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Concrete Design using Native Materials from the Navajo Nation

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16. Abstract
This project investigates the use of volcanic aggregates from the El Malpais region near the Navajo Nation to optimize concrete mix designs for Jointed plain concrete pavements (JPCP). The goal is to reduce reliance on conventional aggregates, minimize adverse impacts, and promote local economic growth. By utilizing locally sourced materials, the study supports responsible development and preserves the Navajo Nation's cultural heritage. The research includes testing the mechanical properties of volcanic aggregate-based concrete, such as compressive strength, particle size distribution, and durability. Results show compressive strength ranging from 2400 to 2930 psi, but further optimization is needed to meet the American Concrete Institute (ACI) guideline standard of 4000–6000 psi for JPCP applications. Beyond technical analysis, the project emphasizes community engagement through workshops and training for local contractors and students, focusing on the benefits and proper use of volcanic aggregates. Long-term monitoring of pavements will evaluate durability and cost-effectiveness. This initiative supports economic development by reducing material transportation costs, empowering the Navajo Nation, with potential for other communities, and promoting responsible construction practices, contributing to resilient infrastructure suited to a community's needs.

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CONCRETE DESIGN USING NATIVE MATERIALS FROM THE NAVAJO NATION

FINAL REPORT
SPTC Project Number: CY1-NTU-01

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List of Abbreviations and Acronyms

DOT .... Department of Transportation
FHWA .... Federal Highway Administration
NTL .... National Transportation Library
ROSA P .... Repository & Open Science Access Portal
JPCP .... Jointed Plain Concrete Pavement

Executive Summary

This project focuses on the use of volcanic aggregates sourced from the El Malpais region near the Navajo Nation to optimize concrete mix designs for jointed plain concrete pavements (JPCP). The initiative aims to reduce reliance on conventional aggregates, minimize adverse impacts, and promote economic growth within the local community. By leveraging locally available materials, this study aligns with development goals while preserving the cultural heritage of the Navajo Nation.

The research involves a systematic evaluation of volcanic aggregates' suitability in concrete applications, including comprehensive testing of mechanical properties such as compressive strength, particle size distribution, and durability. The results indicate that while the average compressive strength of the volcanic aggregate-based concrete ranges between 2400 and 2930 psi, further optimization is required to meet the recommended standards for JPCP applications, typically 4000–6000 psi as per ACI guidelines.

In addition to technical analysis, the project emphasizes technology transfer and community engagement. Workshops and training sessions will be conducted to educate local contractors, construction workers, and students about the benefits and proper use of volcanic aggregates.

Long-term monitoring of constructed pavements will validate the mix's performance under real world conditions, ensuring durability and cost-effectiveness.

The project's broader impact includes fostering economic development by reducing material transportation costs, empowering the Navajo Nation through the use of its natural resources, and promoting responsible construction practices. By integrating local materials into infrastructure projects, this initiative represents a step forward in achieving resilient infrastructure tailored to the needs of the community.

Chapter 1. Introduction

Concrete is a fundamental material in modern construction, valued for its strength, durability, and versatility. However, the production and sourcing of conventional aggregates used in concrete can have significant communal impacts. In regions like the Navajo Nation, incorporating local resources into construction practices offers a viable alternative while supporting the community's economic and cultural goals.

This project explores the use of volcanic rocks and sands from the El Malpais area as fine aggregates in jointed plain concrete pavements (JPCP). By utilizing these locally sourced materials, the study aims to reduce reliance on conventional aggregates, minimize the adverse impacts associated with concrete production, and promote responsible development. Additionally, this initiative empowers the Navajo Nation, and has potential for other communities, by fostering local economic growth and preserving natural resources within the community.

The research focuses on evaluating the mechanical properties of concrete that incorporates locally available fine aggregates having varying particle size distributions. The findings provide insights into the feasibility and performance of volcanic materials in concrete applications and their potential to enhance durability in construction practices. This study represents a step toward integrating these types of engineering solutions into context sensitive scenarios.

Chapter 2. Literature Review

Concrete production is a resource-intensive process that consumes significant quantities of natural aggregates, leading to resource depletion. Studies such as Mehta (2001) [1] highlight the importance of adopting better practices in concrete production by incorporating alternative materials, including industrial by-products and locally sourced aggregates. Utilizing volcanic materials aligns with these goals, offering a renewable and regionally abundant resource that reduces the adverse impacts associated with construction.

Volcanic rocks and sands have been studied extensively for their potential use in concrete. Research by Korkanç et al. (2015)[2] demonstrates that volcanic aggregates can enhance certain mechanical properties, such as compressive strength, durability, and resistance to chemical attack, depending on their mineralogical composition and particle size distribution. Furthermore, the porous nature of some volcanic materials can improve concrete's thermal insulation and energy absorption properties, which is particularly beneficial for pavements in temperature-variable regions.

JPCP are widely used for road construction due to their simplicity, cost-effectiveness, and longevity. However, the performance of JPCP relies heavily on the quality of aggregates used in the concrete mix. Research by Shatnawi et al. (2009) [3] emphasizes the need for durable, high-strength materials in JPCP to withstand repeated loading and environmental stressors. Incorporating volcanic aggregates into JPCP presents a unique opportunity to meet these demands while reducing the adverse impacts of aggregate extraction.

The use of local resources in construction can have significant benefits. Empowering communities by utilizing their natural resources fosters economic development and reduces material transportation costs [4]. The Navajo Nation's rich volcanic landscape provides an untapped resource that could transform local construction practices and stimulate economic activity within the community.

The particle size distribution of fine aggregates plays a critical role in determining the workability, strength, and durability of concrete. Studies by Neville (2011) and Mamlouk & Zaniewski (2017)[5] highlight that an optimized gradation of aggregates can enhance the packing density, reduce void content, and improve the overall performance of concrete. Evaluating the particle size distribution of volcanic sands from the El Malpais area is, therefore, crucial to understanding their suitability for use in JPCP applications.

Chapter 3. Materials and Methodologies

3.1 Materials:

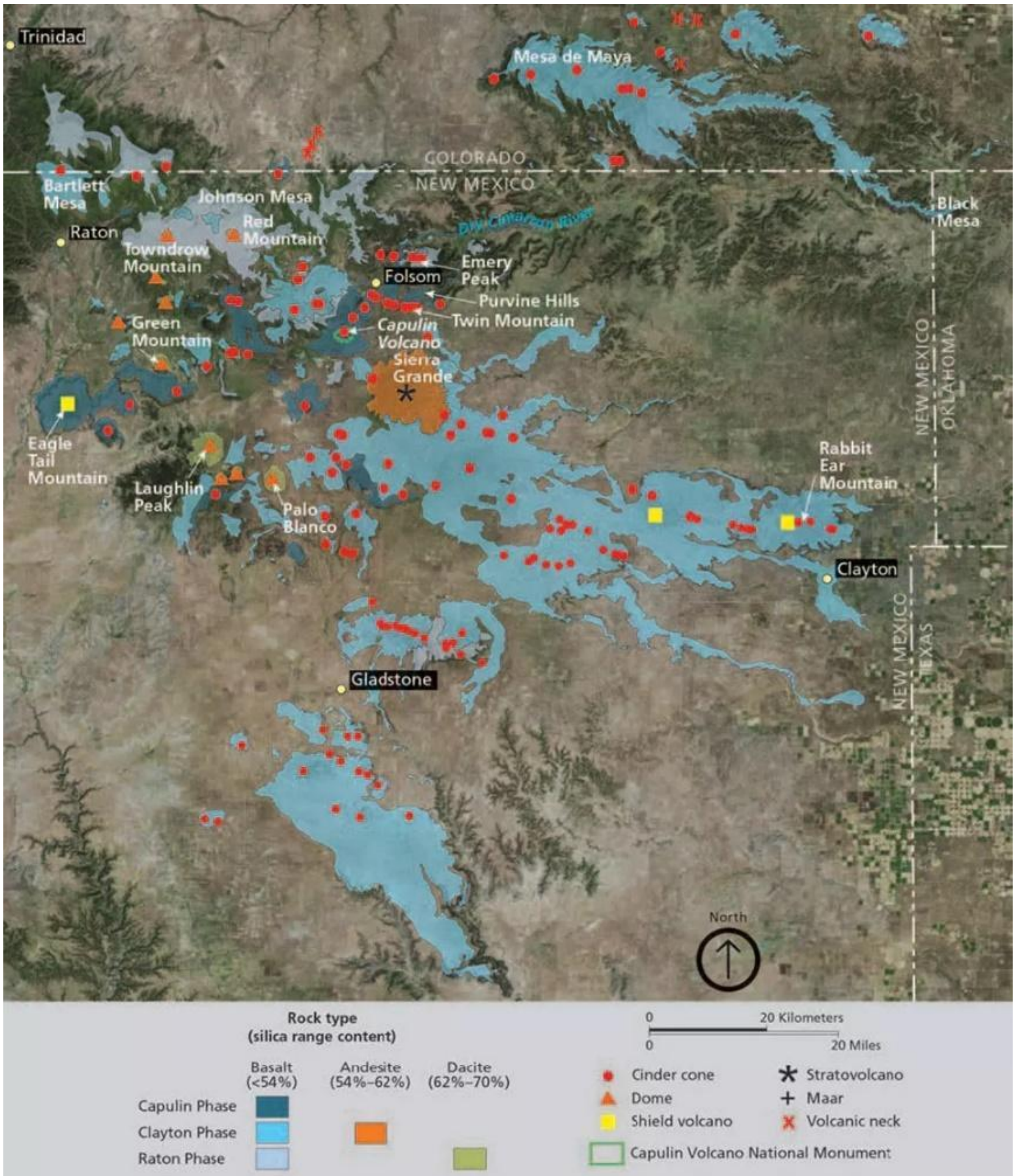
3.1.1 Aggregate

For this project, volcanic aggregates were collected from the El Malpais region near the Navajo Nation. The material was directly sourced from the El Malpais National Monument area, a region characterized by its unique geological formations. According to Clemons and Mack (1988) in their work *Geology of Southwestern New Mexico* (https://nmgs.nmt.edu/publications/guidebooks/details.cfml), the rocks in this area exhibit specific compositions and formations, which are crucial for understanding their potential use in construction.

The El Malpais landscape is dominated by five basaltic lava flows that display a range of surface morphologies and were emplaced through various volcanic processes (https://www.nps.gov/articles/000/monogenetic-volcanic-fields.htm). A significant feature of this area is the Bandera Crater (Qcn), a breached cinder cone that serves as the source of El Malpais' cinder cone material. It is the largest cinder cone in the region and a textbook example of breached cinder cone morphology.

Geologic Background

The El Malpais National Monument spans approximately 179 square miles (464 square kilometers), with the lava flows covering about 133 square miles (344 square kilometers). The Zuni-Bandera Volcanic Field at El Malpais is primarily characterized by basaltic lavas. In contrast, nearby volcanic fields like the Raton-Clayton Volcanic Field display a greater range of compositions, from ultramafic to rhyolitic (36–70 weight % SiO_2).



Map of volcanic features and rock types around Capulin Volcano in northeastern New Mexico

Figure 1: The Raton-Clayton Volcanic Field (https://www.nps.gov/articles/000/monogenetic-volcanic-fields.htm)

The volcanic history of these areas spans millions of years, with notable phases of activity:

- Raton Phase: 9.2–3.5 million years ago.
- Clayton Phase: 3.8–1.7 million years ago.

- Capulin Phase: Last 1.7 million years (https://www.nps.gov/articles/000/monogenetic-volcanic-fields.htm).

Characteristics of Aggregates

The aggregates collected from El Malpais consist primarily of basaltic and other mafic compositions, ideal for evaluating their mechanical properties in concrete. These aggregates are derived from a monogenetic volcanic field, known for producing single-eruption formations, making the material geologically consistent. The basaltic aggregates have desirable engineering properties, including durability, high specific gravity, and angular shapes that improve interparticle friction.

This study leverages these unique volcanic aggregates to explore their suitability in Jointed plain concrete pavements (JPCP), focusing on their mechanical performance, benefits, and potential for economic development within the Navajo Nation.

Rock formation in the El malpais area where samples were collected

Figure 2: Sample collection field

Three labeled containers with geological material samples numbered 1 to 3, collected from the El Malpais area

Figure 3. Sample collected

3.1.2 Cement:

Ordinary Portland Cement (OPC) conforming to ASTM C150 standards was used as the binding material.

3.1.3 Water:

Potable water free of impurities was used for mixing and curing.

3.2 Experimental Design:

3.2.1 Particle size distribution analysis

Stacked sieves arranged in descending mesh size containing a geological sample for particle size analysis

Figure 4 . Sieves

Table 1. Sieve Analysis results

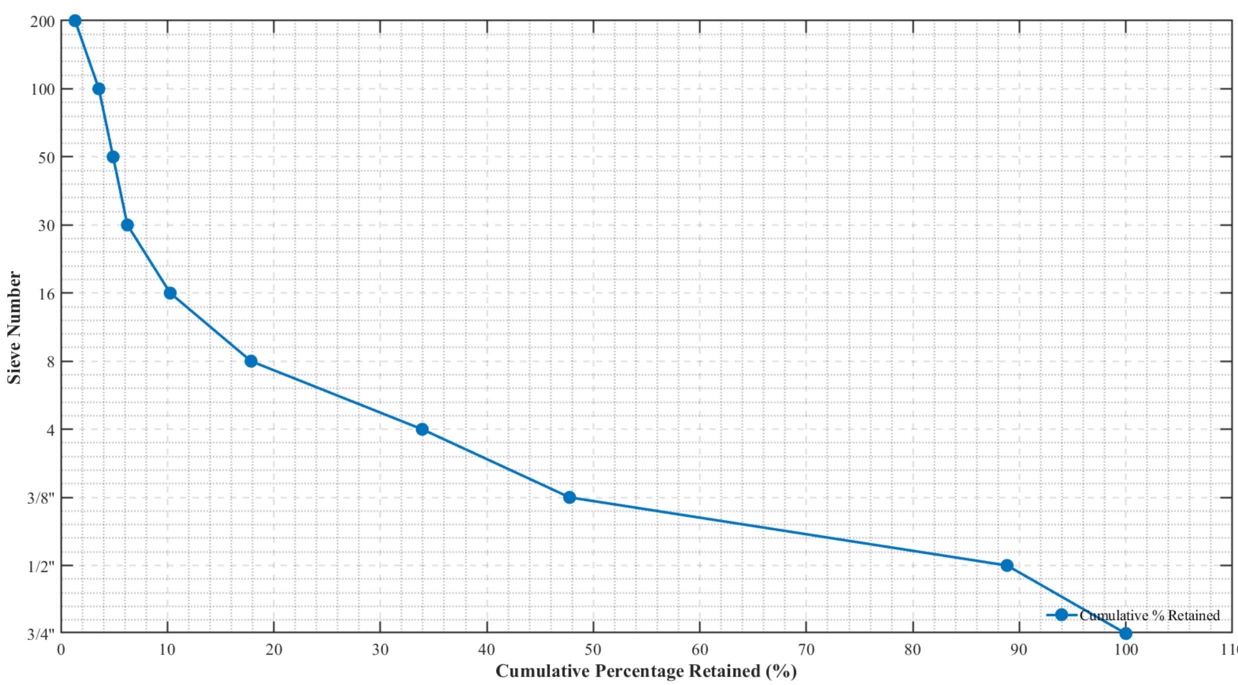
Bag #	Sieve No.	Weight in Pounds	Weight in Ounces	Weight in Kilograms
1	200	0.15	2	0.06
2	100	0.2	4	0.1
3	50	0.1	2	0.06
4	30	0.15	2	0.06
5	16	0.35	6	0.18
6	8	0.7	12	0.34
7	4	1.6	1:1oz	0.72
8	3/8"	1.35	1:1oz	0.62
9	1/2"	4.05	4:1oz	1.84

Bag #	Sieve No.	Weight in Pounds	Weight in Ounces	Weight in Kilograms
10	3/4"	1.1	1:2oz	0.5

The distribution of particle sizes ranges from fine (Sieve no 200) to coarse (3/4”). Larger sieve sizes hold more material, reflecting coarse aggregates.

Table 2. Cumulative percentage remained

Sieve No	Weight (kg)	Cumulative Weight (kg)	Cumulative % Retained
200	0.06	0.06	1.34%
100	0.10	0.16	3.57%
50	0.06	0.22	4.91%
30	0.06	0.28	6.25%
16	0.18	0.46	10.27%
8	0.34	0.8	17.86%
4	0.72	1.52	33.93%
3/8”	0.62	2.14	47.77%
1/2”	1.84	3.98	88.84%
3/4”	0.5	4.48	100%



Graph with plot of cumulative percentage of aggregate retained on the sieve

Figure 5. Particle size distribution curve

The sieve analysis results highlight the particle size distribution of volcanic aggregates sourced from the El Malpais region near the Navajo Nation. The analysis demonstrates a progressive increase in cumulative percentage retained across different sizes, ranging from the finest sieve (No. 200) to the coarsest sieve (3/4"). The cumulative percentage retained begins at 1.34% for the No. 200 sieve and reaches 100% at the 3/4" sieve, reflecting a well-distributed gradation of particle sizes. This distribution ensures a balanced mix of fine and coarse particles, which is essential for optimizing the workability, strength, and durability of concrete. The larger sieves (e.g., 1/2" and 3/4") retained the majority of the material, indicating a higher proportion of coarser aggregates, which is advantageous for structural applications such as Jointed plain concrete pavements (JPCP). These results suggest that the volcanic aggregates possess a favorable gradation suitable for producing high-performance concrete mixes.

3.2 Methodology

3.2.1 Mix design

Table 3. Weights of Component Materials

M15	**Concrete Mixture**	**Concrete Mixture**	**Concrete Mixture**	**Concrete Mixture**	**Concrete Mixture**
Cylinder Sample #	1	2	3	4	5
Portland Cement	229.3 g	298.8 g	316.8 g	221.1 g	198.6g
Medium Sand	576.4 g	558.3 g	634.0 g	535.6 g	541.1g
Volcanic Aggregate	729.5 g	720.5 g	712.8 g	717.4 g	766.5g
Aggregate Sieve #	7, 8, 9	7, 8, 9	7, 8, 9	7, 8, 9	6,7,8,9
Water (H_2O)	9.87 oz	7.16 oz	5.00 oz	6.55 oz	5.32oz

The concrete mix design for the given values corresponds to an M15 grade concrete, commonly used for pavements and structural elements with low load-bearing requirements. The design incorporates Portland cement, medium sand, volcanic aggregates, and water, ensuring a balanced ratio for adequate workability and strength. The cement content ranges from 198.6 g to 316.8 g across samples, reflecting variations in compressive strength potential. Medium sand content, varying between 535.6 g and 634.0 g, ensures improved workability and particle packing, while volcanic aggregates (712.8 g to 766.5 g) provide coarse gradation and structural integrity. The water content, ranging from 5.00 oz to 9.87 oz, directly influences the water-cement ratio (w/c), affecting both workability and strength. This mix design emphasizes the responsible use of locally sourced volcanic aggregates, reducing reliance on conventional materials while maintaining the required performance for applications such as jointed plain concrete pavements (JPCP).

3.2.2 Casting

(a) (b)

Cylindrical mold filled with concrete left figure from top view and right figure shows side view of the cylinder

Figure 6. Cylindrical mold with concrete (a) Top view (b) Side view

Casting of concrete is a critical process that ensures the desired properties and performance of the mix. It begins with the preparation of materials, where Portland cement, sand, volcanic aggregates, and water are measured according to the mix design specifications. The aggregates undergo a final sieve analysis to confirm proper gradation, and all materials are cleaned to remove impurities. Mixing is carried out using a clean mixing pan or concrete mixer, starting with the uniform blending of cement and sand. Volcanic aggregates are then added, followed by water in small increments to achieve the desired workability and consistency.

Once the concrete is mixed, molds or forms, such as cylinder molds, are prepared by cleaning and applying a release agent to prevent adhesion. The mixed concrete is placed into the molds in layers, approximately one-third of the mold height at a time. Each layer is compacted using a tamping rod or mechanical vibrator to eliminate air pockets and ensure uniform density. After placing the final layer, the surface is leveled and finished with a trowel to achieve a smooth and even top.

Curing is a crucial step in the casting process. After 24 hours, the concrete specimens are demolded and placed in a curing tank filled with water maintained at 20°C (68°F). The curing process continues for the required duration, typically 7, 14, or 28 days, to allow the concrete to fully hydrate and develop its strength. Proper curing prevents moisture loss and ensures the specimens achieve the target properties. After the curing period, the specimens are tested for properties such as compressive strength and tensile strength to evaluate the mix's performance. This meticulous process ensures the M15 concrete mix, incorporating volcanic aggregates, meets the structural and durability requirements for its intended applications.

3.2.3 Curing

Demolded Concrete specimen kept in water tank to cure

Figure 7. Specimen under curing process

The curing process is a vital step in concrete production, ensuring the proper hydration of cement and the development of strength and durability. Specimens were cured in a water tank at 23 ± 2°C for specified durations (7, 14, and 28 days) as per ASTM C511. After casting, concrete specimens were kept moist and at a controlled temperature to prevent premature drying, which can lead to cracking and strength reduction. Typically, curing begins immediately after demolding, with the specimens being submerged in water tanks maintained at a constant temperature of around 20°C (68°F). This immersion method is ideal for laboratory samples, as it provides consistent moisture and temperature conditions.

The curing duration, often 7, 14, or 28 days, is critical for achieving the target strength and durability, as the hydration process significantly contributes to the development of the concrete's microstructure. Proper curing ensures the concrete reaches its full potential, enhancing its resistance to environmental stresses and long-term performance.

Chapter 4. Results and Discussions

4.1 Compressive strength test:

Compression testing is a standard method for determining the compressive strength of concrete cylinder. Here we used Instron compression machine at Navajo Technical University for its precision and accuracy. The procedure involves preparing, positioning and loading the concrete specimen until failure to evaluate its maximum load capacity.

a. Specimen preparation:

   Concrete cylinders of standard size of 150mm diameter and 300 mm are measured and specimen surfaces are evaluated for their smoothness and check for defects.

(a) (b)

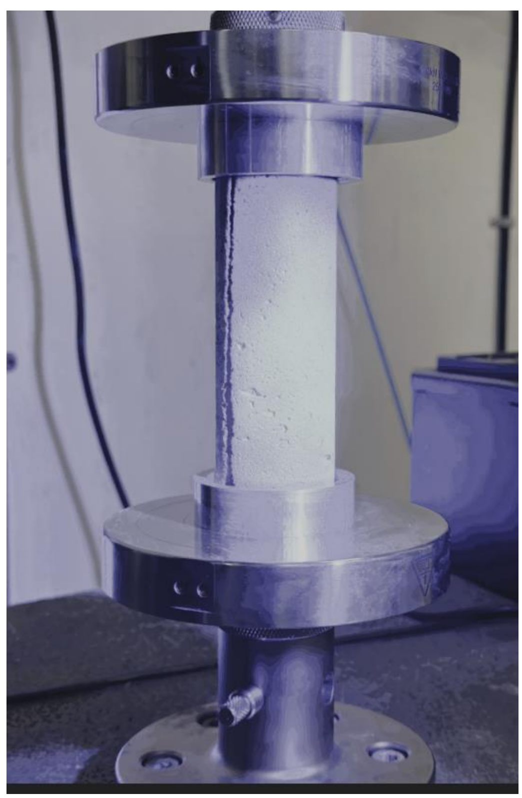
Concrete cylinder samples with measurements

Figure 8. Specimen measurement (a) Length of specimen (b) Width of specimen

b. Machine setup and specimen:

The Instron compression testing machine was meticulously calibrated to conduct the tests in accordance with ASTM C39 standards, ensuring precision and compliance with industry protocols. Steel caps were utilized on the top and bottom surfaces of the concrete cylinders to ensure uniform load distribution during testing. Prior to initiating the test, the loading platens were thoroughly inspected for cleanliness and proper alignment to prevent any inconsistencies during the application of the compressive load.

The machine’s program was configured with the required report formats and measurement units to streamline data acquisition and analysis. Each concrete cylinder specimen was carefully positioned vertically between the machine’s loading platens, with particular attention given to ensuring the specimen was centrally aligned. This step was critical to avoiding eccentric loading, which could introduce uneven stress distribution, thereby compromising the accuracy and reliability of the test results. By adhering to these meticulous preparation steps, the testing process ensured optimal conditions for accurate and reproducible measurements of the specimens' compressive strength.



Specimen kept in position for testing

Figure 9. Testing Setup

c. Testing

The compression testing machine was configured to apply continuous and precisely controlled load rate of 0.3MPa/s, in strict accordance with the relevant engineering standards. During the testing process, real-time monitoring of load application and deformation was performed via the machine's integrated display. The system simultaneously recorded the load-displacement curve, which represents the materials response as the specimen was subjected to increasing compressive stress.

The test proceeded until the concrete cylinder specimens reached their failure point, characterized by the appearance of visible crack and a sudden, significant drop in the applied load. For this experiment, four cylindrical specimens were tested, with each subject continuously loading until structural failure occurred. Throughout the process, critical parameters such as maximum load, yield point and the failure load were monitored in real time and recorded.

The machine's advanced software automatically processed the data, generating detailed results that included the yield load, ultimate load, failure point and other key performance metrics. These results were presented in both tabular and graphical formats, enabling comprehensive analysis of the materials behavior. The compression test results, including the load displacement curve and failure characteristics, are depicted in the accompanying graph (Fig. 4.3). This information provides valuable insights into the mechanical properties and load bearing capacity of the concrete mix, forming the basis for performance evaluation and quality assurance in structural applications.

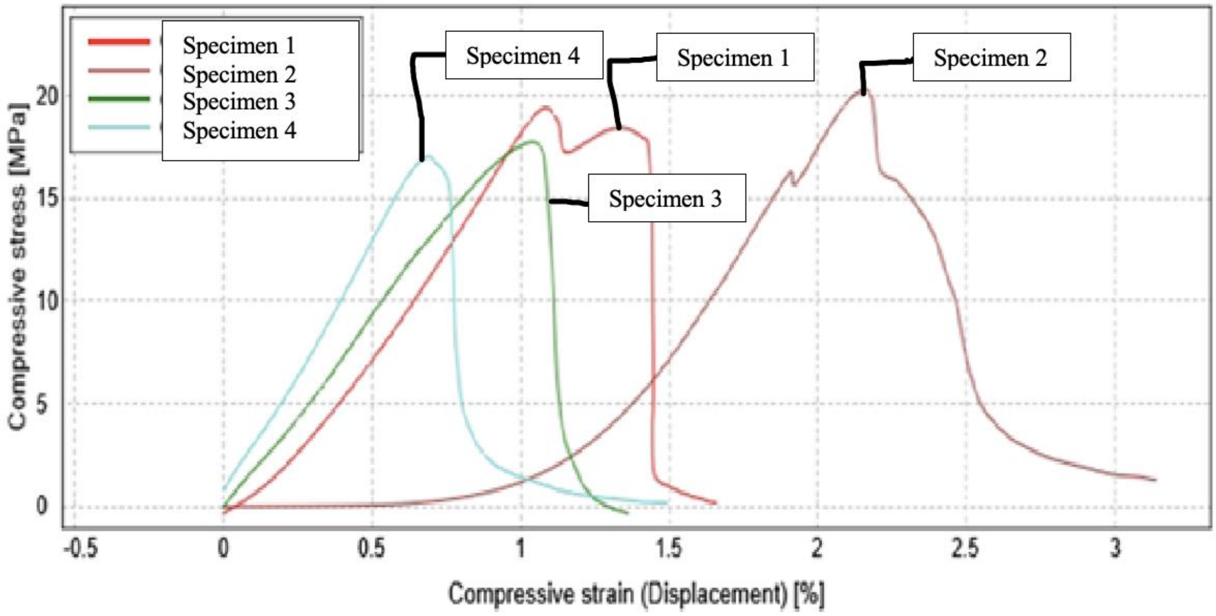
Specimen 1 	**Specimen 2** 2 
Specimen 3  3	**Specimen 4** 

Crushed concrete cylinder specimen after compression test, showing vertical cracks and surface spalling indicating material failure for Specimen 1,2,3 and 4

Figure 10. Images of the specimen failure at compression testing

4.2 Results Discussion:

The compression strength test results graphical representation obtained from Instron machine after the testing is shown as follows. All four specimens stress – strain relationships were plotted.



Graphical plot shows the compression testing results for specimens 1,2,3 and 4
Specimen 1 peaks around 19 MPa at 1.1% strain.
Specimen 2 exhibits the highest peak stress of approximately 22 MPa at 2.1% strain.
Specimen 3 and 4 show lower peak stresses, around 17 MPa and 16 MPa respectively, at approximately 1 % strain. Each curve is individually labeled in the plot to clarify correspondence between specimens.

Figure 11. Compression testing results

During the compression testing, the stress-strain curves for all four specimens were obtained, along with critical parameters such as the failure point and loading patterns. The failure patterns of all four specimens were observed to be similar, indicating consistent material behavior under compressive loading. However, the fourth specimen exhibited a notably shorter displacement at failure, likely due to inherent material characteristics or possible variations in the mix or curing process.

The average compressive strength across the specimens ranged from 2400 to 2900 psi, which is below the standard range recommended for most jointed plain concrete pavements (JPCP). Additionally, the yield strength of the specimens was found to be between 2100 and 2600 psi, further highlighting the limitations of the mix in achieving higher load-bearing capacities. These results underscore the need to refine the mix design or investigate alternative materials to meet the required compressive strength and yield strength for structural and pavement applications.

Table 4. Compression testing results

Specimen	***Yield strength (psi)***	***Compressive strength (Psi)***
1	2496.1	2812.28
2	2667.24	2937.01
3	2488.85	2570.07
4	2129.15	2464.19

For jointed plain concrete pavements (JPCP), the recommended compressive strength typically ranges between 4000-6000 psi at 28 days, as outlined by the American Concrete Institute (ACI) and various pavement design standards. This strength range ensures the concrete can endure the heavy traffic loads, environmental stresses, and long-term wear and tear that pavements experience. In certain cases, such as low-traffic or secondary road applications, concrete with a compressive strength of approximately 3000 psi might be acceptable. However, this is considered the lower limit and is only suitable for specific project requirements where reduced load demands are anticipated.

The tested average compressive strength range of 2400-2930 psi falls significantly below the recommended threshold for most JPCP applications. This level of strength is insufficient to resist the flexural and compressive stresses that pavements experience in high-traffic or heavily loaded scenarios. If such a concrete mix were used for JPCP, it could result in premature failure, cracking, or other structural deficiencies, making it unsuitable for critical applications. For compliance with JPCP standards, the mix design would need to be optimized to achieve higher compressive strength values, ensuring durability and serviceability under the intended loading conditions.

Chapter 5. Conclusions and Recommendations

The tested concrete samples had a compressive strength of 2400–2930 psi, which is generally not suitable for standard JPCP applications. However, with targeted modifications to the mix design and further optimization, it may be possible to improve its performance and meet the required standards. Additional tests, including flexural strength and durability assessments, should be conducted to determine its applicability for specific conditions.

The tested concrete samples had a yield strength of 2100-2800 psi, which is generally not suitable for JPCP designed for high-traffic or heavy-load conditions. However, it may be acceptable for low-traffic or non-critical applications. For standard JPCP, the compressive strength must be increased to at least 28 MPa (4000 psi) or higher. Adopting mix design optimizations and proper curing practices can help achieve the necessary strength while maintaining the other benefits related to using volcanic aggregates.

Chapter 6. Implementation of Project Outputs

The successful implementation of this project’s findings holds the potential to inform construction practices, particularly in regions like the Navajo Nation. By utilizing locally available volcanic aggregates as an alternative to conventional aggregates, this approach significantly reduces adverse impacts while fostering economic growth within the local community.

The outcomes of this project allow for the optimization of mix designs tailored to various concrete applications, paving the way for the effective use of volcanic materials in future construction projects. Educating local contractors and construction workers on the benefits and proper handling of volcanic aggregates is critical to ensuring widespread adoption. Moreover, this initiative provides an invaluable opportunity for local students in construction technology to gain hands-on experience and develop technical expertise in innovative practices.

Long term monitoring of pavements constructed using the proposed concrete mix will be instrumental in validating key performance metrics, including durability, cost effectiveness, and other benefits. This ongoing evaluation will provide the foundation for refining the mix design and expanding its application, contributing to resilient infrastructure and responsible development in the region.

Chapter 7. Technology Transfer and Community Engagement and Participation (CEP) Activities

By prioritizing technology transfer and robust community engagement, this project will not only achieve its technical objectives but also empower the Navajo Nation to lead responsible construction efforts that preserve cultural heritage, promote economic development, and reduce adverse impacts.

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