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Oregon TECH

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Final Report

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by

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16. Abstract

A procedure has been developed for implementing a topically applied Mt. Mazama volcanic ash trail surface amendment for improving trail firmness and stability. This project involved implementation of previously conducted Mt. Mazama volcanic research by applying a Mazama Ash and Portland Cement solution over a 0.2-mile section of the Geo Trail at the Oregon Institute of Technology Klamath Falls campus. Testing was performed to verify ideal Ash-to-Cement-to-Water ratios. A procedure was developed and applied for batching and mixing the dry materials on-site, spreading and integrating the dry material with the existing trail surface, and wetting and compacting the surface. After the pilot application, visual inconsistencies were observed in the treated trail surface. Firmness and stability were measured at different locations along the treated trail surface and on the untreated surface with a rotational penetrometer apparatus. Roughness was quantified using a modified Wheelchair Pathway Roughness Index at different locations along the treated rail surface and on the untreated surface. At each of the testing locations on the treated surface, stability was shown to have improved, firmness was relatively consistent, and the ability to roll an occupied wheelchair without rutting was markedly improved.

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EXECUTIVE SUMMARY

A procedure has been developed for implementing a topically applied Mt. Mazama volcanic ash trail surface amendment for improving trail firmness and stability. This project involved implementation of previously conducted Mt. Mazama volcanic research by applying a Mazama Ash and Portland Cement solution over a 0.2-mile section of the Geo Trail at the Oregon Institute of Technology Klamath Falls campus. Testing was performed to verify ideal Ash-to-Cement-to-Water ratios. A procedure was developed and applied for batching and mixing the dry materials on-site, spreading and integrating the dry material with the existing trail surface, and wetting and compacting the surface. After the pilot application, visual inconsistencies were observed in the treated trail surface. Firmness and stability were measured at different locations along the treated trail surface and on the untreated surface with a rotational penetrometer apparatus. Roughness was quantified using a modified Wheelchair Pathway Roughness Index at different locations along the treated trail surface and on the untreated surface. At each of the testing locations on the treated surface, stability was shown to have improved, firmness was relatively consistent, and the ability to roll an occupied wheelchair without rutting was markedly improved.

1.0 INTRODUCTION

This report documents the continuation of work performed in earlier projects: NITC-RR-1075, The Use of Mt. Mazama Volcanic Ash as Natural Pozzolans for Sustainable Soil and Unpaved Road Improvement (Sleep and Masley, 2018), and NITC-RR-1131, ADA Accessible Trail Improvement with Naturally Occurring, Sustainable Materials (Sleep and Matzen, 2020). Through these previous works, it was demonstrated 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 pozzolan and replacement for Portland cement. Additionally, an extensive laboratory and field program was conducted which indicated that firmness and stability of trails could be improved with the use of Mt. Mazama ash applied topically to improve the accessibility of unpaved recreational trail surfaces.

The work reported here aimed to translate research to practice by expanding upon previous Mt. Mazama volcanic ash research to implement a large-scale trail resurfacing pilot study, as previous work had only conducted testing on small areas. This report details a field program in which a procedure was developed to apply a Mt. Mazama volcanic ash treatment over a 0.2-mile section of the Geo Trail on the Oregon Institution of Technology Klamath Falls campus. First, testing was conducted to verify ideal mixture ratios of Mt. Mazama volcanic ash, Portland cement, and water. Next, a process for on-site batching of materials was developed. It was determined that the most effective method of application involved mixing the dry materials in the proper ratio (1 cement:3 ash), integrating with the existing trail surface, and smoothing. The final step in the application process was to wet and then compact the surface. After application, three treated locations and one untreated location along the trail were chosen to measure firmness, stability, and roughness. Firmness and stability were measured using a Beneficial Designs rotational penetrometer and roughness was measured using a modified Wheelchair Pathway Roughness Index (WPRI).

2.0 BACKGROUND (& PROBLEMS ADDRESSED)

2.1 SURFACE TREATMENTS FOR TRAIL ACCESSIBILITY

The Americans with Disabilities Act (ADA), Section 403.5.1 provides clear guidance for outdoor trail dimensions that include running slopes, cross slopes, trail widths, flat resting areas, and distances between resting areas. Many additional organizations provide dimension guidance that generally originates from these ADA recommendations, though there is occasional variation in these recommendations. In addition to dimension characteristics, design guidelines uniformly require trail surfaces to be “firm and stable,” but there is a lack of guidance that defines the meaning of these terms. ASTM F1951 was developed to allow for direct guidance towards characterizing playground surfaces as firm and stable, but it is limited in application as it requires direct comparison of the effort required to push a wheelchair across the playground surface to the effort required to push a wheelchair up a 1:14 (7%) slope. The necessity of the 1:14 ramp means that ASTM F1951 is not portable. Thus, Beneficial Designs created the rotational penetrometer to measure firmness and stability by simulating a wheelchair wheel and measuring deformation of the surface. Firmness is quantified by the amount the wheel deforms the surface, while stability takes into account deformation as the wheel is rotated on the surface. In each case, the more deformation is registered the worse the performance.

Surface roughness is also a factor for wheelchair users. Even paved surfaces with periodic seams can be uncomfortable due to excessive vibrations. Thus, ASTM E3028 was created to quantify surface roughness similar to traditional pavements on roadways. The WPRI represents the total vertical deflection of a standard wheel traveling over a surface. The WPRI ranges from 0 in/ft (very good) to 1 in/ft (fair) to greater than 2 in/ft (impassible), and requires laser sensing to produce the requisite resolution of vertical deviations along a longitudinal profile used for its computation.

The National Trail Surfaces Study was conducted by the National Center for Accessibility to investigate natural firm and stable surface alternatives when creating accessible pedestrian trails, including crushed stones, packed soil, and other natural material (Montembeault and York, 2014). The longitudinal study evaluated 11 different trail surface materials and their ability to meet firmness and stability requirements. The overarching conclusion of the study is that trails composed of soil/aggregate surfaces can be maintained as firm and stable surfaces.

A number of trail surfaces evaluated in the National Trail Surfaces Study involve “soil stabilizers,” which are products that are either applied topically or mixed into soils or aggregates as binding agents. Soil stabilizers are often “green” products that occur from natural byproducts such as volcanic ash and coal fly ash. Mt. Mazama volcanic ash is a naturally occurring material in the Pacific Northwest formed from the eruption of Mt. Mazama. Sleep and Matzen (2020) demonstrated the potential for Mt. Mazama volcanic ash to be used as a trail surface amendment that improves trail firmness and stability.

2.2 SCALING UP PREVIOUS WORK

Small test patches of a variety of commercial and ash-cement mix surface treatments were applied in the field by Sleep and Matzen . Both strength activity in laboratory specimens and promising improvements to firmness and stability in the field were demonstrated with mixes of 50:50 cement to ash. The previous work noted that pulverizing the larger particles of ash was necessary to ensure activation. The current project avoided this energy intensive processing by working with raw ash and assuming only the finest material would activate, leading to a mix that requires more ash and less cement.

Sleep and Matzen had applied treatments as a slurry with a portable sprayer and experienced clogging that made this process impractical. Both slurry application and dry mixing processes have been employed in cement-modified soil applications used to improve the strength of roadway subgrades when they are incapable of supporting desired loads. The current project employed an approach using dry mixing and placement, given the need to minimize equipment for a recreational trail application and the relative ease of moving dry materials, mixing in place, and wetting by hand.

3.0 METHODOLOGY

3.1 MATERIAL COLLECTED

Mt. Mazama ash was obtained from a commercial pumice mining operation that extracts volcanic ash material from a local source. The ash source is located in southern Oregon approximately 15 miles northeast of Crater Lake National Park, where Mt. Mazama erupted, as shown in Figure 3.1. The material was obtained in raw form and had not been characterized or processed.

Figure 3.1: Source of Mt. Mazama ash deposits northeast of Crater Lake.

3.2 MATERIAL CHARACTERIZATION AND MIX DESIGN

The raw ash material needed to be characterized to compare it to the ash used in prior research. Significant effort was made in the past research to process the ash by either crushing or sieving to ensure fineness of particles to meet the ASTM Class N Pozzolan standard, which requires that at least 66% of the material pass the washed #325 sieve. In the current work, various approaches to address material fineness were explored by teams of first-year engineering students. Bulk sieving processes at various finenesses were attempted in the lab and mortar cubes were tested. Ultimately, given the challenges in terms of labor, equipment and time, bulk processing of the raw ash was discarded in favor of batching the treatment mix with unprocessed raw material. Prior research had identified a 50:50 ratio for cement and pozzolan to ensure adequate strengthening of mortar cubes. An assumption was made that the very fine material passing the #325 washed sieve (approximately 1/3 by volume) would behave as a pozzolan, while the larger material (approximately 2/3 by volume) would behave as inert aggregate in the mix (Figure 3.2). On this basis, the treatment mix was batched with a cement:raw ash ratio of 1:3. This mix proved functional in multiple small test patches, including on a section of the Geo Trail, prior to the trail workday.

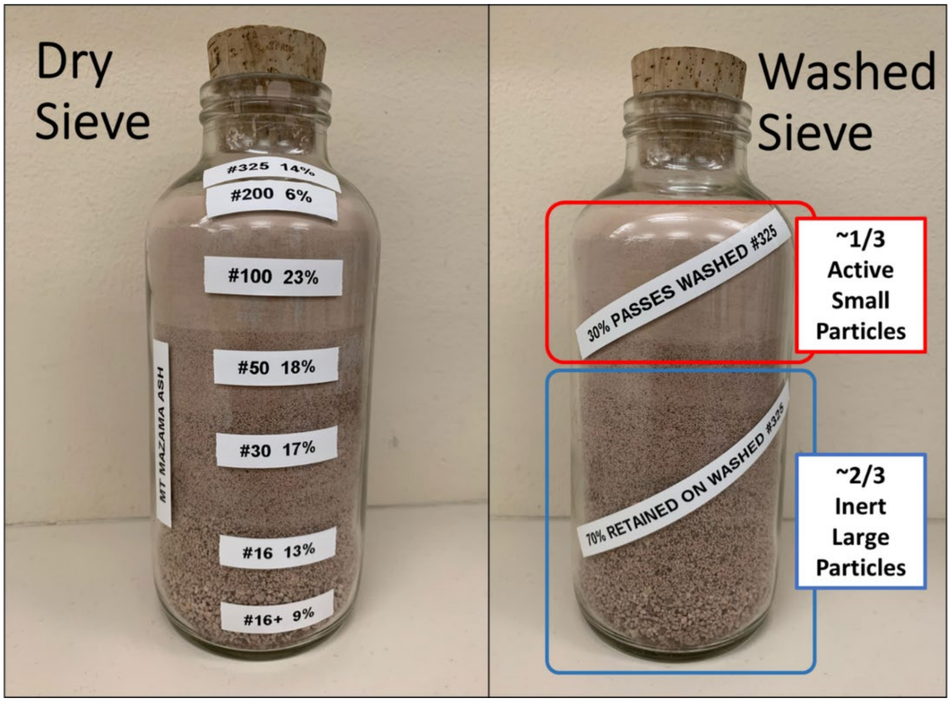

Figure 3.2: Gradation of ash from dry sieve and washed sieve processing.

3.3 SURFACE APPLICATION

Surface application took place in five distinct phases: (1) material mixing, (2) material placement, (3) wetting, (4) compacting, and (5) curing. Each of these steps is indicated in Figure 3.3. A staging area was set up at the beginning of the stretch of trail and used to stockpile and prepare materials. Materials were transported from the staging area to various locations on the trail such that these construction phases could take place in parallel with one another.

First, dry Mt. Mazama volcanic ash was mixed with Portland cement in an ash:cement volumetric ratio of 1:3. For ease of procedure, volumes were not determined precisely; uniform shovels were used to obtain material quantities and visual observation was used to ensure that scoops remained similar in size. Material was added directly to the trough of a narrow track loader and then mixed in an attempt to distribute particles throughout the mixture as evenly as possible.

Next, the narrow track loader was used to transport dry materials to the far end of the trail for application. Material was unloaded directly onto the trail by the loader and then manually spread along the trail surface with rakes. Care was taken to apply the surface evenly and to integrate the ash/cement mixture with the existing trail surface aggregate and soil to a depth determined by the depth of easily loosened material.

Figure 3.3: Process for applying Mt. Mazama ash treatment to trail surface.

Once the trail surface was evenly covered with dry materials, it was wetted to activate cementitious and pozzolanic activity. In this trial, watering cans were used to moisten the dry material. The wetting process was additionally aided by precipitation that occurred during the application period. Thus, while care was taken to distribute water as evenly as possible, there were variations in the level of moisture applied at different locations along the trail surface.

After the surface was sufficiently moistened, a plate compacter was used to compact the surface. A uniform number of passes was taken with the plate compactor across the surface to compact materials as evenly as possible, and water was added to areas that appeared overly dry. The completed trail surface is shown in Figure 3.4.

Finally, the surface was left to cure. In this pilot study, trail access was not restricted after implementation. The trail surface was immediately open to traffic, although trail use was minimal. Ultimately, approximately 0.2 miles of trail were resurfaced over the span of eight hours with 15 workers. Approximately 4 cubic yards of Mt. Mazama volcanic ash, 1.3 cubic yards of Portland cement, and 1 cubic yard of water were used. Equipment used included a narrow-track front-end loader, shovels, rakes, watering cans, and a plate compactor. Roughly 32 feet of 4.5-foot-wide trail was treated with a single bucket load (4.3 cubic feet) of dry material, which equates to an average 0.36-inch depth of dry material placed, or 0.3 cubic feet of dry material per square foot of trail.

Figure 3.4: Completed trail surface.

3.4 SURFACE TESTING

The treated and untreated trail surfaces were investigated in terms of firmness and stability, roughness, and qualitative performance. The trail was observed over the course of four months.

3.4.1 Firmness and Stability

A rotational penetrometer produced by Beneficial Designs was used in prior research to quantify the firmness and stability of the trail surface as a way of measuring improvement. The prior research had shown minor improvements in firmness and stability in treated surfaces (Sleep and Matzen, 2020). The prior research used a slurry approach rather than the dry mixing, wetting, and compacting of the current work. The latter approach allowed for more thorough mixing with existing trail material and a treatment that could be tailored to looser or more compacted material as it was encountered. Because the treated surface varied considerably, firmness and stability were tested in multiple locations where the surface was either smooth, inconsistent, or still loose with less apparent binding of the topmost material. The testing process is depicted in Figure 3.5, photographs of the different surfaces in Figure 3.6, and the results of the testing in Figure 3.7. While the firmness of each surface tested falls within the bounds to be considered firm, it is clear that stability is substantially improved when surface material is more effectively bound with an ash-cement binder.

Figure 3.5: Testing with the Beneficial Designs rotational penetrometer.

Figure 3.6: Treated surfaces (left to right: smooth, inconsistent, loose) and untreated surface (far right).

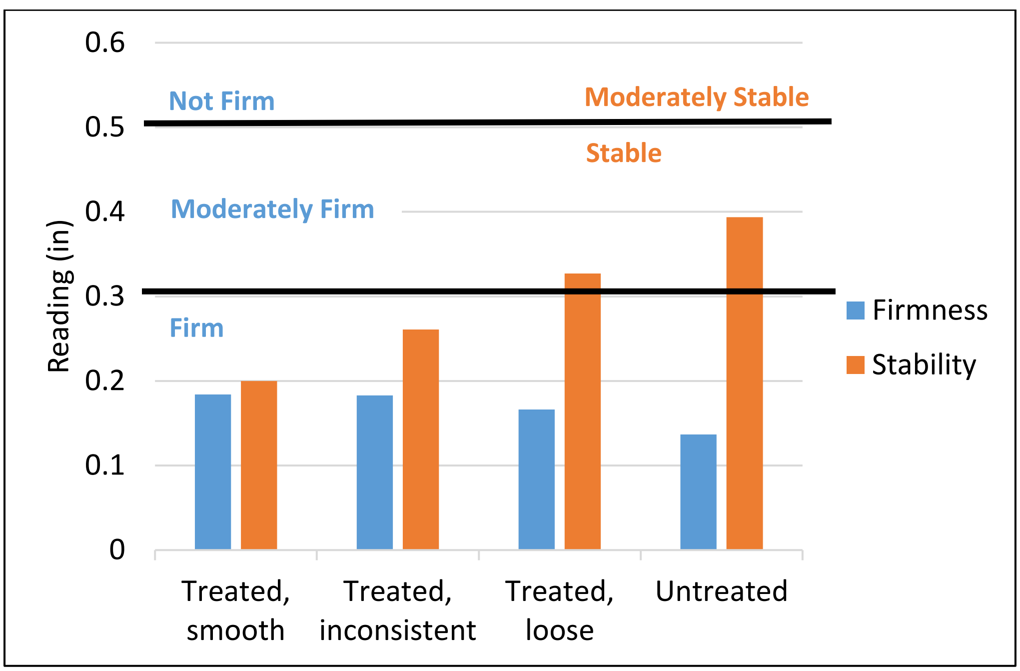

Figure 3.7: Firmness and stability measurements for treated and untreated trail sections.

3.4.2 Roughness

Profile measurements were taken manually in an attempt to approximate the WPRI. The results of these measurements are listed in Appendix A: Surface Roughness measurements. Figure 7.1 shows the data collection setup, Figure 7.2 shows the results in graphical format, and Table 7.1 provides the raw data. These measurements indicated that the untreated surface is already relatively smooth but, because it is also softer, the experience of moving a small-wheeled vehicle across the surface is more challenging. The treated surface has the potential to be smoother depending primarily on the wetness of the material during compaction, but roughness can also be exacerbated if care is not taken in finishing the surface or if the material is overly dry and inconsistent.

3.4.3 Wheelchair Qualitative Performance

The qualitative performance of pushing an occupied wheelchair across both the untreated and treated surfaces is significantly improved. The team considered ways of quantifying this improvement. While firmness, stability, and roughness are all relevant and quantifiable characteristics, they do not quite capture the experience of pushing a wheelchair. The best measure of this change is the effort required to push the wheel-chair and the significance of rutting left after the wheelchair has passed. Figure 3.8 demonstrates the rutting that occurs in the unbound aggregate of the untreated trail surface. No such rutting is experienced on any of the treated surfaces, whether smooth, inconsistent or rough.

Figure 3.8: Wheelchair rutting performance on the untreated and treated surfaces.

4.0 RESULTS

Results of this study include recommendations for large-scale application of a Mt. Mazama volcanic ash-amended trail surface, limitations and ideal conditions of applicability, a comparison with alternative surfaces, and recommended future work.

The mixture recommendations tested herein include a 1:3 Mt. Mazama ash:Portland cement ratio. It is recommended to mix the ash and cement in a dry state, spread evenly and integrate with the existing trail surface, and then add enough water to sufficiently moisten the trail. While moist, the trail should be uniformly compacted and then left to cure. Ideally, trail access would be limited for up to a month during the curing phase so that the trail surface can gain strength before it is subjected to potentially damaging traffic.

It should be noted that the Mt. Mazama ash surface is likely to perform differently in different locations. Different existing trail conditions may affect the ability of the Mt. Mazama ash amendment to integrate. The existing trail surface should already be relatively firm and stable, but loose enough to integrate the ash-cement binder. If existing aggregates are either too small or too large, the Mazama ash solution may not bind sufficiently. If conditions are similar to those in this pilot study, improvements in firmness, stability, and roughness can be expected. Long-term observations of the trail in this pilot study should reveal more information about the degree and frequency of maintenance required.

Technology transfer of this work involves continued interactions with project partners and entities of interest. The commercial ash supplier has an interest in better understanding the applicability of their material for similar use. Local entities such as The City of Klamath Falls, the local hospital system, trail managers, and multiple assisted living facilities, have shown interest in the development of this work; thus, there remain continued efforts to disseminate the results of this study to those partners.

5.0 CONCLUSION

This project successfully developed a topically applied Mt. Mazama volcanic ash trail surface amendment for improving trail firmness and stability. Testing was performed to verify effective and practical batching ratios. A procedure was developed and applied for batching and mixing the dry materials on-site, spreading and integrating the dry material into the trail surface, and wetting and compacting the surface. A 0.2-mile section of the Geo Trail at the Oregon Institute of Technology Klamath Falls campus was treated and tested to measure changes to firmness and stability using a rotational wheel penetrometer. After the pilot application, visual inconsistencies were observed in the treated trail surface. Roughness was quantified using a modified Wheelchair Pathway Roughness Index at different locations along the treated trail surface and on the untreated surface. At each of the testing locations on the treated surface, stability was shown to have improved, firmness was relatively consistent, and the ability to roll an occupied wheelchair without rutting was markedly improved. An ash-cement amendment was ultimately shown to improve the wheelchair accessibility of a trail surface initially composed of a loose gravel and native soil surface.

6.0 REFERENCES

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Sleep, M. D., and M.B. Masley. The use of Mt. Mazama volcanic ash as natural pozzolans for sustainable soil and unpaved road improvement. National Institute for Transportation and Communities, Portland State University. 2018.

Sleep, M. D., and D.K. Matzen. Mount Mazama Ash Offers Sustainable Solution for ADA Accessibility on Unpaved Trails. National Institute for Transportation and Communities, Portland State University. 2020.

7.0 APPENDICES

APPENDIX A

SURFACE ROUGHNESS MEASUREMENTS

Figure 7.1: Roughness profile measurement setup: vertical distances between the level and the ground were measured at 10 cm increments.

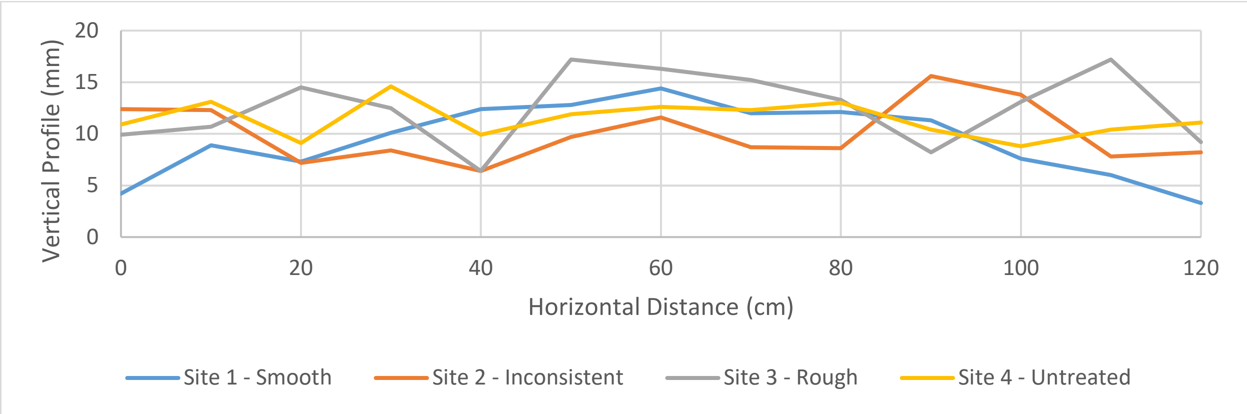

Figure 7.2: Vertical profile measurements along smooth, inconsistent, and rough treated surfaces and untreated surface

Table 7.1: Raw roughness profile measurement data

	Deflection (mm)			
Distance (cm)	Site 1 - Smooth	Site 2 - Inconsistent	Site 3 - Rough	Site 4 - Untreated
0	4.2	12.4	9.9	10.9
10	8.9	12.3	10.7	13.1
20	7.3	7.2	14.5	9.1
30	10.1	8.4	12.5	14.6
40	12.4	6.4	6.4	9.9
50	12.8	9.7	17.2	11.9
60	14.4	11.6	16.3	12.6
70	12	8.7	15.2	12.3
80	12.1	8.6	13.3	13
90	11.3	15.6	8.2	10.4
100	7.6	13.8	13.1	8.8
110	6	7.8	17.2	10.4
120	3.3	8.2	9.2	11.1