoilTac Liquid Topical stabilizer diluted to a 30% concentration with water.	18%	29%
Geotrail Lot 7	9/19/2019	0.175	0.506	0.681	A slurry of 3.5lbs water, 1.94lbs volcanic ash, and 1.56lbs of portland cement was topically applied for the second time after testing.	29%	32%
Geotrail Lot 1	9/24/2019	0.188	0.345	0.533	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	23%	58%
Geotrail Lot 2	9/24/2019	0.183	0.354	0.537	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	27%	38%
Geotrail Lot 3	9/24/2019	0.178	0.259	0.437	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	2677%	132%
Geotrail Lot 8	9/24/2019	0.182	0.569	0.751	A slurry of 4.2lbs water, 1.56lbs volcanic ash, and 1.24lbs of portland cement was topically applied, and cured for one week	27%	75%
Geotrail Lot 9	9/24/2019	0.159	0.406	0.565	A slurry of 7lbs water, 1.68lbs volcanic ash, and 1.12lbs of portland cement was topically applied, and cured for one week	15%	100%
Geotrail Lot 10	9/24/2019	0.166	0.545	0.711	A slurry of 4.2lbs water, 1.78lbs volcanic ash, and 1.02lbs of portland cement was topically applied, and cured for one week	38%	70%

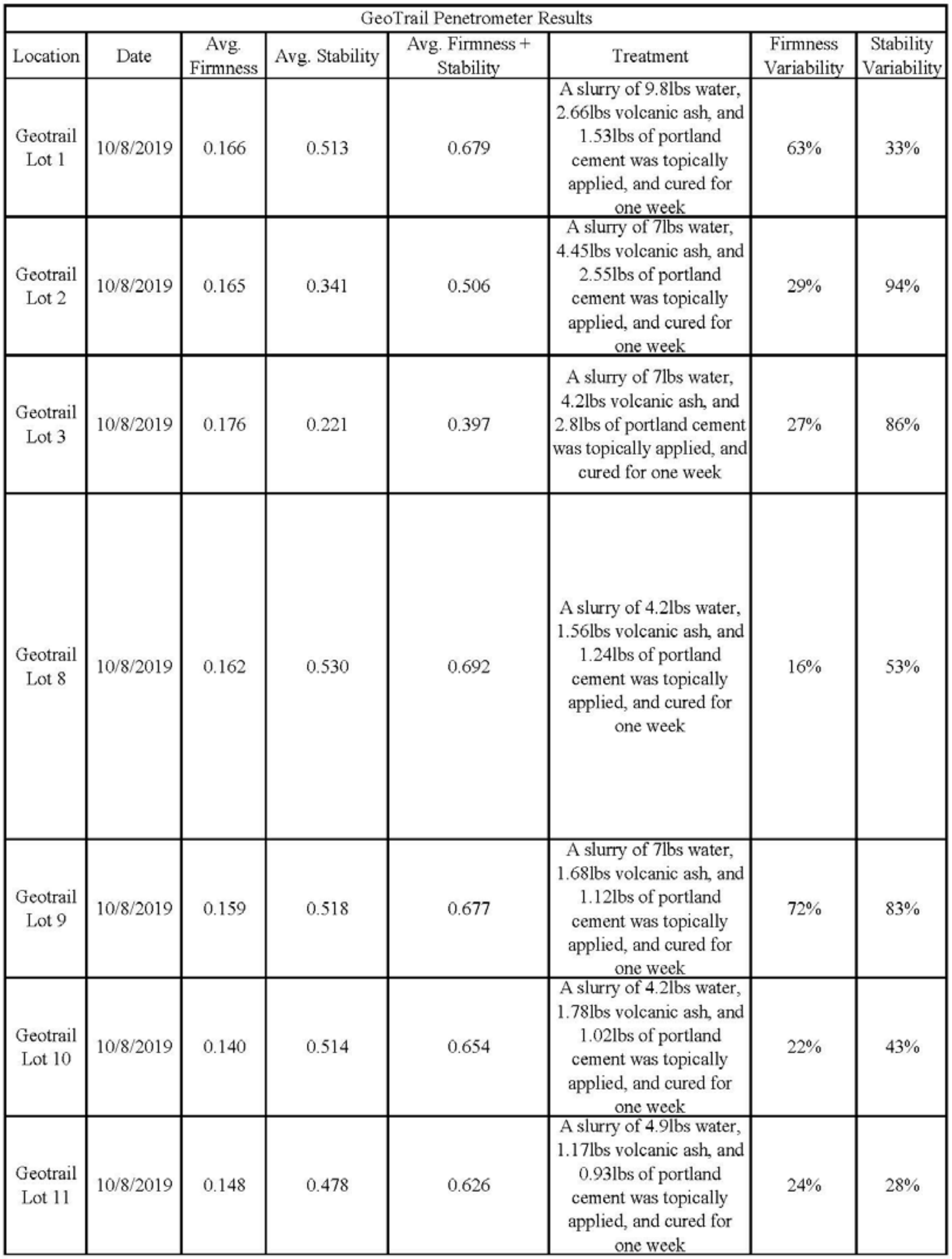
GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 11	9/24/2019	0.185	0.307	0.492	A slurry of 4.9lbs water, 1.17lbs volcanic ash, and 0.93lbs of portland cement was topically applied, and cured for one week	38%	58%
Geotrail Lot 12	9/24/2019	0.171	0.459	0.630	A slurry of 4.9lbs water, 1.26lbs volcanic ash, and 0.84lbs of portland cement was topically applied, and cured for one week	27%	121%
Geotrail Lot 4	9/25/2019	0.174	0.180	0.354	Surficially treated with Klingstone Amber.	33%	99%
Geotrail Lot 5	9/25/2019	0.156	0.316	0.472	Surficially treated with ~1 gallon of G3 stabilizer	23%	36%
Geotrail Lot 6	9/26/2019	0.150	0.239	0.389	Surficially treated with ~1 gallon of SoilTac Liquid Topical stabilizer diluted to a 30% concentration with water.	34%	36%
Geotrail Lot 7	9/26/2019	0.168	0.448	0.616	A slurry of 3.5lbs water, 1.94lbs volcanic ash, and 1.56lbs of portland cement was topically applied for the second time after testing.	21%	21%
Geotrail Lot 1	10/1/2019	0.172	0.269	0.441	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	36%	68%
Geotrail Lot 2	10/1/2019	0.195	0.270	0.465	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	12%	32%
Geotrail Lot 3	10/1/2019	0.189	0.217	0.406	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	30%	53%



GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 8	10/1/2019	0.169	0.537	0.706	A slurry of 4.2lbs water, 1.56lbs volcanic ash, and 1.24lbs of portland cement was topically applied, and cured for one week	72%	86%
Geotrail Lot 9	10/1/2019	0.159	0.410	0.569	A slurry of 7lbs water, 1.68lbs volcanic ash, and 1.12lbs of portland cement was topically applied, and cured for one week	26%	83%
Geotrail Lot 10	10/1/2019	0.155	0.510	0.665	A slurry of 4.2lbs water, 1.78lbs volcanic ash, and 1.02lbs of portland cement was topically applied, and cured for one week	38%	35%
Geotrail Lot 11	10/1/2019	0.176	0.394	0.570	A slurry of 4.9lbs water, 1.17lbs volcanic ash, and 0.93lbs of portland cement was topically applied, and cured for one week	22%	61%
Geotrail Lot 12	10/1/2019	0.169	0.463	0.632	A slurry of 4.9lbs water, 1.26lbs volcanic ash, and 0.84lbs of portland cement was topically applied, and cured for one week	36%	85%
Geotrail Lot 4	10/2/2019	0.199	0.254	0.453	Surficially treated with Klingstone Amber.	48%	33%
Geotrail Lot 5	10/2/2019	0.171	0.266	0.437	Surficially treated with ~1 gallon of G3 stabilizer	36%	82%
Geotrail Lot 6	10/3/2019	0.171	0.277	0.448	Surficially treated with ~1 gallon of SoilTac Liquid Topical stabilizer diluted to a 30% concentration with water.	19%	33%
Geotrail Lot 7	10/3/2019	0.143	0.425	0.568	A slurry of 3.5lbs water, 1.94lbs volcanic ash, and 1.56lbs of portland cement was topically applied for the second time after testing.	21%	32%

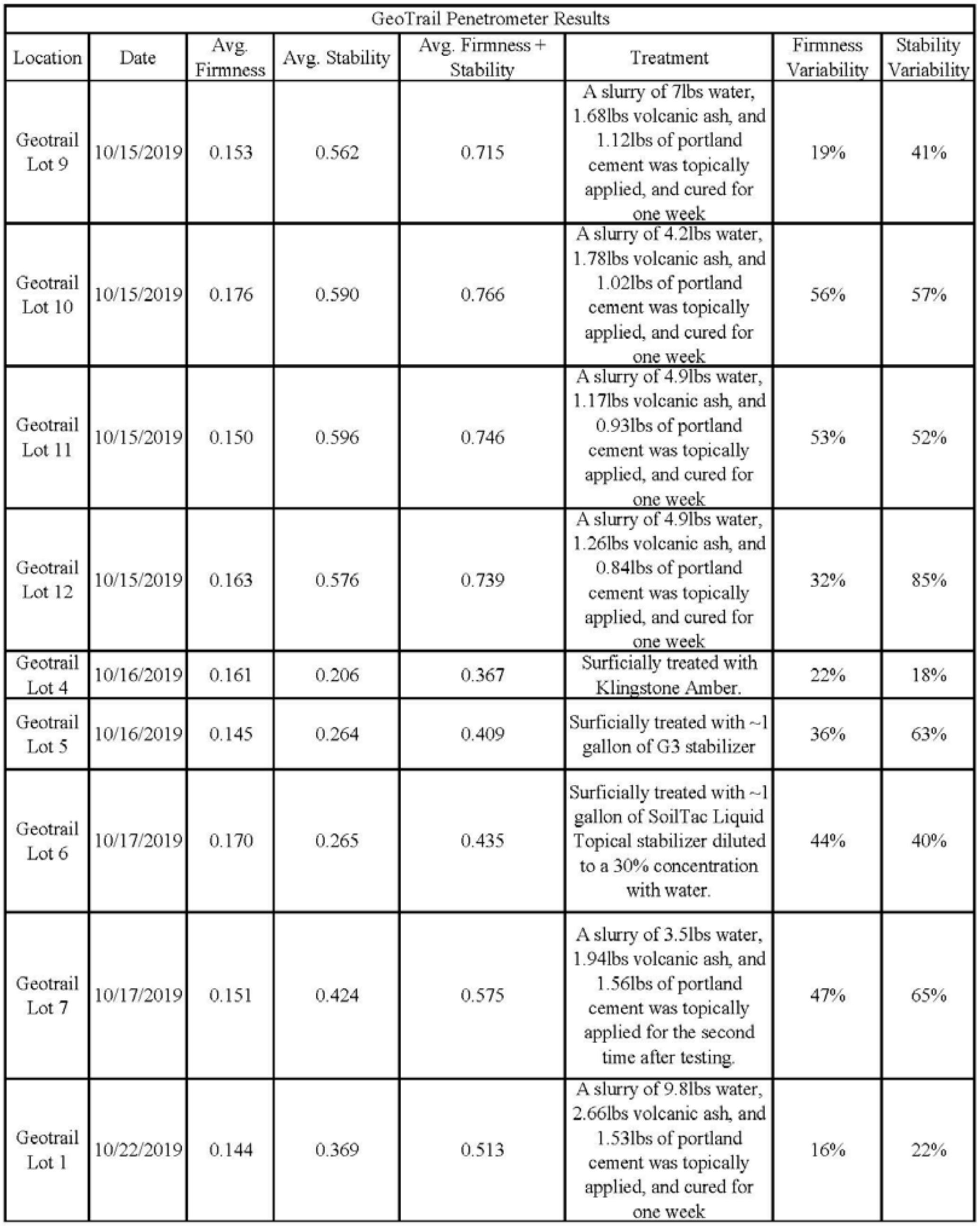


GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 1	10/8/2019	0.166	0.513	0.679	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	63%	33%
Geotrail Lot 2	10/8/2019	0.165	0.341	0.506	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	29%	94%
Geotrail Lot 3	10/8/2019	0.176	0.221	0.397	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	27%	86%
Geotrail Lot 8	10/8/2019	0.162	0.530	0.692	A slurry of 4.2lbs water, 1.56lbs volcanic ash, and 1.24lbs of portland cement was topically applied, and cured for one week	16%	53%
Geotrail Lot 9	10/8/2019	0.159	0.518	0.677	A slurry of 7lbs water, 1.68lbs volcanic ash, and 1.12lbs of portland cement was topically applied, and cured for one week	72%	83%
Geotrail Lot 10	10/8/2019	0.140	0.514	0.654	A slurry of 4.2lbs water, 1.78lbs volcanic ash, and 1.02lbs of portland cement was topically applied, and cured for one week	22%	43%
Geotrail Lot 11	10/8/2019	0.148	0.478	0.626	A slurry of 4.9lbs water, 1.17lbs volcanic ash, and 0.93lbs of portland cement was topically applied, and cured for one week	24%	28%

GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 12	10/8/2019	0.154	0.505	0.659	A slurry of 4.9lbs water, 1.26lbs volcanic ash, and 0.84lbs of portland cement was topically applied, and cured for one week	37%	54%
Geotrail Lot 4	10/9/2019	0.188	0.199	0.387	Surficially treated with Klingstone Amber.	39%	45%
Geotrail Lot 5	10/9/2019	0.170	0.308	0.478	Surficially treated with ~1 gallon of G3 stabilizer	44%	59%
Geotrail Lot 6	10/10/2019	0.176	0.277	0.453	Surficially treated with ~1 gallon of SoilTac Liquid Topical stabilizer diluted to a 30% concentration with water.	22%	31%
Geotrail Lot 7	10/10/2019	0.152	0.512	0.664	A slurry of 3.5lbs water, 1.94lbs volcanic ash, and 1.56lbs of portland cement was topically applied for the second time after testing.	35%	48%
Geotrail Lot 1	10/15/0219	0.146	0.469	0.615	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	44%	94%
Geotrail Lot 2	10/15/2019	0.158	0.200	0.358	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	36%	128%
Geotrail Lot 3	10/15/2019	0.173	0.258	0.431	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	34%	113%
Geotrail Lot 8	10/15/2019	0.185	0.667	0.852	A slurry of 4.2lbs water, 1.56lbs volcanic ash, and 1.24lbs of portland cement was topically applied, and cured for one week	36%	91%



GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 9	10/15/2019	0.153	0.562	0.715	A slurry of 7lbs water, 1.68lbs volcanic ash, and 1.12lbs of portland cement was topically applied, and cured for one week	19%	41%
Geotrail Lot 10	10/15/2019	0.176	0.590	0.766	A slurry of 4.2lbs water, 1.78lbs volcanic ash, and 1.02lbs of portland cement was topically applied, and cured for one week	56%	57%
Geotrail Lot 11	10/15/2019	0.150	0.596	0.746	A slurry of 4.9lbs water, 1.17lbs volcanic ash, and 0.93lbs of portland cement was topically applied, and cured for one week	53%	52%
Geotrail Lot 12	10/15/2019	0.163	0.576	0.739	A slurry of 4.9lbs water, 1.26lbs volcanic ash, and 0.84lbs of portland cement was topically applied, and cured for one week	32%	85%
Geotrail Lot 4	10/16/2019	0.161	0.206	0.367	Surficially treated with Klingstone Amber.	22%	18%
Geotrail Lot 5	10/16/2019	0.145	0.264	0.409	Surficially treated with ~1 gallon of G3 stabilizer	36%	63%
Geotrail Lot 6	10/17/2019	0.170	0.265	0.435	Surficially treated with ~1 gallon of SoilTac Liquid Topical stabilizer diluted to a 30% concentration with water.	44%	40%
Geotrail Lot 7	10/17/2019	0.151	0.424	0.575	A slurry of 3.5lbs water, 1.94lbs volcanic ash, and 1.56lbs of portland cement was topically applied for the second time after testing.	47%	65%
Geotrail Lot 1	10/22/2019	0.144	0.369	0.513	A slurry of 9.8lbs water, 2.66lbs volcanic ash, and 1.53lbs of portland cement was topically applied, and cured for one week	16%	22%

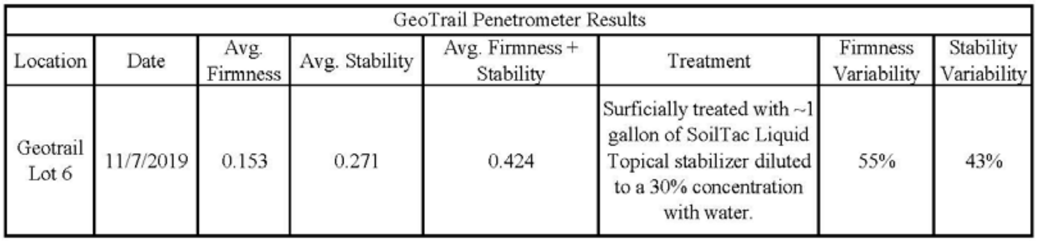
GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 2	10/22/2019	0.145	0.319	0.464	A slurry of 7lbs water, 4.45lbs volcanic ash, and 2.55lbs of portland cement was topically applied, and cured for one week	62%	111%
Geotrail Lot 3	10/22/2019	0.161	0.221	0.382	A slurry of 7lbs water, 4.2lbs volcanic ash, and 2.8lbs of portland cement was topically applied, and cured for one week	13%	114%
Geotrail Lot 8	10/22/2019	0.156	0.598	0.754	A slurry of 4.2lbs water, 1.56lbs volcanic ash, and 1.24lbs of portland cement was topically applied, and cured for one week	23%	60%
Geotrail Lot 9	10/22/2019	0.166	0.446	0.612	A slurry of 7lbs water, 1.68lbs volcanic ash, and 1.12lbs of portland cement was topically applied, and cured for one week	36%	75%
Geotrail Lot 10	10/22/2019	0.163	0.428	0.591	A slurry of 4.2lbs water, 1.78lbs volcanic ash, and 1.02lbs of portland cement was topically applied, and cured for one week	21%	51%
Geotrail Lot 11	10/22/2019	0.162	0.414	0.576	A slurry of 4.9lbs water, 1.17lbs volcanic ash, and 0.93lbs of portland cement was topically applied, and cured for one week	26%	18%
Geotrail Lot 12	10/22/2019	0.164	0.411	0.575	A slurry of 4.9lbs water, 1.26lbs volcanic ash, and 0.84lbs of portland cement was topically applied, and cured for one week	8%	91%

GeoTrail Penetrometer Results							
Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 4	10/23/2019	0.164	0.411	0.575	Surficially treated with Klingstone Amber.	8%	91%
Geotrail Lot 5	10/23/2019	0.163	0.320	0.483	Surficially treated with ~1 gallon of G3 stabilizer	34%	23%
Geotrail Lot 6	10/24/2019	0.162	0.255	0.417	Surficially treated with ~1 gallon of SoilTac Liquid Topical stabilizer diluted to a 30% concentration with water.	19%	39%
Geotrail Lot 7	10/24/2019	0.158	0.414	0.572	A slurry of 3.5lbs water, 1.94lbs volcanic ash, and 1.56lbs of portland cement was topically applied for the second time after testing.	19%	32%
Geotrail Lot 8	10/29/2019	0.147	0.490	0.637	A slurry of 4.2lbs water, 1.56lbs volcanic ash, and 1.24lbs of portland cement was topically applied, and cured for one week	21%	24%
Geotrail Lot 9	10/29/2019	0.156	0.555	0.711	A slurry of 7lbs water, 1.68lbs volcanic ash, and 1.12lbs of portland cement was topically applied, and cured for one week	31%	52%
Geotrail Lot 10	10/29/2019	0.157	0.496	0.653	A slurry of 4.2lbs water, 1.78lbs volcanic ash, and 1.02lbs of portland cement was topically applied, and cured for one week	25%	48%
Geotrail Lot 11	10/29/2019	0.145	0.473	0.618	A slurry of 4.9lbs water, 1.17lbs volcanic ash, and 0.93lbs of portland cement was topically applied, and cured for one week	32%	28%
Geotrail Lot 12	10/29/2019	0.140	0.559	0.699	A slurry of 4.9lbs water, 1.26lbs volcanic ash, and 0.84lbs of portland cement was topically applied, and cured for one week	53%	91%

GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 6	10/31/2019	0.183	0.264	0.447	Surficially treated with ~1 gallon of SoilTac Liquid Topical stabilizer diluted to a 30% concentration with water.	15%	15%
Geotrail Lot 7	10/31/2019	0.140	0.462	0.602	A slurry of 3.5lbs water, 1.94lbs volcanic ash, and 1.56lbs of portland cement was topically applied for the second time after testing.	34%	27%
Geotrail Lot 8	11/5/2019	0.122	0.546	0.668	A slurry of 4.2lbs water, 1.56lbs volcanic ash, and 1.24lbs of portland cement was topically applied, and cured for one week	20%	54%
Geotrail Lot 9	11/5/2019	0.152	0.584	0.736	A slurry of 7lbs water, 1.68lbs volcanic ash, and 1.12lbs of portland cement was topically applied, and cured for one week	21%	42%
Geotrail Lot 10	11/5/2019	0.133	0.580	0.713	A slurry of 4.2lbs water, 1.78lbs volcanic ash, and 1.02lbs of portland cement was topically applied, and cured for one week	34%	35%
Geotrail Lot 11	11/5/2019	0.135	0.483	0.618	A slurry of 4.9lbs water, 1.17lbs volcanic ash, and 0.93lbs of portland cement was topically applied, and cured for one week	30%	38%
Geotrail Lot 12	11/5/2019	0.151	0.485	0.636	A slurry of 4.9lbs water, 1.26lbs volcanic ash, and 0.84lbs of portland cement was topically applied, and cured for one week	33%	64%



GeoTrail Penetrometer Results

Location	Date	Avg. Firmness	Avg. Stability	Avg. Firmness + Stability	Treatment	Firmness Variability	Stability Variability
Geotrail Lot 6	11/7/2019	0.153	0.271	0.424	Surficially treated with ~1 gallon of SoilTac Liquid Topical stabilizer diluted to a 30% concentration with water.	55%	43%

7.5 COMMERCIAL STABILIZER DATA SHEETS

G3® Pathway

Liquid Polymer Stabilizer for DG & Crushed Stone Mixes

TechniSoil®

PRODUCT SUMMARY:

TechniSoil G3® Pathway Stabilizer (G3-PS) is a simple solution for creating custom pathways and patio areas. This eco-friendly liquid polymer stabilizer for decomposed granite (DG) and crushed stone materials yields a durable, dust-free surface in only a few basic steps. By bonding crushed aggregates and fines, G3-PS enhances natural surfaces for the modern landscape.

PACKAGES:

- 1-Gal bottle Dilutable Concentrate
- 5-Gal bottle • 55-Gal drum

FEATURES & BENEFITS:

- Reduces tracking of loose materials
- Improves surface stability
- Easy to apply using standard equipment
- Minimizes dust, weeds, and erosion
- Low-maintenance
- Eco-friendly

TYPICAL USES:

- Pathways
- Patios
- Garden Trails
- Landscaping

COVERAGE:

- Mix 1-Gal Dilutable Concentrate bottle 4:1 with Water (Water : G3-PS)
- Up to 75 Ft² Per 5 Gallons

TechniSoilGlobal TechniSoil TechniSoil TechniSoil.com ☎ 877-356-2250 Mon - Fri: 7AM - 4PM (PST)

TechniSoil G3® Pathway Stabilizer

1. PRODUCT & COMPANY IDENTIFICATION

TRADE NAME: TechniSoil Global, Inc.
PRODUCT NAME: G3® Pathway Stabilizer
DISTRIBUTED BY:
TechniSoil Global, Inc.
5660 Westside Rd. Redding, CA 96001
Toll Free: 877.356.2250

24-HOUR EMERGENCY TELEPHONE NUMBER:
Chemtrec: US: 800-424-9300
INTL: 703-527-3887

2. COMPOSITION / INFORMATION ON INGREDIENTS

COMPONENT:	RANGE:	CAS NO:
Proprietary Polymer Blend	5.8% – 30.8%	Not Hazardous
Water	69.2% – 94.2%	Not Hazardous

Volatile organic compound (VOC) levels for this product are < = 5g/l.

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW PHYSICAL APPEARANCE:	HAZARD SUMMARY: <u>CAUTION!</u>
Form: Liquid Color: White, Milky Odor: Acrylic	Inhalation of vapor or mist can cause headache, nausea and irritation of the nose, throat, and lungs. May cause eye and skin irritation

Potential Health Effects Primary Routes of Entry:
Inhalation, Eye contact, Skin contact
Eyes: Direct contact with material can cause the following: slight irritation
Skin: Prolonged or repeated skin contact can cause the following: slight irritation
Inhalation: Inhalation of vapor or mist can cause the following: irritation of nose, throat, and lungs headache nausea

4. FIRST AID MEASURES

- Inhalation: Move to fresh air.
- Skin contact: Wash with water and soap as a precaution. If skin irritation persists, call a physician.
- Eye contact: Rinse with plenty of water. If eye irritation persists, consult a specialist.
- Ingestion: Drink 1 or 2 glasses of water. Consult a physician if needed.
- Never give anything by mouth to an unconscious person.

5. FIRE FIGHTING MEASURES

- Flash point: Noncombustible
- Lower explosion limit: Not Applicable
- Upper explosion limit: Not Applicable
- Thermal decomposition: May yield acrylic monomers.
- Suitable extinguishing media: Media appropriate for surrounding fire.
- Specific hazards during fire fighting: Material can splatter above 100C/212F. Dried product can burn.
- Special protective equipment for fire-fighters: Wear self-contained breathing apparatus and protective suit.

6. ACCIDENTAL RELEASE MEASURES

PERSONAL PRECAUTIONS

Use personal protective equipment.
Keep people away from and upwind of spill/leak.
Material can create slippery conditions.

ENVIRONMENTAL PRECAUTIONS

Keep spills and cleaning runoff out of municipal sewers and open bodies of water.

METHODS FOR CLEANING UP

Contain spills immediately with inert materials (e.g., sand, earth). Transfer liquids and solid diking material to separate suitable containers for recovery or disposal.

7. HANDLING & STORAGE

HANDLING

Avoid contact with eyes, skin and clothing. Wash thoroughly after handling. Keep container tightly closed. Do not breathe vapors, mist or gas. Further information on storage conditions: Keep from freezing - product stability may be affected. Stir well before use.

STORAGE

Storage temperature: 40 - 90 °F (4.44 - 32.2 °C)
Other data: Monomer vapors can be evolved when material is heated during processing operations. See SECTION 8, for types of ventilation required. NOTE: Formaldehyde will be generated under acidic conditions. Maintain adequate ventilation under these conditions to prevent exposure to formaldehyde above the Rohm and Haas Co. recommended ceiling of 0.3 ppm.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

EXPOSURE LIMIT(S)

Exposure limits are listed below, if they exist.

COMPONENTS	REGULATION	LISTING TYPE	VALUE
---------------------------------- Not Applicable ----------------------------------			

EYE PROTECTION: Safety glasses with side-shields Eye protection worn must be compatible with respiratory protection system employed.

HAND PROTECTION: The glove(s) listed below may provide protection against permeation. (Gloves of other chemically resistant materials may not provide adequate protection): Neoprene gloves published by the American Conference of Governmental Industrial Hygienists for information on the design, installation, use, and maintenance of exhaust systems.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION (CONTINUED)

RESPIRATORY PROTECTION: A respiratory protection program meeting OSHA 1910.134 and ANSI Z88.2 requirements or equivalent must be followed whenever workplace conditions warrant a respirator's use. None required if airborne concentrations are maintained below the exposure limit listed in Exposure Limit Information. For airborne concentrations up to 10 times the exposure limit, wear a properly fitted NIOSH approved (or equivalent) half-mask, air-purifying respirator. Air-purifying respirators should be equipped with NIOSH approved (or equivalent) N95 filters. If oil mist is present, use R95 or P95 filters.

PROTECTIVE MEASURES: Facilities storing or utilizing this material should be equipped with an eyewash facility.

ENGINEERING MEASURES: Use local exhaust ventilation with a minimum capture velocity of 100 ft/min. (0.5 m/sec.) at the point of vapor evolution. Refer to the current edition of Industrial Ventilation: A Manual of Recommended Practice published by the American Conference of Governmental Industrial Hygienists for information on the design, installation, use, and maintenance of exhaust systems.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE
Form: liquid
Colour: white milky
Odor: acrylic

COMPONENT	VALUE
pH	7.0 - 9.0
Boiling point/boiling range	100 °C (212.00 °F) Water
Melting point/range	0 °C (32 °F)
Flash point	Noncombustible
Lower explosion limit	Not Applicable
Upper explosion limit	Not Applicable
Vapour pressure	17.0 mmHg at 20 °C (68.00 °F) Water
Relative vapour density	<1.0 Water
Water solubility	Miscible
Relative density	1.00 - 1.20
Viscosity, dynamic	250.000 mPa.s maximum
Evaporation rate	<1.00 Water
Percent volatility	49 - 51 % Water
Volatile organic compounds (VOC)	<= 5 g/L

NOTE: The physical data presented above are typical values and should not be construed as a specification.

10. STABILITY & REACTIVITY

Hazardous reactions	None known. Stable
Materials to avoid	There are no known materials which are incompatible with this product.
Polymerization	Product will not undergo polymerization.

11. TOXICOLOGICAL INFORMATION

No data are available for this material. The information shown is based on profiles of compositionally similar materials.

Acute oral toxicity	LD50 rat > 5,000 mg/kg
Acute dermal toxicity	LD50 rabbit > 5,000 mg/kg
Skin irritation	rabbit May cause transient irritation.
Eye irritation	rabbit No eye irritation

12. ECOLOGICAL INFORMATION

THERE IS NO DATA AVAILABLE FOR THIS PRODUCT.

13. DISPOSAL CONSIDERATIONS

ENVIRONMENTAL PRECAUTIONS

Keep spills and cleaning runoff out of municipal sewers and open bodies of water. **DISPOSAL WASTE CLASSIFICATION:** When a decision is made to discard this material as supplied, it does not meet RCRA's characteristic definition of ignitability, corrosivity, or reactivity, and is not listed in 40 CFR 261.33. The toxicity characteristic (TC), however, has not been evaluated by the Toxicity Characteristic Leaching Procedure (TCLP). Coagulate the emulsion by the stepwise addition of ferric chloride and lime. Remove the clear supernatant and flush to a chemical sewer. For disposal, incinerate or landfill at a permitted facility in accordance with local, state, and federal regulations.

14. TRANSPORT INFORMATION

DOT	Not regulated for transport
IMO/IMDG	Not regulated (Not hazardous)

15. REGULATORY INFORMATION

WORKPLACE CLASSIFICATION	This product is considered non-hazardous under the OSHA Hazard Communication Standard (29CFR1910.1200). This product is not a 'controlled product' under the Canadian Workplace Hazardous Materials Information System (WHMIS).
SARA TITLE III: SECTION 311/312 CATEGORIZATIONS (40CFR370):	This product is not a hazardous chemical under 29CFR 1910.1200, and therefore is not covered by Title III of SARA.
SARA TITLE III: SECTION 313 INFORMATION (40CFR372)	This product does not contain a chemical which is listed in Section 313 at or above de minimis concentrations.
CERCLA INFORMATION (40CFR302.4)	Releases of this material to air, land, or water are not reportable to the National Response Center under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or to state and local emergency planning committees under the Superfund Amendments and Reauthorization Act (SARA) Title III Section 304.

15. REGULATORY INFORMATION (CONTINUED)

US. TOXIC SUBSTANCES CONTROL ACT (TSCA):	All components of this product are in compliance with the inventory listing requirements of the U.S. Toxic Substances Control Act (TSCA) Chemical Substance Inventory.
PENNSYLVANIA	Any material listed as "Not Hazardous" in the CAS REG NO. column of SECTION 2, Composition/Information On Ingredients, of this MSDS is a trade secret under the provisions of the Pennsylvania Worker and Community Right-to-Know Act.

16. OTHER INFORMATION

HAZARD RATING:

	HEALTH	**FIRE**	**REACTIVITY**
HMIS	**1**	**0**	**0**

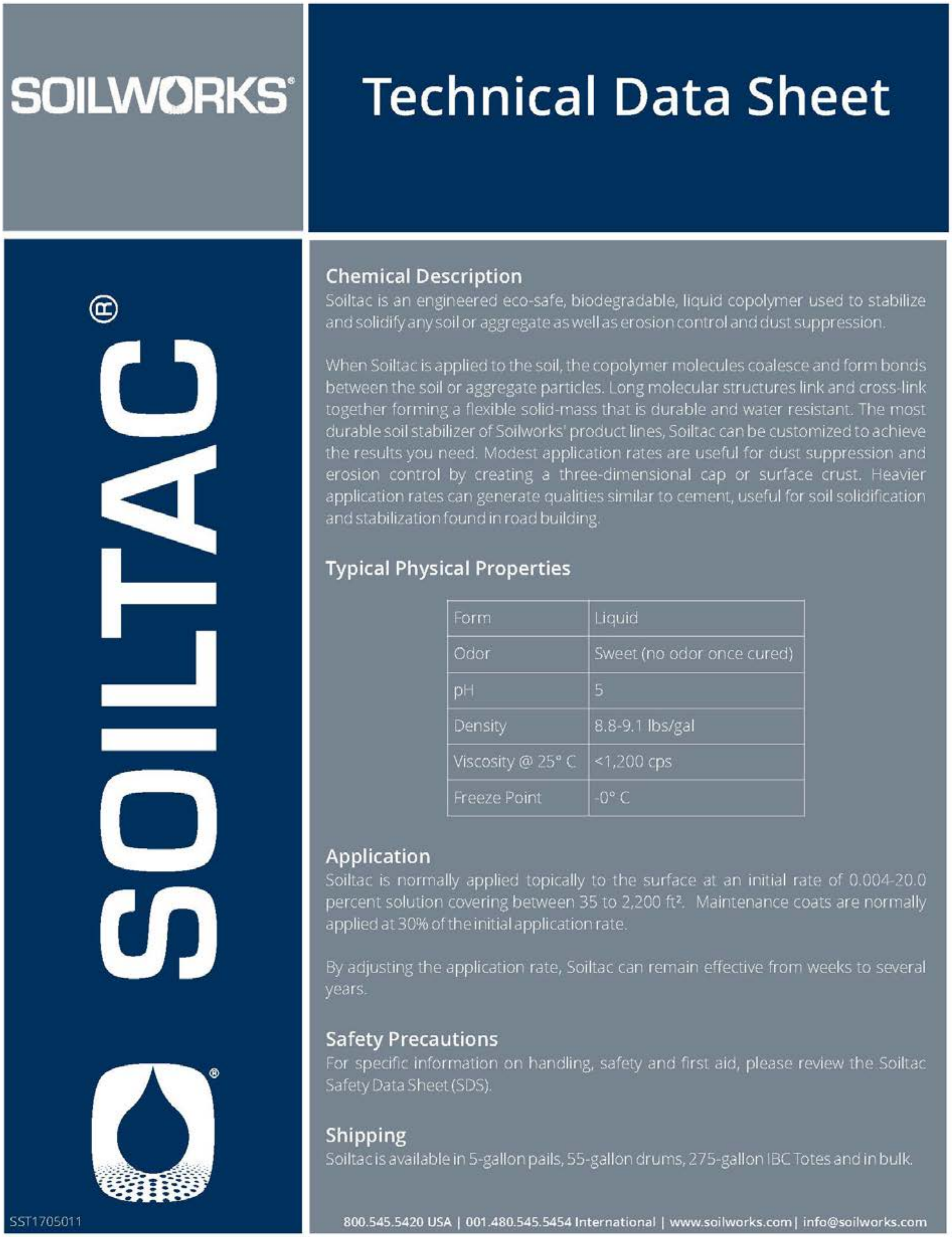
LEGEND

ACGIH	American Conference of Governmental Industrial Hygienists
BAC	Butyl acetate
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
STEL	Short Term Exposure Limit (STEL)
TLV	Threshold Limit Value
TWA	Time Weighted Average (TWA)
"|"	Bar denotes a revision from prior SDS

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication.

The information given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification.

The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.



SOILWORKS®

Technical Data Sheet

SOILTAC®

Chemical Description

Soiltac is an engineered eco-safe, biodegradable, liquid copolymer used to stabilize and solidify any soil or aggregate as well as erosion control and dust suppression.

When Soiltac is applied to the soil, the copolymer molecules coalesce and form bonds between the soil or aggregate particles. Long molecular structures link and cross-link together forming a flexible solid-mass that is durable and water resistant. The most durable soil stabilizer of Soilworks' product lines, Soiltac can be customized to achieve the results you need. Modest application rates are useful for dust suppression and erosion control by creating a three-dimensional cap or surface crust. Heavier application rates can generate qualities similar to cement, useful for soil solidification and stabilization found in road building.

Typical Physical Properties

Form	Liquid
Odor	Sweet (no odor once cured)
pH	5
Density	8.8-9.1 lbs/gal
Viscosity @ 25° C	<1,200 cps
Freeze Point	-0° C

Application

Soiltac is normally applied topically to the surface at an initial rate of 0.004-20.0 percent solution covering between 35 to 2,200 ft^2. Maintenance coats are normally applied at 30% of the initial application rate.

By adjusting the application rate, Soiltac can remain effective from weeks to several years.

Safety Precautions

For specific information on handling, safety and first aid, please review the Soiltac Safety Data Sheet (SDS).

Shipping

Soiltac is available in 5-gallon pails, 55-gallon drums, 275-gallon IBC Totes and in bulk.

SST1705011

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