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Usage of recycled asphalt pavement on Minnesota gravel roads: performance evaluation and analysis

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Usage of recycled asphalt pavement on Minnesota gravel roads: Performance evaluation and analysis

by

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NOMENCLATURE

RAP	Recycled Asphalt Pavement
AADT	Average Annual Daily Traffic
RAS	Recycled Asphalt Shingles
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetrometer
LWD	Light Weight Deflectometer
IRI	International Roughness Index
OMC	Optimum Moisture Content
MDD	Modified Dry Density
TCLP	Toxicity Characteristic Leaching Procedure
SPLP	Synthetic Precipitation Leaching Procedure
RCRA	Resource Conservation and Recovery Act

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ABSTRACT

In the United States, 53 percent of all the roads are unpaved. That translates into 1.6 million miles of unpaved roadways most of which are gravel roads. Currently they are being exposed to increased amounts of agricultural and industrial traffic. Also the problem of fugitive dust causes the loss of fine, binding material which increases the amount of floating aggregate and the tendency to develop washboards or corrugations. With use, fine and course portions of the aggregate segregate which also diminishes road performance. As the aggregate sources have been depleted and reduced in quality, unpaved roads increasingly have performance and economic challenges. The use of Recycled Asphalt Pavement (RAP) on gravel roads helps to improve the overall performance and life. Past studies also show substantial dust reduction when RAP is included in the road surface. However no clear relationship or methodology has been established to understand the connection between the RAP percentage and performance.

A primary objective of this research project is to assess RAP as a material that can be incorporated into unpaved road surfaces to reduce dust, wash boarding, and their negative effects on performance. Case study on Recycled Asphalt Shingle (RAS) road sections was performed to understand the interaction of asphalt binder and gravel roads, results suggest that an optimal binder content percentage should be targeted for best performance. A subsequent laboratory test program was conducted on various RAP mixes to draw comparisons. This was followed by construction of test sections in Minnesota and testing of the performance of the road on the ground. This investigation attempts to identify factors can be traded off between RAP percentage, road performance, environmental sustainability and economic feasibility in order to achieve the goals of the road agency.

CHAPTER 1: INTRODUCTION

Background and Motivation

The State of Minnesota has a total length of 132,250 miles of roads out of which approximately 66,000 miles are gravel or crushed rock roads herein after called aggregate roads. Aggregate roads play a vital role in connecting the remote farmlands with main stream economy. Due to increased traffic and loads from heavy agricultural equipment, these roads are facing durability issues. Due to heavier loads, roads surfaces loose the bond between fine and course aggregate particles producing dust and a loose aggregate surface. To tackle this problem there is a need to consider some alternative ways to construct a base course and surface course that could provide better performance. Also the issue of the depletion of virgin aggregate sources is faced in Minnesota and many other locations. Due to the scarcity of virgin aggregate, hauling distances have increased which increases the overall cost of the road maintenance and construction. The increased cost of maintaining these roads has also increased with increasing fuel costs.

Road design starts with the soil on which the road is to be constructed. To carry the weight of the layers and the vehicles above it without deforming and degrading is the purpose of the subgrade; sufficient structural strength has to be provided. Soil strengths can be estimated from the results of various tests such as California bearing ratio (CBR), resistance value (R-value), pavement dynamic cone penetrometer (DCP), or falling weight deflectometer (FWD). Road carrying capacity of the subsoil is therefore an important aspect of road design. (Beaudry, 1992)

In Figure 1: Minnesota Soil Types prepared by the Minnesota Geological Survey, approximate knowledge of soil types in the state are provided. More precise information is available at the county level on the web soil survey hosted by United States Department of Agriculture's Natural Resources Conservation Service. Figure1 depicts the diverse soil types that are present throughout Minnesota. The required aggregate thickness depends on the soil type and traffic volume. Once the soil type it known, it is possible to estimate respective strength parameters. After strength parameters and traffic counts have been selected, layer thickness can be selected. Thickness will also vary because of the range in the subsoil strength within specific soil class. The design guide also recommends the use of Class 1 material for top surface, increasing the thickness by 33% if Class 3 and 4 are used as a surface over a base of Class 5 and/or 6. The CBR is a measurement of the bearing capacity of the subsoil or base. If a soil has low CBR, an increase in the thickness of the road base will be necessary. Compaction also plays important role in this. Typically, the CBR will decrease by 25 to 50 percent for each 5 percent decrease in T-99 compaction below 95%. (Service, 1974)

In this research project, conventional aggregate road design methods will be modified to include the use of Recycled Asphalt Pavement (RAP) with the objective of improving road performance by increasing the extent to which fine particles are bound to the road surface.

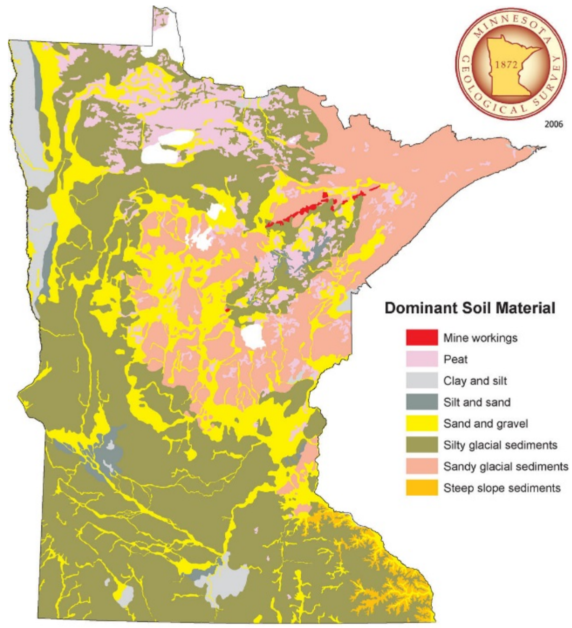


Figure 1. Minnesota Soil Types

When used appropriately, recycled materials provide good quality, cost effective road construction materials that benefit the environment and lessen the use of raw materials. (Board, 2008)

Considering the increased demands on the road surface and scarcity of virgin aggregates, RAP can be a viable alternative material that can be incorporated into aggregate road surfaces. Increases in CBR have been reported when RAP has been incorporated into road materials and an increase in CBR can reduce the required thickness of certain road layers. Also reductions in fugitive dust emissions have been reported. RAP is a byproduct of milling of asphalt roads which can be incorporated into hot mix asphalt and used for pavements. But not all of it is used on the asphalt roads. Minnesota Department of Transportation (MnDOT) allows about 30% RAP to be incorporated into hot mix asphalt; however, in some cases not all if it is used for hot mix and the RAP is kept in stockpiles until a use for it is found. If no use is found, the stockpiles can continue to increase in size. Instead, using RAP on gravel roads could possibly address both the previously mentioned problem associated with aggregate roads and those associated with stockpiling. Hot mix plants all around the county are recycling RAP and transportation agencies are encouraging increased use. Seventy percent of the cost for asphalt production involves materials. Below Figure 2 shows the role that materials play in asphalt production costs. Given the limitations for the use of RAP in hot mix asphalt production, there is often excess RAP which can be procured for other uses, sometimes at a reasonable cost.

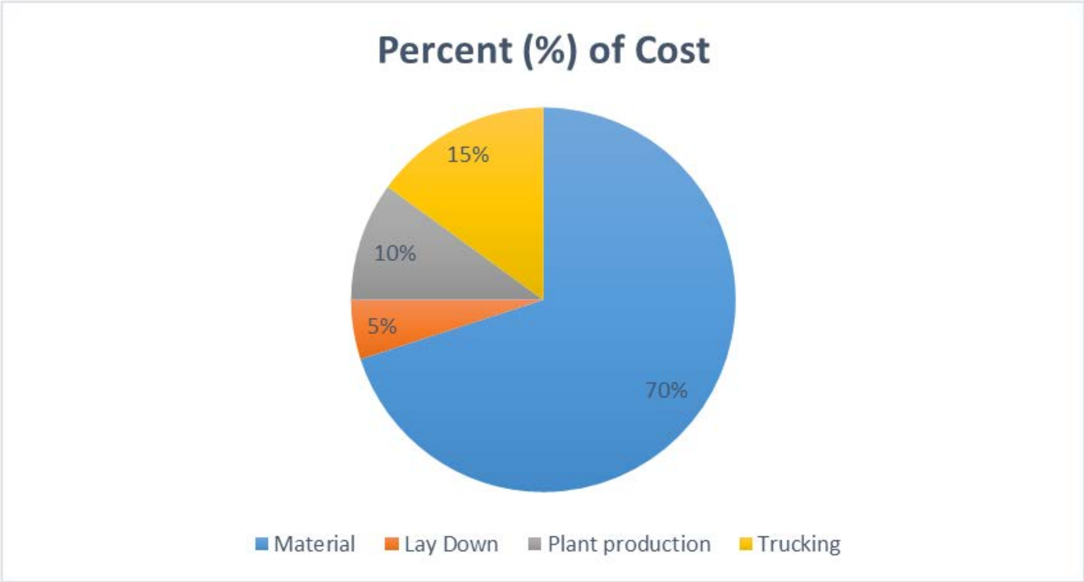


Figure 1. Pie Chart for Estimated asphalt production cost categories. (FHWA, Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice, 2011)

RAP is collected from several sources: milling, full depth pavement removal, and waste hot mix Asphalt (HMA) materials generated at the plant. (FHWA, Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice, 2011). There are different types of RAP that come from milling projects, depending on how the milling is performed. The milling that is performed on only upper layer of asphalt road produces a material that is designated classified RAP in Iowa that does not have contamination or impurities. The milling that is performed to a greater depth and that contains soil and other impurities is called unclassified RAP in Iowa. The classified RAP can be used readily for hot mix asphalt without processing while the unclassified RAP requires additional processing before it can be used in hot mix and this increases the cost of the RAP.

This unclassified RAP and also excess stockpiled RAP that will not probably not be used for hot mix asphalt production could possibly be used as aggregate for aggregate surfaced roads. Therefore it is possible for RAP to be available locally within a feasible transportation distance and at a reasonable cost, if given a well devised logistics plan and construction process is available.

Present construction practices

There are many ways that RAP can be used for paved roads such as hot mix asphalt, Hot In-Place Recycling, Cold Mix Asphalt produced at a Central Processing Facility (this is rare in Minnesota) and Cold-In-Place Recycling.

For unpaved roads RAP can be incorporated in three ways:

1. Blade Mixed
   In this case surface is scarified to a depth of 2 to 3 inches using a motor grader and then RAP is placed in windrow, preferably with bottom-discharge trucks. Then RAP and scarified aggregate are blended and spread with a motor grader. Road shape and crown is established by the motor grader.

2. Stockpile mixed
   RAP and aggregates blended together in a pug mill. Alternatively, loaders can build a stockpiled mixture by alternately taking buckets of material from separate stockpiles of virgin aggregate and RAP. Another method is to use a cold feed system from a hot mix asphalt plant. Bins are charged with virgin aggregate and RAP and system is operated so that material is fed from each bin onto the conveyor in proper proportion and the conveyor can stack a stock pile or load a truck. The existing roadway shaped with motor grader. The RAP and aggregate mixture hauled to the section and placed in windrow with bottom-discharge trucks or spread thru the tailgate of an end dump truck. Then shaping and compaction is accomplished.

3. Reclaimer mixed
   An existing asphalt surface is scarified and the resulting RAP is hauled to section and placed in windrow with bottom-discharge trucks or spread thru the tailgate of an end dump truck. Then motor grader is used to spread it out and a rotary mixer reclaimer is used to blend the underlying, existing surface with RAP. At the end motor grader is used to shape the cross section of the road. Considerable compaction will be required, mostly using purpose built compaction equipment such as a pneumatic roller.

RAP has also been used as a base course material for asphalt roads; such a use has some similarities to in construction and handling as with unpaved roads. Table 1 shows how various state transportation agencies use RAP as a base course, the percentage used, and the test methods required.

Table 1. State DOT Survey (McGarrah, 2007)

State	Rap Allowed(1)	Max %(2)	Processed(3)	Testing(4)
Florida	No	---	---	---
Illinois	No	---	---	---
Montana	Yes	50-60%	No	Corrected Nuclear Gauge
New Jersey	Yes	50%(5)	Yes - Gradation	Corrected Nuc. Gauge + Sample
Minnesota	Yes	3%(6)	Yes - Gradation	Dynamic Cone Penetrometer
Colorado	Yes	50%(5)	Yes - Max Agg. Size	Roller Compaction Strip
Utah	Yes	2%6	Yes - Gradation	Nuc. Gauge or Breakdown Curve
Texas(7)	Yes	20%	Unknown	Various (including Nuc. Gauge)
California(7)	Yes	50%	Unknown	No special testing procedure listed
New Mexico(7)	Yes	Unknown	Unknown	Corrected Nuc. Gauge
Rhode Island(7)	Yes	Unknown	Yes - Gradation	Unknown
South Dakota(7)	No	---	---	---

1. Describes whether state allows RAP to be used as a base course material.
2. The maximum percentage of RAP (by weight) allowed.
3.Describes whether the listed state requires the RAP blend to be processed prior to placement and what requirements must be met
4. Describes the type of QA testing required.
5. These are modified values. The current values are 100%, but the materials department is in the process of modifying current values.
6. These values are the maximum AC content allowed in the RAP blend.
7. These states were not contacted and the information listed in the table is from the state's current standard specification.

Existing RAP Sections in Minnesota

An online survey was conducted to identify existing unpaved RAP sections in Minnesota. Table 2 below shows that there is a broad variance in use of RAP on unpaved roads.

Table 1 : RAP online Survey

Name of County	Place of application	Percentage
Lesueur County	On surface Course	50-100%
Traverse County	Repair of soft spots	100%
Benton County	Shoulders	100%
Mahnomen County	On surface course	100%
Aitkin County	On surface course	100% with emulsion on surface
Chippewa County	On surface course	10%
Goodhue County	Shoulders	67% RAP + 33% Virgin aggregate
Hennepin County	On surface course	100% millings from a mill and overlay project
St. Louis County	On surface course	50%
Clearwater County	Base course covered with class 1 aggregate	50%

Cost

In Wyoming it was found that using RAP on unpaved roads is not economically feasible when an alternative exists to use it in hot mix plants. (Koch, 2011) However, there is typically a limit for the proportion of RAP that can be used in hot mix and for Minnesota that is about 30% so in some cases, using RAP for unpaved roads may be economically feasible. As this project is funded and supported by MnDOT, a Technical Advisory Panel (TAP) was available for guidance. Discussions with the TAP members during the kickoff meeting suggest that this may be true in many cases. If cost of RAP is less than the cost of virgin aggregate including hauling expenses, if the life cycle cost analysis for using RAP on unpaved roads is favorable due to greater durability for such roads and if using RAP improves road performance sufficiently to avoid paving, then using RAP may be an attractive option for improving unpaved road performance.

Research Objectives

This research project considers RAP as a material which can potentially increase the strength of the road structure and reduce dust to make an unpaved road more durable and emit a lower amount of fugitive dust by identifying specific parameters that would help local road officials select an optimal RAP content for unpaved roads. Another objective is to develop a design guide for using RAP on unpaved roads based on lab and field analysis of blended mixes. It is the intention of this research project to address following hypothesis: Proper used of a mixture of RAP and virgin aggregate as a road surface will result in the following advantages compared to using pure virgin aggregate:

- Reduction in fugitive dust
- Reduction in maintenance cost
- An economical alternate use for RAP
- Improved performance and durability of aggregate roads

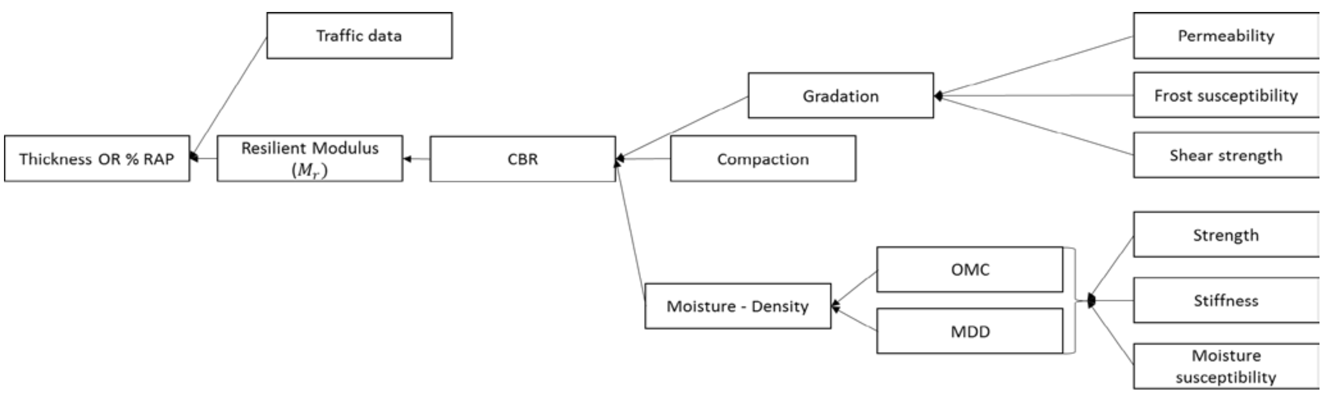


Figure 2. Properties of the RAP and design correlations

The design guide for Minnesota for Low volume aggregate surfaced roads (Beaudry, 1992) considers the CBR of the subgrade soil and traffic data in order to calculate the design thickness of the road structural layers and surface. Roads surfaced with a mixture of RAP and aggregate could be designed using a similar procedure. Figure 3 shows how gradation, compaction and moisture density lead to the final CBR value which could be controlled if desired. So according to Figure 3, it can be inferred that after the CBR value of the existing road and the traffic data are known, it would be possible to calculate the thickness required for a RAP and aggregate mixture, if all the parameters above are considered. The asphalt content of the RAP and its properties all influence the gradation, amount of compaction that can be achieved, and moisture-density relationships. Also temperature changes will affect the properties of the asphalt and therefore the performance of the road. However, at this point, the author has not found an analysis or design procedure that completely accounts for the influence that the asphalt amount and properties in the RAP mixture and temperature changes have on road performance. One objective for this research effort is to address how the asphalt content in the RAP mixture influences road performance and include the findings of that effort in the design guide that will be produced as part of this project.

Thesis Organization

This thesis has been arranged in various chapters starting with Introduction as the first chapter. This is followed by Chapter 2 which is a literature review. Later a case study (Chapter 3) which was performed on test sections in Goodhue County on roads where a crushed rock surface was mixed with tear off shingles is presented. The reason for performing a case study was to understand how virgin road surfacing materials behave with recycled materials that include asphalt binder. As the mixture is non-cohesive, it is important to understand this phenomenon. As part of this study, an extensive laboratory test program (Chapter 4) was conducted to understand the mechanical and physical properties of the RAP and its various mixtures. Then based on this lab study, test sections were constructed in two counties in Minnesota to ascertain how these trial section behave; this is documented in Chapter 5. All the data from these trial sections have been collected up to this point and analyzed; the results of the analysis is discussed later in the same chapter. To understand the economic feasibility of using RAP and virgin aggregate mixtures for road surfacing, an economic and feasibility study was performed and is documented in Chapter 6. Chapter 7 is a discussion about the environmental impact of using RAP on gravel roads and a review the studies that have addressed this issue. Finally in Chapter 8 conclusions and recommendations have been developed as a result of this investigation.

CHAPTER 2: LITERATURE REVIEW

Overview of RAP as a Material

Typical physical properties of RAP are shown below in Table 3. Less than 40% of typical RAP materials are retained on a #8 sieve. This relatively low percentage may be due to the amount of reduction of particle size that occurs during the milling process.

Table 2. Typical physical properties of RAP (T., 2009)

Physical Properties	
Unit Weight	1940 - 2300 kg/m^3 (120 - 140 pcf)
Moisture Content	Normal: Up to 5% Maximum: 7 - 8%
Asphalt Content	Normal: 4.5 – 6%
Asphalt Penetration	Normal: 10 – 80% at 25°C (77°F)
Absolute Viscosity or Recovered Asphalt Cement	Normal: 4000 – 25000 poises at 60°C (140°F)
Mechanical Properties	
Compacted Unit Weight	1600 – 2000 kg/m^3 (100 – 125 pcf)
California Bearing Ratio (CBR)	100% RAP: 20 – 25% 40% RAP and 60% Natural Aggregate: 150% or Higher

Another Utah based study shows that the quantity of RAP and its source affects the mechanical properties of recycled base material (Guthrie S., 2006). RAP reduces the moisture susceptibility of materials and therefore may be especially valuable in areas with high water tables. Another situation where RAP may be helpful could be areas with poor drainage which go through repeated freeze-thaw cycles and have sustained freezing temperature that leads to frost. RAP reduces CBR, so thick layers are recommended to provide a sustainable road. Stabilization should be considered using agents such as asphalt emulsion, Portland cement or combinations of lime and fly ash to increase durability.

A study based in Oman claimed that the dry density & CBR values increase with increases in proportions of virgin aggregate and that a RAP content of about 10% is expected be a good starting point for road bases. RAP was also reported to provide comparatively good support as a sub base. Results have shown that using 100% RAP yields a CBR of 11% (Ramzi .T, 1999). Table 4 shows physical properties of the RAP and virgin aggregates that were examined in this study.

Table 3: Physical Properties of RAP and Virgin Aggregates (Ramzi .T, 1999)

Property	RAP	Virgin Aggregate
Moisture Content (%)	0.23	0.86
Specific Gravity (SSD)	2.12	-
Water Absorption (%)	1.0	-
Sand Equivalent (%)	97	67
Los Angeles Abrasion (%)	33.6	18.8

Principal reference

As part of a study conducted in Wyoming, performance of RAP on unpaved roads at 3 sites was examined. RAP from three sources and fifteen material and dust suppressants combinations were examined. (Koch, 2011) Three different construction methods using various combinations of equipment were used including, using a motor grader alone to blend RAP and aggregate on the road, combining motor grader with reclaimer to blend aggregate on the road, and blending virgin aggregate and RAP at a stockpile and placing on the road using a motor graded and compacting with a roller. Construction methods were found to directly affect road performance. Assessment was accomplished by using the Colorado State University (CSU) Dustometer, and conducting the Unpaved Road Condition Index (URCI) surveys in addition to performing material testing. RAP proved to be effective as fugitive dust emissions were reduced. Economic analysis suggested that using RAP on unpaved roads was not economical alternative when it could be recycled in a hot mix plant. When RAP was used on unpaved roads, it was found to be more economically advantageous when used as surface course rather than as a base material. An adequate amount of binding action from the RAP and a certain proportion virgin aggregate was required for good performance of a road surface that was made with a RAP and aggregate mixture. If adequate binder was not available, dust, loose aggregates and wash boarding occurred. Depending on binding properties of the fines, as little as 20% RAP can be successfully used. If an aggregates has a comparatively low binding capacity, because it has a relatively low PI (Particle Index) and percentage passing #200 (0.075 um) sieve, about 50% RAP should be added.

Summary of Literature Review

Recycled aggregate properties that were determined to affect performance of unbound pavement layers are shear strength, frost susceptibility, durability, stiffness and toughness. (Saeed, 2008) The following tests were found to produce statistically significant performance indicators for recycled aggregates when unbound pavement analysis is performed:

1. Screening tests for sieve analysis and the moisture -density relationship,
2. Micro-Deval for toughness
3. Resilient modulus for stiffness,
4. Static triaxial and repeated load at optimum moisture and saturated condition for shear strength and
5. Frost susceptibility (tube suction)

A clear relation between RAP content and relevant properties is presented in a report by FHWA (FHWA, User Guidelines for waste and byproduct materials in pavement construction, 1997). The relationship from this FHWA report along with relationships from selected other reference are summarized below.

- Increasing the RAP content results in a decrease in the bearing capacity of a granular base.
- Placing RAP - The depth of processing must be closely monitored since cutting too deep can incorporate sub base material while cutting too shallow increases the percentage of RAP in the blend. Bearing strength - Decreasing with increasing RAP content.
- Compacted Density - Decreasing with increasing RAP content.
- Moisture content - Depends on how RAP is processed. If RAP is crushed (as opposed to being milled for pulverized) it will have coarser particles and will have lower moisture content as the asphalt on the aggregates inhibits water absorption.
- If milling is performed to produce RAP then the moisture content in the RAP increases as the proportion of fine aggregates increases.
- Permeability - Decreasing with increasing RAP content.
- Durability - Increases with RAP but will increase more if additives are added.
- Substantial strengthening effects with time have been observed. CBR values for 40% RAP exceeded 150 after 1 week. - (Hanks, 1989)
- RAP produced by milling or pulverizing has a lower bearing capacity than crushed RAP due to the comparatively fine gradation for milled or pulverized RAP - FHWA - RD- 93-008
- Thickness designs that include RAP in base or sub base should be executed by consulting the AASHTO design guide.

Experiment design outline

One task for this research project will be to conduct performance surveys on existing RAP roads and design RAP roads test sections in order to evaluate performance. The following design methodology for the road test sections is proposed:

1. The selection of potential test road sections will be finalized with the guidance of the committee,
2. DCP testing on the selected sections will be conducted.
3. Respective CBR values will be calculated.
4. Samples from these sections will be collected. Those samples will be mixed with various percentages of RAP that will be used.
5. Laboratory CBR tests will be conducted these mixed samples.
6. The three samples that yield the highest CBR values will be noted.
7. Three test sections will be designed according to the characteristics of the samples noted in the previous step.

For example, suppose 10 %, 20%, 30%, 40% & 50% have been noted as yielding the highest CBR. Three test sections of 10%, 20%, 30%, 40%, and 50% RAP will be recommended. Because the RAP compacted density and road dimensions are known, the required tonnage of RAP can be calculated. This desired RAP mixtures will be produced by blade mixing on the road test sections.

RAP performance and properties study

While preparing to construct the trial/test sections, the research team will conduct a preconstruction survey to record the characteristic properties of the existing road. During construction, observations regarding the construction process will be recorded. After construction, post construction surveys will be conducted (Figure 4). A complete analysis will be conducted that considers the recommended designs, the preconstruction survey, construction observations, post construction surveys, and all laboratory testing. Conclusions will be drawn from the results of the analysis.

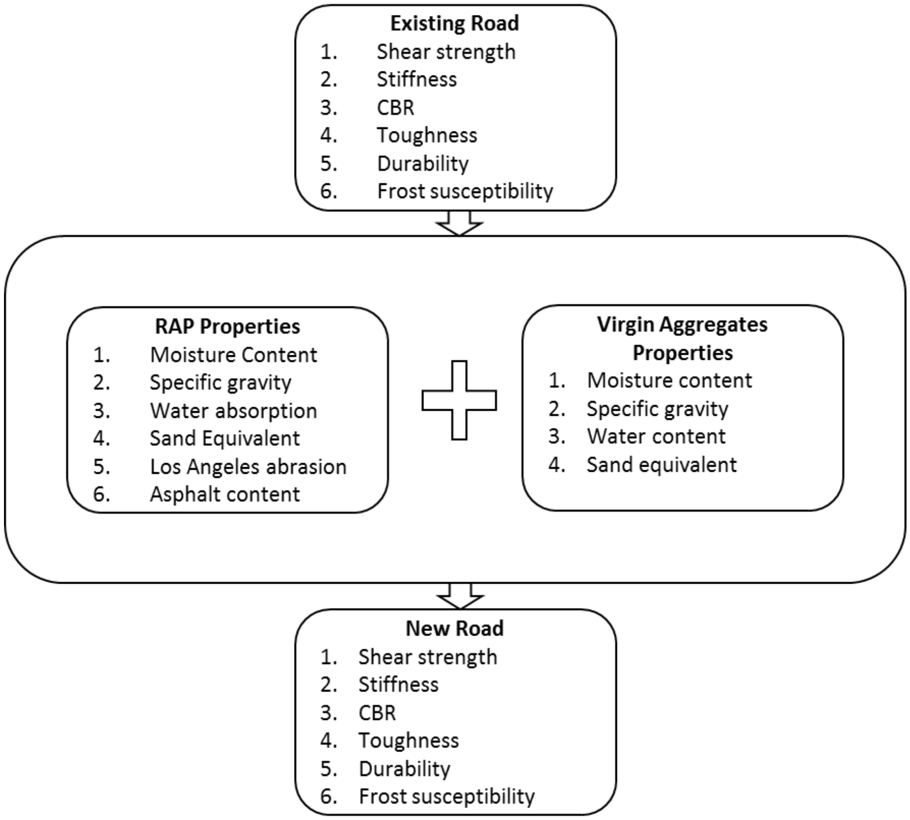


Figure 3. Schematic flowchart of properties of material and roads

Our research will aim to find relationships between the combined properties of the existing road, RAP, and virgin aggregate, along with the properties and performance of the new road.

In order to perform this analysis, lab tests will be conducted to record the various characteristic properties of the road material. An outline of these lab tests are provided below:

1. Lab CBR for various mixes of aggregate and RAP with varying percentages of RAP
2. Relationship between moisture content of existing road and new road should be established so that the Optimum Moisture content can be determined.
3. Test such as Ignition, extraction, BBR and G* should be included to determine the asphalt content and binder properties of RAP.
4. Chronologic order of Lab test for RAP:
    a. Moisture content + dry materials
    b. RAP gradation + Optimum Moisture Content
    c. Specific gravity + Sand equivalent + water absorption
    d. Ignition + Extraction
    e. Binder Characterization – G* and BBR

In addition to the previously mentioned properties of the unpaved roads, there should be an overall condition assessment of road. Applicable assessment methods can be classified into the following categories: visual, combination (visual and direct measurement), and indirect data acquisition with specialized equipment (Brooks C., 2011). One such method involving specialized equipment that will be used for this study involves the measurement of fugitive dust levels, as this appears to be one of the most critical user and stakeholder performance measures and because it plays vital role in determining the durability of unpaved roads. This is because when fugitive dust is emitted from unpaved roads, fine binding material is also being lost which results in an increase in loose floating aggregate on the surface which increases wash boarding and makes vehicle control difficult.

Because the need to limit fugitive dust emissions is a critical aspect of unpaved road performance, there is a need to measure dust emissions in a manner that is as objective as is reasonably possible. Two dust measuring tools can be considered which has been in common use for dust emission assessments. They are the Colorado State University (CSU) Dustometer and the Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER). TRAKER is a more precise and accurate dust measuring device that is mounted under a vehicle and is connected to a GPS unit and computer inside the vehicle; it has been used for several environmental studies (Etyemezian V., 2003).

The CSU Dustometer is a straightforward assembly of a vacuum pump and filter mounted truant the rear of a truck (Morgan R. J., 2005). The measurements taken from this device is also sufficiently precise for many purposes and it is more economical than the TRACKER. The CSU Dustometer is more suited to road assessment tasks, as a long stretch of road can be assessed economically. The CSU Dustometer, which employs a filtration technique, was an improvement in comparison to similar contemporary mobile devices at the time it was developed. Although the CSU Dustometer technique involves weighing of filters in the laboratory, the technique can be executed quickly, and it enables large amounts of reasonably precise dust data to be gathered in a short period of time (Sanders T.G., 2000). It has the potential standardize and normalize the way in which road conditions with regard to fugitive dust emissions are assessed.

The amount of fugitive dust emitted directly depends on the moisture in the road. Unless precipitation occurs, one factor that affects dust emissions is evaporation and the other is moisture from beneath the road surface coming up from sub grade due to capillary action. If the sub grade has sufficient moisture content, moisture can be fed to the top surface by capillary action during dry periods and the generation of dust can be mitigated. In such a case, the preferred subgrade moisture content is one that keeps the surface moist yet still maintains bearing capacity should be determined. Care should be taken to avoid allowing the subgrade to permanently lose its bearing capacity due to oversaturation; if this occurs the subgrade may fail to the point that it must be replaced or strengthened by adequate means.

CHAPTER 3: CASE STUDY

Introduction

In order to better understand the mechanism between asphalt binder and unpaved gravel roads, this case study was done partially based on final report on Recycled Asphalt Shingles (RAS) sections in Goodhue County (Woods, January 2014). Further field observations, lab and field test have been prepared to investigate further details regarding the separate properties of each section. An attempt to find correlations amongst various properties of these sections and their implications for Optimal RAP project have been considered.

Two field visits to Goodhue County were successfully carried out on 7/31/2014 and 8/9/2014. Figure 5 shows a rough plan of the three sections in Goodhue County. Also Figure 6 shows a satellite image of the same.

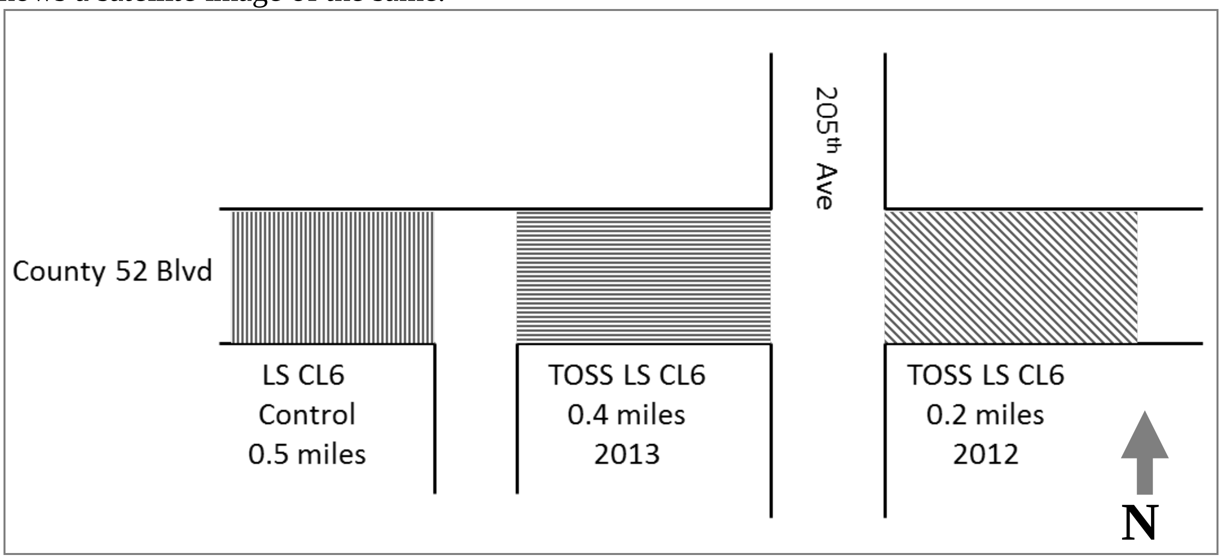


Figure 5. Plan of Goodhue county Shingles Section

Figure 6. Satellite image of Goodhue county Shingles section

Field Observations

On 7/31/2014 field observations were conducted. Pictures were taken from various perspectives to provide an overview of the road sections. Figure 3 shows TOSS LS CL6 2013 facing west. Figures 7 through 12 provide images of road sections with their respective titles.

Figure 7. TOSS LS CL6 2013 Section facing west

During the field visit and also comparing Figure 7 and Figure 8 it was visually noted that the dust emission reduction when vehicles transited from control section to TOSS sections.

Figure 8. TOSS LS CL6 2013 facing east

Figure 9. TOSS LS CL6 2013 Section facing west from 205th Avenue

Figure 10. Close-up shot of TOSS LS CL6 2013 Section

Figure 11. Close-up shot of TOSS LS CL6 2013 Section facing east

Figure 12. TOSS LS CL6 2012 Section facing east

It should be noted that the section TOSS LS CL6 2013 as shown in Figure 10 and 11 has a hard surface, which has been formed due to amalgamation of asphalt binder present in the shingle milling over the time after construction. Whereas as shown above in figure 12 TOSS LS CL6 2012 section looks more consolidated and firm with no amalgamation on surface.

Laboratory and Field Tests

Sieve analysis

Considering the amount of fine particles below #200 ASTM C117-13 (C117-13, Standard Test Method for Material Finer than 75-um (No.200) Sieve in Mineral Aggregates by Washing, 2013) with ASTM C136-06 (C136-06, 2006) were used as protocols for sieve analysis. Details regarding the individual sieve analysis and soil classification can be seen in the Appendix A. Looking at the Figure 13 it could be inferred that TOSS CL6 2012 has a large amount of fine and sand content compared to other two sections. Control section has gravel combined with coarser sand with relatively low fines. TOSS CL6 2013 has relatively high coarse sand and gravel than control section. Here it has to be noted that TOSS CL6 2012 has shingles, but still there is a considerable amount of fines and sand in the road surfacing material, however, the surface is still tightly bound and emits comparatively less dust.

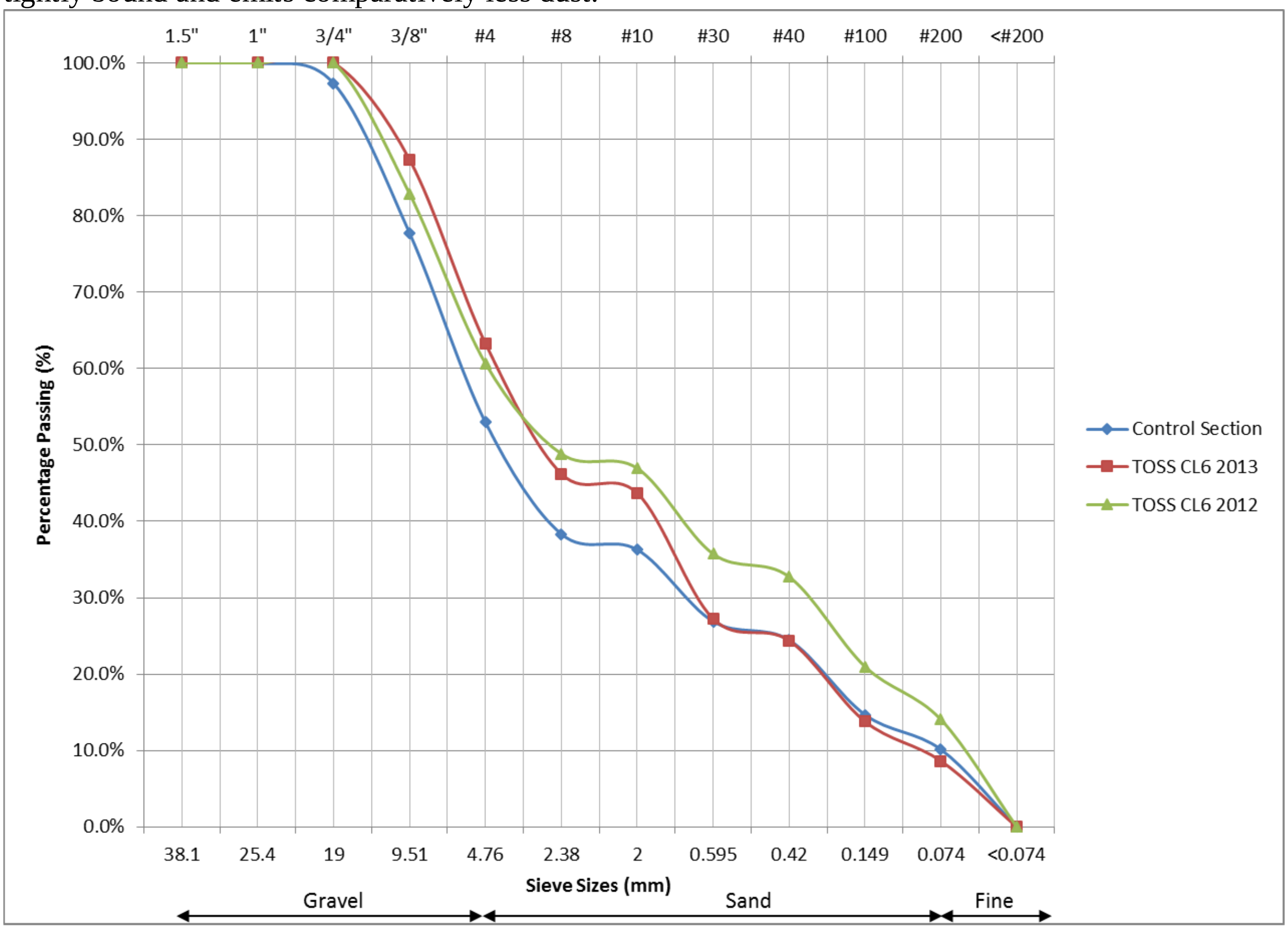


Figure 13. Comparative gradation of all three sections

Standard laboratory procedures were followed as depicted by Figure 14.

Figure 14. Sieve Analysis in Lab

Roughness index (IRI)

A quantitative approach was used for conducting road condition assessment by measuring the International Roughness Index (IRI) using mobile phone. The mobile phone application Roadroid was used to measure the IRI on these sections during both visits. The recorded data on the mobile phone was then uploaded to the roadroid website and then a zip file was downloaded which included data such as the time stamp, latitude, longitude, altitude and respective estimated IRI (eIRI) and caluculated IRI (cIRI). For detail data sheets of the recordings please refer to the Appendix A. Figure 11 shows how an android phone has been fixed on the front dashboard with a fix stand. Field data were taken on 7/31/2014 and 8/9/2014 respectively. Data was then cleaned and matched with section locations using coordinates.

Figure 15. Roadroid Application used in Android phoneRe

Calculated IRI (cIRI) - is based on the original quarter car formula. The cIRI can be adjusted with regard to sensitivity to a known reference, and the section length can also be adjusted. It should be used at speeds of 60-80 km/h. The cIRI aims to be classified as IQL2 (Information Quality Level). The estimated IRI (eIRI) - is based on a Peak and Root Mean Square vibration analysis – and correlated to Swedish laser measurements on paved roads. The eIRI is intended to be classified as IQL3. Even though the cIRI is classified as IQL2, it has to be adjusted with regard to sensitivity to known reference. Therefore we would refer to the eIRI. Scale of the eIRI indexes and their respective levels have been given below:

Good/Green – eIRI < 2.2
Satisfactory/Yellow – eIRI 2.2-3.8
Unsatisfied/Red – eIRI 3.8-5.4
Poor/Black – eIRI < 5.4

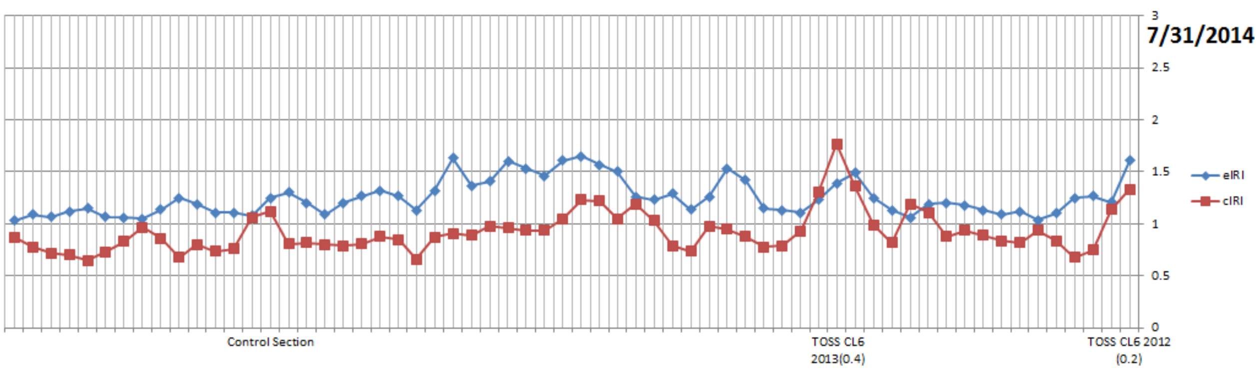


Figure 16. IRI profiling of all three sections on 7/31/2014

On 7/31/2014, a Honda Odyssey was used to collect data, however, the specifications of the tires and the suspension were not recorded. It can be seen in Figure 16 that eIRI of all sections do not exceed 2. Also it should be noted that comparatively that the eIRI for TOSS CL62013 is more than that of the control section and TOSS CL6 2012.

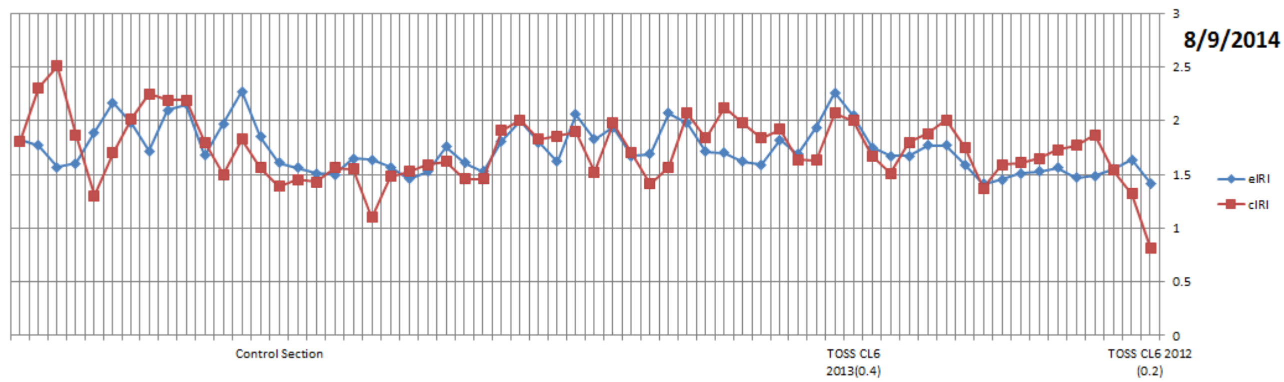


Figure 17. IRI profiling of all three sections on 8/9/2014

As a proper reference point was not considered before starting the test, the reliability of cIRI is questionable. Also Figure 17 shows the section profile based on data collected on 8/9/2014. A Honda civic was used during this test again the specifications of the tires and the suspension were not been recorded. The eIRI as an IQL3 class a comparison and this was done to check the reliability of the eIRI indices. Figure 18 shows the comparison of the eIRI measurements for both visits. It can be seen that there is no such similarity between the data streams but that the trend line can be seen matching. Also it should be noted that different vehicles were used during these visits.

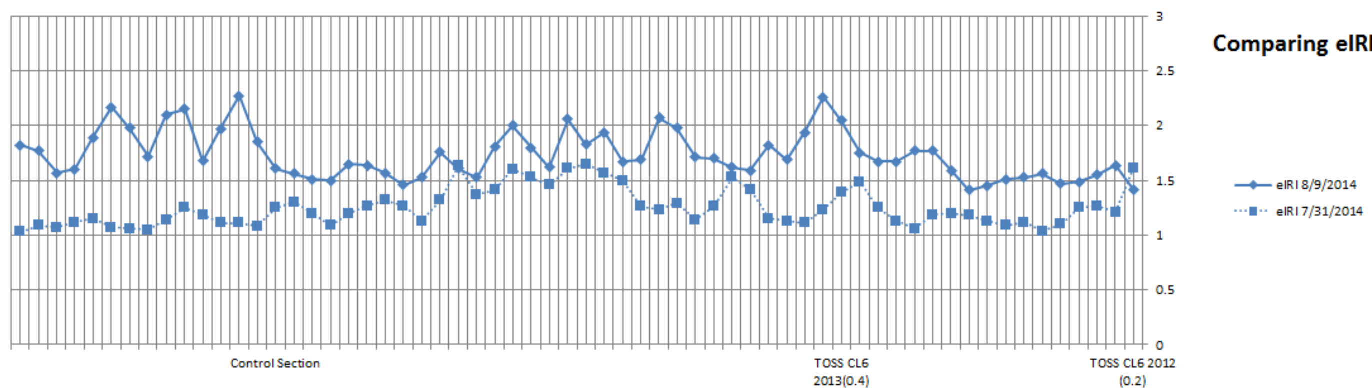


Figure 18. All section profile comparing eIRI

Light weight deflectometer (LWD)

In order to calculate the stiffness of the sections, test protocol ASTM E2583-07 (E2583-07, 2007) was executed using a light weight deflectometer. Four data points were considered across each cross section covering shoulders and wheel paths. Below in Figure 19 it can be clearly seen that TOSS CL6 2012 has the highest stiffness. TOSS CL6 2013 is comparatively stiffer than the control section. Overall, observation have indicated increased stiffness subsequent to TOSS stabilization.

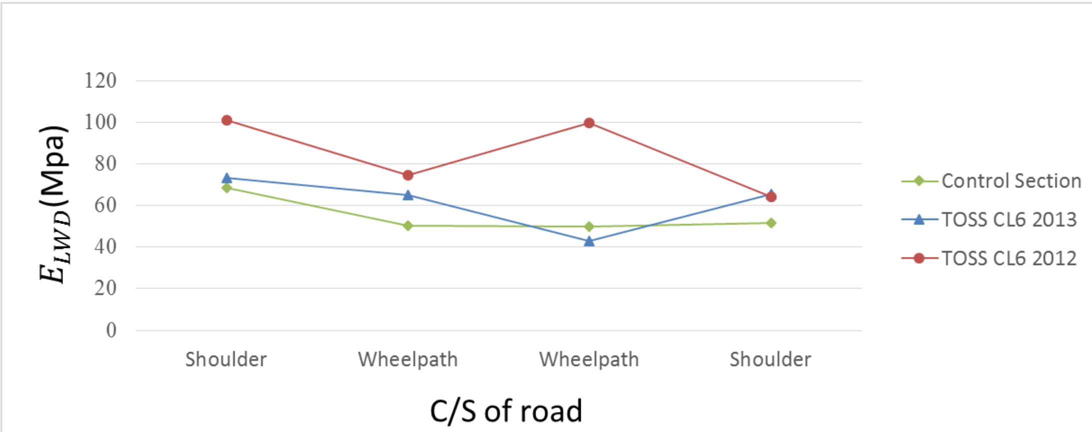


Figure 19. LWD test data for all sections

Moisture content

A procedure was followed as per the ASTM D2216-10 (D2216-10, 2010) to determine the moisture content of the road surface of the test sections. Samples were taken from both top and bottom surface of the test sections. The purpose was to determine the relations between the moisture content and fugitive dust emissions from the surface of the road. Table 5 shows that the control section has a considerably dryer top compared to its bottom. Meanwhile the TOSS stabilized sections show fairly equal moisture content on top as well as the bottom. More measurement will be required to provide more definite data. Notably the TOSS CL6 2012 has the highest moisture content. A comparison might possibly be drawn between the moisture content and dust emission for these sections.

Table 5. Moisture Content for all shingle sections

Moisture Content						
	Control Section		TOSS CL6 2013		TOSS CL6 2012	
	TOP	BOTTOM	TOP	BOTTOM	TOP	BOTTOM
Pan Weight	778.4	697.4	736.6	738.3	738.5	767.4
Material Weight	2209.6	2098.9	2333.9	2220.8	2479.2	2127
Total Wt.	2988	2796.3	3070.5	2959.1	3217.7	2894.4
Total Wt. After Drying	2982.7	2766.9	3030.8	2921.7	3165.7	2852.3
Moisture Content	**0.24%**	**1.42%**	**1.73%**	**1.71%**	**2.14%**	**2.02%**

Binder content

In order to find the binder content for the material in these sections and whether that has any effect on other properties, ignition tests were conducted. All standard procedures as per ASTM D6307-10 (D6307-101, 2010) were followed to provide the result. The result was that TOSS CL6 2013 has more asphalt content than TOSS CL6 2012. It is clearly visible in the field that TOSS CL6 2013 has a higher asphalt content. Also, in Figure 20, it can be seen that the material can be removed in clumps from the surface of TOSS CL6 2013. A relation between the fineness of the TOSS and asphalt content that may cause clump formation is recommended to be further investigated. Also a need to find an optimal binder content can be realized after comparing asphalt content with other properties.

Table 6. Binder Content for TOSS Stabilized sections

	TOSS CL6 2013	TOSS CL6 2012
Wt. of the Pan	1138.3	1138.3
Wt. of the Sample	3434.8	2084.1
Total Wt.	4573.1	3222.4
Total Wt. after ignition	3332	2961.8
Wt. of Sample after ignition	2193.7	1823.5
Percentage Asphalt Content	**36.133%**	**12.504%**

Figure 20. TOSS LS CL6 2013 Section with Shingle clumps

Scrape test

Scrape test were conducted on the sections using a standard hoe with sides. The test were conducted by a single person applying normal horizontal force to pull the hoe across the cross section of the road. All of the top loose material that dragged along due to this action was collected and weighed. This provides a comparison regarding the amount of floating materials on the surface of the sections. Further testing could be conducted to provide more reliable values. Table 7 shows how TOSS stabilization has reduced the amount of floating material on the road surface. Also it can be seen that TOSS CL6 2012 has comparatively less floating material than TOSS CL6 2013. Visually it can be seen that TOSS CL6 2013 has a lot of floating material on the shoulders. Figure 20 shows the control section after the scrape test was performed.

Table 7. Scrape test results for all sections

Scrape Test			
	CONTROL SECTION	**TOSS CL6 2013**	**TOSS CL6 2012**
Wt. of loose material on top	32	18	18
	53	23	35
	75	49	54
Total (wt. in pounds)	**160**	**90**	**107**

Figure 21. Control Section after scrape test

Case study Conclusion

Table 8. Comparing properties of sections

Properties	Control Section	TOSS CL6 2013	TOSS CL6 2012
1. Sieve Analysis	Fine – 11%	Fine – 8.6 %	Fine – 14%
2. IRI Indexes	1.8 mm/m	1.7 mm/m	1.5 mm/m
3. Stiffness	54.94 Mpa	61.56 Mpa	84.87 Mpa
4. Moisture	1.42%	1.72%	2.08%
5. Binder Content	-	36.13%	12.50%
6. Float	160 pounds	90 pounds	107 pounds
7. Dust Reduction	-	61 % (After 14 days)	34% (After 298 days)

Proposes Table 8, a Ranking of certain properties in the order of their relationship with better road performance. Red, green and blue have been given in descending rank values. As there has not been an established relationship between asphalt content and performance of asphalt road it cannot be said that with higher asphalt content, better performance is expected.

Also, parameters that compare dust reduction are unlikely to be appropriate as the previous data were collected at a different from when the dust emission data were collected. However it seems that the TOSS CL6 2012 section is still performing well after 298 days since there still is a reduction of 34%.

Further, it may be possible to draw a correlation between these properties after further investigation. It would be interesting to investigate correlation equation would improves the predictability of other properties and also give us the optimum range of material with specific properties that would be desirable for the best performance.

Findings from Optimum RAP project can be compared to the project investigating the use of recycled shingles (Woods, January 2014) in order to learn interesting insights. The research methodology and experiment design for the Optimal RAP project is highly influenced by recycled shingles project and further comparison can be drawn to understand how to incorporate recycled material that include asphalt binders into unpaved roads.

CHAPTER 4: LABORATORY TEST PROGRAM

Research Methodology

The interaction of asphalt binder in a soil mass is difficult to understand as the properties of both the constituents, change with the material, location, weather conditions and traffic volume. In order to answer our research goal of finding the optimal RAP content for Minnesota gravel roads, analysis of material properties and their relationships with each other should be understood primarily.

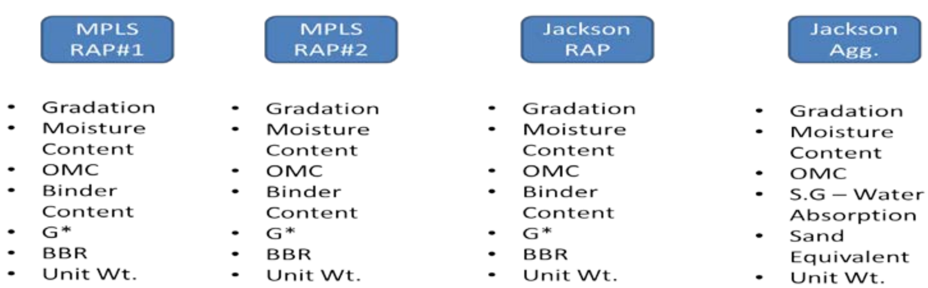
Field testing after this will give important performance feedback regarding the test sections that we suggest in this test program.

In Conclusions we also suggest more research with different materials and more iteration on the same to increase the precision of our results.

Our research methodology can be divided into two stages as shown below. First, the individual properties of materials were observed. Below can be seen all important individual properties of material listed with descending priorities which impact the performance of the material. Second, samples of various mix designs were prepared in order to carry test on them as shown below in Figure 22.

Stage 1: Individual properties of materials

Individual laboratory test will be carried out on each material to be used for the mix.



Stage 2: Test on different percentage of mix

Different mixes will be tested based on RAP content.

Mix	Different mixes					Test
MPLS RAP#1 + Jackson Agg.	10%	20%	30%	40%	50%	CBR
						IDT
						Unconfined Compaction Test
MPLS RAP#2 + Jackson Agg.						CBR
						IDT
						Unconfined Compaction Test
Jackson RAP + Jackson Agg.						CBR
						IDT
						Unconfined Compaction Test

Figure 22. Research experiment design

Selection of Samples

Material sources:

1. RAP Minneapolis (MPLS RAP#1 & MPLS RAP#2)

   MPLS RAP#1 as shown in Figure 23: MPLS RAP#1 has large chunks of aggregates also this material is not milled and is certainly unprocessed RAP. MPLS RAP#2 as shown in Figure 24: MPLS RAP#2 is processed and milled RAP which appears to be finer. Also the company details that provided us this material has been given below:

   Commercial Asphalt Company (Tiller Corporation)
   Maple Grove
   Plant #904
   10000 81st Ave
   Maple Grove, MN 55311
   Plant: (763) 424-4714
   Quality Management: (763) 424-4493

Figure 23. MPLS RAP#1

Figure 24. MPLS RAP#2

2. Jackson RAP and Jackson Aggregates

Tim Stahl, Jackson County Engineer generously provided the materials shown below. As seen in Figure 25 the Jackson County RAP includes some particles of relatively large size as the material is not processed or milled. Figure 26: Jackson Aggregate shows that the aggregate includes a considerable amount of fine materials and looks dry.

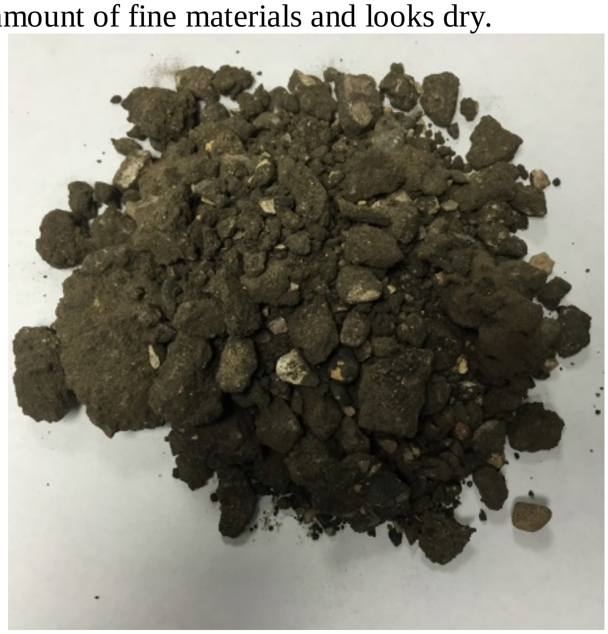


Figure 25. Jackson RAP

Figure 26. Jackson Aggregate

Laboratory Test Results

Sieve analysis

Standard procedures for sieve analysis as per ASTM C117 (C117-13, Standard Test Method for Material Finer than 75-um (No.200) Sieve in Mineral Aggregates by Washing, 2013) with ASTM C136 (C136-06, 2006) were carried out, as the fineness of aggregate in our case is important. Also a comparison between material gradations can be seen below in Figure 27. The Jackson County aggregate and MPLS RAP#2 have a much higher proportion of sand compared to other material. It can also be said that the Jackson County RAP and the MPLS RAP#1 have more coarse material comparatively.

A more detailed description of the sieve analysis has been given below in the Appendix B.

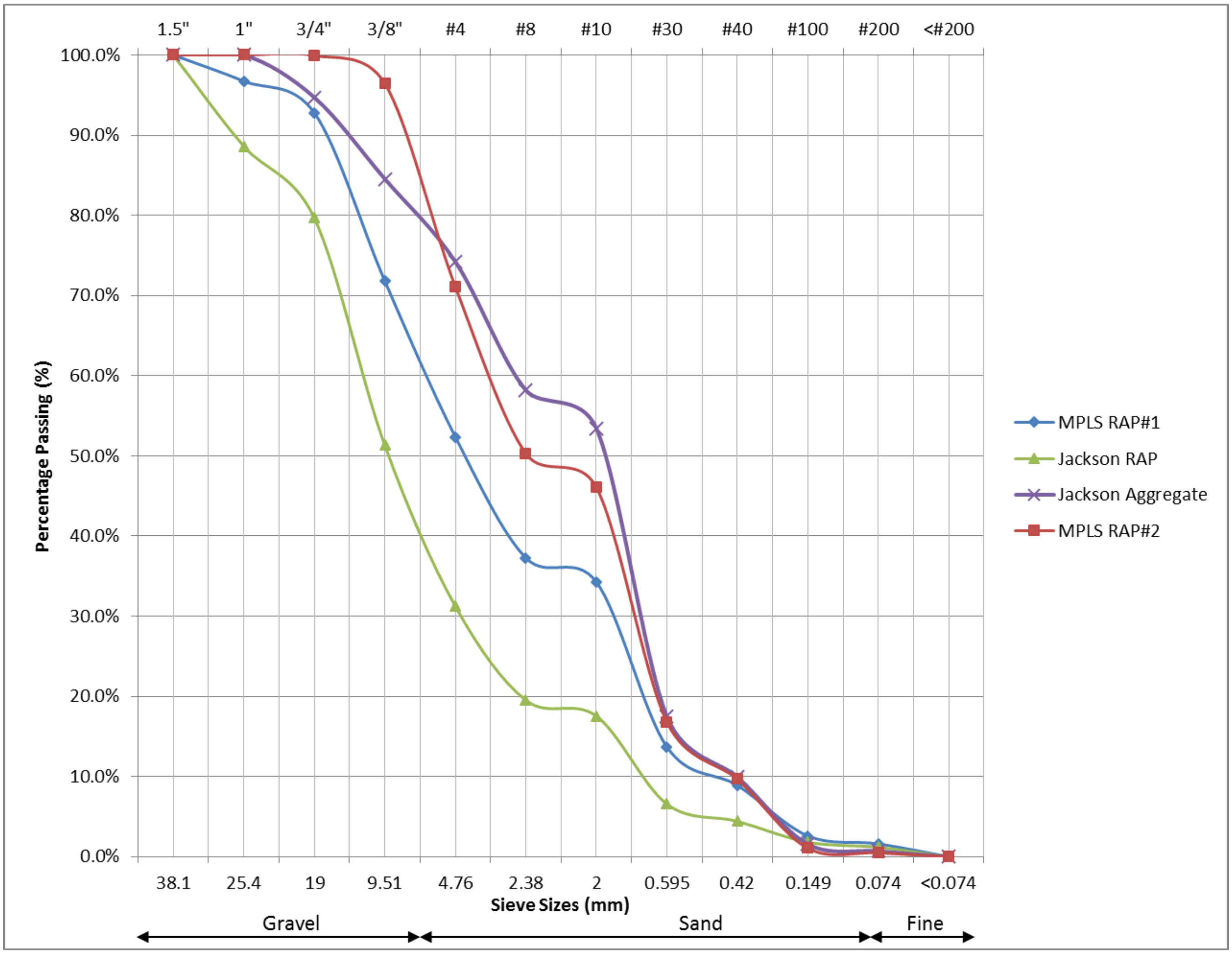


Figure 27. Combined Gradation of materials

Moisture content

The moisture Content of the materials have been calculated as per the ASTM D2216 (D2216-10, 2010). The moisture content in the RAP is relatively low, as asphalt absorbs little water. Also the Jackson County aggregate is dry and has a very low moisture content.

MPLS RAP#1 = **0.1606%**
MPLS RAP#2 = **0.2153%**
Jackson RAP = **0.2119%**
Jackson Aggregate = **0.2644%**

As mentioned above, all of the material was quite dry with the Jackson County Aggregate having the highest moisture content comparatively. More details regarding all of the iterations of moisture content calculations have been provided in Appendix B.

Optimum moisture content

An attempt was made to find out the Optimum Moisture Content of the materials with respect to ASTM D698 (D698-12, 2012). Below in Figure 28 various stages of sample preparation and testing have been shown: Starting from top left apparatus, molds, and samples in small plates to keeping it in oven.

Figure 28. Optimum moisture content Lab test

Also a failed attempt was made to draw OMC curve based on the data. But due to the coarseness of the material and its non-cohesive nature no perfect curves emerged out of the data. For more details of the OMC test data please refer Appendix B. Many of the optimum moisture content plots do not follow the classic expected shape that is typical of many such plots. After a decision with committee members it was decided not to show the OMC curves as they have no perfect curves to define a single point of optimal moisture.

Binder content

In order to determine the Asphalt binder content of the various RAP materials Ignition test were conducted with reference to ASTM D6307 (D6307-101, 2010).

Under this process, in the first step, the RAP sample are kept in an ignition oven and heated to allow evaporation of all the binder. The next step is to conduct binder weight calculations. Below in Figure 29: Ignition Test Ignition oven with RAP sample is seen.

Figure 29. Ignition Test

Table 9. Ignition Test Results

Material	**MPLS RAP#1**			**MPLS RAP#2**		**Jackson RAP**	
Sample name	Sample1 (MRSP11)	Sample2 (MRSP12)	Sample 3 (MRSP13)	Sample 1 (MRSP21)	Sample 2 (MRSP22)	Sample1 (JRSP1)	Sample2 (JRSP2)
Wt. of the Pan	1136.3	1136.4	1136	1135.9	1136	1135.2	1134.7
Wt. of the Sample	2382.2	2127.5	2453.7	2641.1	2410.8	2371.4	2265.7
Total Wt.	3518.5	3263.9	3589.7	3777	3546.8	3506.6	3400.4
Total Wt. after ignition	3382.9	3126.3	3432.5	3615	3405.2	3351.8	3242.2
Wt. of Sample after ignition	2246.6	1989.9	2296.5	2479.1	2269.2	2216.6	2107.5
Percentage Asphalt Content	**5.69%**	**6.47%**	**6.41%**	**6.13%**	**5.87%**	**6.53%**	**6.98%**
Average Asphalt Content %	**6.1889%**			**6.0037%**		**6.7551%**	

As seen above in Table 9, the Jackson County RAP had the highest asphalt binder compared to both of the MPLS samples.

Loose unit weight

Using ASTM C29 (C29/C29M-09, 2009), the Unit Weight of the materials was calculated. Also it should be noted that most of the materials gave consistent result except for the Jackson County RAP which had considerable variation due to the large aggregate sizes and lack of uniformity with regard to aggregate sizes.

MPLS RAP#1 = **108.11028 pcf**
MPLS RAP#2 = **132.125434 pcf**
Jackson RAP = **117.090235 pcf**
Jackson Aggregate = **145.504527 pcf**

Detailed test result and analysis can be found in the Appendix B.

Bending Beam Rheometer

In order to calculate low temperature stiffness and relaxation properties of asphalt binders, Bending Beam Rheometer (BBR) tests were conducted on the RAP samples. This test commences with the extraction of asphalt binder which is performed by following ASTM D7906 (D7906-14, 2014) using toluene and rotary evaporator. This is followed by the separation of the asphalt binder from toluene and finally the preparation of the beams of asphalt binder and testing them in a beam rheometer as per ASTM D6648 (D6648-08, 2008). All of the procedures are shown below in Figure 30: Starting with Rotary evaporator in the top left followed by distillation of toluene, preparing beams and testing them in the Rheometer.

Figure 30. Test Procedure for BBR

The speed at which distillation is performed affects the stiffness of the asphalt binder. Considering that test should be carried carefully. In our case Jackson RAP asphalt binder was less stiff to be tested in two different temperatures i.e. -12° C and -15° C (as the bath was not able to reach -18° C) respectively.

Both the MPLS RAP Asphalt binder samples were very stiff to be used on other temperature so they were tested at -12°C and 0°C.

Results of all these tests are provided in Appendix A and based on those results, the Master Stiffness Curve will be produced. Due to the relatively high stiffness of the material second tests were not performed and therefore flexural creep stiffness was not calculated. A reason given for this failed attempt was the age of the asphalt that is tested, older the asphalt lesser chances of running this test.

Dynamic shear rheometer

This test is carried out to characterize the viscous and elastic behavior of asphalt binders at medium to high temperatures. Following ASTM D7552 (D7552-09, 2009) samples were prepared and tested on the Rheometer with various temperatures. In Figure 13, the Rheometer with a computer, samples and the plates on which samples are tested are shown.

Figure 31. DSR Test

Samples in our case are too stiff and it was difficult to test them. A failed attempt was also performed to test the samples on the DSR.

Unconfined compaction test

In order to determine the strength of each mix with various percentages of RAP, samples were prepared using the Marshall Hammer method (D6926-10, 2010) and then tested according to ASTM D2166 (D2166/D2166M-13, 2013). The samples were prepared to provide the OMC that was calculated previously. It was difficult for sample to hold its shape due to the properties of the material. Also only 35 blows were given on each side, since this number of blows was appropriate for samples that represent low traffic roads.

Below in Figure 32, a representation of the workflow for the entire procedure is depicted starting from left to right: Marshall Hammer apparatus, samples covered with foil paper to retain moisture and finally the testing process for the samples after one day.

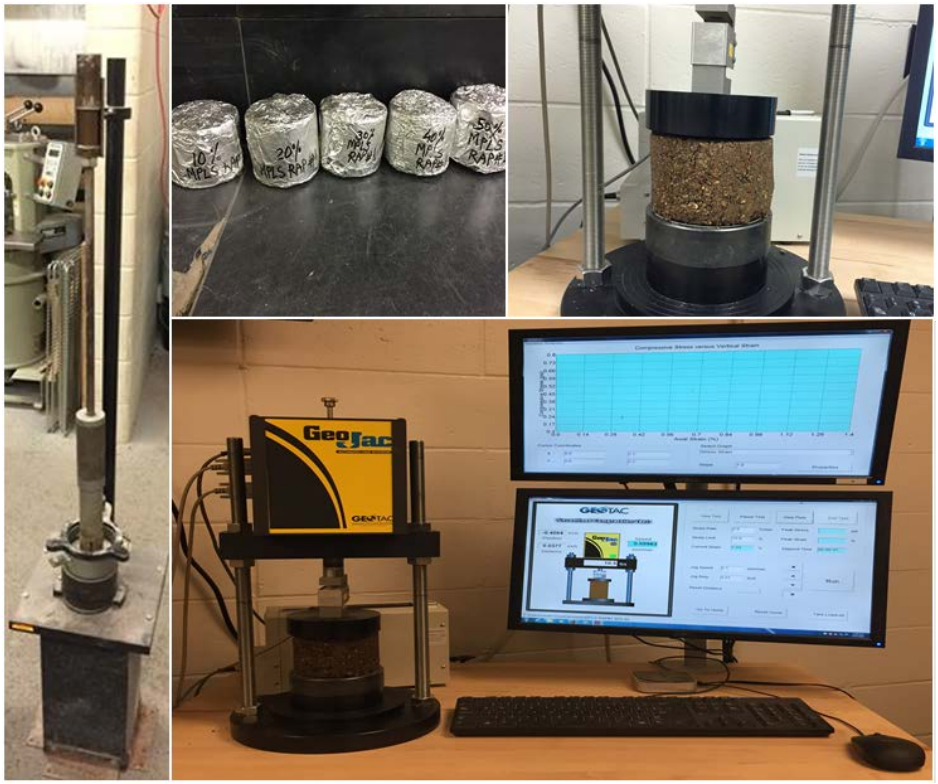


Figure 32. Compaction test procedure

4 inch diameter samples were prepared with varying depths from 2.5 inch to 3 inch. All of the dimensions were measured carefully with a Vernier scale were entered into the computer system for calculations. Ideally soil samples with fines are tested using this procedure but in our case we used samples of material that contained little fine material and mixed them to the extent possible. This provided more realistic data regarding the actual strength of the mixes that can be used when plans are made for the test sections. Below in Figure 33, Figure 34, and Figure 35 stress-strain curves of MPLS RAP#1, MPLS RAP#2 and Jackson County RAP have been given respectively. The various RAP mixtures with the Jackson County aggregate provided a more valid and direct comparison with various RAP materials.

Many different interpretations can be derived from the data that have been collected so far. Strongest material mix was the Jackson County RAP mix with 50% RAP. The weakest material mix was seen to be Jackson RAP mix with 20% RAP. For MPLS RAP#2 and the Jackson RAP, 50% mixes provided the highest strength whereas in case of MPLS RAP#1, the 20% mix showed the highest strength. It can be noticed that in all three of the RAP material test data for the 30% RAP mix, the strength achieved is the second highest for that material.

Defining what "Optimal RAP Content" means and understanding what exactly is optimal is an important aspect of this investigation. Road sections with highest stiffness may not be desirable. Gravel and crushed rock roads need to allow some material movement so they can be shaped using motor grader. Unpaved roads that are too stiff develop potholes and other defects under traffic, which are difficult to repair with a motor grader because the blade tends to tear us stiff material in chunks that are difficult to manipulate using standard motor grader maintenance procedures. It might look like a pattern to have 30% having second highest stress in all three mixes but considering the mixes to be non-cohesive there is no relation. Correlation always doesn't equal causation. Using Marshall Compaction, pucks were made but due to the non-cohesive nature of the mix the pucks were barely holding their forms.

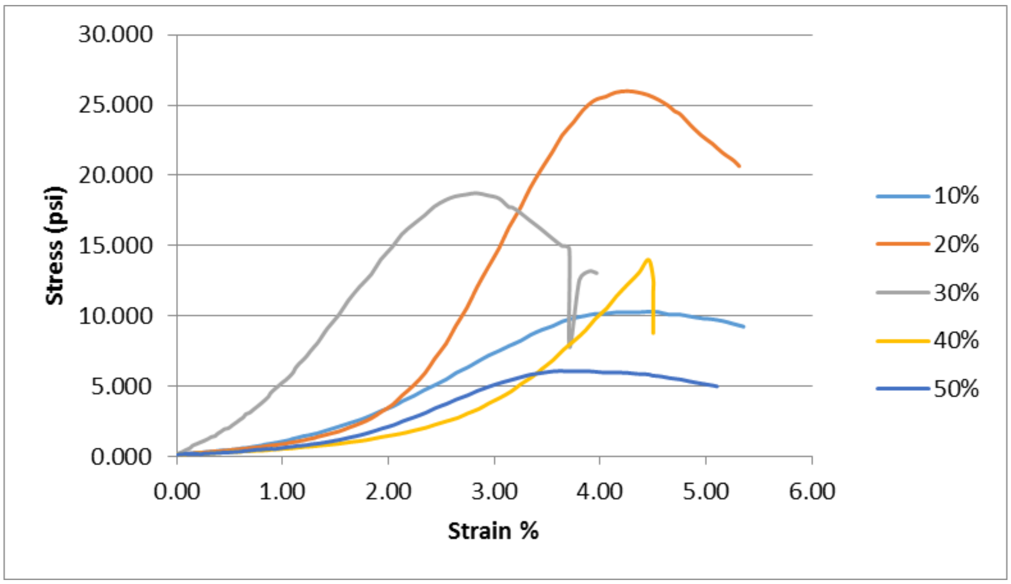


Figure 33. Stress-Strain Curve MPLS RAP#1

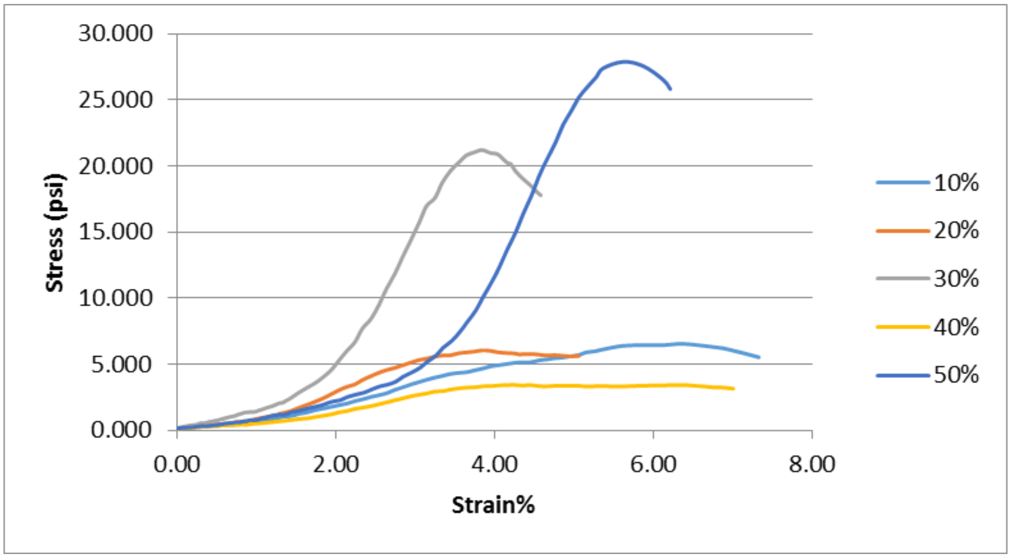


Figure 34. Stress-Strain Curve MPLS RAP#2

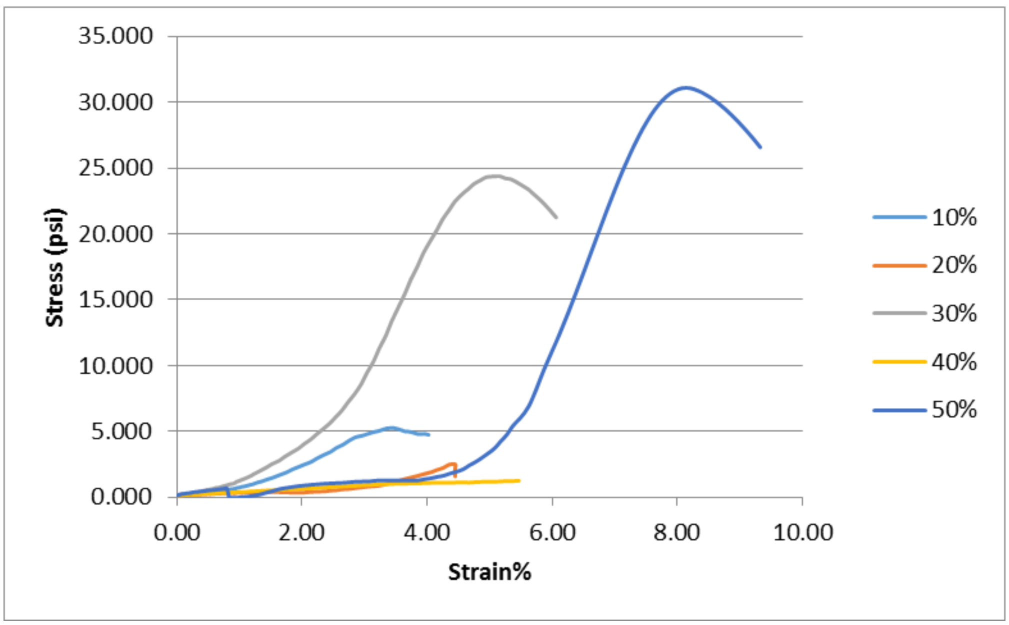


Figure 35. Stress-Strain Curve Jackson RAP

California bearing ratio (Un-soaked)

Using Marshall Compaction procedures, this material cannot be compacted to form a puck that can be easily subjected to unconfined compression test. Therefore the CBR (California bearing ratio) test which is more suited to this type of material, is likely to be better suited for finding the bearing strength of the mixes. Unpaved roads are made out of soil aggregates which tend to be cohesive, but by the introduction of RAP in these aggregates, a non-cohesive mix is formed. Also RAP tends retain less moisture compared to soil aggregate mixtures, which makes the mix relatively less bonded by water molecules. These can produce localized effects in the mix where RAP and soil aggregate segregates. It would seem desirable to identify a mix of RAP and other materials that will provide some cohesion that would provide a reasonably high CBR. As per the literature review, it can be seen that CBR of RAP mixes with soil tend to reduce with the increase of RAP in the mix.

As seen the Figure 36 below CBR apparatus consists of a mold, loading apparatus with a piston and measuring gauge. Un-soaked CBR tests were carried out.

Figure 36. CBR Test

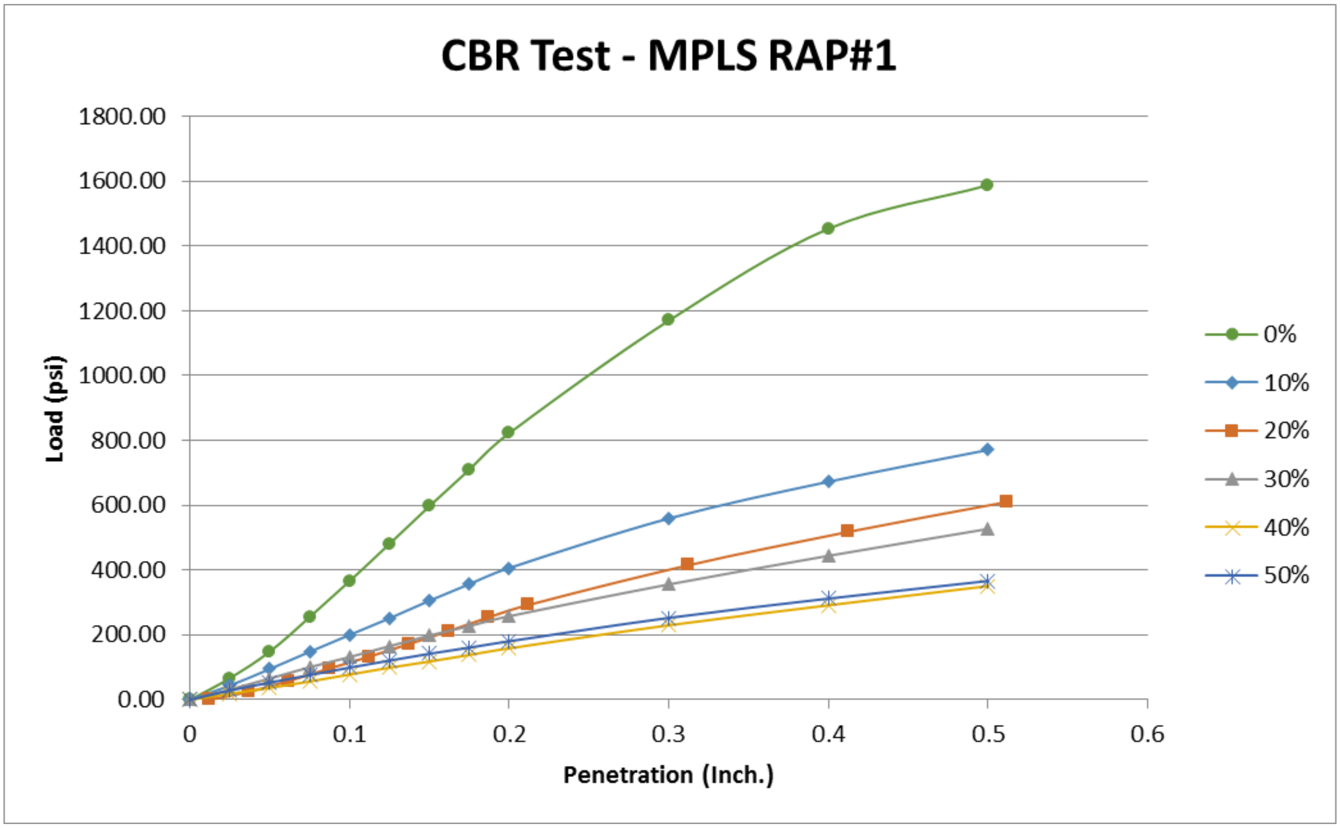


Figure 37. MPLS RAP#1 - Load vs Penetration

As seen above in the Figure 37 it is clear that the soil aggregate alone can take more load (i.e. result in a higher CBR) compared to mixes with different various percentages of RAP. Also it can be seen that 40% and 50% mixes almost result in the same CBR load profile.

Table 10. MPLS RAP#1 - CBR Result

Mix	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**
CBR at 0.1"	37%	20.0%	11.5%	13.2%	7.8%	9.9%
CBR at 0.2"	55%	27.1%	18.3%	17.2%	10.6%	12.0%
CBR	**55%**	**27.1%**	**18.3%**	**17.2%**	**10.6%**	**12.0%**

As given in the Table 10 above, percentages of CBR are calculated considering 0.1" and 0.2" penetration and the maximum is considered to be the final CBR. Based on these tests, it is now appears that increases of RAP in mix is directly proportional to decreases in the CBR value. Also a 50% mix provided a CBR of more than 40%.

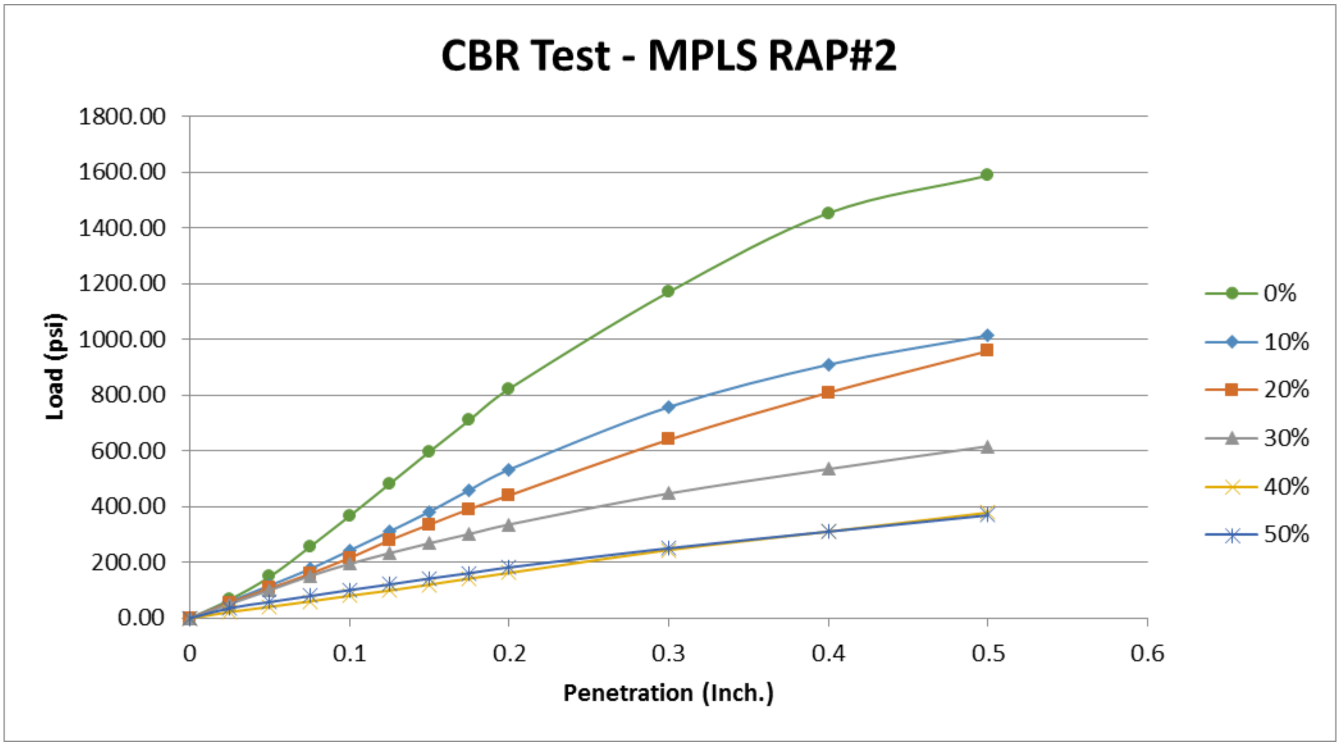


Figure 38. MPLS RAP#2 - Load vs Penetration

Figure 38 shows how MPLS RAP#2 behaves under loading. Various mixes with various amounts of RAP shows that MPLS RAP#2 shows better result than RAP#1. As 10 % and 20% mixes can take a load of almost 1000 psi compared to MPLS RAP#1 which take about 800 and 600 psi respectively. Also 20% mix appears to have a CBR that is similar to that of a 10% mix.

Table 11. MPLS RAP#2 - CBR Result

Mix	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**
CBR at 0.1"	37%	21.6%	19.5%	19.5%	8.1%	10.1%
CBR at 0.2"	55%	35.6%	29.4%	22.4%	10.8%	12.2%
CBR	**55%**	**35.6%**	**29.4%**	**22.4%**	**10.8%**	**12.2%**

Again, the 50% mix provided a higher CBR in comparison to a 40% mix. 10% has the highest CBR comparatively.

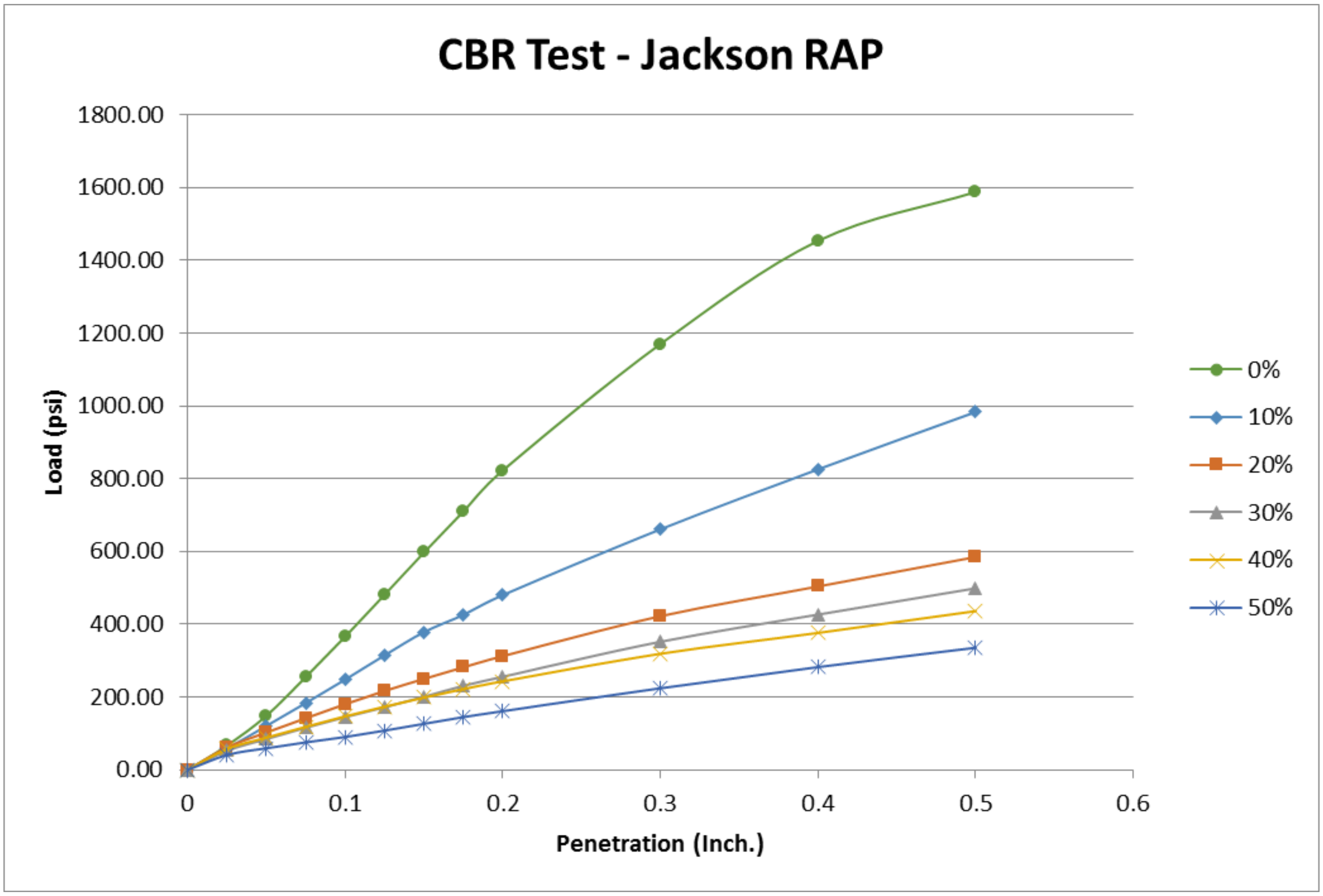


Figure 39. Jackson RAP - Load vs Penetration

In case of the Jackson RAP as shown above in Figure 39, a clear separation between 40% and 50% is visible. Also the load taken by 10 % mix is also relatively high.

Table 12. Jackson RAP - CBR Result

Mix	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**
CBR at 0.1"	37%	24.8%	18.1%	14.5%	14.7%	9.0%
CBR at 0.2"	55%	32.0%	20.8%	17.1%	16.2%	10.8%
CBR	**55%**	**32.0%**	**20.8%**	**17.1%**	**16.2%**	**10.8%**

The testing results from the Jackson RAP show a sudden drop of CBR from 10% to 20% which is about 11% which is comparatively more than that of the MPLS RAP.

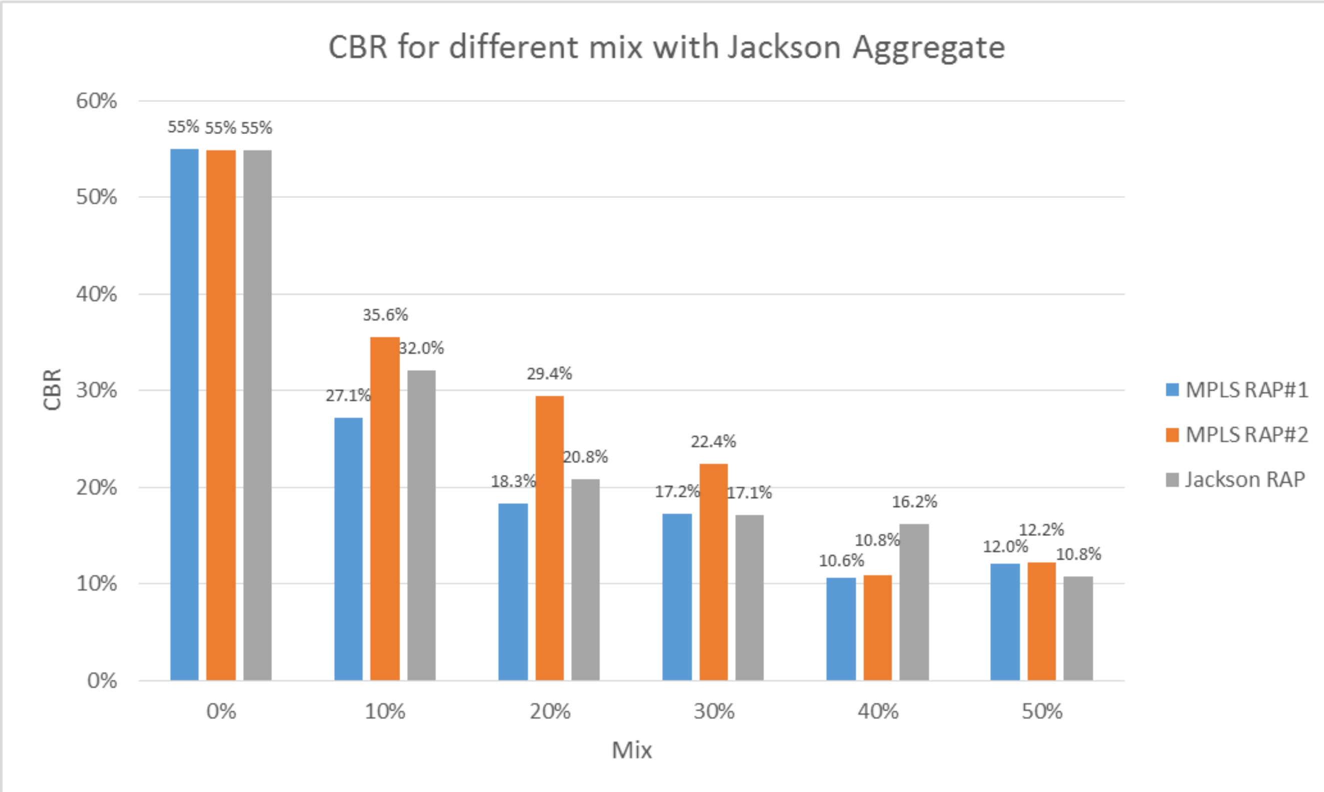


Figure 40. Comparative CBR

To clearly understand and compare all the various mixes of all three materials, a comparative graph has been created (Figure 40). Here it is clear that the highest CBR among all mixes and various percentages is MPLS RAP#2 10% i.e. a CBR of 35.6%. Also it should be noted that MPLS RAP#1 and RAP#2 are the same material, except for a difference I gradation. So, based on these results, it could be concluded that the finer the RAP the better the strength and better the binding capability with the soil aggregates. More study should be performed to understand these relationships. In further studies this research team intents to develop a statistical relationship between CBR and individual material properties.

Results of Test Program

In the report for Task1, a literature review was documented which outlined the basic characteristics of RAP material. Also, many studies suggested a clear decrease in CBR values with incremental additions of RAP in the mix.

Table 13. Summary: Material lab test result

Material	Gradation in (Coefficient of Uniformity) Cu=D60/D10	Moisture Content	Dry Density g/cc	Binder Content	Unit Weight g/cc
MPLS RAP#1	16.01	0.16%	3.70	6.19%	1.73
MPLS RAP#2	8.00	0.22%	1.84	6.00%	2.12
Jackson RAP	9.50	0.21%	2.72	6.76%	1.87
Jackson Agg.	11.33	0.26%	1.20	Not Applicable	2.33

Based on the testing that was conducted for Task 2, it was evident that the results match those that would be expected based on the literature review. As seen in Table 13 the materials and their various characteristics have been measured. Then the CBR values for various mixes were determined (Table 14). Also, after detailed analysis of the results from lab test program a relationship between the fineness of the material and its CBR value became evident. As shown in Table 14 which provides a summary of all the mixes and their respective CBR values, it can be seen that the CBR value for MPLS RAP#2 10% is much higher than MPLS RAP#1 10%. The only difference between MPLS RAP#1 and MPLS RAP#2 is that the prior is not crushed and the subsequent is.

Table 14. CBR Values of different mixes

CBR VALUES			
Mix	**MPLS RAP #1 + Jackson Agg.**	**MPLS RAP #2 + Jackson Agg.**	**Jackson RAP + Jackson Agg.**
10%	27.1%	35.6%	32.0%
20%	18.3%	29.4%	20.8%
30%	17.2%	22.4%	17.1%
40%	10.6%	10.8%	16.2%
50%	12.0%	12.2%	10.8%

A more detailed analysis should be executed to draw a more certain relationship between CBR values and other values. Based on the lab study, the performance of the field trial test sections will be compared to the results of similar lab tests for the materials used in the field test sections.

A statistical model will be developed with all the parameters to be considered. The relationship between binder content, fineness of aggregates and strength of the mix will likely be the key drivers to find the optimal RAP content for gravel roads. Considering all above test result can be said surely be said that Optimal RAP content for gravel roads will change according to the properties of the RAP and other factors. A rational road design procedure will be consider several factors such as traffic data, climate data, material properties and field properties; they can likely be combined to provide an optimal mix design.

As per the Committee meeting dated march 16th 2015 it was decided to consider three test sections locations namely, Jackson County (predominantly silty glacial sediments subgrade and gravel surfacing), Goodhue County (predominantly sand and gravel subgrade and crushed limestone surfacing) and Carlton County(predominantly sandy glacial sediment subgrade and gravel surfacing) covering all three major sub soils of the State of Minnesota and both gravel and crushed limestone unpaved road surfacing.

This selection of sections locations will help us understand more about various subgrade structures affect crushed rock and gravel roads and how the addition of RAP influences all combinations or subgrade and road surface.

Sections with varying percentages of RAP can be constructed in order to conduct a field test and observe the performance of these sections.

Mixtures of RAP and crushed rock for road surfacing fall in neither the unpaved nor flexible pavement category, therefore no particular design criteria is available to be considered. Design guide should be prepared based on the observations that will be forthcoming from this investigation and possibly a combination of both design methods. Also various stabilizing agents such as Chlorides, resins, natural clays and others should be considered in various combinations with RAP on gravel and crushed rock roads to understand its effects. Also road performance based on various distresses and various responses should be understood.

CHAPTER 5: FIELD TEST SECTIONS

Construction

According to the methodology that has been adopted for this research project, construction of two test sections was accomplished in Carlton and Goodhue Counties. Officials from both counties showed considerable interest and constructed these test sections with the material that was available locally. According to Minnesota Geological Survey data of 2006, these counties typically have different subgrades soil types. Carlton County has sand and gravel soil material whereas Goodhue has silty glacial sediments soil material (Survey, 2006). As shown in Figure 41 the counties are different parts of the state. Also apart that there are topological differences such as altitude from sea level which is 293 m and 325 m for Carlton and Goodhue County respectively.

Figure 41. Test sections on county map of Minnesota

The Annual average daily traffic (AADT) according to the traffic data shared by MnDOT is 45 and 145 for Carlton and Goodhue test sections respectively. (MnDOT, 2015)

Goodhue County

The test section at Goodhue County is close to the municipality of Zumbrota and situated on county road 55. As shown below in Figure 42 approximate quarter mile sections of various mixtures of crushed rock and RAP materials were separated by control sections. Also a longer control section on 500th street is provided.

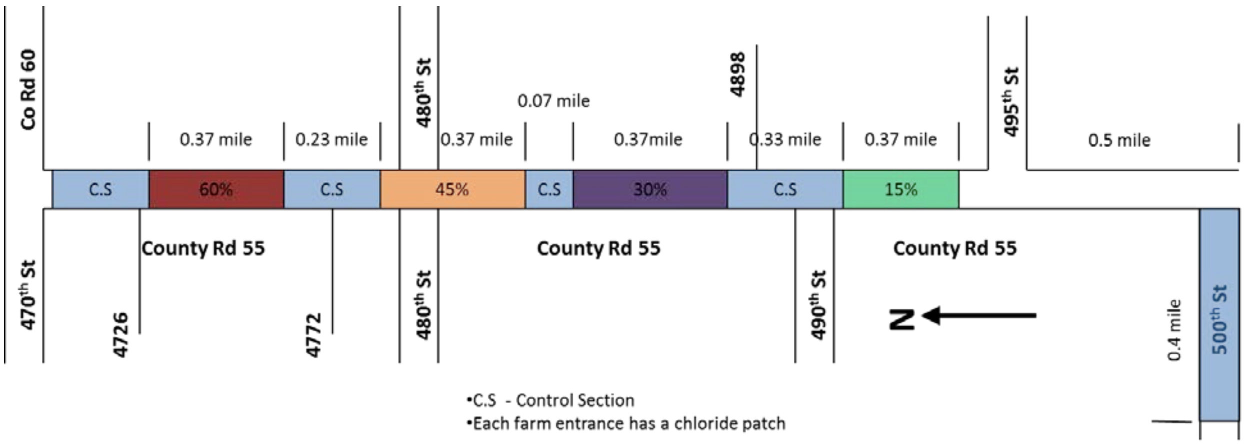


Figure 42. Goodhue county test section plan

Construction was accomplished under a regular contract for furnishing and placing crushed rock held by Goodhue County. Mathy Construction Co. donated the RAP material, paid for crushing it, and blended it with crushed rock using a set of bins and a conveyor belt that would be suitable for a portable hot mix plant. The RAP was deliver Keilmeyer's quarry by Mathy from a location on Olmsted County and crushed and mixed at the quarry. Crushing and blending of the material was accomplished on 14th July 2015 and was placed on 16th July 2015. A calcium chloride treatment was placed by the county later on 22 July.

250 tons of material was placed and spread on each quarter mile sections using bottom dump trucks and a motor grader as shown in Figure 43.

Figure 43. Construction in Goodhue County

As previously mentioned, later county provided a calcium chloride treatment (Figure 44) by regrading, applying the calcium chloride and then compacting with a pneumatic roller.

Figure 44. Chloride treatment at Goodhue County

Carlton County

The test sections in Carlton County are close to Barnum and situated on East County Road 103. As shown below in Figure 45 there are two test sections (RAP 30% and 50%) having length of 0.7 mile and 0.3 mile respectively. Also as shown a control section is provided for comparison with the test sections.

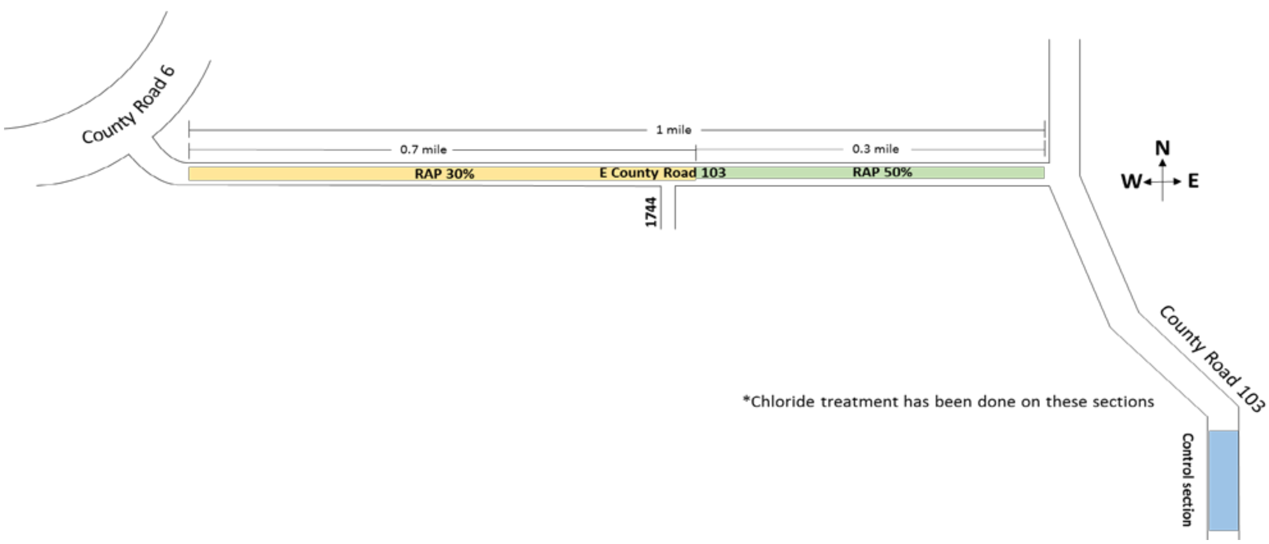


Figure 45. Carlton County test section plan

Construction for these test sections as executed by the county itself by using the RAP 30% material from their Barnum stockpile and RAP 50% material from their Carlton stockpile. Construction was accomplished on May 28th 2015. Construction process adopted was similar to that for Goodhue County: material was placed by bottom dump trucks and then a motor grader was used to spread the material. However, no roller for compaction was used here.

Before laying the RAP material on the surface, a 2 inch layer of red clay was placed on the subgrade as recounted by the Maintenance Supervisor of the county. A layer of 4 inch RAP has been placed on its top for both sections. RAP material was blended with Class 1 material consisting of around 9% #200 material. As shown below in Figure 46 Barnum and Carlton stock piles and pits.

Figure 46. Barnum and Carlton pit

Field Testing

Field trips were planned to collect data and document all of the new sections, also to record the construction process and methods that would be adopted. As show below in Figure 47 the field trip is divided into different phases for both pre and post construction.

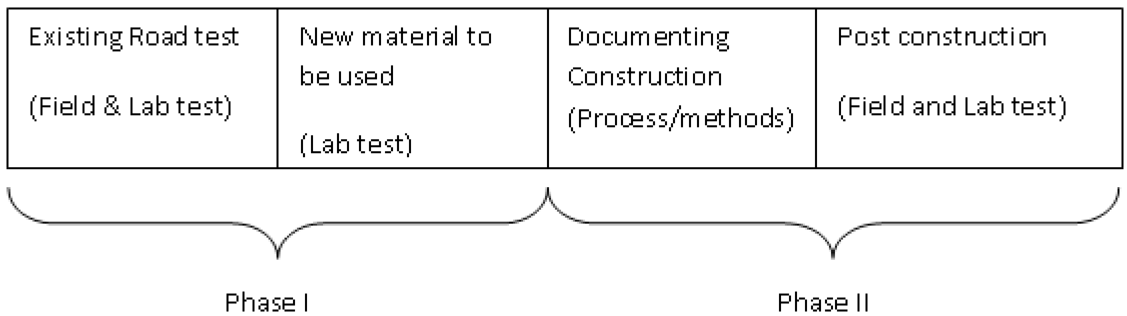


Figure 47. Field trip plan

County maintenance data will also be collected during these visits.
Data coming out of these field trips and lab test will be further discussed in the next reports.

Road cross-sectional survey

To record geometric properties of test sections a cross sectional survey was performed. The cross slope and crown of each test section was calculated based on these readings. Also the width of these sections differed which is important point to consider while comparing test results.
As cross slope and crown play important role in shedding water off the road during rains, it can be considered as an indicator for road performance. The recommended crown is approximately ½ inch per foot (4%) (Skorseth, 2000)

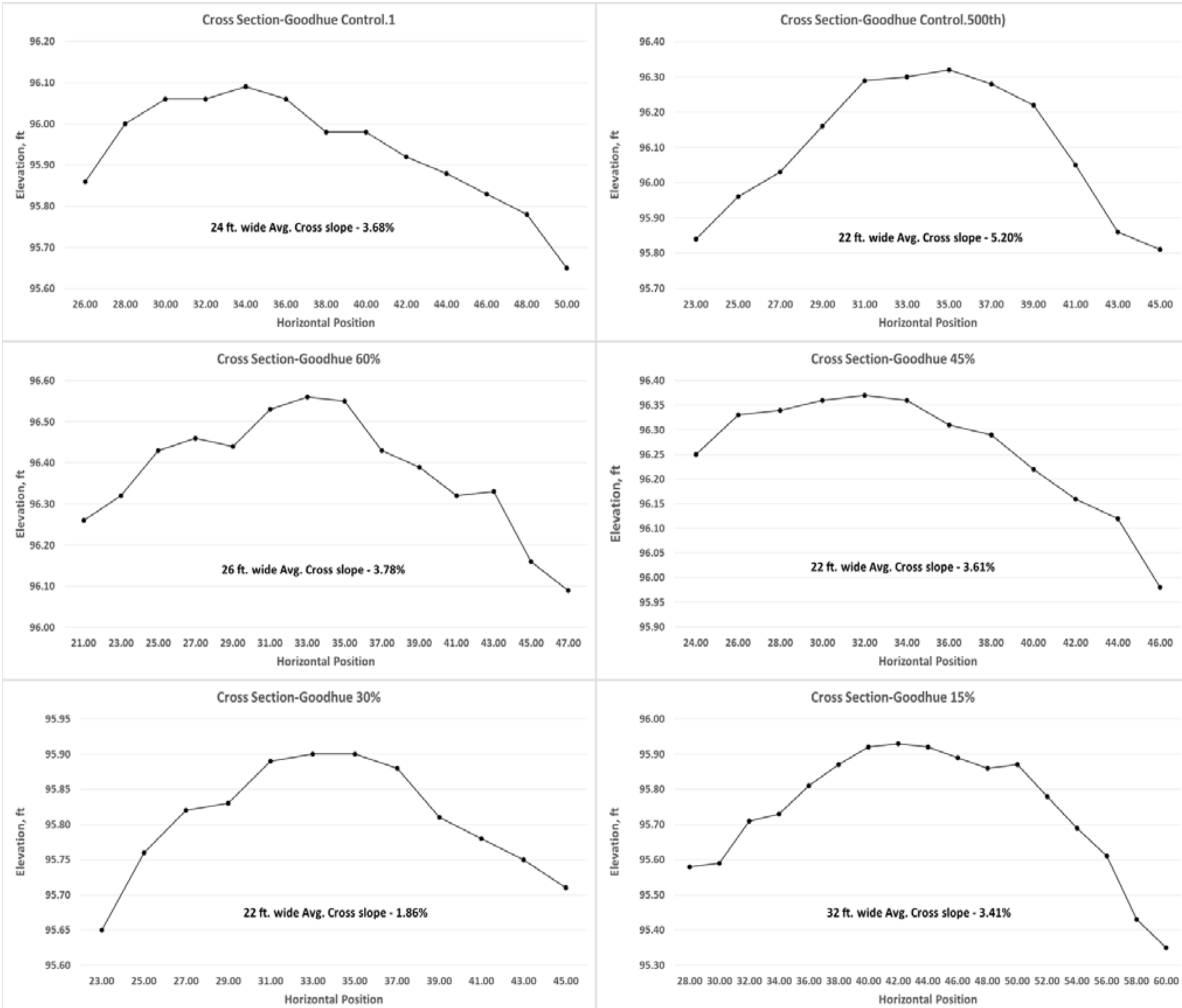


Figure 48. Cross-sectional survey Goodhue County with average cross slope

As shown above in Figure 48 starting with the control.1 section which is the first control section before the 60% section in Goodhue County, most of the test sections have a reasonably good cross slope except for the 30% test section which has a crown of 1.86%. Also it should be noted that the width of the section the 15% test section is comparatively more than that of the average width of other sections, i.e. 32 feet.

A similar cross sectional survey was carried out in Carlton County as shown below in Figure 49. Here the control section has a relatively flat cross slope compared with other sections. Also the cross slope of 30% section is also low at 2.3%.

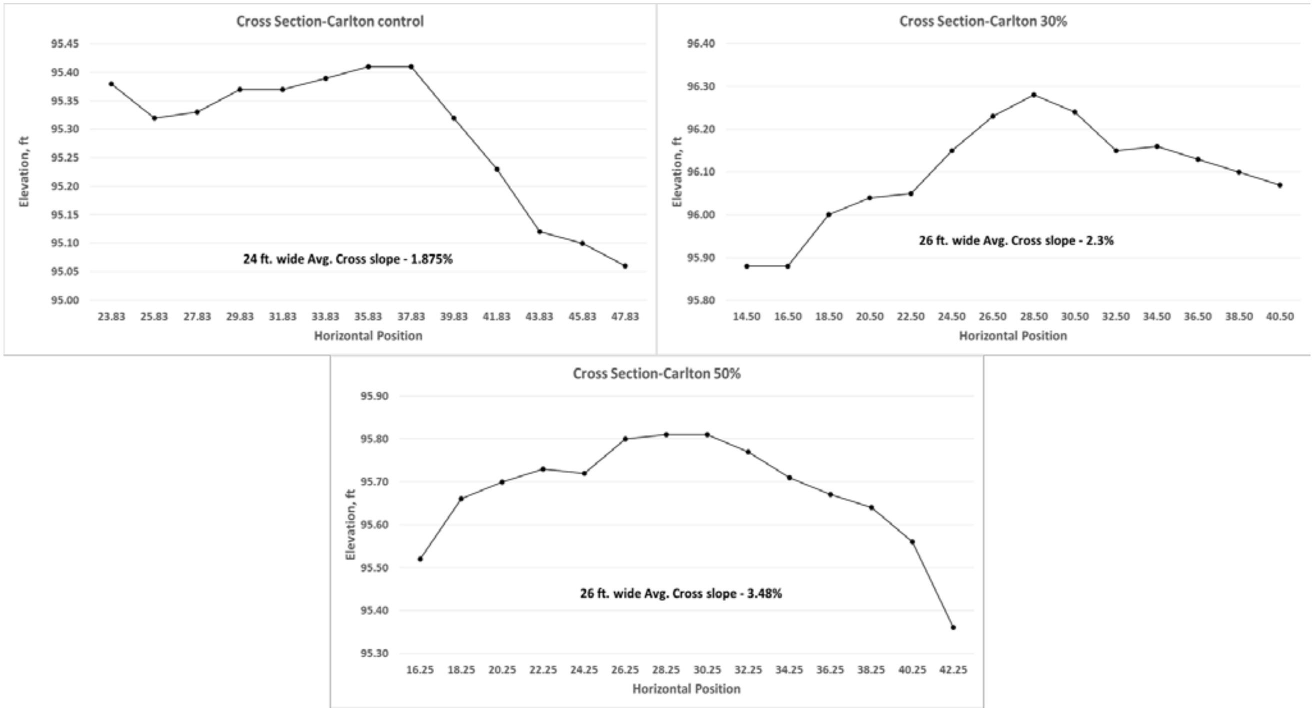


Figure 49. Cross-sectional survey Carlton County

Scrape test

A modified garden hoe as mentioned earlier is used to scrape and collect material from across the road. Two slide plates are welded to a regular garden hoe to collect loose material on the top of the road. Three scrapes at random are performed on each test section to estimate the total float on the road surface and then the average weight of this floating materials that was collected is compared. This method provides an indications of the amount of floating material found on each test section.

Table 15. Float calculation for Scrape test

Location	Section	Float (Average of 3 scrapes in Pounds)	Road Width (ft.)	Float (Pounds)/Ft.
Goodhue 9/4/2015	Control 1	8.901	24	0.371
	15%	9.459	32	0.295
	30%	7.296	22	0.332
	45%	7.798	22	0.354
	60%	6.989	26	0.268
	Control 500th	11.510	22	0.523
Carlton 9/3/2015	Control	12.123	24	0.505
	30%	14.762	26	0.567
	50%	6.873	26	0.264

Here again it is important to note the width of each test section to compare the average amount of floating material per unit area. As given in Table 15 above it can be said that the amount of floating material for control sections for both the counties is comparatively more than that of the test sections, except the 15% test section in Goodhue County section which has a width of 32 feet and the 30% test section in Carlton County where gradation data should be considered. Moreover it is difficult to determine whether or not there is a relationship between data for floating material and RAP percentage in the various blends based on these results. The case study of Goodhue County results indicated a considerable reduction in floating material for the sections with higher asphalt content.

Modified PASER

A modified PASER (Pavement surface evaluation and rating) chart as shown in Table 16 was used for visual road condition assessment.

Table 16. Modified PASER Chart

Rutting	9	8	7	6	5	4	3	2	1
	Very Good	Good		Fair		Poor		Very Poor	Failed
Discription	No or negligible ruts	Ruts <1" deep; ruts over <5% roadway		Ruts 1" to 3" deep; ruts over 5% to 15% of road way		Ruts 3" to 6" deep; Rut over 10% to 40% of roadway; Drivers tend to drive between the ruts not through them		Ruts 6" to 12" deep;	Ruts over 12" deep;

Washboarding	9	8	7	6	5	4	3	2	1
	Very Good	Good		Fair		Poor		Very Poor	Failed
Discription	No or negligible corrugations	Corrugations generally <1" deep; less than 10% of roadway with significant corrugations; little loss of vehicle control		Corrugations generally 1"-2" deep; 10%-25% of roadway with significant corrugations;some area safety is significantly compromised as vehicle lost control		Corrugations generally 2"-3" deep;over 25% of roadway with significant corrugations; Major safety issue as drivers are tempted to driver faster, skimming over the top of the corrugations		Similar to "Poor" but deeper and more extensive corrugations	Similar to "Very Poor" but deeper and more extensive corrugations

Potholes	9	8	7	6	5	4	3	2	1
	Very Good	Good		Fair		Poor		Very Poor	Failed
Discription	No or negligible potholes	Some small potholes; most <1" deep and <1' in diameter		Up to 3" deep though most <2" ; <2' diameter;		Many potholes; up to 4" deep and 3' in diameter		Up to 8" deep and >4' in diameter	Impassable

Loose Aggregate	9	8	7	6	5	4	3	2	1
	Very Good	Good		Fair		Poor		Very Poor	Failed
Discription	No or negligible loose aggregate; Negligible risk of chipped windshields	Loose aggregate in berms <1" deep; Loose aggregate usu. <3/4" thick		Loose aggregate in berms <2" deep; Loose aggregate usu. <1.5" thick		Loose aggregate in berms 2"- 4" deep;		Loose aggregate in berms >4" deep;	Sand dunes

Dust	3	2	1	0	U	Note
	None	Low	Medium	High	Not Rated	
Discription	No visible dust	Minor dust emissions; No visibility obstruction	Significant dust emissions; Dust loss is major concern from a material	Heavy dust emission; Dust loss is major concern from a material loss standpoint but this	Due to the moisture in the top road surface material, dust was not assessed	

Crown	3	2	1	Note
	Good	Fair	Poor	
Discription	Cross slope >3%; Good rooftop shape	Cross slope 1% to 3%;	Cross slope <1%	

Roadside Drainage	3	2	1	Note
	Good	Fair	Poor	
Discription	Roadway above surrounding terrain; Good foreslopes; Ditches and culverts	Roadway near the grade of surrounding terrain; Good foreslopes; Marginal foreslopes,	Roadway at or below the grade of the surrounding terrain; Few or no ditches: Runoff stays on	

This method is a visual rating system by which road conditions can be recorded as seen on the road. Also the results depends on the judgement of the, observer who is recording this data and is

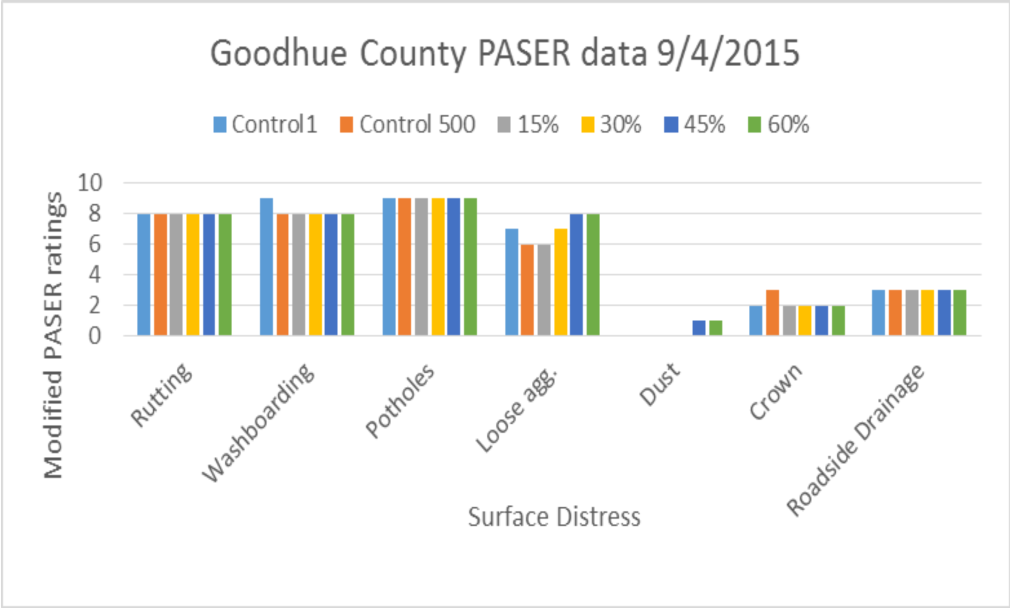


Figure 50. Goodhue county PASER data

therefore subjective. PASER data from both the test sections were collected and are summarized below.

As seen above in Figure 50, PASER ratings indicated that comparatively less dust and loose aggregate was visible on 45% and 60% sections.

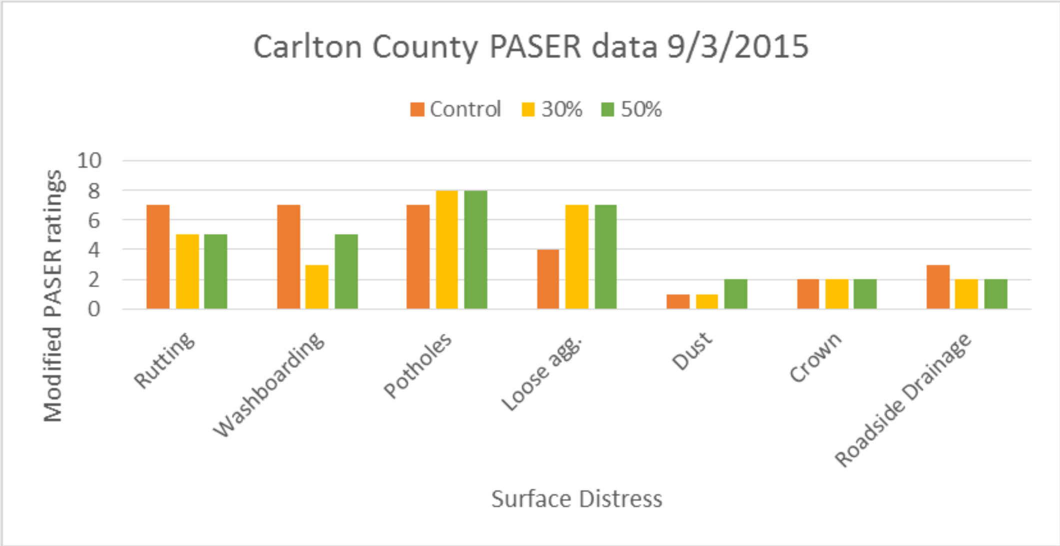


Figure 51. Carlton County PASER data

Similarly PASER data for Carlton County was also recorded. As shown above in Figure 51 there is comparatively less dust and loose aggregate on RAP sections. Also the RAP sections were rated to have considerably more rutting and wash boarding.

LWD test

Light weight Deflectometer (LWD) was used to measure the elastic modulus of the surface material. This is considered an important measurement for pavement design as stiffness of various material is different as their load carrying capacity is different. Below are details of the calculation method by which the elastic modulus was calculated for this investigation.
Determination of Elastic Modulus

$$E_{LWD} = \frac{(1 - v^2)\sigma_0 \alpha f}{d_0}$$

Where,

$E_{LWD} = Elastic\ Modulus\ (Mpa)$

$v = Poisson's\ ratio\ = 0.4$

$\sigma_0 = 0.1\ Mpa\ (300mm\ \emptyset\ Plate\ @71\ cm\ drop\ ht.)$

$0.2\ Mpa\ (200mm\ \emptyset\ Plate\ @50\ cm\ drop\ ht.)$

$\alpha = Plate\ radius\ = 150\ OR\ 100$

$f = Shape\ factor\ (\text{White, 2009})$

$\frac{8}{3}\ for\ flexible\ plate\ type\ and\ cohesionless\ sand\ with\ a\ parabolic\ stress\ distribution$

$d_0 = Settlement\ average\ of\ 3\ drops\ (mm)$

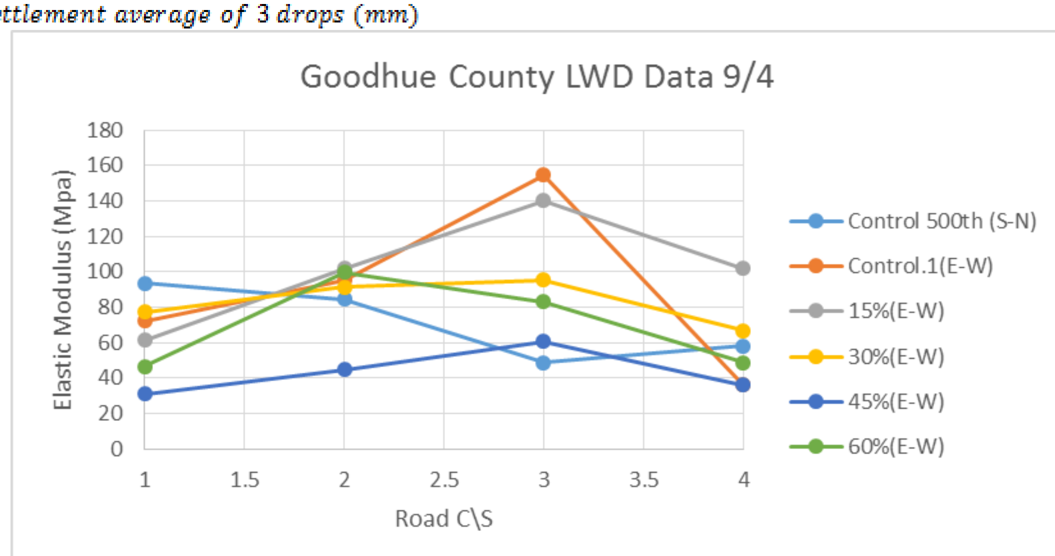


Figure 52. Goodhue County LWD data

As shown above in Figure 52 Goodhue county LWD data was collected for each test section in a cross sectional manner, where both shoulders and wheel paths of the road consist of the 4 data points in the cross section. In many cases, the stiffness at the shoulders was less than that at the wheel tracks. Also for the higher the RAP percentage, the recorded stiffness was generally lower has been recorded which would be expected as the RAP mixes are generally non-cohesive.

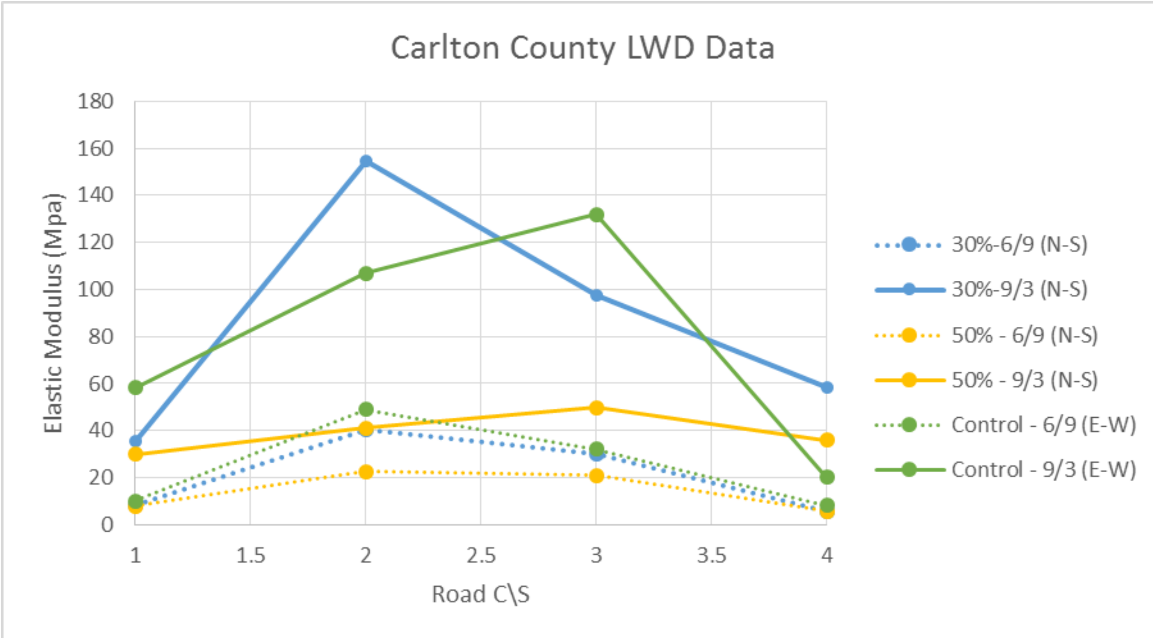


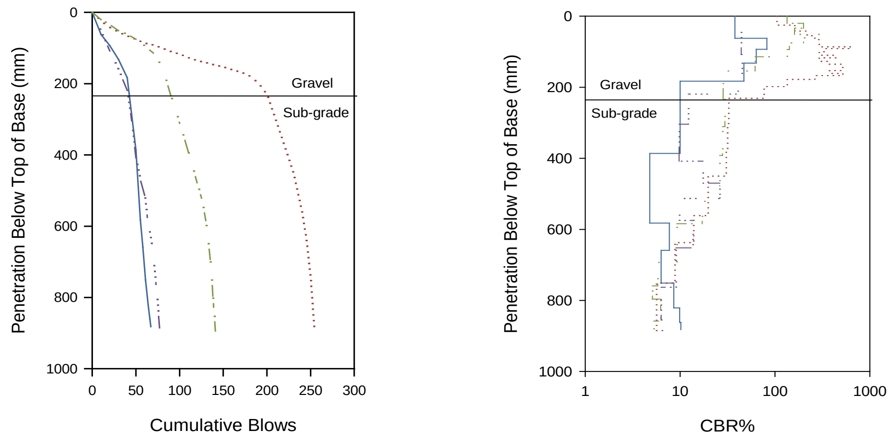
Figure 53. Carlton County LWD data

Similarly cross sectional LWD data was collected on Carlton county sections as shown above in Figure 53. Where both 150 mm diameter and 100 mm diameter plates were used on different dates 6/9 and 9/3 respectively. Here it can be seen as shown above in Figure 53 that 30% section has a higher stiffness at the later date. Also the control section has a higher stiffness at the later date.

DCP test

Dynamic Cone Penetrometer (DCP) test were carried out on both the Goodhue and Carlton County test sections. DCP data can be correlated to CBR (California Bearing Ratio) values and also shows how the strength changes as the probe penetrates the layers of the surface, base and subgrade. The bearing strength is important factor in road design which dictates the thickness to which the road should be constructed. Two figures per test section have been provided below which consist of cumulative blows vs penetration below the top surface and CBR vs penetration below the top surface. Also a separation between Gravel and Subgrade is done based on the sudden change of strength which is clearly evident as seen below.

Control Section



RAP 60% Section

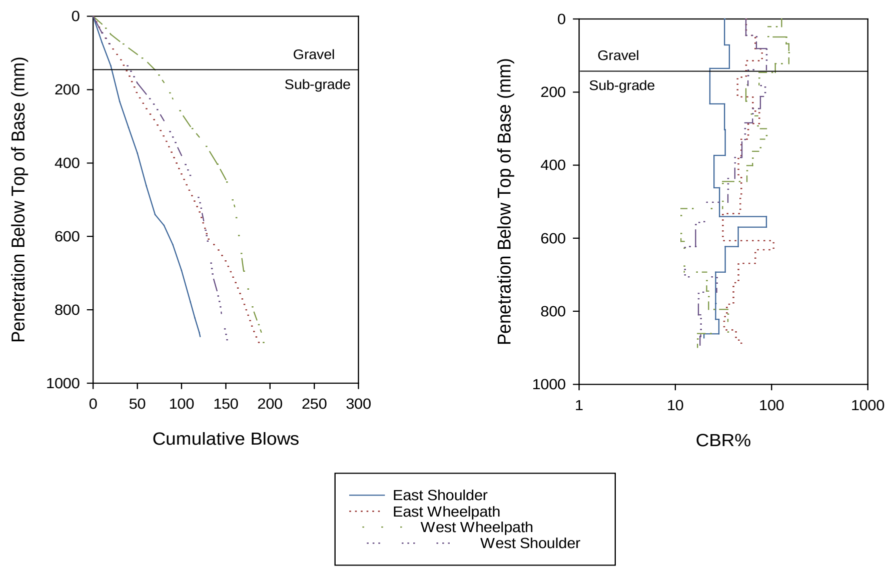


Figure 54. Control.1 & RAP 60% section DCP data (Goodhue County)

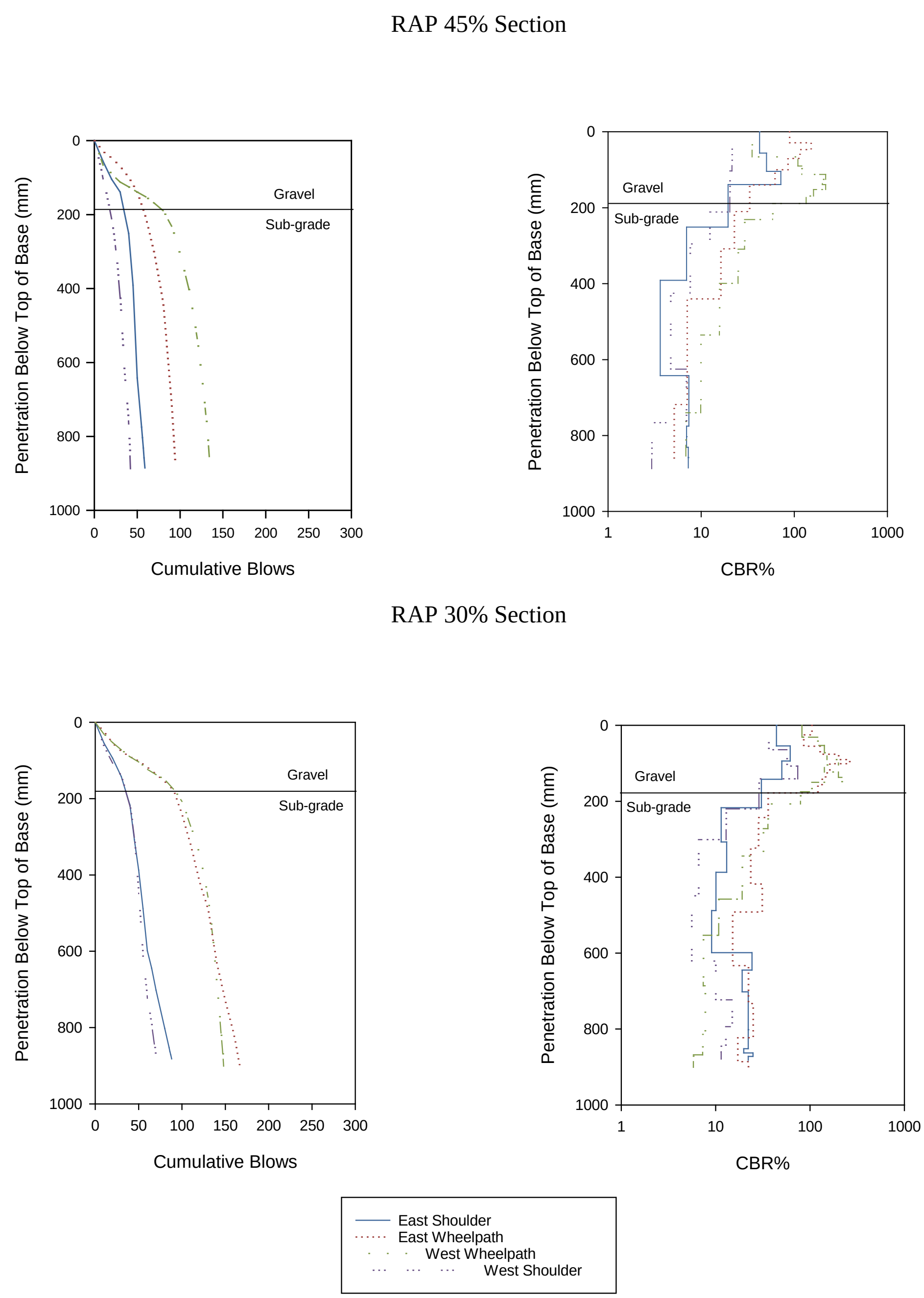


Figure 55. RAP 45% & RAP 30% section DCP data (Goodhue County)

As seen above in Figure 54 Control.1 section has hard gravel layer as the CBR values are consistently above 100 but as the subgrade layer starts a sudden decrease in the CBR values is seen (Particularly the east wheelpath). Whereas the RAP 60% section's gravel layers has comparatively low CBR but again the CBR for subgrade is more than the control.1.

For RAP 45% Section and RAP 30% Section as seen in Figure 55 similar pattern are seen where gravel layer above the subgrade maintains a CBR above 100 and then drops as it reaches subgrade.

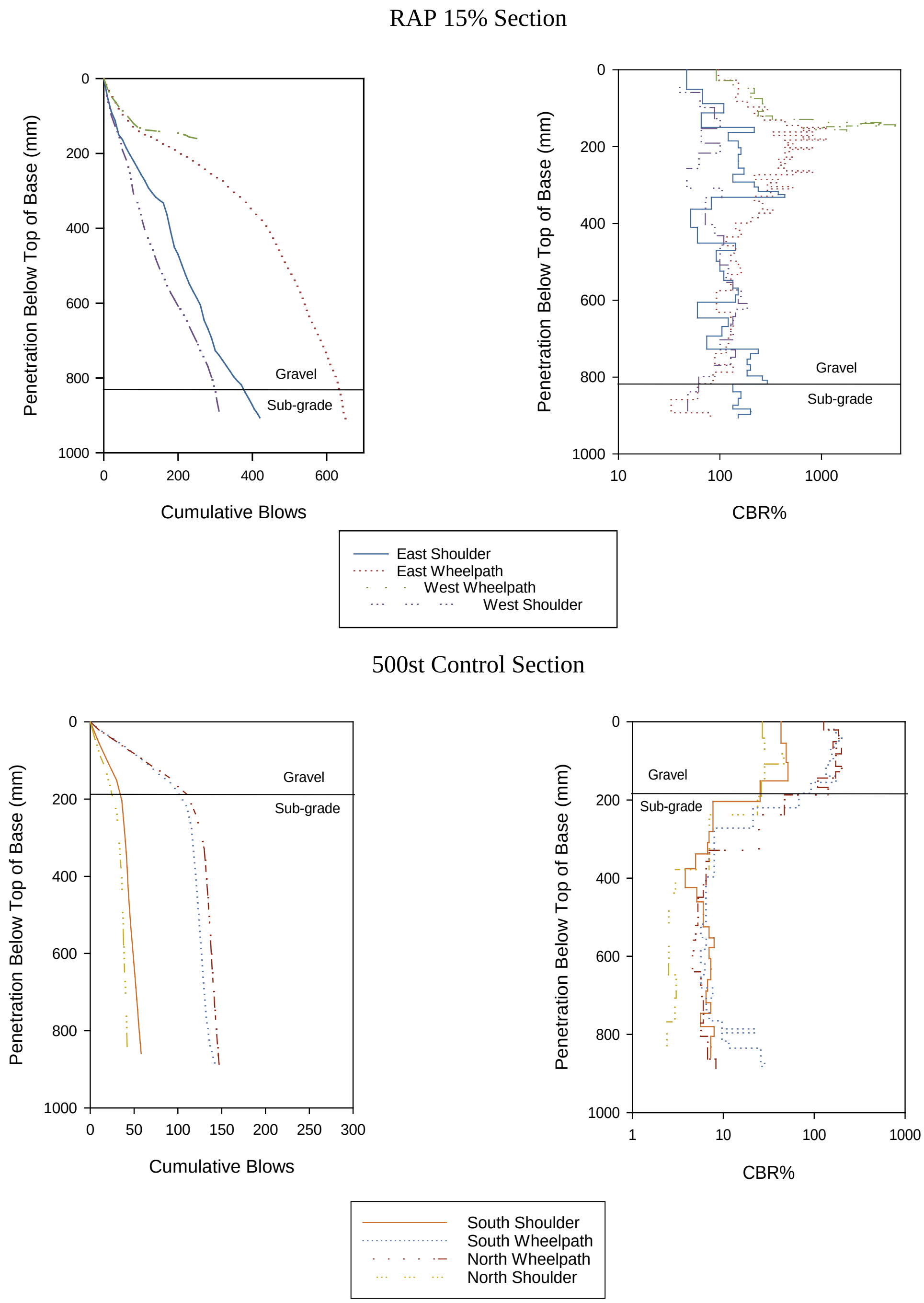


Figure 56. RAP 15% & 500st. control section DCP data (Goodhue County)

RAP 15% Section as shown above in Figure 56 was the hardest section that was encountered as repeated trials on this section failed and final readings was concluded with an incomplete west wheelpath reading. Whereas the control section 500st was normal comparatively.

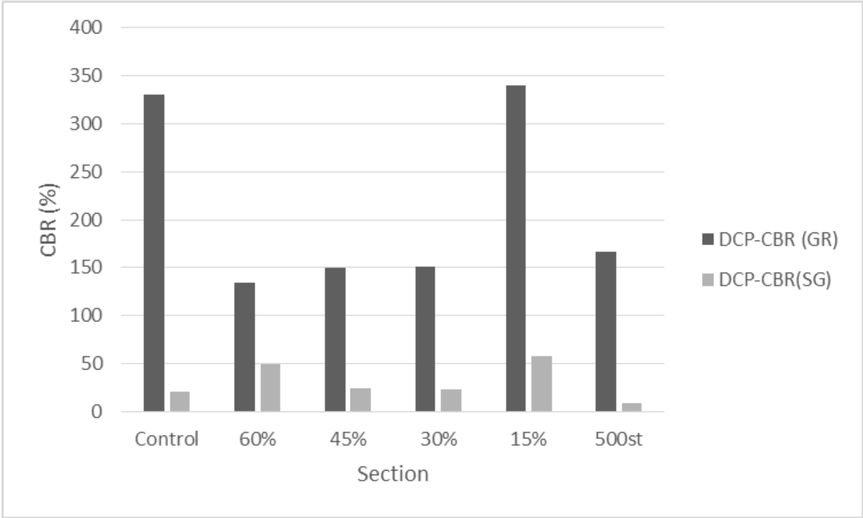


Figure 57. Avg. CBR Section-wise (Goodhue County)

Above in Figure 57 a comparative CBR chart is depicted by averaging gravel and subgrade CBR values and selecting the highest. It can be clearly seen that the gravel DCP-CBR (GR) values are more than subgrade DCP-CBR (SG) and also that, RAP 15% Section has the highest CBR and RAP 60% lowest. Carlton county DCP data is as shown below in Figure 58 and Figure 59. The 30% RAP section has the highest strength followed by the 50% RAP section and the control section.

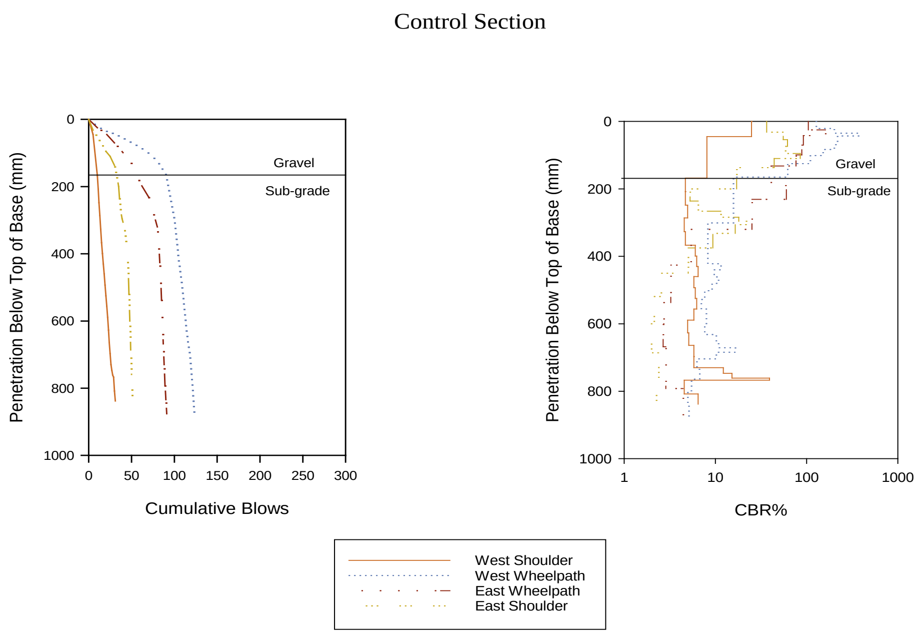
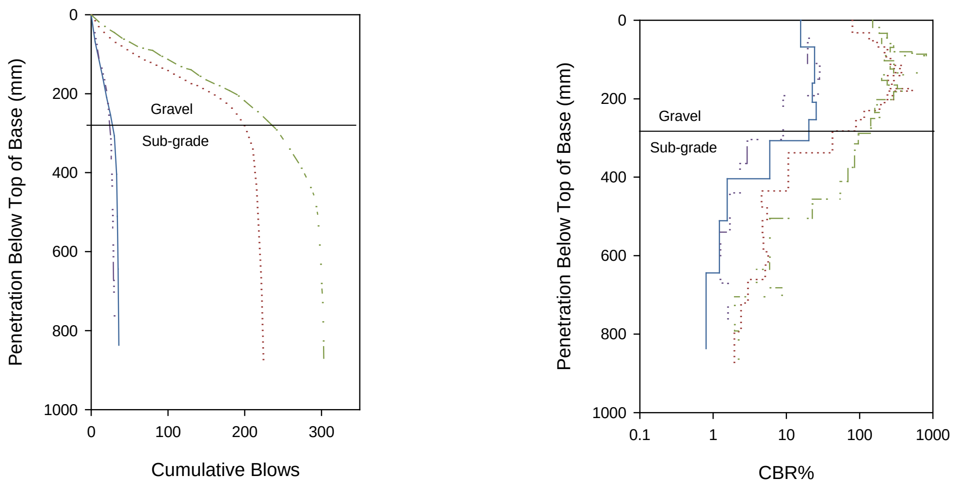


Figure 58. Control section DCP data (Carlton County)

RAP 30% Section



RAP 50% Section

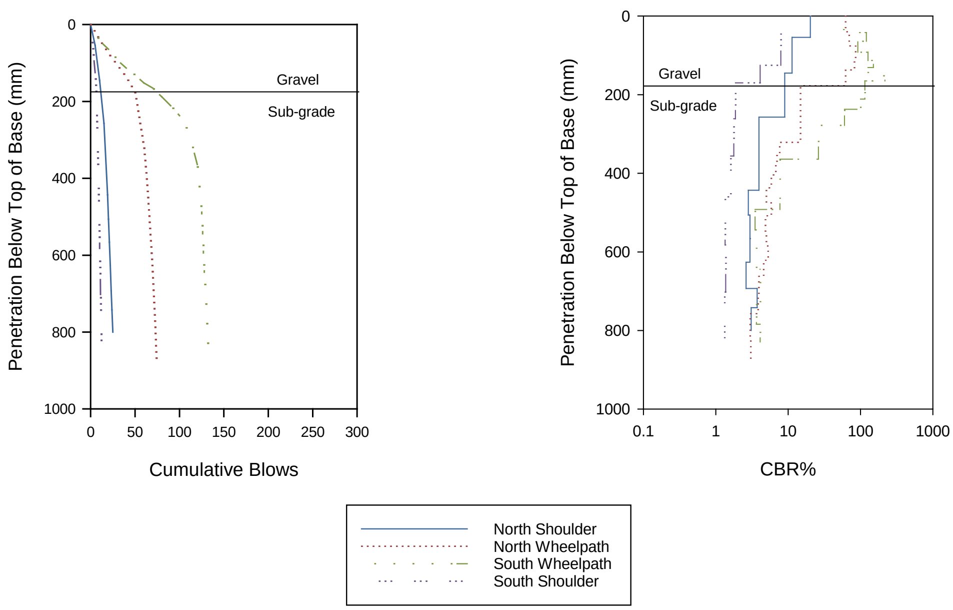


Figure 59. RAP 30% & RAP 50% section DCP data (Carlton County)

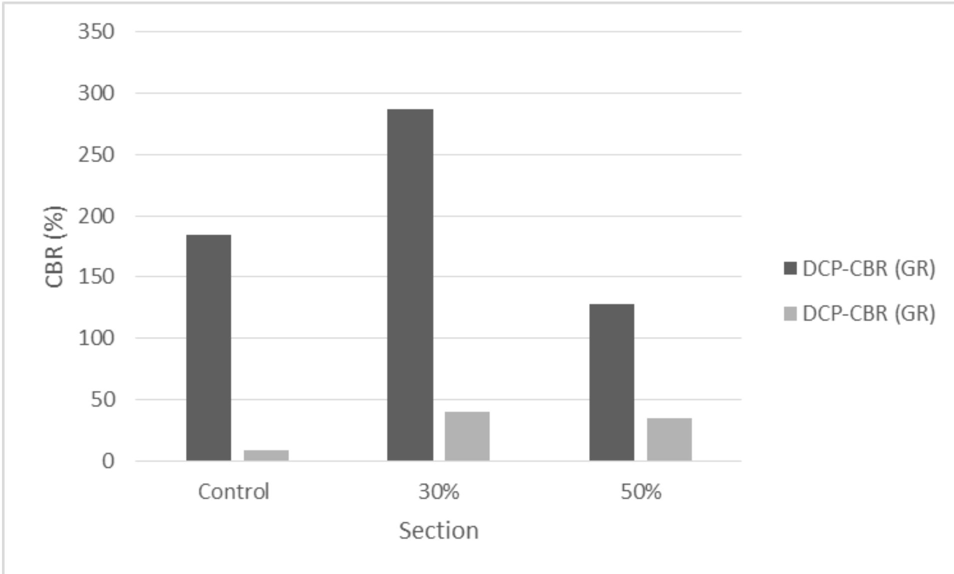


Figure 60. Avg. CBR Section-wise (Carlton County)

Here at Carlton County it is clear that the CBR values increases as the RAP content increases. Which is also seen the Figure 60 above, RAP 30% with the highest CBR values for both gravel DCP-CBR (GR) and subgrade DCP-CBR (SG) averages. And Control section with the lowest CBR values. This is contrary with the Goodhue County test section.

Roughness index (IRI)

At both Goodhue and Carlton Counties, the Roadroid mobile application was used to estimate the IRI values known as the eIRI. A car was driven on both sides of the road and average IRI value was calculated using the web application support by Roadroid. Here it is important to note that the eIRI serves as a comparative parameter for various sections as stated before in Chapter 3. A longitudinal profile of the test section is then generated to document the roughness of the sections. More detailed information on the sectional values such as the time stamp, co-ordinates and distances are available in Appendix C.

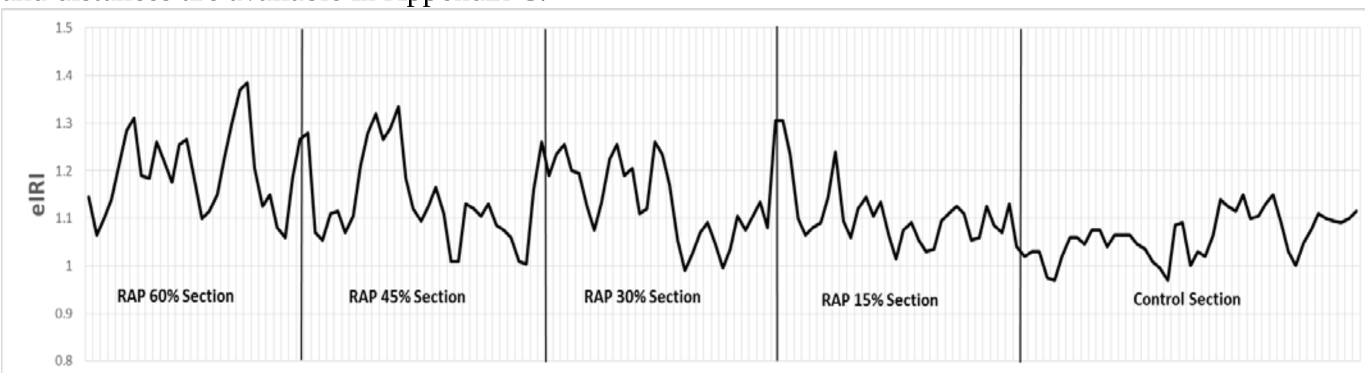


Figure 61. Avg. eIRI Longitudinal profile (Goodhue County)

As seen in Figure 61, the eIRI values tend to have more peaks in RAP sections then the control section. Whereas in Figure 62, the longitudinal profile for Carlton County test section is difficult to understand as the section lengths vary. Here as known the length of RAP 30% section is 0.7 mile and length of RAP 50% section is 0.3 mile.

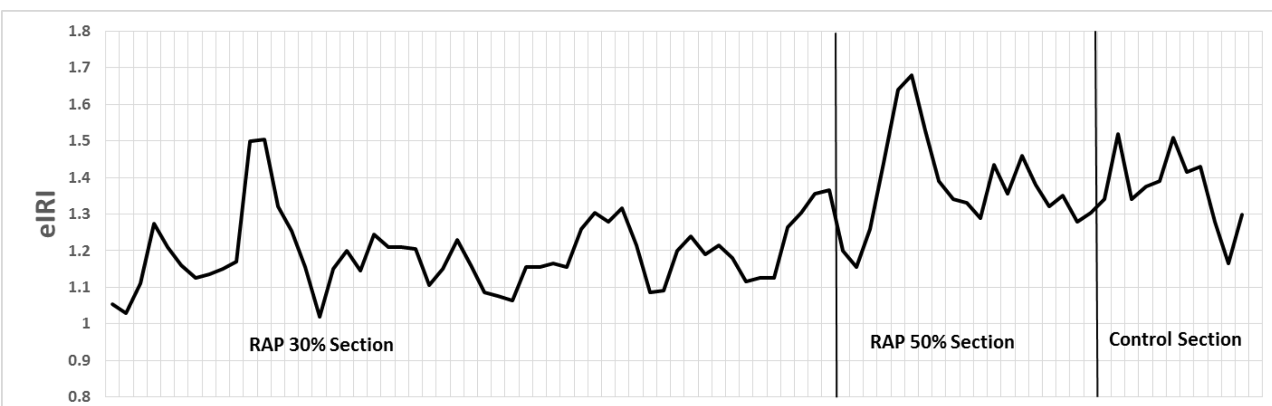


Figure 62. Avg. eIRI Longitudinal profile (Carlton County)

Overall, the Roadroid measurements an economical and efficient option to estimate IRI values for gravel roads. Road condition assessment is an important aspect of road health diagnosis and IRI values are in important part of that.

Dustometer data

Colorado State University (CSU) Dustometer (Koch, 2011) was used on both these sections to provide measurements that can be used to compare the amount of fugitive dust that is generated as traffic traverses the various test section surfaces. Dust is an important parameter that affects road performance as the fines from the road surface are uplifted in the form of dust by the turbulence created by moving vehicles and then deposited elsewhere, possibly on the shoulders or adjacent property. Without the fine binding material, larger particles in the middle of the road become loose, floating aggregate. This repetitive cycle degrades the road surface and increases required maintenance effort.

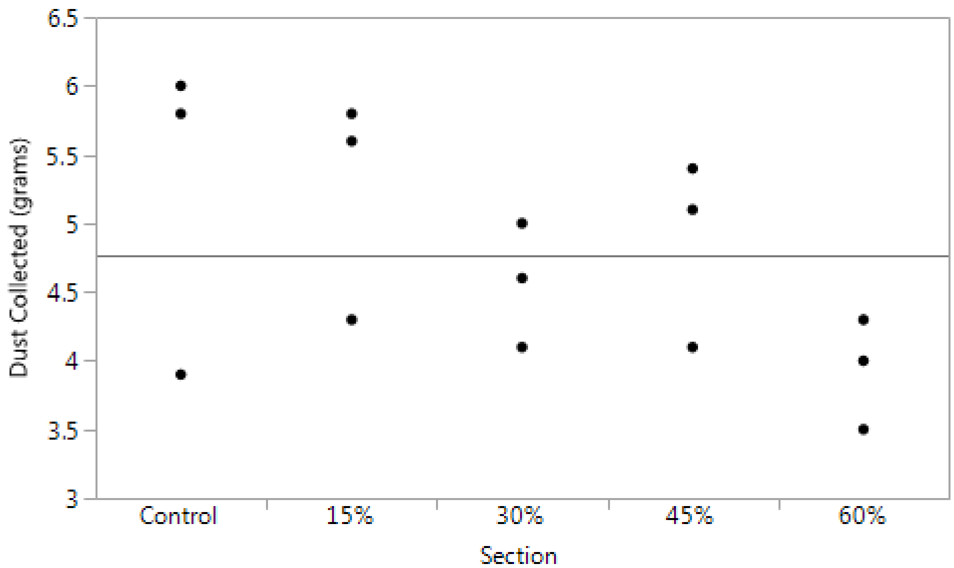


Figure 63. Dust collection per section (Goodhue County)

As shown in Figure 63, three runs were conducted on each section to complete one mile collection effort as required in the test procedure. The data suggest that there is a pattern in which dust reduction occurs as the percentage of RAP increases. Here only anomaly visible is 45% RAP section which indicated an increase in dust generation in comparison to the 30% RAP material. High variance is seen between the dust collection runs. Also a regression analysis was performed between percentage RAP and total dust collection per mile which gave an $R^2 = 0.73$ which indicates a correlation between these two variables.

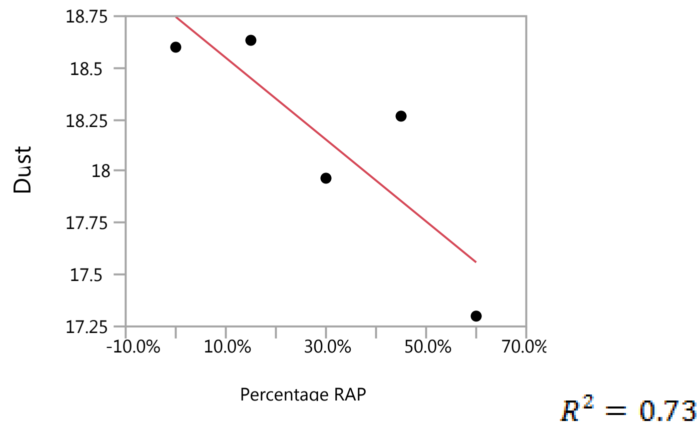


Figure 64. Goodhue County Regression plot (Dust Collected vs Percentage RAP)

Similarly Dustometer data from Carlton County supports the same finding. As shown in Figure 65 there is a noticeable reduction in dust as the RAP percentage increases and vice versa.

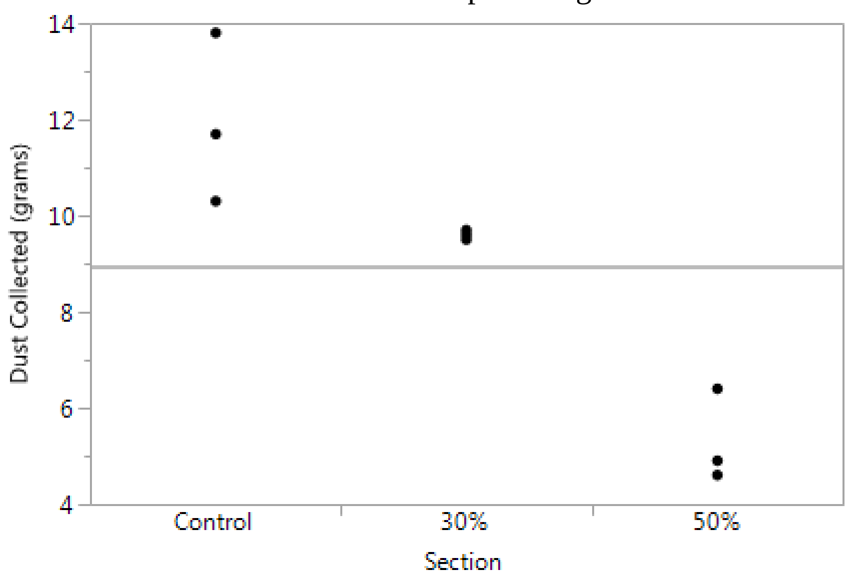


Figure 65. Dust collection per section (Carlton County)

Also the regression plot shown in Figure 66 gives a clear indication of the trend which calculates as $R^2 = 0.92$. This indicates strong evidence for a correlation between the dust amount and the percentage of RAP.

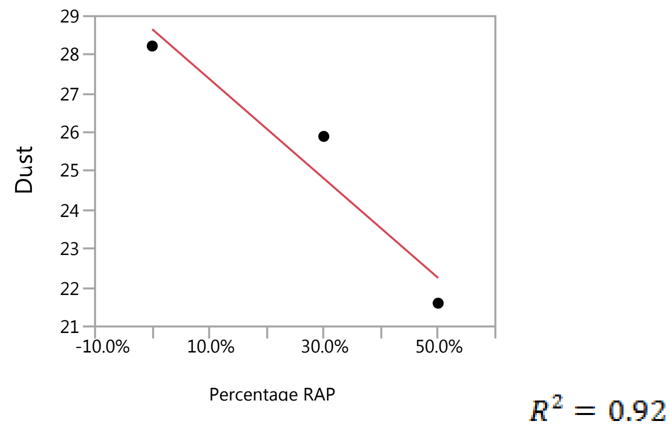


Figure 66. Carlton County Regression plot (Dust Collected vs Percentage RAP)

Study conducted by Wyoming DOT showed a significant dust reduction of almost 41% with no changes in serviceability to the gravel road (Koch, 2011). Whereas in our case the maximum dust reduction was recorded on Carlton County using 50% RAP i.e. approximately 28.57%.

Laboratory Testing

Sieve analysis

Sieve analyses were carried out on the materials that were used on both test sections. Gradation data shows how the proportion of various sizes of which the material is constituted, which is a deciding factor in road performance. For unpaved gravel roads, material availability and cost often limits options for improving the gradation. However, knowing the gradation can be the first step in identifying ways to recommend economical adjustments that may improve material performance.

Sieve analysis was first performed and then parameters such as coefficient of uniformity (Cu) and coefficient of curvature (Cc) were calculated and used to classify the material according to the unified soil classification system.

$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_c = \frac{(D_{30})^2}{D_{10} X D_{60}}$$

$$D_{10} = grain\ diameter\ at\ 10\%\ passing$$

$$D_{30} = grain\ diameter\ at\ 30\%\ passing$$

$$D_{60} = grain\ diameter\ at\ 60\%\ passing$$

For a gravel to be classified as well graded, the following criteria must be met:

$C_u > 4$ & $1 < C_c < 3$

If both of these criteria are not met, the gravel is classified as poorly graded or GP. If both of these criteria are met, the gravel is classified as well graded or GW.

For a sand to be classified as well graded, the following criteria must be met:

$C_u \geq 6$ & $1 < C_c < 3$

If both of these criteria are not met, the sand is classified as poorly graded or SP. If both of these criteria are met, the sand is classified as well graded or SW (Holtz, 1981). As shown below in Figure 67 all RAP material except 100% and 30% have gradations that are similar to that of the road rock material or control section material at Goodhue. One hundred percent RAP material is more course and 30% RAP material is finer in comparison to the road rock. Considering the likelihood that RAP particles might clump together because of the adhesion of the included binder, it can be understood that 100% RAP material would have a comparatively courser gradation.

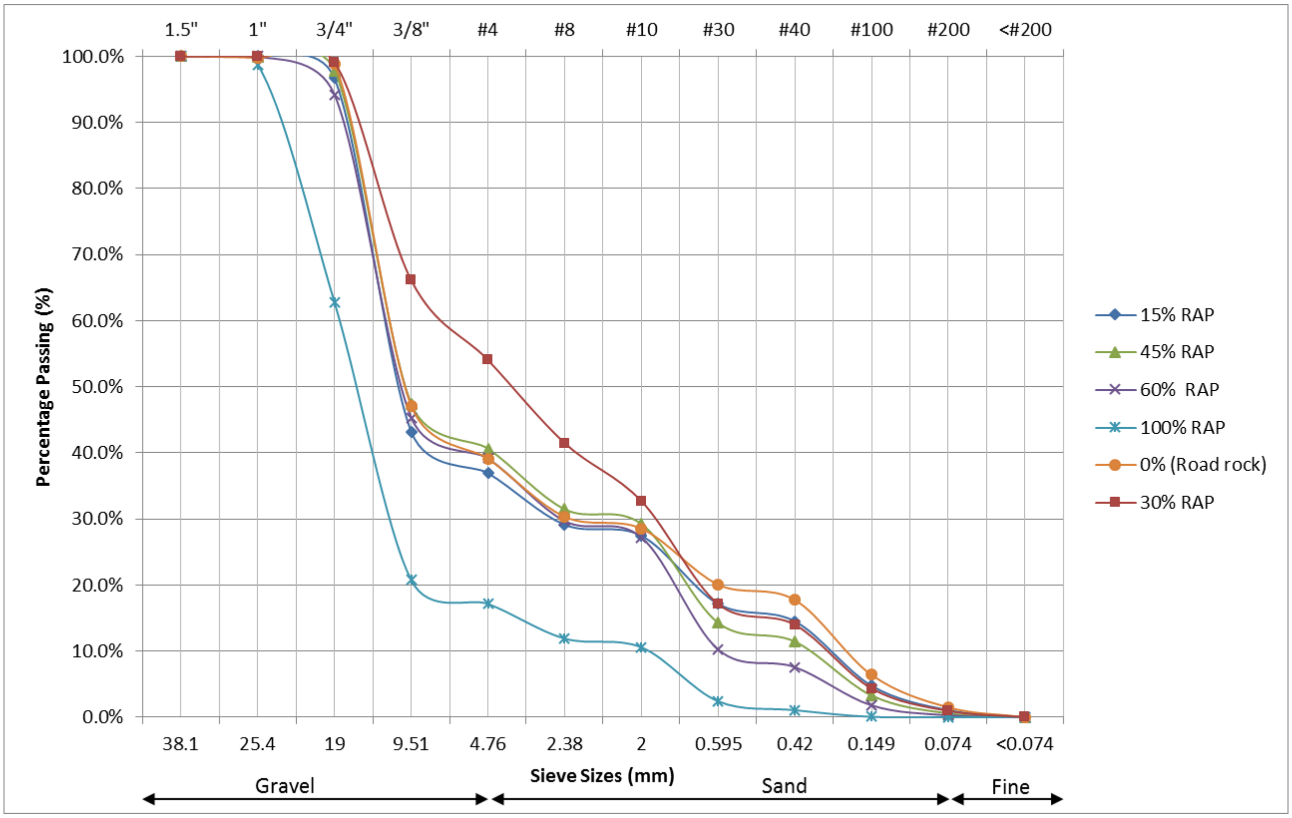


Figure 67. Combined gradation Goodhue County

Table 17. Soil Classification Goodhue County

Material	D60	D30	D10	Cu	Cc	Classification
15%	19.0	4.76	0.42	45.23	2.83	GW
30%	9.5	2.00	0.42	22.64	1.00	SW
45%	19.0	2.38	0.42	45.23	0.70	GP
60%	19.0	4.76	0.59	31.93	2.00	GW
100%	19.0	19.00	2.00	9.50	9.50	GP
0%(Road rock)	19.0	2.38	0.42	45.23	0.70	GP

Considering Table 17 above it can be said that 15% and 60% RAP are well graded gravel while 30% falls in as well graded sand.

Below in Figure 68 the combined gradation of the various Carlton County materials is provided. As expected 100% RAP is the coarsest of the four materials, whereas Class 5 material (denoted as 0%) is the finest.

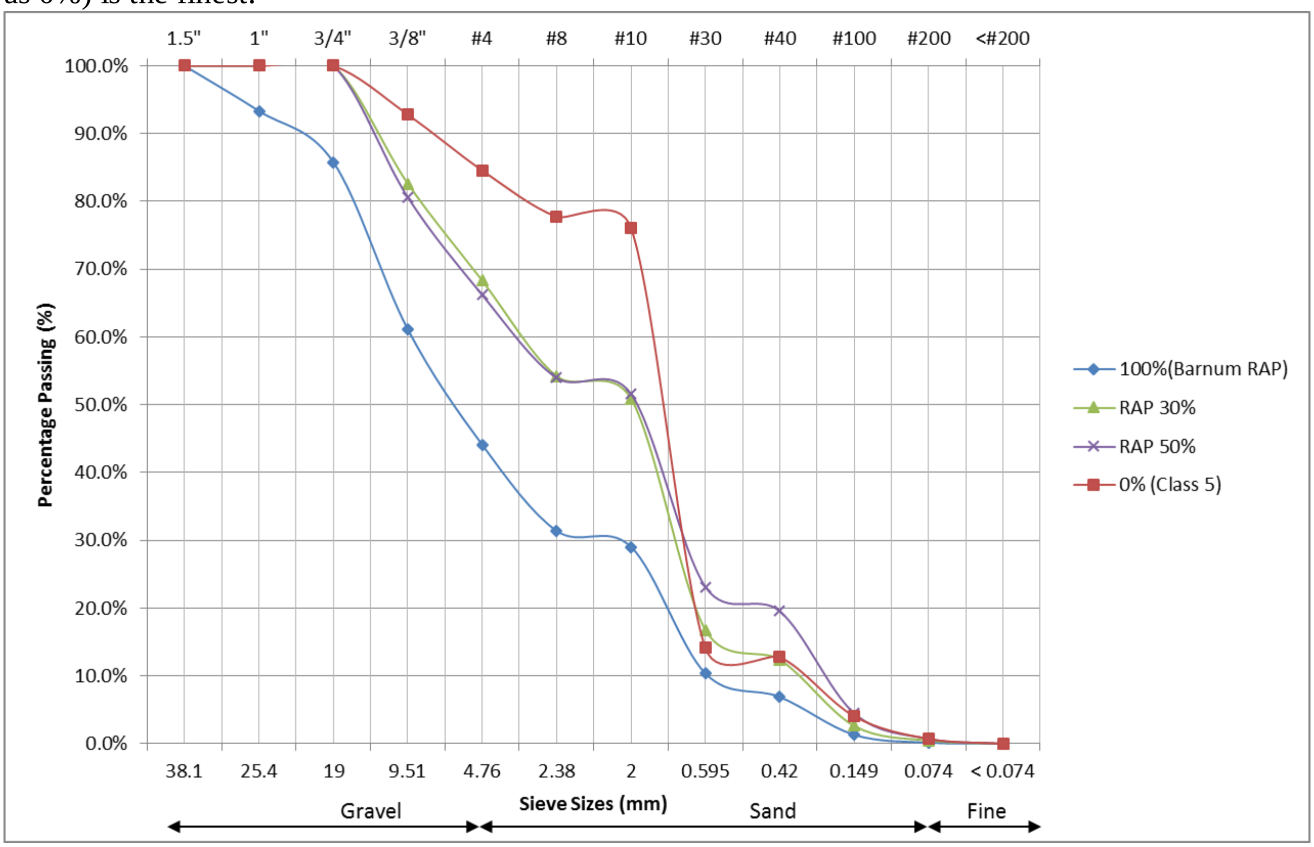


Figure 68. Combined gradation Carlton County

Also the soil classification data shown below in Table 18 shows RAP mixes (30% & 50%) as well graded sands and class 5 as poorly graded sand. Also the 100% RAP material is shown as well graded gravel.

Table 18. Soil classification Carlton County

Material	D60	D30	D10	Cu	Cc	Classification
100%(Barnum RAP)	9.51	2.38	0.59	15.98	1.00	GW
0%(Class 5)	2.00	2.00	0.42	4.76	4.76	SP
RAP 30%	4.76	2.00	0.42	11.33	2.00	SW
RAP 50%	4.76	2.00	0.42	11.33	2.00	SW

CBR Test

California bearing ratio (CBR) for different materials of both the counties was calculated using the laboratory method. Here we calculate material CBR values as compared to layered CBR as derived from DCP field test. This gives understanding of how the material might behave in a homogenous layer.

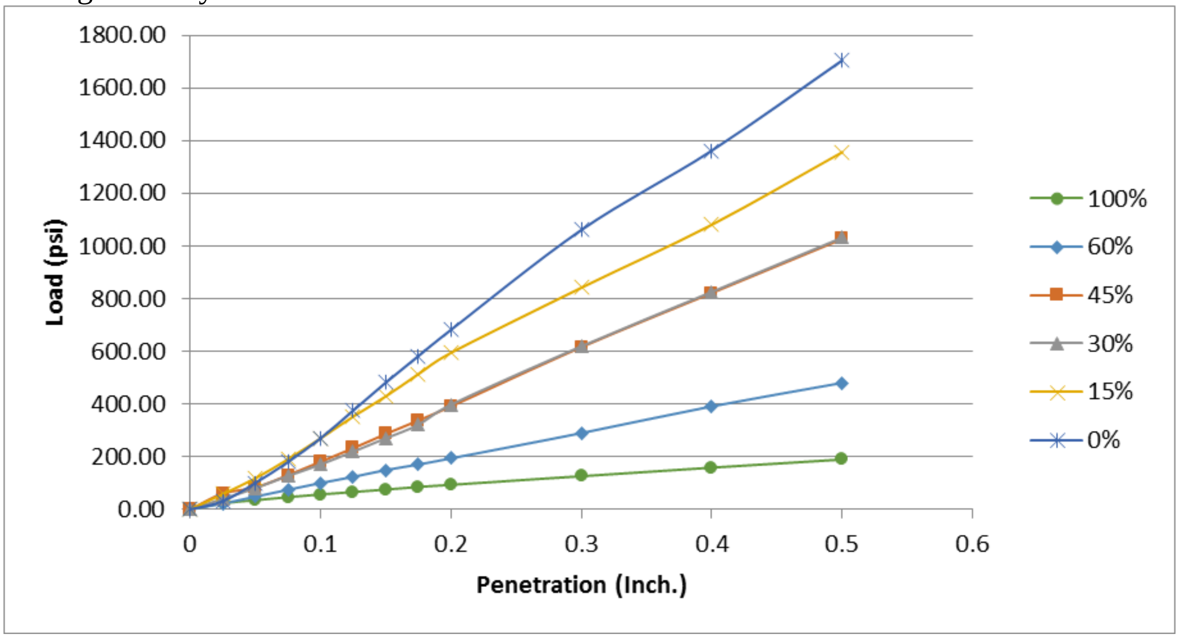


Figure 69. Laboratory CBR test Goodhue County (Load vs Penetration)

As seen above in Figure 69 all materials in the Goodhue County seem to follow a pattern whereas the percentage of RAP decreases the load bearing strength increases. Here it should be noted that 30% and 45% RAP have quite similar load bearing strengths. Also the comparative CBR shown in Figure 70 justifies this observation.

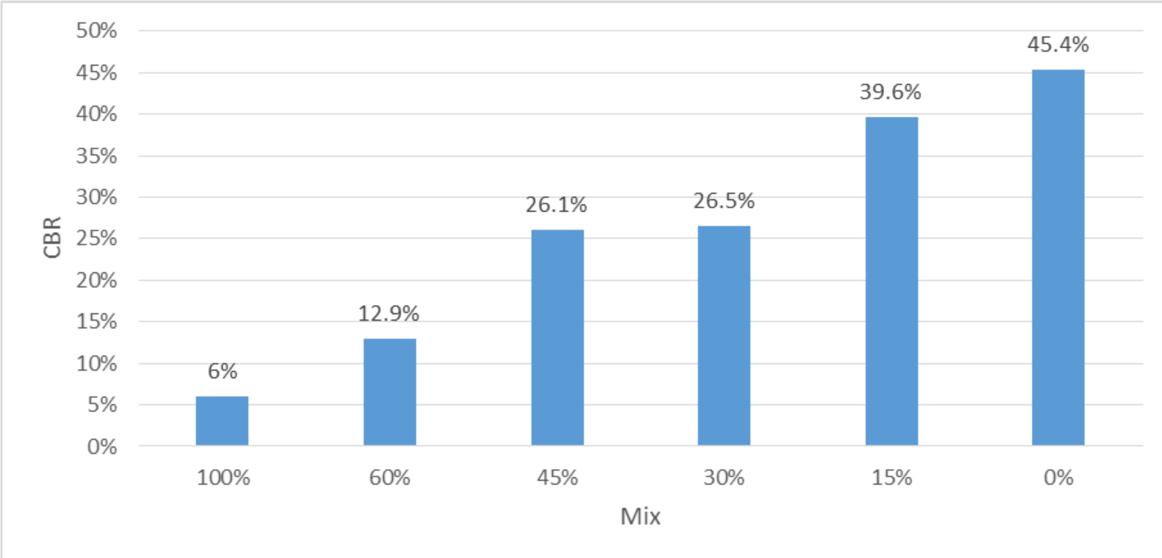


Figure 70. Comparative Laboratory CBR Goodhue County

This confirms finding from the literature review stating CBR decrease with RAP increase. However, Figure 71 and Figure 72 do not confirm the literature review findings as strongly: the 30% RAP has a higher CBR in comparison to 0% or 50% RAP materials. Here as expected 100% RAP has the lowest CBR but the 0% is below 30% and 50%. Still, when the previously mentioned gradation data is considered, such as when the 30% RAP is mixed with the Class 5 material that is available in Carlton County a well graded mix results which can be expected to increase the CBR. More detailed regarding dry unit weight and moisture content data of the CBR test in laboratory is available in Appendix C.

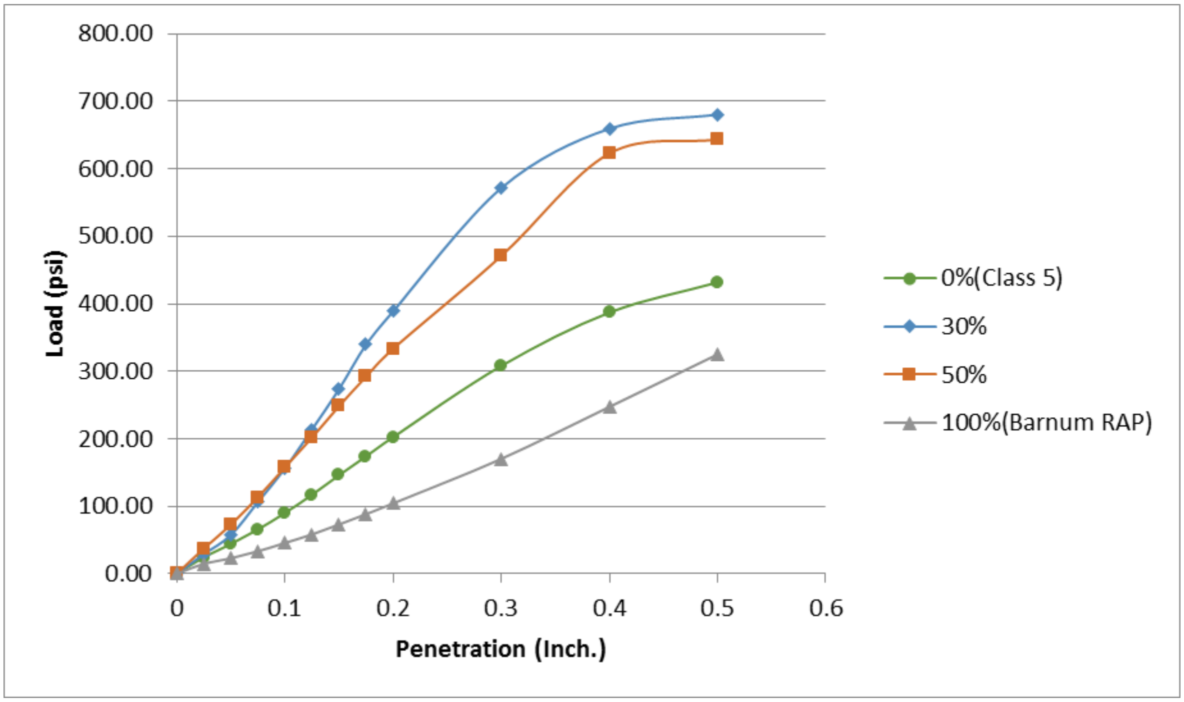


Figure 71. Laboratory CBR test Carlton County (Load vs Penetration)

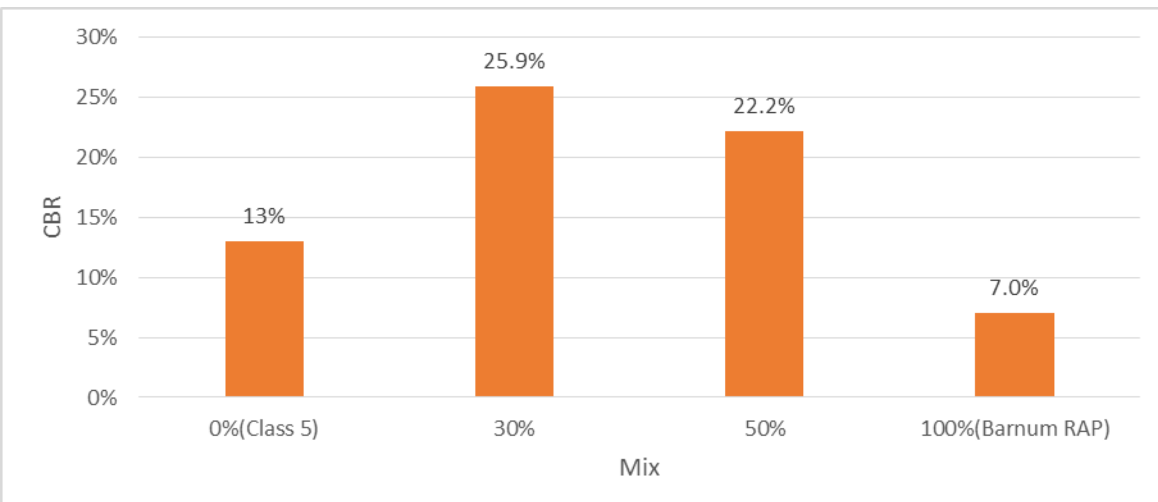


Figure 72. Comparative Laboratory CBR Carlton County

Moisture content

Goodhue county material is dry with the lowest moisture recorded for road rock material and highest for only RAP material as seen below.

RAP 15% - 0.3621%
RAP 30% - 0.1624%
RAP 45% - 0.5049%
RAP 60% - 0.5049%
RAP 100% - 0.5716%
Road rock – 0.2183%

In Carlton county materials highest moisture for 30% RAP was recorded and lowest for 100% RAP.
RAP 100% - 0.3563%
Class 5 - 3.8982%
RAP 30% - 4.0315%
RAP 50% - 3.9304%

Conventionally RAP should have lowest moisture and the moisture of the mixes should go on increasing as the RAP percentage goes on decreasing which is not seen in both the counties.

Binder Content

Goohue county materials with binder content was determined with the help of Ignition ovens stated below:
RAP 15% - 0.46%
RAP 30% - 1.06%
RAP 45% - 3.04%
RAP 60% - 3.68%
RAP 100% - 5.52%

Carlton county materials with respective binder content:

RAP 30% - 2.74%
RAP 50% - 4.54%
RAP 100% - 6.12%

Findings

The following was noted based on laboratory and field observations of the

- The amount of floating aggregate decreases as the percentage of RAP in the mix increases.
- The addition of RAP can [cause/exacerbate] rutting and wash boarding if the material it is mixed with is poorly graded sand and if the base is soft, based on the PASER ratings.
- Elastic modulus decreases as percentage of RAP in the mix increases.
- RAP can be used to improve the gradation of materials that lack large particle sizes, if the RAP gradation includes sufficient amounts of large particles.
- CBR decreases with increasing percentages of RAP; however, exceptions can occur if adding RAP improves the load carrying capacity of the resulting mixture.
- The typical moisture content increases with increasing RAP percentage up to 30% mix and then decreases with increasing RAP percentage.
- Measurements indicated the amount of dust generation reduce as the percentage of RAP in a road surface mixture increases.

CHAPTER 6: ECONOMIC AND FEASIBILITY ANALYSIS

Cost Analysis

In order to evaluate the economic feasibility of the alternative of using RAP on unpaved roads, it is necessary to understand an evaluation method that is suitable for such an analysis.

To simplify and normalize costs, it is assumed that the length of the road section is **1 mile** and that it will be constructed in **Goodhue County**. It is also assumed that that the project will not involve constructing a new road section but will only require maintaining the existing road section, thus excluding costs of land acquisition and other items required for new road construction.

Many studies have been performed to understand costs involved with maintaining a gravel road and not paving it. One such study suggested that if the annual average daily traffic (AADT) is more than 199 then paving should be considered for gravel or crushed rock roads (Jahren C.T., January 2005). So to develop an understanding and demonstrate the concept, MnDOT traffic data for County Road 52 Goodhue County was found (Figure 73) and then cross-referenced on a bar chart showing maintenance cost/mile by categories of traffic by AADT (Figure 74).

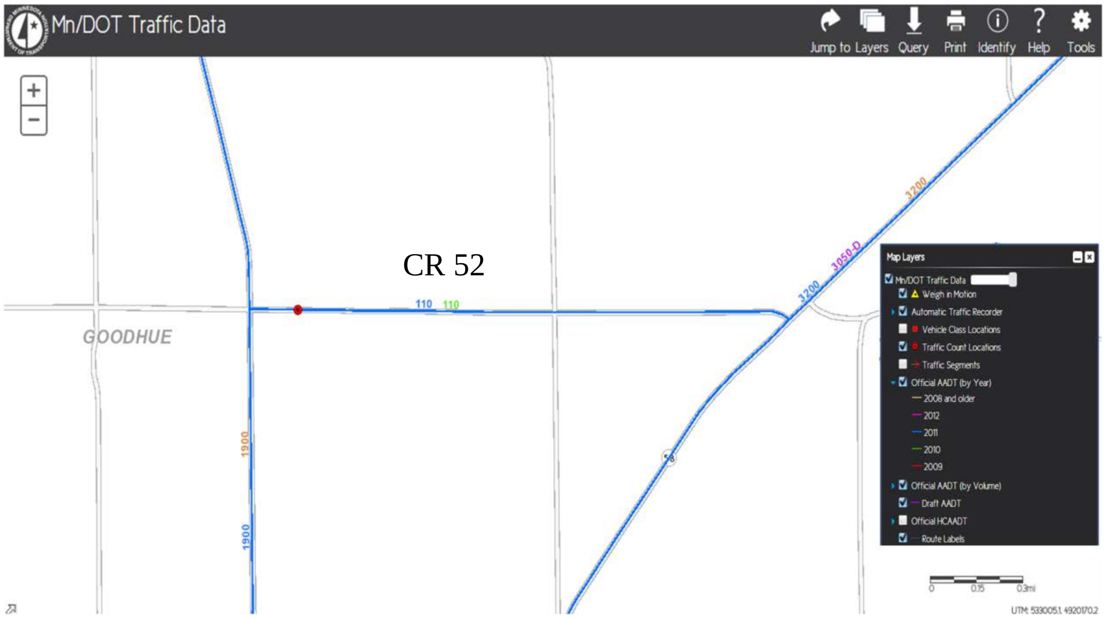


Figure 73. Online MnDOT traffic data portal

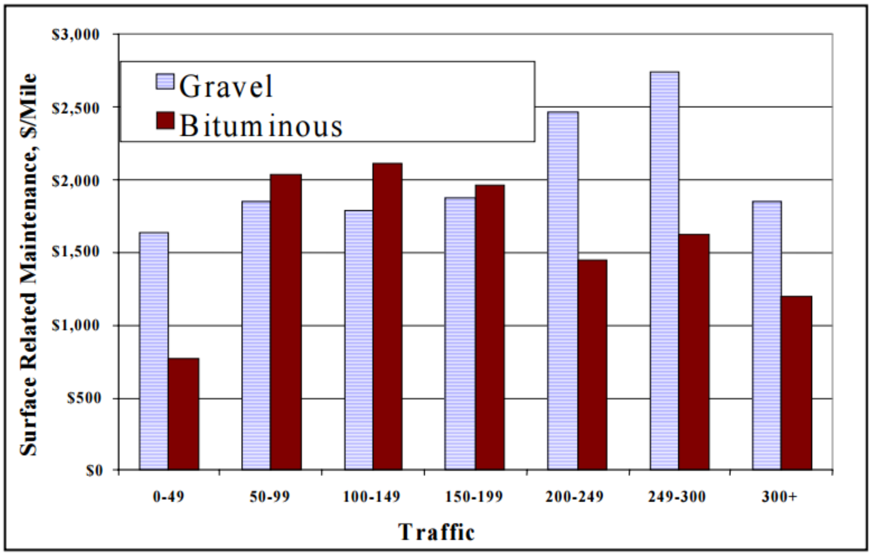


Figure 74. Maintenance Cost/mile categorized by traffic (Gravel vs Bituminous)

The report "Economics of Upgrading an Aggregate Road" (Jahren C.T., January 2005) outlines procedures on maintenance cost estimates. It provides an estimate of the cost of maintenance and improvements such as road construction for paving.

Maintenance Cost Estimates

For the cost estimates for gravel road maintenance, it is assumed that the roadway cross-section is as showninFigure3. The costs included ongoing grading activities and re- graveling every five years. Table1 provides a tabulation of the calculations.

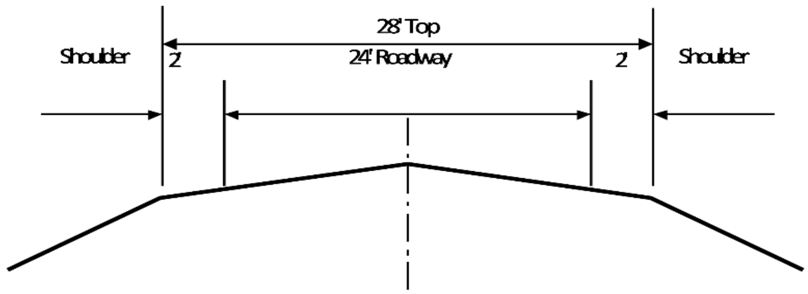


Figure 75. Typical Roadway Cross Section

Thefollowingcalculationsareforyearlymaintenancecostsforonemileofroad. It is assumed that routine grading activities are required each year and re-graveling is required every five years on a repeating cycle. The costs were provided by county personnel. The following includes a list of the assumptions made, and calculations of the motor grader work hours, maintaining/grading costs, and re- graveling/surfacing costs. Many aspects of these calculations are based on methods presented in the Caterpillar Performance Handbook (Caterpiller, 2015).

a)Assumptions

- A 24-foot top roadway one mile long: (24ft)(5280ft)=126,720ft2 of surface
- A nominal thickness of 2 inches of new gravel is assumed for re-graveling, which requires 1000yd3/mile or 1000 ton /mile
- The ratio of thickness of loose gravel to compacted gravel is 1.28:1; therefore, a 2 inch compacted gravel lift requires placement of 2.56 inches of loose gravel, (Skorseth K., 2000),pp. C1-C2.
- Based on conversation during interviews with county personnel, gravel costs approximately $7.00/cubic yard.
- The road is graved 3 times per month from April to October, for a total of 21 times
- The cost for the motor grader is $58/hr - including fuel, oil, etc.
- The motor grader travels at about 4 mph during grading operations
- Assume a 12 foot mold board wit carry angle of 60 degrees
- 3 passes of the motor grader are needed per mile
- Motor grader operator labor cost is $30/hr - includes fringe benefits
- The motor grader operating at a efficiency of a 45 minute-hour(0.75)

- This provides an additional allowance of 5 min per hour (40 minutes in an 8 hour day) for the time spent dead heading to and from, the maintenance are in addition to the standard allowance for unproductive construction equipment time of ten minutes per hour.
- Trucks at $40/hr - includes fuel, oil, etc.
- Truck capacity is 12 cubic yard
- Truck driver labor cost is $25/hr - includes fringe benefits
- Round trip for 1 load of material takes about 1.25 hours.

b) Calculation of Motor grader Work Hours

A = S x (Le – Lo) x 5280 x E

A: Hourly operating area (ft/hr)

S: Operating speed (mph) = 4mph

L_e: Effective blade length (ft) = 10.4ft (from Caterpillar Performance Handbook)

L_o: Width of overlap (ft) = 2.4 ft for 3 passes

E: Job efficiency = 0.75

$$A = 4m/hr \times (10.4\ ft - 2.4\ ft) \times 5280\ ft/mi \ \ \times 0.75$$
$$A = \ 126{,}720\ ft^2/hr$$

Time (t) to blade 1-mileroadwith24footwidetop:

$$t = \frac{SurfacingArea}{Motorgrader\ rate}$$

$$t = \frac{126{,}720\ ft^2}{126{,}720\ ft^2/hr} = 1.00\ hrs$$

Working at an efficiency of 0.75 and operating at 4 mph means the motor grader will take one pass on 3.0miles of road in one hour. If three passes are needed per mile of road, then the motor grader can cover 1.0 mile of road in one hour.

Blade 1-mile stretch of road 21 times throughout the year.

Time (T) =Annual time spent on 1-mile of roadway:

T = 1.00hrs./mile x 21miles = **21.0hours**

c) Maintaining/Grading Costs :(for 1year)

$$Equipment: \quad \$58/hr \times \$21.0\ hr = \$1218 \approx \$1200$$

$$Labor: \quad \$30/hr \times \$21.0\ hr = \$630 \approx \$600$$

Total: $1800/year

d) Re-graveling/Surfacing Costs: (done every 5 years, watering and compaction included)

$$Material: \$7.00/yd^3 \times 1000\ yd^3/mile = \$7000$$

$$Equipment: \#loads/mile = \frac{1\ load}{12\ yd^3} \times 1000\ yd^3/mile = 83.33 \approx 84\ loads$$

$$84\ loads \times 1.25\ hrs/load = 105\ hrs$$

$$105\ hrs \times \$58/hr = \$6000$$

$$Labor: \quad \$25/hr \times 105\ hrs = \$2625 \approx \$2600$$

Total re-graveling/surfacing costs = $7000+$6000+$2600 = $15600

Table 19 shows the primary cost for maintaining a gravel road, grading and resurfacing, for a five year re-graveling cycle. Notice that the majority of the cost associated with maintaining a gravel road occurs when gravel is hauled to the road for resurfacing. Depending on the equality of the gravel being used and the amount of gravel lost each year, this resurfacing operation may occur at different intervals for each county.

Table 19. Maintaining/Grading and Re-graveling/surfacing costs for five -year cycle

Year	1	2	3	4	5	6	Totals
Grading Equip.	$1200	$1200	$1200	$1200	$1200	$1200	$7200
Labor	$600	$617	$634	$651	$669	$688	$3851
Resurfacing Material	$7000					$7000	$14000
Equip.	$6000					$6000	$12000
Labor	$2600					$2981	$5581
Annual Totals	$17400	$1817	$1834	$1851	$1869	$17869	$42640
Cumulative Costs		$1817	$3651	$5502	$7371	$25240	

The cost of a typical five year maintenance cycle can be found by assuming the cost for years 2, 3, 4, 5 and 6 will be increasing considering wage increases from year 1 and obtaining $25240.

Please see that the average annual wage increase has been calculated as 2.8% annually. Assuming it as an arithmetic progression rate and not a geometric progression rate which is present normally. This wage increase includes inflation in it. Reference to this wage increase is Mercer, *2014/2015 US Compensation Planning Survey.*

The average annual cost can be calculated by dividing by five years. The result is $5048 per year.

If RAP is used to replace surfacing material, using the material cost per ton and percentage of surfacing material to RAP, a good comparison of the cost saving can be drawn as follows:

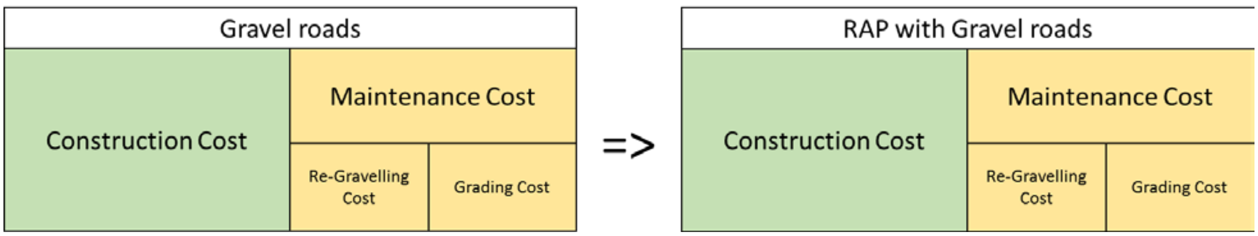


Figure 76. Cost comparison between conventional and RAP with gravel roads

Since some of the material costs and maintenance requirements for RAP roads are not currently known, a limited comparison of the two options side by side will be provided as outlined in Figure 76. Here it can be said that using RAP on gravel roads will only be more economically feasible than conventional gravel roads when the total cost of conventional gravel roads is equal to or greater than gravel roads with RAP. After the cost data from the construction and monitoring of test sections has been collected, it will be possible to provide a better comparison. In the case of 1000yd^{3,} if we use 200 yd^3 as RAP and 800yd^3 as regular gravel, it will represent 20%RAP roads.

$$\text{Material cost} = \$7*800yd^3 + \$7.65*200yd^3 = \$7,130$$

Cost of typical five-year maintenance cycle will be $25370 and average annual cost will be $5074.

A previous study involving the placement of processed recycled asphalt shingles (RAS) in test sections in Goodhue County (Thomas J. Wood, 2014) documented a noticeable amount of dust reduction for the RAS test sections. A dust reduction amount of approximately 30% and 60% was noted for these test sections which included two different amounts of RAS. This might have important implications with regard to the durability of the surface road, since the loss of fines, possibly caused by fugitive dust emission, can reduce the binding capacity and therefore the stability of the road surface, possibly resulting in excessive floating aggregate. Therefore, a reduction in fugitive dust emissions may ultimately increase the durability of the gravel or crushed rock road surface and eventually reduce the maintenance cost. It is difficult to quantify the amount of money that would be saved due to a possible reduction in maintenance before examining the performance of the test sections that will be built under this project. However, for this initial feasibility analysis, it is proposed to consider an expectedly conservative reduction of maintenance cost of 20%. If that consideration comes to pass, Option 2 would result in the cost for a typical five-year maintenance cycle to be $20,192 and the average annual cost would be $4,038.

If it is considered that there will be a 20% reduction in the maintenance cost, a cost for 20 % RAP can be incurred of up to $12.18/yd^3(more than $7/yd^3 that of gravel) in order to break even with the cost of conventional road construction or provide savings. There also would be other benefits that the agency won't recover monetarily such dust reduction for neighbors and road user comfort. As the information needed to perform a detailed cost benefit analysis was unavailable, a format for the same is provided below along with discussion about the details of two possible options. There was also insufficient data to perform a sensitivity analysis. Considering the amount of traffic that these gravel roads experience it is likely that gravel roads prove to be cost effective, but with the introduction of RAP the benefit /cost ratio will likely improve further.

A study conducted by Wyoming DOT evaluated three possible uses for RAP: RAP in Hot Plant Mix, RAP in base and RAP on gravel roads (Burt Andreen, 2011). A method developed by the National Asphalt Pavement Association was used. A new process was developed including factors such as savings from reducing materials loss by reducing dust loss, and having better layer coefficients, less hauling activity and decreased requirements for virgin aggregates because of having less dust loss. Based on the cost analysis, it was concluded that are savings of about $40.87/ton for RAP in Hot Plant mix, $17.07/ton for RAP on gravel roads and $15.71 for RAP in road base.

In a FHWA report (Mallick, 1997), the saving obtained by using various percentages of RAP are provided in Table 20.

Table 20: Savings vs RAP Percentage

%RAP	Cost/Ton	Savings $/Ton	Savings%
0%	11.90		
20%	10.26	1.64	14%
30%	9.44	2.46	21%
40%	8.62	3.28	28%
50%	7.80	4.10	34%

Above savings have been calculated by comparing the use of RAP with the use of virgin aggregate use on paved roads.
Overall direct savings and indirect benefits are achieved by the usage of RAP on gravel roads.

CHAPTER 7: ENVIRONMENTAL IMPACT

Using RAP on gravel roads raises questions about its environmental impact as large amount of RAP is spread out and exposed to the environment. Also there is possible concern that chemicals might leach for the RAP and affect ground or surface water. To measure the toxicity of RAP both as a stockpile and also as a fill material on roads many, studies have been performed, which indicate minimal or no environmental concern.
The toxicity characteristic leaching procedure (TCLP) leaching test performed on six RAP samples from various parts of Illinois met guidelines for maximum concentration of contamination under Resource Conservation and Recovery Act (RCRA) (Kriech, 1991). This study suggested that using RAP as a clean fill material is safe. Simialrly, another study was performed on six samples from around Florida which went under the Toxicity Characteristic Leaching Procedure (TCLP), Synthetic Precipitation Leaching Procedure (SPLP) and deionized water tests. The result indicated that the RAP possed minimal risk to groundwater as a result of pollutants leaching under normal land disposal screnarios (Townsend, 1998). The parameters that were considered included Volatile oraganic compounds(VOCs), Polycyclic aromatic hydrocarbons (PAHs) and selected heavy metals.

Other environmental benefits include room saved in landfills, transportaion cost and dust reduction.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

General Summary

The objective of this research project is to an understanding about how the use of various mixtures of gravel or crushed rock and RAP for road surfacing material affect the performance and economics of unpaved roads. The project commenced with a literature review that identified typical material properties for RAP and similar studies that described research regarding the use of RAP on unpaved roads. Next, a case study about the use of recycled asphalt shingles on a crushed rock road was undertaken, which provided insight regarding the behavior of asphalt binder from recycled materials with unpaved road surfacing materials. Then a lab test program was conducted to investigate testing procedures that could be used to analyze the properties of RAP and mixtures of RAP and various unpaved road surfacing materials. Using knowledge from the previous efforts, test sections were designed and constructed so that researchers could observe the actual performance of RAP and unpaved road surfacing materials. Finally field and lab test were conducted to assess the performance of the test sections.

Specific Research Findings

As a result of the previously mentioned activities the following specific research findings were identified:

- The case study regarding the shingles test sections indicated that the binder content affects the behavior of the mix and the section as a whole. TOSS sections having RAS exhibited better performance in comparison to the control section. Float was reduced by 40 to 50% and other properties such as stiffness and moisture retention were improved. So however, the test section with 12.50% binder content tended to perform better than the test section that had 36.13% binder content. This suggests that there may be an optimum binder content that may provide the best road performance.
- Lab RAP mixes follow the trend as mentioned in the literature review that CBR values of mixtures decrease with increases in RAP percentages in the mixes. But again for both MPLS RAP#1 and MPLS RAP#2 mixes CBR values decrease up to 40% mixture and then exhibit a modest increase for a 50% mixture.
- CBR tests on Goodhue County test section samples confirmed the convention found in the literature that the CBR decreases as RAP content increases. However, for Carlton County, CBR values exhibited an initial increase when RAP was added to road surfacing gravel mixture that was used for the test section. This particular road surfacing gravel was classified as a poorly graded sand, thus it appears that adding RAP can actually

improve the stability of the mixture by adding large particles to the gradation and increase the CBR values.

- The regression plots for both of the test sections indicates strong evidence for a correlation between the dust amount and the percentage of RAP.
  The maximum dust reduction recorded was 28% for a 50% RAP mixture in Carlton County.
- According to preliminary calculations, if there is a 20% reduction in the maintenance cost, an additional investment of up to $7/yd^3 can be made to add RAP to a mixture in order to break even between additional initial investment cost for road surfacing and reduced maintenance cost.
- The CBR was found to be the most appropriate test that might be used to evaluate various possible RAP and gravel or crushed rock mixtures for use as unpaved road surfacing material. Various other testing protocols were tried, but found to be unsatisfactory. Unconfined Compression test failed due to the non-cohesive nature of the mixtures. Proctor test to calculate optimal moisture content failed to come at a single point due to the inclusion of coarse particles in the mixture and the non-cohesive character of the mixture. And asphalt test such BBR and DSR were uninformative because the aged binder material that was associated with the RAP was too stiff to be measured by these methods.
- Use of new tools for road condition assessment like Roadroid proved helpful to understand the road profile roughness with convenience and ease.

Recommendations for Future Study

Pursuant to this research effort, the following recommendations are made

- A comparative study of the test sections built with recycled shingles and RAP should be undertaken in order to understand how fineness of the asphalt material affects dust emissions and road performance.
- An extensive assessment regarding the amount of floating materials should be undertaken on the test sections in order to record quantitative differences between the control and the treated test sections.
- Multiple years of observation of test sections is would be desirable in order to observe the effect of annual climatic and traffic variations as well as a few extreme events. This should include the collection of date regarding maintenance efforts and dust emissions. Also, the extent of amalgamation of asphalt material should be noted.

- As the thickness of the RAP mix layer on the test sections is limited to approximately 2 inches, undertaking alternative studies with thicker layers of RAP mixtures would be desirable.
- Consideration should be given to the development of Geographical Information System (GIS) based map that indicates the location of RAP stockpiles in order to calculate feasible hauling distances. Hauling costs may influence decisions regarding feasible percentages of RAP mixtures.
- To further observe the interaction of RAP with road surfacing materials and soils, the use of a Scanning Electron Microscope (SEM) should be investigated.
- As there are many variables involved in this investigation, network science might be implemented in order to better understand various cause and effect phenomenon with time as a variable An example of this is provided in Figure 77 which indicates how this concept could be used:
  Closeness/distances of the nodes indicate high/low correlation. With time as a system variable new nodes appear and disappear with time.

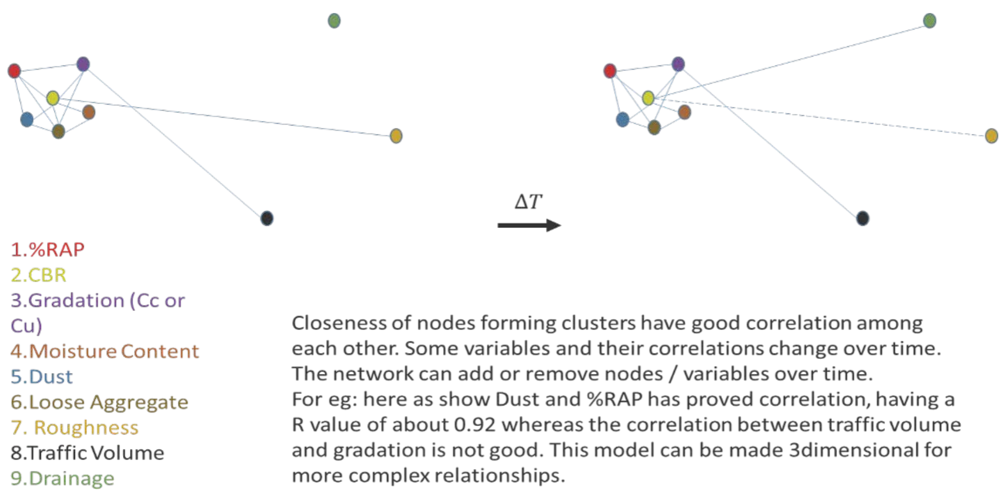


Figure 77. Analysis using Network Science

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APPENDIX A: CASE STUDY DATA

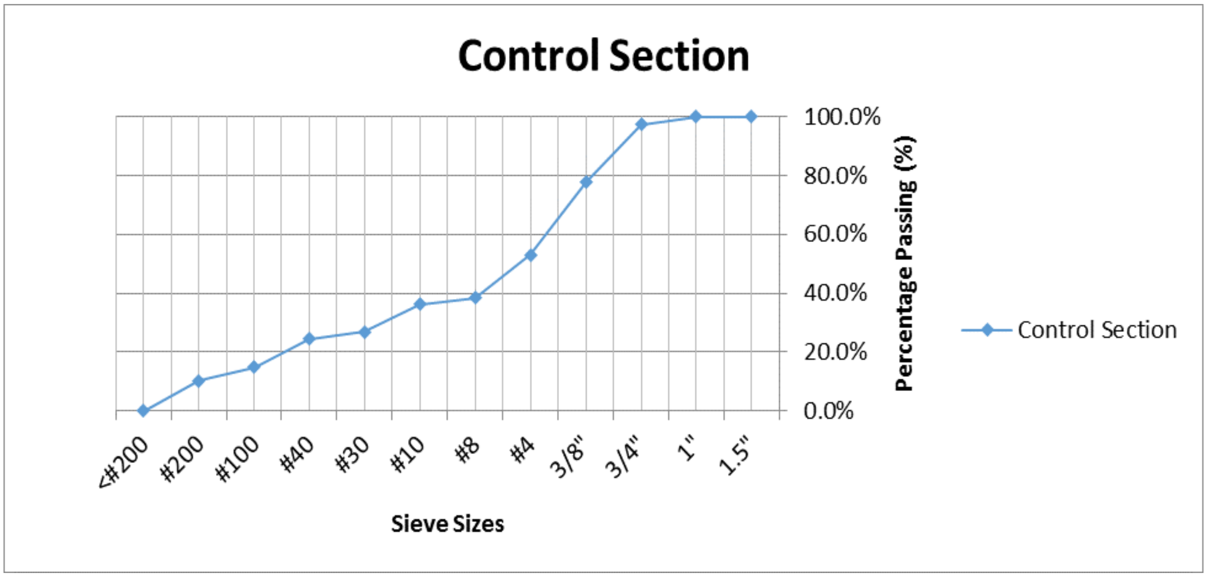
Sieve Analysis

1. Control Sections

Nominal Max Aggregate Size (mm)=	0.95
Sample Weight (g)=	4308.50
Pan Weight (g)	1475.80
Sieve less than #200	
After dry #1 (g)	5749.60
Gradation test	
After dry #2 (g)	5392.40
Material weight transferred into pan (g)	3913.30

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	116.20	116.20	2.7%	97.3%	19.00	3.8
3/8"	844.70	844.70	19.6%	77.7%	9.51	2.8
#4	1068.50	1068.50	24.8%	52.9%	4.76	2.0
#8	630.50	630.50	14.6%	38.3%	2.38	1.5
#10	88.30	88.30	2.0%	36.3%	2.00	1.4
#30	405.30	405.30	9.4%	26.9%	0.60	0.8
#40	104.20	104.20	2.4%	24.5%	0.42	0.7
#100	422.20	422.20	9.8%	14.7%	0.15	0.4
#200	196.00	196.00	4.5%	10.1%	0.07	0.3
<#200	393.00	393.00	10.1%	0.0%	0.01	0.1
Total (g)	3875.90	3875.90	100%			

% Gravel	Coarse Gravel	2.7%
	Fine Gravel	44.4%
% Sand	Coarse Sand	16.7%
	Medium Sand	11.8%
	Fine Sand	14.3%
% Fine	Silt and Clay	10.1%
Total		100.0%

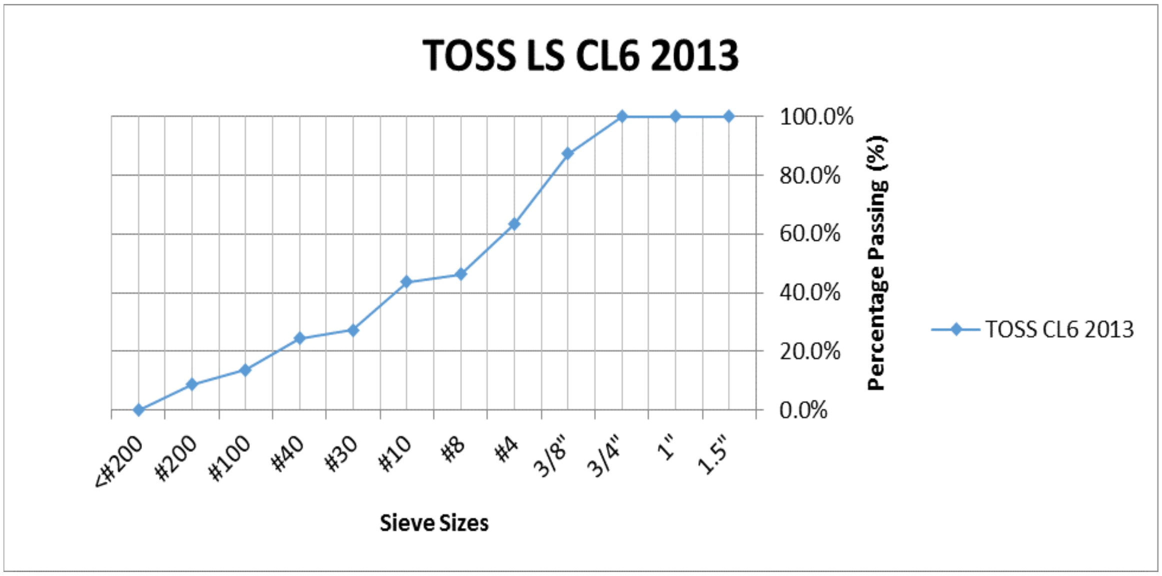


2. TOSS LS CL6 2013

Nominal Max Aggregate Size (mm)=	0.95
Sample Weight (g)=	4342.60
Pan Weight (g)	1506.40
Sieve less than #200	
After dry #1 (g)	5741.50
Gradation test	
After dry #2 (g)	5460.10
Material weight transferred into pan (g)	3997.90

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	0.00	0.00	0.0%	100.0%	19.00	3.8
3/8"	544.80	544.80	12.7%	87.3%	9.51	2.8
#4	1036.30	1036.30	24.1%	63.3%	4.76	2.0
#8	734.50	734.50	17.1%	46.2%	2.38	1.5
#10	108.90	108.90	2.5%	43.7%	2.00	1.4
#30	708.40	708.40	16.5%	27.2%	0.60	0.8
#40	122.60	122.60	2.8%	24.4%	0.42	0.7
#100	456.10	456.10	10.6%	13.8%	0.15	0.4
#200	222.10	222.10	5.2%	8.6%	0.07	0.3
<#200	339.90	339.90	8.6%	0.0%	0.01	0.1
Total (g)	3933.70	3933.70	100%			

% Gravel	Coarse Gravel	0.0%
	Fine Gravel	36.7%
% Sand	Coarse Sand	19.6%
	Medium Sand	19.3%
	Fine Sand	15.8%
% Fine	Silt and Clay	8.6%
Total		100.0%

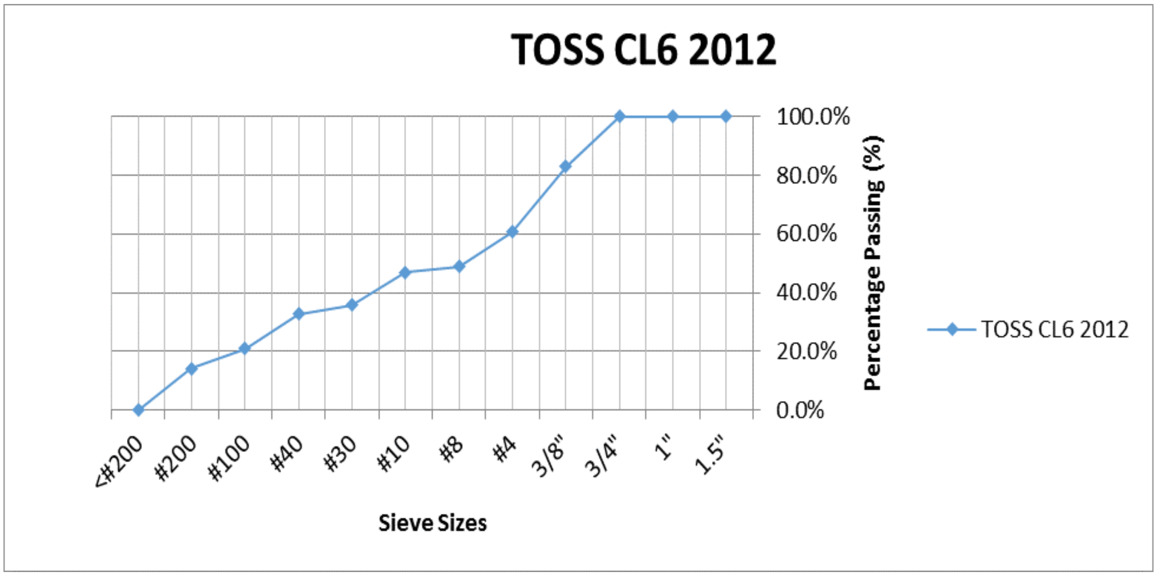


3. TOSS LS CL6 2012

Nominal Max Aggregate Size (mm)=	0.95
Sample Weight (g)=	4495.70
Pan Weight (g)	1480.50
Sieve less than #200	
After dry #1 (g)	5921.60
Gradation test	
After dry #2 (g)	5475.40
Material weight transferred into pan (g)	3990.70

U.S. Sieve Size	Weight Retained (g) #1	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	0.00	0.00	0.0%	100.0%	19.00	3.8
3/8"	773.90	773.90	17.1%	82.9%	9.51	2.8
#4	1003.90	1003.90	22.2%	60.7%	4.76	2.0
#8	534.50	534.50	11.8%	48.8%	2.38	1.5
#10	85.30	85.30	1.9%	46.9%	2.00	1.4
#30	507.00	507.00	11.2%	35.7%	0.60	0.8
#40	134.90	134.90	3.0%	32.7%	0.42	0.7
#100	531.40	531.40	11.8%	21.0%	0.15	0.4
#200	313.30	313.30	6.9%	14.1%	0.07	0.3
<#200	545.80	545.80	14.1%	0.0%	0.01	0.1
Total (g)	3884.20	3884.20	100%			

% Gravel	Coarse Gravel	0.0%
	Fine Gravel	39.3%
% Sand	Coarse Sand	13.7%
	Medium Sand	14.2%
	Fine Sand	18.7%
% Fine	Silt and Clay	14.1%
Total		100.0%



Roughness Index

1. 7/31/2014

cIRI-constant: 1.5

DateTime	Latitude	Longitude	Distance(m)	Distance(m)	Altitude (m)	eIRI	cIRI
7/31/2014 15:04	44.441447	-92.61757531	TOSS CL6 2012 (0.2)	20	322.4	1.61	1.33
7/31/2014 15:04	44.44144206	-92.61798015		40	323.78	1.21	1.14
7/31/2014 15:04	44.44144034	-92.61808		60	325.4	1.27	0.75
7/31/2014 15:04	44.44143328	-92.61856383		80	326.92	1.25	0.68
7/31/2014 15:04	44.44143198	-92.61868663		100	327.55	1.1	0.84
7/31/2014 15:04	44.44143116	-92.61880942		120	327.59	1.04	0.94
7/31/2014 15:04	44.441431	-92.6192962		140	327.28	1.12	0.82
7/31/2014 15:04	44.441431	-92.61940897		160	327.09	1.09	0.84
7/31/2014 15:04	44.441431	-92.61951774		180	326.65	1.13	0.89
7/31/2014 15:04	44.4414304	-92.61997352		200	326.17	1.18	0.94
7/31/2014 15:04	44.44143	-92.62007029		220	325.47	1.2	0.88
7/31/2014 15:04	44.441431	-92.62052107		240	324.47	1.19	1.11
7/31/2014 15:04	44.4414313	-92.62062385		260	323.51	1.06	1.19
7/31/2014 15:04	44.441432	-92.62108662		280	322.73	1.13	0.82
7/31/2014 15:04	44.44143246	-92.6211834		300	322.26	1.25	0.99
7/31/2014 15:04	44.441433	-92.62127617		320	321.57	1.49	1.36
7/31/2014 15:04	44.44143353	-92.62170995	TOSS CL6 2013(0.4)	340	320.86	1.39	1.77
7/31/2014 15:04	44.441434	-92.62180072		360	320.18	1.23	1.3
7/31/2014 15:05	44.44143341	-92.6222325		380	319.59	1.11	0.93
7/31/2014 15:05	44.441433	-92.62233827		400	319.02	1.13	0.79
7/31/2014 15:05	44.44143671	-92.62283607		420	318.13	1.15	0.78

7/31/2014 15:05	44.44143841	-92.62294389		440	317.16	1.42	0.88
7/31/2014 15:05	44.44144395	-92.62336871		460	316.38	1.53	0.95
7/31/2014 15:05	44.44144504	-92.62346351		480	315.92	1.26	0.98
7/31/2014 15:05	44.44144604	-92.6235543		500	315.58	1.14	0.74
7/31/2014 15:05	44.441448	-92.62395308		520	314.93	1.29	0.79
7/31/2014 15:05	44.44145292	-92.62436591		540	314.05	1.23	1.03
7/31/2014 15:05	44.44145444	-92.62445473		560	313.37	1.26	1.19
7/31/2014 15:05	44.44145601	-92.62454355		580	312.5	1.5	1.05
7/31/2014 15:05	44.44146101	-92.62496536		600	311.62	1.57	1.22
7/31/2014 15:05	44.44146598	-92.62537616		620	311.06	1.65	1.23
7/31/2014 15:05	44.44146695	-92.62545797		640	310.45	1.61	1.05
7/31/2014 15:05	44.44147297	-92.62588281		660	309.94	1.46	0.94
7/31/2014 15:05	44.44147451	-92.62596963		680	309.6	1.53	0.94
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7/31/2014 15:05	44.44149811	-92.62832962		880	309.69	1.2	0.79
7/31/2014 15:05	44.44150319	-92.62876343		900	309.62	1.09	0.8
7/31/2014 15:05	44.44150413	-92.62885622		920	309.65	1.2	0.82
7/31/2014 15:05	44.44150768	-92.62929502		940	309.68	1.3	0.81
7/31/2014 15:05	44.44151344	-92.6298476		960	309.56	1.25	1.12
7/31/2014 15:05	44.44151482	-92.62995443		980	309.52	1.08	1.06
7/31/2014 15:05	44.44151598	-92.63006421		1000	309.36	1.11	0.76
7/31/2014 15:05	44.441514	-92.63055399		1020	309.11	1.11	0.74
7/31/2014 15:05	44.44151433	-92.63067877		1040	308.71	1.19	0.8
7/31/2014 15:05	44.44151402	-92.63116854		1060	308.17	1.25	0.68
7/31/2014 15:05	44.44151277	-92.63128632		1080	307.7	1.14	0.86
7/31/2014 15:05	44.44151284	-92.63141114		1100	306.87	1.05	0.97
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7/31/2014 15:05	44.44151762	-92.63204071		1140	305.31	1.07	0.73
7/31/2014 15:05	44.44151825	-92.63215749		1160	304.45	1.15	0.65
7/31/2014 15:06	44.44152463	-92.63263732		1180	303.73	1.12	0.7
7/31/2014 15:06	44.44152651	-92.63275216		1200	303.31	1.07	0.72
7/31/2014 15:06	44.44152841	-92.632868		1220	302.68	1.09	0.78
7/31/2014 15:06	44.44153532	-92.63335381	Control Section	1240	301.88	1.03	0.87

2. 8/9/2014

cIRI-constant: 1.5

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8/9/2014 13:46	44.44143782	-92.61828207		60	322.66	1.55	1.54
8/9/2014 13:46	44.44143853	-92.61838889		80	322.73	1.49	1.87
8/9/2014 13:46	44.44143888	-92.61849367		100	322.92	1.47	1.77
8/9/2014 13:46	44.44143553	-92.61896546		120	323.02	1.56	1.73
8/9/2014 13:46	44.44143463	-92.61908325		140	322.89	1.53	1.65
8/9/2014 13:46	44.441434	-92.61920902		160	322.06	1.51	1.61
8/9/2014 13:46	44.441434	-92.61974679		180	320.94	1.45	1.59
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8/9/2014 13:46	44.44143136	-92.62006237		220	319.77	1.59	1.75
8/9/2014 13:46	44.4414299	-92.62022315		240	319.12	1.77	2.01
8/9/2014 13:46	44.44142808	-92.62081493		260	318.46	1.77	1.88
8/9/2014 13:46	44.44142726	-92.62099171		280	318.08	1.67	1.8
8/9/2014 13:46	44.44142756	-92.62116748		300	317.72	1.67	1.51
8/9/2014 13:47	44.441428	-92.62133626		320	317.36	1.75	1.67
8/9/2014 13:47	44.44142823	-92.62149105	TOSS CL6 2013 (0.4)	340	316.8	2.05	2
8/9/2014 13:47	44.44143017	-92.62201983		360	316.2	2.26	2.07
8/9/2014 13:47	44.44143051	-92.62214761		380	315.73	1.94	1.63
8/9/2014 13:47	44.44143082	-92.62227639		400	314.85	1.69	1.64
8/9/2014 13:47	44.44143021	-92.62275217		420	314	1.82	1.92
8/9/2014 13:47	44.44143	-92.62284495		440	313.39	1.59	1.84
8/9/2014 13:47	44.44142632	-92.62326874		460	312.8	1.62	1.98
8/9/2014 13:47	44.441426	-92.62336254		480	312.23	1.7	2.12
8/9/2014 13:47	44.44142506	-92.62380331		500	311.83	1.71	1.84
8/9/2014 13:47	44.441425	-92.62389109		520	311.73	1.98	2.07
8/9/2014 13:47	44.4414298	-92.62429789		540	311.72	2.07	1.57
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8/9/2014 13:47	44.44144862	-92.62620145		700	307.32	2	2.01
8/9/2014 13:47	44.44144919	-92.62627328		720	306.63	1.81	1.91
8/9/2014 13:47	44.44145407	-92.62667907		740	306.2	1.53	1.46

8/9/2014 13:47	44.44145502	-92.62675986		760	306.25	1.61	1.46
8/9/2014 13:47	44.44145904	-92.62717567		780	306.32	1.76	1.62
8/9/2014 13:47	44.44146004	-92.62725947		800	306.35	1.53	1.59
8/9/2014 13:47	44.44146504	-92.62767828		820	306.35	1.46	1.53
8/9/2014 13:47	44.44146602	-92.62776207		840	306.32	1.57	1.48
8/9/2014 13:47	44.44147001	-92.62817588		860	306.21	1.64	1.1
8/9/2014 13:47	44.441474	-92.62859167		880	306.15	1.65	1.55
8/9/2014 13:47	44.44147496	-92.62867048		900	306.16	1.5	1.56
8/9/2014 13:47	44.44147985	-92.62906429		920	306.14	1.51	1.43
8/9/2014 13:47	44.44148186	-92.62912224		940	306.01	1.56	1.45
8/9/2014 13:47	44.44149168	-92.62948725		960	305.86	1.61	1.39
8/9/2014 13:47	44.44149224	-92.62955805		980	305.76	1.85	1.56
8/9/2014 13:47	44.44149713	-92.62995386		1000	305.64	2.27	1.83
8/9/2014 13:47	44.44149801	-92.63002565		1020	305.46	1.97	1.5
8/9/2014 13:47	44.44150193	-92.63042346		1040	304.98	1.68	1.8
8/9/2014 13:47	44.441502	-92.63084425		1060	304.29	2.15	2.19
8/9/2014 13:47	44.44150249	-92.63093402		1080	303.64	2.1	2.19
8/9/2014 13:47	44.44150307	-92.6310338		1100	302.52	1.72	2.25
8/9/2014 13:48	44.441505	-92.63152258		1120	301.34	1.98	2.02
8/9/2014 13:48	44.441505	-92.63166035		1140	300.5	2.17	1.7
8/9/2014 13:48	44.44150518	-92.63181013		1160	299.64	1.89	1.3
8/9/2014 13:48	44.441506	-92.6319829		1180	298.52	1.6	1.87
8/9/2014 13:48	44.44150683	-92.63258168		1200	297.48	1.57	2.51
8/9/2014 13:48	44.441507	-92.63274545		1220	296.9	1.77	2.31
8/9/2014 13:48	44.44150742	-92.63291223	Control Section	1240	296.39	1.82	1.81

APPENDIX B: LAB TEST PROGRAM DATA

Sieve Analysis Data

	MPLS RAP#1
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	5056.00
Pan Weight (g)	356.70
Sieve less than #200	
After dry #1 (g)	5406.30
Gradation test	
After dry #2 (g)	5331.70
Material weight transferred into pan (g)	4981.10

Location: Asphalt Company

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	164.90	164.90	3.3%	96.7%	25.40	4.3
3/4"	199.70	199.70	3.9%	92.8%	19.00	3.8
3/8"	1060.70	1060.70	21.0%	71.8%	9.51	2.8
#4	983.20	983.20	19.4%	52.4%	4.76	2.0
#8	763.00	763.00	15.1%	37.3%	2.38	1.5
#10	151.90	151.90	3.0%	34.3%	2.00	1.4
#30	1040.00	1040.00	20.6%	13.7%	0.60	0.8
#40	242.70	242.70	4.8%	8.9%	0.42	0.7
#100	319.10	319.10	6.3%	2.6%	0.15	0.4
#200	50.00	50.00	1.0%	1.6%	0.07	0.3
<#200	79.70	79.70	1.6%	0.0%	0.01	0.1
Total (g)	4975.20	4975.20	100%			
	4980.30					
Loss	0.80					

Soil Classification
Coarse Gravel Soil
Less than 50% passes No. 200 Sieve
Sands
50% or more of coarse fraction passes No.4 sieve
Clean Sands
Less than 5% passes through No.200 sieve
SW - Well graded sands, gravelly sands

	MPLS RAP#2
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	5137.00
Pan Weight (g)	350.30
Sieve less than #200	
After dry #1 (g)	5475.30
Gradation test	
After dry #2 (g)	5451.50
Material weight transferred into pan (g)	5102.00
Location: Asphalt Company	

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	4.00	4.00	0.1%	99.9%	19.00	3.8
3/8"	178.50	178.50	3.5%	96.4%	9.51	2.8
#4	1300.00	1300.00	25.3%	71.1%	4.76	2.0
#8	1067.50	1067.50	20.8%	50.3%	2.38	1.5
#10	216.50	216.50	4.2%	46.1%	2.00	1.4
#30	1501.00	1501.00	29.3%	16.8%	0.60	0.8
#40	366.00	366.00	7.1%	9.7%	0.42	0.7
#100	442.00	442.00	8.6%	1.1%	0.15	0.4
#200	29.00	29.00	0.6%	0.5%	0.07	0.3
<#200	24.80	24.80	0.5%	0.0%	0.01	0.1
Total (g)	5104.50	5104.50	100%			
	5105.50					
Loss	-3.50					

Soil Classification
Coarse Gravel Soil
Less than 50% passes No. 200 Sieve
Sands
50% or more of coarse fraction passes No.4 sieve
Clean Sands
Less than 5% passes through No.200 sieve
SW - Well graded sands, gravelly sands

	Jackson RAP
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	5398.90
Pan Weight (g)	734.90
Sieve less than #200	
After dry #1 (g)	6128.30
Gradation test	
After dry #2 (g)	6073.40
Material weight transferred into pan (g)	5342.20

Location: Jackson RAP

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	156.40	156.40	0.0%	100.0%	37.50	5.1
1"	597.20	597.20	11.4%	88.6%	25.40	4.3
3/4"	468.50	468.50	8.9%	79.7%	19.00	3.8
3/8"	1486.10	1486.10	28.4%	51.3%	9.51	2.8
#4	1052.30	1052.30	20.1%	31.2%	4.76	2.0
#8	613.60	613.60	11.7%	19.5%	2.38	1.5
#10	103.60	103.60	2.0%	17.5%	2.00	1.4
#30	575.20	575.20	11.0%	6.6%	0.60	0.8
#40	112.90	112.90	2.2%	4.4%	0.42	0.7
#100	136.50	136.50	2.6%	1.8%	0.15	0.4
#200	33.30	33.30	0.6%	1.2%	0.07	0.3
<#200	60.90	60.90	1.2%	0.0%	0.01	0.1
Total (g)	5179.20	5179.20	100%			
	5341.60					

Soil Classification
Coarse Gravel Soil
Less than 50% passes No. 200 Sieve
Sands
50% or less of coarse fraction passes No.4 sieve
Clean Gravels
Less than 5% passes through No.200 sieve
GP - Poorly graded gravels, gravel-sand mixtures, or sand-gravel-cobble mixtures.

	Jackson Aggregates
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	2692.20
Pan Weight (g)	366.30
Sieve less than #200	
After dry #1 (g)	3053.90
Gradation test	
After dry #2 (g)	3053.90
Material weight transferred into pan (g)	2691.60

Location: Jackson Agg.

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	142.20	142.20	5.3%	94.7%	19.00	3.8
3/8"	273.50	273.50	10.2%	84.5%	9.51	2.8
#4	277.60	277.60	10.3%	74.2%	4.76	2.0
#8	431.10	431.10	16.0%	58.2%	2.38	1.5
#10	128.20	128.20	4.8%	53.4%	2.00	1.4
#30	966.00	966.00	35.9%	17.5%	0.60	0.8
#40	203.00	203.00	7.5%	10.0%	0.42	0.7
#100	225.90	225.90	8.4%	1.6%	0.15	0.4
#200	23.50	23.50	0.9%	0.7%	0.07	0.3
<#200	18.40	18.40	0.7%	0.0%	0.01	0.1
Total (g)	2671.00	2671.00	100%			
	2689.40					
Loss	2.20					

Soil Classification
Coarse Gravel Soil
Less than 50% passes No. 200 Sieve
Sands
50% or more of coarse fraction passes No.4 sieve
Clean Sands
Less than 5% passes through No.200 sieve
SW - Well graded sands, gravelly sands

Moisture Content

Material	MPLS RAP#1									
Pan Weight	748.3	356.7	363.7	808.9	366.2	751	1059	739.4	746.8	364.5
Material Weight	2128.3	5056	10231	12253.7	10211.7	10203.7	16420.3	6161.7	10268.9	2456.5
Total Wt.	2876.6	5412.7	10594.7	13062.6	10577.9	10954.7	17479.3	6901.1	11015.7	2821
Total Wt. After Drying	2875.1	5406.3	10568.6	13045.3	10569.9	10939	17448.3	6887.8	10987.5	2818.6
Moisture Content	0.071%	0.127%	0.256%	0.141%	0.078%	0.154%	0.189%	0.216%	0.275%	0.098%
Average Moisture Content %	0.1606%									

MPLS RAP#2						
350.3	364.4	750.6	739.4	739.3	750.8	739.3
5137	2648.4	10151.8	7423.3	5435	2425.69	10290.1
5487.3	3012.8	10902.4	8162.7	6174.3	3176.49	11029.4
5475.3	3005.5	10880.6	8155.6	6164.6	3169.7	11006.2
0.234%	0.276%	0.215%	0.096%	0.179%	0.281%	0.226%
0.2153%						

Jackson RAP					
363.7	355.1	735	1056.5	364.3	734.9
10015.6	9390.1	10349	16239.3	10572.9	5398.9
10379.3	9745.2	11084	17295.8	10937.2	6133.8

10349.3	9726.8	11073.1	17254.3	10904.4	6128.3
0.300%	0.196%	0.105%	0.256%	0.311%	0.102%
0.2119%					
Jackson Aggregate					

350.4	363.7	366.3	759.4
7554.8	5509.6	2692.2	1577.3
7905.2	5873.3	3058.5	2336.7
7874.3	5854.5	3053.9	2334.6
0.411%	0.342%	0.171%	0.133%
0.2644%			

Unit Weight

Material	MPLS RAP#1				MPLS RAP#2				Jackson RAP				Jackson Agg.			
T - Mass of Measure (Grams)	3856.3				2542.8				3856.3				2542.8			
G - Mass of Aggregates + mass of measure (Grams)	13932.3	14267.2	14312.4	14382.7	6547.7	6416	6621.4	6661.9	14309.6	14316.1	14397.3	14100.5	7087.5	7158.9	7224.5	7176.4
V - Volume of Measure (m3)	0.0071				0.0028				0.0071				0.0028			
M - Bulk density of Aggregates	1419.1549	1466.3239	2015.8309	2025.7323	1430.3214	2291.4285	2364.7857	2379.	1472.295	2016.352	2027.788	1985.985	1623.1071	2556.	2580.1785	256

(Kg/m3)	3	44	86	94	29	71	14	25	775	113	732	915	43	75	71	3
Average Bulk Density (Kg/m3)	1731.760563				2116.446429				1875.605634				2330.758929			
Average Loose Unit Wt.(pcf)	108.11028				132.125434				117.090235				145.504527			

CANNON® Instrument Company, USA 1.24 03/04/2015 07:57:27 PM

Project :
Operator :
Specimen : MPLS1 -12C B1
Test Time : 02:21:59 PM
Test Date : 03/04/2015
File Name : MPLS1 -12C B1
BBR ID : TE-BBR 3147-A2098

Target Temp (°C) : -12.0
Min. Temp (°C) : -12.1
Max. Temp (°C) : -11.9
Temp Cal Date : 03/04/2015
Soak Time (min) : 55.0
Beam Width (mm) : 12.79
Thickness (mm) : 6.35

Conf Test (GPa) : 209
Conf Date : 03/04/2015
Force Const (mN/bit) : 0.15
Defl Const (μm/bit) : 0.153
Cmpl (μm/N) : 7.37
Cal Date : 03/04/2015
Software Version : BBRw 1.24

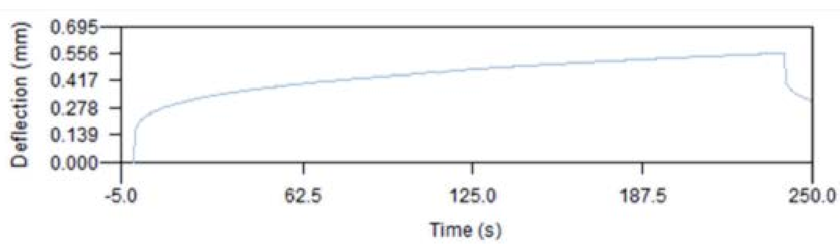
t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	1125	0.260	346	346	0.000	0.190
15.0	1124	0.295	305	306	0.328	0.202
30.0	1123	0.341	264	265	0.379	0.214
60.0	**1124**	**0.397**	**227**	**227**	**0.000**	**0.227**
120.0	1138	0.467	195	193	-1.03	0.239
240.0	1129	0.557	162	163	0.617	0.251

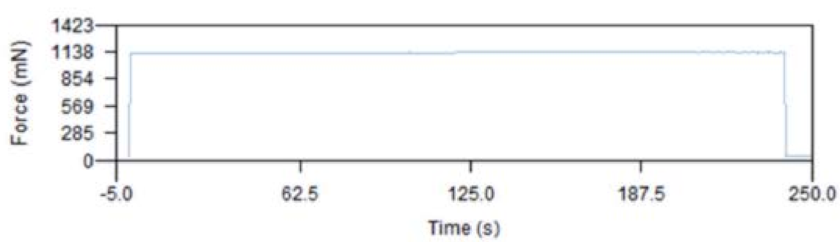
A = 2.69 B = -0.153 C = -0.0207 R² = 0.999662

Force (t=0.0s) = 37 mN Deflection (t=0.0s) = 0.000 mm
Force (t=0.5s) = 1113 mN Deflection (t=0.5s) = 0.154 mm

Max Force Deviation (t=0.5 - 5.0s) = -14, +0 mN
Max Force Deviation (t=5.0 - 240.0s) = -4, +11 mN

Average Force (t=0.5 - 240.0s) = 1127 mN
Maximum Force (t=0.5 - 240.0s) = 1138 mN
Minimum Force (t=0.5 - 240.0s) = 1113 mN





CANNON® Instrument Company, USA 1.24 03/04/2015 07:57:52 PM

Project :		Target Temp (°C) :	-12.0	Conf Test (GPa) :	209
Operator :		Min. Temp (°C) :	-12.1	Conf Date :	03/04/2015
Specimen :	MPLS1 -12C B2	Max. Temp (°C) :	-11.9	Force Const (mN/bit) :	0.15
Test Time :	02:29:59 PM	Temp Cal Date :	03/04/2015	Defl Const (µm/bit) :	0.153
Test Date :	03/04/2015	Soak Time (min) :	55.0	Cmpl (µm/N) :	7.37
File Name :	MPLS1 -12C B2	Beam Width (mm) :	12.79	Cal Date :	03/04/2015
BBR ID :	TE-BBR 3147-A2098	Thickness (mm) :	6.35	Software Version :	BBRw 1.24

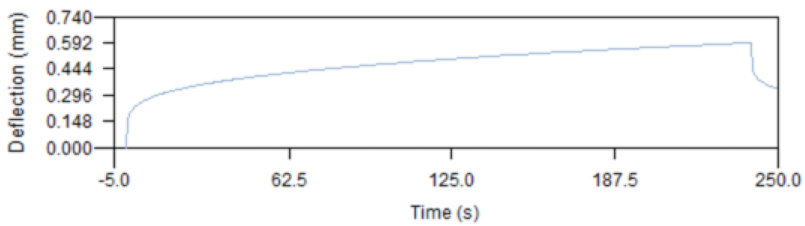
t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	1121	0.272	330	330	0.000	0.193
15.0	1120	0.309	290	291	0.345	0.206
30.0	1120	0.358	250	251	0.400	0.221
60.0	1119	0.418	214	214	0.000	0.235
120.0	1119	0.495	181	181	0.000	0.250
240.0	1117	0.591	151	151	0.000	0.264

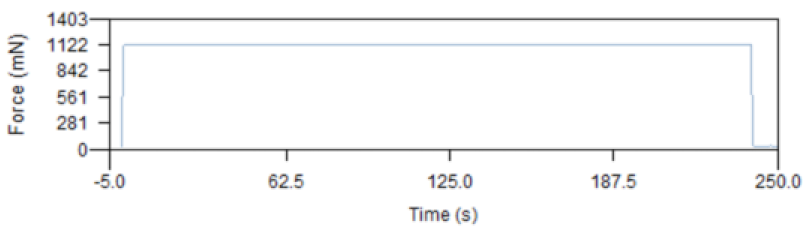
A = 2.67 B = -0.15 C = -0.0239 R^2 = 0.999983

Force (t=0.0s) = 31 mN Deflection (t=0.0s) = 0.000 mm
Force (t=0.5s) = 1108 mN Deflection (t=0.5s) = 0.160 mm

Max Force Deviation (t=0.5 - 5.0s) = -10, +4 mN
Max Force Deviation (t=5.0 - 240.0s) = -2, +3 mN

Average Force (t=0.5 - 240.0s) = 1118 mN
Maximum Force (t=0.5 - 240.0s) = 1122 mN
Minimum Force (t=0.5 - 240.0s) = 1108 mN





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Project :		Target Temp (°C) :	-12.0	Conf Test (GPa) :	209
Operator :		Min. Temp (°C) :	-12.1	Conf Date :	03/04/2015
Specimen :	MPLS1 -12C B3	Max. Temp (°C) :	-12.0	Force Const (mN/bit) :	0.15
Test Time :	02:36:15 PM	Temp Cal Date :	03/04/2015	Defl Const (µm/bit) :	0.153
Test Date :	03/04/2015	Soak Time (min) :	55.0	Cmpl (µm/N) :	7.37
File Name :	MPLS1 -12C B3	Beam Width (mm) :	12.79	Cal Date :	03/04/2015
BBR ID :	TE-BBR 3147-A2098	Thickness (mm) :	6.35	Software Version :	BBRw 1.24

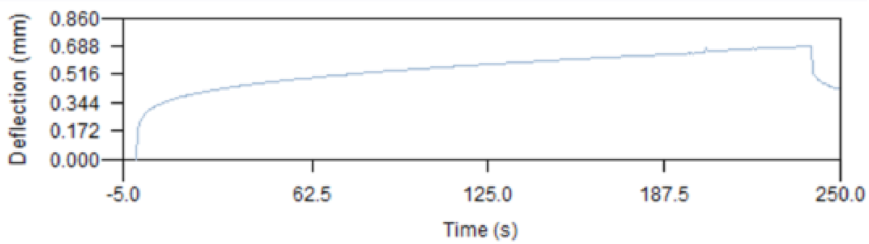
t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	1141	0.332	275	274	-0.364	0.168
15.0	1141	0.373	245	246	0.408	0.184
30.0	1141	0.427	214	215	0.467	0.202
60.0	**1139**	**0.491**	**186**	**186**	**0.000**	**0.221**
120.0	1138	0.572	159	158	-0.629	0.239
240.0	1138	0.687	133	133	0.000	0.257

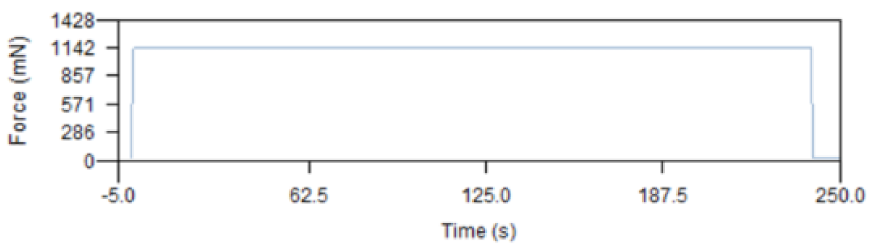
A = 2.56 B = -0.113 C = -0.0304 R^2 = 0.999726

Force (t=0.0s) = 31 mN Deflection (t=0.0s) = 0.000 mm
Force (t=0.5s) = 1131 mN Deflection (t=0.5s) = 0.179 mm

Max Force Deviation (t=0.5 - 5.0s) = -7, +4 mN
Max Force Deviation (t=5.0 - 240.0s) = -4, +4 mN

Average Force (t=0.5 - 240.0s) = 1138 mN
Maximum Force (t=0.5 - 240.0s) = 1142 mN
Minimum Force (t=0.5 - 240.0s) = 1131 mN





MPLS RAP#2

CANNON® Instrument Company, USA 1.24 03/04/2015 07:58:55 PM

Project :		Target Temp (°C) :	-12.0	Conf Test (GPa) :	209
Operator :		Min. Temp (°C) :	-12.2	Conf Date :	03/04/2015
Specimen :	MPLS2 -12C B1	Max. Temp (°C) :	-12.0	Force Const (mN/bit) :	0.15
Test Time :	05:16:25 PM	Temp Cal Date :	03/04/2015	Defl Const (µm/bit) :	0.153
Test Date :	03/04/2015	Soak Time (min) :	55.0	Cmpl (µm/N) :	7.37
File Name :	MPLS2 -12C B1	Beam Width (mm) :	12.79	Cal Date :	03/04/2015
BBR ID :	TE-BBR 3147-A2098	Thickness (mm) :	6.35	Software Version :	BBRw 1.24

WARNING! - Temperature out of tolerance (± 0.1 °C)

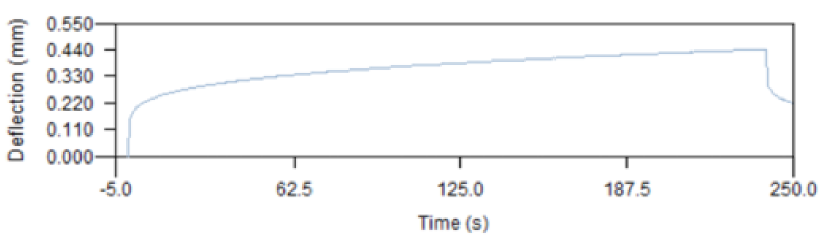
t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	1128	0.233	388	387	-0.258	0.162
15.0	1128	0.259	349	349	0.000	0.171
30.0	1128	0.293	308	309	0.325	0.182
60.0	**1128**	**0.333**	**271**	**271**	**0.000**	**0.192**
120.0	1128	0.381	237	237	0.000	0.202
240.0	1128	0.441	205	205	0.000	0.212

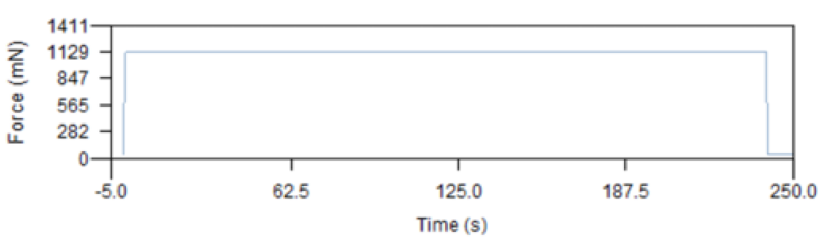
A = 2.72 B = -0.132 C = -0.0168 R^2 = 0.999977

Force (t=0.0s) = 33 mN Deflection (t=0.0s) = 0.000 mm
Force (t=0.5s) = 1115 mN Deflection (t=0.5s) = 0.147 mm

Max Force Deviation (t=0.5 - 5.0s) = -13, +1 mN
Max Force Deviation (t=5.0 - 240.0s) = -1, +1 mN

Average Force (t=0.5 - 240.0s) = 1128 mN
Maximum Force (t=0.5 - 240.0s) = 1129 mN
Minimum Force (t=0.5 - 240.0s) = 1115 mN





CANNON® Instrument Company, USA 1.24 03/04/2015 07:59:09 PM

Project :		Target Temp (°C) :	-12.0	Conf Test (GPa) :	209
Operator :		Min. Temp (°C) :	-12.0	Conf Date :	03/04/2015
Specimen :	MPLS2 -12C B2	Max. Temp (°C) :	-11.7	Force Const (mN/bit) :	0.15
Test Time :	05:22:21 PM	Temp Cal Date :	03/04/2015	Defl Const (µm/bit) :	0.153
Test Date :	03/04/2015	Soak Time (min) :	55.0	Cmpl (µm/N) :	7.37
File Name :	MPLS2 -12C B2	Beam Width (mm) :	12.79	Cal Date :	03/04/2015
BBR ID :	TE-BBR 3147-A2098	Thickness (mm) :	6.35	Software Version :	BBRw 1.24

WARNING! - Temperature out of tolerance (± 0.1 °C)

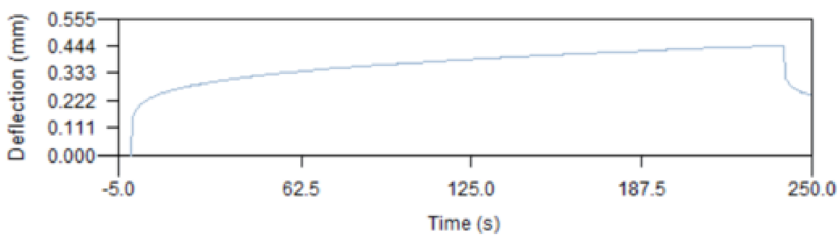
t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	1130	0.235	385	385	0.000	0.170
15.0	1130	0.262	345	345	0.000	0.177
30.0	1130	0.297	305	305	0.000	0.184
60.0	1129	0.338	267	268	0.375	0.191
120.0	1129	0.386	234	234	0.000	0.198
240.0	1130	0.445	203	203	0.000	0.205

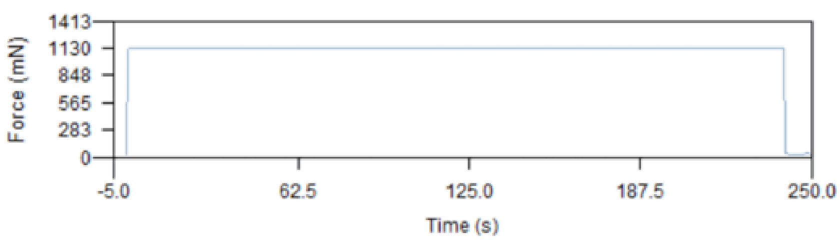
A = 2.73 B = -0.149 C = -0.0118 R^2 = 0.999992

Force (t=0.0s) = 32 mN Deflection (t=0.0s) = 0.000 mm
Force (t=0.5s) = 1117 mN Deflection (t=0.5s) = 0.147 mm

Max Force Deviation (t=0.5 - 5.0s) = -12, +1 mN
Max Force Deviation (t=5.0 - 240.0s) = -1, +1 mN

Average Force (t=0.5 - 240.0s) = 1129 mN
Maximum Force (t=0.5 - 240.0s) = 1130 mN
Minimum Force (t=0.5 - 240.0s) = 1117 mN





Jackson RAP

CANNON® Instrument Company, USA 1.24 03/04/2015 07:54:57 PM

Project :		Target Temp (°C) :	-12.0	Conf Test (GPa) :	209
Operator :		Min. Temp (°C) :	-12.1	Conf Date :	03/04/2015
Specimen :	Jackson -12C B1	Max. Temp (°C) :	-11.9	Force Const (mN/bit) :	0.15
Test Time :	01:57:15 PM	Temp Cal Date :	03/04/2015	Defl Const (µm/bit) :	0.153
Test Date :	03/04/2015	Soak Time (min) :	55.0	Cmpl (µm/N) :	7.37
File Name :	Jackson -12C B1	Beam Width (mm) :	12.79	Cal Date :	03/04/2015
BBR ID :	TE-BBR 3147-A2098	Thickness (mm) :	6.35	Software Version :	BBRw 1.24

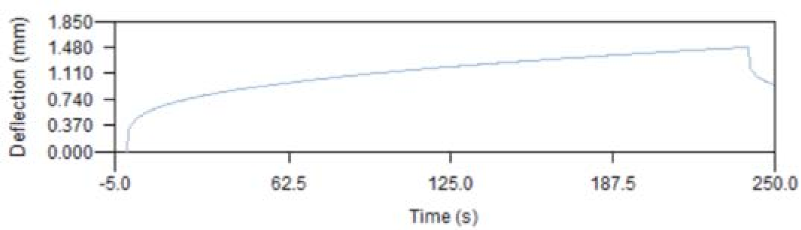
t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	1116	0.557	160	160	0.000	0.253
15.0	1115	0.656	136	136	0.000	0.267
30.0	1113	0.792	113	113	0.000	0.282
60.0	**1110**	**0.964**	**92.2**	**92.1**	**-0.108**	**0.297**
120.0	1107	1.189	74.5	74.6	0.134	0.312
240.0	1104	1.480	59.7	59.7	1.28e-006	0.327

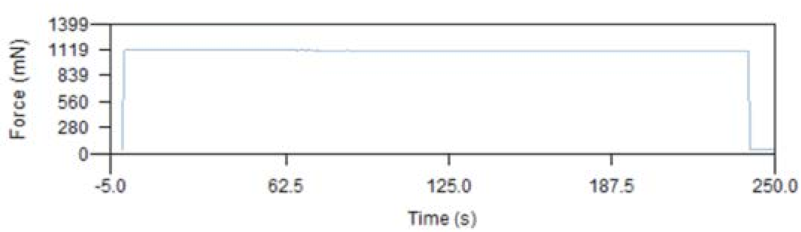
A = 2.41 B = -0.208 C = -0.0251 R^2 = 0.999997

Force (t=0.0s) = 41 mN Deflection (t=0.0s) = 0.000 mm
Force (t=0.5s) = 1108 mN Deflection (t=0.5s) = 0.283 mm

Max Force Deviation (t=0.5 - 5.0s) = -0, +11 mN
Max Force Deviation (t=5.0 - 240.0s) = -4, +9 mN

Average Force (t=0.5 - 240.0s) = 1108 mN
Maximum Force (t=0.5 - 240.0s) = 1119 mN
Minimum Force (t=0.5 - 240.0s) = 1104 mN





CANNON® Instrument Company, USA 1.24 03/04/2015 07:55:59 PM

Project :		Target Temp (°C) :	-12.0	Conf Test (GPa) :	209
Operator :		Min. Temp (°C) :	-12.1	Conf Date :	03/04/2015
Specimen :	Jackson -12C B2	Max. Temp (°C) :	-11.9	Force Const (mN/bit) :	0.15
Test Time :	02:05:27 PM	Temp Cal Date :	03/04/2015	Defl Const (µm/bit) :	0.153
Test Date :	03/04/2015	Soak Time (min) :	55.0	Cmpl (µm/N) :	7.37
File Name :	Jackson -12C B2	Beam Width (mm) :	12.79	Cal Date :	03/04/2015
BBR ID :	TE-BBR 3147-A2098	Thickness (mm) :	6.35	Software Version :	BBRw 1.24

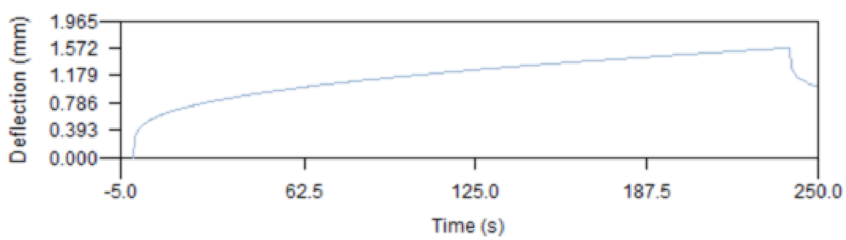
t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	1117	0.572	156	156	0.000	0.246
15.0	1116	0.673	133	133	0.000	0.266
30.0	1115	0.814	110	110	0.000	0.287
60.0	1113	0.998	89.3	89.3	3.42e-006	0.309
120.0	1111	1.241	71.7	71.5	-0.279	0.331
240.0	1107	1.573	56.3	56.4	0.178	0.353

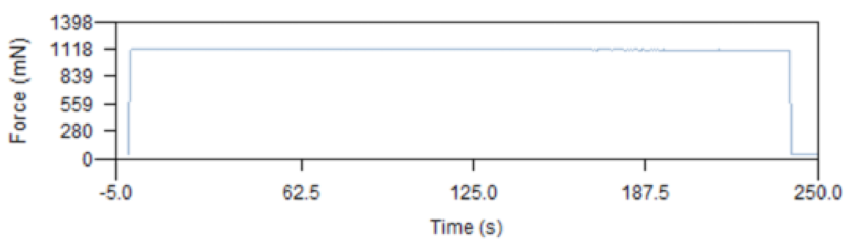
A = 2.39 B = -0.181 C = -0.0361 R^2 = 0.999983

Force (t=0.0s) = 40 mN Deflection (t=0.0s) = 0.000 mm
Force (t=0.5s) = 1107 mN Deflection (t=0.5s) = 0.292 mm

Max Force Deviation (t=0.5 - 5.0s) = -4, +7 mN
Max Force Deviation (t=5.0 - 240.0s) = -4, +6 mN

Average Force (t=0.5 - 240.0s) = 1111 mN
Maximum Force (t=0.5 - 240.0s) = 1118 mN
Minimum Force (t=0.5 - 240.0s) = 1107 mN





CANNON® Instrument Company, USA 1.24 03/04/2015 07:56:47 PM

Project :		Target Temp (°C) :	-12.0	Conf Test (GPa) :	209
Operator :		Min. Temp (°C) :	-12.1	Conf Date :	03/04/2015
Specimen :	Jackson -12C B3	Max. Temp (°C) :	-12.0	Force Const (mN/bit) :	0.15
Test Time :	02:13:17 PM	Temp Cal Date :	03/04/2015	Defl Const (µm/bit) :	0.153
Test Date :	03/04/2015	Soak Time (min) :	55.0	Cmpl (µm/N) :	7.37
File Name :	Jackson -12C B3	Beam Width (mm) :	12.79	Cal Date :	03/04/2015
BBR ID :	TE-BBR 3147-A2098	Thickness (mm) :	6.35	Software Version :	BBRw 1.24

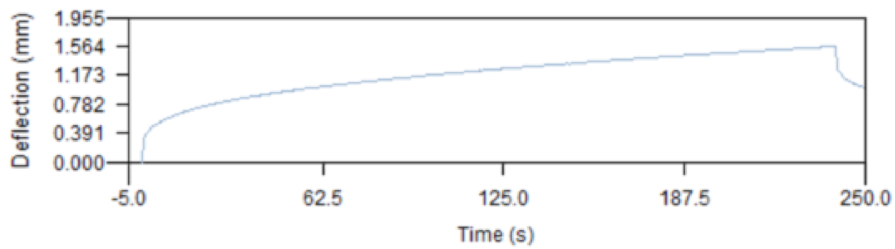
t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	1119	0.580	154	154	0.000	0.248
15.0	1119	0.683	131	131	0.000	0.265
30.0	1118	0.825	108	109	0.926	0.283
60.0	**1116**	**1.006**	**88.8**	**88.7**	**-0.113**	**0.301**
120.0	1113	1.245	71.6	71.5	-0.140	0.320
240.0	1110	1.562	56.9	56.9	2.68e-006	0.338

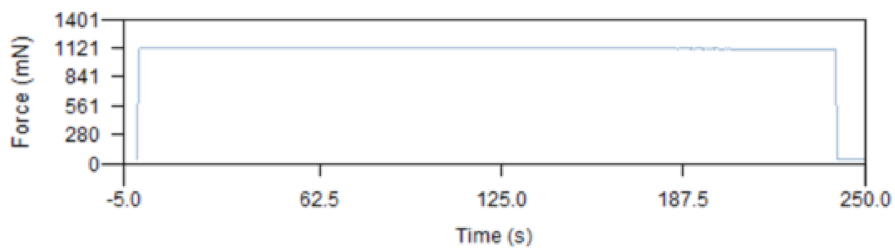
A = 2.39 B = -0.193 C = -0.0304 R^2 = 0.999990

Force (t=0.0s) = 42 mN Deflection (t=0.0s) = 0.000 mm
Force (t=0.5s) = 1110 mN Deflection (t=0.5s) = 0.294 mm

Max Force Deviation (t=0.5 - 5.0s) = -4, +7 mN
Max Force Deviation (t=5.0 - 240.0s) = -4, +6 mN

Average Force (t=0.5 - 240.0s) = 1114 mN
Maximum Force (t=0.5 - 240.0s) = 1121 mN
Minimum Force (t=0.5 - 240.0s) = 1110 mN





Mix	Wt. of CBR mold without collor (EMPTY) Mm	Wt. of CBR mold without collor (FULL) Mw+ws		Can name	Empty Can	Full can	After Oven	Wac	Dry Density Before Lodaing (g/cm3)	Dry Density After Loading (g/cm3)
MPLS RAP#1 10%	14404.1	19559.6	Before Loadaing	R2	49.48	383.98	359.22	0.0799	2.059839969	2.055246791
			After Loading	RM42	50.38	318.63	298.22	0.0824		
MPLS RAP#1 20%	14408	19363.5	Before Loadaing	TL8	50.73	365.61	339.57	0.0902	1.961377811	1.964884786
			After Loading	W	50.04	331.32	308.52	0.0882		
MPLS RAP#1 30%	14406.5	19297.6	Before Loadaing	PP	49.29	217.98	203.64	0.0929	1.931013703	1.941262577
			After Loading	DG	49.59	355.51	330.99	0.0871		
MPLS RAP#1 40%	14408	19246.7	Before Loadaing	II	49.3	386.73	358.25	0.0922	1.911589877	1.933760215
			After Loading	DD	49.38	389.97	364.84	0.0797		
MPLS RAP#1 50%	14407.3	19223.2	Before Loadaing	GUM	49.66	336.33	315.77	0.0773	1.928936481	1.954879384
			After Loading	SS	49.75	433.98	411.22	0.063		
MPLS RAP#2 10%	14406.6	19484.4	Before Loadaing	Dirt A	50.82	410.71	385.38	0.0757	2.036766978	2.021505191
			After Loading	TX	50.61	410.54	382.7	0.0838		
MPLS RAP#2 20%	14407.2	19366.3	Before Loadaing	Dirt B	49.75	438.34	411.34	0.0747	1.991082131	1.986292687
			After Loading	RM 42	49.3	428.83	401.61	0.0773		
MPLS RAP#2 30%	14407	19309.1	Before Loadaing	RAP A	49.66	431.94	406.63	0.0709	1.975121544	1.967214017
			After Loading	TL8	50.75	391.01	367.21	0.0752		
MPLS RAP#2 40%	14406.6	19105.2	Before Loadaing	ND1	49.76	427.31	402.56	0.0702	1.894454129	1.892497957
			After Loading	RM42	49.33	374.65	353.01	0.0713		
MPLS RAP#2 50%	14406.3	19140	Before Loadaing	TX	50.6	404.17	384.02	0.0604	1.926098475	1.917361114
			After Loading	DirtB	49.78	402.33	380.73	0.0653		
Jackson RAP 10%	14406.8	19413.3	Before Loadaing	ND 1	49.81	422.46	395.34	0.0785	2.002997342	2.002851271
			After Loading	IA	49.8	380.92	356.8	0.0786		
Jackson RAP 20%	14407	19229.3	Before Loadaing	#4	49.86	459.91	430.96	0.076	1.933828138	1.951275452
			After Loading	PP	49.28	460.75	435.15	0.0663		
Jackson RAP 30%	14406.9	19084.3	Before Loadaing	GUM	49.81	415.87	393.28	0.0658	1.893662434	1.89769276
			After Loading	R2	49.49	401.5	380.48	0.0635		
Jackson RAP 40%	14407.3	19019.8	Before Loadaing	TL8	50.78	404.95	384.05	0.0627	1.872760958	1.875680432
			After Loading	IA	49.83	377.23	358.39	0.0611		
Jackson RAP 50%	14406	18957.8	Before Loadaing	#4 M	49.88	465.94	442.07	0.0609	1.851335975	1.842453988
			After Loading	W	50.07	330.55	313.19	0.066		
Jackson Agg 100%	14405.6	19699.5	Before Loadaing	Dirt A	50.82	395.95	371.12	0.0775	2.11988098	2.0945458
			After Loading	RC	50.2	497.6	460.45	0.0906		

APPENDIX C: FIELD TEST DATA

Cross Sectional Survey Data

Cross section elevation data-Goodhue Control.1					
		Horizontal (ft)	Reading (ft)	Elevation (ft)	Weather (5 days prior):
Benchmark (nail on power pole)	1	0.00	1.35	101.35	
Foreslope close to Benchmark	2	26.00	5.49	95.86	
	3	28.00	5.35	96.00	
	4	30.00	5.29	96.06	
Drive way	5	32.00	5.29	96.06	
	6	34.00	5.26	96.09	Time 9/4/2015
	7	36.00	5.29	96.06	
	8	38.00	5.37	95.98	
	9	40.00	5.37	95.98	Location RAP 30%
	10	42.00	5.43	95.92	
	11	44.00	5.47	95.88	
	12	46.00	5.52	95.83	
	13	48.00	5.57	95.78	
	14	50.00	5.70	95.65	Notes: Slope: North bound 3/8" per 24", South bound 3/8" per 24" Weight of sample collected: Top material 14.03lb, bottom material 36.86lb Shots are 2' away from each other starting from 2nd point Road width: 24'

Cross section elevation data-Goodhue 60%					
		Horizontal (ft)	Reading (ft)	Elevation (ft)	Weather (5 days prior):
Benchmark (nail on power pole)	1	0.00	1.31	101.31	
Foreslope close to Benchmark	2	21.00	5.05	96.26	
	3	23.00	4.99	96.32	
	4	25.00	4.88	96.43	
Drive way	5	27.00	4.85	96.46	
	6	29.00	4.87	96.44	Time 9/4/2015
	7	31.00	4.78	96.53	
	8	33.00	4.75	96.56	
	9	35.00	4.76	96.55	Location RAP 50%
	10	37.00	4.88	96.43	
	11	39.00	4.92	96.39	
	12	41.00	4.99	96.32	
	13	43.00	4.98	96.33	
	14	45.00	5.15	96.16	Notes: Slope: North bound 1/8" per 24", South bound 3/8" per 24" Weight of sample collected: Top material 21.29lb, buttom material 39.39lb Shots are 2' away from each other starting from 2nd point Road width: 24'
	15	47.00	5.22	96.09	

Cross section elevation data-Goodhue 45%					
		Horizontal (ft)	Reading (ft)	Elevation (ft)	Weather (5 days prior):
Benchmark (nail on power pole)	1	0.00	0.84	100.84	
Foreslope close to Benchmark	2	24.00	4.59	96.25	
	3	26.00	4.51	96.33	
	4	28.00	4.50	96.34	
	5	30.00	4.48	96.36	
Drive way	6	32.00	4.47	96.37	Time 9/4/2015
	7	34.00	4.48	96.36	
	8	36.00	4.53	96.31	
	9	38.00	4.55	96.29	Location Control section
	10	40.00	4.62	96.22	
	11	42.00	4.68	96.16	
	12	44.00	4.72	96.12	
	13	46.00	4.86	95.98	

Cross section elevation data-Goodhue 30%					
		Horizontal (ft)	Reading (ft)	Elevation (ft)	Weather (5 days prior):
Benchmark (nail on power pole)	1	0.00	3.06	103.06	
Foreslope close to Benchmark	2	23.00	5.19	95.65	
	3	25.00	5.08	95.76	
	4	27.00	5.02	95.82	
	5	29.00	5.01	95.83	
Drive way	6	31.00	4.95	95.89	Time 9/4/2015
	7	33.00	4.94	95.90	
	8	35.00	4.94	95.90	
	9	37.00	4.96	95.88	Location Control section
	10	39.00	5.03	95.81	
	11	41.00	5.06	95.78	
	12	43.00	5.09	95.75	
	13	45.00	5.13	95.71	

Cross section elevation data-Goodhue 15%					
		Horizontal (ft)	Reading (ft)	Elevation (ft)	Weather (5 days prior):
Benchmark (nail on power pole)	1	0.00	4.46	104.46	
Foreslope close to Benchmark	2	28.00	5.26	95.58	
	3	30.00	5.25	95.59	
	4	32.00	5.13	95.71	
	5	34.00	5.11	95.73	
Drive way	6	36.00	5.03	95.81	Time 9/4/2015
	7	38.00	4.97	95.87	
	8	40.00	4.92	95.92	
	9	42.00	4.91	95.93	Location Control section
	10	44.00	4.92	95.92	
	11	46.00	4.95	95.89	
	12	48.00	4.98	95.86	
	13	50.00	4.97	95.87	
	14	52.00	5.06	95.78	
	15	54.00	5.15	95.69	
	16	56.00	5.23	95.61	
	17	58.00	5.41	95.43	
	18	60.00	5.49	95.35	Notes: Slope: North bound 3/8" per 24", South bound 5/8" per 24" Weight of sample collected: Top material 16.54lb, buttom material 48.92lb Shots are 2' away from each other starting from 2nd point Road width: 26'

Cross section elevation data-Goodhue Control.2 (500th)					
		Horizontal (ft)	Reading (ft)	Elevation (ft)	Weather (5 days prior):
Benchmark (nail on power pole)	1	0.00	2.69	102.69	
Foreslope close to Benchmark	2	23.00	5.00	95.84	
	3	25.00	4.88	95.96	
	4	27.00	4.81	96.03	
	5	29.00	4.68	96.16	
Drive way	6	31.00	4.55	96.29	Time 9/4/2015
	7	33.00	4.54	96.30	
	8	35.00	4.52	96.32	
	9	37.00	4.56	96.28	Location Control section
	10	39.00	4.62	96.22	
	11	41.00	4.79	96.05	
	12	43.00	4.98	95.86	
	13	45.00	5.03	95.81	

<table>
<tr><th colspan="6">Cross section elevation data-Carlton 30%</th></tr>
<tr><td></td><td></td><td>Horizontal (ft)</td><td>Reading (ft)</td><td>Elevation (ft)</td><td rowspan="6">Weather (5 days prior):</td></tr>
<tr><td>Benchmark (nail on power pole)</td><td>1</td><td>0.00</td><td>1.25</td><td>101.25</td></tr>
<tr><td rowspan="3">Foreslope close to Benchmark</td><td>2</td><td>14.50</td><td>5.37</td><td>95.88</td></tr>
<tr><td>3</td><td>16.50</td><td>5.37</td><td>95.88</td></tr>
<tr><td>4</td><td>18.50</td><td>5.25</td><td>96.00</td></tr>
<tr><td rowspan="11">Drive way</td><td>5</td><td>20.50</td><td>5.21</td><td>96.04</td></tr>
<tr><td>6</td><td>22.50</td><td>5.20</td><td>96.05</td><td rowspan="3">Time
9/3/2015</td></tr>
<tr><td>7</td><td>24.50</td><td>5.10</td><td>96.15</td></tr>
<tr><td>8</td><td>26.50</td><td>5.02</td><td>96.23</td></tr>
<tr><td>9</td><td>28.50</td><td>4.97</td><td>96.28</td><td rowspan="5">Location
RAP 30%</td></tr>
<tr><td>10</td><td>30.50</td><td>5.01</td><td>96.24</td></tr>
<tr><td>11</td><td>32.50</td><td>5.10</td><td>96.15</td></tr>
<tr><td>12</td><td>34.50</td><td>5.09</td><td>96.16</td></tr>
<tr><td>13</td><td>36.50</td><td>5.12</td><td>96.13</td></tr>
<tr><td>14</td><td>38.50</td><td>5.15</td><td>96.10</td><td rowspan="2">Notes:
Slope: North bound 3/8" per 24", South bound 3/8" per 24"
Weight of sample collected:
Top material 14.03lb, buttom material 36.86lb
Shots are 2' away from each other starting from 2nd point
Road width: 24'</td></tr>
<tr><td>15</td><td>40.50</td><td>5.18</td><td>96.07</td></tr>
</table>

Cross section elevation data-Carlton 50%					
		Horizontal (ft)	Reading (ft)	Elevation (ft)	Weather (5 days prior):
Benchmark (nail on power pole)	1	0.00	0.92	100.92	
Foreslope close to Benchmark	2	16.25	5.40	95.52	
	3	18.25	5.26	95.66	
	4	20.25	5.22	95.70	
Drive way	5	22.25	5.19	95.73	
	6	24.25	5.20	95.72	Time 9/3/2015
	7	26.25	5.12	95.80	
	8	28.25	5.11	95.81	
	9	30.25	5.11	95.81	Location RAP 50%
	10	32.25	5.15	95.77	
	11	34.25	5.21	95.71	
	12	36.25	5.25	95.67	
	13	38.25	5.28	95.64	
	14	40.25	5.36	95.56	Notes: Slope: North bound 1/8" per 24", South bound 3/8" per 24" Weight of sample collected: Top material 21.29lb, buttom material 39.39lb Shots are 2' away from each other starting from 2nd point Road width: 24'
	15	42.25	5.56	95.36	

Cross section elevation data-Carlton Control					
		Horizontal (ft)	Reading (ft)	Elevation (ft)	Weather (5 days prior):
Benchmark (nail on power pole)	1	0.00	1.57	101.57	
Foreslope close to Benchmark	2	23.83	6.19	95.38	
	3	25.83	6.25	95.32	
	4	27.83	6.24	95.33	
	5	29.83	6.20	95.37	
Drive way	6	31.83	6.20	95.37	Time 9/3/2015
	7	33.83	6.18	95.39	
	8	35.83	6.16	95.41	
	9	37.83	6.16	95.41	Location Control section
	10	39.83	6.25	95.32	
	11	41.83	6.34	95.23	
	12	43.83	6.45	95.12	
	13	45.83	6.47	95.10	
	14	47.83	6.51	95.06	Notes: Slope: North bound 3/8" per 24", South bound 5/8" per 24" Weight of sample collected: Top material 16.54lb, buttom material 48.92lb Shots are 2' away from each other starting from 2nd point Road width: 26'

DCP Data

Goodhue RAP 60% Section

East Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	71	0					
10	142	71	71	7.1	1	7.1	32.50675
10	206	135	64	6.4	1	6.4	36.51416
10	303	232	97	9.7	1	9.7	22.91915
10	374	303	71	7.1	1	7.1	32.50675
10	444	373	70	7	1	7	33.0273
10	533	462	89	8.9	1	8.9	25.23865
10	612	541	79	7.9	1	7.9	28.84301
10	641	570	29	2.9	1	2.9	88.61293
10	694	623	53	5.3	1	5.3	45.1018
10	764	693	70	7	1	7	33.0273
10	850	779	86	8.6	1	8.6	26.22676
5	893	822	43	8.6	1	8.6	26.22676
5	933	862	40	8	1	8	28.43951
1	944	873	11	11	1	11	19.90779

East Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	61	0					
10	106	45	45	4.5	1	4.5	54.17324
10	143	82	37	3.7	1	3.7	67.45232
10	175	114	32	3.2	1	3.2	79.36242
10	220	159	45	4.5	1	4.5	54.17324
10	274	213	54	5.4	1	5.4	44.1674
10	313	252	39	3.9	1	3.9	63.59024
10	347	286	34	3.4	1	3.4	74.15261
10	390	329	43	4.3	1	4.3	57.00306
10	440	379	50	5	1	5	48.14337
10	493	432	53	5.3	1	5.3	45.1018
10	543	482	50	5	1	5	48.14337
10	594	533	51	5.1	1	5.1	47.08735
10	668	607	74	7.4	1	7.4	31.0344

10	693	632	25	2.5	1	2.5	104.6381
10	730	669	37	3.7	1	3.7	67.45232
10	783	722	53	5.3	1	5.3	45.1018
10	842	781	59	5.9	1	5.9	39.99711
5	876	815	34	6.8	1	6.8	34.11716
5	912	851	36	7.2	1	7.2	32.00151
5	940	879	28	5.6	1	5.6	42.40453
2	950	889	10	5	1	5	48.14337

West Wheelbase

#Blows	**Cumulative Penetration**		**Penetration between reading**	**Penetration per Blow mm**	**Hammer Factor**	**DCP Index mm/blow**	**CBR%**
0	41	0					
10	62	21	21	2.1	1	2.1	127.203
10	90	49	28	2.8	1	2.8	92.16496
10	109	68	19	1.9	1	1.9	142.2915
10	127	86	18	1.8	1	1.8	151.1742
10	145	104	18	1.8	1	1.8	151.1742
10	163	122	18	1.8	1	1.8	151.1742
10	187	146	24	2.4	1	2.4	109.5333
10	221	180	34	3.4	1	3.4	74.15261
10	266	225	45	4.5	1	4.5	54.17324
10	306	265	40	4	1	4	61.81241
10	341	300	35	3.5	1	3.5	71.78383
10	370	329	29	2.9	1	2.9	88.61293
10	403	362	33	3.3	1	3.3	76.67384
10	442	401	39	3.9	1	3.9	63.59024
10	486	445	44	4.4	1	4.4	55.55407
10	560	519	74	7.4	1	7.4	31.0344
5	650	609	90	18	1	18	11.46773
5	734	693	84	16.8	1	16.8	12.38901
5	786	745	52	10.4	1	10.4	21.19852
5	836	795	50	10	1	10	22.15047
5	869	828	33	6.6	1	6.6	35.27716
5	902	861	33	6.6	1	6.6	35.27716

3	940	899	38	12.66666667	1	12.66666667	16.99813

West Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	42	0					
10	87	45	45	4.5	1	4.5	54.17324
10	123	81	36	3.6	1	3.6	69.55431
20	181	139	58	2.9	1	2.9	88.61293
10	224	182	43	4.3	1	4.3	57.00306
10	254	212	30	3	1	3	85.3114
10	287	245	33	3.3	1	3.3	76.67384
10	326	284	39	3.9	1	3.9	63.59024
10	372	330	46	4.6	1	4.6	52.85597
10	421	379	49	4.9	1	4.9	49.24512
10	478	436	57	5.7	1	5.7	41.5722
10	544	502	66	6.6	1	6.6	35.27716
5	599	557	55	11	1	11	19.90779
5	665	623	66	13.2	1	13.2	16.2308
5	748	706	83	16.6	1	16.6	12.5563
5	790	748	42	8.4	1	8.4	26.92713
5	852	810	62	12.4	1	12.4	17.40807
5	911	869	59	11.8	1	11.8	18.40242
2	935	893	24	12	1	12	18.05926

Goodhue RAP 45% Section

East
Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	59	0					
10	115	56	56	5.6	1	5.6	42.40453
10	163	104	48	4.8	1	4.8	50.39561
10	198	139	35	3.5	1	3.5	71.78383
10	310	251	112	11.2	1	11.2	19.51006
5	450	391	140	28	1	28	6.991427
5	701	642	251	50.2	1	50.2	3.635756
5	834	775	133	26.6	1	26.6	7.404836
1	862	803	28	28	1	28	6.991427
1	890	831	28	28	1	28	6.991427
1	917	858	27	27	1	27	7.28208
1	944	885	27	27	1	27	7.28208

East
Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	50	0					
10	79	29	29	2.9	1	2.9	88.61293
10	97	47	18	1.8	1	1.8	151.1742
10	120	70	23	2.3	1	2.3	114.8809
10	150	100	30	3	1	3	85.3114
10	190	140	40	4	1	4	61.81241
10	260	210	70	7	1	7	33.0273
10	358	308	98	9.8	1	9.8	22.65738
10	490	440	132	13.2	1	13.2	16.2308
10	768	718	278	27.8	1	27.8	7.047786
4	916	866	148	37	1	37	5.116782

West

Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	51	0					
10	117	66	66	6.6	1	6.6	35.27716
10	141	90	24	2.4	1	2.4	109.5333
10	163	112	22	2.2	1	2.2	120.7451
10	176	125	13	1.3	1	1.3	217.6538
10	190	139	14	1.4	1	1.4	200.3178
10	203	152	13	1.3	1	1.3	217.6538
10	220	169	17	1.7	1	1.7	161.1685
10	240	189	20	2	1	2	134.3474
10	282	231	42	4.2	1	4.2	58.5253
10	360	309	78	7.8	1	7.8	29.25748
10	450	399	90	9	1	9	24.92477
10	586	535	136	13.6	1	13.6	15.69709
10	791	740	205	20.5	1	20.5	9.913306
4	905	854	114	28.5	1	28.5	6.854197

West Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	55	0					
10	158	103	103	10.3	1	10.3	21.42916
10	266	211	108	10.8	1	10.8	20.32115
5	350	295	84	16.8	1	16.8	12.38901
5	480	425	130	26	1	26	7.596485
5	680	625	200	40	1	40	4.688951
5	821	766	141	28.2	1	28.2	6.935916
2	942	887	121	60.5	1	60.5	2.949965

Goodhue RAP 30% Section

East
Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	66	0					
10	120	54	54	5.4	1	5.4	44.1674
10	160	94	40	4	1	4	61.81241
10	208	142	48	4.8	1	4.8	50.39561
10	283	217	75	7.5	1	7.5	30.57132
5	373	307	90	18	1	18	11.46773
5	453	387	80	16	1	16	13.08484
5	554	488	101	20.2	1	20.2	10.07835
5	665	599	111	22.2	1	22.2	9.067082
5	711	645	46	9.2	1	9.2	24.31871
5	768	702	57	11.4	1	11.4	19.12711
10	868	802	100	10	1	10	22.15047
5	918	852	50	10	1	10	22.15047
1	929	863	11	11	1	11	19.90779
1	938	872	9	9	1	9	24.92477
1	948	882	10	10	1	10	22.15047

East
Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	37	0					
10	62	25	25	2.5	1	2.5	104.6381
10	92	55	30	3	1	3	85.3114
10	113	76	21	2.1	1	2.1	127.203
10	127	90	14	1.4	1	1.4	200.3178
10	138	101	11	1.1	1	1.1	262.4358
10	155	118	17	1.7	1	1.7	161.1685
10	173	136	18	1.8	1	1.8	151.1742
10	193	156	20	2	1	2	134.3474
10	215	178	22	2.2	1	2.2	120.7451
10	280	243	65	6.5	1	6.5	35.88557
10	360	323	80	8	1	8	28.43951
10	455	418	95	9.5	1	9.5	23.46024
10	529	492	74	7.4	1	7.4	31.0344
10	670	633	141	14.1	1	14.1	15.075
10	770	733	100	10	1	10	22.15047

10	860	823	90	9	1	9	24.92477
5	923	886	63	12.6	1	12.6	17.09889
1	933	896	10	10	1	10	22.15047
1	943	906	10	10	1	10	22.15047

West
Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	47	0					
10	78	31	31	3.1	1	3.1	82.2352
10	100	53	22	2.2	1	2.2	120.7451
10	119	72	19	1.9	1	1.9	142.2915
10	137	90	18	1.8	1	1.8	151.1742
10	151	104	14	1.4	1	1.4	200.3178
10	170	123	19	1.9	1	1.9	142.2915
10	184	137	14	1.4	1	1.4	200.3178
10	197	150	13	1.3	1	1.3	217.6538
10	222	175	25	2.5	1	2.5	104.6381
10	254	207	32	3.2	1	3.2	79.36242
10	319	272	65	6.5	1	6.5	35.88557
10	391	344	72	7.2	1	7.2	32.00151
10	505	458	114	11.4	1	11.4	19.12711
5	600	553	95	19	1	19	10.79391
5	733	686	133	26.6	1	26.6	7.404836
5	861	814	128	25.6	1	25.6	7.729548
2	915	868	54	27	1	27	7.28208
1	948	901	33	33	1	33	5.816306

West

Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	69	0					
10	133	64	64	6.4	1	6.4	36.51416
10	176	107	43	4.3	1	4.3	57.00306
10	210	141	34	3.4	1	3.4	74.15261
10	289	220	79	7.9	1	7.9	28.84301
5	370	301	81	16.2	1	16.2	12.90405
5	518	449	148	29.6	1	29.6	6.569558
5	690	621	172	34.4	1	34.4	5.551846
5	792	723	102	20.4	1	20.4	9.967748
5	863	794	71	14.2	1	14.2	14.95615
3	912	843	49	16.33333333	1	16.33333333	12.78613
1	930	861	18	18	1	18	11.46773
1	948	879	18	18	1	18	11.46773

Goodhue RAP 15% Section

East
Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	42	0					
10	93	51	51	5.1	1	5.1	47.08735
10	130	88	37	3.7	1	3.7	67.45232
10	154	112	24	2.4	1	2.4	109.5333
10	192	150	38	3.8	1	3.8	65.46742
10	205	163	13	1.3	1	1.3	217.6538
10	227	185	22	2.2	1	2.2	120.7451
10	245	203	18	1.8	1	1.8	151.1742
10	262	220	17	1.7	1	1.7	161.1685
10	280	238	18	1.8	1	1.8	151.1742
10	298	256	18	1.8	1	1.8	151.1742
10	314	272	16	1.6	1	1.6	172.4918
10	334	292	20	2	1	2	134.3474
10	347	305	13	1.3	1	1.3	217.6538
10	359	317	12	1.2	1	1.2	238.0674
10	367	325	8	0.8	1	0.8	374.9057
10	374	332	7	0.7	1	0.7	435.3846
10	405	363	31	3.1	1	3.1	82.2352
10	452	410	47	4.7	1	4.7	51.59805
10	493	451	41	4.1	1	4.1	60.12636
10	512	470	19	1.9	1	1.9	142.2915
10	540	498	28	2.8	1	2.8	92.16496
10	566	524	26	2.6	1	2.6	100.1412
10	590	548	24	2.4	1	2.4	109.5333
10	610	568	20	2	1	2	134.3474
10	628	586	18	1.8	1	1.8	151.1742
10	647	605	19	1.9	1	1.9	142.2915
10	688	646	41	4.1	1	4.1	60.12636
10	710	668	22	2.2	1	2.2	120.7451
10	735	693	25	2.5	1	2.5	104.6381
10	769	727	34	3.4	1	3.4	74.15261
10	781	739	12	1.2	1	1.2	238.0674
10	795	753	14	1.4	1	1.4	200.3178
10	810	768	15	1.5	1	1.5	185.4217
10	824	782	14	1.4	1	1.4	200.3178

10	839	797	15	1.5	1	1.5	185.4217
10	850	808	11	1.1	1	1.1	262.4358
10	860	818	10	1	1	1	292
10	880	838	20	2	1	2	134.3474
10	897	855	17	1.7	1	1.7	161.1685
10	915	873	18	1.8	1	1.8	151.1742
5	925	883	10	2	1	2	134.3474
5	932	890	7	1.4	1	1.4	200.3178
5	939	897	7	1.4	1	1.4	200.3178
5	948	906	9	1.8	1	1.8	151.1742

East
Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	37	0					
10	64	27	27	2.7	1	2.7	95.99651
10	82	45	18	1.8	1	1.8	151.1742
10	100	63	18	1.8	1	1.8	151.1742
10	119	82	19	1.9	1	1.9	142.2915
10	134	97	15	1.5	1	1.5	185.4217
10	144	107	10	1	1	1	292
10	157	120	13	1.3	1	1.3	217.6538
10	168	131	11	1.1	1	1.1	262.4358
10	175	138	7	0.7	1	0.7	435.3846
10	182	145	7	0.7	1	0.7	435.3846
10	187	150	5	0.5	1	0.5	634.6532
10	190	153	3	0.3	1	0.3	1124.623
10	195	158	5	0.5	1	0.5	634.6532
10	199	162	4	0.4	1	0.4	814.8462
10	208	171	9	0.9	1	0.9	328.5725
10	212	175	4	0.4	1	0.4	814.8462
10	217	180	5	0.5	1	0.5	634.6532
10	220	183	3	0.3	1	0.3	1124.623
10	227	190	7	0.7	1	0.7	435.3846
10	233	196	6	0.6	1	0.6	517.4322
10	240	203	7	0.7	1	0.7	435.3846
10	244	207	4	0.4	1	0.4	814.8462
10	250	213	6	0.6	1	0.6	517.4322
10	257	220	7	0.7	1	0.7	435.3846
10	264	227	7	0.7	1	0.7	435.3846

10	270	233	6	0.6	1	0.6	517.4322
10	278	241	8	0.8	1	0.8	374.9057
10	285	248	7	0.7	1	0.7	435.3846
10	293	256	8	0.8	1	0.8	374.9057
10	300	263	7	0.7	1	0.7	435.3846
10	304	267	4	0.4	1	0.4	814.8462
10	310	273	6	0.6	1	0.6	517.4322
10	323	286	13	1.3	1	1.3	217.6538
10	331	294	8	0.8	1	0.8	374.9057
10	341	304	10	1	1	1	292
10	347	310	6	0.6	1	0.6	517.4322
10	357	320	10	1	1	1	292
10	366	329	9	0.9	1	0.9	328.5725
10	379	342	13	1.3	1	1.3	217.6538
10	390	353	11	1.1	1	1.1	262.4358
10	401	364	11	1.1	1	1.1	262.4358
10	410	373	9	0.9	1	0.9	328.5725
10	422	385	12	1.2	1	1.2	238.0674
10	436	399	14	1.4	1	1.4	200.3178
10	455	418	19	1.9	1	1.9	142.2915
10	472	435	17	1.7	1	1.7	161.1685
10	495	458	23	2.3	1	2.3	114.8809
10	514	477	19	1.9	1	1.9	142.2915
10	535	498	21	2.1	1	2.1	127.203
10	553	516	18	1.8	1	1.8	151.1742
10	570	533	17	1.7	1	1.7	161.1685
10	591	554	21	2.1	1	2.1	127.203
10	612	575	21	2.1	1	2.1	127.203
10	640	603	28	2.8	1	2.8	92.16496
10	668	631	28	2.8	1	2.8	92.16496
10	689	652	21	2.1	1	2.1	127.203
10	709	672	20	2	1	2	134.3474
10	730	693	21	2.1	1	2.1	127.203
10	752	715	22	2.2	1	2.2	120.7451
10	775	738	23	2.3	1	2.3	114.8809
10	804	767	29	2.9	1	2.9	88.61293
10	824	787	20	2	1	2	134.3474
10	854	817	30	3	1	3	85.3114
10	895	858	41	4.1	1	4.1	60.12636
5	930	893	35	7	1	7	33.0273
6	949	912	19	3.166666667	1	3.166666667	80.29865

West
Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	44	0					
10	72	28	28	2.8	1	2.8	92.16496
10	92	48	20	2	1	2	134.3474
10	105	61	13	1.3	1	1.3	217.6538
10	119	75	14	1.4	1	1.4	200.3178
10	130	86	11	1.1	1	1.1	262.4358
10	141	97	11	1.1	1	1.1	262.4358
10	152	108	11	1.1	1	1.1	262.4358
10	164	120	12	1.2	1	1.2	238.0674
10	173	129	9	0.9	1	0.9	328.5725
10	177	133	4	0.4	1	0.4	814.8462
10	181	137	4	0.4	1	0.4	814.8462
10	182	138	1	0.1	1	0.1	3849.31
10	183	139	1	0.1	1	0.1	3849.31
10	184	140	1	0.1	1	0.1	3849.31
20	187	143	3	0.15	1	0.15	2444.335
40	190	146	3	0.075	1	0.075	5312.687
10	192	148	2	0.2	1	0.2	1771.044
10	195	151	3	0.3	1	0.3	1124.623
10	200	156	5	0.5	1	0.5	634.6532
20	204	160	4	0.2	1	0.2	1771.044

West
Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	52	0					
10	111	59	59	5.9	1	5.9	39.99711
10	150	98	39	3.9	1	3.9	63.59024
10	179	127	29	2.9	1	2.9	88.61293
10	205	153	26	2.6	1	2.6	100.1412
10	243	191	38	3.8	1	3.8	65.46742
10	269	217	26	2.6	1	2.6	100.1412
10	309	257	40	4	1	4	61.81241
10	360	308	51	5.1	1	5.1	47.08735
10	385	333	25	2.5	1	2.5	104.6381
10	420	368	35	3.5	1	3.5	71.78383
10	455	403	35	3.5	1	3.5	71.78383
10	484	432	29	2.9	1	2.9	88.61293
10	508	456	24	2.4	1	2.4	109.5333
10	534	482	26	2.6	1	2.6	100.1412
10	560	508	26	2.6	1	2.6	100.1412
10	582	530	22	2.2	1	2.2	120.7451
10	605	553	23	2.3	1	2.3	114.8809
10	625	573	20	2	1	2	134.3474
10	642	590	17	1.7	1	1.7	161.1685
10	660	608	18	1.8	1	1.8	151.1742
10	675	623	15	1.5	1	1.5	185.4217
10	694	642	19	1.9	1	1.9	142.2915
10	714	662	20	2	1	2	134.3474
10	735	683	21	2.1	1	2.1	127.203
10	755	703	20	2	1	2	134.3474
10	781	729	26	2.6	1	2.6	100.1412
10	800	748	19	1.9	1	1.9	142.2915
10	821	769	21	2.1	1	2.1	127.203
10	850	798	29	2.9	1	2.9	88.61293
10	890	838	40	4	1	4	61.81241
5	915	863	25	5	1	5	48.14337
5	940	888	25	5	1	5	48.14337

Goodhue CONTROL Section 500th ST.

South Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	67	0					
10	122	55	55	5.5	1	5.5	43.26898
10	171	104	49	4.9	1	4.9	49.24512
10	218	151	47	4.7	1	4.7	51.59805
6	271	204	53	8.833333333	1	8.833333333	25.45208
3	348	281	77	25.66666667	1	25.66666667	7.707065
1	376	309	28	28	1	28	6.991427
1	405	338	29	29	1	29	6.721978
1	443	376	38	38	1	38	4.966212
1	491	424	48	48	1	48	3.822898
1	528	461	37	37	1	37	5.116782
1	560	493	32	32	1	32	6.020255
1	592	525	32	32	1	32	6.020255
1	620	553	28	28	1	28	6.991427
1	645	578	25	25	1	25	7.937615
1	673	606	28	28	1	28	6.991427
1	700	633	27	27	1	27	7.28208
1	727	660	27	27	1	27	7.28208
1	756	689	29	29	1	29	6.721978
1	786	719	30	30	1	30	6.471531
1	813	746	27	27	1	27	7.28208
1	847	780	34	34	1	34	5.625051
1	872	805	25	25	1	25	7.937615
1	899	832	27	27	1	27	7.28208
1	926	859	27	27	1	27	7.28208

South Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	55	0					
10	74	19	19	1.9	1	1.9	142.2915
10	90	35	16	1.6	1	1.6	172.4918
10	104	49	14	1.4	1	1.4	200.3178
10	120	65	16	1.6	1	1.6	172.4918
10	138	83	18	1.8	1	1.8	151.1742

10	155	100	17	1.7	1	1.7	161.1685
10	174	119	19	1.9	1	1.9	142.2915
10	194	139	20	2	1	2	134.3474
10	210	155	16	1.6	1	1.6	172.4918
10	238	183	28	2.8	1	2.8	92.16496
10	275	220	37	3.7	1	3.7	67.45232
5	327	272	52	10.4	1	10.4	21.19852
5	452	397	125	25	1	25	7.937615
4	573	518	121	30.25	1	30.25	6.411659
1	607	552	34	34	1	34	5.625051
1	637	582	30	30	1	30	6.471531
1	671	616	34	34	1	34	5.625051
1	702	647	31	31	1	31	6.238178
1	736	681	34	34	1	34	5.625051
1	762	707	26	26	1	26	7.596485
1	792	737	30	30	1	30	6.471531
1	820	765	28	28	1	28	6.991427
1	841	786	21	21	1	21	9.649332
1	851	796	10	10	1	10	22.15047
1	872	817	21	21	1	21	9.649332
1	890	835	18	18	1	18	11.46773
4	925	870	35	8.75	1	8.75	25.72372
1	933	878	8	8	1	8	28.43951
2	950	895	17	8.5	1	8.5	26.57258

North Wheelbase

#Blows	**Cumulative Penetration**		**Penetration between reading**	**Penetration per Blow mm**	**Hammer Factor**	**DCP Index mm/blow**	**CBR%**
0	53	0					
10	74	21	21	2.1	1	2.1	127.203
10	89	36	15	1.5	1	1.5	185.4217
10	104	51	15	1.5	1	1.5	185.4217
10	121	68	17	1.7	1	1.7	161.1685
10	135	82	14	1.4	1	1.4	200.3178
10	151	98	16	1.6	1	1.6	172.4918
10	167	114	16	1.6	1	1.6	172.4918
10	181	128	14	1.4	1	1.4	200.3178
10	197	144	16	1.6	1	1.6	172.4918
10	221	168	24	2.4	1	2.4	109.5333
10	240	187	19	1.9	1	1.9	142.2915

10	291	238	51	5.1	1	5.1	47.08735
10	382	329	91	9.1	1	9.1	24.61821
1	410	357	28	28	1	28	6.991427
1	440	387	30	30	1	30	6.471531
1	470	417	30	30	1	30	6.471531
1	502	449	32	32	1	32	6.020255
1	538	485	36	36	1	36	5.276234
1	574	521	36	36	1	36	5.276234
1	612	559	38	38	1	38	4.966212
1	652	599	40	40	1	40	4.688951
1	693	640	41	41	1	41	4.561051
1	727	674	34	34	1	34	5.625051
1	760	707	33	33	1	33	5.816306
1	792	739	32	32	1	32	6.020255
1	824	771	32	32	1	32	6.020255
1	858	805	34	34	1	34	5.625051
1	887	834	29	29	1	29	6.721978
1	916	863	29	29	1	29	6.721978
1	940	887	24	24	1	24	8.308952

North
Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	52	0					
5	94	42	42	8.4	1	8.4	26.92713
5	134	82	40	8	1	8	28.43951
5	160	108	26	5.2	1	5.2	46.07434
5	200	148	40	8	1	8	28.43951
5	243	191	43	8.6	1	8.6	26.22676
5	290	238	47	9.4	1	9.4	23.73994
5	430	378	140	28	1	28	6.991427
1	490	438	60	60	1	60	2.977512
1	560	508	70	70	1	70	2.505377
1	630	578	70	70	1	70	2.505377
1	700	648	70	70	1	70	2.505377
1	759	707	59	59	1	59	3.034091
1	820	768	61	61	1	61	2.922896
1	893	841	73	73	1	73	2.390349

Carlton County Control Section

West
Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	85	0					
5	130	45	45	9	1	9	24.92477
5	253	168	123	24.6	1	24.6	8.082311
1	293	208	40	40	1	40	4.688951
1	333	248	40	40	1	40	4.688951
1	371	286	38	38	1	38	4.966212
1	412	327	41	41	1	41	4.561051
1	452	367	40	40	1	40	4.688951
1	484	399	32	32	1	32	6.020255
1	515	430	31	31	1	31	6.238178
1	545	460	30	30	1	30	6.471531
1	578	493	33	33	1	33	5.816306
1	610	525	32	32	1	32	6.020255
1	641	556	31	31	1	31	6.238178
1	674	589	33	33	1	33	5.816306
1	712	627	38	38	1	38	4.966212
1	749	664	37	37	1	37	5.116782
1	782	697	33	33	1	33	5.816306
1	815	730	33	33	1	33	5.816306
1	832	747	17	17	1	17	12.22588
1	846	761	14	14	1	14	15.19566
1	852	767	6	6	1	6	39.25125
1	893	808	41	41	1	41	4.561051
1	923	838	30	30	1	30	6.471531

West
Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	50	0					
10	71	21	21	2.1	1	2.1	127.203
10	85	35	14	1.4	1	1.4	200.3178
10	93	43	8	0.8	1	0.8	374.9057
10	106	56	13	1.3	1	1.3	217.6538
10	119	69	13	1.3	1	1.3	217.6538
10	133	83	14	1.4	1	1.4	200.3178
10	151	101	18	1.8	1	1.8	151.1742
10	175	125	24	2.4	1	2.4	109.5333
10	215	165	40	4	1	4	61.81241
10	351	301	136	13.6	1	13.6	15.69709
5	472	422	121	24.2	1	24.2	8.232081
1	490	440	18	18	1	18	11.46773
1	511	461	21	21	1	21	9.649332
1	530	480	19	19	1	19	10.79391
1	552	502	22	22	1	22	9.159451
1	578	528	26	26	1	26	7.596485
1	606	556	28	28	1	28	6.991427
1	631	581	25	25	1	25	7.937615
1	656	606	25	25	1	25	7.937615
1	682	632	26	26	1	26	7.596485
1	702	652	20	20	1	20	10.19129
1	721	671	19	19	1	19	10.79391
1	734	684	13	13	1	13	16.51073
1	754	704	20	20	1	20	10.19129
1	785	735	31	31	1	31	6.238178
1	814	764	29	29	1	29	6.721978
1	849	799	35	35	1	35	5.445361
1	887	837	38	38	1	38	4.966212
1	924	874	37	37	1	37	5.116782

East Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	45	0					
10	70	25	25	2.5	1	2.5	104.6381
10	87	42	17	1.7	1	1.7	161.1685
10	115	70	28	2.8	1	2.8	92.16496
10	144	99	29	2.9	1	2.9	88.61293
10	177	132	33	3.3	1	3.3	76.67384
10	235	190	58	5.8	1	5.8	40.77026
10	276	231	41	4.1	1	4.1	60.12636
10	365	320	89	8.9	1	8.9	25.23865
3	471	426	106	35.33333333	1	35.33333333	5.387857
2	582	537	111	55.5	1	55.5	3.249187
1	647	602	65	65	1	65	2.722199
1	713	668	66	66	1	66	2.676046
1	775	730	62	62	1	62	2.870147
1	837	792	62	62	1	62	2.870147
1	879	834	42	42	1	42	4.439598
1	921	876	42	42	1	42	4.439598

East Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	64	0					
5	96	32	32	6.4	1	6.4	36.51416
5	118	54	22	4.4	1	4.4	55.55407
5	138	74	20	4	1	4	61.81241
5	159	95	21	4.2	1	4.2	58.5253
5	174	110	15	3	1	3	85.3114
5	201	137	27	5.4	1	5.4	44.1674
5	264	200	63	12.6	1	12.6	17.09889
1	300	236	36	36	1	36	5.276234
1	330	266	30	30	1	30	6.471531
1	348	284	18	18	1	18	11.46773
1	360	296	12	12	1	12	18.05926
1	370	306	10	10	1	10	22.15047
2	396	332	26	13	1	13	16.51073
2	439	375	43	21.5	1	21.5	9.398354
2	514	450	75	37.5	1	37.5	5.040433
1	583	519	69	69	1	69	2.546079
1	664	600	81	81	1	81	2.127549
1	750	686	86	86	1	86	1.989503
1	823	759	73	73	1	73	2.390349
1	900	836	77	77	1	77	2.251714

Carlton RAP 30% Section

North Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	80	0					
5	148	68	68	13.6	1	13.6	15.69709
10	240	160	92	9.2	1	9.2	24.31871
5	289	209	49	9.8	1	9.8	22.65738
5	333	253	44	8.8	1	8.8	25.56008
5	387	307	54	10.8	1	10.8	20.32115
3	484	404	97	32.33333333	1	32.33333333	5.950786
1	591	511	107	107	1	107	1.557661
1	724	644	133	133	1	133	1.220869
1	917	837	193	193	1	193	0.80456

North Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	40	0					
10	72	32	32	3.2	1	3.2	79.36242
10	92	52	20	2	1	2	134.3474
10	108	68	16	1.6	1	1.6	172.4918
10	120	80	12	1.2	1	1.2	238.0674
10	133	93	13	1.3	1	1.3	217.6538
10	144	104	11	1.1	1	1.1	262.4358
10	155	115	11	1.1	1	1.1	262.4358
10	163	123	8	0.8	1	0.8	374.9057
10	173	133	10	1	1	1	292
10	181	141	8	0.8	1	0.8	374.9057
10	193	153	12	1.2	1	1.2	238.0674
10	203	163	10	1	1	1	292
10	214	174	11	1.1	1	1.1	262.4358

10	220	180	6	0.6	1	0.6	517.4322
10	232	192	12	1.2	1	1.2	238.0674
10	242	202	10	1	1	1	292
10	255	215	13	1.3	1	1.3	217.6538
10	270	230	15	1.5	1	1.5	185.4217
10	293	253	23	2.3	1	2.3	114.8809
10	322	282	29	2.9	1	2.9	88.61293
10	378	338	56	5.6	1	5.6	42.40453
5	475	435	97	19.4	1	19.4	10.54496
1	516	476	41	41	1	41	4.561051
1	551	511	35	35	1	35	5.445361
1	591	551	40	40	1	40	4.688951
1	630	590	39	39	1	39	4.823813
1	664	624	34	34	1	34	5.625051
1	701	661	37	37	1	37	5.116782
1	761	721	60	60	1	60	2.977512
1	834	794	73	73	1	73	2.390349
1	922	882	88	88	1	88	1.938931

South Wheelbase

#Blows	**Cumulative Penetration**		**Penetration between reading**	**Penetration per Blow mm**	**Hammer Factor**	**DCP Index mm/blow**	**CBR%**
0	45	0					
10	63	18	18	1.8	1	1.8	151.1742
10	78	33	15	1.5	1	1.5	185.4217
10	90	45	12	1.2	1	1.2	238.0674
10	104	59	14	1.4	1	1.4	200.3178
10	114	69	10	1	1	1	292
10	125	80	11	1.1	1	1.1	262.4358
10	131	86	6	0.6	1	0.6	517.4322
10	135	90	4	0.4	1	0.4	814.8462
10	148	103	13	1.3	1	1.3	217.6538
10	158	113	10	1	1	1	292
10	169	124	11	1.1	1	1.1	262.4358

10	179	134	10	1	1	1	292
10	184	139	5	0.5	1	0.5	634.6532
10	198	153	14	1.4	1	1.4	200.3178
10	210	165	12	1.2	1	1.2	238.0674
10	219	174	9	0.9	1	0.9	328.5725
10	227	182	8	0.8	1	0.8	374.9057
10	237	192	10	1	1	1	292
10	247	202	10	1	1	1	292
10	263	218	16	1.6	1	1.6	172.4918
10	280	235	17	1.7	1	1.7	161.1685
10	295	250	15	1.5	1	1.5	185.4217
10	314	269	19	1.9	1	1.9	142.2915
10	333	288	19	1.9	1	1.9	142.2915
10	360	315	27	2.7	1	2.7	95.99651
10	390	345	30	3	1	3	85.3114
10	420	375	30	3	1	3	85.3114
10	456	411	36	3.6	1	3.6	69.55431
10	501	456	45	4.5	1	4.5	54.17324
5	550	505	49	9.8	1	9.8	22.65738
4	680	635	130	32.5	1	32.5	5.916617
1	727	682	47	47	1	47	3.914112
1	750	705	23	23	1	23	8.714604
1	837	792	87	87	1	87	1.963909
1	915	870	78	78	1	78	2.219407

South Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	80	0					
5	134	54	54	10.8	1	10.8	20.32115
5	190	110	56	11.2	1	11.2	19.51006
5	230	150	40	8	1	8	28.43951
5	272	192	42	8.4	1	8.4	26.92713
5	384	304	112	22.4	1	22.4	8.976459
1	445	365	61	61	1	61	2.922896
1	520	440	75	75	1	75	2.319072
1	620	540	100	100	1	100	1.680285

1	750	670	130	130	1	130	1.252467
1	855	775	105	105	1	105	1.590929

Carlton RAP 50% Section

North Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	90	0					
5	144	54	54	10.8	1	10.8	20.32115
5	235	145	91	18.2	1	18.2	11.32669
5	347	257	112	22.4	1	22.4	8.976459
4	533	443	186	46.5	1	46.5	3.96128
1	596	506	63	63	1	63	2.819171
1	656	566	60	60	1	60	2.977512
1	716	626	60	60	1	60	2.977512
1	783	693	67	67	1	67	2.631353
1	832	742	49	49	1	49	3.735625
1	890	800	58	58	1	58	3.092741

North Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	53	0					
10	93	40	40	4	1	4	61.81241
10	129	76	36	3.6	1	3.6	69.55431
10	159	106	30	3	1	3	85.3114
10	190	137	31	3.1	1	3.1	82.2352
10	230	177	40	4	1	4	61.81241
10	374	321	144	14.4	1	14.4	14.7237
1	400	347	26	26	1	26	7.596485
1	428	375	28	28	1	28	6.991427
1	457	404	29	29	1	29	6.721978
1	490	437	33	33	1	33	5.816306
1	528	475	38	38	1	38	4.966212
1	561	508	33	33	1	33	5.816306
1	600	547	39	39	1	39	4.823813
1	638	585	38	38	1	38	4.966212
1	674	621	36	36	1	36	5.276234
1	715	662	41	41	1	41	4.561051
1	762	709	47	47	1	47	3.914112
1	810	757	48	48	1	48	3.822898

1	870	817	60	60	1	60	2.977512
1	929	876	59	59	1	59	3.034091

South Wheelbase

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	46	0					
10	88	42	42	4.2	1	4.2	58.5253
10	110	64	22	2.2	1	2.2	120.7451
10	138	92	28	2.8	1	2.8	92.16496
10	159	113	21	2.1	1	2.1	127.203
10	177	131	18	1.8	1	1.8	151.1742
10	198	152	21	2.1	1	2.1	127.203
10	211	165	13	1.3	1	1.3	217.6538
10	234	188	23	2.3	1	2.3	114.8809
10	257	211	23	2.3	1	2.3	114.8809
10	283	237	26	2.6	1	2.6	100.1412
10	324	278	41	4.1	1	4.1	60.12636
10	410	364	86	8.6	1	8.6	26.22676
5	538	492	128	25.6	1	25.6	7.729548
1	590	544	52	52	1	52	3.495096
1	640	594	50	50	1	50	3.652048
1	690	644	50	50	1	50	3.652048
1	735	689	45	45	1	45	4.109461
1	780	734	45	45	1	45	4.109461
1	830	784	50	50	1	50	3.652048
1	875	829	45	45	1	45	4.109461

South Shoulder

#Blows	Cumulative Penetration		Penetration between reading	Penetration per Blow mm	Hammer Factor	DCP Index mm/blow	CBR%
0	82	0					
5	207	125	125	25	1	25	7.937615
1	252	170	45	45	1	45	4.109461
1	343	261	91	91	1	91	1.867482
1	438	356	95	95	1	95	1.779641
1	542	460	104	104	1	104	1.608072
1	664	582	122	122	1	122	1.344807
1	784	702	120	120	1	120	1.369935

1	908	826	124	124	1	124	1.320537

International Roughness Index Data

Goodhue County

Section (N to S)	Co-ordinates	Distance (miles)	Distance (m)
60%	44.263531,-92.610743	0.37	595.4574642
c.s.	44.258114,-92.610711	0.23	370.1492345
45%	44.254832,-92.610701	0.37	595.4574642
c.s.	44.249403,-92.610730	0.07	112.6541149
30%	44.248312,-92.610756	0.37	595.4574642
c.s.	44.242857,-92.610757	0.33	531.0836843
15%	44.238023,-92.610763	0.37	595.4574642

Run1

DateTime	Latitude	Longitude	Distance(m)	Speed (km/h)	Altitude (m)	eIRI	cIRI
6/11/2015 6:56	44.26358608	-92.61082893	4180	61.2	301	1.23	1.5
6/11/2015 6:56	44.26346205	-92.61083184	4160	61.2	301	1.12	1.51
6/11/2015 6:56	44.26333702	-92.61083344	4140	61.2	301	1.03	1.52
6/11/2015 6:56	44.26320896	-92.6108313	4120	61.65	300.5	1.02	1.39
6/11/2015 6:56	44.26276592	-92.61081631	4100	63	300	1.05	1.38
6/11/2015 6:56	44.26262882	-92.61080945	4080	64.8	300	1.13	1.65
6/11/2015 6:56	44.2624857	-92.61080382	4060	65.7	300	1.21	1.81
6/11/2015 6:56	44.26233164	-92.61079954	4040	66.15	300	1.25	1.97
6/11/2015 6:56	44.26217562	-92.61079691	4020	66.6	300.5	1.29	2.09
6/11/2015 6:56	44.2620236	-92.61079508	4000	66.6	301	1.2	2.21
6/11/2015 6:56	44.26186457	-92.61079561	3980	66.6	301.5	1.15	1.94
6/11/2015 6:56	44.26170155	-92.61079835	3960	67.5	302	1.23	1.68
6/11/2015 6:56	44.26154154	-92.61079871	3940	68.4	302	1.13	1.5
6/11/2015 6:56	44.26138151	-92.61079893	3920	69.3	302	1.15	1.31
6/11/2015 6:56	44.26121649	-92.61080239	3900	70.65	302	1.18	1.61
6/11/2015 6:56	44.26105032	-92.61080235	3880	71.55	302	1.19	1.91
6/11/2015 6:56	44.26088028	-92.61079272	3860	72	302	1.24	1.78
6/11/2015 6:56	44.26069826	-92.6107907	3840	72	302	1.12	1.34
6/11/2015 6:56	44.26051624	-92.61078855	3820	72	302.5	1.15	1.28
6/11/2015 6:55	44.26033023	-92.61078582	3800	71.1	303.5	1.19	1.61
6/11/2015 6:55	44.26014921	-92.61078468	3780	70.2	304.5	1.22	1.47
6/11/2015 6:55	44.2599742	-92.610783	3760	69.3	306	1.25	1.26

6/11/2015 6:55	44.25980318	-92.61078267	3740	68.4	307.5	1.21	1.65
6/11/2015 6:55	44.25964516	-92.61078008	3720	67.5	308.5	1.28	2.04
6/11/2015 6:55	44.25915814	-92.61077329	3700	66.3	310	1.17	1.44
6/11/2015 6:55	44.25900307	-92.61076769	3680	65.25	311	1.05	1.19
6/11/2015 6:55	44.25885101	-92.6107662	3660	64.8	311.5	1.06	1.24
6/11/2015 6:55	44.25870599	-92.61076389	3640	64.8	312.5	1	1.5
6/11/2015 6:55	44.25856597	-92.61076184	3620	64.35	313	1.04	1.75
6/11/2015 6:55	44.25842595	-92.61076055	3600	63.9	313.5	1.16	1.54
6/11/2015 6:55	44.25828693	-92.6107587	3580	63.9	314	1.11	1.33
6/11/2015 6:55	44.25814689	-92.6107552	3560	63.9	314.5	1.14	1.31
6/11/2015 6:55	44.25482248	-92.61074514	3200	63.9	314	1.13	1.64
6/11/2015 6:55	44.25468746	-92.61074268	3180	63.9	314	1.15	1.5
6/11/2015 6:55	44.25454645	-92.610742	3160	64.35	314	1.23	1.35
6/11/2015 6:55	44.25440444	-92.610742	3140	64.8	314	1.15	1.51
6/11/2015 6:55	44.25393441	-92.61074104	3120	63.9	314.33	1.04	1.64
6/11/2015 6:55	44.25379638	-92.610741	3100	62.55	315.5	1.07	1.6
6/11/2015 6:55	44.25366437	-92.61074172	3080	62.1	316	1.2	2.18
6/11/2015 6:55	44.25353233	-92.61074537	3060	62.1	315.5	1.31	2.77
6/11/2015 6:55	44.25339929	-92.61074759	3040	62.55	315	1.4	2.2
6/11/2015 6:55	44.25326927	-92.61074675	3020	63	314.5	1.39	1.63
6/11/2015 6:55	44.25313424	-92.61074647	3000	63.9	313.5	1.36	1.67
6/11/2015 6:55	44.25267323	-92.61074801	2980	64.8	313	1.36	1.57
6/11/2015 6:55	44.25253021	-92.61075325	2960	64.35	313	1.12	1.3
6/11/2015 6:55	44.25238814	-92.61075095	2940	63.45	313	1.04	1.42
6/11/2015 6:55	44.25225111	-92.61074811	2920	62.55	313	0.97	1.54
6/11/2015 6:55	44.25211909	-92.610747	2900	61.65	313	1.03	1.29
6/11/2015 6:55	44.25198908	-92.61074668	2880	60.75	313	1.15	1.03
6/11/2015 6:55	44.25186607	-92.610746	2860	60.3	312.5	1.13	1.01
6/11/2015 6:55	44.25144894	-92.61075037	2840	60.3	312	0.99	1.12
6/11/2015 6:55	44.2513279	-92.61075286	2820	60.3	311.5	0.95	1.39
6/11/2015 6:55	44.25120683	-92.61075762	2800	60.75	311	0.99	1.26
6/11/2015 6:55	44.25108075	-92.61076272	2780	61.2	310.5	1.02	1.13
6/11/2015 6:55	44.25094972	-92.61076638	2760	61.65	309.5	1.06	1.27
6/11/2015 6:54	44.25081871	-92.61076803	2740	62.1	309	1.11	1.41
6/11/2015 6:54	44.25037665	-92.61077053	2720	62.7	308.67	1.09	1.04
6/11/2015 6:54	44.25024362	-92.61076784	2700	63.45	308	1.16	1.05
6/11/2015 6:54	44.25010759	-92.61076758	2680	63.9	307.5	1.12	1.24
6/11/2015 6:54	44.24996758	-92.61076936	2660	63.45	307	1.05	1.3
6/11/2015 6:54	44.24983056	-92.61077163	2640	63.45	307	1.03	1.36
6/11/2015 6:54	44.24969254	-92.61077319	2620	63.45	307.5	1.07	1.31
6/11/2015 6:54	44.2495505	-92.61077436	2600	63	307.5	1.3	1.27

6/11/2015 6:54	44.24820233	-92.61076013	2480	56.7	306	1.28	1.58
6/11/2015 6:54	44.2481013	-92.61076206	2460	57.15	304.5	1.21	1.71
6/11/2015 6:54	44.24800526	-92.61076453	2440	58.5	303.5	1.27	1.81
6/11/2015 6:54	44.24790023	-92.6107674	2420	59.4	303	1.26	1.71
6/11/2015 6:54	44.24748821	-92.61077474	2400	60.6	302	1.23	1.46
6/11/2015 6:54	44.24736218	-92.61077573	2380	61.65	300.5	1.19	1.16
6/11/2015 6:54	44.24723717	-92.610776	2360	62.1	300	1.12	1.66
6/11/2015 6:54	44.24711316	-92.61077674	2340	63	300	1.13	2.16
6/11/2015 6:54	44.24698215	-92.610778	2320	63.9	300	1.21	1.88
6/11/2015 6:54	44.24684714	-92.610778	2300	63.9	300	1.28	1.6
6/11/2015 6:54	44.24637413	-92.61077506	2280	64.5	300	1.26	1.66
6/11/2015 6:54	44.2462281	-92.610775	2260	64.8	300	1.25	1.42
6/11/2015 6:54	44.24607709	-92.61077422	2240	63.9	300.5	1.09	1.15
6/11/2015 6:54	44.24593108	-92.6107733	2220	63	301	1.11	1.36
6/11/2015 6:54	44.24579607	-92.61077245	2200	62.55	301.5	1.23	1.57
6/11/2015 6:54	44.24566005	-92.61077324	2180	61.65	302	1.23	1.32
6/11/2015 6:54	44.24553102	-92.61077573	2160	61.2	302	1.22	1.07
6/11/2015 6:54	44.24540401	-92.610778	2140	61.2	302	1.14	1.05
6/11/2015 6:54	44.24496494	-92.61078583	2120	61.8	301	1.02	1.08
6/11/2015 6:54	44.24483691	-92.61079048	2100	62.55	299.5	1.04	1.2
6/11/2015 6:54	44.24470785	-92.610792	2080	63	299	1.07	1.17
6/11/2015 6:54	44.24457784	-92.61079116	2060	62.55	299	1.11	1.14
6/11/2015 6:54	44.24444778	-92.61079156	2040	62.1	299	1.07	1.26
6/11/2015 6:54	44.24431975	-92.61079617	2020	61.65	299.5	0.96	1.38
6/11/2015 6:54	44.24388674	-92.61080182	2000	61.2	299.33	1	1.08
6/11/2015 6:54	44.24375872	-92.61080348	1980	61.2	299	1.09	1.19
6/11/2015 6:54	44.24363168	-92.61080058	1960	60.75	299	1.07	1.46
6/11/2015 6:54	44.24350863	-92.61079762	1940	60.3	299	1.1	1.55
6/11/2015 6:54	44.24338062	-92.610797	1920	60.75	299	1.08	1.64
6/11/2015 6:54	44.2432516	-92.61079713	1900	61.2	299	1.03	2.05
6/11/2015 6:54	44.24282157	-92.61080046	1880	61.5	298.33	1.25	2.12
6/11/2015 6:53	44.23803866	-92.61081606	1320	62.1	288	1.21	1.66
6/11/2015 6:53	44.23760463	-92.61082372	1300	62.1	288	1.23	1.21
6/11/2015 6:53	44.23747461	-92.61082193	1280	62.1	287.5	1.1	1.6
6/11/2015 6:53	44.23734359	-92.61082154	1260	62.1	287	1.09	1.57
6/11/2015 6:53	44.23721357	-92.61082312	1240	62.1	287	1.12	1.55
6/11/2015 6:53	44.23708355	-92.610825	1220	62.1	287	1.12	1.57
6/11/2015 6:53	44.23695354	-92.610825	1200	61.65	287	1.15	1.6
6/11/2015 6:53	44.23652052	-92.61083051	1180	61.8	286.67	1.3	1.28
6/11/2015 6:53	44.23639549	-92.61083238	1160	62.1	286	1.12	1.43
6/11/2015 6:53	44.23626447	-92.61083194	1140	62.1	286.5	1.02	1.74

6/11/2015 6:53	44.23613445	-92.61083211	1120	62.1	286.5	1.08	1.68
6/11/2015 6:53	44.23600743	-92.6108336	1100	62.1	286	1.1	1.62
6/11/2015 6:53	44.23587336	-92.6108324	1080	62.1	286	1.1	1.66
6/11/2015 6:53	44.23542535	-92.61083808	1060	62.1	286	1.17	1.77
6/11/2015 6:53	44.23529229	-92.61084635	1040	62.1	286	1.05	1.89
6/11/2015 6:53	44.23515913	-92.61085085	1020	62.1	286	0.97	1.46
6/11/2015 6:53	44.23502908	-92.61085427	1000	62.1	286	1.03	1.03
6/11/2015 6:53	44.23490004	-92.61085585	980	62.1	286.5	1.05	1.26
6/11/2015 6:53	44.23476791	-92.61085431	960	62.1	287	1.09	1.48
6/11/2015 6:53	44.23432785	-92.61087185	940	62.1	287	1.07	1.43
6/11/2015 6:53	44.23419678	-92.61087282	920	62.1	286.5	1.02	1.25
6/11/2015 6:53	44.23406376	-92.61087566	900	62.55	286	1.06	1.1
6/11/2015 6:53	44.23393071	-92.61088009	880	63	286	1.05	1.31
6/11/2015 6:53	44.23379762	-92.61088556	860	63.45	286	1.03	1.53
6/11/2015 6:53	44.23366057	-92.61089047	840	63.9	286.5	1.06	1.44
6/11/2015 6:53	44.23351954	-92.61089246	820	65.25	286.5	1.02	1.34
6/11/2015 6:53	44.23337453	-92.61089598	800	66.6	286	1.01	1.18
6/11/2015 6:53	44.23288351	-92.61089016	780	67.2	286.33	1.09	1.31
6/11/2015 6:53	44.23273047	-92.61088389	760	67.95	287	1.09	1.89
6/11/2015 6:53	44.2325684	-92.610883	740	68.4	287.5	1.11	1.5
6/11/2015 6:51	44.22410138	-92.61297602	1000	62.55	316	1.18	1.11
6/11/2015 6:51	44.22410377	-92.61337673	980	63.3	316	0.97	1.18
6/11/2015 6:51	44.22410485	-92.61349099	960	63.9	316	0.93	1.46
6/11/2015 6:51	44.22410549	-92.61353819	940	63.9	315.67	1.01	1.27
6/11/2015 6:51	44.22411149	-92.61395395	920	63.9	315.67	1.01	1.27
6/11/2015 6:51	44.22411425	-92.61414968	900	64.35	315	1.01	1.23
6/11/2015 6:51	44.22411563	-92.61435343	880	64.8	314.5	1	1.28
6/11/2015 6:51	44.22411904	-92.61455714	860	64.8	314	1.03	1.32
6/11/2015 6:51	44.224122	-92.61521386	840	64.8	314.33	1.06	1.36
6/11/2015 6:51	44.22412453	-92.61541656	820	65.25	315	1.06	1.37
6/11/2015 6:51	44.2241248	-92.61554151	800	66.15	315.5	1.06	1.55
6/11/2015 6:51	44.2241247	-92.615583	780	66.6	316	1.1	1.64
6/11/2015 6:51	44.224124	-92.61592831	760	66.6	316	1.1	1.64
6/11/2015 6:51	44.224124	-92.61597739	740	66	316.33	1.06	1.35
6/11/2015 6:51	44.22412405	-92.61635764	720	66	316.33	1.06	1.35
6/11/2015 6:51	44.22412421	-92.6163948	700	64.8	317	1.06	1.14
6/11/2015 6:51	44.22412611	-92.6168365	680	64.8	317	1.06	1.14
6/11/2015 6:51	44.224126	-92.6172642	660	64.8	317	1.04	1.21
6/11/2015 6:51	44.22412589	-92.61769591	640	64.5	317	1.02	1.07
6/11/2015 6:51	44.2241292	-92.61789862	620	63	317	0.98	1.1
6/11/2015 6:51	44.22413067	-92.61809038	600	61.2	317	0.95	1.19

6/11/2015 6:51	44.2241315	-92.61826708	580	60.3	317	1.02	1.21
6/11/2015 6:51	44.22413318	-92.61843084	560	59.85	316.5	1.15	1.24
6/11/2015 6:51	44.224136	-92.61859356	540	59.4	316	1.08	1.06
6/11/2015 6:51	44.22413628	-92.61910848	520	59.4	314.67	0.99	1.11
6/11/2015 6:51	44.22413634	-92.61913096	500	59.7	312.33	1.08	1.42
6/11/2015 6:51	44.22413731	-92.61942666	480	59.7	312.33	1.08	1.42
6/11/2015 6:51	44.22413794	-92.61946345	460	60.9	310.67	1.16	1.18
6/11/2015 6:51	44.22414508	-92.62005217	440	60.9	310.67	1.16	1.18
6/11/2015 6:51	44.22415413	-92.62044291	420	62.4	309.67	1.06	1.22
6/11/2015 6:51	44.22416104	-92.62063	400	63	309	1.04	1.32
6/11/2015 6:51	44.22416423	-92.62081692	380	63.45	308.5	1.16	1.67
6/11/2015 6:51	44.22416512	-92.62092797	360	63.9	308	1.19	2.02
6/11/2015 6:51	44.22416532	-92.62097233	340	64.2	308	1.22	1.71
6/11/2015 6:51	44.224167	-92.62138103	320	64.2	308	1.22	1.71
6/11/2015 6:51	44.22416647	-92.62179873	300	64.8	307.5	1.19	1.19
6/11/2015 6:51	44.22416442	-92.62218526	280	65.1	307	1.01	0.96
6/11/2015 6:51	44.22416433	-92.62219615	260	66.3	307	0.92	1.25
6/11/2015 6:51	44.22416133	-92.62256094	240	66.3	307	0.92	1.25
6/11/2015 6:51	44.22416104	-92.62260458	220	67.5	307	1.06	1.38
6/11/2015 6:51	44.22415976	-92.62297595	200	67.5	307	1.06	1.38
6/11/2015 6:51	44.22416045	-92.62303004	180	67.8	307	1.1	1.51
6/11/2015 6:51	44.22416793	-92.62348287	160	67.8	307	1.1	1.51
6/11/2015 6:51	44.22417236	-92.62370365	140	68.4	307	1.06	1.18
6/11/2015 6:51	44.22417389	-92.62392538	120	68.85	307	1.08	1.2
6/11/2015 6:50	44.22417574	-92.62415609	100	69.3	307	1.07	1.22
6/11/2015 6:50	44.22417454	-92.6243918	80	68.85	307.5	1.08	1.56

Run2

DateTime	Latitude	Longitude	Distance(m)	Speed (km/h)	Altitude (m)	eIRI	cIRI
6/11/2015 6:45	44.26327539	-92.610822	220	60.75	301	1.26	2.63
6/11/2015 6:45	44.26314338	-92.61082041	240	61.2	301	1.11	2.19
6/11/2015 6:45	44.26301436	-92.61081937	260	61.2	300.5	1.15	1.76
6/11/2015 6:45	44.26288435	-92.61081853	280	61.2	300	1.15	1.34
6/11/2015 6:45	44.26275433	-92.61081738	300	61.2	300	1.22	1.29
6/11/2015 6:45	44.26262627	-92.61081519	320	61.2	300	1.32	1.64
6/11/2015 6:45	44.26219322	-92.610806	340	60.75	300	1.33	2.41
6/11/2015 6:45	44.26206721	-92.61080364	360	60.3	300	1.18	1.98
6/11/2015 6:45	44.26194918	-92.61080124	380	59.85	300.5	1.22	1.54
6/11/2015 6:45	44.26183816	-92.61079965	400	59.4	301	1.29	1.54
6/11/2015 6:45	44.26172914	-92.61079921	420	59.4	301.67	1.31	2

6/11/2015 6:45	44.26131908	-92.61080132	440	59.4	301.5	1.2	2.94
6/11/2015 6:45	44.26119802	-92.61080269	460	59.85	301	1.33	2.24
6/11/2015 6:45	44.26107198	-92.61080045	480	60.3	301	1.34	1.55
6/11/2015 6:45	44.26094791	-92.61079606	500	60.75	301	1.12	1.67
6/11/2015 6:45	44.26082388	-92.61079185	520	61.2	301.33	1.08	1.75
6/11/2015 6:45	44.26039487	-92.61078808	540	60.75	302.5	1.08	1.65
6/11/2015 6:45	44.26027684	-92.61078572	560	59.85	303	1.11	1.36
6/11/2015 6:45	44.26016081	-92.6107861	580	59.4	303.5	1.24	1.08
6/11/2015 6:45	44.2600518	-92.6107867	600	58.95	304.5	1.35	1.55
6/11/2015 6:45	44.25994578	-92.61078591	620	57.6	305.67	1.53	2.09
6/11/2015 6:45	44.25957476	-92.61078528	640	56.7	306.5	1.49	2.22
6/11/2015 6:45	44.25947265	-92.61078061	660	56.7	307.5	1.24	2.04
6/11/2015 6:45	44.25936855	-92.61077466	680	57	309	1.2	1.67
6/11/2015 6:45	44.25898053	-92.61077646	700	57.6	310	1.24	1.32
6/11/2015 6:45	44.25887043	-92.61078155	720	58.05	310.5	1.16	1.74
6/11/2015 6:45	44.25875835	-92.61078568	740	58.5	311	1.08	2.16
6/11/2015 6:45	44.25864531	-92.61078739	760	58.8	311.67	1.21	1.51
6/11/2015 6:45	44.25823323	-92.6107761	780	59.85	312.5	1.42	1.44
6/11/2015 6:45	44.25810617	-92.61076809	800	60.75	313.5	1.42	1.69
6/11/2015 6:46	44.2548144	-92.61075524	1180	63.45	314.5	1.01	0.94
6/11/2015 6:46	44.25467839	-92.61075424	1200	63	315	0.96	0.73
6/11/2015 6:46	44.25454436	-92.61075526	1220	62.7	315	0.99	0.75
6/11/2015 6:46	44.25410535	-92.61076268	1240	62.1	315	1.08	0.99
6/11/2015 6:46	44.25397531	-92.61076453	1260	61.65	315	1.1	1.23
6/11/2015 6:46	44.2538473	-92.6107656	1280	61.2	315.5	1.14	1.18
6/11/2015 6:46	44.25372327	-92.61076435	1300	61.2	316	1.22	1.12
6/11/2015 6:46	44.2536032	-92.61076073	1320	61.2	316	1.25	1.38
6/11/2015 6:46	44.25348118	-92.610756	1340	62.1	315.33	1.24	1.46
6/11/2015 6:46	44.25303111	-92.61075	1360	63.45	314.5	1.14	1.1
6/11/2015 6:46	44.25289609	-92.61074621	1380	63.9	314	1.22	1.19
6/11/2015 6:46	44.25276205	-92.61074561	1400	63.45	314	1.31	1.28
6/11/2015 6:46	44.25262502	-92.61074837	1420	63	314	1.25	1.54
6/11/2015 6:46	44.25249597	-92.61075221	1440	62.55	314.5	1.2	1.81
6/11/2015 6:46	44.25237294	-92.61075525	1460	61.5	314.67	1.22	1.5
6/11/2015 6:46	44.25194587	-92.61075931	1480	61.2	314	1.22	1.59
6/11/2015 6:46	44.25181483	-92.610759	1500	61.65	314	1.18	1.83
6/11/2015 6:46	44.25167981	-92.61075653	1520	62.55	314	1.09	1.81
6/11/2015 6:46	44.25154479	-92.61075452	1540	63	313.5	1.03	1.79
6/11/2015 6:46	44.25140777	-92.61075297	1560	63.45	312.5	1.07	1.54
6/11/2015 6:46	44.25126475	-92.610751	1580	63.9	311.5	1.27	1.28
6/11/2015 6:46	44.25112174	-92.61075111	1600	64.5	310	1.22	1.73

6/11/2015 6:46	44.25065773	-92.61075397	1620	64.8	309	1.15	1.77
6/11/2015 6:46	44.25051471	-92.61075577	1640	64.8	309	1.15	1.59
6/11/2015 6:46	44.25037267	-92.61076209	1660	64.8	308.5	1.08	1.31
6/11/2015 6:46	44.25023157	-92.61076593	1680	64.8	308	0.99	1.02
6/11/2015 6:46	44.25009055	-92.61076596	1700	64.35	308	1	0.98
6/11/2015 6:46	44.24995054	-92.6107654	1720	63.45	308	0.97	0.94
6/11/2015 6:46	44.24981553	-92.61076575	1740	62.55	308	0.98	1.09
6/11/2015 6:46	44.24968351	-92.61076509	1760	62.1	308	1.25	1.34
6/11/2015 6:46	44.2492415	-92.61077078	1780	62.1	307.5	1.22	1.57
6/11/2015 6:46	44.24799035	-92.61076411	1920	64.35	303.5	1.1	1.38
6/11/2015 6:46	44.24784433	-92.61076165	1940	65.25	302.5	1.26	2.03
6/11/2015 6:46	44.24769328	-92.61075546	1960	66.15	301.5	1.24	2.67
6/11/2015 6:46	44.2475372	-92.61075238	1980	67.05	301	1.14	1.93
6/11/2015 6:46	44.24738018	-92.61075421	2000	67.5	300.5	1.16	1.2
6/11/2015 6:46	44.24722508	-92.61076079	2020	67.5	300	1.06	1.55
6/11/2015 6:46	44.24707199	-92.6107664	2040	67.05	300	1.03	1.91
6/11/2015 6:46	44.24692298	-92.6107664	2060	66.15	300	1.14	1.73
6/11/2015 6:46	44.24677696	-92.6107652	2080	65.25	300	1.24	1.55
6/11/2015 6:46	44.24663486	-92.61076656	2100	63.9	300	1.23	1.84
6/11/2015 6:46	44.24619383	-92.61078036	2120	62.1	300	1.12	1.44
6/11/2015 6:46	44.24606774	-92.61077808	2140	60.75	300.5	1.16	0.9
6/11/2015 6:46	44.24594471	-92.61077755	2160	59.85	301	1.13	1.26
6/11/2015 6:46	44.24583265	-92.61077986	2180	58.95	301.5	1.13	1.61
6/11/2015 6:46	44.24572362	-92.610784	2200	58.5	302	1.29	1.48
6/11/2015 6:47	44.2453126	-92.61077995	2220	59.4	302	1.24	1.68
6/11/2015 6:47	44.24518354	-92.610779	2240	60.75	301.5	1.12	1.95
6/11/2015 6:47	44.24505153	-92.61077952	2260	61.65	301	0.97	1.58
6/11/2015 6:47	44.24491252	-92.61078079	2280	62.55	300.5	0.96	1.2
6/11/2015 6:47	44.2447725	-92.6107812	2300	63.45	299.5	1.01	1.11
6/11/2015 6:47	44.24463848	-92.61077923	2320	63.6	299	1.07	1.22
6/11/2015 6:47	44.24419146	-92.61078397	2340	63	299	1.07	1.62
6/11/2015 6:47	44.24405845	-92.61078564	2360	62.55	299	1.03	1.43
6/11/2015 6:47	44.24392642	-92.61078333	2380	62.1	299	1.03	1.23
6/11/2015 6:47	44.2437914	-92.610782	2400	62.1	299	1.07	1.22
6/11/2015 6:47	44.24365438	-92.61078277	2420	62.1	299	1.12	1.21
6/11/2015 6:47	44.24352434	-92.6107851	2440	62.1	298.5	1.08	1.23
6/11/2015 6:47	44.24339532	-92.61078906	2460	62.1	298	1.11	1.23
6/11/2015 6:47	44.2429493	-92.61079164	2480	62.1	298	1.19	1.19
6/11/2015 6:47	44.24281226	-92.61079509	2500	62.55	297.5	1.13	1.25
6/11/2015 6:47	44.23808223	-92.61080498	3040	68.4	288	1.36	1.91
6/11/2015 6:47	44.23792915	-92.61081176	3060	67.95	288	1.4	2.19

6/11/2015 6:47	44.23777412	-92.61081644	3080	67.05	288	1.24	1.98
6/11/2015 6:47	44.23762108	-92.61081853	3100	66	287.67	1.1	1.56
6/11/2015 6:47	44.23717199	-92.61083387	3120	64.35	287	1.04	1.14
6/11/2015 6:47	44.23703694	-92.61083482	3140	63.45	287.5	1.04	1.39
6/11/2015 6:47	44.23689893	-92.61083431	3160	63	288	1.06	1.65
6/11/2015 6:47	44.2367689	-92.61083615	3180	62.55	287.5	1.14	1.45
6/11/2015 6:47	44.23664288	-92.61083836	3200	62.1	287	1.18	1.26
6/11/2015 6:47	44.23650884	-92.61083789	3220	62.1	287	1.07	1.27
6/11/2015 6:47	44.23637282	-92.610834	3240	62.1	287	1.1	1.4
6/11/2015 6:47	44.23593279	-92.61083792	3260	62.1	287	1.16	1.62
6/11/2015 6:48	44.23580677	-92.61084244	3280	62.1	287	1.19	1.39
6/11/2015 6:48	44.23568071	-92.61084513	3300	62.1	287	1.11	1.16
6/11/2015 6:48	44.23555669	-92.61084714	3320	61.65	287	1.1	1.55
6/11/2015 6:48	44.23543267	-92.6108486	3340	61.2	287	1.08	1.94
6/11/2015 6:48	44.23530959	-92.61084702	3360	61.2	287	1.06	1.7
6/11/2015 6:48	44.23487558	-92.61085334	3380	61.65	287	1.12	1.26
6/11/2015 6:48	44.23474853	-92.61085839	3400	62.1	287	1.13	0.93
6/11/2015 6:48	44.23462444	-92.61086197	3420	61.65	287	1.02	1.32
6/11/2015 6:48	44.23449741	-92.61086425	3440	61.2	287	0.99	1.7
6/11/2015 6:48	44.23436939	-92.610867	3460	61.5	287	1.05	1.43
6/11/2015 6:48	44.23392937	-92.61087698	3480	62.1	287	1.13	1.38
6/11/2015 6:48	44.23380125	-92.61087864	3500	62.1	287.5	1.17	1.46
6/11/2015 6:48	44.23367324	-92.61087834	3520	61.65	288	1.22	1.54
6/11/2015 6:48	44.23354622	-92.61087993	3540	61.2	287.5	1.16	1.62
6/11/2015 6:48	44.23341619	-92.61088168	3560	61.2	287.5	1.09	1.37
6/11/2015 6:48	44.23328818	-92.610881	3580	61.2	287.67	1.11	1.22
6/11/2015 6:48	44.23284717	-92.61087501	3600	61.2	287	1.16	1.46
6/11/2015 6:48	44.23271912	-92.61087334	3620	61.2	287.5	1.08	1.52
6/11/2015 6:48	44.2325931	-92.610873	3640	61.2	288	1.03	1.59
6/11/2015 6:49	44.224092	-92.61279	20	54	316	1.08	0
6/11/2015 6:49	44.22409676	-92.61298085	40	59.4	316.67	1.11	0.95
6/11/2015 6:49	44.22410213	-92.61361266	60	59.4	316.67	1.11	0.95
6/11/2015 6:49	44.22410204	-92.61365354	80	62.7	317	1.05	1.44
6/11/2015 6:49	44.2241057	-92.61401008	100	62.7	317	1.05	1.44
6/11/2015 6:49	44.22410625	-92.61406059	120	64.8	316.33	0.94	1.18
6/11/2015 6:49	44.22410764	-92.61442251	140	64.8	316.33	0.94	1.18
6/11/2015 6:49	44.22410772	-92.61445665	160	65.7	316	1.01	1.19
6/11/2015 6:49	44.224108	-92.61482691	180	65.1	316	1.06	1.2
6/11/2015 6:49	44.22411192	-92.61547261	200	65.1	316	1.06	1.2
6/11/2015 6:49	44.224112	-92.61548064	220	64.35	316.5	1.03	1.19
6/11/2015 6:49	44.22411343	-92.61563705	240	63.9	317	1.05	1.2

6/11/2015 6:49	44.22411742	-92.61582383	260	63.45	317.5	1.05	1.48
6/11/2015 6:49	44.22412214	-92.61601168	280	63	318	1.02	1.77
6/11/2015 6:49	44.224125	-92.61619342	300	62.4	318.67	1.07	1.4
6/11/2015 6:49	44.22412717	-92.61658014	320	62.1	319.67	1.07	1.34
6/11/2015 6:49	44.22412614	-92.61718586	340	62.1	319.67	1.07	1.34
6/11/2015 6:49	44.22412602	-92.61720377	360	62.1	320	1.05	1.36
6/11/2015 6:50	44.22412281	-92.61755428	380	62.1	320	1.05	1.36
6/11/2015 6:50	44.22412239	-92.61760085	400	62.1	319.33	1.04	1.3
6/11/2015 6:50	44.22412596	-92.61793773	420	62.1	319.33	1.04	1.3
6/11/2015 6:50	44.22412642	-92.61797216	440	62.7	319	0.92	1.24
6/11/2015 6:50	44.22412958	-92.61832019	460	63	319	1.02	1.06
6/11/2015 6:50	44.22412918	-92.6187329	480	63	319	1.1	0.89
6/11/2015 6:50	44.2241298	-92.61892762	500	63	318.5	1.01	1
6/11/2015 6:50	44.22413067	-92.61912132	520	63.9	317	0.98	1.11
6/11/2015 6:50	44.22413155	-92.61931902	540	64.8	315.5	0.96	1.24
6/11/2015 6:50	44.224132	-92.61952873	560	65.7	314.5	0.97	1.36
6/11/2015 6:50	44.22413161	-92.61974843	580	67.05	313.5	1.12	1.35
6/11/2015 6:50	44.22413233	-92.61996817	600	68.1	312.33	1.19	1.41
6/11/2015 6:50	44.22413758	-92.6204369	620	68.1	312.33	1.19	1.41
6/11/2015 6:50	44.22413794	-92.62048111	640	68.85	311	1.14	1.55
6/11/2015 6:50	44.22413942	-92.62065833	660	68.85	310	1.01	1.51
6/11/2015 6:50	44.22414132	-92.62088705	680	68.4	310	0.99	1.48
6/11/2015 6:50	44.22414337	-92.62110881	700	68.4	309.5	1.04	1.34
6/11/2015 6:50	44.22414722	-92.62133161	720	68.1	309.67	1.11	1.28
6/11/2015 6:50	44.22415306	-92.62201935	740	67.05	309.5	1.17	1.4
6/11/2015 6:50	44.22415747	-92.62222808	760	66.6	309	1.14	1.58
6/11/2015 6:50	44.22415958	-92.62243287	780	66.15	309	1.08	1.76
6/11/2015 6:50	44.22416139	-92.62263859	800	65.25	309.5	1.04	1.52
6/11/2015 6:50	44.22416375	-92.62283732	820	64.35	310	1.09	1.28
6/11/2015 6:50	44.224165	-92.62302804	840	63.45	310	1.12	1.67
6/11/2015 6:50	44.22416411	-92.62321277	860	62.55	310	1.1	2.07
6/11/2015 6:50	44.22416213	-92.62339348	880	61.5	310	1.13	1.61
6/11/2015 6:50	44.224162	-92.62399418	900	61.2	310	1.1	1.23
6/11/2015 6:50	44.22416431	-92.62416689	920	60.75	310	1.13	1.08
6/11/2015 6:50	44.22416382	-92.62433963	940	60.3	310	1.15	1.52

Carlton County

Section (N to S)	Co-ordinates	Distance (miles)	Distance (m)
30%	46.519195, -92.486751	0.7	1126.541149
50%	46.519128, -92.472024	0.3	482.8033494
	46.519106, -92.467085		
C.S	44.248312,-92.610756	0.37	595.4574642

Run1

DateTime	Latitude	Longitude	Distance(m)	Speed (km/h)	Altitude (m)	eIRI	cIRI
6/10/2015 7:01	46.51920187	-92.48640322	2160	45.6	266	1.01	1.15
6/10/2015 7:01	46.51920001	-92.48634067	2140	48.15	265	1.02	1.43
6/10/2015 7:01	46.51918912	-92.48593113	2120	49.2	264	1.13	1.69
6/10/2015 7:01	46.51918767	-92.48582965	2100	51.3	263	1.29	1.47
6/10/2015 7:01	46.51918223	-92.48534125	2080	53.7	262	1.11	1.28
6/10/2015 7:01	46.51918141	-92.48521184	2060	55.35	260.5	1.09	1.2
6/10/2015 7:01	46.51918189	-92.48507044	2040	55.8	260	1.1	1.21
6/10/2015 7:01	46.51918599	-92.48452606	2020	55.2	260.33	1.04	1.39
6/10/2015 7:01	46.51918391	-92.48438767	2000	54.45	261.5	1.04	1.77
6/10/2015 7:01	46.51917821	-92.48424584	1980	53.55	263	1.09	2.08
6/10/2015 7:01	46.51917106	-92.48411117	1960	52.65	264	1.14	1.75
6/10/2015 7:01	46.51917	-92.48359879	1940	51.9	265.33	1.15	1.72
6/10/2015 7:01	46.51916928	-92.48347641	1920	51.3	266	1.16	2.32
6/10/2015 7:01	46.51916218	-92.48299898	1900	51.6	265.67	1.18	1.68
6/10/2015 7:01	46.51916093	-92.48288856	1880	52.2	265.5	1.11	1.24
6/10/2015 7:01	46.51915982	-92.48276718	1860	52.2	265	0.99	1.13
6/10/2015 7:01	46.51915521	-92.48226876	1840	52.2	265	0.95	1.13
6/10/2015 7:01	46.51915628	-92.48214736	1820	52.2	265	1	1.33
6/10/2015 7:01	46.51915807	-92.48202397	1800	52.2	265	1.09	1.52
6/10/2015 7:01	46.51915574	-92.48154056	1780	52.2	265	1.15	1.32
6/10/2015 7:01	46.51915309	-92.48141507	1760	52.2	265.5	1.18	1.56
6/10/2015 7:00	46.51914877	-92.48091849	1740	52.2	266	1.33	1.96
6/10/2015 7:00	46.51915056	-92.48080901	1720	52.2	265.5	1.34	2.1
6/10/2015 7:00	46.51915188	-92.48069661	1700	51.75	265.5	1.16	1.94
6/10/2015 7:00	46.51914922	-92.48020319	1680	51.3	265.67	1.08	1.65
6/10/2015 7:00	46.51914833	-92.48009771	1660	51.3	266	1.24	1.39

6/10/2015 7:00	46.51914517	-92.47961234	1640	51	265.67	1.14	1.19
6/10/2015 7:00	46.51914753	-92.47951185	1620	50.4	265.5	0.97	1.38
6/10/2015 7:00	46.51914974	-92.47941233	1600	50.4	265	1.02	1.68
6/10/2015 7:00	46.51914143	-92.4789389	1580	51	265	1.03	1.37
6/10/2015 7:00	46.51914	-92.47883148	1560	51.3	265	0.99	1.19
6/10/2015 7:00	46.51913964	-92.47836608	1540	51.3	264.33	1.02	1.35
6/10/2015 7:00	46.51913938	-92.47825467	1520	51.3	264	1.05	1.69
6/10/2015 7:00	46.51914191	-92.4777803	1500	51.3	264	1.11	2.79
6/10/2015 7:00	46.51914369	-92.47766689	1480	51.3	264	1.31	3.08
6/10/2015 7:00	46.51914422	-92.47754743	1460	51.3	264	1.41	2.81
6/10/2015 7:00	46.51914157	-92.47706004	1440	51.9	264	1.39	2.29
6/10/2015 7:00	46.51914371	-92.47693661	1420	52.2	264	1.44	1.47
6/10/2015 7:00	46.51914607	-92.4768122	1400	52.2	264	1.24	0.91
6/10/2015 7:00	46.51914274	-92.47632878	1380	52.2	264	1.04	1.03
6/10/2015 7:00	46.51914072	-92.47621032	1360	51.75	264	1.06	1.07
6/10/2015 7:00	46.51913608	-92.47571491	1340	51.3	264.67	1.1	1.19
6/10/2015 7:00	46.51913648	-92.47561153	1320	50.85	265	1.06	1.46
6/10/2015 7:00	46.519137	-92.47550217	1300	50.4	265	1.06	1.67
6/10/2015 7:00	46.51913531	-92.47501679	1280	50.4	265	1.11	1.72
6/10/2015 7:00	46.51913228	-92.47492562	1260	50.4	265.5	1.21	1.37
6/10/2015 7:00	46.51912334	-92.47445803	1240	50.4	265.67	1.03	1.33
6/10/2015 7:00	46.51912436	-92.47435162	1220	50.85	265.5	0.98	2.07
6/10/2015 7:00	46.51913256	-92.47388721	1200	52.2	266	1.19	2.69
6/10/2015 7:00	46.519133	-92.47376666	1180	53.55	266	1.5	2.42
6/10/2015 7:00	46.51913262	-92.47363927	1160	54.45	265.5	1.43	2.35
6/10/2015 7:00	46.5191293	-92.47310089	1140	56.4	265	1.22	2.31
6/10/2015 7:00	46.51912838	-92.47294949	1120	58.05	265	1.2	2.39
6/10/2015 7:00	46.51912908	-92.47279609	1100	59.4	265	1.18	2.4
6/10/2015 7:00	46.51913075	-92.47263969	1080	60.3	265	1.14	2.41
6/10/2015 7:00	46.51912523	-92.47202631	1060	60.6	265.67	1.18	2.72
6/10/2015 7:00	46.51912272	-92.4718479	1040	62.55	266	1.41	4.56
6/10/2015 7:00	46.51912257	-92.4716675	1020	63.9	266	1.83	6.25
6/10/2015 7:00	46.51912386	-92.47146912	1000	64.8	265.5	1.95	5.55
6/10/2015 7:00	46.51912355	-92.47127167	980	67.05	265.5	1.68	4.85
6/10/2015 7:00	46.51911979	-92.47105826	960	68.4	266	1.56	3.53
6/10/2015 7:00	46.51911963	-92.47080887	940	68.4	265.5	1.42	2.22
6/10/2015 7:00	46.51912184	-92.47056149	920	68.4	265	1.34	3.8
6/10/2015 7:00	46.51912009	-92.47032295	900	67.5	265	1.29	5.38
6/10/2015 7:00	46.51911396	-92.47009056	880	66.6	265	1.57	4
6/10/2015 7:00	46.51911107	-92.46938219	860	64.2	265	1.49	2.43
6/10/2015 7:00	46.51911371	-92.46916981	840	60.75	265	1.7	2.03

6/10/2015 6:59	46.51911325	-92.4689784	820	59.4	265	1.58	2.49
6/10/2015 6:59	46.51911357	-92.46880203	800	58.5	265	1.42	2.95
6/10/2015 6:59	46.51911247	-92.46862362	780	56.25	265	1.45	3.01
6/10/2015 6:59	46.51911013	-92.46845722	760	54	265	1.26	3.07
6/10/2015 6:59	46.51911122	-92.46796082	740	51.3	265	1.32	2.77
6/10/2015 6:59	46.51911168	-92.46785441	720	47.25	264.5	1.34	4.02
6/10/2015 6:59	46.519114	-92.46744099	700	42.3	264	1.72	4.57
6/10/2015 6:59	46.51911401	-92.46740659	680	37.35	263.5	1.86	2.88
6/10/2015 6:59	46.51905276	-92.46691677	660	35.1	262.75	1.68	1.83
6/10/2015 6:59	46.51632857	-92.46336688	220	43.65	251.5	1.54	2.83
6/10/2015 6:59	46.51608295	-92.46334488	200	43.2	250.67	1.51	3.11
6/10/2015 6:59	46.51582933	-92.46340559	180	44.4	249	1.54	3.47
6/10/2015 6:59	46.51579214	-92.46342048	160	46.35	248	1.65	2.44
6/10/2015 6:59	46.51552666	-92.46352147	140	47.7	247.67	1.42	2.24
6/10/2015 6:59	46.51546795	-92.46354539	120	48.6	246.5	1.3	1.96
6/10/2015 6:59	46.51518224	-92.46365278	100	48.3	246	1.22	2.05
6/10/2015 6:59	46.51512541	-92.46367349	80	46.8	245.5	1.16	2.6
6/10/2015 6:59	46.51485894	-92.46378515	60	43.8	244.33	1.41	2.83

Run2

DateTime	Latitude	Longitude	Distance(m)	Speed (km/h)	Altitude (m)	eIRI	cIRI
6/10/2015 6:55	46.51916	-92.4864	60	52.2	271	1.1	1.48
6/10/2015 6:55	46.51916	-92.4859	80	53.55	270	1.04	1.71
6/10/2015 6:55	46.51915	-92.4858	100	54	269.5	1.09	1.6
6/10/2015 6:55	46.51915	-92.4857	120	54.6	268.33	1.26	1.47
6/10/2015 6:55	46.51915	-92.4851	140	54.9	267.5	1.31	2.19
6/10/2015 6:55	46.51915	-92.485	160	54.45	267	1.23	2.97
6/10/2015 6:55	46.51915	-92.4848	180	52.5	268	1.15	2.58
6/10/2015 6:55	46.51915	-92.4844	200	49.05	269	1.23	1.77
6/10/2015 6:55	46.51915	-92.4843	220	47.1	269.67	1.26	1.32
6/10/2015 6:55	46.51916	-92.4839	240	46.8	270.5	1.25	1.65
6/10/2015 6:55	46.51916	-92.4838	260	47.7	271	1.86	1.74
6/10/2015 6:55	46.51916	-92.4833	280	48.6	271	1.86	2.78
6/10/2015 6:55	46.51916	-92.4832	300	49.5	271	1.48	3.71
6/10/2015 6:55	46.51915	-92.4828	320	49.95	271	1.33	3.61
6/10/2015 6:55	46.51915	-92.4827	340	49.5	271	1.2	2.56
6/10/2015 6:55	46.51915	-92.4822	360	49.5	271	1.05	1.7
6/10/2015 6:55	46.51915	-92.4822	380	48.9	271	1.35	1.64
6/10/2015 6:55	46.51915	-92.4817	400	48.6	271	1.4	2.18
6/10/2015 6:55	46.51915	-92.4816	420	48.6	271	1.2	1.83

6/10/2015 6:55	46.51915	-92.4812	440	48.6	271	1.34	1.89
6/10/2015 6:55	46.51915	-92.4811	460	48.6	271	1.24	2.35
6/10/2015 6:55	46.51915	-92.4806	480	48.6	271	1.09	2.82
6/10/2015 6:55	46.51915	-92.4805	500	48.6	271	1.07	2.22
6/10/2015 6:55	46.51915	-92.4805	520	48.6	270.33	1.05	1.57
6/10/2015 6:55	46.51914	-92.48	540	48.6	270	1.22	1.44
6/10/2015 6:55	46.51914	-92.4799	560	48.6	270	1.22	2.03
6/10/2015 6:55	46.51914	-92.4795	580	48.6	270	1.18	1.87
6/10/2015 6:55	46.51914	-92.4794	600	48.6	269.67	1.2	1.37
6/10/2015 6:55	46.51914	-92.4789	620	48.6	269	1.13	1.28
6/10/2015 6:55	46.51914	-92.4789	640	48.6	268.67	1.1	1.31
6/10/2015 6:55	46.51913	-92.4784	660	48.6	269	1.32	1.45
6/10/2015 6:55	46.51913	-92.4783	680	48.3	268.33	1.29	1.68
6/10/2015 6:55	46.51914	-92.4779	700	47.7	268	1.28	1.88
6/10/2015 6:55	46.51914	-92.4778	720	47.4	268.33	1.2	2.01
6/10/2015 6:55	46.51914	-92.4774	740	47.25	269	1.21	1.67
6/10/2015 6:56	46.51914	-92.4773	760	47.7	269	1.2	1.49
6/10/2015 6:56	46.51913	-92.4769	780	47.7	269	1.17	1.93
6/10/2015 6:56	46.51913	-92.4768	800	47.7	269	1.19	1.95
6/10/2015 6:56	46.51913	-92.4764	820	47.7	269.5	1.19	1.74
6/10/2015 6:56	46.51913	-92.4763	840	47.7	270	1.13	1.54
6/10/2015 6:56	46.51912	-92.4758	860	47.7	270	1.12	1.57
6/10/2015 6:56	46.51912	-92.4758	880	47.7	269.67	1.3	1.25
6/10/2015 6:56	46.51912	-92.4753	900	48.15	269	1.42	1.68
6/10/2015 6:56	46.51912	-92.4752	920	48.6	269	1.32	2.27
6/10/2015 6:56	46.51912	-92.4748	940	48.6	269	1.32	2.28
6/10/2015 6:56	46.51912	-92.4747	960	48.6	269	1.15	1.76
6/10/2015 6:56	46.51913	-92.4743	980	48.6	268.5	1.2	1.49
6/10/2015 6:56	46.51913	-92.4742	1000	48	268	1.27	1.83
6/10/2015 6:56	46.51913	-92.4737	1020	47.7	267.5	1.06	2.53
6/10/2015 6:56	46.51913	-92.4737	1040	47.7	267.67	1.03	1.47
6/10/2015 6:56	46.51913	-92.4734	1060	48.3	267.33	1.18	1.2
6/10/2015 6:56	46.51912	-92.473	1080	48.15	267	1.49	2.08
6/10/2015 6:56	46.51912	-92.4727	1100	47.7	267	1.53	2.82
6/10/2015 6:56	46.51912	-92.4726	1120	47.7	267	1.22	1.93
6/10/2015 6:56	46.51912	-92.4722	1140	47.7	267	1.17	2.02
6/10/2015 6:56	46.51912	-92.4721	1160	47.7	267	1.34	1.88
6/10/2015 6:56	46.51912	-92.4718	1180	47.7	267	1.47	1.75
6/10/2015 6:56	46.51911	-92.4716	1200	48.3	267	1.45	3.03
6/10/2015 6:56	46.51911	-92.4711	1220	48.6	266.5	1.41	3.04
6/10/2015 6:56	46.51911	-92.471	1240	48.6	266.67	1.38	2.53

6/10/2015 6:56	46.51911	-92.4708	1260	48.6	266.33	1.22	2.41
6/10/2015 6:56	46.51911	-92.4705	1280	48.6	266	1.26	1.72
6/10/2015 6:56	46.5191	-92.4702	1300	48.6	266	1.32	1.71
6/10/2015 6:56	46.5191	-92.47	1320	48.6	266	1.29	1.91
6/10/2015 6:56	46.5191	-92.4697	1340	48.15	266	1.3	2.33
6/10/2015 6:56	46.5191	-92.4694	1360	47.7	266	1.22	2.11
6/10/2015 6:56	46.5191	-92.4688	1380	47.7	266	1.22	2.11
6/10/2015 6:56	46.5191	-92.4688	1400	48.3	265.67	1.18	1.45
6/10/2015 6:56	46.5191	-92.4685	1420	48.6	265	1.22	1.97
6/10/2015 6:56	46.5191	-92.4684	1440	48.6	265	1.25	2.23
6/10/2015 6:56	46.5191	-92.4681	1460	48.6	265	1.3	2.2
6/10/2015 6:56	46.5191	-92.4679	1480	48	264.33	1.29	1.75
6/10/2015 6:56	46.51909	-92.4675	1500	42.9	264	1.34	1.34
6/10/2015 6:56	46.51909	-92.4672	1520	35.4	263.33	1.32	1.69
6/10/2015 6:57	46.51906	-92.467	1540	30.38	262.5	2.65	1.81
6/10/2015 6:57	46.519	-92.4668	1560	29.25	262.5	6.28	2.21
6/10/2015 6:57	46.51627	-92.4634	1980	48.6	252.5	1.14	1.31
6/10/2015 6:57	46.5162	-92.4634	2000	48.6	251.5	1.24	1.53
6/10/2015 6:57	46.51577	-92.4635	2020	48.6	251.5	1.24	1.53
6/10/2015 6:57	46.51575	-92.4635	2040	51.6	249.67	1.37	2.24
6/10/2015 6:57	46.51547	-92.4636	2060	53.55	248	1.41	3.06
6/10/2015 6:57	46.51538	-92.4636	2080	54	247	1.56	3.43
6/10/2015 6:57	46.51529	-92.4637	2100	54.3	245.67	1.34	3.26
6/10/2015 6:57	46.51493	-92.4638	2120	54.45	245	1.17	2.16
6/10/2015 6:57	46.51484	-92.4638	2140	54	244.5	1.19	2.01

Dustometer

Goodhue County

Filter	WB	WB+F	WB+F+Material	Run	% of Material applied
8083503	9.0g	13.3	17.3	1	60%
8083504	8.9g	13.4	17.7	2	60%
8083505	8.9g	13.4	16.9	3	60%
8083506	9.0g	13.4	18.5	1	45%
8083507	9.0g	13.4	17.5	2	45%
8083508	8.9g	13.4	18.8	3	45%
8083509	8.9g	13.4	17.5	1	30%
8083510	9.0g	13.4	18	2	30%
8083511	9.0g	13.4	18.4	3	30%
8083512	9.0g	13.4	19.2	1	15%
8083513	9.0g	13.4	17.7	2	15%
8083514	9.0g	13.4	19	3	15%
8083516	8.9g	13.3	19.1	1	Control
8083517	9.0g	13.4	17.3	2	Control
8083518	8.9g	13.4	19.4	3	Control

Material	Can #	can wt.	Material before burn	Material After Burn	Loss (G)	Moisture Content %
Control	2	50.6g	350	342	8	2.286
15% Rap	69	50.2g	350	343.2	6.8	1.943
30% Rap	10	49.9g	350	342.2	7.8	2.229
45% Rap	96	49.8g	350	340.8	9.2	2.629
60% Rap	1	50.0g	350	340.4	9.6	2.743
chloride	13	50.4g	350	340.5	9.5	2.714

Carlton County

Filter	Run	Material	Bag wt.	filter wt.	Filter+Bag wt.	Filter +bag+Material	collected Material on filter
8083094	1	30% Rap	11.8g	4.5g	16.3	26	9.7g
8083096	2	30% Rap	11.8g	4.5g	16.3	**25.8**	9.5g
8083095	3	30% Rap	11.8g	4.5g	16.3	**25.9**	9.6g
8083097	1	50% Rap	11.8g	4.5g	16.3	**21.2**	4.9g
8083098	2	50% Rap	11.8g	4.5g	16.3	**22.7**	6.4g
8083099	3	50% Rap	11.8g	4.5g	16.3	**20.9**	4.6g
8083502	1	Control	11.8g	4.5g	16.3	**26.6**	10.3g
8083100	2	Control	11.8g	4.5g	16.3	**28**	11.7g
8083501	3	Control	11.8g	4.5g	16.3	**30.1**	13.8g

Material	Can wt.	Can #	Material B 4 burn	Material after burn	loss	Moisture Content %
30% Rap	50.7g	18	350	343.8	6.2	1.771
50% Rap	49.8g	100	350	342.9	7.1	2.029
Control	50.5g	15	350	344.8	5.2	1.486

Sieve Analysis

Goodhue County

	15% RAP
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	10153.00
Pan Weight (g)	1105.80
Sieve less than #200	
After dry #1 (g)	11222.20
Gradation test	
After dry #2 (g)	10285.60
Material weight transferred into pan (g)	9188.00

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	305.00	305.00	3.3%	96.7%	19.00	3.8
3/8"	4911.00	4911.00	53.5%	43.2%	9.51	2.8
#4	574.00	574.00	6.3%	36.9%	4.76	2.0
#8	718.00	718.00	7.8%	29.1%	2.38	1.5
#10	154.00	154.00	1.7%	27.5%	2.00	1.4
#30	947.00	947.00	10.3%	17.1%	0.60	0.8
#40	242.00	242.00	2.6%	14.5%	0.42	0.7
#100	896.00	896.00	9.8%	4.7%	0.15	0.4
#200	339.00	339.00	3.7%	1.1%	0.07	0.3
<#200	96.00	96.00	1.1%	0.0%	0.01	0.1

Total (g)	9086.00	9086.00	100%	
	8245.40			
Loss	942.60			

	30% RAP
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	10052.50
Pan Weight (g)	1499.10
Sieve less than #200	
After dry #1 (g)	11535.30
Gradation test	
After dry #2 (g)	10687.00
Material weight transferred into pan (g)	9194.00

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	90.00	90.00	0.9%	99.1%	19.00	3.8
3/8"	3227.00	3227.00	33.0%	66.1%	9.51	2.8
#4	1183.00	1183.00	12.1%	54.0%	4.76	2.0
#8	1231.00	1231.00	12.6%	41.5%	2.38	1.5
#10	859.00	859.00	8.8%	32.7%	2.00	1.4
#30	1525.00	1525.00	15.6%	17.1%	0.60	0.8
#40	308.00	308.00	3.1%	14.0%	0.42	0.7
#100	943.00	943.00	9.6%	4.3%	0.15	0.4
#200	333.00	333.00	3.4%	0.9%	0.07	0.3

<#200	92.00	92.00	0.9%	0.0%	0.01	0.1
Total (g)	9699.00	9699.00	100%			
	8942.70					
Loss	251.30					

	45% RAP
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	10170.20
Pan Weight (g)	1210.70
Sieve less than #200	
After dry #1 (g)	11326.30
Gradation test	
After dry #2 (g)	10566.70
Material weight transferred into pan (g)	9317.00

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	9.00	9.00	0.1%	99.9%	25.40	4.3
3/4"	189.00	189.00	2.0%	97.9%	19.00	3.8
3/8"	4701.00	4701.00	50.5%	47.4%	9.51	2.8
#4	631.00	631.00	6.8%	40.6%	4.76	2.0
#8	855.00	855.00	9.2%	31.5%	2.38	1.5
#10	208.00	208.00	2.2%	29.2%	2.00	1.4
#30	1394.00	1394.00	15.0%	14.3%	0.60	0.8
#40	265.00	265.00	2.8%	11.4%	0.42	0.7
#100	760.00	760.00	8.2%	3.3%	0.15	0.4

#200	252.00	252.00	2.7%	0.6%	0.07	0.3
<#200	53.00	53.00	0.6%	0.0%	0.01	0.1
Total (g)	9264.00	9264.00	100%			
	8557.40					
Loss	759.60					

	60% RAP
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	10149.60
Pan Weight (g)	1493.10
Sieve less than #200	
After dry #1 (g)	11591.80
Gradation test	
After dry #2 (g)	11132.20
Material weight transferred into pan (g)	9643.00

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	559.00	559.00	5.8%	94.2%	19.00	3.8
3/8"	4712.00	4712.00	48.9%	45.3%	9.51	2.8
#4	594.00	594.00	6.2%	39.2%	4.76	2.0
#8	913.00	913.00	9.5%	29.7%	2.38	1.5
#10	238.00	238.00	2.5%	27.2%	2.00	1.4
#30	1637.00	1637.00	17.0%	10.2%	0.60	0.8
#40	257.00	257.00	2.7%	7.6%	0.42	0.7

#100	558.00	558.00	5.8%	1.8%	0.15	0.4
#200	145.00	145.00	1.5%	0.3%	0.07	0.3
<#200	27.00	27.00	0.3%	0.0%	0.01	0.1
Total (g)	9613.00	9613.00	100%			
	9180.40					
Loss	462.60					

	100% RAP
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	10060.00
Pan Weight (g)	704.90
Sieve less than #200	
After dry #1 (g)	10707.50
Gradation test	
After dry #2 (g)	10631.30
Material weight transferred into pan (g)	9823.00

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	128.00	128.00	1.3%	98.7%	25.40	4.3
3/4"	3558.00	3558.00	36.0%	62.7%	19.00	3.8
3/8"	4156.00	4156.00	42.0%	20.7%	9.51	2.8
#4	354.00	354.00	3.6%	17.2%	4.76	2.0
#8	520.00	520.00	5.3%	11.9%	2.38	1.5
#10	131.00	131.00	1.3%	10.6%	2.00	1.4
#30	808.00	808.00	8.2%	2.4%	0.60	0.8

#40	133.00	133.00	1.3%	1.1%	0.42	0.7
#100	100.00	100.00	1.0%	0.1%	0.15	0.4
#200	4.00	4.00	0.0%	0.0%	0.07	0.3
<#200	1.00	1.00	0.0%	0.0%	0.01	0.1
Total (g)	9892.00	9892.00	100%			
	9816.80					
Loss	6.20					

	Road rock
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	10104.60
Pan Weight (g)	964.70
Sieve less than #200	
After dry #1 (g)	11047.30
Gradation test	
After dry #2 (g)	9891.20
Material weight transferred into pan (g)	8932.00

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	20.00	20.00	0.2%	99.8%	25.40	4.3
3/4"	84.00	84.00	0.9%	98.8%	19.00	3.8
3/8"	4619.00	4619.00	51.7%	47.1%	9.51	2.8
#4	712.00	712.00	8.0%	39.1%	4.76	2.0
#8	786.00	786.00	8.8%	30.3%	2.38	1.5
#10	161.00	161.00	1.8%	28.5%	2.00	1.4

#30	757.00	757.00	8.5%	20.1%	0.60	0.8
#40	208.00	208.00	2.3%	17.7%	0.42	0.7
#100	1013.00	1013.00	11.3%	6.4%	0.15	0.4
#200	439.00	439.00	4.9%	1.5%	0.07	0.3
<#200	130.00	130.00	1.5%	0.0%	0.01	0.1
Total (g)	8799.00	8799.00	100%			
	7772.90					
Loss	1159.10					

Carlton County

	Barnum RAP
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	10004.00
Pan Weight (g)	1448.50
Sieve less than #200	
After dry #1 (g)	11417.00
Gradation test	
After dry #2 (g)	11316.50
Material weight transferred into pan (g)	9863.00

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	1208.00	1208.00	0.0%	100.0%	37.50	5.1
1"	577.00	577.00	6.7%	93.3%	25.40	4.3
3/4"	653.00	653.00	7.5%	85.8%	19.00	3.8
3/8"	2135.00	2135.00	24.7%	61.1%	9.51	2.8
#4	1473.00	1473.00	17.0%	44.1%	4.76	2.0
#8	1098.00	1098.00	12.7%	31.4%	2.38	1.5
#10	205.00	205.00	2.4%	29.0%	2.00	1.4

#30	1617.00	1617.00	18.7%	10.3%	0.60	0.8
#40	299.00	299.00	3.5%	6.9%	0.42	0.7
#100	483.00	483.00	5.6%	1.3%	0.15	0.4
#200	100.00	100.00	1.2%	0.2%	0.07	0.3
<#200	13.00	13.00	0.2%	0.0%	0.01	0.1
Total (g)	8640.00	8640.00	100%			
	9760.50					
Loss	102.50					

	Class 5
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	10035.00
Pan Weight (g)	1411.50
Sieve less than #200	
After dry #1 (g)	11070.00
Gradation test	
After dry #2 (g)	10182.00
Material weight transferred into pan (g)	8738.00

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	0.00	0.00	0.0%	100.0%	19.00	3.8
3/8"	627.00	627.00	7.2%	92.8%	9.51	2.8
#4	721.00	721.00	8.3%	84.6%	4.76	2.0

#8	597.00	597.00	6.8%	77.7%	2.38	1.5
#10	142.00	142.00	1.6%	76.1%	2.00	1.4
#30	5414.00	5414.00	62.0%	14.1%	0.60	0.8
#40	116.00	116.00	1.3%	12.8%	0.42	0.7
#100	762.00	762.00	8.7%	4.0%	0.15	0.4
#200	291.00	291.00	3.3%	0.7%	0.07	0.3
<#200	61.00	61.00	0.7%	0.0%	0.01	0.1
Total (g)	8670.00	8670.00	100%			
	7843.00					
Loss	895.00					

	RAP 30%
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	10014.00
Pan Weight (g)	1471.00
Sieve less than #200	
After dry #1 (g)	11097.00
Gradation test	
After dry #2 (g)	10590.50
Material weight transferred into pan (g)	9098.00

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	0.00	0.00	0.0%	100.0%	19.00	3.8
3/8"	1580.00	1580.00	17.4%	82.6%	9.51	2.8

#4	1302.00	1302.00	14.3%	68.3%	4.76	2.0
#8	1284.00	1284.00	14.1%	54.2%	2.38	1.5
#10	299.00	299.00	3.3%	50.9%	2.00	1.4
#30	3105.00	3105.00	34.1%	16.8%	0.60	0.8
#40	398.00	398.00	4.4%	12.4%	0.42	0.7
#100	889.00	889.00	9.8%	2.6%	0.15	0.4
#200	197.00	197.00	2.2%	0.5%	0.07	0.3
<#200	41.00	41.00	0.5%	0.0%	0.01	0.1
Total (g)	9054.00	9054.00	100%			
	8588.50					
Loss	509.50					

	RAP 50%
Nominal Max Aggregate Size (mm)=	
Sample Weight (g)=	10014.50
Pan Weight (g)	1387.00
Sieve less than #200	
After dry #1 (g)	11023.00
Gradation test	
After dry #2 (g)	10386.00
Material weight transferred into pan (g)	8989.00

	Weight Retained (g)	Aver.	Weight Retained	Weight Passing	mm	0.45 Power
U.S. Sieve Size	#1					
1.5"	0.00	0.00	0.0%	100.0%	37.50	5.1
1"	0.00	0.00	0.0%	100.0%	25.40	4.3
3/4"	0.00	0.00	0.0%	100.0%	19.00	3.8

3/8"	1742.00	1742.00	19.4%	80.6%	9.51	2.8
#4	1292.00	1292.00	14.4%	66.2%	4.76	2.0
#8	1098.00	1098.00	12.2%	54.0%	2.38	1.5
#10	212.00	212.00	2.4%	51.6%	2.00	1.4
#30	2556.00	2556.00	28.5%	23.1%	0.60	0.8
#40	322.00	322.00	3.6%	19.5%	0.42	0.7
#100	1352.00	1352.00	15.1%	4.5%	0.15	0.4
#200	337.00	337.00	3.8%	0.7%	0.07	0.3
<#200	64.00	64.00	0.7%	0.0%	0.01	0.1
Total (g)	8911.00	8911.00	100%			
	8338.00					
Loss	651.00					

CBR Data

Goodhue County

Mix	Wt. of CBR mold without collor (EMPTY) Mm	Wt. of CBR mold without collor (FULL) Mw+ws		Can name	Empty Can	Full can	After Oven	Wac	Dry Density Before Lodaing (g/cm3)	Dry Density After Loading (g/cm3)
			Before Loadaing	B2	49.6	266.7	265.9	0.003699		
100%	14504.1	18154.4	After Loading	^H	50.1	425.4	424.3	0.00294	1.569230614	1.57041811
			Before Loadaing	H	50.8	435.1	434.1	0.002609		
60%	14504.1	18764.8	After Loading	V1/L2	50.4	512.5	511	0.003257	1.833626635	1.832442851
			Before Loadaing	MG	49.6	418.5	417.6	0.002446		
45%	14503.8	18995.1	After Loading	333	50.2	411.9	411	0.002494	1.933182016	1.933087903
			Before Loadaing	2	49.8	375.8	375	0.00246		
30%	14503.6	18981.1	After Loading	3	49.7	459.7	458.5	0.002935	1.927214476	1.926300967
			Before Loadaing	ZP	49.8	500.1	498.9	0.002672		
15%	14503.3	19128.3	After Loading	TACO	49.5	448.8	447.8	0.002511	1.990280844	1.990601152
			Before Loadaing	EE2	49.5	449.1	448.3	0.002006		
0%	14503.3	19205	After Loading	RI	49.5	583.3	582.1	0.002253	2.024632028	2.024132906

Carlton County

Mix	Wt. of CBR mold without collor	Wt. of CBR mold without collor		Can name	Empty Can	Full can	After Oven	Wac	Dry Density Before Lodaing (g/cm3)	Dry Density After Loading (g/cm3)

	(EMPTY) Mm	(FULL) Mw+ws								
CLASS 5	14502.3	18990	Before Loadaing	G	49.4	224.3	216.3	0.047933	1.847786807	1.845580468
			After Loading	SFG	50.4	372.5	357.4	0.049186		
30%	14503.9	19480.6	Before Loadaing	KSG	49.6	349.8	335.4	0.050385	2.044346543	2.046271883
			After Loading	Q	49.7	423.6	406	0.049397		
50%	14504	19112	Before Loadaing	N	49.9	366.1	351.4	0.048756	1.895830208	1.894026446
			After Loading	LSG	49.9	328.4	315.2	0.049755		
100%	14504	18706.9	Before Loadaing	DING	49.6	348.8	345.5	0.011152	1.793469315	1.791687398
			After Loading	WIN	50.6	383.6	379.6	0.012158		