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Temporal and Spatial Variability in Base Materials Treated with Asphalt Emulsion

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Temporal and Spatial Variability of Base Materials Treated with Asphalt Emulsion

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

Temporal and Spatial Variability of Base Materials Treated with Asphalt Emulsion

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The first objective of this research was to investigate temporal trends in the mechanical properties of base materials stabilized with asphalt emulsion and to assess the rate at which emulsion-treated base (ETB) design properties are achieved. The second objective of this research was to identify construction and environmental factors most correlated to specific mechanical properties of ETB layers and to determine which construction factors exhibit the greatest variability. Additional statistical analysis was performed to determine if significant differences existed between different test sections on a given project.

In this research, three experimental sections were established along a pavement reconstruction project near Saratoga Springs, Utah. Field tests were performed to assess the structural properties of the ETB immediately following construction and at 2, 3, 7, and 14 days; 4 months; and 1 year. Measured values were plotted against time to determine trends in ETB strength development. Several statistical analyses were then performed on the collected data.

Modulus values were consistently low in all three sections during the first two weeks of testing, increased dramatically by 4 months, and then decreased considerably by 1 year. During the first two weeks following construction, the average ETB structural coefficient was 0.04. Only two of the three sections reached the design structural coefficient of 0.25, which occurred after approximately 3 months; however, the average structural coefficient measured for all three sections after 1 year of curing, which included a winter, was only 47 percent of the design strength. The results of this research show that, while pavement capacity is sufficient at 4 months, it is severely reduced during the first two weeks and at 1 year. Trafficking under these reduced capacities is not recommended.

Statistical analysis showed that gradation, binder change during emulsion treatment, and moisture content have the most significant impact on ETB structural properties. Gradation and binder change during emulsion treatment also exhibited significant variability; tighter specifications on material gradations and improved uniformity in emulsion distribution should therefore be considered. Because of the negative impacts of moisture on ETB strength development, construction should not be performed in conditions of excess moisture.

Key words: asphalt emulsion, Clegg impact soil tester, dynamic cone penetrometer, emulsion-treated base, modulus, portable falling-weight deflectometer, reclaimed asphalt pavement, soil stiffness gauge, spatial variability, stabilization, stiffness, strength gain, temporal variability

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1 INTRODUCTION

1.1 Problem Statement

Full-depth reclamation (FDR) has become increasingly prevalent in the transportation industry during the last few decades as a means of rehabilitating and reconstructing flexible pavements (*1*, *2*). The FDR process involves recycling of the existing pavement structure by milling the in-place asphalt layer into the upper portion of the existing base to form a new base layer. FDR provides a feasible solution to problems such as pavement geometry restrictions, lack of quality aggregate, and the cost of asphalt disposal (*3*); however, the reclamation process can cause a reduction in the strength of the base layer because it disturbs the existing base material and mixes reclaimed asphalt pavement (RAP) into the base material, which has been shown to decrease the bearing capacity of some base materials and possibly impede proper compaction of the base material (*4*, *5*). For these reasons, stabilization is often needed to improve the structural properties of reclaimed base materials (*5*). One product that has been used in road stabilization since the early 1900s is asphalt emulsion (6). The application of asphalt emulsion is an easy method for adding asphalt binder to road base during the reclamation process. The resulting product, emulsion-treated base (ETB), may then be surfaced with a wearing course for trafficking.

Several studies have been performed to assess the long-term strength of ETB in the field. In pavement tests performed six months or more following pavement reconstruction, Illinois

Department of Transportation personnel measured resilient modulus values as high as 200 ksi, and researchers at the Texas Transportation Institute measured resilient modulus values as high as 275 ksi (*1, 2*). Although these studies have determined that long-term ETB strengths are sufficient to support even heavy traffic loads, little research has been performed to determine the rate at which ETB develops strength in the period between construction and the time that ETB design properties are achieved. In particular, the ability of a pavement to withstand early trafficking depends on the strength developed in the pavement system immediately following construction. If the strength of the pavement system is not sufficiently high before traffic is reintroduced, early trafficking will cause permanent deformation in the treated layer, compromising long-term pavement performance. Furthermore, if the ETB does not reach design strengths for an extended period of time, continued trafficking may cause premature failure of the pavement system. For these reasons, an understanding of early strength development in ETB is vital for pavement engineers interested in utilizing FDR in conjunction with emulsion treatment. The first objective of this research was therefore to investigate temporal trends in the mechanical properties of base materials stabilized with asphalt emulsion and to assess the rate at which ETB design properties are achieved.

Many factors such as moisture content, aggregate gradation, and temperature have been shown to influence the mechanical properties of ETB (*1, 6, 7, 8*). Consequently, variability in these factors can cause variability in pavement structural capacity, ultimately reducing the reliability of the pavement system and leading to premature failure of some sections. Development of improved specifications governing construction of ETB layers requires an understanding of the factors that most directly influence ETB performance and identification of those that are most variable; however, a thorough study on this subject has not been performed.

Therefore, the second objective of this research was to identify construction and environmental factors most correlated to specific mechanical properties of ETB layers and to determine which construction factors exhibit the greatest variability. Additional statistical analysis was performed to determine if significant differences existed between different test sections on a given project.

1.2 Scope

The research conducted in this study involved field and laboratory evaluations of both temporal and spatial variability in properties of ETB. Field testing was performed on a test site located just north of Saratoga Springs, Utah. The experimental area was divided into three 800-ft by 24-ft test sections, each containing 10 individual test stations randomly located throughout the section. The field instruments utilized in this research included the portable falling-weight deflectometer (PFWD), dynamic cone penetrometer (DCP), heavy Clegg impact soil tester (CIST), soil stiffness gauge (SSG), and nuclear density gauge (NDG). Field tests were conducted immediately following construction and at 2, 3, 7, and 14 days; 4 months; and 1 year following construction.

Laboratory testing involved moisture content determinations and sieve analyses of untreated material samples, as well as burn-off testing of both the untreated and treated material samples taken from each field test station. In addition, unconfined compressive strength (UCS) tests were performed on one emulsion-treated sample from each test station at 7 days, 28 days, 3 months, and 1 year following construction of the test section.

1.3 Outline of Report

This report contains five chapters. Chapter 1 introduces the problem statement and scope of the research. Chapter 2 provides background information on ETB construction processes and factors that affect ETB performance. Chapter 3 gives a description of the test layout, field and laboratory procedures, and analysis techniques applied in this research. Chapter 4 presents the results of testing and analysis, and Chapter 5 offers conclusions and recommendations based on the findings of this research.

2 BACKGROUND

2.1 Overview

The following sections provide background information obtained through a literature review on ETB construction processes, ETB strength gain, construction and environmental factors affecting ETB performance, and the effects of early trafficking on ETB.

2.2 ETB Construction Processes

The process of FDR with emulsion stabilization begins with the pulverization of the existing asphalt layer with a specified thickness of the underlying base material. Partial milling of the existing asphalt layer may be needed before reclamation to ensure uniform RAP contents within the reclaimed base layer (*8*). The reclaimed material is then graded and compacted to approximate final elevations before emulsion treatment (*9*). Water can be added during the initial reclamation process to facilitate uniform distribution of the emulsion (*10, 11*). Emulsion is then injected into the base material using a reclaimer and mixed to ensure uniform distribution. Figure 2-1 shows the emulsion injection process. Additional water can be added during injection as needed to reach the optimum moisture content of the ETB material. The treated base is compacted using sheep’s foot rollers or vibratory breakdown rollers. Figure 2-2 shows the compactors following directly behind the reclaimer. Following compaction, the ETB is graded

Figure 2-1: Injection of emulsion.

Figure 2-2: Compaction of emulsion-treated base.

and finish-rolled. Paving of the ETB is delayed as much as two weeks following construction to allow moisture to escape from the ETB during the early curing process (7, *10, 11*); maximum allowable ETB moisture contents before paving are typically 2 to 3 percent (*11*); however, traffic is often reintroduced immediately following final compaction of the ETB layer, even before paving. If no visually apparent deflections are observed under a heavy truck, the ETB layer is usually judged to be ready for traffic (*10, 11*).

2.3 ETB Strength Gain

Asphalt emulsion is typically considered an oil-in-water emulsion, meaning it consists of asphalt binder particles that are suspended in water through the use of an emulsifier (*6*, *12*). Emulsifiers create charges on the surfaces of the asphalt particles that cause them to repel each other, stabilizing the particles within the emulsion. Asphalt emulsions typically contain between 25 to 60 percent water, 40 to 75 percent bitumen, and 0.1 to 2.5 percent emulsifier (*12*). Solvents are sometimes added to modify emulsion properties and behavior. The specific composition of an asphalt emulsion determines emulsion characteristics such as reactivity, viscosity, and stability.

The process of curing involves the gradual evaporation and expulsion of water from the emulsion. Curing of ETB begins when the emulsion begins to destabilize due to compaction and water evaporation (*7*). During compaction, the asphalt particles are forced together, causing them to overcome static repulsion and begin to coalesce into larger asphalt droplets. The asphalt droplets eventually become large enough to bind aggregate particles together. The rate of curing depends on several factors, including the reactivity of both the emulsion and the aggregate, emulsion chemistry, and environmental factors such as wind speed, humidity, and temperature (*7, 13*). Compaction or trafficking of the ETB can increase curing rates by forcing asphalt particles closer together (*12*).

Curing to the design strength may require from a few weeks to a couple of years depending on the properties of the emulsion used (*7, 12, 13*). ETB exhibits low strengths immediately following construction due to the lack of curing in the emulsion. One study found that the stiffness of ETB after compaction was actually lower than the reclaimed material before emulsion treatment (*14*); however, ETB layers have been found to exhibit large increases in resilient modulus during the first 28 days of curing (*15, 16*). Others have measured a 300 percent increase in resilient modulus during the first 10 months (*17*). The Asphalt Institute (AI) suggests that ETB remains relatively weak during the first month following construction, stiffens dramatically for the next few months, and then levels out after approximately 6 months. The AI has also found that curing times longer than 6 months do not significantly increase ETB strength (*18*). Other studies have found that ETB can take as long as 2 years to fully cure (*13*). These results show that, although the final strength of ETB can be very high, the ETB layer remains fairly weak during the period of time immediately following construction while the emulsion is curing.

2.4 Construction Factors Affecting ETB Performance

Several construction factors can affect the performance of ETB materials. Some of these factors include gradation, strength of subgrade, degree of ETB compaction, and total moisture content (TMC) of the ETB.

The gradation of the reclaimed base material before emulsion treatment can impact ETB strength (*8*). The fraction of material passing the No. 200 sieve should be less than 25 percent to avoid weakening the ETB (*6*). Therefore, the inclusion of portions of subgrade in the reclaiming process can introduce fines into the reclaimed base that may also present problems (*1*).

The subgrade strength is especially important in the period of time immediately following construction (*2*). The stabilized base layer is fairly weak following pulverization and reclamation, so the ability of the subgrade to withstand construction and early traffic loads will greatly affect the support offered to the ETB. The strength of the subgrade will also affect the degree of compaction possible in the ETB (*8*).

The degree of ETB compaction affects strength development in ETB. Compaction can aid in the initial destabilization of the asphalt emulsion but also affects the rate of curing within the ETB. The percentage of voids remaining after compaction should be low enough to prevent water ingress but sufficiently high to allow water to evaporate from the emulsion during the curing process.

TMC includes the in-situ moisture that exists before emulsion injection and the water added during the injection process, including the water contained in the emulsion. If the TMC is not within an acceptable percentage of the OMC for the ETB material, compaction of the ETB layer to the specified density may not be possible. If TMC approaches saturation, compaction of the ETB can be extremely difficult if not impossible. If in-situ moisture contents are such that the addition of emulsion will increase TMC to unacceptable values, the reclaimed material must be allowed to dry before emulsion can be added (*7*).

2.5 Environmental Factors Affecting ETB Performance

Environmental factors such as temperature and moisture content can also affect the performance of ETB materials. Because of the nature of the asphalt material, the structural properties of ETB are affected by ETB temperature (*6, 13, 19*). As pavement temperature increases, the strength of the ETB layer decreases due to the softening of the asphalt binder material (*2*, *20*).

Several studies have found that, during the early stages of curing, excessive moisture contents due to rain or other water sources can cause pavement weakness and even failure (*2*, *21*). After the emulsion has fully cured, the ability of moisture to affect the pavement system is limited, but high moisture contents in the period immediately following construction can slow the curing process and lower the early strength of the ETB (*7*).

Ambient air temperature and relative humidity also affect the rate at which the ETB will cure because they affect evaporation rates. Low temperatures and high humidity will reduce evaporation rates, thus preventing expelled water from being removed from the pavement system and slowing curing rates (*7*).

2.6 Effect of Early Trafficking on ETB Performance

The degree to which emulsion has cured has a large effect upon the stiffness and strength of the ETB during the first two years following construction (*13*). During this time, Permanent deformation is the primary failure mechanism for the ETB layer because the curing process is not yet completed (*12*). Because of the nature of this failure mechanism, the stiffness of the ETB will in large part govern its ability to support traffic loads (*19*). In current pavement design methods, the stiffness of a pavement layer is directly tied to pavement structural capacity. If the layer modulus is low, pavement structural capacity is significantly reduced.

One of the stated benefits of ETB is that the pavement can be opened to traffic within hours following construction (*1, 2, 7, 10, 11, 22)*; however, some ETB projects have experienced severe rutting problems during early pavement life due to the adverse effects of traffic on the weak pavement (*2*, *22*). One study found that the life of a pavement comprised of an ETB layer increases by more than 400 percent when traffic is withheld from the pavement for 48 hours following construction compared to allowing trafficking within 2 hours following construction (*22*).

2.7 Summary

The process of FDR with emulsion stabilization involves the pulverization of the existing asphalt layer with a specified thickness of the underlying base material. Emulsion is injected into the base material using a reclaimer, after which the treated base is compacted, graded, and finish-rolled. Paving of the ETB is delayed as much as two weeks following construction to allow moisture to escape from the ETB during the early curing process. The process of curing involves the gradual evaporation and expulsion of water from the emulsion, which leaves behind just the asphalt binder. Curing to the design strength may require from a few weeks to a couple of years depending on the properties of the emulsion used. ETB exhibits low strengths immediately following construction due to the lack of curing in the emulsion. The performance of ETB materials can be affected by several construction factors, including aggregate gradation, subgrade strength, degree of ETB compaction, and total ETB moisture content. ETB performance can also be affected by environmental factors such as temperature, relative humidity, and moisture. One of the stated benefits of ETB is that the pavement can be opened to traffic within hours following construction; however, several ETB projects have experienced severe rutting problems during early pavement life due to the adverse effects of traffic on the weak pavement.

3 PROCEDURES

3.1 Overview

The following sections detail the site layout, field procedures, laboratory procedures, pavement analyses, and statistical analyses performed during this research.

3.2 Site Layout

The test site chosen for this research was a section of Redwood Road (SR-68) located just north of Saratoga Springs, Utah. This section of Redwood Road was part of a multi-phase reconstruction project. Figure 3-1 shows Redwood Road before reconstruction, and Figure 3-2 shows Redwood Road during the reconstruction process. The pavement design applied to the test section included the use of 1 in. of open-graded surface course on 5 in. of hot-mix asphalt (HMA) on 8 in. of ETB. Construction of the Redwood Road test area occurred in June 2009. The test section was neither paved nor opened to regular traffic for two weeks after construction so that it could dry following a couple of rain storms.

The experimental area was divided into three 800-ft by 24-ft test sections, labeled as sections A, B, and C. Ten individual test stations were established in each of the three sections. These stations were randomly located throughout each test section. The same layout, shown in Figure 3-3, was used for all three sections.

Figure 3-1: Redwood Road before reconstruction.

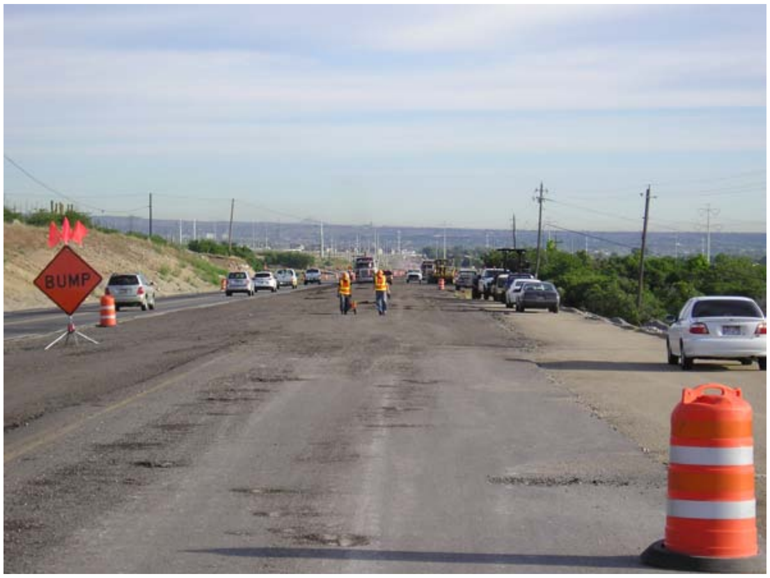

Figure 3-2: Redwood Road during reconstruction.

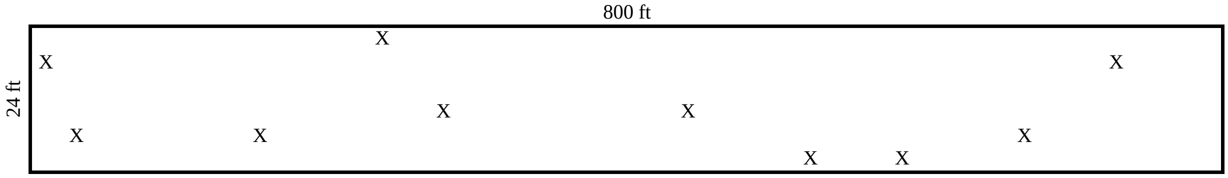

Figure 3-3: Test station layout.

3.3 Field Procedures

Field testing was performed over the course of the project to characterize the in-situ structural properties of the ETB layer. The field instruments utilized in this research include the PFWD, DCP, CIST, SSG, and NDG. Testing was conducted several times following construction of the pavement sections. The first series of field tests were begun within 30 minutes following final compaction of the ETB layer. Additional tests were performed at 2, 3, 7, and 14 days; 4 months; and 1 year. The NDG test was performed on the day of construction to determine compaction and moisture content of the ETB layer but was not repeated on later days. The CIST and SSG tests were performed on each test date through day 14; however, these tests were not performed at 4 months or 1 year due to the presence of asphalt on the pavement section. The stations tested at 4 months and 1 year with the PFWD and DCP were limited to those in the right lane due to constraints associated with traffic control.

The PFWD test shown in Figure 3-4 was performed in general accordance with American Society for Testing and Materials (ASTM) E2583 (Standard Test Method for Measuring Deflections with a Light Weight Deflectometer (LWD)). The PFWD consisted of a 44.1-lb weight dropped 30 in. onto a 7.87-in.-diameter load plate. Three sensors were used to measure pavement deflection at radial distances of 0, 12, and 24 in. from the point of impact. A seating load was applied before actual measurements were taken to ensure that the load plate was

Figure 3-4: Portable falling-weight deflectometer.

properly situated on the pavement surface. Three PFWD tests were performed at each station during each series of testing, and the average deflections were used to backcalculate the modulus of each layer of the pavement system in each case.

The DCP test shown in Figure 3-5 was performed in general accordance with ASTM D6951 (Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications). Penetration rates from DCP testing were used to characterize the pavement layers in terms of mm/blow. In this research, the DCP test was performed to a depth of 31.5 in., which allowed determination of average penetration rates for both the ETB and subgrade layers. One test was performed at each station during each series of testing. Because the DCP cannot penetrate asphalt, holes were drilled through the asphalt layer during the 4-month and 1-year tests to allow DCP tests to be performed directly on the ETB.

Figure 3-5: Dynamic cone penetrometer.

The CIST test displayed in Figure 3-6 was performed in general accordance with ASTM D5874 (Standard Test Method for Determination of the Impact Value (IV) of a Soil). A heavy Clegg hammer, consisting of a 44-lb weight dropped through a height of 12 in., was utilized in this research. CIST testing was used to determine the Clegg impact value (CIV) value of the ETB layer. Three CIST measurements were taken at each station during each series of testing. The SSG test shown in Figure 3-7 was performed in general accordance with ASTM D6758 (Standard Test Method for Measuring Stiffness and Apparent Modulus of Soil and Soil-Aggregate In-Place by Electro-Mechanical Method). The SSG was used to determine the stiffness of the ETB layer. A thin layer of moist sand was placed between the SSG and the ETB surface during testing, and the SSG was removed and replaced between readings. Three SSG measurements were taken at each station during each series of testing.

Figure 3-6: Clegg impact soil tester.

NDG tests were performed in general accordance with ASTM D6031 (Standard Test Method for Logging In Situ Moisture Content and Density of Soil and Rock by the Nuclear Method in Horizontal, Slanted, and Vertical Access Tubes). The NDG was used to measure in-situ wet density, moisture content, and percent moisture of the compacted ETB on the day of construction. One test was performed at each test station. NDG tests were not repeated on later days. The NDG utilized on this project is shown in Figure 3-8.

On the day of construction, samples of the reclaimed base material were removed from each test station both before and after emulsion treatment. Sampling of the untreated material is shown in Figure 3-9. The samples of untreated material were bagged and transported to the Brigham Young University (BYU) Highway Materials Laboratory for sieve, moisture content, and burn-off analyses. The samples of treated material were compacted on site using the

Figure 3-7: Soil stiffness gauge.

modified Proctor compaction protocol in general accordance with ASTM D1557 (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))) Method B. This method involved compaction of the ETB material in 4-in.-diameter molds in five lifts of 25 blows each. The modified compaction set-up is shown in Figure 3-10. Four or five samples were created for each of the test stations. At the laboratory, these samples were subjected to UCS, moisture content, and burn-off analyses.

Figure 3-8: Nuclear density gauge.

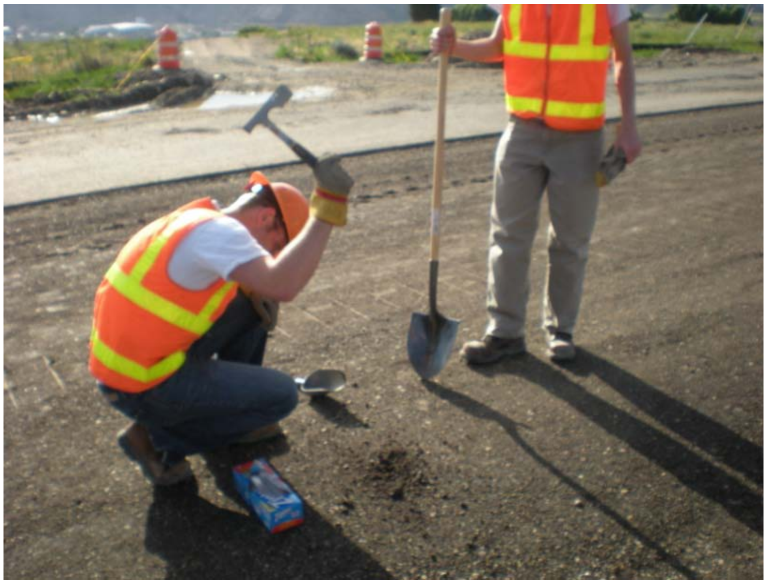

Figure 3-9: Untreated material sampling.

Figure 3-10: Manual compaction.

3.4 Laboratory Procedures

At the BYU Highway Materials Laboratory, material characterization testing was conducted on field-sampled base material from each test station to determine average properties for each of the three test sections. A sieve analysis was performed on the untreated material in general accordance with ASTM D422 (Standard Test Method for Particle-Size Analysis of Soils) to determine the soil classification of the untreated material sampled from each test section. The material was determined to be non-plastic, so Atterberg limits could not be determined. A burn-off test was performed on both untreated and treated materials in general accordance with ASTM D6307 (Standard Test Method for Asphalt Content of Hot-Mix Asphalt by Ignition Method) using the burn-off oven shown in Figure 3-11. These tests were used to determine the asphalt content of the reclaimed base material at each test station both before and after emulsion

Figure 3-11: Burn-off testing.

injection. The amount of emulsion injected at each station was then calculated as the measured difference in the asphalt content of the base material before and after emulsion treatment divided by the design asphalt content of 64 percent by weight of the emulsion.

UCS tests were performed as shown in Figure 3-13 in general accordance with ASTM D1633 (Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders) on one emulsion-treated sample from each test station at 7 days, 28 days, 3 months, and 1 year following construction of the test section. Samples were allowed to cure at room temperature in an open-air condition prior to testing as shown in Figure 3-12, and then they were capped with gypsum and subjected to UCS testing at a strain rate of 0.05 in./minute. UCS values were plotted to develop strength-gain curves for ETB under laboratory curing conditions.

Figure 3-12: Laboratory curing.

Figure 3-13: Unconfined compressive strength testing.

3.5 Pavement Analysis

The soil properties measured during field testing were analyzed to determine equivalent resilient modulus values for the ETB layer. Modulus values were determined from the PFWD test using BAKFAA backcalculation software (*23*). The original pavement design layer thicknesses were used during backcalculation; these thicknesses were confirmed using DCP testing. A Poisson's ratio of 0.35 and full interface bonding were assumed for all backcalculations. DCP penetration rates were used to determine ETB CBR and modulus values using Equations 3-1 and 3-2 (*24*):

$$CBR = \frac{292}{PR^{1.12}} \tag{3-1}$$

where CB = California bearing ratio, %

PR = penetration rate, mm/blow

$$M_R = 2550 \cdot CBR^{0.64} \tag{3-2}$$

where M_R = resilient modulus, psi

CBR = California bearing ratio, %

The impact values measured during CIST testing were correlated to modulus values using Equation 3-3 (*25*), and soil stiffness values were converted to modulus values using Equation 3-4 (*26*). A Poisson's ratio of 0.35 was used to calculate moduli from SSG readings.

$$M_R = 33.56 \cdot CIV^2 \tag{3-3}$$

where M_R = resilient modulus, psi

CIV = Clegg impact value

$$M_R = 0.2511 \cdot SS(1 - \nu^2) \tag{3-4}$$

where M_R= resilient modulus, psi

SS = soil stiffness, lbf/in.

ν = Poisson's ratio

American Association of State Highway and Transportation Officials (AASHTO) correlation charts were used to determine an equivalent structural coefficient (a_2) for the ETB modulus values determined during testing (*18*). The structural coefficients were plotted against time to determine trends in ETB strength development and to determine the time at which the ETB had reached the design structural coefficient value of 0.25.

The structural capacity of the pavement at each testing period was calculated using the AASHTO flexible pavement design method. The process involved calculating the total structural number of the pavement system using the structural coefficient of the ETB layer measured at each time period as shown in Equation 3-5 (18):

$$SN = a_1 \cdot D_1 + a_2 \cdot D_2 \cdot m_2 \tag{3-5}$$

where SN = structural number

a_1 = structural coefficient for HMA layer

D_1 = thickness of HMA layer

a_2 = structural coefficient for ETB layer

D_2 = thickness of ETB layer

m_2 = drainage coefficient for ETB layer

The allowable number of passes of equivalent single axle loads (ESALs) before failure was then computed using Equation 3-6 (*18*):

$$\log W_{t18} = Z_R S_0 + 9.36 \log(SN + 1) - 0.20 + \frac{\log \frac{\Delta PSI}{2.7}}{0.4 + \frac{1094}{(SN + 1)^{5.19}}} + 2.32 \log M_R - 8.07 \qquad \text{(3-6)}$$

where W_{t18} = allowable ESALs before pavement failure

Z_R = standard normal deviate

S_0 = standard deviation

SN = structural number

ΔPSI = allowable change in present serviceability index over pavement life

M_R = effective roadbed soil resilient modulus (psi)

For computation of the structural number, a structural coefficient of 0.40 was used for the HMA layer, and a drainage coefficient of 1.0 was used for the ETB layer. For computation of the allowable number of ESALs, a reliability level of 95 percent, a standard deviation of 0.45, and a change in present serviceability index of 2.0 were used with the design subgrade modulus of 11.4 ksi. Although all three test sections remained unpaved for two weeks following construction, analysis of the 2-week capacity was performed with and without considering the

ETB to be paved to provide an understanding of pavement strengths under both conditions. Analysis of pavement capacity after two weeks was performed with the assumption that the ETB was paved.

3.6 Statistical Analysis

The field and laboratory data were evaluated using several statistical analyses, including multivariate regression, coefficient of variation (CV) comparisons, analysis of variance (ANOVA), and Tukey's mean separation procedure to examine spatial variability and significant correlations between predictor and response variables. SAS software was used to perform the analyses as presented in the following sections.

3.6.1 Multivariate Regression

In the stepwise, multivariate regression analysis, the level of significance, or *p*-value, of each of the potential predictor variables in predicting a given response variable was determined. Once the *p*-value of each predictor variable was determined, regression models were formed for each response variable. Consistent with previous research, regression models were formed using predictor variables having *p*-values less than or equal to 0.15 (*9*). The coefficient of determination, or R^2 value, for each regression model was then computed. The R^2 value is a measure of the percentage of variation in the response variable that can be explained by variation in the predictor variables used in the model (*27*). The response variables considered in this study were categorized as laboratory or field response variables, with each category being analyzed with a different set of predictor variables.

The laboratory response variables were 7-day, 28-day, 91-day, and 365-day UCS. UCS was chosen because it is an effective measure of material strength for materials tested in a laboratory setting. The predictor variables investigated in this portion of the analysis were the corresponding 7-day, 28-day, 91-day, and 365-day moisture contents, dry densities, and wet densities, RAP binder content, total binder content, binder change, and percent passing each sieve used in the sieve analysis. The moisture content, dry density, and wet density of a given UCS specimen were used only in regression analyses corresponding to that UCS test. However, RAP binder content, total binder content, binder change, and percent passing each sieve were considered constant in all analyses of UCS tests performed for a given test station.

The field response variables investigated were 1-day, 2-day, 3-day, 7-day, and 14-day CIV and SSG soil stiffness, as well as 1-day, 2-day, 3-day, 7-day, 14-day, 121-day, and 365-day DCP penetration rate, CBR, and modulus measured using the PFWD. The predictor variables used to analyze the field response variables were the RAP binder content, total binder content, binder change, percent passing each sieve used in the sieve analysis, and the wet density, moisture content, and percent moisture measured using the NDG.

3.6.2 Coefficient of Variation Comparisons

CV values were computed for each response variable to determine which parameters were the most variable. The CV for a given data set is the ratio of the standard deviation to the mean. CV values are useful for comparing the variability of dissimilar variables because the CV is scaled according to the mean value of the parameter (*28*).

3.6.3 Analysis of Variance and Tukey's Mean Separation Procedure

An ANOVA was performed to determine if significant differences existed between the three test sections for each of the response variables. The ANOVA method compares multiple population means while controlling the possibility of incorrectly claiming that significant differences exist (*29*). A *p*-value less than or equal to 0.05 indicated significant differences between the sections. Tukey's mean separation procedure was then used to determine which specific sections were significantly different from the others (*30*).

3.7 Summary

The test site chosen for this research was a section of Redwood Road (SR-68) located just north of Saratoga Springs, Utah. The experimental area was divided into three 800-ft by 24-ft test sections, labeled as sections A, B, and C. Ten individual test stations were established in each of the three sections. These stations were randomly located throughout each test section. Field testing was used over the course of the project to characterize the in-situ structural properties of the ETB layer. The field instruments utilized in this research include the PFWD, DCP, CIST, SSG, and NDG. The first series of field tests were begun within 30 minutes following final compaction of the ETB layer. Additional tests were performed at 2, 3, 7, and 14 days; 4 months; and 1 year. On the day of construction, samples of the reclaimed base material were removed from each test station both before and after emulsion treatment. The samples of untreated material were bagged and transported to the BYU Highway Materials Laboratory for sieve, moisture content, and burn-off analyses. The samples of treated material were compacted on site. At the laboratory, these samples were subjected to UCS, moisture content, and burn-off analyses.

The soil properties measured during field testing were analyzed to determine equivalent modulus values for the ETB layer. The structural capacity of the pavement at each testing period was calculated using the AASHTO flexible pavement design method.

The collected data were processed using several statistical analyses, including multivariate regression, CV comparisons, ANOVA, and Tukey’s mean separation procedure. In the stepwise, multivariate regression analysis, the level of significance, or *p*-value, of each of the potential predictor variables in predicting a given response variable was determined. Regression models were formed using predictor variables having *p*-values less than or equal to 0.15. The coefficient of determination, or R^2 value, for each regression model was then computed. CV values were calculated for each response variable to determine which parameters were the most variable. An ANOVA was performed to determine if significant differences existed between the three test sections for each of the response variables. Tukey’s mean separation procedure was then used to determine which specific sections were significantly different from the others.

4 RESULTS

4.1 Overview

The following sections describe the results of laboratory and field testing, the results of pavement analysis, and the results of statistical analysis. The raw laboratory and field data are presented in Appendices A and B, respectively, in which the presence of a hyphen in a table indicates that the data were not measured.

4.2 Laboratory Results

The results of the sieve analysis indicated that all three sections can be classified as A-1-a and GW using the AASHTO and Unified Soil Classification System methods, respectively. Minimal variation in aggregate gradation existed between the three test sections.

The results of the burn-off tests are shown in Table 4-1. The asphalt content was fairly consistent between the three sections, implying the three sections had comparable RAP contents. However, variability in the emulsion content added to each section during treatment was higher. The design emulsion content, specified as a percentage of asphalt, water, and emulsifier by dry weight of reclaimed base material, was 4.0 percent for the ETB layer. Both sections A and B had emulsion contents higher than the design specification; however, section C had an emulsion content lower than the design specification.

Results of the UCS testing are shown in Figure 4-1. While sections B and C had nearly identical values, section A had consistently lower UCS values. The reduced compressive strength of the samples from section A may have been due to the higher amount of emulsion, which could act as a lubricant. The average UCS values for all three sections were 30, 96, 145, and 179 psi at 7 days, 28 days, 3 months, and 1 year, respectively. Although no direct correlation between UCS and modulus for ETB materials was identified in the literature review

Table 4-1: Burn-off Test Data

Section	Asphalt Content before Treatment (%)		Emulsion Added during Treatment (%)	
	Average	Std. Dev.	Average	Std. Dev.
A	4.98	0.61	4.77	2.02
B	4.46	0.49	4.15	1.08
C	4.78	0.44	3.32	1.24

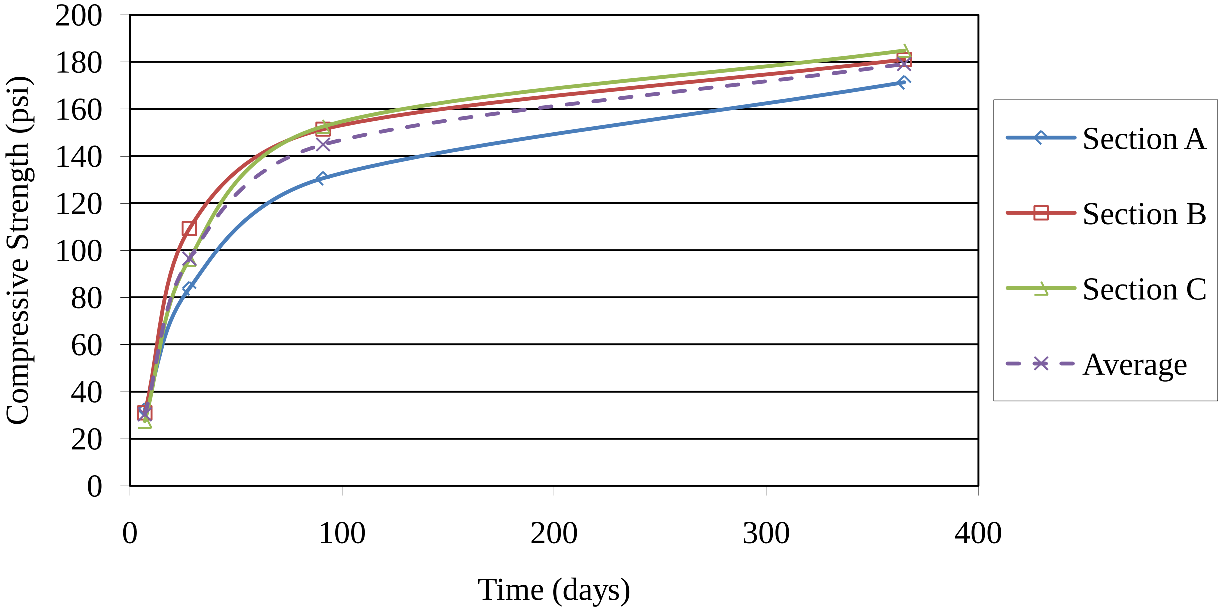

Figure 4-1: Average unconfined compressive strengths for each section.

performed in this research, resilient modulus determined under laboratory conditions would be expected to exhibit a similar pattern of strength development. The percentage of 1-year ETB strength developed after 7 days, 28 days, and 3 months was 17, 54, and 80 percent, respectively. The ETB compressive strength was very low immediately following compaction and remained below 50 percent of the 1-year strength during at least the first two weeks.

4.3 Field Results

Results from both the PFWD and DCP tests are shown in Table 4-2, while results of the SSG and CIST tests are given in Table 4-3. The average modulus values obtained for each section during the first two weeks of testing are shown in Figures 4-2 to 4-4. With few exceptions, all four tests produced similarly shaped curves for each section; however, the magnitude of the modulus values varied slightly by test. The modulus values computed from the DCP data were generally slightly higher than those computed from the PFWD data, which were in turn higher than the modulus values computed from the SSG and CIST data. Strength generally increased over the first two weeks. Overall average modulus values during this two-week period were 26.0, 28.6, 21.0, and 16.5 ksi determined using the PFWD, DCP, SSG, and CIST, respectively.

The average ETB modulus values obtained for each section from PFWD testing during the entire testing period are shown in Figure 4-5. Modulus values were not determined from the DCP test at 4 months and 1 year because the penetration rates measured in the DCP test were below the recommended range for the given equations (*31*). Modulus values measured using the PFWD were consistently low in all three sections during the first two weeks of testing, increased

Table 4-2: PFWD and DCP Test Data

Curing Time (days)	PFWD		DCP			
	Modulus (ksi)		Penetration Rate (mm/blow)		Modulus (ksi)	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Section A						
1	21.7	4.4	6.4	1.2	26.1	3.7
2	22.0	3.6	6.7	1.3	25.2	3.8
3	31.2	5.9	4.3	0.8	34.7	4.8
7	39.5	8.9	3.2	0.9	43.2	7.1
14	36.6	11.0	3.4	0.5	40.5	4.0
113	342.4	90.1	1.1	0.6	-	-
365	85.4	11.9	1.4	0.1	-	-
Section B						
1	13.8	4.1	9.5	2.0	19.6	3.0
2	18.9	3.3	8.0	1.1	21.9	2.1
3	22.9	4.5	6.7	0.6	24.8	1.7
7	23.4	4.5	5.9	1.1	27.5	3.3
14	27.2	4.0	5.4	0.8	29.1	3.0
113	339.9	87.4	1.0	0.3	-	-
365	94.3	11.1	1.8	0.3	-	-
Section C						
1	17.2	3.1	9.2	1.1	19.9	1.8
2	22.0	4.7	8.4	1.2	21.2	2.2
3	28.7	5.2	6.3	0.7	25.9	2.3
7	30.4	6.1	4.6	0.5	32.7	2.9
14	35.5	6.3	4.1	0.6	35.6	4.0
113	176.9	29.3	1.2	0.3	-	-
365	89.2	8.2	2.0	0.1	-	-
Average						
1	17.6	3.9	8.4	1.4	21.9	2.8
2	21.0	3.9	7.7	1.2	22.8	2.7
3	27.6	5.2	5.8	0.7	28.5	2.9
7	31.1	6.5	4.6	0.8	34.5	4.4
14	33.1	7.1	4.3	0.6	35.1	3.7
113	286.4	68.9	1.1	0.4	-	-
365	89.6	10.4	1.7	0.2	-	-

Table 4-3: SSG and CIST Test Data

Curing Time (days)	SSG		CIST	
	Stiffness (MN/m)		Clegg Impact Value	
	Average	Std. Dev.	Average	Std. Dev.
Section A				
1	21.0	2.8	14.9	1.7
2	20.7	2.0	15.6	2.0
3	28.5	2.8	18.6	2.2
7	29.9	5.6	23.8	2.5
14	27.4	2.4	22.4	2.2
Section B				
1	13.6	3.6	8.8	4.5
2	17.1	3.0	13.2	3.3
3	18.9	2.8	14.8	2.9
7	19.0	2.3	17.4	3.0
14	22.7	3.1	19.6	3.0
Section C				
1	16.1	2.3	11.6	1.7
2	18.0	1.5	13.1	1.8
3	20.6	2.3	14.1	1.8
7	26.0	1.8	18.6	3.2
14	26.4	1.5	23.7	2.7
Average				
1	16.9	2.9	11.8	2.6
2	18.6	2.1	14.0	2.4
3	22.7	2.7	15.9	2.3
7	24.9	3.2	19.9	2.9
14	25.5	2.3	21.9	2.6

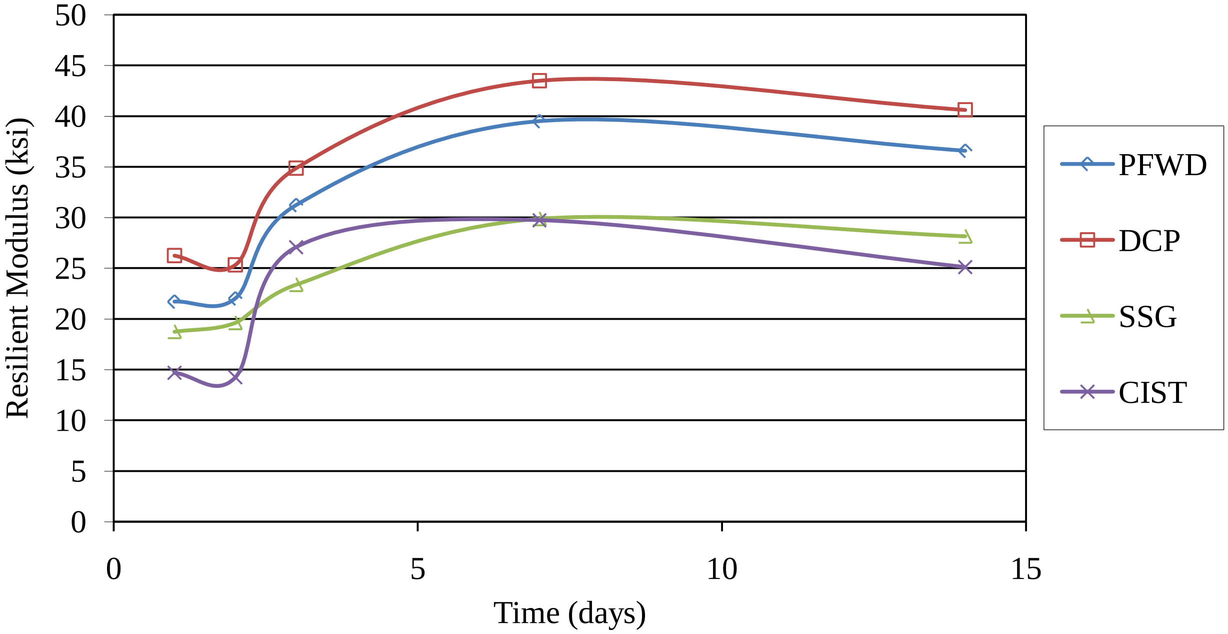

Figure 4-2: ETB modulus values for section A during the first two weeks.

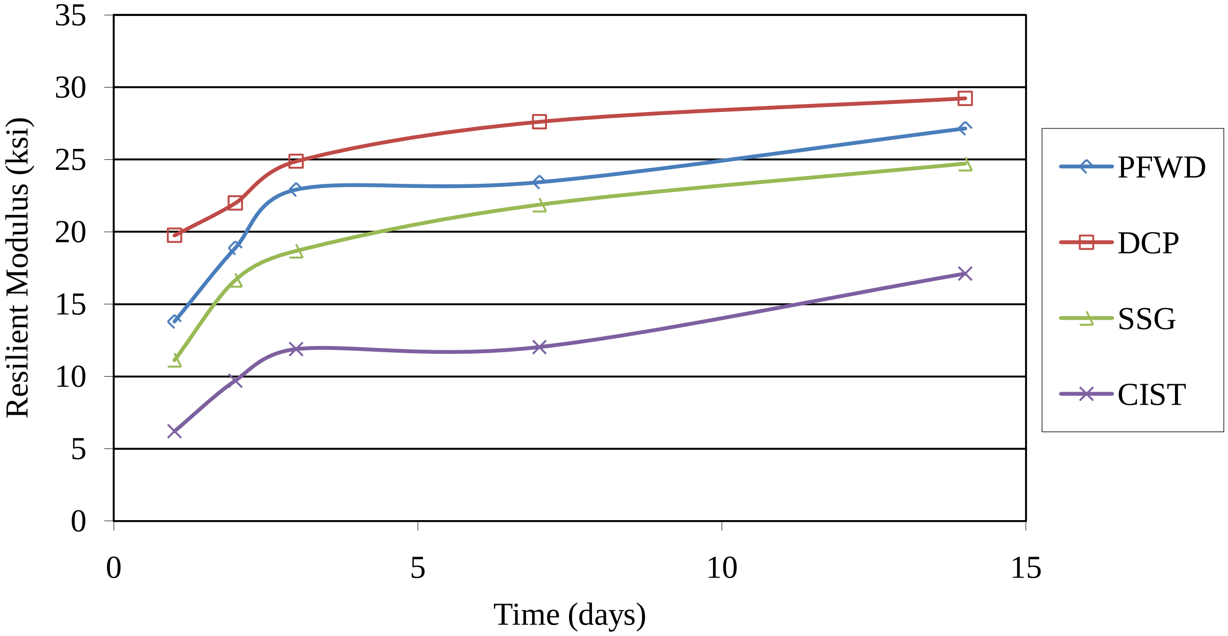

Figure 4-3: ETB modulus values for section B during the first two weeks.

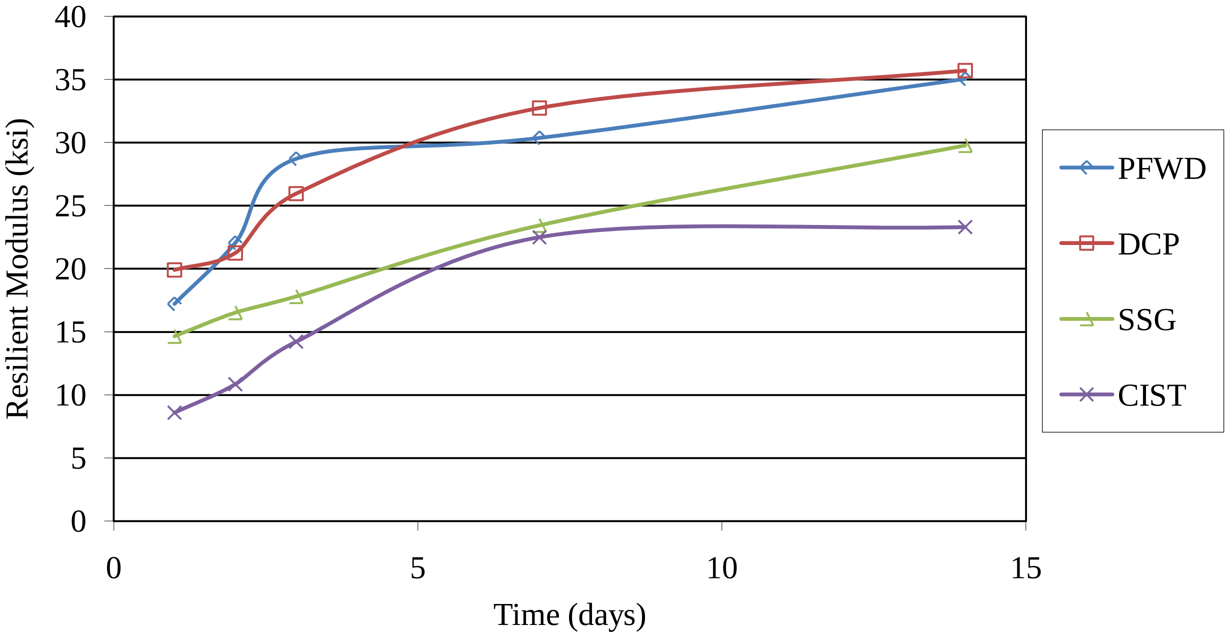

Figure 4-4: ETB modulus values for section C during the first two weeks.

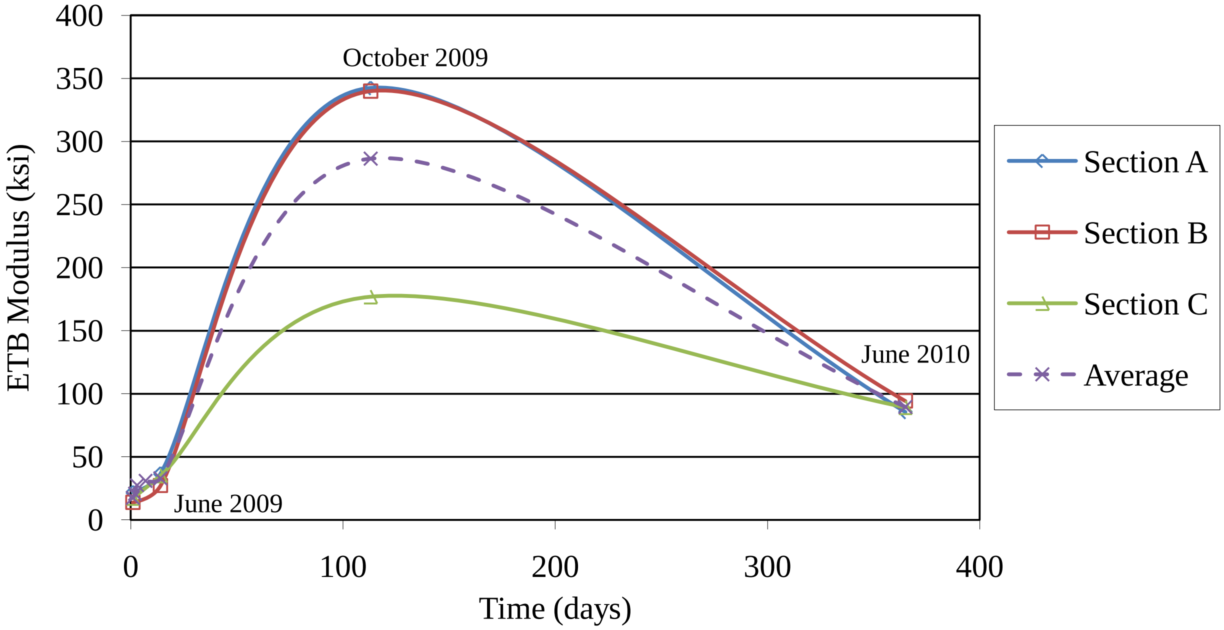

Figure 4-5: ETB modulus values during the first year.

dramatically by 4 months, and then decreased considerably by 1 year. The average ETB moduli were 286.4 and 89.6 ksi at 4 months and 1 year, respectively. Therefore, the ETB moduli at 2 weeks and 1 year were only 9 and 31 percent, respectively, of the ETB modulus at 4 months. These trends are confirmed by the DCP penetration rates; the average penetration rates were 4.3, 1.1, and 1.7 mm/blow at 2 weeks, 4 months, and 1 year, respectively.

Much of the increase observed at 4 months was probably due to the curing of the base, but the lower temperatures experienced during late fall may also have caused an apparent increase in stiffness. Although the air temperature of 57°F at 4 months was only slightly different than the air temperature of 64°F at 2 weeks, the difference in subsurface temperatures was most likely greater due to the onset of colder nights by 4 months. Section C had a lower emulsion content, so it might not have been as affected by colder temperatures, possibly causing it to exhibit lower strengths at 4 months as observed; however, at 1 year, all three sections had approximately the same modulus value. The modulus decreased significantly between 4 months and 1 year despite the additional curing of the emulsion that may have occurred during this time. While a comparatively high air temperature of 80°F may have contributed to the apparent reduction in ETB strength at 1 year, freeze-thaw cycling may also have occurred in the layer during the winter.

Although the trend shown in Figure 4-5 may not account for fluctuations in ETB strength that occurred between 2 weeks and 4 months or between 4 months and 1 year, the results still show that the sections exhibited strengths at least as high as those measured at 4 months and that those strengths were significantly reduced by 1 year. The laboratory UCS data shown in Figure 4-1 depict the trend that would have been expected in the field without environmental effects.

4.4 Pavement Analysis

The equivalent AASHTO structural coefficients of the ETB are shown in Figure 4-6 for each section. Because modulus values were not be determined from the DCP penetration rates measured at 4 months and 1 year, structural coefficients were determined using only the modulus values measured using the PFWD. The design structural coefficient for the ETB layer was 0.25 as indicated by the bold line. During the first two weeks following construction, the average ETB structural coefficients for sections A, B, and C were 0.04, 0.03, and 0.04, respectively. Sections A and B, which behaved similarly, reached a structural coefficient of 0.25 after approximately 3 months and actually exceeded design values by about 0.05 after 4 months; however, after 1 year, sections A and B had much lower structural coefficients of 0.11 and 0.12, respectively. Section C never reached a structural coefficient of 0.25. At 4 months, the ETB structural coefficient in section C was only 0.21, and after 1 year it had decreased to 0.12. For all three sections, the average structural coefficient measured after 1 year of curing was only 47 percent of the design value. These results show that ETB materials similar to those investigated in this research should not be expected to reach design values in the first few months following construction; this conclusion is supported by the laboratory UCS results. Furthermore, ETB materials may exhibit substantial decreases in strength after the first winter in regions characterized by freeze-thaw cycling.

The value of design ESALs for this pavement was 10.9 million. However, the number of allowable ESALs during the first two weeks for the scenario in which the ETB is unpaved was calculated to be less than 50,000 ESALs, which is 0.5 percent of the design requirement. For the scenario in which the ETB is paved immediately following construction, the numbers of allowable ESALs were calculated to be 0.4, 14.5, and 1.7 million ESALs at 2 weeks, 4 months,

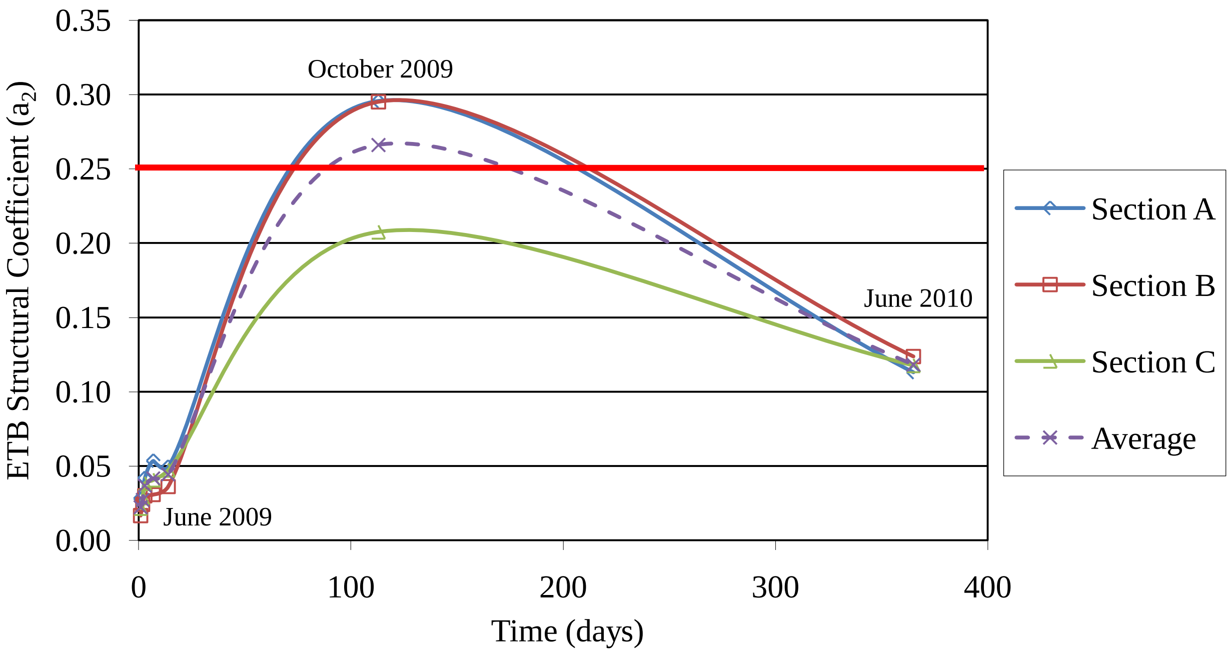

Figure 4-6: ETB structural coefficient during the first year.

and 1 year, respectively. These values are equivalent to 4, 133, and 16 percent of design. While pavement capacity was sufficient at 4 months, it was severely reduced during the first two weeks and at 1 year. Trafficking under these reduced capacities would be expected to greatly compromise long-term performance and may cause premature failure of the pavement system.

4.5 Statistical Analysis

The results of the multivariate regression, CV comparisons, ANOVA, and Tukey's mean separation procedure are presented in the following sections.

4.5.1 Multivariate Regression

The results of multivariate regression are presented for the laboratory and field data in the following sections.

4.5.1.1 Laboratory Results

Table 4-4 presents the *p*-values associated with the significant predictor variables and the R^2 values from each UCS regression model. Gradation was significant for both the 28-day and 91-day tests but not for the 7-day or 365-day tests. Pre-treatment moisture content was significant for the 7-day and 91-day tests. The RAP binder content was significant for both the 91-day and 365-day UCS tests. Binder change was determined to be a significant factor for the UCS tests performed at all four curing times. Moisture content was a significant factor for all but the 91-day tests. Dry density was only significant for the 28-day test. The R^2 values indicate that the percentage of variation in the response variable that can be explained by variation in the predictor variables varied from 57.7 to 82.1 percent.

Regression analyses on the laboratory-related response and predictor variables resulted in Equations 4-1 through 4-4:

$$UCS_7 = 53.209 + 2.2147 \cdot MC_{pre} - 2.3052 \cdot B_{change} - 5.959 \cdot MC_7 \tag{4-1}$$

where UCS_7 = 7-day unconfined compressive strength, psi

MC_{pre} = moisture content before emulsion treatment, %

Table 4-4: Results of Multivariate Regression for Laboratory Data

Response Variable	Predictor Variable p-Values										R^2
	Percent Passing the No. 4 Sieve	Percent Passing the No. 8 Sieve	Percent Passing the No. 100 Sieve	Pretreatment Moisture Content	RAP Binder Content	Binder Change	7-Day Moisture Content	28-Day Moisture Content	365-Day Moisture Content	28-Day Dry Density	
7-Day UCS				0.0391		0.0071	<0.0001				0.7694
28-Day UCS		0.005	0.0008			0.0015		0.0005		0.001	0.7569
91-Day UCS	0.1185			0.0041	0.0068	<0.0001					0.821
365-Day UCS					0.0021	<0.0001			0.0515		0.5772

B_{change} = change in asphalt binder content during emulsion treatment, %

MC_7 = 7-day moisture content, %

$$UCS_{28} = -391.558 - 3.2541 \cdot P_{No.8} + 29.235 \cdot P_{No.100} - 10.073 \cdot B_{change} - 33.695 \cdot MC_{28} + 4.8948 \cdot DD_{28} \quad (4\text{-}2)$$

where UCS_{28} = 28-day unconfined compressive strength, psi

$P_{No.8}$ = percent passing the No. 8 sieve, %

$P_{No.100}$ = percent passing the No. 100 sieve, %

B_{change} = change in asphalt binder content during emulsion treatment, %

MC_{28} = 28-day moisture content, %

DD_{28} = 28-day dry density, pcf

$$UCS_{91} = 264.15 - 1.2690 \cdot P_{No.4} + 14.602 \cdot MC_{pre} - 18.983 \cdot B_{RAP} - 26.565 \cdot B_{change} \quad (4\text{-}3)$$

where UCS_{91} = 91-day unconfined compressive strength, psi

$P_{No.4}$ = percent passing the No. 4 sieve, %

MC_{pre} = moisture content before emulsion treatment, %

B_{RAP} = asphalt binder present in the untreated material, %

B_{change} = change in asphalt binder content during emulsion treatment, %

$$UCS_{365} = 524.44 - 43.151 \cdot B_{RAP} - 33.163 \cdot B_{change} - 205.70 \cdot MC_{365} \quad (4\text{-}4)$$

where UCS_{365} = 365-day unconfined compressive strength, psi

B_{RAP} = asphalt binder present in the untreated material, %

B_{change} = change in asphalt binder content during emulsion treatment, %

MC_{365} = 365-day moisture content, %

The regression equations developed from the laboratory data quantify several relationships between the compositional and structural characteristics of the tested specimens. Gradation was shown to have a significant effect on ETB strength. Increasing amounts of material passing the No. 4 and No. 8 sieves decreased strength, while increasing amounts of material passing the No. 100 sieve increased strength. Increasing pre-treatment moisture content also increased strength. Pre-treatment moisture may have helped to disperse the emulsion in the soil matrix during mixing. Increasing RAP content and binder change decreased strength, which was contrary to expectations. Uncured emulsion present in the ETB specimens could have acted as a lubricant inside the material matrix during testing, thereby reducing the apparent strengths of the specimens. Within the range of moisture contents investigated in this study, increases in moisture content were associated with decreases in UCS; higher moisture contents are indicative of less curing and therefore less strength gain.

4.5.1.2 Field Results

Table 4-5 presents the *p*-values associated with the significant predictor variables and the R^2 values from each field test regression model. Gradation was significant in predicting 23 of the 31 field response variables. Pre-treatment moisture content was shown to be significant for 10 of the 31 response variables. RAP binder was a significant factor for eight of the response variables. Binder change was a significant factor for four of the seven PFWD tests but not for any other test; the emulsion added was not a significant factor for the DCP, SSG, or CIST and was not significant for the PFWD by 121 days. Moisture content was significant for 19 of the 31 field variables, and percent moisture was significant for 12 of the 31 variables. Only the PFWD results were not influenced by either moisture content or percent moisture. Moisture content and percent moisture as measured using the NDG were only significant for tests performed during the first two weeks. Wet density was significant for 11 of the 31 tests. The R^2 values indicate that the percentage of variation in the response variable that can be explained by variation in the predictor variables varied from 32.0 to 85.0 percent.

Regression analyses on the field-related response and predictor variables resulted in Equations 4-5 through 4-32:

$$CBR_1 = 76.018 + 41.802 \cdot P_{1/2''} - 1.7200 \cdot P_{No.30} + 7.9686 \cdot B_{RAP} + 2.8208 \cdot B_{change} - 0.90655 \cdot NDG_{WD} \tag{4-5}$$

where CBR_1 = 1-day California bearing ratio, %

$P_{1/2''}$ = percent passing the ½” sieve, %

$P_{No.30}$ = percent passing the No. 30 sieve, %

B_{RAP} = asphalt binder present in the untreated material, %

B_{change} = change in asphalt binder content during emulsion treatment, %

NDG_{WD} = wet density measured using the NDG, pcf

$$CBR_2 = -35.626 - 2.4890 \cdot MC_{pre} - 7.0255 \cdot NDG_M + 4.8152 \cdot NDG_{M\%} + 0.95617 \cdot NDG_{WD} \tag{4-6}$$

where CBR_2 = 2-day California bearing ratio, %

MC_{pre} = moisture content before emulsion treatment, %

NDG_M = moisture content measured using the NDG, pcf

Table 4-5: Results of Multivariate Regression for Field Data

Response Variable	Predictor Variable p-Value														R^2
	Percent Passing the 0.5 in. Sieve	Percent Passing the No. 4 Sieve	Percent Passing the No. 8 Sieve	Percent Passing the No. 16 Sieve	Percent Passing the No. 30 Sieve	Percent Passing the No. 50 Sieve	Percent Passing the No. 100 Sieve	Percent Passing the No. 200 Sieve	Pretreatment Moisture Content	RAP Binder Content	Binder Change	NDG Wet Density	NDG Moisture Content	NDG Percent Moisture	
1-Day CBR	0.061				0.1445					0.0064	0.0561	0.0558			0.69
2-Day CBR									0.127			0.0237	<0.0001	0.0006	0.61
3-Day CBR			0.0363			0.0017							0.0112	0.1029	0.59
7-Day CBR						0.0593						0.0132	0.0002	<0.0001	0.74
14-Day CBR							0.0603		0.03				0.0006	0.0021	0.59
91-Day CBR															
365-Day CBR					0.0005		0.0096	0.0012	0.0011	0.0056		0.002	0.0154		1.00
1-Day PR	0.039						0.1106			0.0004	0.0279				0.57
2-Day PR													0.0033	0.0449	0.32
3-Day PR			0.0047			0.0003							0.0376		0.53
7-Day PR							0.0666		0.0207				0.0014	0.0001	0.61
14-Day PR							0.0771		0.0064				0.0017	0.0051	0.59
91-Day PR															
365-Day PR				0.145	0.0108			0.0033	0.0102	0.0397		0.0101			1.00
1-Day Modulus						0.1064						0.0048			0.35
2-Day Modulus		0.0242	<0.0001								0.0429				0.56
3-Day Modulus			0.0644								0.031	0.0028			0.56
7-Day Modulus		0.0541	0.0078			0.0034					0.0919	0.0107	0.0054		0.85
14-Day Modulus				<0.0001	0.0019			0.0591			0.0995		0.0078		0.73
91-Day Modulus					0.0678										0.40
365-Day Modulus															
1-Day CIV									0.1219	0.035			0.0002	0.0247	0.65
2-Day CIV						0.1404				0.1363			0.0009	0.0221	0.65
3-Day CIV							0.012	0.113		0.0106			0.0004	0.0007	0.70
7-Day CIV					0.0152	0.0021							<0.0001	0.0005	0.67
14-Day CIV						0.0244		0.0848	0.0004				0.0022	0.0341	0.68
1-Day Stiffness						0.0334			0.0721			0.0866	0.0096		0.62
2-Day Stiffness												0.051	0.0461		0.34
3-Day Stiffness										0.1117	0.0396	0.1008			0.43
7-Day Stiffness		0.0004			0.0035	0.0244			0.0001				0.0172		0.65
14-Day Stiffness				<0.0001	0.0013										0.62

$NDG_{M\%}$ = percent moisture measured using the NDG, %

NDG_{WD} = wet density measured using the NDG, pcf

$$CBR_3 = 71.760 + 2.3082 \cdot P_{No.8} - 12.365 \cdot P_{No.50} - 6.8234 \cdot NDG_M + 4.5272 \cdot NDG_{M\%} \tag{4-7}$$

where CBR_3 = 3-day California bearing ratio, %

$P_{No.8}$ = percent passing the No. 8 sieve, %

$P_{No.50}$ = percent passing the No. 50 sieve, %

NDG_M = moisture content measured using the NDG, pcf

$NDG_{M\%}$ = percent moisture measured using the NDG, %

$$CBR_7 = 311.33 - 6.3508 \cdot P_{No.50} - 12.334 \cdot NDG_M + 14.800 \cdot NDG_{M\%} - 1.9863 \cdot NDG_{WD} \tag{4-8}$$

where CBR_7 = 7-day California bearing ratio, %

$P_{No.50}$= percent passing the No. 50 sieve, %

NDG_M = moisture content measured using the NDG, pcf

$NDG_{M\%}$ = percent moisture measured using the NDG, %

NDG_{WD} = wet density measured using the NDG, pcf

$$CBR_{14} = 147.06 - 13.038 \cdot P_{No.100} - 6.9109 \cdot MC_{pre} - 9.9676 \cdot NDG_M + 9.0869 \cdot NDG_{M\%} \tag{4-9}$$

where CBR_{14} = 14-day California bearing ratio, %

P_{100} = percent passing the No. 100 sieve, %

MC_{pre} = moisture content before emulsion treatment, %

NDG_M = moisture content measured using the NDG

$NDG_{M\%}$ = percent moisture measured using the NDG, %

$$CBR_{365} = 3095.7 - 82.155 \cdot P_{No.30} - 27.199 \cdot P_{No.100} + 584.41 \cdot P_{No.200} \\ -30.330 \cdot MC_{pre} + 22.463 \cdot B_{RAP} + 2.0555 \cdot NDG_M - 21.443 \cdot NDG_{WD} \tag{4-10}$$

where CBR_{365} = 365-day California bearing ratio, %

$P_{No.30}$ = percent passing the No. 30 sieve, %

$P_{No.100}$ = percent passing the No. 100 sieve, %

$P_{No.200}$ = percent passing the No. 200 sieve, %

MC_{pre} = moisture content before emulsion treatment, %

B_{RAP} = asphalt binder present in the untreated material, %

NDG_M = moisture content measured using the NDG

NDG_{WD} = wet density measured using the NDG, pcf

$$PR_1 = 28.248 - 0.11840 \cdot P_{1/2"} + 1.4365 \cdot P_{No.100} - 2.3138 \cdot B_{RAP} \\ -0.72938 \cdot B_{change} \tag{4-11}$$

where PR_1 = 1-day DCP penetration rate, mm/blow

$P_{1/2"}$ = percent passing the ½” sieve, %

$P_{No.100}$ = percent passing the No. 100 sieve, %

B_{RAP} = asphalt binder present in the untreated material, %

B_{change} = change in asphalt binder content during emulsion treatment, %

$$PR_2 = 2.1999 + 0.92138 \cdot NDG_M - 0.60804 \cdot NDG_{M\%} \tag{4-12}$$

where PR_2 = 2-day DCP penetration rate, mm/blow

NDG_M = moisture content measured using the NDG

$NDG_{M\%}$ = percent moisture measured using the NDG, %

$$PR_3 = 0.98730 - 0.27519 \cdot P_{No.8} + 1.3320 \cdot P_{No.50} + 0.44733 \cdot NDG_M \tag{4-13}$$

where PR_3 = 3-day DCP penetration rate, mm/blow

$P_{No.8}$ = percent passing the No. 8 sieve, %

$P_{No.50}$ = percent passing the No. 50 sieve, %

NDG_M = moisture content measured using the NDG, pcf

$$PR_7 = 1.8302 + 1.0230 \cdot P_{No.30} + 0.59761 \cdot MC_{pre} + 0.73353 \cdot NDG_M - 0.96865 \cdot NDG_{M\%} \tag{4-14}$$

where PR_7 = 7-day DCP penetration rate, mm/blow

$P_{No.30}$ = percent passing the No. 30 sieve, %

MC_{pre} = moisture content before emulsion treatment, %

NDG_M = moisture content measured using the NDG

$NDG_{M\%}$ = percent moisture measured using the NDG, %

$$PR_{14} = -1.7383 + 0.77687 \cdot P_{No.100} + 0.57043 \cdot MC_{pre} + 0.56559 \cdot NDG_M - 0.51608 \cdot NDG_{M\%} \tag{4-15}$$

where PR_{14} = 14-day DCP penetration rate, mm/blow

$P_{No.100}$ = percent passing the No. 100 sieve, %

MC_{pre} = moisture content before emulsion treatment, %

NDG_M = moisture content measured using the NDG

$NDG_{M\%}$ = percent moisture measured using the NDG, %

$$PR_{365} = -21.721 + .066488 \cdot P_{No.16} + 0.53657 \cdot P_{No.30} - 4.9443 \cdot P_{No.200} + 0.24053 \cdot MC_{pre} - 0.18435 \cdot B_{RAP} + 0.17308 \cdot NDG_{WD} \tag{4-16}$$

where PR_{365} = 365-day DCP penetration rate, mm/blow

$P_{No.16}$ = percent passing the No. 16 sieve, %

$P_{No.30}$ = percent passing the No. 30 sieve, %

$P_{No.200}$ = percent passing the No. 200 sieve, %

MC_{pre} = moisture content before emulsion treatment, %

B_{RAP} = asphalt binder present in the untreated material, %

NDG_{WD} = wet density measured using the NDG, pcf

$$MOD_1 = 121.32 - 1.9286 \cdot P_{No.50} - 0.77258 \cdot NDG_{WD} \tag{4-17}$$

where MOD_1 = 1-day modulus measured using the PFWD, ksi

$P_{No.50}$ = percent passing the No. 50 sieve, %

NDG_{WD} = wet density measured using the NDG, pcf

$$MOD_2 = 1.0822 - 0.55535 \cdot P_{No.4} + 1.7451 \cdot P_{No.8} + 1.3500 \cdot B_{change} \tag{4-18}$$

where MOD_2 = 2-day modulus measured using the PFWD, ksi

$P_{No.4}$ = percent passing the No. 4 sieve, %

$P_{No.8}$ = percent passing the No. 8 sieve, %

B_{change} = change in asphalt binder content during emulsion treatment, %

$$MOD_3 = 134.15 + 0.75569 \cdot P_{No.8} + 2.1831 \cdot B_{change} - 1.0156 \cdot NDG_{WD} \tag{4-19}$$

where MOD_3 = 3-day modulus measured using the PFWD, ksi

$P_{No.8}$ = percent passing the No. 8 sieve, %

B_{change} = change in asphalt binder content during emulsion treatment, %

NDG_{WD} = wet density measured using the NDG, pcf

$$MOD_7 = 217.26 - 0.89838 \cdot P_{No.4} + 2.6552 \cdot P_{No.8} - 7.1411 \cdot P_{No.50} + 1.7270 \cdot B_{change} - 1.0422 \cdot NDG_{WD} - 3.9200 \cdot NDG_M \tag{4-20}$$

where MOD_7 = 7-day modulus measured using the PFWD, ksi

$P_{No.4}$ = percent passing the No. 4 sieve, %

$P_{No.8}$ = percent passing the No. 8 sieve, %

$P_{No.50}$ = percent passing the No. 50 sieve, %

B_{change} = change in asphalt binder content during emulsion treatment, %

NDG_{WD} = wet density measured using the NDG, pcf

NDG_M = moisture content measured using the NDG

$$MOD_{14} = 39.677 + 644.93 \cdot P_{No.16} - 7.0165 \cdot P_{No.30} + 14.394 \cdot P_{No.200} + 2.0200 \cdot B_{change} - 3.2821 \cdot NDG_M \tag{4-21}$$

where MOD_{14} = 14-day modulus measured using the PFWD, ksi

$P_{No.16}$ = percent passing the No. 16 sieve, %

$P_{No.30}$ = percent passing the No. 30 sieve, %

$P_{No.200}$ = percent passing the No. 200 sieve, %

B_{change} = change in asphalt binder content during emulsion treatment, %

NDG_M = moisture content measured using the NDG

$$MOD_{121} = 676.00 - 73.544 \cdot P_{No.30} \tag{4-22}$$

where MOD_{121} = 121-day modulus measured using the PFWD, ksi

$P_{No.30}$ = percent passing the No. 30 sieve, %

$$CIV_1 = 32.978 - 1.3120 \cdot MC_{pre} + 2.6388 \cdot B_{RAP} - 2.8559 \cdot NDG_M + 1.6426 \cdot NDG_{M\%} \tag{4-23}$$

where CIV_1 = 1-day CIV

MC_{pre} = moisture content before emulsion treatment, %

B_{RAP} = asphalt binder present in the untreated material, %

NDG_M = moisture content measured using the NDG

$NDG_{M\%}$ = percent moisture measured using the NDG, %

$$CIV_2 = 28.667 - 1.0608 \cdot P_{No.50} + 1.3001 \cdot B_{RAP} - 1.9206 \cdot NDG_M + 1.1678 \cdot NDG_{M\%} \tag{4-24}$$

where CIV_2 = 2-day CIV

$P_{No.50}$ = percent passing the No. 50 sieve, %

B_{RAP} = asphalt binder present in the untreated material, %

NDG_M = moisture content measured using the NDG

$NDG_{M\%}$ = percent moisture measured using the NDG, %

$$CIV_3 = 15.855 - 6.9103 \cdot P_{No.100} + 8.0288 \cdot P_{No.200} + 3.2526 \cdot B_{RAP} - 2.9807 \cdot NDG_M + 3.0486 \cdot NDG_{M\%} \tag{4-25}$$

where CIV_3 = 3-day CIV

$P_{No.100}$ = percent passing the No. 100 sieve, %

$P_{No.200}$ = percent passing the No. 200 sieve, %

B_{RAP} = asphalt binder present in the untreated material, %

NDG_M = moisture content measured using the NDG

$NDG_{M\%}$ = percent moisture measured using the NDG, %

$$CIV_7 = 46.665 + 3.3649 \cdot P_{No.30} - 7.4828 \cdot P_{No.50} - 4.1886 \cdot NDG_M + 3.4090 \cdot NDG_{M\%} \tag{4-26}$$

where CIV_7 = 7-day CIV

$P_{No.30}$ = percent passing the No. 30 sieve, %

$P_{No.50}$ = percent passing the No. 50 sieve, %

NDG_M = moisture content measured using the NDG

$NDG_{M\%}$ = percent moisture measured using the NDG, %

$$CIV_{14} = 50.937 - 1.8069 \cdot P_{No.50} + 5.2475 \cdot P_{No.200} - 2.1620 \cdot MC_{pre} - 1.5689 \cdot NDG_M + 1.0321 \cdot NDG_{M\%} \tag{4-27}$$

where CIV_{14} = 14-day CIV

$P_{No.50}$ = percent passing the No. 50 sieve, %

$P_{No.200}$ = percent passing the No. 200 sieve, %

MC_{pre} = moisture content before emulsion treatment, %

NDG_M = moisture content measured using the NDG

$NDG_{M\%}$ = percent moisture measured using the NDG, %

$$SSG_1 = 95.007 - 1.6821 \cdot P_{No.50} - 1.5023 \cdot MC_{pre} - 1.5931 \cdot NDG_M - 0.35232 \cdot NDG_{WD} \quad (4\text{-}28)$$

where SSG_1 = 1-day soil stiffness, MN/m

$P_{No.50}$ = percent passing the No. 50 sieve, %

MC_{pre} = moisture content before emulsion treatment, %

NDG_M = moisture content measured using the NDG

NDG_{WD} = wet density measured using the NDG, pcf

$$SSG_2 = 68.989 - 1.0504 \cdot NDG_M - 0.30752 \cdot NDG_{WD} \quad (4\text{-}29)$$

where SSG_2 = 2-day soil stiffness, MN/m

NDG_M = moisture content measured using the NDG

NDG_{WD} = wet density measured using the NDG, pcf

$$SSG_3 = 44.139 + 1.7737 \cdot B_{RAP} - 0.31239 \cdot NDG_{WD} \quad (4\text{-}30)$$

where SSG_3 = 3-day soil stiffness, MN/m

B_{RAP} = asphalt binder present in the untreated material, %

NDG_{WD} = wet density measured using the NDG, pcf

$$SSG_7 = 49.277 + 0.58877 \cdot P_{No.4} - 4.1163 \cdot P_{No.30} + 4.9975 \cdot P_{No.50} - 4.2358 \cdot MC_{pre} - 1.3827 \cdot NDG_M \tag{4-31}$$

where SSG_7 = 7-day soil stiffness, MN/m

$P_{No.4}$ = percent passing the No. 4 sieve, %

$P_{No.30}$ = percent passing the No. 30 sieve, %

$P_{No.50}$ = percent passing the No. 50 sieve, %

MC_{pre} = moisture content before emulsion treatment, %

NDG_M = moisture content measured using the NDG

$$SSG_{14} = 8.2083 + 2.5122 \cdot P_{No.16} - 2.3744 \cdot P_{No.30} \tag{4-32}$$

where SSG_{14} = 14-day soil stiffness, MN/m

$P_{No.16}$ = percent passing the No. 16 sieve, %

$P_{No.30}$ = percent passing the No. 30 sieve, %

The regression equations developed from the field data quantify several relationships between the compositional and structural characteristics of the tested specimens. Gradation was a significant factor in predicting ETB stiffness. An interesting trend between day of testing and significant sieve size is visible in the analysis results. ETB stiffness during early stages of curing, when the ETB is behaving like a granular base, is most affected by the amount of material passing larger sieve sizes. ETB stiffness later in the curing process, when the ETB is behaving more like a stabilized base, is most affected by the amount of material passing smaller sieve sizes. The No. 30, No. 50, and No. 100 sieves were the most commonly identified as significant. Increasing amounts of material passing these three sieves was shown to decrease stiffness; however, increasing the amount of material passing the No. 200 sieve increased stiffness.

Increasing pre-treatment moisture content decreased ETB stiffness. Increased moisture content before treatment could prevent curing of the emulsion, thereby inhibiting development of stiffness in the ETB. Increasing RAP binder increased ETB stiffness. The presence of RAP in the base material could improve the bond between the emulsion and the base material. Increasing binder change increased ETB modulus. Increasing the moisture content as measured on the day of construction decreased ETB stiffness. This correlation between ETB stiffness and post-construction field moisture content is consistent with the previously documented correlation between laboratory UCS and moisture content at the time of testing in the laboratory. Increased percent moisture, however, was shown to increase stiffness, although a reason for this trend is not readily apparent. For the range of densities in this research, increasing wet density decreased ETB stiffness, perhaps because both lower void ratios and higher water contents impede curing of the material.

4.5.2 Coefficient of Variation Comparisons

Table 4-6 shows the average CV values for each response variable by test section. CV values greater than 40 indicate substantial variation. The results show that substantial variation exists in the 121-day CBR and corresponding DCP penetration rate, as well as in the 1-day SSG. Section A generally exhibited more variability than sections B and C for UCS, DCP, and PFWD results. For CIV and SSG testing, section B exhibited much higher variability. The results also show that variability was typically the highest at 121 days and the lowest at 365 days. This trend might have been due to seasonal effects and the curing of emulsion. The highest variability coincides in this study with the highest values of stiffness.

Table 4-7 displays the CVs of the predictor variables used in this research. Variability was fairly low among the predictor variables except for the amounts of material passing the No. 100 and No. 200 sieves and binder change. Because the amount of material passing the No. 100 and No. 200 sieves is significantly correlated to pavement strength and stiffness as measured using the UCS, DCP, PFWD, and CIST tests, variability in these factors is expected to cause variability in long-term pavement performance. Additionally, because binder change is significantly correlated to both UCS and modulus measured using the PFWD, variability in this factor is also expected to cause variability in long-term pavement performance.

4.5.3 Analysis of Variance and Tukey's Mean Separation Procedure

The results of the ANOVA and Tukey's mean separation procedure are given in Table 4-8. These analyses show that, except for the 28-day test, UCS results were not statistically different between the three sections. However, the analyses show that significant differences existed among the three sections for 26 of the 31 field-measured response variables. Significant variation in the field data but not in the laboratory data suggests that differences between the sections were most likely caused by environmental or construction factors occurring after the samples of treated material were removed on the day of construction.

Sections A and B were significantly different for 23 of the 31 field response variables. Sections A and C were significantly different for 19 of 31 variables. Sections B and C were only significantly different for four of the response variables. Sections A and B were expected to perform more similarly than sections B and C because sections A and B were constructed on the

Table 4-6: Coefficients of Variation for Response Variables

Variable	CV (%)		
	Section A	Section B	Section C
7-Day UCS	26	13	26
28-Day UCS	28	19	12
91-Day UCS	35	16	15
365-Day UCS	32	17	16
1-Day CBR	22	24	14
2-Day CBR	24	15	16
3-Day CBR	22	10	14
7-Day CBR	25	18	14
14-Day CBR	15	16	18
91-Day CBR	46	31	27
365-Day CBR	11	16	8
1-Day PR	19	20	12
2-Day PR	20	14	15
3-Day PR	19	10	12
7-Day PR	27	18	12
14-Day PR	15	14	16
91-Day PR	53	28	26
365-Day PR	10	14	7
1-Day Modulus	20	30	18
2-Day Modulus	16	18	21
3-Day Modulus	19	20	18
7-Day Modulus	22	19	20
14-Day Modulus	30	15	18
91-Day Modulus	26	26	17
365-Day Modulus	14	12	9
1-Day CIV	14	26	14
2-Day CIV	9	18	8
3-Day CIV	10	15	11
7-Day CIV	19	12	7
14-Day CIV	9	14	6
1-Day Stiffness	11	51	15
2-Day Stiffness	13	25	14
3-Day Stiffness	12	19	13
7-Day Stiffness	11	17	17
14-Day Stiffness	10	15	11

Table 4-7: Coefficients of Variation for Predictor Variables

Variable	CV (%)		
	Section A	Section B	Section C
Percent Passing the 0.5 in. Sieve	8	7	7
Percent Passing the 0.375 in. Sieve	10	7	7
Percent Passing the No. 4 Sieve	13	8	9
Percent Passing the No. 8 Sieve	13	9	12
Percent Passing the No. 16 Sieve	19	12	17
Percent Passing the No. 30 Sieve	25	9	23
Percent Passing the No. 50 Sieve	22	12	25
Percent Passing the No. 100 Sieve	33	16	19
Percent Passing the No. 200 Sieve	51	28	21
RAP Binder Content	12	11	9
Binder Change	42	26	37
7-day Moisture Content	20	15	17
28-day Moisture Content	21	20	18
91-day Moisture Content	10	11	5
365-day Moisture Content	14	4	5
7-day Wet Density	3	3	1
28-day Wet Density	2	1	1
91-day Wet Density	2	1	1
365-day Wet Density	2	2	1
7-day Dry Density	3	2	1
28-day Dry Density	2	1	1
91-day Dry Density	2	1	1
365-day Dry Density	2	2	1
NDG Wet Density	4	1	2
NDG Moisture Content	6	6	5
NDG Percent Moisture	9	6	4

Table 4-8: Results of ANOVA and Tukey's Mean Separation Procedure

Variable	ANOVA	Tukey's			
	p-values	Significant Difference between Sites			
		AB	BC	AC	None
7-Day UCS	0.3145				x
28-Day UCS	0.0316	x			
91-Day UCS	0.2948				x
365-Day UCS	0.7644				x
1-Day CBR	<0.0001	x		x	
2-Day CBR	0.0084	x		x	
3-Day CBR	<0.0001	x		x	
7-Day CBR	<0.0001	x		x	
14-Day CBR	<0.0001	x			
91-Day CBR	0.5725				x
365-Day CBR	0.0028	x		x	
1-Day PR	<0.0001	x		x	
2-Day PR	0.0121			x	
3-Day PR	<0.0001	x		x	
7-Day PR	<0.0001	x		x	
14-Day PR	<0.0001	x	x		
91-Day PR	0.8223				x
365-Day PR	0.0021	x		x	
1-Day Modulus	0.0005	x		x	
2-Day Modulus	0.184				x
3-Day Modulus	0.0047	x			
7-Day Modulus	0.0009	x		x	
14-Day Modulus	0.0289	x		x	
91-Day Modulus	0.0246			x	
365-Day Modulus	0.6303				x
1-Day CIV	<0.0001	x		x	
2-Day CIV	0.007	x			
3-Day CIV	<0.0001	x		x	
7-Day CIV	<0.0001	x	x		
14-Day CIV	0.0003	x	x		
1-Day Stiffness	0.0004	x		x	
2-Day Stiffness	0.054				x
3-Day Stiffness	0.0004	x		x	
7-Day Stiffness	<0.0001	x		x	
14-Day Stiffness	0.0067		x		

same day and, therefore, under similar environmental conditions. For this reason, other factors must have existed that caused the significant differences between sections A and B. These significant differences are expected to have important implications on the long-term pavement performance of the three sections.

4.6 Summary

The results of the sieve analysis indicated that all three sections can be classified as A-1-a and GW using the AASHTO and Unified Soil Classification System methods, respectively. Both sections A and B had emulsion contents higher than the design specification of 4.0 percent; however, section C had an emulsion content lower than the design specification. The average UCS values for all three sections were 30, 96, 145, and 179 psi at 7 days, 28 days, 3 months, and 1 year, respectively.

Average modulus values during the two-week period following construction were 26.0, 28.6, 21.0, and 16.5 ksi determined using the PFWD, DCP, SSG, and CIST, respectively. Modulus values measured using the PFWD were consistently low in all three sections during the first two weeks of testing, increased dramatically by 4 months, and then decreased considerably by 1 year. Sections A and B reached a structural coefficient of 0.25 after approximately 3 months; however, after 1 year, sections A and B had much lower structural coefficients of 0.11 and 0.12, respectively. At 4 months, the ETB structural coefficient in section C was only 0.21, and after 1 year it had decreased to 0.12. The pavement capacity during the first two weeks for the scenario in which the ETB is unpaved was calculated to be less than 0.5 percent of the design capacity. For the scenario in which the ETB is paved immediately following construction, the pavement capacity at 2 weeks, 4 months, and 1 year, is 4, 133, and 16 percent of the design capacity, respectively.

Results of multivariate regression for laboratory data showed that gradation was a significant factor in predicting ETB strength. Increasing pre-treatment moisture content increased strength. Increasing RAP content and binder change decreased strength. Within the range of moisture contents investigated in this study, increases in moisture content were associated with decreases in strength.

Results of multivariate regression for field data showed that gradation was a significant factor in predicting ETB stiffness. Increasing pre-treatment moisture content decreased ETB stiffness. Increasing RAP binder increased ETB stiffness. Increasing binder change increased ETB modulus. Increasing the moisture content as measured on the day of construction decreased ETB stiffness. Increased percent moisture, however, was shown to increase stiffness. For the range of densities measured in this research, increasing wet density decreased ETB stiffness.

CV analysis showed that substantial variation exists in the 121-day CBR and corresponding DCP penetration rate, as well as in the 1-day SSG. Variability was fairly low among the predictor variables except for the amounts of material passing the No. 100 and No. 200 sieves and binder change.

The results of the ANOVA and Tukey’s mean separation procedure showed that significant differences existed among the three sections for 26 of the 31 field-measured response variables. These significant differences are expected to have important implications on the long-term pavement performance of the three sections.

5 CONCLUSION

5.1 Summary

The first objective of this research was to investigate temporal trends in the mechanical properties of base materials stabilized with asphalt emulsion and to assess the rate at which ETB design properties are achieved. The second objective of this research was to identify construction and environmental factors most correlated to specific mechanical properties of ETB layers and to determine which construction factors exhibit the greatest variability. Additional statistical analysis was performed to determine if significant differences existed between different test sections on a given project.

The test site chosen for this research was a section of Redwood Road (SR-68) located just north of Saratoga Springs, Utah. The experimental area was divided into three 800-ft by 24-ft test sections, labeled as sections A, B, and C. Ten individual test stations were established in each of the three sections.

Field testing was used over the course of the project to characterize the in-situ structural properties of the ETB layer. The field instruments utilized in this research include the PFWD, DCP, CIST, SSG, and NDG. The first series of field tests were begun within 30 minutes following final compaction of the ETB layer. Additional tests were performed at 2, 3, 7, and 14 days; 4 months; and 1 year. On the day of construction, samples of the reclaimed base material were removed from each test station both before and after emulsion treatment. The samples of untreated material were bagged and transported to the BYU Highway Materials Laboratory for sieve, moisture content, and burn-off analyses. The samples of treated material were compacted on site. At the laboratory, these samples were subjected to UCS, moisture content, and burn-off analyses.

The soil properties measured during field and laboratory testing were analyzed to determine equivalent resilient modulus values for the ETB layer, which were used to determine an equivalent structural coefficient for the ETB. The structural capacity of the pavement at each testing period was calculated using the AASHTO flexible pavement design method. The collected data were processed using several statistical analyses, including multivariate regression, CV comparisons, ANOVA, and Tukey's mean separation procedure.

5.2 Findings

The average UCS values for all three sections were 30, 96, 145, and 179 psi at 7 days, 28 days, 3 months, and 1 year, respectively. Average modulus values during the two-week period following construction were 26.0, 28.6, 21.0, and 16.5 ksi determined using the PFWD, DCP, SSG, and CIST, respectively. Modulus values measured using the PFWD were consistently low in all three sections during the first two weeks of testing, increased dramatically by 4 months, and then decreased considerably by 1 year. Only two of the three sections reached the design structural coefficient of 0.25, which occurred after approximately 3 months; however, the average structural coefficient measured for all three sections after 1 year of curing, which included a winter, was only 47 percent of the design strength. The pavement capacity during the first two weeks for the scenario in which the ETB is unpaved was calculated to be less than 0.5 percent of the design capacity. For the scenario in which the ETB is paved immediately following construction, the pavement capacity at 2 weeks, 4 months, and 1 year, is 4, 133, and 16 percent of the design capacity, respectively.

Results of multivariate regression for laboratory data showed that gradation was a significant factor in predicting ETB strength. Increasing pre-treatment moisture content increased strength. Increasing RAP content and binder change decreased strength. Within the range of moisture contents investigated in this study, increases in moisture content were associated with decreases in strength. Results of multivariate regression for field data showed that gradation was a significant factor in predicting ETB stiffness. Increasing pre-treatment moisture content decreased ETB stiffness. Increasing RAP binder increased ETB stiffness. Increasing binder change increased ETB modulus. Increasing the moisture content as measured on the day of construction decreased ETB stiffness. Increased percent moisture, however, was shown to increase stiffness. For the range of densities measured in this research, increasing wet density decreased ETB stiffness.

CV analysis showed variability was fairly low among the predictor variables except for the amounts of material passing the No. 100 and No. 200 sieves and binder change. The results of the ANOVA show that significant differences existed among the three sections for 26 of the 31 field-measured response variables. These significant differences are expected to have important implications on the long-term pavement performance of the three sections.

5.3 Recommendations

The results of this research show that, while pavement capacity is sufficient at 4 months, it is severely reduced during the first two weeks and at 1 year. Trafficking under these reduced capacities would be expected to greatly compromise long-term performance and may cause premature failure of the pavement system. Specifically, trafficking of materials similar to those investigated in this research would severely damage the pavement during at least the first two weeks following construction, especially before paving of the ETB. The results at 4 months suggest that ETB could be suitable for long-term projects that will not be trafficked for an extended period of time following construction; however, the low strengths at 1 year suggest that ETB may fail to meet design standards in the long term, despite additional curing. Furthermore, these research results suggest that ETB strength can be affected by temperature and moisture changes and that ETB materials may sustain damage due to freeze-thaw cycling during the winter in cold regions. Portland cement could be added to ETB to increase early strength if traffic must be reintroduced before paving, improve ETB durability, and reduce the susceptibility of ETB to environmental factors (*32*). Further research on these topics is needed.

The results of the spatial variability analysis show that gradation, binder change during emulsion treatment, and moisture content have a significant impact on ETB structural properties. Two of these three factors, gradation and binder change, exhibited large amounts of variability. For this reason, tighter specifications on material gradations and improved uniformity in emulsion distribution should be considered. Because excess moisture during construction is detrimental to ETB strength development, construction should not be performed when in-situ moisture contents are high, precipitation is expected, or water evaporation rates are low.

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APPENDIX A LABORATORY DATA

Table A-1: Sieve Analysis Results

Sieve Size	Percent Passing (%)									
	Section A									
	1	2	3	4	5	6	7	8	9	10
3/4"	89.8	96.6	91.4	-	-	84.8	93.1	95.2	75.9	90.9
1/2"	79.9	84.5	81.3	-	-	70.5	78.2	83.4	68.4	81.2
3/8"	66.2	74.6	71.3	-	-	57.3	64.9	70.3	56.2	70.6
No. 4	41.9	47.5	44.7	-	-	32.6	40.3	42.3	33.2	44.4
No. 8	23.2	25.6	25.9	-	-	17.8	21.5	22.8	18.5	24.3
No. 16	8.8	10.5	13.3	-	-	7.9	8.8	10.1	7.4	9.5
No. 30	4.4	4.8	5.8	-	-	3.8	3.6	4.1	2.2	4.8
No. 50	2.9	3.0	3.3	-	-	2.4	1.7	2.2	2.0	3.0
No. 100	1.5	1.9	1.8	-	-	1.2	0.7	1.0	0.9	1.6
No. 200	0.6	0.3	1.0	-	-	0.5	0.3	0.3	0.3	0.6
	Section B									
	1	2	3	4	5	6	7	8	9	10
3/4"	95.2	83.6	90.0	84.6	85.5	89.6	90.0	89.7	94.1	74.5
1/2"	81.8	73.8	77.9	72.8	75.6	76.2	75.2	76.9	81.6	61.9
3/8"	68.1	62.3	65.7	61.2	64.8	62.6	62.9	64.8	66.9	51.9
No. 4	41.0	39.5	41.4	35.4	39.8	35.9	36.9	39.0	39.1	32.2
No. 8	23.3	22.9	24.3	19.8	22.5	19.7	18.8	20.0	20.3	19.2
No. 16	12.1	10.7	10.8	10.2	10.4	8.8	8.3	8.7	9.1	9.3
No. 30	6.3	6.2	5.8	5.4	5.0	4.9	5.0	5.2	5.4	5.0
No. 50	3.5	4.2	3.8	2.8	3.0	3.3	3.4	3.5	3.6	3.2
No. 100	1.7	2.1	1.9	1.2	1.3	1.7	1.6	1.6	1.8	1.5
No. 200	0.6	0.8	0.7	0.4	0.3	0.7	0.7	0.5	0.5	0.6
	Section C									
	1	2	3	4	5	6	7	8	9	10
3/4"	94.4	95.0	90.1	77.8	91.3	90.7	79.6	89.3	91.6	82.0
1/2"	83.1	81.3	77.5	67.9	76.3	80.4	72.5	79.0	80.8	70.7
3/8"	67.9	67.6	63.8	57.9	63.9	68.3	61.0	66.5	69.0	57.9
No. 4	40.5	39.6	39.2	35.4	40.5	43.1	39.3	39.0	45.0	32.2
No. 8	23.7	21.9	22.4	21.3	26.1	26.1	23.4	22.9	18.7	18.2
No. 16	12.7	10.0	10.1	10.9	14.1	13.1	11.4	12.1	8.0	9.5
No. 30	6.7	4.8	4.9	5.6	7.8	6.3	5.8	6.4	3.1	5.3
No. 50	3.6	2.8	2.8	3.4	4.3	3.3	3.2	3.5	1.3	2.9
No. 100	1.0	1.3	1.3	1.6	1.9	1.5	1.4	1.6	1.2	1.2
No. 200	0.6	0.4	0.4	0.6	0.7	0.5	0.5	0.6	0.4	0.4

Table A-2: Pretreated Moisture Content Test Results

Pretreated Moisture Content (%)									
Section A									
1	2	3	4	5	6	7	8	9	10
6.6	6.9	4.9	-	-	6.2	5.8	5.6	5.4	7.1
Section B									
1	2	3	4	5	6	7	8	9	10
5.1	6.6	6.6	5.1	6.4	6.6	7.2	7.9	7.0	5.9
Section C									
1	2	3	4	5	6	7	8	9	10
5.4	5.6	6.3	6.7	5.3	5.6	5.5	5.4	6.4	5.3

Table A-3: Unconfined Compressive Strength Test Results

Curing Time (days)	Unconfined Compressive Strength (psi)									
	Section A									
	1	2	3	4	5	6	7	8	9	10
7	22.7	44.6	37.4	31.4	23.9	43.0	27.1	33.8	19.1	41.0
28	84.0	80.4	69.2	80.8	50.5	116.6	62.9	94.7	68.0	131.3
91	124.5	117.4	95.5	170.3	85.9	184.2	109.4	114.6	75.2	228.4
365	148.0	155.6	124.5	176.7	126.9	246.3	158.8	146.0	128.9	301.2
	Section B									
	1	2	3	4	5	6	7	8	9	10
7	23.5	35.4	29.8	30.6	31.0	31.0	30.6	26.7	31.4	39.4
28	153.2	127.3	93.5	93.1	113.0	107.0	109.0	77.2	122.5	96.3
91	140.1	179.4	143.6	115.0	150.0	137.3	193.8	161.5	173.5	120.2
365	250.3	179.4	152.0	141.3	189.0	175.9	219.2	177.1	177.1	149.2
	Section C									
	1	2	3	4	5	6	7	8	9	10
7	31.8	27.5	19.5	43.0	22.3	33.4	25.9	21.1	19.1	31.4
28	89.9	91.9	80.8	106.2	89.5	97.1	93.1	122.9	84.4	106.6
91	185.0	136.9	143.6	188.2	122.2	170.3	130.9	162.3	123.3	163.1
365	241.5	163.9	149.2	230.8	197.4	183.4	151.6	188.2	162.3	180.2

Table A-4: Moisture Content Test Results

Curing Time (days)	Moisture Content (%)									
	Section A									
	1	2	3	4	5	6	7	8	9	10
7	5.6	4.0	3.5	5.2	4.4	4.7	4.4	3.7	5.4	2.7
28	1.5	1.3	1.4	1.9	1.6	1.6	1.4	1.0	0.8	1.4
91	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.4
365	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.2
	Section B									
	1	2	3	4	5	6	7	8	9	10
7	6.3	5.4	5.3	4.3	5.0	5.1	6.6	6.0	5.2	3.9
28	1.2	1.3	1.9	1.4	1.5	1.6	2.0	2.3	1.5	1.3
91	0.3	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.5	0.4
365	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Section C									
	1	2	3	4	5	6	7	8	9	10
7	5.1	4.9	6.9	3.8	5.9	5.6	5.5	6.5	7.1	5.1
28	1.7	1.0	1.5	1.6	1.3	1.9	1.3	1.1	1.7	1.6
91	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4
365	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Table A-5: Wet Density Test Results

Curing Time (days)	Wet Density (pcf)									
	Section A									
	1	2	3	4	5	6	7	8	9	10
7	129.0	123.2	122.0	124.5	123.4	132.5	126.7	122.7	123.6	130.4
28	123.6	118.8	120.6	121.3	119.3	125.3	121.9	118.9	118.0	124.7
91	121.4	117.6	118.7	119.1	116.8	122.9	120.0	119.2	114.5	122.9
365	121.3	117.0	116.6	116.4	117.8	124.3	123.0	118.0	116.5	121.1
	Section B									
	1	2	3	4	5	6	7	8	9	10
7	131.8	131.5	132.2	121.4	129.2	128.4	131.9	132.4	127.4	124.4
28	125.1	124.0	124.1	122.0	125.9	124.3	124.8	123.8	125.6	121.1
91	123.4	124.0	122.2	121.0	123.9	120.7	122.3	124.0	119.2	119.9
365	122.6	120.3	121.5	115.3	122.9	121.8	123.7	123.4	120.1	121.2
	Section C									
	1	2	3	4	5	6	7	8	9	10
7	127.9	128.2	129.8	126.2	128.1	132.0	127.7	130.7	131.7	129.2
28	128.0	123.3	123.1	122.7	122.5	124.9	120.9	124.6	123.4	122.3
91	124.8	121.8	122.1	119.7	119.0	122.1	120.9	123.2	119.7	122.5
365	123.3	119.6	120.4	120.2	121.6	124.1	121.4	123.3	119.9	120.9

Table A-6: Dry Density Test Results

Curing Time (days)	Dry Density (pcf)									
	Section A									
	1	2	3	4	5	6	7	8	9	10
7	122.2	118.5	117.8	118.3	118.2	126.5	121.4	118.3	117.3	127.0
28	121.7	117.3	119.0	119.1	117.4	123.3	120.2	117.8	117.1	122.9
91	121.0	117.3	118.3	118.7	116.4	122.4	119.6	118.8	114.1	122.4
365	121.1	116.9	116.4	116.2	117.7	124.1	122.7	117.8	116.4	120.8
	Section B									
	1	2	3	4	5	6	7	8	9	10
7	124.0	124.8	125.5	116.4	123.1	122.2	123.8	124.9	121.1	119.7
28	123.6	122.3	121.8	120.3	124.0	122.4	122.4	121.0	123.7	119.5
91	123.0	123.5	121.7	120.4	123.4	120.3	121.8	123.6	118.6	119.5
365	122.2	119.8	121.1	115.0	122.5	121.4	123.3	123.0	119.8	120.8
	Section C									
	1	2	3	4	5	6	7	8	9	10
7	121.8	122.2	121.4	121.6	121.0	125.0	121.1	122.7	122.9	123.0
28	125.9	122.1	121.3	120.8	121.0	122.6	119.3	123.2	121.4	120.3
91	124.3	121.3	121.6	119.2	118.6	121.6	120.4	122.7	119.2	122.0
365	122.9	119.3	120.0	119.8	121.3	123.8	121.0	122.9	119.5	120.5

Table A-7: Burn-off Test Results

Time of Sampling	Binder Content (%)									
	Section A									
	1	2	3	4	5	6	7	8	9	10
Before Injection	4.1	5.6	5.8	-	-	4.8	4.3	5.2	5.4	4.6
After Injection	8.3	9.0	8.7	7.6	9.5	6.3	8.6	8.1	9.8	5.5
	Section B									
	1	2	3	4	5	6	7	8	9	10
Before Injection	4.5	4.2	4.1	5.6	4.7	3.9	-	4.3	4.3	4.6
After Injection	6.1	6.1	6.3	8.1	7.7	7.6	6.1	6.9	7.2	7.9
	Section C									
	1	2	3	4	5	6	7	8	9	10
Before Injection	3.9	4.4	4.8	4.8	4.6	5.1	5.1	5.5	4.8	4.8
After Injection	5.9	7.3	6.8	6.9	7.9	5.9	7.6	6.5	7.1	7.3

APPENDIX B FIELD DATA

Table B-1: Portable Falling-Weight Deflectometer Results for Section A

Curing Time (days)	Test	Resilient Modulus (ksi)									
		Station									
		1	2	3	4	5	6	7	8	9	10
1	1	21.7	20.9	20.1	15.8	28.9	16.7	23.8	19.8	24.4	9.6
	2	24.7	23.2	21.2	17.9	28.2	19.1	25.1	21.4	25.2	13.8
	3	25.5	24.5	22.3	19.6	27.4	20.7	26.4	22.3	25.8	14.9
	Average	24.0	22.9	21.2	17.8	28.2	18.8	25.1	21.2	25.1	12.8
2	1	27.6	22.4	20.0	18.6	21.8	17.4	23.0	22.9	19.2	14.1
	2	29.8	24.0	21.8	21.8	22.6	20.2	24.4	24.1	20.2	15.8
	3	30.9	24.8	22.8	22.7	23.2	20.6	24.3	21.7	21.4	16.6
	Average	29.4	23.7	21.5	21.0	22.5	19.4	23.9	22.9	20.2	15.5
3	1	32.9	29.3	36.9	25.6	32.5	22.9	32.9	30.3	38.1	18.3
	2	34.6	32.6	38.4	28.0	33.7	24.4	36.8	30.4	38.4	20.4
	3	34.7	34.1	38.7	25.4	35.9	25.6	37.2	31.7	35.3	21.0
	Average	34.0	32.0	38.0	26.3	34.0	24.3	35.6	30.8	37.3	19.9
7	1	39.4	39.3	50.4	36.0	46.5	31.2	41.9	45.3	30.0	18.9
	2	41.0	40.8	51.8	39.3	50.6	35.0	42.6	45.1	32.8	21.3
	3	41.4	41.4	52.6	41.1	50.4	36.5	40.6	45.3	33.8	22.5
	Average	40.6	40.5	51.6	38.8	49.2	34.2	41.7	45.2	32.2	20.9
14	1	41.4	27.0	60.9	29.3	41.3	28.3	33.9	39.4	27.1	21.2
	2	44.2	30.7	60.9	31.6	38.8	31.7	36.0	41.1	27.4	23.7
	3	44.1	31.9	64.7	33.4	41.6	33.0	38.8	41.0	29.3	23.5
	Average	43.2	29.9	62.2	31.4	40.6	31.0	36.2	40.5	27.9	22.8
113	1	310.7	-	-	245.1	-	299.5	-	-	-	635.1
	2	291.0	-	-	242.4	-	409.9	-	-	-	398.8
	3	281.5	-	-	256.4	-	415.2	-	-	-	322.9
	Average	294.4	-	-	248.0	-	374.9	-	-	-	452.2
365	1	94.1	-	-	74.3	-	74.1	-	-	-	98.2
	2	93.4	-	-	74.6	-	75.6	-	-	-	98.7
	3	93.2	-	-	77.8	-	74.7	-	-	-	96.4
	Average	93.6	-	-	75.6	-	74.8	-	-	-	97.7

Table B-2: Portable Falling-Weight Deflectometer Results for Section B

Curing Time (days)	Test	Resilient Modulus (ksi)									
		Station									
		1	2	3	4	5	6	7	8	9	10
1	1	20.4	9.3	8.4	15.5	7.7	15.5	12.5	8.2	11.8	11.6
	2	23.0	11.8	9.7	17.0	11.2	16.9	13.6	10.3	13.8	14.9
	3	24.1	13.1	8.4	17.8	12.7	17.6	14.5	11.6	14.8	16.2
	Average	22.5	11.4	8.8	16.8	10.5	16.7	13.5	10.0	13.5	14.2
2	1	21.8	17.8	-	12.0	20.5	17.0	19.0	14.2	17.5	-
	2	24.1	18.9	-	13.2	22.4	19.2	19.9	15.6	19.4	-
	3	24.9	19.7	-	14.3	23.0	19.6	20.7	16.9	21.3	-
	Average	23.6	18.8	-	13.2	22.0	18.6	19.9	15.6	19.4	-
3	1	30.7	21.4	15.1	17.3	21.8	23.7	25.8	23.7	20.2	20.3
	2	32.6	23.1	16.1	18.7	23.8	24.7	26.3	24.5	21.2	22.5
	3	32.9	21.3	15.7	18.9	24.2	25.5	26.5	25.0	21.8	22.7
	Average	32.1	21.9	15.6	18.3	23.3	24.6	26.2	24.4	21.1	21.8
7	1	-	-	-	29.5	25.7	21.6	23.0	17.9	19.4	-
	2	-	-	-	31.3	26.3	22.1	22.4	18.0	21.1	-
	3	-	-	-	32.0	26.4	22.8	22.5	18.1	21.8	-
	Average	-	-	-	30.9	26.1	22.2	22.6	18.0	20.8	-
14	1	29.1	29.2	19.5	29.0	29.5	24.9	28.1	20.4	-	22.7
	2	32.3	29.4	22.0	30.3	30.4	27.1	29.5	21.6	-	24.1
	3	33.9	28.9	23.3	31.8	30.5	27.8	30.9	21.9	-	25.3
	Average	31.7	29.1	21.6	30.4	30.1	26.6	29.5	21.3	-	24.0
113	1	341.9	-	-	192.0	-	-	-	-	-	-
	2	204.5	-	-	422.9	-	-	-	-	-	-
	3	288.0	-	-	590.2	-	-	-	-	-	-
	Average	278.1	-	-	401.7	-	-	-	-	-	-
365	1	86.0	-	-	103.2	-	-	-	-	-	-
	2	87.0	-	-	101.8	-	-	-	-	-	-
	3	86.2	-	-	101.3	-	-	-	-	-	-
	Average	86.4	-	-	102.1	-	-	-	-	-	-

Table B-3: Portable Falling-Weight Deflectometer Results for Section C

Curing Time (days)	Test	Resilient Modulus (ksi)									
		Station									
		1	2	3	4	5	6	7	8	9	10
1	1	16.9	15.0	16.3	16.6	14.5	20.3	14.3	14.1	9.8	14.8
	2	19.2	17.3	18.1	20.2	19.8	24.0	17.6	16.1	10.6	15.7
	3	20.1	18.8	18.2	21.5	18.1	24.2	19.3	16.8	11.8	16.4
	Average	18.7	17.0	17.5	19.4	17.5	22.8	17.1	15.7	10.7	15.6
2	1	19.7	19.1	23.6	24.4	27.3	22.2	21.9	24.2	11.9	14.9
	2	23.1	21.8	25.2	24.0	29.8	24.5	21.2	24.1	12.5	16.6
	3	23.6	22.0	25.8	24.8	29.0	26.7	22.6	25.0	12.6	17.5
	Average	22.1	21.0	24.9	24.4	28.7	24.5	21.9	24.4	12.3	16.3
3	1	27.7	27.7	29.9	32.0	36.8	28.2	28.0	29.6	15.8	23.4
	2	28.5	28.5	30.9	32.0	37.4	31.1	30.1	29.8	17.2	25.3
	3	29.2	29.0	30.8	29.6	37.6	31.6	31.7	29.1	17.6	24.8
	Average	28.5	28.4	30.6	31.2	37.3	30.3	30.0	29.5	16.9	24.5
7	1	-	32.8	-	32.7	38.4	30.7	26.4	25.5	20.3	24.7
	2	-	33.9	-	35.4	40.1	33.1	29.4	27.1	20.1	27.1
	3	-	35.9	-	35.9	40.3	33.6	30.4	26.4	20.2	28.3
	Average	-	34.2	-	34.7	39.6	32.5	28.7	26.3	20.2	26.7
14	1	36.3	34.5	32.5	-	43.2	36.1	32.4	32.1	23.4	27.5
	2	36.2	37.9	32.7	-	46.5	37.6	32.9	32.7	24.2	30.7
	3	39.5	39.5	34.0	43.9	46.8	38.6	34.2	33.1	25.5	31.9
	Average	37.3	37.3	33.1	43.9	45.5	37.4	33.2	32.7	24.4	30.1
113	1	143.3	-	-	203.7	-	136.1	-	-	-	184.4
	2	191.1	-	-	211.6	-	129.9	-	-	-	187.5
	3	215.0	-	-	192.0	-	138.2	-	-	-	189.9
	Average	183.2	-	-	202.4	-	134.7	-	-	-	187.3
365	1	93.3	-	-	101.4	-	76.6	-	-	-	91.2
	2	93.5	-	-	94.2	-	80.2	-	-	-	88.2
	3	81.5	-	-	99.1	-	78.2	-	-	-	92.7
	Average	89.4	-	-	98.2	-	78.3	-	-	-	90.7

Table B-4: Dynamic Cone Penetrometer Results for Section A

Curing Time (days)	Penetration Rate (mm/blow)									
	Station									
	1	2	3	4	5	6	7	8	9	10
1	7.5	5.5	4.5	7.7	6.7	7.0	5.6	6.1	5.1	8.0
2	4.5	6.0	5.5	7.0	6.6	5.7	7.0	8.5	8.0	8.5
3	4.4	3.4	3.3	4.9	4.9	4.2	3.5	3.5	5.2	5.6
7	2.8	2.6	2.3	2.8	2.5	3.7	3.5	3.6	3.1	5.3
14	3.2	3.1	2.9	3.8	3.1	3.2	3.4	4.0	3.1	4.5
113	0.8	-	-	1.9	-	0.9	-	-	-	0.6
365	1.5	-	-	1.3	-	1.2	-	-	-	1.4

Table B-5: Dynamic Cone Penetrometer Results for Section B

Curing Time (days)	Penetration Rate (mm/blow)									
	Station									
	1	2	3	4	5	6	7	8	9	10
1	6.9	11.9	11.9	7.1	7.7	8.8	9.3	11.4	9.0	11.2
2	7.4	8.7	9.0	7.5	6.4	7.2	7.6	9.4	7.2	9.6
3	6.2	6.8	7.4	5.8	6.4	6.6	6.5	7.9	6.0	7.2
7	4.7	6.0	5.9	5.5	4.9	5.2	6.8	8.2	5.1	6.6
14	4.4	5.4	5.6	4.4	5.5	5.5	6.5	6.7	4.6	5.3
113	1.2	-	-	0.8	-	-	-	-	-	-
365	1.6	-	-	2.0	-		-	-	-	-

Table B-6: Dynamic Cone Penetrometer Results for Section C

Curing Time (days)	Penetration Rate (mm/blow)									
	Station									
	1	2	3	4	5	6	7	8	9	10
1	9.2	9.0	11.0	8.8	9.7	7.9	7.4	8.6	10.7	9.6
2	6.8	7.1	10.9	9.0	9.0	7.4	7.9	8.2	9.4	8.6
3	5.7	6.6	7.3	5.8	7.3	4.9	6.1	6.1	6.6	6.8
7	4.0	5.0	5.0	3.7	4.8	4.0	4.3	4.9	5.4	4.7
14	3.1	3.5	5.1	3.9	4.2	3.8	3.8	4.3	5.1	4.3
113	1.0	-	-	1.7	-	1.3	-	-	-	1.0
365	2.0	-	-	1.8	-	2.1	-	-	-	2.1

Table B-7: Clegg Impact Soil Tester Results for Section A

Curing Time (days)	Test	Clegg Impact Value									
		Station									
		1	2	3	4	5	6	7	8	9	10
1	1	23.5	21.8	29.3	20.9	19.7	19.7	19.4	18.6	19.3	21.5
	2	22.7	22.8	27.5	16.6	20.4	19.0	19.3	21.4	16.9	17.5
	3	21.3	21.1	27.0	18.0	22.7	20.3	17.3	23.1	18.7	22.2
	Average	22.5	21.9	27.9	18.5	20.9	19.7	18.7	21.0	18.3	20.4
2	1	23.9	22.4	23.7	21.4	19.6	21.0	19.0	20.7	19.3	19.1
	2	23.3	23.4	23.1	21.5	19.2	17.8	17.4	19.4	18.0	18.5
	3	23.4	23.9	22.7	20.9	18.4	19.4	21.0	20.2	19.8	18.6
	Average	23.5	23.2	23.2	21.3	19.1	19.4	19.1	20.1	19.0	18.7
3	1	31.9	31.3	32.1	29.9	27.1	25.5	28.4	27.5	27.0	24.0
	2	30.6	29.3	33.7	25.9	31.4	25.7	27.0	30.5	27.7	23.5
	3	28.9	30.3	34.8	25.0	27.4	26.5	32.6	29.1	27.9	22.3
	Average	30.5	30.3	33.5	26.9	28.6	25.9	29.3	29.0	27.5	23.3
7	1	34.1	33.2	35.0	32.4	33.7	30.0	32.7	19.6	20.9	18.6
	2	37.2	36.2	37.4	26.3	32.5	32.2	32.9	27.6	22.0	22.4
	3	34.7	34.2	35.2	27.4	32.8	31.2	33.1	25.3	22.9	22.0
	Average	35.3	34.5	35.9	28.7	33.0	31.1	32.9	24.2	21.9	21.0
14	1	34.8	27.2	32.8	25.2	26.7	27.4	29.2	26.8	25.7	27.2
	2	30.3	25.0	32.5	20.7	30.6	26.7	27.8	26.7	29.1	25.8
	3	29.1	22.4	29.2	27.6	28.6	25.7	24.3	25.7	26.2	26.1
	Average	31.4	24.9	31.5	24.5	28.6	26.6	27.1	26.4	27.0	26.4

Table B-8: Clegg Impact Values for Section B

Curing Time (days)	Test	Clegg Impact Value									
		Station									
		1	2	3	4	5	6	7	8	9	10
1	1	20.9	12.5	8.4	19.1	13.1	16.1	13.9	9.7	13.4	14.3
	2	19.1	12.8	7.8	18.0	12.5	15.7	11.7	9.1	12.6	15.0
	3	17.8	11.9	7.0	18.4	13.0	14.4	13.0	9.2	13.2	15.3
	Average	19.3	12.4	7.7	18.5	12.9	15.4	12.9	9.3	13.1	14.9
2	1	22.2	14.8	10.8	21.4	19.7	19.5	17.2	15.1	17.1	16.8
	2	19.2	14.1	11.2	19.8	19.1	18.8	17.4	13.9	17.0	16.1
	3	18.6	16.4	12.0	21.5	18.3	20.3	16.0	12.7	18.3	16.4
	Average	20.0	15.1	11.3	20.9	19.0	19.5	16.9	13.9	17.5	16.4
3	1	22.8	17.8	14.8	22.1	20.7	18.5	17.3	12.9	19.8	18.8
	2	21.3	18.2	15.9	24.0	22.2	20.4	15.8	15.3	18.0	20.6
	3	21.0	19.0	16.0	24.0	20.2	18.2	15.9	15.2	21.0	18.6
	Average	21.7	18.3	15.6	23.4	21.0	19.0	16.3	14.5	19.6	19.3
7	1	20.4	19.3	15.9	21.4	20.6	22.4	18.2	14.6	18.7	22.5
	2	22.6	18.9	17.1	22.6	17.5	21.3	15.7	17.5	19.1	19.0
	3	20.8	17.0	14.7	19.9	20.9	21.8	17.1	14.6	17.9	19.7
	Average	21.3	18.4	15.9	21.3	19.7	21.8	17.0	15.6	18.6	20.4
14	1	25.9	21.0	19.7	26.3	23.7	22.8	22.7	17.6	24.7	22.4
	2	27.7	23.8	20.6	28.8	21.0	23.8	19.5	18.3	24.3	22.9
	3	28.2	20.1	18.1	27.9	21.3	23.3	19.7	18.1	22.6	22.8
	Average	27.3	21.6	19.5	27.7	22.0	23.3	20.6	18.0	23.9	22.7

Table B-9: Clegg Impact Values for Section C

Curing Time (days)	Test	Clegg Impact Value									
		Station									
		1	2	3	4	5	6	7	8	9	10
1	1	16.3	14.0	15.3	19.6	15.1	15.5	18.5	20.0	13.0	14.6
	2	16.1	15.8	15.5	18.9	14.4	14.0	19.1	17.3	10.4	14.0
	3	15.7	15.3	16.5	19.4	15.9	18.5	18.1	18.1	11.7	15.0
	Average	16.0	15.0	15.8	19.3	15.1	16.0	18.6	18.5	11.7	14.5
2	1	17.8	16.3	18.7	20.3	17.7	16.4	-	-	-	-
	2	18.0	16.2	18.5	20.5	16.2	15.4	-	-	-	-
	3	17.6	17.3	18.2	21.6	17.9	20.1	-	-	-	-
	Average	17.8	16.6	18.5	20.8	17.3	17.3	-	-	-	-
3	1	22.9	18.6	19.1	25.9	20.9	22.9	23.8	21.8	18.2	19.3
	2	20.3	18.1	19.3	22.6	21.2	18.6	23.8	22.5	18.6	17.2
	3	19.5	18.0	18.2	25.7	19.5	21.5	22.5	23.3	18.3	17.3
	Average	20.9	18.2	18.9	24.7	20.5	21.0	23.4	22.5	18.4	17.9
7	1	28.6	20.4	23..4	30.1	27.2	24.8	25.9	27.0	23.7	26.3
	2	25.7	28.1	24.8	33.2	22.0	27.1	25.3	29.6	24.9	30.0
	3	24.5	21.7	24.9	25.2	24.8	22.9	27.1	24.4	26.9	27.2
	Average	26.3	23.4	24.9	29.5	24.7	24.9	26.1	27.0	25.2	27.8
14	1	29.5	24.2	25.3	34.5	24.2	27.1	28.3	29.7	27.4	25.2
	2	27.6	23.6	21.8	33.1	23.8	28.7	28.5	23.7	24.8	24.2
	3	24.6	23.2	23.4	26.5	24.9	26.2	24.9	24.5	26.8	34.5
	Average	27.2	23.7	24.3	27.3	27.2	26.0	26.3	28.0	26.3	28.0

Table B-10: Soil Stiffness Gauge Results for Section A

Curing Time (days)	Test	Soil Stiffness (MN/m)									
		Station									
		1	2	3	4	5	6	7	8	9	10
1	1	14.8	13.2	18.4	12.0	16.4	13.3	15.3	14.8	15.7	13.4
	2	15.0	13.1	18.3	12.3	16.4	13.4	15.5	14.7	15.5	14.4
	3	15.8	13.0	18.0	13.4	16.8	14.2	15.4	14.3	15.7	14.6
	Average	15.2	13.1	18.2	12.6	16.6	13.6	15.4	14.6	15.6	14.1
2	1	17.2	14.7	19.4	14.9	16.8	14.1	16.6	13.6	15.0	11.5
	2	16.7	14.9	19.7	15.5	15.8	16.0	15.8	14.0	15.6	12.6
	3	16.8	14.7	20.1	15.6	15.8	15.7	17.3	14.3	15.3	12.2
	Average	16.9	14.8	19.8	15.3	16.1	15.3	16.6	13.9	15.3	12.1
3	1	20.5	18.4	21.8	17.1	19.2	16.4	18.9	19.1	19.8	14.1
	2	19.3	16.5	22.6	16.2	18.3	16.3	20.4	19.5	19.2	14.2
	3	20.5	18.9	22.8	18.0	18.5	17.4	19.7	19.4	20.3	14.5
	Average	20.1	18.0	22.4	17.1	18.7	16.7	19.7	19.3	19.8	14.2
7	1	24.3	26.2	28.5	21.6	26.3	19.5	24.4	22.5	25.0	19.5
	2	26.6	25.4	25.3	23.4	26.1	21.0	24.4	23.8	25.5	18.8
	3	27.0	22.0	25.4	23.3	27.2	21.4	22.3	21.4	26.1	18.7
	Average	25.9	24.5	26.4	22.7	26.5	20.6	23.7	22.6	25.6	19.0
14	1	20.1	24.4	18.7	26.2	21.1	15.5	24.3	26.2	25.0	21.0
	2	22.6	20.2	28.9	24.9	22.2	19.4	20.1	20.5	21.0	19.2
	3	18.8	21.3	26.3	23.2	28.1	18.2	27.4	21.0	23.6	22.3
	Average	20.5	22.0	24.6	24.8	23.8	17.7	23.9	22.5	23.2	20.8

Table B-11: Soil Stiffness Gauge Results for Section B

Curing Time (days)	Test	Soil Stiffness (MN/m)									
		Station									
		1	2	3	4	5	6	7	8	9	10
1	1	14.6	2.8	2.9	14.6	5.5	12.9	8.7	4.3	9.0	11.1
	2	13.8	3.2	3.6	14.9	6.3	13.3	8.4	4.1	8.5	11.2
	3	15.2	3.6	4.0	14.8	6.5	13.7	8.8	4.5	9.5	11.2
	Average	14.5	3.2	3.5	14.7	6.1	13.3	8.6	4.3	9.0	11.2
2	1	16.4	7.7	9.5	16.0	14.8	17.8	13.2	10.3	13.4	11.7
	2	17.0	8.1	9.7	16.8	14.4	17.7	13.2	9.9	13.8	12.4
	3	17.1	7.9	9.7	16.7	14.4	17.3	13.5	10.2	14.2	12.7
	Average	16.8	7.9	9.6	16.5	14.5	17.6	13.3	10.2	13.8	12.3
3	1	18.7	10.9	12.6	18.0	15.1	18.1	14.6	11.0	15.0	14.1
	2	19.1	10.7	12.7	18.7	15.1	17.3	14.7	11.2	15.0	14.7
	3	19.2	10.9	12.5	18.9	15.0	17.1	14.6	10.9	15.5	13.7
	Average	19.0	10.8	12.6	18.5	15.0	17.5	14.6	11.0	15.1	14.2
7	1	22.0	16.5	18.3	21.9	15.6	22.5	14.9	12.7	18.1	15.8
	2	20.8	16.6	18.9	21.2	15.5	21.3	16.0	11.8	14.6	15.8
	3	20.4	16.1	17.8	21.9	16.0	19.4	15.3	12.9	15.1	15.7
	Average	21.0	16.4	18.3	21.7	15.7	21.1	15.4	12.5	15.9	15.8
14	1	26.1	22.0	22.7	21.3	18.7	18.4	17.3	12.5	20.3	16.4
	2	23.8	19.6	20.4	20.4	19.1	23.0	19.9	13.0	18.0	18.7
	3	22.3	20.3	20.6	24.1	18.7	23.6	17.5	14.3	18.8	17.6
	Average	24.1	20.6	21.2	21.9	18.8	21.7	18.2	13.2	19.1	17.6

Table B-12: Soil Stiffness Gauge Results for Section C

Curing Time (days)	Test	Soil Stiffness (MN/m)									
		Station									
		1	2	3	4	5	6	7	8	9	10
1	1	11.8	11.0	12.5	11.8	11.9	12.1	13.2	12.6	7.7	9.4
	2	11.5	12.1	12.9	14.0	12.0	11.8	13.3	12.9	7.9	9.5
	3	11.3	12.3	12.3	13.8	12.5	12.1	13.4	12.4	7.8	9.7
	Average	11.6	11.8	12.6	13.2	12.1	12.0	13.3	12.6	7.8	9.5
2	1	13.5	12.2	15.1	14.6	11.9	14.2	11.2	14.2	9.7	10.5
	2	13.9	13.0	14.3	14.7	12.1	14.8	15.1	15.1	9.7	10.7
	3	13.6	12.8	14.8	14.6	12.1	14.8	14.8	15.0	9.9	10.8
	Average	13.7	12.7	14.7	14.7	12.0	14.6	13.7	14.8	9.8	10.7
3	1	14.1	13.3	15.3	17.0	15.0	17.1	14.2	15.3	11.5	11.6
	2	13.5	12.7	12.7	16.6	14.4	16.7	13.1	15.0	11.7	11.7
	3	13.8	12.4	14.6	17.3	13.7	16.3	15.7	14.6	11.7	12.0
	Average	13.8	12.8	14.2	16.9	14.3	16.7	14.3	15.0	11.7	11.7
7	1	21.8	17.8	17.0	15.3	21.9	20.5	21.8	24.8	18.8	14.0
	2	21.9	17.2	16.2	16.6	20.9	18.1	18.5	23.1	19.2	14.5
	3	20.9	17.8	12.1	14.8	16.6	22.1	18.8	24.8	18.2	13.1
	Average	21.5	17.6	15.1	15.6	19.8	20.2	19.7	24.2	18.7	13.9
14	1	25.2	20.6	21.2	26.6	26.9	28.6	21.6	27.5	25.2	21.8
	2	24.5	23.1	24.9	19.8	27.0	24.5	23.3	26.5	18.4	12.9
	3	25.1	20.5	24.9	27.3	20.9	27.3	25.9	27.3	20.4	20.4
	Average	24.9	21.4	23.7	24.6	24.9	26.8	23.6	27.1	21.4	18.4

Table B-13: Nuclear Density Gauge Results

Measurement	Nuclear Density Gauge Readings									
	Section A									
	1	2	3	4	5	6	7	8	9	10
Wet Density (pcf)	130.6	126.2	117	127.3	116	128.7	125.7	123.4	122.9	128
Moisture (pcf)	13.2	14.8	14.1	14.9	13.9	14	15.3	15.3	16.5	15.1
Percent Moisture (%)	15.2	16.3	14.5	16.5	14.2	12.2	13.6	14.2	15.3	13.4
	Section B									
	1	2	3	4	5	6	7	8	9	10
Wet Density (pcf)	126.8	129.7	130.2	126.5	129.7	128.7	129.6	129.1	129.5	127.3
Moisture (pcf)	16.4	16.3	17.2	14.1	15.7	15.4	16.2	15.5	15.7	14.2
Percent Moisture (%)	14.8	14.4	15.2	12.5	13.8	13.6	14.3	13.7	13.8	12.6
	Section C									
	1	2	3	4	5	6	7	8	9	10
Wet Density (pcf)	125.8	128.3	121.8	127.6	123.1	126.1	129.7	128.2	131.3	127.2
Moisture (pcf)	14.2	15.2	14.8	15.5	14.4	15.2	16.2	15.4	16.5	16.2
Percent Moisture (%)	12.7	13.5	13.8	13.8	13.2	13.7	14.3	13.7	14.4	14.6