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APPLYING MODERN TECHNOLOGY IN THE PRESERVATION OF HISTORIC CONCRETE PICNIC TABLES

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ABSTRACT

Preserving historical concrete structures recognizes the work and skills of past generations and allows the communities surrounding these pieces of history the opportunity to enjoy the character and purpose of their construction. Restoration of concrete picnic tables, constructed in the 1930s by the Civilian Conservation Corps, required researching materials and methods of construction during the original construction period. Eight decades of environmental and weather cycles did not decay the historic structures. Acts of vandalism destroyed the purpose of the tables and benches. Restoration of the historic picnic tables required extensive literature review for the materials and methods used during the period. Changes in the manufacturing of cement products from 1933 to today added to the challenge. To design a new concrete that would maintain the performance of original picnic tables required new materials and modern technology. Scanning electron microscopes and petrographic analysis provided the information as to the materials used in the historic concrete mix design. Discoveries by the technology provided the evidence the research questions asked. The results were determined through review of historic literature, investigating historic mix designs, use of modern technology, and laboratory experiments.

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CHAPTER 1: INTRODUCTION

1.1. Background

In the years 1933 through 1934, the Federal government utilized the Civilian Conservation Corps (CCC) to construct picnic areas north of Albuquerque, New Mexico, in the foothills of the Sandia Mountains (Figure 1) (Melzer, 2000). The CCC used construction material available during the period and incorporated the natural materials located in the surrounding site area as the basis for each picnic table. Concrete table and bench slabs were formed and placed onto natural rock or rock mortar pedestals (Figure 2). The concrete mix design for the slabs contained mostly fine aggregate and a green dye. The concrete was placed in forms containing rebar hand tied and positioned at or near the bottom of the slabs. All materials used in the construction of the tables and benches required them to be hand carried up the mountainside to the site. Eighty-three years later, the tables and benches are still being used by visitors to the Cibola National Forest and the United States Forest Service (USFS). Access to the picnic sites is still limited today to parking at the general parking lot and hiking to the picnic areas. After eighty-three years of high desert heat and mountain snows, the structures retain their original characteristics. This includes the exact green dye color; from their sun beaten surface through to the underside of the slabs that have never seen sunshine.

Figure 1. Juan Tabo Picnic Area, Albuquerque, New Mexico (Source: Google Earth).

Figure 2. CCC picnic table constructed on natural rock (Source: Joelle Hertel)

Today, the simple concrete picnic tables stand without any obvious environmental or chemical defects. The only noticeable wear to the concrete structures is vandalism to the tables and benches (Figure 3). So too do many other historic concrete structures, such as the first concrete road built in 1891, the first reinforced concrete skyscraper known as the Ingalls Building built in 1903, Thomas Edison's house circa 1908, and the Hoover (Boulder) Dam built in 1936. Over time, however, concrete mix designs have changed such that they may not be compatible with historic mix designs. This can be an issue in the case of the simple concrete picnic tables, which need to be repaired due to vandalism.

Figure 3. Picnic table and bench vandalized (Source: Joelle Hertel).

Proper restoration of the historic picnic tables should focus on preserving the characteristics and performance requirements to extend the useful years these concrete structures have to offer future generations. Discovering the materials and methods used during the early 20th century that keeps the historic tables and benches from showing signs of deterioration is a key requirement. Producing a quality concrete restoration product to rehabilitate the tables without causing unintentional consequences is another key requirement. The investigation process reached back in time to search for findings from recorded history as well as explore the concrete's molecular structure using modern science and technology. Piecing the past and the present provided the clues necessary to take the next step of concrete laboratory testing to replicate the historic mix design used for the concrete picnic tables and benches.

1.2. Study Objectives

The objective of this paper are to present research finding on the techniques used in the 1930s for concrete construction in conjunction with evaluating modern methods to restore or replicate the existing historic structures. The questions the research aims to answer are the following:

1. What construction methods were used in Albuquerque during the 1930s such that the technology and materials in that era show no signs of deterioration in the structures?

2. What mix design, using technical advances in the Portland cement and concrete industry, will repair, or replicate the concrete in the historic tables and benches to return them to their original performance requirements and color?

By answering these questions, this work aims to identify appropriate mix design and dye requirements for the USFS and their contractor to properly restore the historic landmarks to their original performance requirements and unique characteristics without causing future deterioration.

1.3. Methodology

In order to answer the first research question, extensive review of historic literature was conducted to including Portland cement manufacturing and standards, concrete mix designs, and tools and construction techniques used in the era of the 1930's. The research produced information on Portland cement production, concrete mix designs, admixtures, and the ways and means contractors worked concrete during the period of construction of the picnic tables. Modern technology and the use of digital microscopes, scanning electron microscopes, and petrographic analysis provided additional data as to the composition of the historic concrete used in the structures.

Resolution to the second question required several trials of a new concrete mix design combining all the information gathered from literature review and finding from the scanning electron microscope and petrographic analysis. Digital microscope comparison of the new mix and the historic mix in terms of aggregate size and texture was an additional requirement. Testing color dyes to match the historic concrete was the final requirement. The new mix, once placed, finished, and cured should closely replicate characteristics found in the historic concrete related to conformation and performance requirements originally prescribed by the CCC.

The results of this study and answers to the research questions are presented in the following chapters. The structure of this thesis includes the following chapters:

Literature Review (Chapter 2), Methodology (Chapter 3), Findings (Chapter 4), Discussion of Results (Chapter 5), and Conclusion (Chapter 6).

CHAPTER 2: LITERATURE REVIEW

In order to determine solutions to the research questions, a comprehensive exploration, and review of relevant literature was conducted. The first research question required retrieving the standards of cement and concrete manufacturing during the early 1930's in pursuance of determining the materials, technology and construction methods. The second research question engaged the technical sciences and laboratory trials to gain insight for a concrete mix design. Together the answers to the research questions should produce preferred concrete mix for preserving or replicating the historic tables and benches to their original characteristics and performance requirements. The literature review covers the three main areas of research for this topic: historic cement and concrete, restoration and preservation, and current technology in concrete.

2.1. Historic Cement, Concrete, and Construction Methods

The United States, in the mid-19th century, witnessed a rising demand for cement fill the requirements of an expanding nation. As American manufacturing increased so did the demand for factory construction and quality concrete. The country was rich in natural cement but the demand for the new Portland cement grew due to the reliability of Portland cement over natural cement and the significantly lower cost of Portland cement. European-made Portland cement was used as ballast on empty wooden sailing ships crossing the Atlantic Ocean to America. Once in port, the shipping companies would pay as high as ten cents a barrel to have the cement removed in order to load high revenue American grain and cotton for their return voyage to Europe (Lesley, 1924).

David Saylor received the first U.S. patent for Portland cement in 1871 (Saylor, 1871). The country underwent a major growth cycle during the late 19th century, when an urban construction boom generated strong demand for the versatile material. In 1890, the American Portland cement industry supplied just 3% of the 2.3 million barrels of cement consumed in the United States but by 1913, 99% of the 90 million barrels of cement consumed was American Portland cement, offered at one-third the asking price in 1890 (Prentice, 2012). The composition of Portland cement in the early 20th century was 20 per cent silica, 10 per cent alumina, plus ferric oxide, 65 per cent of lime and 5 per cent of other compounds (Lesley, 1924). Standardized testing of cement, during this period, was first required by New York Department of Docks. The test required a tensile strength of 250 pounds per square inch after seven days when mixed neat, and that 75 per cent should pass through a sieve having 2,500 meshes to the square inch (Lesley, 1924).

Scientific studies and the related literature documenting the manufacture or use of cement was a rarity in the United States during the late 1800's. American scientific papers contained little reference to Portland cement (Lesley, 1924). Testing standards of Portland cement were being developed in the late 19th century by the American Society of Civil Engineers (ASCE) but not any specification for the chemical properties or the manufacturing of the Portland cement. The ASCE committee on Portland cement issued the following tensile testing standard in their January 21, 1885 report:

> "American and foreign Portland cements, neat: 1 day, 1 hour, or until set, in air; the rest of the 24 hours in water, from 11 pounds to 140 pounds. 1 week, 1 day in air, 6 days in water, from 250 pounds to 550 pounds. 1 month (28 days), 1 day in air, 27 days in water, from 350 pounds to 700 pounds. 1 year, 1 day in air, the remainder in water, from 450 pounds to 800 pounds" (Lesley, 1924).

The American Society for Testing and Materials (ASTM) formed Committee C-1 on Cement, Lime, and Clay Products in 1902. The C-1 committee played a key role in standardizing test methods in the Portland cement and concrete sector (ASTM, 1998).

The early years of the 20th century continued the rapid growth and expansion of urban areas and the demand for Portland cement in concrete buildings. American industry on a global scale surpassed Great Britain in the early 20th century by industrial output per capita (Wright, 1990). Federal government buildings were among the greatest consumer of concrete. The National Bureau of Standards (NBS) was established by Congress in 1901 with broad functions, which included not only the development and custody of the standards of weight and length, but the standardization of measuring apparatus, the determination of physical constants, and the determination of the properties of materials for general use in technology and trade (Wig, 1913). The testing of Portland cement originated with the Technologic Branch of the United States Geological Survey. Transfer of duties for testing cement was given to the NBS in July of 1910 (Wig, 1913). While the NBS was testing and standardizing cement, the United States Patent Office was issuing patents for Portland cement including the materials, process, and manufacturing of the product. Thomas Edison, in his later years (Simonton,

2015) submitted and received 49 patents concerning Portland cement (Rutgers, 2016). In June 1911 the Department of Commerce and Labor and various departments, met for a conference of Government engineers for unifying the specifications for Portland cement used by the United States Government. The conference provided the specifications for all government departments in construction work connected with Portland cement. An Executive Order was issued by President Taft on April 30, 1912, covering the United States Government Specification for Portland cement (Wig, 1913).

As the standards for testing concrete continued through the early 20th century, so did the standardization of mix designs to achieve the strengths and performance requirements desired for concrete. Concrete strengths were being achieved by use of large quantities of cement. The cost of construction, or economics, of using concrete began playing an important role in the decision-making. ASCE and the Canadian Engineering Standards Association (CESA) held a joint committee on the economics of water-cement-ratios. The published report, “The Design of Concrete Mixtures” (Wynn, 1930) states the minimum ultimate 28-day strengths to be used in terms of gallons per sack of cement in U.S. and Canadian measurement standards. Aggregates were also listed in the joint report under “Concrete Proportions and Consistency” but with wide latitude in proportioning the fine and coarse aggregates (Wynn, 1930).

The American Civil Engineer’s Handbook, 5th edition (Merriman & Wiggin, 1930), begins the section on concrete by stating concrete is a comparatively new major structural material and the technique of its manufacture is subject to constant revision as more is learned concerning concrete by experience and scientific research. Water-cement-ratio (w/c) is a prime requisite for quality concrete particularly for strength and durability factors. The Handbook notes classes of concrete given by their 28-day compressive strength to be used for a type of structure or degree of exposure to the elements. For example, a class of 3,000 psi, using a maximum of 6 gallons of water to one sack of cement, was used for roadways, piles, pressure pipe, and tanks in addition to concrete members exposed to severe action of water and frost. Aggregates, both sand (fines) and stones (course) were covered in the Handbook for their size classification, grading, and sampling requirement. Proportioning the concrete mix design was listed as a function of the structure's load requirements. An example given in the Handbook for construction of an abutment requiring a relatively stiff mix had the dry ingredients, listed as proportions of Portland cement to fine aggregate to course aggregate, as 1: 3: 5 and water of 7.5 gallons for maximum 2 inch aggregate.

In the late 1920s high strength concrete, for use in beams and arches, up to 7,000 psi was a theoretical discussion (Towels, 1932). Calculations for lengths of beams that high strength concrete in conjunction with steel could achieve were based on more cement in the mix design and not on improvements in the chemistry and manufacturing of Portland cement. A few years later high early strength Portland cement was being achieved through improvements in the manufacturing and quality of the product. Quality in the manufacturing process included careful control in the selection and proportioning of the raw materials, thoroughly grinding and blending the materials, scientific calcination, and a finer grinding of the finished product (Herber, 1933).

Admixtures for concrete were listed in the Handbook as sometimes used to increase workability; to increase impermeability; to hasten setting; and to facilitate curing. Admixtures for concrete have been used since ancient times. Some of the early admixtures were organic materials to achieve plasticity. The lime-pozzolan concrete mixtures included milk, blood, and lard (Mielenz, 1984). The late 19th century and early 20th century used common and natural materials such as salt for anti-freezing, and calcium chloride to accelerate setting and assist in the curing process. Workability admixtures in concrete included diatomaceous earth, kaolin, hydrated lime, and mineral oils.

Proportioning and testing of calcium chloride as an admixture to accelerate and provide early strength in concrete using Portland cement increased the demand and use of the material in construction (Abrams, 1924). Measuring workability required standardization of conditions necessary to the plasticity of the material and a device to measure the change in shape, or remolding of the concrete (Powers, 1932).

Admixtures, in the early 20th century, included anything added to the concrete including color. Color stains and pigments standards were introduced by the American Concrete Institute’s committee 408 (Allan, 1931). There was soon after a patent for chromium oxide, a green pigment, approved by the US Patent Office (Low, 1929).

Construction methods in the early 20th century experienced the end of the horse drawn carts and the populating of machines at construction sites. As construction methods and materials improved, the size of the projects grew ever larger. Reinforced concrete standard requirements for the size and quantity of reinforce steel members were set in practice (Merriman & Wiggin, 1930). Cost for labor and the cement in large building and government projects became an issue for the owners.

A study on mechanical vibration and hand placing concrete was produced and found to produce cost savings in the reduction of cement required when mechanical vibration was used (Powers, 1933). The Mississippi River 9-Foot Channel project provided the means to test both mechanical vibration directly against hand placement under a controlled and identical environment. Among the finding of the report, cement requirements per yard of concrete could be reduced with mechanical vibration, thus producing savings for the owner.

The literature review for historic cement and concrete has covered early natural cements and Portland cement, the manufacturing processes, standards and testing, concrete mix designs, and admixtures primarily from the mid-19th century through and up to the time the picnic tables were constructed by the CCC. Actual materials and concrete mixture designs used by the CCC were unavailable for this paper due to the limited historic data recorded and stored at the Cibola National Forest and the USFS.

Information from the literature review provided clues to the materials in use during the construction of the 1933 tables and benches, the standards for Portland cement and concrete, and ways and means proportioning the concrete mix design to facilitate the historic structures standing and being used today.

2.2. Restoration, Remediation, and Preservation

Restoration of concrete structures is dependent upon the causes of concrete deterioration. Deterioration in concrete can be caused by environmental factors, inferior materials, poor workmanship, inherent structural design defects, and inadequate maintenance (Coney, 1987).

Environmental factors contributing to the deterioration of concrete structures include precipitation, carbon dioxide, and acid rain. Of these factors, carbon dioxide and carbonation produce a corrosive reaction to the reinforcement and a degradation mechanism in reinforced concrete structures (Visser, 2014).

Inferior materials, such as reactive aggregates, induce a chemical ramification known as alkaline-silica-reaction. A reaction between the hydroxyl ions (OH) in alkaline cement and silica in aggregate produces a gel that increases in volume. The expansion of the gel causes cracking in the concrete.

Other factors in concrete deterioration occurs primarily because of corrosion of the embedded steel, degradation of the concrete itself, use of improper techniques or materials in construction, or structural problems (Gaudette & Slaton, 2007).

In order to remediate a concrete structure properly, several factors need to be in place for a successful restoration to the degree the historic preservation committee, or persons in-charge, requires the structure to be returned. Success of repairs for historic preservation purposes depends on numerous factors including the degree of damages, skill and experience of the contracted company, the planning architect and responsible engineer, and the costs that the owners are willing to cover (Schmidt, 2012).

The cost of the restoration is a key concern in the decision to move forward with the project. The question of a partial or full remediation depends on the overall size of the concrete structure and the amount of deterioration the concrete is experiencing. For large scale concrete remediation, say a building or bridge, the degree of deteriorated concrete of the overall surface needs to be established to determine whether a partial or full restoration is technically feasible and economically sensible (Schmidt, 2012).

Small-scale, ‘cautious’ concrete repair procedures are a preferable procedure to repair particular areas of damaged surfaces (Schmidt, 2012). In the restoration of the Liederhalle located in Stuttgart, Germany, the goal was to preserve the original surfaces. Detail of the original surface included composition and original color of the concrete aggregate and color of the cement along with the bush-hammered, very rough concrete surface. The characteristics of the repaired mortar, its composition, and color were to match the original concrete. Restoration construction methods included cleaning the surfaces, areas to be restored were outlined and delimited by vertical and horizontal lines, concrete was cut and removed, and reinforcement exposed up to the uncarbonated concrete. The prepared demolition area was wetted, cement based bonding agent applied, and colored repair mortar was infilled with a trowel. The repair mortar was then treated with stonemason methods to adapt the area to the original surface structure.

The restoration of Bahai Temple (Akkaya, Eckerson, Konsta-Gdoutos, & Shah, 2003) concerned failure of the white concrete ornamental stairs and exposed surfaces of the entire building faces. The deterioration was due to exposure to deicing salts, chemical cleaners and sandblasting of the structure built from 1942 to 1953. Documents by the architectural firm of John Earley and the Earley Studios provided details for the design and construction methods of the Temple located in Wilmette, Illinois. The 1942 original concrete was made with no performance-enhancing admixtures. During the restoration in 1989, cores were taken of the 1942 stairs for analysis before a concrete mixture was chosen. Both the cores and the original documentation revealed the 1942 concrete mix design was batched based on the weight and volume of one-bag of cement. Vibration techniques to settle the concrete and remove air voids was done by a craftsman hitting the sides of the molds with a piece of wood. Testing of the 1942 and 1989 restoration included core samples under split tension and compressive strength. The use of core testing in conjunction with scanning electron microscope and optical microscope observation provided information as to the entrapped voids, paste-aggregate interface, and deficiencies found in both concretes.

2.3. Cement, Concrete, and Modern Methods

Research and development of Portland cement and concrete greatly expanded after World War II. Changes to Portland cement and improved manufacturing techniques expanded the potential for this technology and increased uses in the concrete industry and construction. Studies on the permeability of Portland cement pastes (Powers, 1954) and new types of Portland cements designed for specific applications under ASTM 150 provided the fuel to identify concrete applications beyond the single Portland cement compound developed for use in the 1933 picnic tables. These materials provide the structure for super highways, taller buildings and water-less Martian Concrete (Wan, 2015).

The basic manufacturing of cement has changed very little over the decades. Raw materials for making cement are calcium, silica, alumina, iron and sulfate. The ground raw materials are blended and fed through a rotating kiln. Within the kiln, the materials are heated to a temperature of approximately 1450°C (2700°F) when chemical reactions occur and the raw materials change into Portland cement clinker. When the clinker exits the kiln, in the form of grey pellets, it consists of four chemical phases or compounds: alite or tricalcium silicate (C_3S), belite or dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF) (Kosmatka & Wilson, 2016). In recent years, the manufacturing of the cement product has achieved significant progress in the field of processes and energy savings. Temperatures in the cement kilns are better controlled, however, the thermodynamics of the four chemical phases governs Portland cement manufacturing (Aïtcin, 2000).

Improvements in technology enable scientists, researchers, and engineers to peer into the molecular make-up of the materials. Several techniques and procedures are available to explore the identification, characteristics, mineral content, and deformation of concrete samples. These included petrographic examination and scanning electron microscope analysis.

Petrographic examination or analysis has provided information for numerous investigations on cement and concrete projects including the deterioration of concrete by seawater (Gjorv, 1971), shotcrete longevity on a dam spillway (Zhang, Ezzet, Shanahan, Morgan, & Sukumar, 2011), alkali-reactive aggregates (Lanza & Alaejos, 2012), and alkali-silica reaction (ASR) at Pease Air National Guard Base in New Hampshire (Reed-Gore, Klaus, & Moser, 2016).

Scanning electron microscopes (SEM) have been used to provide images of concrete reactions with static fatigue (Husak & Krokosky, 1971) , cracking and corrosion in concrete (Lloyd & Heidersbach, 1985) , and microscopy on corrosion in concrete (Silva, T.J. da, 2008).

There are also issues related to modern concrete such as alkali-silica reactivity (ASR), which is a known problem in New Mexico and especially in the Albuquerque area. Studies on additives, including fly ash and lithium nitrate, have been conducted to reduce or eliminate the effects of ASR on concrete pavements (McKeen, Lenke, & Pallachulla, 2000).(Kolio, Niemela, & Lahdensivu, 2015)

Carbonation is another issue with modern concrete. Carbonation is a chemical reaction that occurs in concrete due to environmental factors, precipitation, and the age of the concrete. Alkaline hydrates and carbon dioxide dissolve within the concrete pore water producing calcium carbonate. Pore water pH is naturally lowered to the point where steel reinforcement begins to corrode. Modeling of carbonation and the rate it occurs is determined using the square root of time relationship (Kolio, Niemela, & Lahdensivu, 2015).

Concrete restoration systems and materials provide new methods of interfacing the new to the old concrete (Tayeh, Abu Bakar, Johari, & Zeyad, 2013). The transition zone from old to new concrete is the weakest link in the repair of concrete (Li, Xie, & Xiong, 2001). The use of the correct binder when restoration of old concrete comes in contact with the new concrete is a main factor affecting the mechanical properties and durability of the repaired concrete. In order to protect the transition zone from penetration of moisture or chemicals, the performance of the repaired concrete depends on the quality of the restoration system. One such system is reactive powder concrete (RPC). RCP and its component of silica fume enhances the adhesion strength between

RCP and ordinary concrete. The mix design for RPC contains Type I Portland cement, densifies silica fume, well-graded sieved mining sand, micro-steel fibers, and polycarboxylate ether based (PCE) superplasticizer.

2.4. Literature Review Summary

Portland cement and advancements in the concrete industry have played a vital role in the development of this country. Innovation and discovery provided constant improvements to both industries. The literature review brings together historic events in Portland cement and the concrete industry alongside current concrete concerns and technologies. Discovery of standards used in the Handbook for concrete and w/c ratio was the stepping-stone needed to move forward with a new mix design for use in restoring the historic picnic tables.

Procedures and construction methods for restoring historic concrete structures provide many scenarios, techniques, and chemical compounds used over the years by craftsmen in the industry. The interface between old and new concrete is a factor in the concrete picnic table restoration process.

A standardized concrete design mix for the period, admixtures, restoration and preservation difficulties, chemical reactions within the concrete, and modern technology's ability to probe into the historic concrete and extract the secrets 1930s concrete holds will be tested and presented in the following chapters.

CHAPTER 3: METHODOLOGY

3.1. Overview of Methodology

This chapter presents the methodology used to answer the research questions posed in Chapter 1. Three independent steps: literature review, modern technology, and laboratory experimentation, came together to answer the questions:

1. What construction methods were used in Albuquerque during the 1930s such that the technology and materials in that era show no signs of deterioration in the structures?
2. What mix design, using technical advances in the Portland cement and concrete industry, will repair, or replicate the concrete in the historic tables and benches and return them to their original performance requirements and color?

The three independent steps provided not only information extracted from the in-depth investigation each step offered, but verified one another. The research approach was designed to determine a preferred new concrete design mix for the restoration project in order to match the existing historic tables and restore the structures to the performance requirement and characteristics.

3.2. Literature Review to Identify Potential Mix Design Issues

Information obtained by the literature review revealed the materials used in concrete during the early 1930s and provided a starting point for lab experiments on a new concrete mix design for restoring the picnic tables. Portland cement manufacturing, concrete mix design and materials were found to be concise and standardized for the time period of interest in the American Civil Engineer's Handbook (Merriman & Wiggin, 1930). The Handbook pointed to the probable concrete mix for the historic picnic tables and benches. The manufacturing of Portland cement, during this time, included the ingredients of calcium carbonate ($CaCO_3$), silica (SiO_2) and alumina (Al_2O_3). Structures and their degree of exposure to actions of water and frost determined the class or strength of the concrete required. The historic picnic tables and benches were constructed as a 4 inch reinforced slab. According to the Handbook, a class of 2,500 psi was used for walls in all weather conditions and moderate action of water and frost. The maximum quantity of water per 94-pound sack of Portland cement was taken from the Handbook Figure 5 chart (page 1024) using curve B. The w/c ratio of 0.79 was combined with the mix ratio of Portland cement to sand to aggregate indicated 1:2.25:3.25 for a stiff concrete. Stiff was taken from the consistency table over plastic and soft concrete due to the workability required in the forms and reinforcement for the table and bench slabs.

Observation of the historic picnic tables in their natural environment displayed a green color to the concrete. The green color of the concrete was consistent throughout the slabs that made up the tabletops and bench seats when broken pieces of the concrete were examined. The literature review identified patents for concrete dye using chromium oxide to produce a green color (Low, 1929).

The literature review also covered restoration of historic structures. Deterioration of concrete has been attributed to improper maintenance, water infiltration with freezing and thawing contributing to the decay of the concrete, and corrosion from embedded reinforcement that may be linked to the use of calcium chloride (Gaudette & Slaton, 2007). Although the restoration of the historic picnic tables was required due to vandalism and not maintenance or water infiltration, calcium chloride was used during this time as an admixture (Abrams, 1924). Another contributing factor could be poorly consolidated concrete containing voids that reduced the strength of the structure. Mechanical vibration improves the flowability of concrete and eliminates the honeycombing of air voids (Gaudette & Slaton, 2007). The remoteness of the historic tables and lack of electricity virtually eliminates the ability of the CCC workers to use mechanical vibration when pouring the slabs for the tabletops and benches (Powers, 1933). Air voids or honeycombing of the concrete could weaken the structural strength of the slabs, thus making the destruction of the tables easier.

Chemical and environmental infiltration has known carbonation effects that penetrate through the concrete and caused corrosion in the embedded reinforcement. Carbonation of concrete is a reaction of carbon dioxide (CO_2) in the atmosphere and alkaline hydrates, formed in the alite stage as tricalcium silicate, producing calcium carbonate ($Ca(OH)_2$). Calcium carbonate lowers the pH of the concrete over time to the depth of the reinforcing steel. Corrosion of the steel occurs when the protective level of the alkaline concrete is lowered to a level that can corrode the reinforcement. (Kolio et al., 2015). ASR is a known problem in New Mexico with deteriorating effects within concrete (McKeen et al., 2000).

The literature review was the basis for determining the new restoration concrete mix design, based on the science and construction methods of the time. The review brought to light means and methods used during the 1930s that may have contributed to internal structural decay that could cause the historic slabs to be easily destroyed. Modern technology is the second of the three independent steps and a means of going into the molecular composition of the historic concrete.

3.3. Modern Technology to Understand Materials in Historic Concrete

The methodology to understand the materials and elements used in the historic concrete consisted of digital microscopes, scanning electron microscopes (SEM), petrographic analysis, and color analysis. In addition, a non-destructive test using the rebound (Schmidt) hammer was performed. The technology was used to discover, analyze, confirm, or eliminate causes of materials used in the historic mix and determine the current condition of the historic concrete. Professional laboratories performed SEM and petrographic analysis as well as color analysis. All historic concrete tested by the various forms of technical apparatus came from the same broken bench (Figure 4).

Figure 4. Historic concrete broken bench used for testing samples.

The first apparatus used to examine the historic concrete was a digital microscope. The digital microscope amplified the surface areas of the historic concrete as illustrated in Figure 5. Information gathered showed aggregate size and distribution of the historic mix. Maximum aggregate size and distribution of smaller aggregates were used in the new concrete mix design. After each new mix was cured and tested for compression strength, a sample of the surface was checked using the digital microscope and compared against the historic concrete for quality of aggregate distribution and finish characteristics.

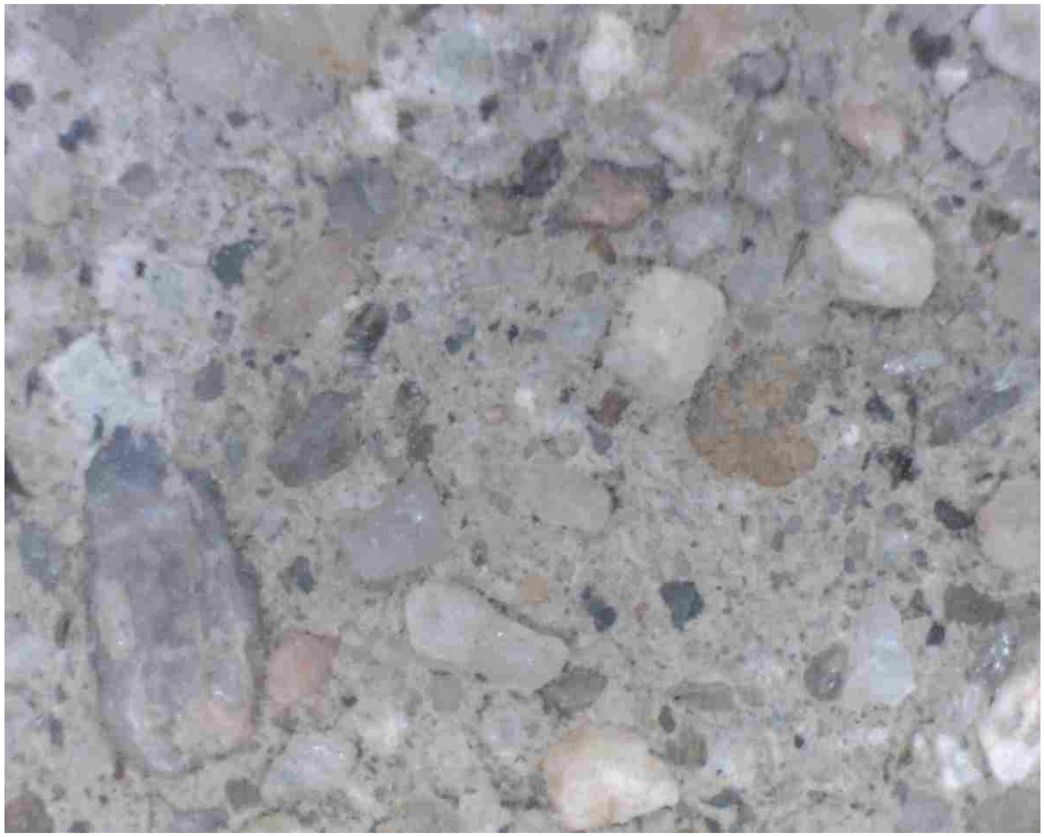

Figure 5. Digital microscope image of historic concrete surface.

A scanning electron microscope (SEM) in conjunction with x-ray analysis was used to determine the chemical make-up of a sample of the historic concrete. SEM testing and analysis was performed by Dr. Adrian J. Brearley, Earth and Planetary Science Department, University of New Mexico. The primary investigation for the use of the SEM was to analyze and determine the source for the green coloring of the concrete. In order to eliminate false readings due to chemicals adhering to old finished surfaces of the bench, the outer surface areas of the historic concrete were not used in the sampling. Only internal surfaces, exposed after breaking up the bench were used. The initial photo was taken from an internal exposed surface (Figure 6). Surface particles were analyzed for chemical composition.

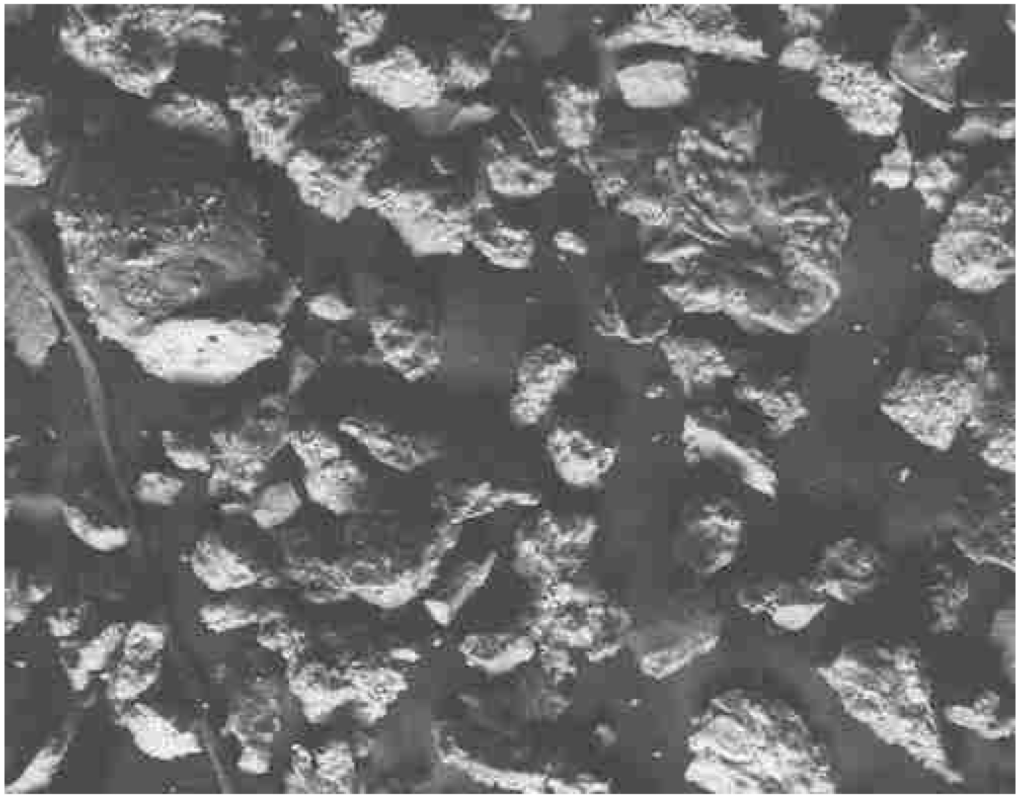

Figure 6. SEM image of historic concrete surface (Source Dr. Brearley).

Petrographic analysis was performed on samples taken from the bench and sent to DRP, A Twining Company, under the direction of Dr. David Rothstein. Testing of the historic concrete included light photomicrographs, aggregate composition, and phenolphthalein test for carbonation, calcite test, and ASR. Photos were taken in cross-polarized light and plane-polarized light. An example of plane-polarization is shown in Figure 7.

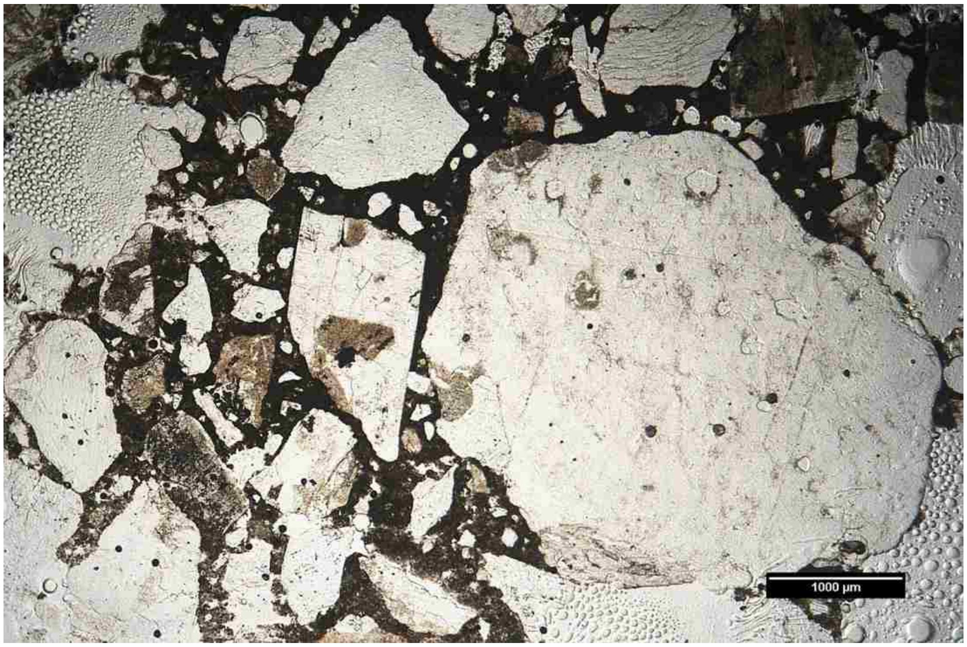

Figure 7. Petrographic analysis in plane-polarization (Source: DRP).

Color analysis was performed at L.M. Scofield Company. The findings of the color scan were matched with commercial dyes to produce a color sample. It was determined the color needed to produce the dye for new concrete mix designs was pure chromium oxide. A sample of the dye color was produced by L.M. Scofield for consideration (Figure 8).

Non-destructive testing using the rebound hammer to determine the strength of the hardened concrete was performed using ASTM C 805-97 methods and ACI 228.1R-03. The methodology of using the rebound hammer provided an estimated strength of the present condition of the historic concrete in order to design a new concrete mix best suited for repair or replacement of picnic tables and benches. Calibration of the rebound hammer was conducted at the UNM civil engineering department's concrete lab while the testing of the historic concrete was performed on the same day of calibration at the site of the broken bench in the national forest.

Figure 8. Concrete dye sample.

3.4. Development of New Concrete Mix Design

The final step was determining a new concrete mix design in order to restore the tables and benches to their original characteristics and performance requirements. This step was performed in the University of New Mexico, Department of Civil Engineering concrete lab and consisted of testing several mixes. From the information found in the literature review, the first mix design was a mix ratio of Portland cement to sand to aggregate of 1:2.25:3.25 with a compressive strength (f'_c) of 2,500 psi and a w/c of 0.79 (Merriman & Wiggin, 1930). From samples taken from the broken bench, a visual observation indicated only very small aggregate was used in the historic concrete. This observation was further clarified with the digital microscope. The largest pieces of aggregates were no greater than 3/8 inch (9mm), with a majority of the aggregates in the 1/16 inch (2mm) to 1/8 inch (3mm) range. For the new concrete mix, local washed aggregates were sieved to retain 3/8 inch minus. Local washed sand was also used in the mix design. The Portland cement used for all batches of the various mix designs was a Type I, II, low alkaline cement sold in the Albuquerque area due to the high alkaline naturally found in the soils. Small batches of 0.25 cubic foot (0.007 m3) concrete mix were assembled, cured, and tested under ASTM C192 and C39 standard performance criteria.

Data collected from the rebound hammer, using ASTM C 805-97 procedures, from 10 test locations on a large piece of the broken bench in the vertical down position at the site, produced a mean compressive strength of 4,600 psi (32MPa) and a sample standard deviation of 396 psi (2.7 MPa). Limitations as to the accuracy of the rebound hammer are discussed in detail by ASTM C 805-97 and ACI 228.1R-03. Factors including carbonation, surface conditions, type of course aggregate, and type of cement influence and can significantly affect reliability of the hammer and readings (Hannachi & Guetteche, 2014). Finding from the petrographic analysis indicate the broken bench samples were carbonated throughout the 4-inch (100mm) thickness of the slab. ASTM C 805-97 states data is not available on the relationship between rebound number and thickness of carbonated concrete. Hannachi & Guetteche (2014) also state carbonation of concrete significantly affects the rebound hammer results; up to 50% higher than that of an un-carbonated surface. Core samples were not taken on the broken bench due to the remoteness of the project location and economic factors. Taking the information of carbonation from the reports given, estimated compression strength of the historic concrete currently at the site is approximately 3,067 psi (21MPa).

The new concrete mix design incorporated Type I, II LA cement. Modern Type I cement is the closest in chemical formula to cement manufactured in the 1930's. Due to the high alkaline conditions found in the Albuquerque area, Type I is not used or readily available for concrete construction. Type I,II LA is specifically manufactured for use in northern New Mexico by the plant located near Albuquerque

The first mix design, using mix proportions replicating information found in the Handbook, was labeled Batch 1. Each subsequent mix design was adjusted for quality and strength. Batch 2 reduced the w/c to 0.59 and used aggregates sieved for 3/8 inch (9mm) to #20. All materials passing #20 were eliminated for quality of the cured mix to have the appearance of the historic concrete. The final mix, Batch #3, increased the Portland cement content for early high strength. Due to the remoteness and unsecured area of the picnic tables, an early strength was produced to achieve greater than 2,500 psi (17 MPa) on the first compression test break at 7-days. Large wild animals, including bears and mountain lions, roam the national forest unchecked. The site possessed no feasible course of action to protect the concrete forms from unintended consequences. A small volume of Batch #3 was made due to the limited amount of aggregates remaining.

The final step in the concrete lab was to match the green color of the historic concrete (Figure 9) using the Batch #3 mix design. With each concrete mix, a measured amount of a green dye was added and cured in two-inch cube molds. The amount of dye added to subsequent mixes and cured depended upon the results of the previous batch after curing and unmolding then compared to the color of the historic concrete. Three batches of color-dyed cubes were produced in all (Figure 10). Mix #1 used 18 oz./ft^3 (18 kg/m^3), mix #2 used 7.2 oz./ft^3 (7.2 kg/m^3), and Mix #3 used 3.6 oz./ft^3 (3.6 kg/m^3) to develop the samples for the new concrete that would match the historic concrete.

Figure 9. Sample of historic concrete from broken bench.

Figure 10. Color dyed cubes.

3.5. Methodology Summary

The methodology used throughout the process to determine what materials were used in the historic concrete and creating a new concrete mix design that possessed the same characteristics and performance requirement were achieved using modern technology, non-destructive testing, and laboratory experiment. Subsequent chapters will present the results of testing of the new concrete mix designs and conclusions as to how research and technology played a vital role in order to meet the challenge of preserving the CCC picnic tables for future generations.

CHAPTER 4: FINDINGS

4.1. Overview of Findings

This chapter examines the findings from literature review, current methods in restoration, and all tests performed on the samples of concrete retrieved from the broken bench. Literature review findings exposed the ways and means of the Portland cement manufacturing as well as concrete methods and standards. In addition, the literature review disclosed the use of admixtures and construction methods pertinent to the era the picnic tables were constructed. The tests included digital microscope, SEM, and petrographic analysis along with laboratory trial concrete mix designs. Digital microscope and trial concrete mix designs were performed in the UNM Civil Engineering Department's concrete laboratory. SEM was executed in the UNM Earth and Planetary Science Department by Dr. Adrian J. Brearley, while petrographic analysis was examined by DRP, a Twining Company, under the direction of Dr. David Rothstein by Taylor van Hoorebek, MS, Petrographer and Gaines Green, Petrographer/Lab Supervisor in Boulder, Colorado.

4.2. Literature Findings

Information obtained through the literature review revealed the materials used for concrete construction consisted of Portland cement, fine aggregate, course aggregate, and water with the availability of admixtures including pigmentation. Mix designs were based on the structure to be built and weather conditions imposed on the structure. A basic concrete design with proportions of 1:2.25:3.25 and a w/c of 0.79 would produce a compressive strength of 2,500 psi for all weather condition with moderate frost and water.

This information was used as the basis for the new concrete mix design. Admixtures of pigmentation, including chromium oxide, were patented and available in the 1930s when the picnic tables were constructed. Calcium chloride was used during this period to provide early strength.

Findings from the restoration, remediation, and preservation literature exposed factors that cause deterioration in concrete structures. The factors included environmental, inferior materials, poor workmanship, design defects, and inadequate maintenance practices. The success of restoration depended on the degree of damage, skill and expertise of the workers, and the costs to the owner. Successful restoration, remediation, and preservation of a concrete structure are dependent on the decision made if the project is technically feasible and economically sensible.

Technology has been used to probe the depths of concrete since the early 1970s. SEM and petrographic analysis have provided insight as to the materials used in concrete construction and the defects uncovered when structural failure occurs. Non-destructive tests provided data on the estimated compressive strength as the historic tables stand today.

4.3. New Concrete Mix Design Findings

Three batches of concrete mix designs were produced. The three batches were mixed using the information found in chapter 3.4. All three concrete mix designs are given in pounds of material per cubic foot (lb./ft^3) and results of the compression tests, conducted under ASTM C39, are found in Table 1. Batch #1, the 1930s mix design, required the full 28 days to reach the desired 2,500 psi (17 MPa). Batch #2, modified to a w/c of 0.59, and produced a compressive strength of 2206 psi (15 MPa) on day 7 and 2,401 psi (16.5 MPa) at the 14-day break. The final mix, batch #3, was first reduced by 75% in all amounts due to the limited quantity of fine and course aggregates remaining then the Portland cement content was increased by 25% in order to test for a higher early strength for use in restoration with the current estimated strength of the concrete found with the rebound hammer testing. The 28-day compression test for batch #2 was not completed due to time constraints with the use of the lab. Testing of batch #3 was completed after the 7-day compression test because it exceeded the historic equivalent mix compression strength of 2,500 psi (17MPa), produced a 0.98f'c of the estimated current strength from the rebound hammer tests of 3067 psi (21MPa), and again time constraints for use of the lab.

Table 1. New Concrete Mix Design and Compression Test Results.

Batch No.	Portland Cement lb./ft^3	Fine Agg. lb./ft^3	Course Agg. lb./ft^3	W/C	7-day Test psi	14-day Test psi	28-day Test psi
1	32	72	104	0.79	1838	2422	2585
2	32	64	96	0.59	2206	2401	N/A
3	40	64	96	0.59	3015	N/A	N/A

4.4. Digital Microscope Findings

Samples from all three batches were evaluated using a digital microscope after each of their 7-day compression tests and these images were compared with the historic concrete surface image. The images were compared in order to evaluate the characteristics of the new mix in relation to the historic concrete (Figure 11a) for particularities required for the finished surface of the restoration. The image of batch #1 (Figure 11b) displayed excess amounts of exiguous course aggregate. The sample broke apart easily. This initiated the elimination of course aggregate passing the #20 sieve. The image of batch #2 (Figure 11c) presented qualities closer to the historic image for the course aggregate however the distance between aggregates were to close. From the finding of batch #2, the change to batch #3 (Figure 11d) increased the amount of Portland cement in the mix design.

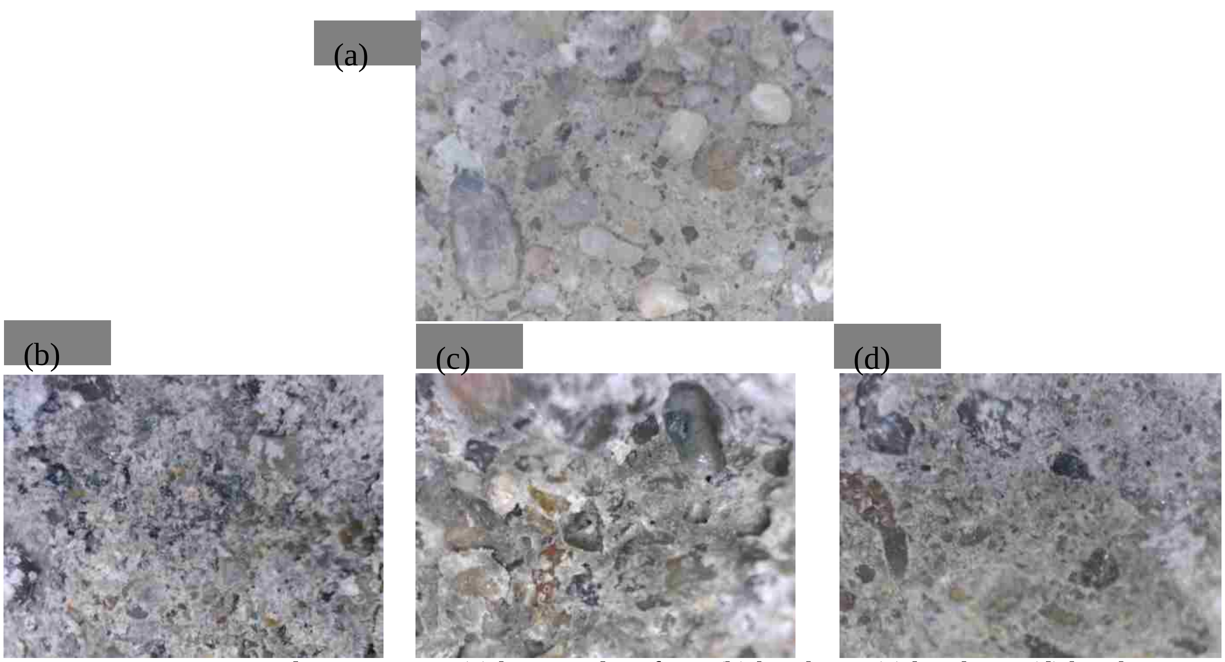

Figure 11. Digital microscope; (a) historical surface; (b) batch #1; (c) batch #2; (d) batch #3.

4.5. SEM Findings

The scanning electron microscope's primary mission was to evaluate and determine what made the historic concrete green. The SEM in conjunction with x-ray, provided by Dr. Adrian J. Brearley of the Earth and Planetary Science Department at the University of New Mexico, scrutinized a small fragment taken from a sample from the broken bench. Discussion with Dr. Brearley of his findings with the SEM ascertained the presence of a multitude of elements including aluminum, calcium, carbon, calcium carbonate, iron, magnesium, oxygen, silicon, sodium, and sulfur.

The most noteworthy discovery SEM provided was the existence of chromium (Figure 12) in the sample. The image highlights the chromium as bright green in color. The finding indicated a chromium amount in excess of what is natural. In addition, chromium and calcium carbonate were found together, in close proximity to each other, throughout the fragment. According to Dr. Brearley, the unnatural occurrence of chromium and calcium carbonate required an external introduction of the chromium into the sample taken from the broken bench.

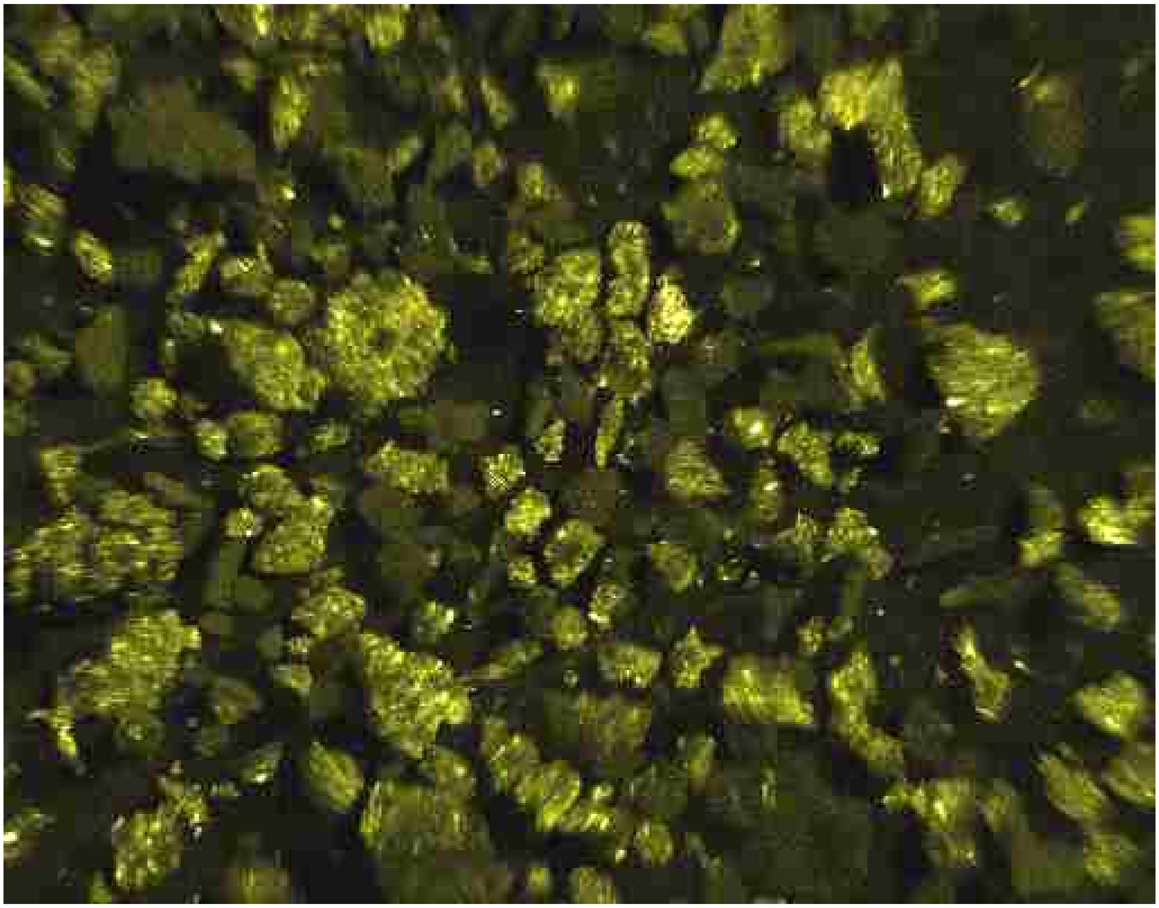

Figure 12. SEM image of chromium (Source: Dr. Brearley).

4.6. Petrographic Analysis Findings

Petrographic analysis of the material was performed by DRP, a Twining Company, (DRP emails, October 16, 2017) at their laboratory in Boulder, Colorado. The results of this analysis and accompanying photomicrographs detailed the findings.

The sample was polished and thin sliced before testing (Figure 13). Photos were taken in cross-polarized light (xpl) and plane-polarized light (ppl). Analysis of the historic concrete proved problematic and time consuming due to the age of the samples and weathering. When quality samples were achieved for the thin section required for the tests, the following information was given:

- Cement is typical of a historic Portland cement with large nests of belite in the paste
- Cement paste contained hydrated Portland cement with no fly ash, slag cement or other supplemental cementitious material
- Concrete is non-air-entrained but numerous entrapped voids and water voids were observed and mostly free of secondary deposits (Figure 14)
- Void spaces were seen due to the age and weathering of the Portland cement paste which took on a muddy appearance in xpl. (Figure 15)
- Coarse aggregate was natural pea gravel with a nominal 3/8 inch (9.5mm) top size
- The course aggregates are siliceous in composition and consist of quartzite, quartz, feldspar, limestone, chert, siliceous volcanic rock, and greywacke (muddy stone)
- Quartize, chert and siliceous volcanic rocks potentially susceptible to ASR
- Fine aggregates are natural sand similar to course aggregates which indicate they came from a common geological source
- The phenolphthalein (phenol) test indicated highly carbonated (Figure 16)
- Very little calcite observed which implies the sample is old and extremely weathered
- Very minor deposits of ettringite were observed
- Aggregate is in good condition and did not show any signs of chemical attack or chemical reaction with the other concrete ingredients, ASR, in xpl (Figure 17)

The petrographic analysis further noted that although ASR is well-known durability issue in northern New Mexico, no evidence of reactions was observed on any of the samples. The report continues the findings may reflect initially low alkali content of the concrete and/or the pervasive carbonation of the concrete, which reduces pH to levels below that which ASR occurs.

Carbonation throughout the depth of the historic concrete was determined by the phenolphthalein test. As discussed in section 3.2, concrete over time draws in CO_2 from the atmosphere and a chemical reaction occurs when it encounters the alkaline hydrates of the concrete and dissolves in the concrete pore water. Corrosion of the embedded reinforcing steel was present within the broken bench used for testing samples.

Figure 13 Sample polished and thin sliced for testing (Source: DRP).

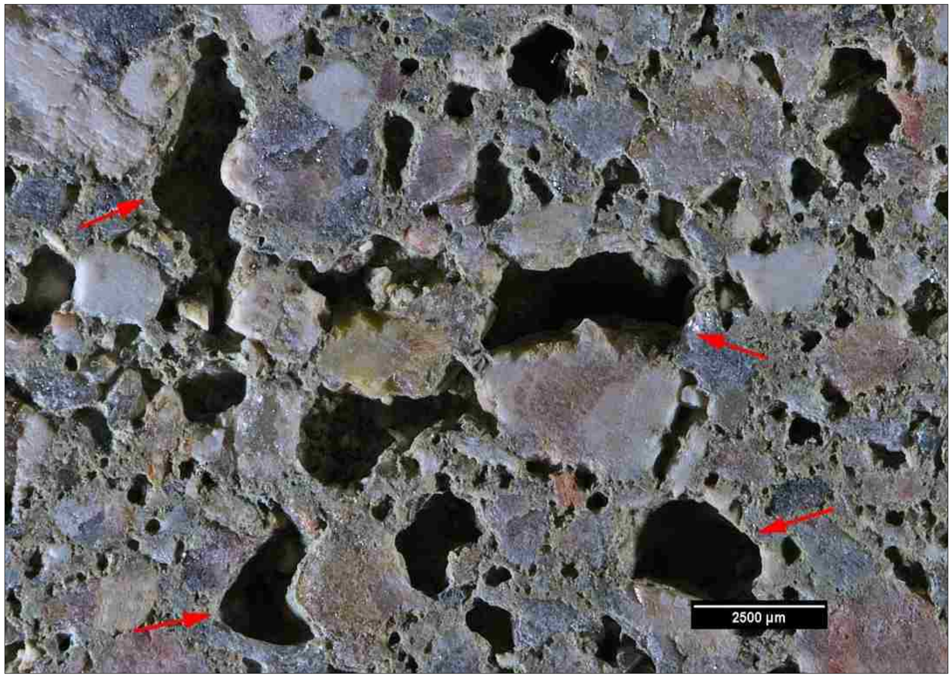

Figure 14. Entrapped voids (Source DRP)

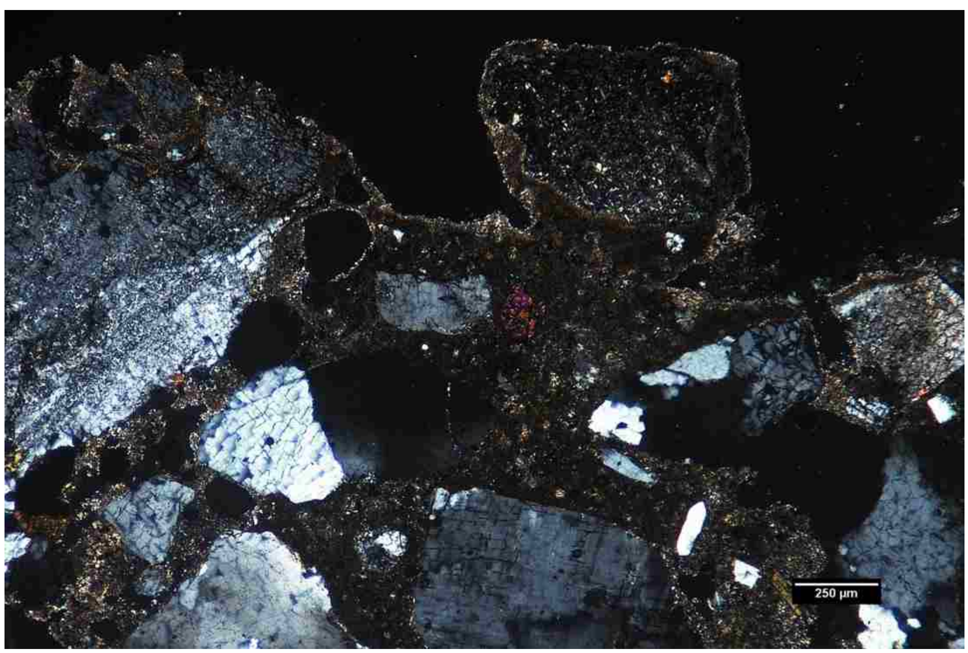

Figure 15. Aged and weathered Portland cement paste (Source: DRP).

Figure 16. Phenolphthalein test, no staining (Source: DRP).

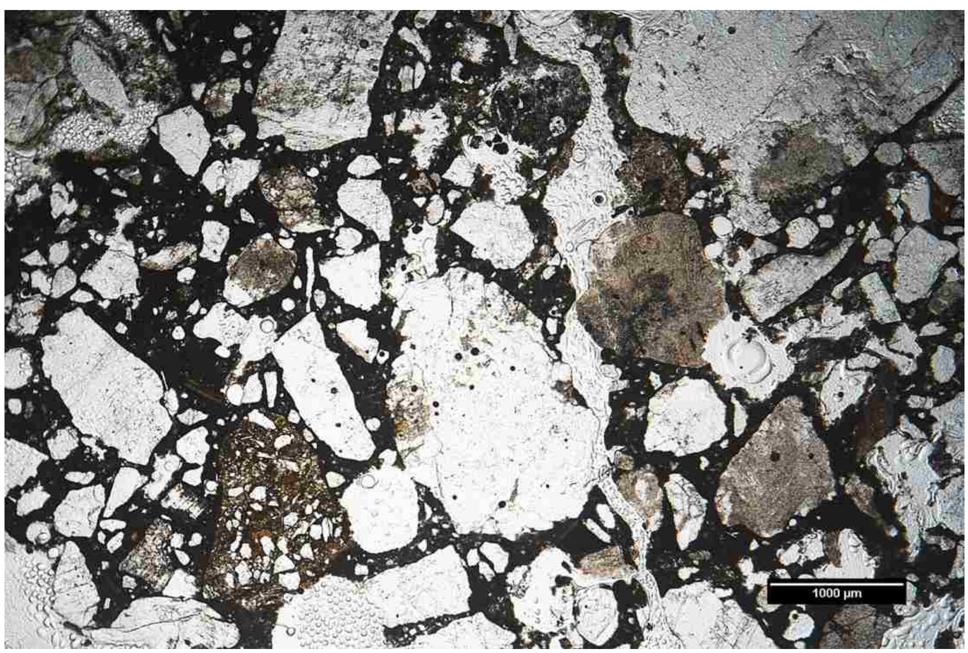

Figure 17. Aggregate with no signs of ASR (Source: DRP).

4.7. Color Dye Analysis Findings

The historic concrete sample was sent to L.M. Scofield Company for analysis of the original color. The testing and investigation into a comparable color dye, using new material to match the historic concrete, came up with pure chromium oxide (Figure 17).

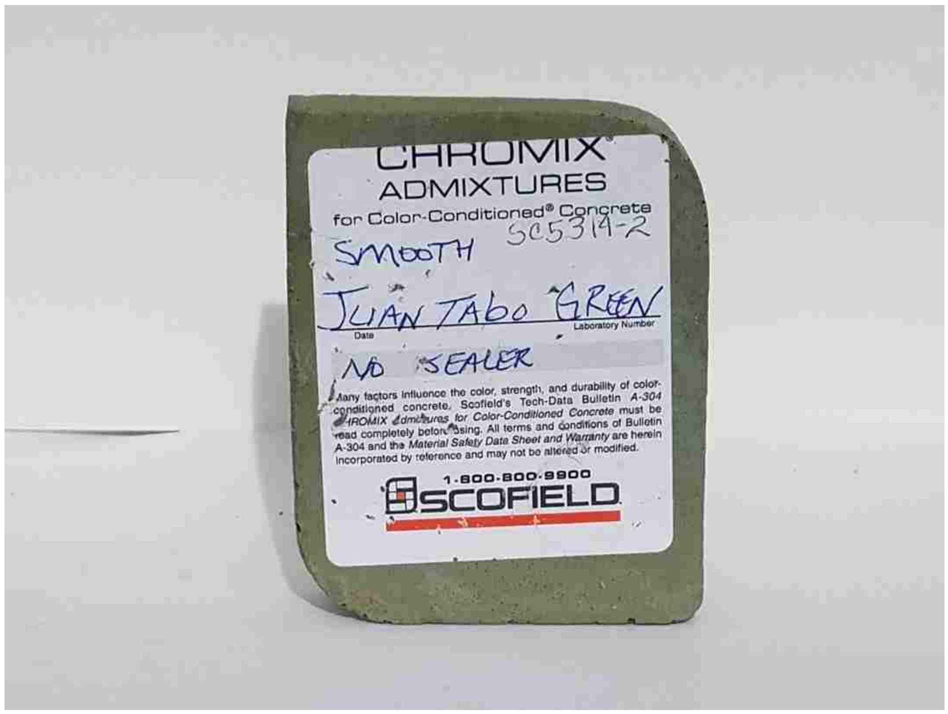

Figure 18. Concrete dye color match using chromium oxide.

4.8. Findings Summary

Discoveries in this chapter culminate the work required to answer the research questions. A new concrete mix design was confirmed in strength, composition and texture. Color dye used in the historic mix was shown to possess the same chemical compound as dyes patented in the period the picnic tables were constructed. ASR was not found in the samples tested thus preserving the integrity and performance of the tables and benches from deterioration. Finally, the tables could not escape time and the environment as carbonation creeped deep into the concrete.

CHAPTER 5: DISCUSSION OF RESULTS

5.1. Review of Research Questions

Two research questions were presented at the beginning of this paper. The first question guided the exploration of historic findings and the remarkable yet curious observations of the picnic tables' condition after decades in the desert sun and mountainous snows. The second question required examination and testing to identify a new concrete mix design capable of restoring the historic picnic tables to their performance requirements. The answers were found.

5.2. Research Question 1

What construction methods were used in Albuquerque during the 1930s such that the technology and materials in that era show no signs of deterioration in the structures?

Portland cement was manufactured and used during this period for construction of concrete structures. Admixtures of calcium chloride were used to accelerate the curing process. Chromium oxide, a green concrete pigment, was patented by the US Patent Office. Albuquerque soils and aggregates tests high on the pH scale for alkalinity that caused ASR in concrete.

Concrete in the Albuquerque area requires low alkaline Portland cement along with fly ash, lithium nitrate, or other chemicals to reduce the effects of alkaline-silica reaction. ASR was not found in the samples tested under petrographic analysis. The aggregates showed no signs of the ASR gel. The condition of the aggregates was good and did not show any signs of chemical attack or chemical reaction with the concrete ingredients.

Carbonation was found throughout the samples tested. Time, precipitation, and environmental conditions contribute to the chemical change to the concrete and eventually creep into the reinforcing steel causing corrosion. Precipitation is a minimal factor contributing to carbonation due to the dry high desert climate where the tables are located in Albuquerque. The picnic tables are also located in a remote area, high on a mountainside, away from high concentration of carbon dioxide as noted for environmental contributions to carbonation.

Chromium was detected in the historic broken bench sample by the SEM. Pure chromium oxide was the recommended dye by the L.M. Scofield laboratory in order to match the historic concrete's character.

The findings from the literature review, methodology for a new concrete mix design, and the compression testing of batch #1, based on the Handbooks information for a 2,500 psi (17MPa) with w/c of 0.79 developed a feasible mix for constructing new picnic tables to replace the historic tables and benches that are beyond repair. Although batch #1 required the full 28-days of curing to obtain the 2,500 psi strength, the 1930s mix proportions of 1:2.25:3.25 produce a new concrete with the expected strength.

The picnic tables located in the Cibola National Forest are in excellent condition, except for the vandalism scars, and do not display any symptoms of ASR. Confirmations of the findings are listed on Table 2. Further research is needed to determine if ASR was prevented due to any one or a combination of factors that were also present in the historic concrete.

Table 2. Materials used in Historic Concrete and Concrete Condition

Methods and Materials 1930s	Literature Review	Materials Found in Historic Conc.	Attributes to Concrete Conditions
Portland cement	Merriman, T. & Wiggin, T.H. 1930	Portland cement Petrographic analysis	Historical Portland cement with no supplemental cementitious materials
Calcium Chloride	Abrams, D.A. 1924	NA	NA
Chromium oxide	Low, F. 1929 patent	Chromium SEM	Green color dye retained original characteristics
Aggregates	Merriman, T. & Wiggin, T.H. 1930	Natural to the site. Quartzite, chert and volcanic rock susceptible to ASR Petrographic analysis	No ASR present
Reinforcing Steel	Merriman, T. & Wiggin, T.H. 1930	Visual	Carbonation and corrosion on rebar without further damage
Remote high desert site	Melzer, R. 2000	Visual	Carbonation over time
Mechanical vibration	Powers T.C. 1933	Entrapped voids and water voids Petrographic analysis	No method of mechanical vibration accessibility. Non-air-entrained concrete, no freeze-thaw damage

5.3. Research Question 2

What mix design, using technical advances in the Portland cement and concrete industry, will repair, or replicate the concrete in the historic tables and benches and return them to their original performance requirements and color?

The literature review provided the basis for the new concrete mix design. Laboratory trials, compression testing, and digital microscope comparisons contributed to a mix design that will obtain an early high strength and mimics the characteristics of the finished historic concrete (Figure 19). Color evaluation and SEM provided the connection to the chromium oxide pigments patented in the era. Petrographic analysis proved ASR was not present in the historic concrete but ASR is a modern day problem with concrete in the Albuquerque area.

Three mix designs were produced to provide the data required to determine the optimal new concrete mix for the project. As discussed earlier in this section, batch #1, using information from the Handbook, produced a concrete mix obtaining a 28-day strength of 2,500 psi (17MPa). Although the strength was achieved with the 1930s proportions, examination by the digital microscope indicated the visual characteristics of batch #1 were not similar to the historic concrete. The amount of fine aggregates in batch #1 exceeded that which was seen in the historic mix. The proportions of 1:2.25:3.25 for batch #1 developed the required strength but failed in the visual attributes of the finished product.

Batch #2 was developed from the information taken from batch #1 by adjusting the proportions of aggregates and w/c ratio. The excess amounts of visual grains of small aggregates were eliminated by discarding course aggregates that passes the #20 sieve. The proportions for batch #2, 1:2:3, adjusted the amounts of both coarse and fine aggregates to improve the visual characteristics of the finished mix. A w/c of 0.59 was used in batch #2 to test for increased compressive strength. Added benefits of a reduced w/c include increased durability and resistance to weathering. This would be a benefit in the high desert and mountainous climate the historic picnic tables are located. Compression tests on batch #2, with the w/c of 0.59, initially showed a higher early strength at 7-day but quickly diminished by the 14-day break with results less than that of batch #1 at the same time period.

The non-destructive rebound hammer testing of the historic concrete, although documented as problematic for aged and carbonated concrete, produced an estimated current strength between 4,600 psi (32MPa) to 3,067 psi (21MPa) for 50% higher than that of un-carbonated concrete surfaces. Batch #3 was developed to be a higher strength material, than batch #1 and #2, in order to repair the picnic tables with a comparable concrete mix. Using the aggregate proportions from batch #2, and increasing the amount of cement by 25% and the water content to maintain a w/c of 0.59, batch #3 tested at the 7-day break to 3,015 psi (20.8 MPa) or $0.98f'_c$ of the estimated current strength. Although the full 28-day testing was not accomplished due to constraints with use of the concrete lab, batch #3 is a vital mix design for restoration of the historic picnic tables in comparable strength and visual characteristics.

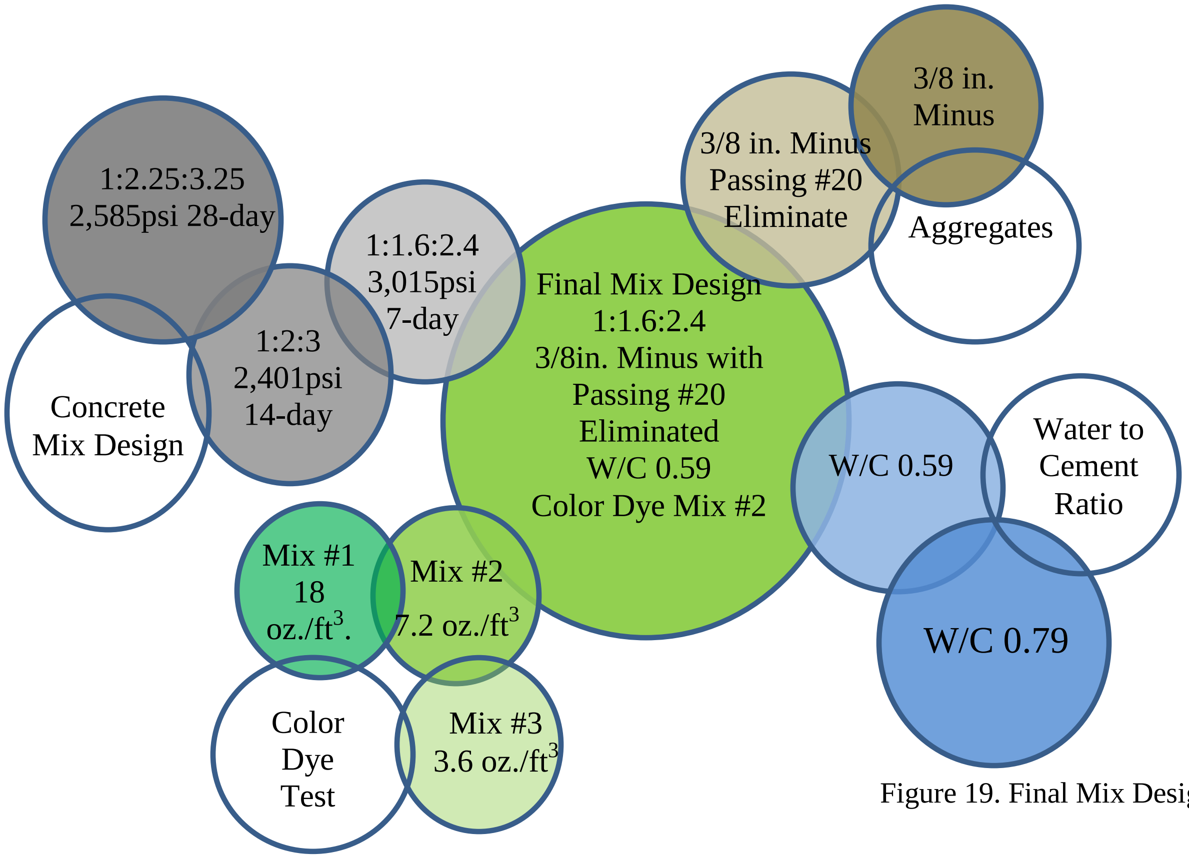

Figure 19. Final Mix Design

Further study and research needs to happen before the restoration of the picnic tables takes place. Could the new concrete, with the ASR factors, induce a reaction to the historic concrete that is free of ASR? What bonding agent should be used to shield the historic from the new?

While the results answered the research questions, they also brought about additional question.

CHAPTER 6: CONCLUSION

When restoration is required on an historical concrete structure and historical documents are not available as to the materials and methods in construction; a combination of research of that era and advanced technology can provide the information needed. Portland cement and concrete evolved throughout the 19th and 20th centuries as the country experienced rapid growth. Standardization, testing, and construction methods evolved and improved the industries into the 21st century. The picnic tables have stood the test of time and the environment due to the materials used during the period and the workmanship of the CCC even under the conditions of the Great Recession.

Portland cement, w/c ratio, mix proportions, chromium oxide patents, and admixtures found in the historical documents were used as the starting point for discovery of a suitable new concrete mix to restore the tables and benches. Digital microscope, SEM, color analysis, and petrographic analysis technology confirmed the materials and exposed the absence of ASR.

The research questions were answered using the literature and technology to detect and confirm each other. As the findings evolved, more questions developed. The future of restoration and preservation for concrete structures requires involving both historical research and technology in order to produce the optimal concrete design.

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