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Performance Based Testing Specifications For Asphalt Pavement Construction In North Dakota

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PERFORMANCE BASED TESTING SPECIFICATIONS FOR ASPHALT PAVEMENT CONSTRUCTION IN NORTH DAKOTA

by

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Bachelor of Science in Civil Engineering, Iowa State University 2016

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This thesis, submitted by Jun Liu in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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Department	Civil Engineering
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Jun Liu
5/2/2019

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ABSTRACT

Asphalt pavement distresses reduce the comfort, safety, and efficiency of operations. In North Dakota, low temperature cracking, fatigue cracking and rutting are three common types of distress. The main objective of this thesis is to test, analyze, compare and evaluate low temperature cracking, fatigue cracking, rutting and moisture resistance of field and laboratory mixes that are commonly used in North Dakota. The effects of using Reclaimed Asphalt Pavement (RAP) performance in terms of cracking and rutting was also investigated.

Low-temperature cracking, fatigue cracking, rutting and moisture damage resistance were determined using Disc shaped compact Tension (DCT), Semi Circular Bend Test (SCB), Asphalt Pavement Analyzer (APA) and Indirect Tensile Test (IDT). Field mix and raw materials for laboratory mix were obtained from seven districts in North Dakota, a total of 20 projects. Field mixes were replicated in the laboratory for seven of the 20 projects, one project from each district. Mixes were compacted using Superpave Gyratory Compactor (SGC) at 7±0.5% air voids. Three specimens each for low-temperature and fatigue cracking, and four specimens for rutting were tested for all projects. In addition six specimens were tested for moisture damage resistance for one project in each district. At least total of 354 samples are made.

Test results showed that for the virgin mix, PG 58H-28 was the most rut resistant. PG 64S-28 and PG 58-28 showed similar fatigue cracking performance. PG 58H-28 and PG 64S-28 had better low- temperature cracking resistance performance. For 10-20% RAP mix, PG 58S-34 was the most rut resistant, PG 58V-28 was the most low-temperature and fatigue cracking resistant. For 25%

RAP mixes, PG 58S-28 had similar rutting and low temperature cracking resistance performance, higher fatigue cracking resistance performance than virgin mix. Lab mixes had better fatigue cracking resistance whereas field mixes had higher flexibility indices. Also, lab mixes had better low-temperature performance than field mixes. The fracture energy reduces with the increase in RAP percentages in general. For 20% and 40% RAP mixes the fracture energies was 26% and 22% less than the virgin HMA, respectively.

CHAPTER I

INTRODUCTION

1.1 Background

North Dakota is one of the coldest states in the United States. During winter season, the low temperature can reach below -40-degree Fahrenheit. As a result, asphalt distress can be seen everywhere. Distress reduces comfort, efficiency and safety on highways.

1.2 Types of Asphalt Mix Used in North Dakota

Hot Mix Asphalt (HMA) is the most commonly used asphalt mix in the North Dakota. Hot mix asphalt usually consists of 3 layers: surface layer, intermediate layer, and base layer. The surface layer usually contains highest quality materials such as crushed gravel, stone, and sands, bounded by asphalt binder to ensure highest friction, smoothness, rut resistance and noise control. The intermediate layer usually contains less quality materials. Its purpose is to distribute traffic loads from the surface layer so that excessive stresses from the surface layer won't transmit and permanently damage the base layer. Typical intermediate layer is made of aggregates, Reclaimed Asphalt pavement (RAP), limited crushed gravel and stone. The base layer usually serves as foundation to the asphalt layers. Its major function is to provide principal support to the pavement structure. It contains most rugged materials like double aggregates, RAP, etc. (Jose Garcia, 2001) Traditional HMA must be mixed at around 300 degree Fahrenheit before paving the road.

Warm Mix Asphalt (WMA): WMA similar to HMA, but organic additives, chemical additives, foaming materials are added to reduce mixing temperature. Typical chemical additives used by

North Dakota Department of Transportation (NDDOT) is Evotherm. The mix temperature of warm mix asphalt is around 30 to 100-degree Fahrenheit lower than regular HMA (FHWA,2016). Due to reduced mixing temperature, it generates less heat and smoke to the environment, reduces fuel emission, fewer energy cost compared to HMA. It also creates safer working environment. making WMA ideal for sustainability. After doing various types testing and field investigation, the NDDOT issued its first WMA specifications in 2013.

Stone Matrix Asphalt (SMA) is a special type of gap-graded HMA. It uses premium materials to improve rutting resistance and durability. Due to the use of premium materials, its initial cost is high, but it last longer, making less maintenance and rehabilitation than traditional HMA. Typical SMA is made of crushed stones, sand, asphalt, fiber or mineral filler and additives. Most SMA are almost exclusively used for high volume interstates and U.S highways. (WSDOT, 2000) The NDDOT, has used SMA on I-29 and I-94 projects so far.

1.3 Reclaimed Asphalt Pavement (RAP) in North Dakota

Reclaimed Asphalt Pavement is obtained by milling or removal of the original pavement after service life. Most RAP materials are recycled on site. Recycling the RAP is one of the most attractive and sustainable option for numerous advantages. Certain amount of RAP materials in the asphalt mix helps reducing emission of carbon dioxide, it saves and reduces the energy and cost of materials, it speeds up the construction time on a project, etc. It greatly improves the material sustainability. However, due to its aged material, excessive percentage of RAP materials in the mix may degrade cracking performance. According to NDDOT (Beise, 2019), 42% of total 81,233 tons of HMA materials were recycled in 2018.

1.4 Superpave Performance Grading in North Dakota

Superpave performance grading is a specification used to test durability and viscosity of an asphalt binder. The grading scale has two numbers: the first number is average 7-day maximum pavement temperature in Celsius, the second number is minimum pavement design temperature. For example: the abbreviation of performance grading PG 58 -28 means that the average 7-day maximum temperature is 58 Celsius, the minimum pavement temperature is -28 Celsius. Current performance grading scale ranges from PG 46 -46 to PG 82 -34, total 37 types of performance grading. In the new grading scale, letters are added after average 7-day maximum temperature to specify amount of traffic to the pavement. "S" stands for standard, "H" stands for high traffic, "V" stands for very high traffic, and "E" stands for extremely high traffic. (Peter, 2017) In North Dakota's highway flexible pavements, NDDOT use PG 58 - 28 with variation traffic of S, H and V, and PG 58 - 34 with variation traffic of S and H. Other binders include PG 64S - 28.

1.5 Major Asphalt Pavement Distresses in North Dakota

Most asphalt pavment distresses are due to traffic load or environment. There are four major asphalt pavement distresses in North Dakota: low-emperature cracking, fatigue cracking, rutting and moisture damage.

Low-temperature cracking: cracks formed due to low temperature. As the temperature drop, the pavement begins to shrink and becomes brittle. After critical number of axles applied, cracks are formed. Low temperature cracking can be initiated by a single low temperature event or multiple warming and cooling. Transverse cracking are typical types of low temperature cracking. (MnDOT)

Fatigue cracking: cracks formed due to repeated heavy loads. Due to heavy traffic or repeated loads, the asphalt pavement loses its structural support. The base and subbase of the asphalt pavement becomes less stiff. Interconnected cracks are formed. Crocodile or alligator cracking are typical types of fatigue cracking. (Alpha Paving Industries)

Rutting: due to repeated heavy loads, extremely hot weather, excessive dirt or rain water into the asphalt pavement or improper asphalt mix, the surface layer of the asphalt pavement starts to deform. Wheel path depression of the asphalt can be seen on the surface of the pavement. (Chance, 2018)

Moisture damage: moisture damage is one of the most important factors determining the durability of the asphalt pavement. The water penetrates through mixes and can't be drained properly. The mix becomes less viscous and brittle. Dents will be formed at the weakest point after load application. Potholes are typical example. Several factors may cause moisture damage. They include excessive rains and snows, poor highway drainage, dramatic change in temperature, etc. (Dong-Woo, Kyoungchui, 2010)

1.6 Problem Statement

Research and development at the federal level has introduced new test methods and a design methodology that are more closely related to in-service performance through enhanced material characterization by considering loading time, temperature, and aging. In addition, the concepts of visualization and force measurement during compaction have been recently upgraded by providing direct measurements of mixture aggregate structure and shear stability versus estimation based on density.

In contrast to these technological improvements, methods used to accept mixtures during production and placement (i.e. volumetric properties and density) remain unchanged and may not be indicative of performance. Given the maturity of recently developed test methods, there is a need to define a performance based mixture acceptance framework that applies to the mix design, production, and placement phases of constructing asphaltic mixtures.

Development of performance based specifications for design and acceptance of HMA is a topic of significant interest nationally as a Leading Edge Workshop focused on integrating performance considerations into the mixture design process was held at the 2013 Association of Asphalt Pavement Technologists (AAPT) meeting.

1.7 Objective

The objectives of this thesis are as follows:

1. Determine low-termperature cracking, fatigue cracking, rutting, and moisture damage resistance of mixes commonly used in North Dakota.
2. Investigate effect of RAP on HMA mixes.
3. Develop a performance-based specification for NDDOT.

1.8 Organization of Thesis

Chapter I introduces types of asphalt distresses in North Dakota, and the objectives to this thesis. Chapter II deals with literature review of past research as it relates to field and laboratory mix performances. Chapter III describes test methodology. Chapter IV includes test results and discussions. Chapter V stated conclusions, recommendations, limitations, and future work.

CHAPTER II

LITERATURE REVIEW

2.1 Low-Temperature Cracking Performance

Low-temperature cracking (thermal cracking) is a transverse cracking due to an increase in thermal tensile stress beyond the tensile strength of the asphalt material. It occurs due to a rapid temperature change. The tension force inside the asphalt-aggregate is pulling apart and forces aggregate to form transverse cracks. Low-temperature cracking can be commonly seen in northern states of the United States such as North Dakota, Minnesota, Illinois, Wisconsin, and Canada. Common used laboratory tests to determine low-temperature cracking performance tests used are DCT, SCB, and IDT.

Different studies were conducted on the low-temperature performance of asphalt mixes. Mihai et al (2012) conducted a study on the low-temperature performance of asphalt specimen collected from nine locations. Seven of the locations were from Minnesota and the rest were from Wisconsin and New York. The DCT and SCB tests were conducted at the PG low-temperature +10°C and at PG low-temperature. The tests were done on both 4% and 7% air void specimens from laboratory and fields samples. The results showed that as the testing temperature decreases, the specimens become more brittle. For all samples, the specimens that had a 4% air voids tended to have slightly greater fracture energy than 7% air voids specimens in both DCT and SCB test results. The fracture energy results from SCB tests for both 4% and 7% air voids showed similar trends to DCT tests, but slightly lower than DCT fracture energy. The fracture energy result for the 7% air void DCT samples at PG low-temperature +10°C ranged from 400 to 671 J/M^2 (Mihai et al. 2012).

Hussain et al. (2016) conducted a study on four experiments related to mixture specification, mixture sensitivity, performance testing guidelines, and field validation. For the low-temperature cracking performance, the study used DCT and SCB tests on the laboratory mixed and compacted specimens. The study was conducted in the University of Wisconsin based on aggregates commonly used by Wisconsin DOT. The result showed that both DCT and SCB test produced a favorable result. The SCB result was slightly higher and less consistent than DCT fracture energy result. The study recommended the minimum low temperature fracture energy specification limit of 300, 400, and 500 J/m^2 for low, medium, and high traffic levels respectively. (Hussain et al. 2016).

Chelsea (2016) studied cracking performance evaluation of Minnesota asphalt pavement by investigating asphalt mixture parameters and laboratory tests such as permeability, fracture energy volumetric properties, asphalt content and gradation. Twenty-five pavement sections on 18 highways in Minnesota were considered to evaluate the effect of mix design parameters on the performance of mix design. The study also conducted the transverse and longitudinal field cracking performance of 295 pavement sections on 28 highways with respect to their binder type and polymer modification. The transverse cracking performance of these pavements was obtained from the pavement management system and through crack surveys. The cracking amounts were converted to a set of cracking performance measures that allowed comparisons between various sections. At the end sensitivity of flexible pavement thermal cracking performance to variation in

DCT fracture energy by considering 200 simulations representing a combination of 3 climates, 3 asphalt thickness, and 3 asphalt mixture with 6 fracture energy level to investigate the sensitivity to 400 J/m^2 threshold. DCT facture energy result showed that only seven out of 12 mixtures were above the threshold value of 400 J/m^2. Twelve sections had substantially lower fracture energy (less than 300 J/m^2), which were expected to have inferior transverse cracking performance and shorter service life. The research also investigated the effect of asphalt binder type and modification when compared to field cracking performance in relation to construction type, asphalt binder supplier, and dynamic shear rheometer parameters (phase angle and dynamic shear modulus). The polymer-modified PG 58-34 binder performed better than the non-polymer modified version. Out of the asphalt mix designs parameters, only the asphalt binder and the gradation showed a strong trend. The low-temperature grade of the binders with -34-grade showed approximately 12% average transverse cracking rate as opposed to approximately 26% for mixtures with -28 low-temperature grade. Typically used volumetric measures for ensuring the performance of asphalt mixtures, i.e. asphalt film thickness and voids in mineral aggregates did not show a consistent trend with cracking performance. The sensitivity analysis showed that the variation of only 25 J/m^2 is enough to show a difference in cracking performance *(Chelsea 2016).*

Different State DOTs specified the minimum threshold requirement for low- temperature fracture energy mostly based on traffic level, pavement thickness, and pavement aging type.

Minnesota and Iowa State DOTs recommend a minimum fracture energy of 400,460, and 690 J/m^2 while Wisconsin DOT recommends 300, 400, and 500 J/m^{2}for low, medium, and high traffic level, respectively *(Hussain et al. 2016, Chesea 2016).*

2.2 Fatigue Cracking Performance

Fatigue cracking is also known as alligator cracking, which is the type of pavement distress due to the excessive repetition of heavy traffic loads and extreme environmental conditions during the service life of the pavement. Fracture energy and flexibility index are common specification parameters used to identify the fatigue cracking performance of the asphalt pavement. As the asphalt pavement gets stiffer due to the aging of the binder it tends to be brittle and less fatigue cracking resistant, which will further generate extreme pavement distress and failures such as potholes as water enters to the pavement system through the cracks. Common test methods used for fatigue cracking performance are Illinois SCB (I-FIT), and IDT. Many studies were conducted on the fatigue cracking performance of asphalt mixes.

Hussain et al. (2016) used Illinois SCB and Louisiana SCB tests for fatigue cracking performance on mixtures produced in the laboratory. The results indicated that the fatigue cracking performance was sensitive to asphalt binder content and filler content within the allowable tolerance.

Semi-circular bending test was used to measure the fracture energy at the intermediate temperature to come up with a simplified performance-based specification of pavement on Louisiana pavement section. The study proposed the minimum fatigue cracking performance fracture energy (J_c) value of 0.5 and 0.6 KJ/M^2 for low and high traffic level pavement *(Minkyum et al. 2015).*

A practical test method, the Illinois modified semi-circular bending test (IL-SCB) was developed by *Al-Qadi et al (2015)* to determine cracking resistance in a consistent way. The study was done on the asphalt concrete collected from nine different IDOT districts and FHWA ALF section. Pavement system information was provided by the districts to allow correlation between IL-SCB's FI and field performance. Correlation between field performance and the FI developed in this study for validating the approach developed and for determining thresholds that can discriminate performance using a simple index parameter. The FI obtained from the IL-SCB tests was found in very good agreement with performance rankings developed for the mixes, based on fatigue cracking measurements and structural analysis predictions. FI values of 2.0 and 6.0 appear to be cut-off values distinguishing poor- (less than 2.0), intermediate- (2.0 to 6.0), and good-performing (greater than 6.0).

A research conducted for Wisconsin DOT for developing performance-based pavement specification used the FI for fatigue analysis of laboratory prepared mixes from 3 different sources of aggregate, 2 binders (PG 58-28 and PG58-34) with and without polymer and with and without RAP material using SCB test. The study recommended a minimum threshold FI value of 6, 12, and 18 and for a short-term aged asphalt mix and 2.5, 5, and 7.5 for a lon-term aged asphalt mix for low, medium, and high traffic level, respectively for the non-overlay construction. In the case of overlay construction, these threshold values were increased by 50% due to excessive movement at the joint. (Hussain et al. 2016).

2.3 Rutting Performance

Rutting is pavement distress that occurs at the early life of the pavement due to traffic loading, compaction and mix design factors. Rut depth rate of rutting, and rutting index are the key factors used to evaluate rutting performance. Rut depth is the height from the surface of the pavement to the button of the pavement wheel path depression. The rate of rutting is the speed of rutting to achieve the same amount of depth. Common laboratory rutting tests are Asphalt Pavement Analyzer (APA), Driving Wheel Pavement Analyzer (DWPA), Hamburg Wheel Tracking Device

(HWTD), French Pavement Rutting Tester (FPRT), etc. Rutting is the main type of distress considered in the hottest areas of the USA. Many studies were conducted on the rutting performance of asphalt pavement.

Chiu and Lu (2007) conducted a study on the SMA samples with ground tire rubber, regular SMA, and densely graded HMA with the same aggregate. The result indicated that SMA with rubber tends to have less rate of rutting than regular SMA or densely graded HMA. The mixture with a bigger aggregate tends to have more resistance to permanent deformation.

Experiments were conducted to investigate the effects of Nanopolyacrylate Polymer Modifier (NPA) on the rutting behavior of the mix. Two different types of dense-graded HMA mix were developed; Control asphalt mix and NPA mix. After 8000 cycles using APA test, results showed that all mixes performed well with respect to durability and flexibility. The difference in rutting between the control mix and NPA mix was significant. The rut depth after 8000 cycles for Control and NPA mixtures were 5.94 mm and 2.98 mm, respectively. The results of this investigation indicated that NPA had positive effect on the rutting performance of asphalt pavement *(Ekarizan and Juraidah 2014).*

Based on the evaluation of rutting performance of mixes from North Dakota using the APA the maximum limit of the rutting depth for the mixtures was found to be 7 mm for interstate highways *(Suleiman 2008).*

2.4 Moisture Damage Resistance

The structure and viscosity of the asphalt mix start to lose its strength due to high axle repetition, improper tension on the asphalt mix, oxidation, volatilization, etc with time. Moisture damage resistance determines how long the pavement lasts. The moisture sensitivity tests are comprised of two basic tests: quantitative tests and qualitative tests. Qualitative tests provide a subjective evaluation of the stripping potential. These tests include: boiling water test, freeze-thaw pedestal test, and quick bottle test. Quantitative tests provide a value for a specific parameter such as strength before and after conditioning. These tests include: compression test, indirect tensile test, resilient modulus test, and others (Harvey et al. 2003).

Using additives such as anti-stripping agent is common remedial used to improve the moisture damage of the asphalt pavement. Kim et. al (2009) conducted a study on investigating moisture damage by adding three additives: reference additive, hydrated lime, fly ash, and cement into two types specimens: low-traffic volume roadways with PG 64 -22 binder and high-traffic volume roadways with PG 70 -28 binders. Two asphalt mixture quantitative tests were done including standard moisture damage test and APA underwater. Two qualitative tests including the boiling water test and PATTI-Pull off test were also conducted. The standard moisture damage test results showed all mixtures performed well. Results from APA underwater were consistent with standard moisture damage test. The mixture with polymer-modified binder tended to behave better than the regular binder. Results from the two qualitative tests showed identical results. PG 70 -28 was found to be more moisture damage resistant than PG 64 -22. There was no significant difference between fly ash and cement additives. Hydrate lime seemed to perform slightly better than fly ash and cement, especially after longer conditioning time.

2.5 Comparison of Field Mix and Lab Mix Performance

Asphalt plant produces field mix to ensure the best quality of mix in a short amount of time. Since field specimens are produced in large quantity, the temperature of the whole process may not be controlled as accurate as lab specimens. The purpose of comparing field mix and lab mix is to find a better correlation between the two.

Generally, there are four main methods to fabricate asphalt mixture test specimens. They are lab mixed and lab compacted (LMLC), plant mixed and lab compacted (PMLC), plant mixed and plant compacted (PMPC), and the field cores, which is taken directly from the field (Reyhanech 2017). Different studies were conducted on performance comparison of lab and field mixes.

2.5.1 Low-Temperature Cracking Performance

Mihai et al (2012) compared lab and field low-temperature cracking performance using SCB and DCT. The fracture energy test indicated that conditioned lab specimens showed good correlation to the field specimens. The SCB fracture energy values were comparable on both lab and field specimens. The DCT fracture energy values from field specimens were generally lower than non-conditioned lab specimens. Result ranges of DCT and SCB tests from field mix were closer to the lab mix, but less accurate as compared to the lab mix. *Berg (2014)* showed that the lab mix had better thermal cracking performance than the field mix based on PG 58-28 and PG 64-28 mixes.

2.5.2 Fatigue Cracking Performance

A comparison of fatigue cracking performance on 11 plant mix and plant compacted (PMPC) and 11 lab mixed and lab compacted (LMLC) specimens from New Hampshire state route 12 construction site was done. Three binder grades (PG 52 -34, PG 58 -28 and PG 64 -28) were used in this study. The study compared the damage characteristic curves (DCC) of the different plant and lab produced mixtures. The test results showed that the DCC curves of lab produced mixes were very close and slighly higher than plant produced ones, which indicated lab produced mixtures generally had better performance in fatigue cyclic test. The variation of fatigue damage prediction was higher for plant-produced mixtures *(Reyhanech 2017)*. Other studies also indicated that generally, the fatigue performance of the lab mix is better than the field mix *(Berg 2014, Hussain et al. 2016).*

2.5.3 Rutting Performance

The rut depth from lab mix was relatively lower than field mix *(Bouzid et al. 2000). Brown (1991)* stated that there was a little correlation between air voids and rut depths from lab and field mixes.

2.5.4 Moisture Damage Resistance

The correlation between lab and field mix was difficult due to lack of widespread calibration, limitation of all effects causing moisture damage, variability, and difficulty of operation *(Harvey et.al 2003).*

2.6 Effect of Reclaimed Asphalt Pavement (RAP)

Sustainability of asphalt pavement is the development of the asphalt pavement that meets the needs of environmental protection, economic growth, and social equity for long-term welfare. Main factors of sustainable pavement include affordability, resource efficiency, better human equity, pollution prevention, biodiversity, recyclable materials, etc. One of the most widely used recycled material in sustainable asphalt pavements is RAP. The use of RAP has significantly increased in construction and rehabilitation of flexible pavements to ensure proper utilization of limited natural resources.

2.6.1 Effect of RAP on Low-Temperature Cracking

Due to the stiffness of aged binder in the RAP mixes high percentages of RAP tends to have inferior thermal cracking performance in general *(Al-Qadi 2009, Colbert 2012, Saha 2017).* A study was conducted on the thermal cracking performance of 12 HMA mixes with 0%, 10%, 20%, 30%, 40% and 50% of RAP. PG 64-22 and PG 58-28 binders were used in the study and low-temperature fracture energy was determined using DCT. The result indicated that fracture energy reduced significantly from 1,736 to 705 J/m^2 due to the increase in RAP from 10% to 20% for PG 58-28 binders. Fracture energy increased from 0% to 30% RAP for 64-22 binders and decreased significantly for mixes with more than 30% RAP *(Bouzid et al. 2000).*

Another study was conducted with 10 mixtures including two different RAP sources, three RAP content (0%, 20%, and 40%), and two asphalt binders (PG 58-28 and PG 58-34 binders). SCB thermal fracture energy result indicated that mixture that contained 20% RAP had the highest fracture energy at low temperatures while increasing percentages of RAP more than 20% showed a significant reduction in fracture energy *(William et al. 2000).*

2.6.2 Effect of RAP on Fatigue Cracking

William et al. (2000) conducted a research on the effect of RAP on fatigue performance of HMA. The study was conducted with 10 mixtures including two different RAP sources, three RAP content (0%, 20%, and 40%), and two asphalt binders (PG 58-28 and PG 58-34 binders). Test results showed that the asphalt mixtures containing RAP had higher dynamic modulus than mixtures than with no RAP. The result also showed that RAP sources were not a significant factor for dynamic modulus at low temperature, but significant at high temperatures.

2.6.3 Effects of RAP on Rutting

RAP increases rutting resistance due to the stiff binder in general. A study by *West et al. (2009)* that there was no significant difference in the rutting performances of the mixes without and with 25% RAP.

2.6.4 Effects of RAP on Moisture Damage Resistance

A study was conducted by *Taha et al (2014)* to compare the effect of RAP from both HMA and WMA samples on ten mixtures from Iowa, Minnesota, and Ohio. Five samples of HMA and WMA mixture from each state that contained 20%, 30%, 40%, 50%, and 75% RAP were prepared. Hamburg Wheel Tracking (HWT) tests were performed to evaluate rutting performance and moisture sensitivity for both HMA and WMA. Test results indicated that RAP improved moisture sensitivity in both WMA and HMA mixtures. With RAP less than 50%, WMA mixtures did not perform as well as HMA mixtures. With RAP more than 50%, both WMA and HMA mixtures performed well with little to no rutting. All HMA and WMA mixtures passed HWT tests, showing high resistance to rutting and moisture damage.

Feipeng and Serji (2009) conducted a study on moisture damage in rubberized asphalt mixture containing 0, 15, 25, and 30% RAP. The result indicated that the increase in percentages of RAP significantly improved the moisture resistance and increased bonds between aggregates, rubber, and asphalt binder.

CHAPTER III

METHODOLOGY

3.1 General

The field mix and the raw materials used for the field mix were collected from NDDOT project sites. A total of 20 projects from seven districts of NDDOT: Grand Forks, Williston, Devils Lake, Bismarck, Valley City, Minot, and Dickinson, were selected for this project. For one project from each district, the raw materials (aggregate, RAP and binder) from the project site was collected and mixed in the lab to compare the performance of field mix with lab mix. Rutting, fatigue cracking, low- temperature cracking and moisture damage resistance tests were done using APA, SCB, DCT, and IDT test to develop the performance-based specification for NDDOT. The experimental plan of this study is summarized in Figure 1.

The information of the field mix material used in this study is summarized in Table 1 .

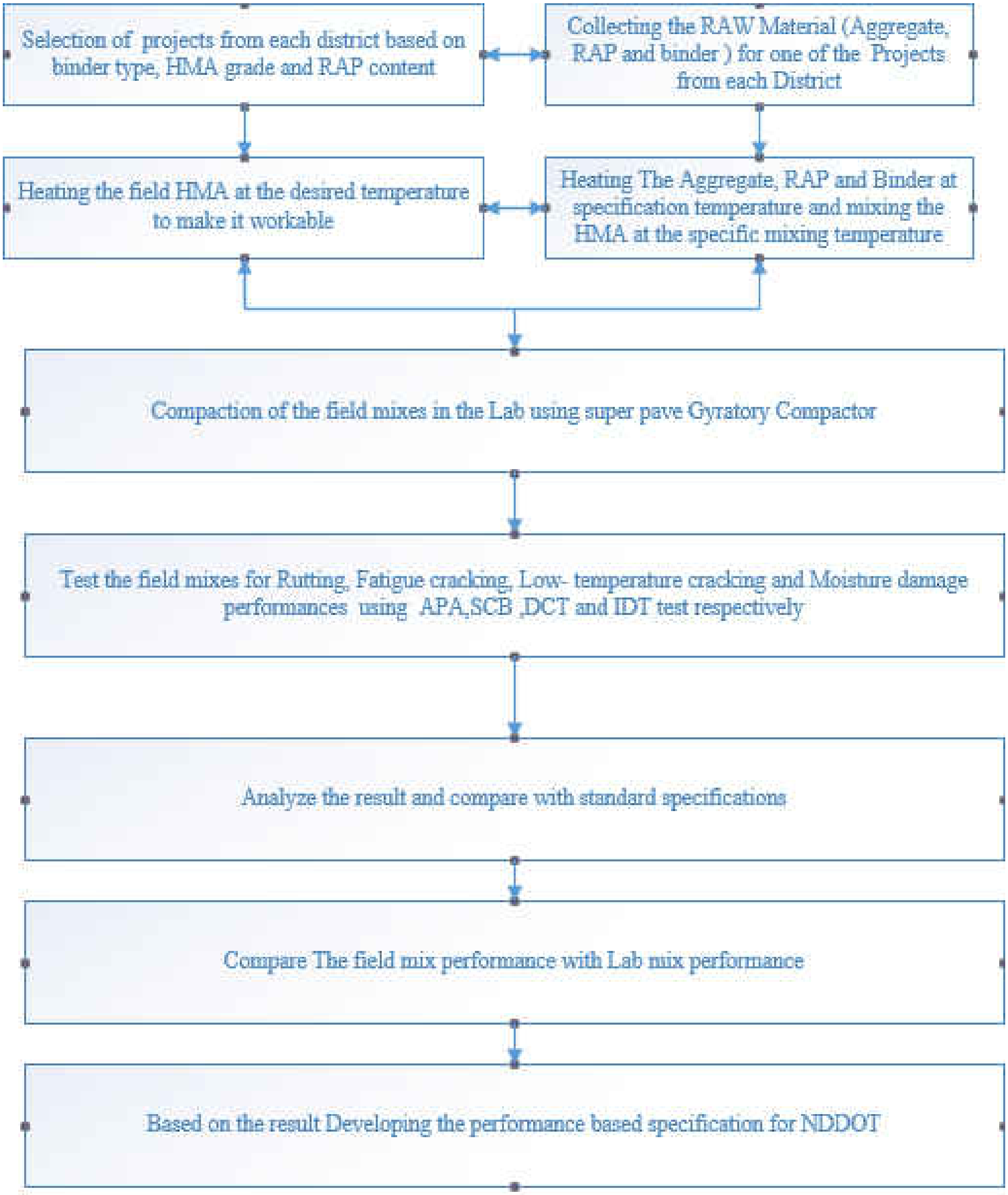

Figure.1 Experimental Plan

Table 1. Project Information

Project Number	HMA Thickness	HMA Grade	Binder Type	Lab Mix	RAP %
Grand Forks					
SS-2-020(017)027	2"	FAA 43	PG 58S-28	Yes	20
SS-6-017(047)082	2"	FAA 43	PG 58S-28		25
SS-6-066(027)124 NH-6-081(095)206	2" 3"	FAA 45	PG 58H-28		15
Bismarck					
NH-1-200(074)213	3"	FAA 42	PG 58S-28		20
NH-1-006(017)042	2"	FAA 45	PG 58S-34	Yes	18
NH-1-003(049)093	3"	FAA 43	PG 58S-34		0
Valley City					
SS-2-046(047)060 SS-2-032(029)049	3"	FAA 42	PG 58S-28		25
IM-2-094(156)221	2.7-2"	FAA 45	PG 58H-28	Yes	0
IM-2-094(156)221	2"	SMA	PG 58H-34		0
Minot					
NH-4-052(083)059	2"	FAA 45	PG 64-28	Yes	0
NH-4-003(015)136	2"	FAA 43	PG 58S-28		0
SNH-4-052(073)112	2"	FAA 45	PG 58H-28		0
SOIB-CPU-TRP-4-083(130)920	4" Bott, 2" Top	FAA 45	PG 64-28		0
Williston					
NH-NHU-7-002(156)022	7"	FAA 45	PG 58V-28	Yes	13
SS-7-008(032)203	2"	FAA 45	PG 58S-28		0
SOIB-7-804(060)267	5.5" & 6"	FAA 45	PG 58H-28		0
Dickinson					
SS-5-008(048)081 SS-5-008(049)093	3"	FAA 43	PG 58S-28	Yes	25
SS-5-016(027)076	2"	FAA 45	PG 58S-28		25
Devils Lake					
NH-3-003(027)177	3"	FAA 42	PG 58S-28	Yes	0

3.2 Mix Design

The mix designs of all selected projects were obtained from NDDOT. The same mix designs were adopted to prepare samples in the laboratory for the projects using the raw material collected from the field to compare field and lab mix performance. Mix design parameters of each project are summarized in Table 2. Gradations are summarized in the Appendix.

Table 2. Mix Design Parameters of Selected Projects

Project	**Abbr**	**AC Binder**	**% RAP**	**AC %**
Grand Forks 027	G	PG 58S-28	20	5.5
Grand Forks 082	G II	PG 58S-28	25	6.0
Grand Forks 206	G III	PG 58H-28	15	5.5
Bismarck 042	B	PG 58S-34	18	6.0
Bismarck 093	B II	PG 58S-34	0	5.4
Bismarck 213	B III	PG 58S-28	20	5.7
Valley City 221 top	V	PG 58H-28	0	5.2
Valley City 221 SMA	V II	PG 58H-34	0	6.6
Valley City 049	V III	PG 58S-28	25	5.9
Minot 059	M II	PG 64S-28	0	5.8
Minot 136	M	PG 58S-28	0	5.8
Minot 112	M III	PG 58H-28	0	5.5
Minot 920	M-1	PG 64S-28	0	5.6
Williston 022	W	PG 58V-28	13	5.5
Williston 267	W II	PG 58H-28	0	5.5
Williston 203	W III	PG 58S-28	0	5.8
Dickinson 093	D II	PG 58S-28	25	5.5
Dickinson 076	D	PG 58S-28	25	5.5
Devils Lake 177	DL	PG 58S-28	0	5.7
Devils Lake 000	DL II	PG 58H-34	15	5.5

3.3 Mix Preparation and Calculations

- 3.3.1 Theoretical Maximum Specific Gravity (Gmm)

Before compaction, theoretical maximum specific gravity (G_{mm}) for all 20 field mixes projects and seven lab mixes was determined. AASHTO T209-12 was following to determine G_{mm}. Figure 2 shows the vacuum chamber used.

Figure 2. Vacuum Chamber used to determine Gmm value

- 3.3.2 Sample Mass Determination

Specimen weight is greatly influenced by various factors including density of the aggregate, compaction temperature, compaction revolution, size of the aggregate, sample mixing, asphalt content etc. Therefore, a trial and error process were used for both field and lab mixes to determine the appropriate mixture weight to be compacted for 7±0.5% air voids.

Field mix mass

Calculations: since the mixes from field were already mixed, no more calculations were needed for field mixes. But still caution is need during the mix progress to make sure to minimize weight loss during mixing.

Lab mix

Lab mix masses were determined based on optimum asphalt content in percent RAP and virgin asphalt content in percent in each project sheet. Since all aggregate were already blended, mass of the asphalt binder, RAP and virgin aggregate were determined before the mix. Mass of the lab mix without and with the RAP was calculated from equation 1, 2 and 3.

Mass of lab mix without RAP are calculated as follows:

$$M_{AC} = M_{Agg} \times \text{Optimum AC}$$

$$M_{No\ RAP} = M_{AC} + M_{Agg} \qquad (1)$$

Mass of lab mix with RAP was calculated as follows:

$$\text{RAP AC} = \frac{Optimum\ AC - Virgin\ AC}{\%\ RAP}, \quad \text{New RAP content} = \left(\frac{\%\ RAP}{1 - RAP\ AC}\right) \quad (2)$$

$$M_{Agg} = M_{mix} \times (1 - \%\text{RAP})$$

$$M_{RAP} = M_{mix} \times \text{New RAP content}$$

$$M_{AC} = M_{mix} \times \text{Virgin AC}$$

$$M_{With\ RAP} = M_{Agg} + M_{RAP} + M_{AC} \quad (3)$$

Where

$M_{\text{No RAP}}$ = mass of mix without RAP (g)

$M_{\text{With RAP}}$ = mass of mix with RAP (g)

M_{RAP} = mass of RAP (g)

M_{Agg} = mass of blended aggregate mix (g)

M_{AC} = mass of asphalt binder (g)

M_{mix} = Designed mass of total mix (g)

Optimum AC = Total asphalt content (%)

Virgin AC = Asphalt content for Virgin aggregate (%)

RAP AC = Asphalt content for RAP (%)

%RAP = % of Rap in designed mix (%)

New RAP content = adjusted RAP content due to compensating RAP asphalt content (%)

- 3.3.3 Mixing and Compaction

Both field and lab mix samples were compacted using SuperPave Gyratory Compactor (SGC) following AASHTO T312. Field mixes were reheated to 290 ^{o}F. For lab mix aggregate mixture first before start mixing. The aggregate blends were heated at 325 ^{o}F for 6 hours, the asphalt binder was heated at 290 ^{o}F for no more than one hour, and the RAP was heated at 240^{o}F for no more than 2 hours. After lab mixes were prepared, they were aged for 3 hours at 290^{o}F.

While heating the HMA sample, the mold, sample trays, mixing bowls and spoons were heated together in the oven to ensure consistent temperature throughout compaction. Before compaction, SGC pressure was calibrated to 600 KPa. An angle of $1.28^{o} \pm 0.03^{o}$ was applied to simulate a vehicle-tire interaction in the field. Compaction stopped when the desired height was reached. The desired specimen heights were 100mm, 75mm, and 95mm for cracking, rutting, and moisture damage resistance respectively. The diameter of all specimens was 150 mm. After 15 hours curing at room temperature, Bulk Specific Gracity (Gmb) and % air voids was determined. Figure 3 shows the SGC used for compaction and mixing bowl used for mixing.

Figure 3. Sample Mixing and Compaction

3.3.4 Bulk Specific Gravity (Gmb) and % air voids determination

After proper curing, bulk specific gravity and percent air voids were determined. AASHTO T166-16 and AASHTO T269-14 were followed to determine Gmb and percent air voids respectively. The bulk specific gravity was calculated from equation 4.

$$\text{Gmb} = \frac{A}{B-C} \qquad (4)$$

Where

G_{mb} = Bulk specific gravity

A = mass of the specimen in air (g)

B = mass of the surface-dry specimen in air (g)

C = mass of the specimen in water (g)

Percent air voids was calculated using Equation 5:

$$\% \text{ Air voids} = \left(1 - \frac{\text{Gmb}}{\text{Gmm}}\right) \times 100\% \qquad (5)$$ Where

G_{mb} = Bulk specific gravity

G_{mm} = theoretically maximum specific gravity

3.4 Sample Resizing

For fatigue and low-temperature cracking performance test 150 mm diameter and 100 mm height sample were compacted initially, which were further resized to 50mm height according to the specification requirement. For DCT resized specimens, two holes of one inch (25 mm) were drilled. Crack mouth opening of 1.378in (35mm) were created. For SCB samples 50mm thick specimen were cut into half and a crack mouth opening of 15mm was created at the center of the specimens. Figure 4 and 7 shows the machines used and prepared specimens for each test. Figure 5 and 6 shows the dimensions of DCT and SCB samples used for test respectively.

Figure 4. Cutting, drilling and sawing machine

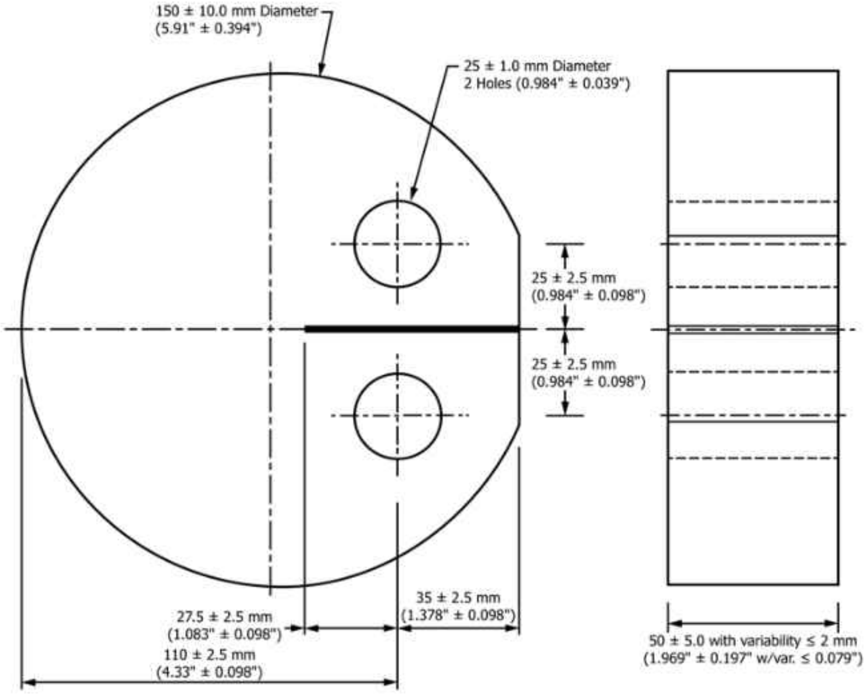

Figure 5. DCT Sample Dimension

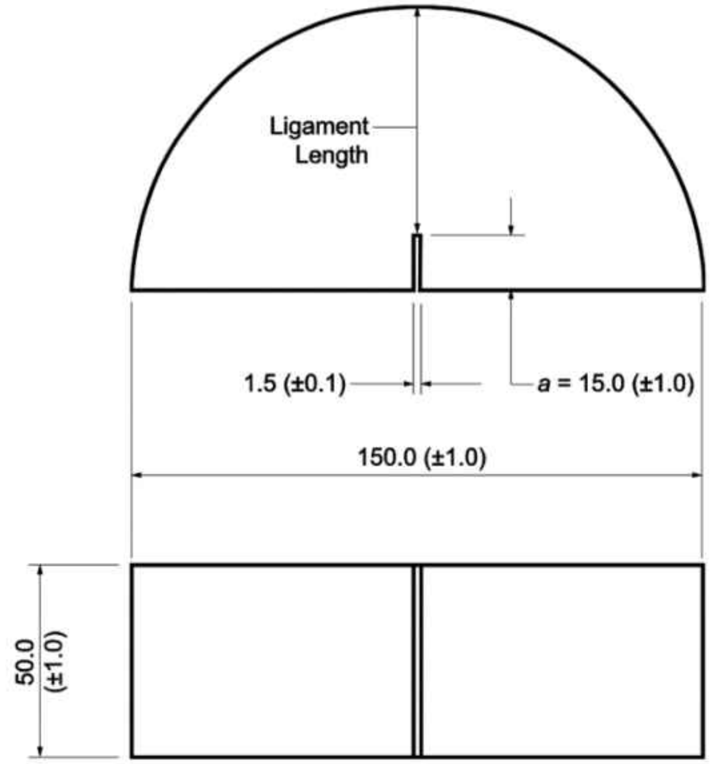

Figure 6. SCB Sample Dimensions

Figure 7. Samples Ready to be Tested

At least 10 specimens were produced for field and lab mixes of each project. Three for low-temperature cracking, three for fatigue cracking and four for rutting. A moisture damage resistance test was done only for one project from each district where field mix was replicated in the lab. Six specimens for both field and lab mixes were tested for moisture damage resistance. There were a total of 20 projects from seven districts. Table 3 lists minimum number of specimens used in this research. A total of 93 samples for low-temperature cracking, 93 samples for fatigue cracking, 114 samples for rutting, and 84 samples for moisture sensitivity tests were tested.

Table 3. Minimum number of specimens needs to produce in the research

District	**Pro.**	**Field Mix**				**Lab mix**				**Total**
		Low	**Fatigue**	**Rutting**	**Moisture**	**Low**	**Fatigue**	**Rutting**	**Moisture**	
Grand Forks	3	9	9	12	6	3	3	4	6	**52**
Williston	3	9	9	12	6	3	3	4	6	**52**
Valley City	3	9	9	12	6	3	3	4	6	**52**
Bismarck	3	9	9	12	6	3	3	4	6	**52**
Devils Lake	2	6	6	8	6	3	3	4	6	**42**
Dickinson	2	6	6	8	6	3	3	4	6	**42**
Minot	4	12	12	16	6	3	3	4	6	**62**
Grand Forks RAP	1					9	9	6	0	**30**
Total	**21**	**60**	**60**	**80**	**42**	**30**	**30**	**34**	**42**	**378**

3.5 Sample Testing

Low-temperature cracking, fatigue cracking, rutting, and moisture damage resistances were determined using DCT, SCB, APA, and IDT, respectively. All samples met 7±0.5% air void content criterion.

3.5.1 DCT Test

The DCT test was used to determine the low-temperature cracking resistance of the specimen. The test was conducted in accordance with ASTM D7313 that determines the fracture energy (G_f) of the specimen. Fracture energy measures cracking resistance of the HMA specimen. All the tests were conducted at the low-temperature PG + 10˚C of the binder used in the mix. Prior to the test, the specimens were conditioned for 8 hours. at low –temperature PG+10°C of the binder. During the test, a constant Crack Mouth Opening Displacement (CMOD) rate of 0.017 mm/s was maintained. Cracks were formed along the cracking mouth during the test and a graph of CMOD versus recorded load was plotted. The final DCT results were the average values of all individual tests. Figure 8 shows the DCT test setup. Figure 9 shows a sample graph. Fracture energy in J/m^2 can be found by taking the area under the CMOD vs peak load graph and normalized by the specimen thickness and the initial ligament length.

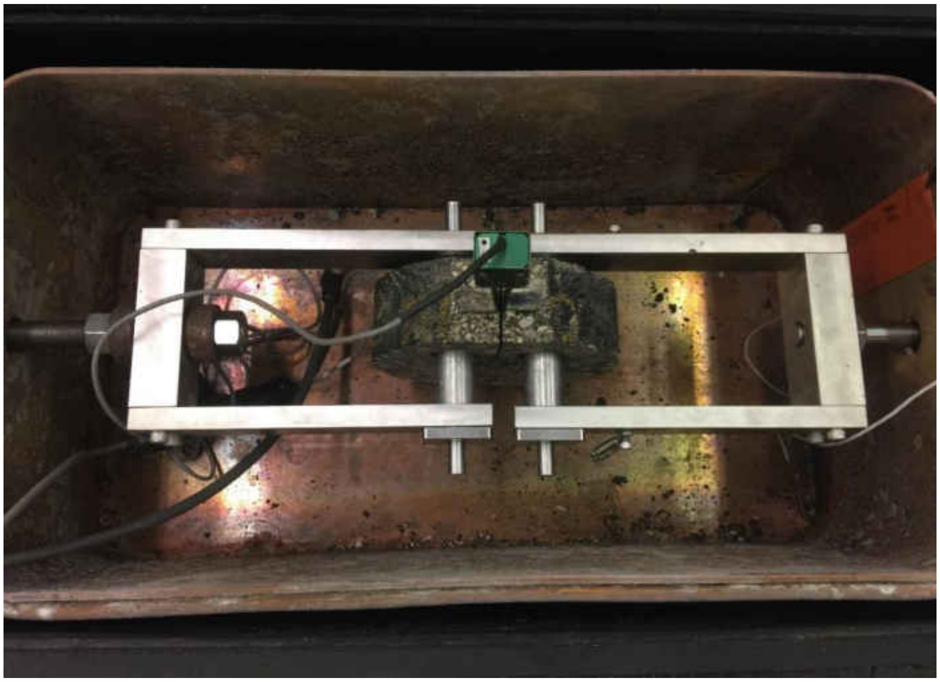

Figure 8. DCT Test Setup

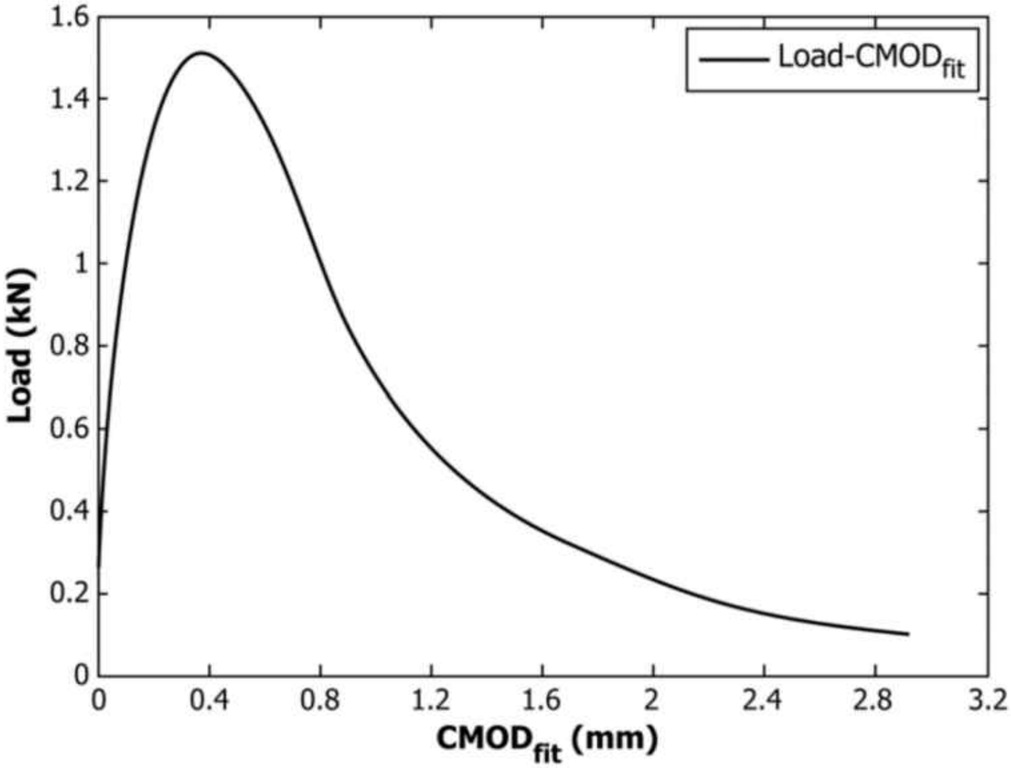

Figure 9. Typical DCT Load vs CMOD Curve

3.5.2 SCB Test

Fatigue resistance was conducted in accordance with AASHTO TP124-16. A 50±2mm samples were tested using SCB to determine fatigue cracking resistance using the Illinois-Flexibility Index Tester (I-FIT) protocol. The samples were conditioned for 2+0.2 hours and tested at 25°C. The test was run, and the data were post-processed to calculate the fracture energy and Flexibility Index (FI) using the I-FIT 2007V1.1 software. The fracture energy is the total area under load vs displacement curve and FI is the slope of the curve post peak load. Figure 10 shows the SCB setup. Typical of load vs displacement curve is shown in Figure 11. The FI index was calculated using Equation 6.

$\mathrm{FI} = \frac{G_f}{|m|} \times A$ (6) Where

G_f = Fracture Energy (J/m^2)

$|m|$ = Absolute value of post-peak load slope m (kN/mm)

A = conversion factor equal to 0.01

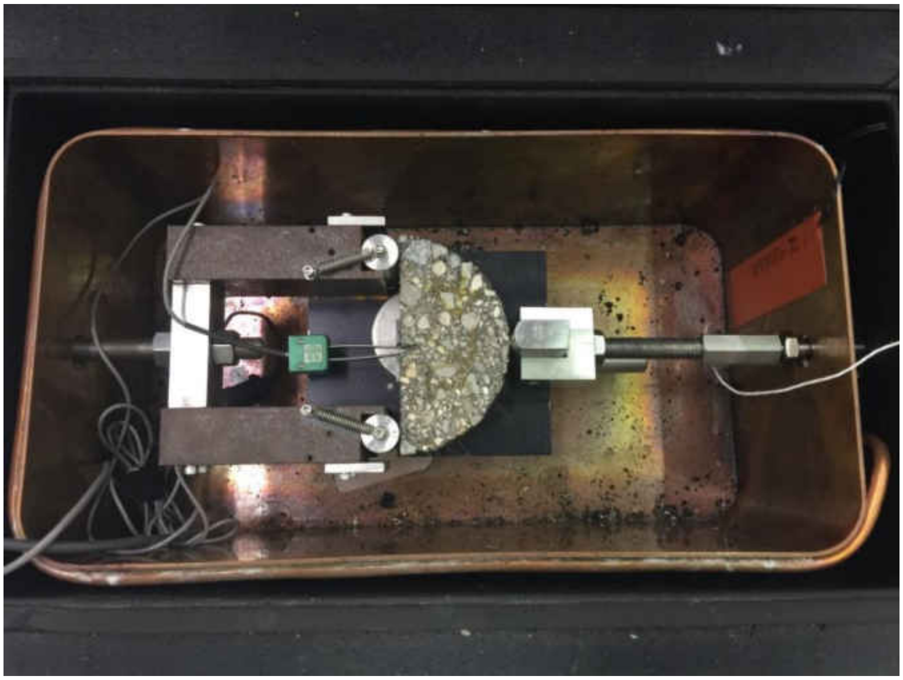

Figure 10. SCB Test Setup

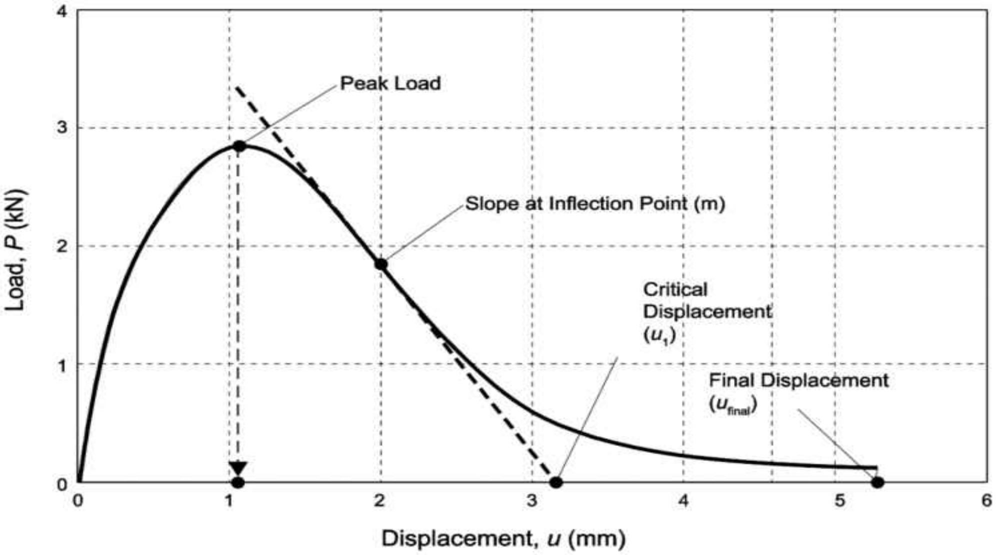

Figure 11. Typical SCB Load vs LLD Curve

3.5.3 APA Test

Rutting resistance was conducted in accordance with AASHTO T 340. Dry conditioned specimens were used for the test. Testing temperature was used based on the mixture virgin binder's high-temperature grade of the binder. The samples were conditioned inside the APA testing chamber for 6 hours before testing. The test was stopped at 8000 cycles. A tire pressure of 100 psi was used. The final APA results were the average rut depth of four specimens. Figure 12 shows APA setup in the lab.

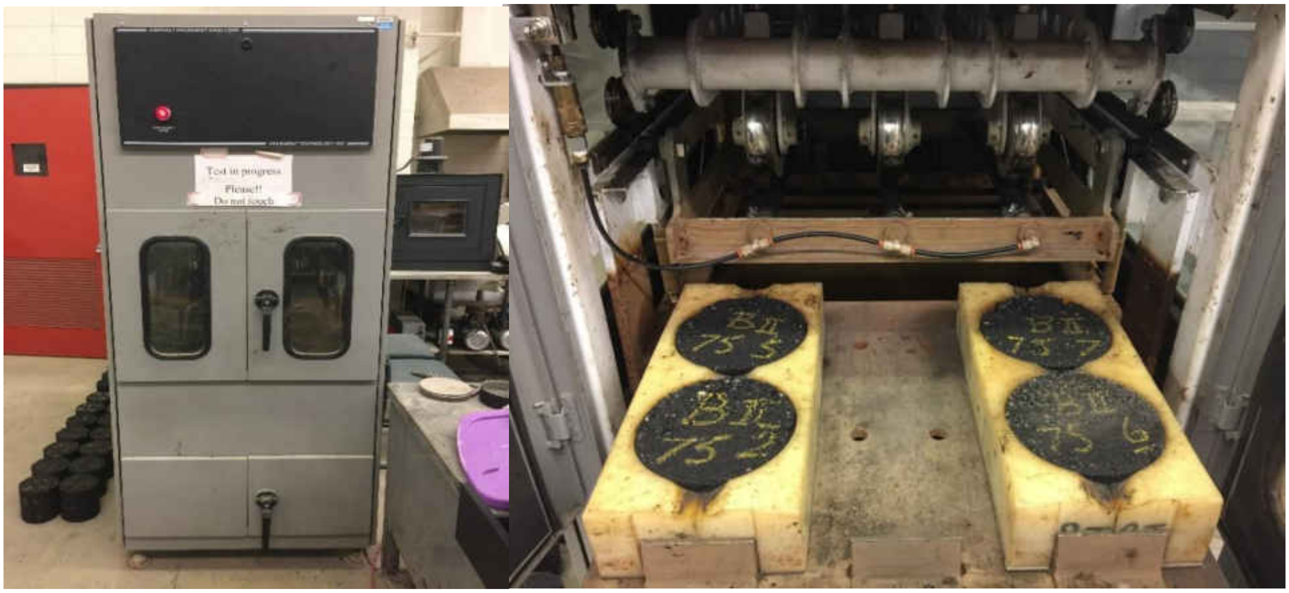

Figure 12. APA Test Setup

3.5.4 IDT Test

The indirect tensile strength test was used to determine the moisture-induced damage performance of an asphalt specimen. AASHTO T283 was followed to determine moisture damage resistance on the 95mm height and 150mm diameter specimens. Six specimens were conditioned and divided into 2 subsets of three-specimens. One subset will be tested dry. While the other will be tested wet.

The 3 dry subset specimens were conditioned at the room temperature (25 ± 0.5°C) in water bath for 2 hours. Three wet conditioned samples were placed in the vacuum container to determine the degree of saturation. The volume, absorbed water (J') and degree of saturation (S') were determined using Equation 7 and 9 respectively.

$$V_a = \frac{P_a E}{100},\ E = \frac{\pi D^2}{4} t \qquad (7)$$

Where

Va = volume of air voids (cm^3)

Pa = % of air voids

E = volume of the specimen (cm^3)

D = diameter of the specimen (cm)

t = thickness of the specimen (cm)

The volume of absorbed water (J') was calculated using Equation 8:

$$J' = B' - A \qquad (8)$$

Where

J' = volume of absorbed water (cm^3)

B' = mass of saturated, surface-dry specimen after vacuum (g)

A = mass of the dry specimen in the air (g) determined

$$S' = \frac{100J'}{V_a} \qquad (9)$$

Where

S' = degree of saturation (%)

J' = volume of absorbed water (cm^3)

Va = volume of air voids (cm^3)

Samples that passed saturation requirement (70 and 80 percent) were further conditioned in a freezer at -18°C for 16 hours. After freezing the samples were conditioned 60 °C water bath for 24 hours. IDT test was performed on wet and dry conditioned samples shown in Figure 13.

Figure 13. IDT Test Setup

Maximum compressive load was recorded after vertical cracks appeared. The tensile strength for all dry and wet conditioned samples were calculated using Equation 10. The tensile strength ratio (TSR) is the ratio of average tensile strength from three dry conditioned over three wet conditioned samples.

$$S_t = \frac{2000P}{\pi t D}, S_{t'} = \frac{2000P}{\pi t' D} \qquad (10)$$

Where

S_t , $S_{t'}$= tensile strength (kPa) for dry and wet conditioned samples

P = maximum load (N)

t, t’ = thickness (mm) for dry and wet conditioned samples

D = specimen diameter (mm)

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Theoretical Specific Gravity (Gmm) Comparison

Table 4 shows the summary of theoretical specific gravity values provided by NDDOT and determined at UND using field and lab mixes. The G_{mm} value from NDDOT is nearly the same as lab mix G_{mm} determined on this project as expected since both mixes were prepared from the same material and gradation. The slight difference is occurred due to workmanship. The G_{mm} values of the field mix is slightly higher than NDDOT and lab mix.

4.2 Low Temperature Cracking Performance

Table 5 and 6 shows field mixed, lab-compacted and lab-mixed, lab-compacted DCT fracture energy, respectively. Results indicate that the majority of projects satisfied the minimum fracture energy of 400 J/m^2 except five projects. The 95% confidence interval distribution of the fracture energy was between 425 J/m^2 to 647 J/m^2, which is above the minimum limit requirement set by MNDOT (400 J/m^2). The lab mix had slightly higher fracture energy than the field mix. This is expected as it is a more controlled mix than the field mix.

Table 4. NDDOT, Field, and Lab Mix Theoretical Specific Gravity

Project Number	Abbr	AC Binder	%RAP	Lab Mix	AC%	G_{mm}		
						DOT	Field mix	Lab mix
Grand Forks								
SS-2-020(017)027 (Virgin)	G	PG 58S-28	0	Yes	5.5			2.495
SS-2-020(017)027 (20% RAP)	G	PG 58S-28	20	Yes	5.5	2.454	2.466	2.457
SS-2-020(017)027 (40% RAP)	G	PG 58S-28	40	Yes	5.5			2.465
SS-2-020(017)027 (60% RAP)	G	PG 58S-28	60	Yes	5.5			2.403
SS-6-017(047)082	G II	PG 58S-28	25		6.0	2.434	2.456	
SS-6-066(027)124	G III	PG 58H-28	15		5.5	2.509	2.510	
NH-6-081(095)206								
Bismarck								
NH-1-200(074)213	B III	PG 58S-28	20		5.7	2.459	2.463	
NH-1-006(017)042	B	PG 58S-34	18	Yes	6.0	2.444	2.423	2.441
NH-1-003(049)093	B II	PG 58S-28	0		5.4	2.466	2.492	
Valley City								
SS-2-046(047)060 SS-2-032(029)049	V1, V III	PG 58S-28	25		5.9	2.422	2.419	
IM-2-094(156)221	V3, V	PG 58H-28	0	Yes	5.2	2.482	2.510	2.500
IM-2-094(156)221	V2, V II	PG 58H-34	0		6.6	2.395	2.420	
Minot								
NH-4-052(083)059	M II	PG 64S-28	0	Yes	5.8	2.512	2.506	2.512
NH-4-003(015)136	M	PG 58S-28	0		5.8	2.442	2.448	
SNH-4-052(073)112	M III	PG 58H-28	0		5.5	2.487	2.492	
SOIB-CPU-TRP-4-083(130)920	M-1	PG 64S-28	0		5.6	2.504	2.506	
Williston								
NH-NHU-7-002(156)022	W	PG 58V-28	13	Yes	5.5	2.507	2.490	2.505
SS-7-008(032)203	W III	PG 58S-28	0		5.8	2.494	2.492	
SOIB-7-804(060)267	W II	PG 58H-28	0		5.5	2.489	2.488	
Dickinson								
SS-5-008(048)081 SS-5-008(049)093	D II	PG 58S-28	25	Yes	5.5	2.409	2.421	2.408
SS-5-016(027)076	D	PG 58S-28	25		5.5	2.441	2.443	
Devils Lake								
NH-3-003(027)177	DL	PG 58S-28	0	Yes	5.7	2.474	2.474	2.469
NH-3-057(056)000	DL II	PG 58H-34	15		5.5	2.489	2.482	

Table 5. Field Mix DCT Test Results

Project	AC Binder	%RAP	Average (J/m^2)	SD (J/m^2)	COV (%)	Status
Grand Forks 027	PG 58S-28	20	377.33	32.89	8.72	Fail
Grand Forks 082	PG 58S-28	25	294.67	7.76	2.63	Fail
Grand Forks 206	PG 58H-28	15	561.00	34.73	6.19	Pass
Bismarck 042	PG 58S-34	18	428.00	13.44	3.14	Pass
Bismarck 093	PG 58S-34	0	400.00	41.21	10.30	Fare
Bismarck 213	PG 58S-28	20	345.67	31.12	9.00	Fail
Valley City 221 top	PG 58H-28	0	425.67	104.67	24.59	Pass
Valley City 221 SMA	PG 58H-34	0	1343.67	142.71	10.62	Pass
Valley City 049	PG 58S-28	25	338.00	24.91	7.37	Fail
Minot 059	PG 64S-28	0	454.50	87.37	19.22	Pass
Minot 136	PG 58S-28	0	368.50	3.50	0.95	Fail
Minot 112	PG 58H-28	0	546.00	53.19	9.74	Pass
Minot 920	PG 64S-28	0	830.33	68.09	8.20	Pass
Williston 022	PG 58V-28	13	809.67	53.21	6.57	Pass
Williston 267	PG 58H-28	0	624.75	103.90	16.63	Pass
Williston 203	PG 58S-28	0	639.00	73.70	11.53	Pass
Dickinson 093	PG 58S-28	25	458.00	32.57	7.11	Pass
Dickinson 076	PG 58S-28	25	1656.67	59.49	3.59	Pass
Devils Lake 177	PG 58S-28	0	398.33	53.11	13.33	Fare
Devils Lake 000	PG 58H-34	15	550.00	76.05	13.83	Pass

Table 6. Lab Mix DCT Test Results

Project	AC Binder	%RAP	Average (J/m^2)	SD (J/m^2)	COV (%)	Status
Grand Forks 027 (Virgin)	PG 58S-28	0	481.00	76.38	15.88	Pass
Grand Forks 027 (20% RAP)	PG 58S-28	20	355.00	61.68	17.38	Fail
Grand Forks 027 (40% RAP)	PG 58S-28	40	371.67	33.49	9.01	Fail
Grand Forks 027 (60% RAP)	PG 58S-28	60	296.67	14.82	4.99	Fail
Bismarck 042	PG 58S-34	18	473.00	2.94	0.62	Pass
Valley City 221 top	PG 58H-28	0	537.00	45.25	8.43	Pass
Minot 059	PG 64S-28	0	669.67	52.16	7.79	Pass
Williston 022	PG 58V-28	13	446.33	22.90	5.13	Pass
Dickinson 093	PG 58S-28	25	447.00	38.11	8.53	Pass
Devils Lake 177	PG 58S-28	0	495.75	58.36	11.77	Pass

Figure 14 and Figure 15 shows the fracture energy result of PG 58-28 and PG 58-34 asphalt binders field mixed, lab-compacted specimens. Comparison is made with respect to binder grade class and percentages of RAP in the mix. However, other variables such as gradation, angularity, type of aggregate, etc. used might have caused the variation. In Figure 14 PG 58-28S category, virgin mix shows higher fracture energy than RAP mix except Dickinson 076. Results also showed that virgin PG 58H-28 has higher fracture energy than virgin PG 58S-28. In 10 -20 % RAP mixes PG 58V-28 had the higher fracture energy than H and S, which is about 25% higher than 58H.

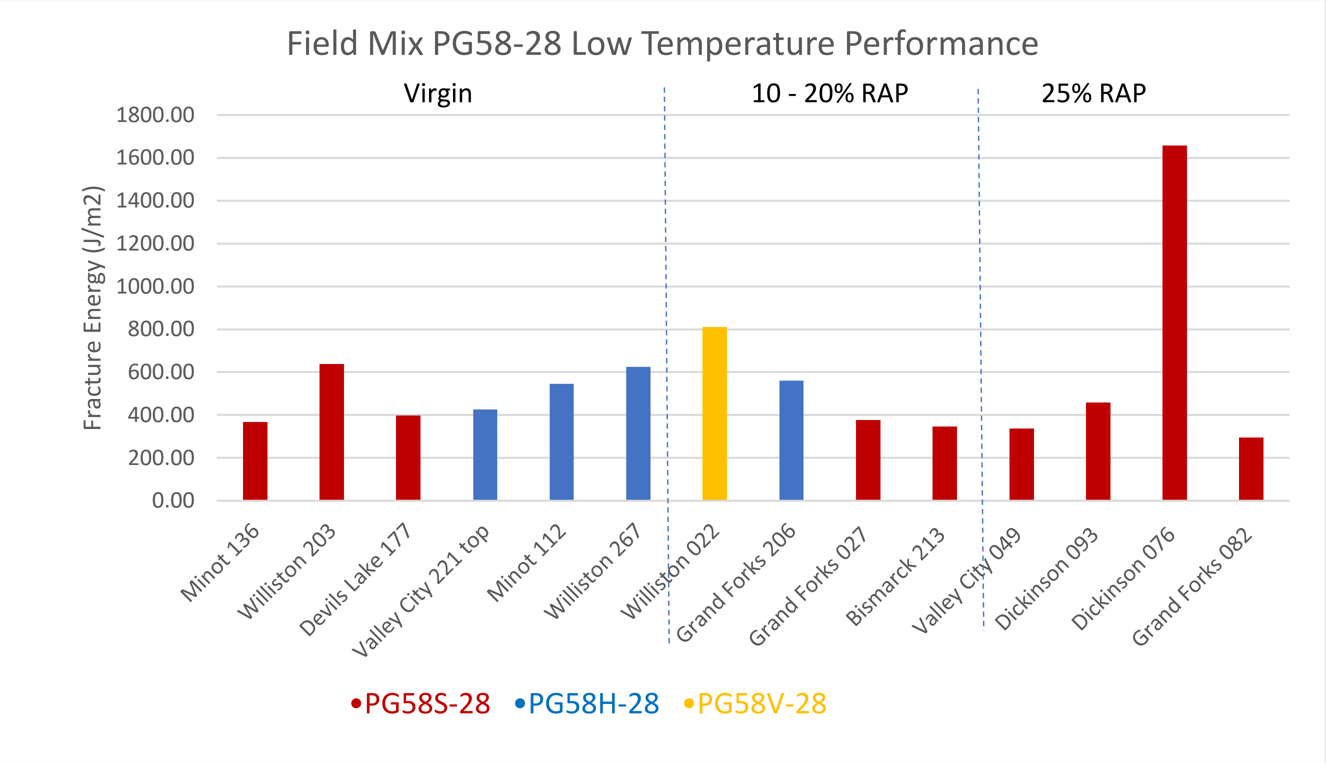

Figure 14. Field Mix PG58-28 Low Temperature Performance

Figure 15 shows a comparison of low-temperature performance with respect to Fine Aggregate Angularity (FAA). The results are not conclusive, which could be due to other variations, such as gradation, binder content, type of aggregate, etc. Results show that in PG58-

28S grade, FAA 45 has the best low-temperature cracking performance as compared to FAA 42 and 43 for both virgin and 25% RAP mixes.

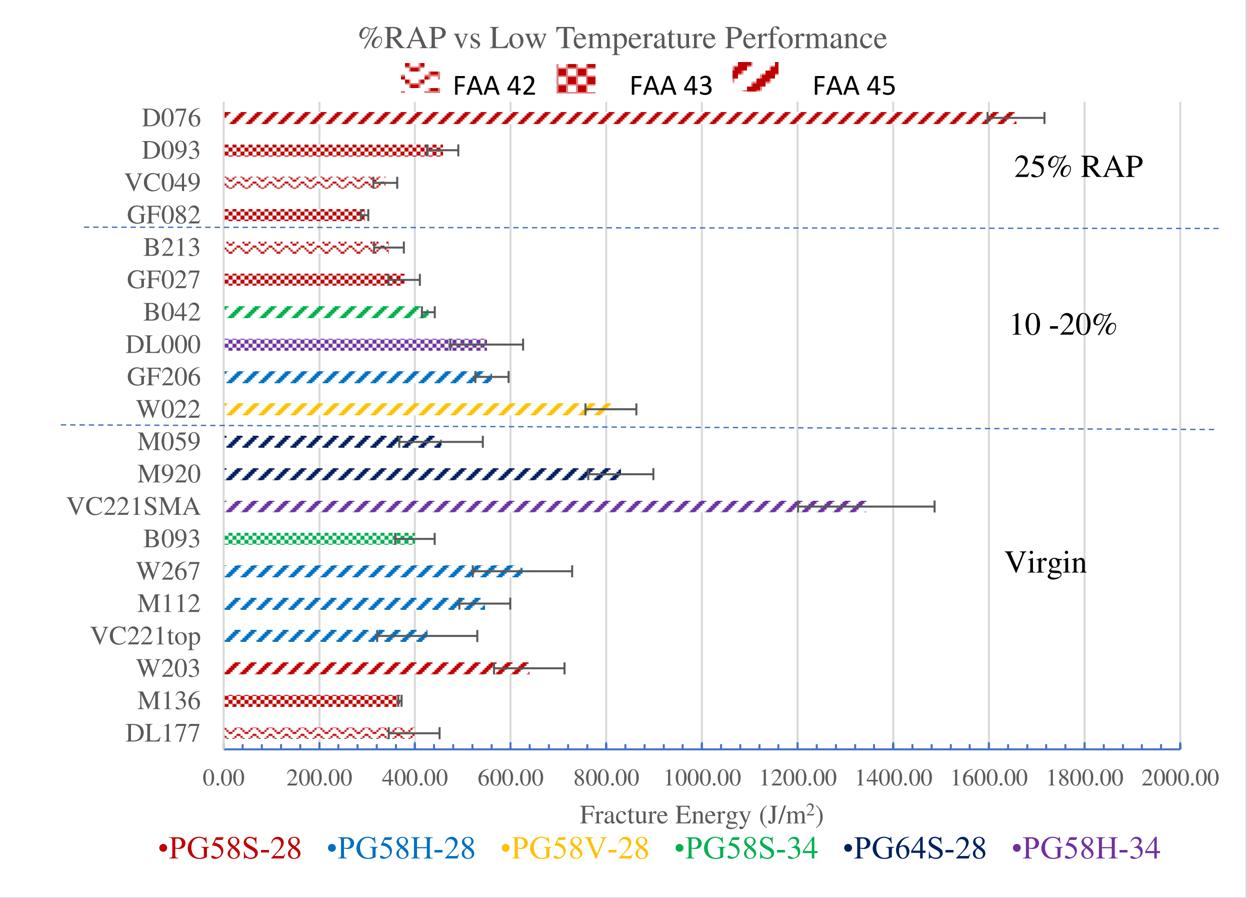

Figure 15. Effect of FAA on Low-temperature Cracking Performance

Figure 16 shows the comparison of field mix and lab mix for the same projects. For all the projects without RAP, the lab mix low-temperature performance is better than field mix. It is not conclusive for mixes with RAP. Figure 17 shows typical specimens after DCT test.

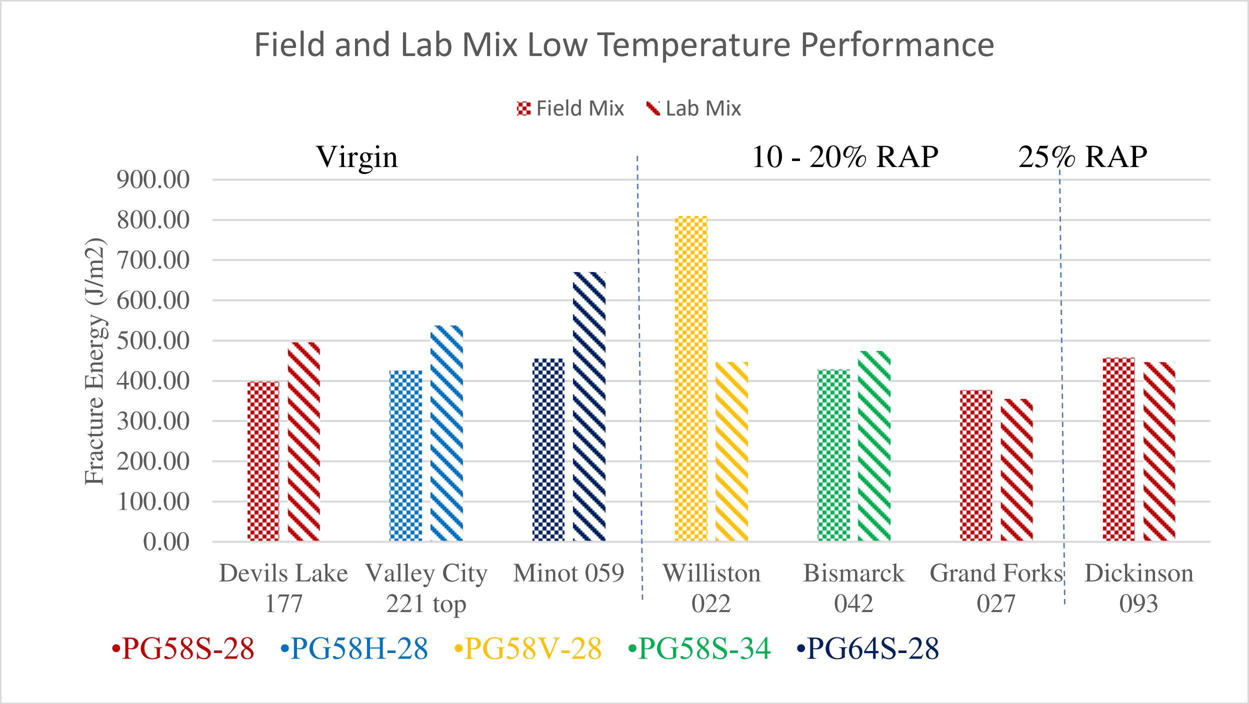

Figure 16. Field vs Lab Mix Low-Temperature Performance

Figure 17. TypicalTested DCT Specimens

Table 7 shows independent t-test for field mixes. All t-tests were done at a 0.05 significance level. A cell with an 'N' indicates no significant difference whereas a cell with a 'Y' means there is a significant difference between each project. The result shows that it is statistically inconclusive.

Table 7. Field Mix DCT T-Test Results

	G	**G II**	**G III**	**B**	**B II**	**B III**	**V**	**V II**	**V III**	**M II**	**M**	**M III**	**M-1**	**W**	**W II**	**W III**	**D II**	**D**	**DL**	**DL II**
G	/	Y	N	Y	Y	Y	Y	N	Y	Y	Y	N	N	N	N	N	Y	N	Y	Y
G II	X	/	N	N	N	Y	Y	N	Y	Y	Y	N	N	N	N	N	N	N	Y	N
G III	X	X	/	Y	N	N	Y	N	N	Y	N	Y	Y	Y	Y	Y	N	N	Y	Y
B	X	X	X	/	Y	N	Y	N	N	Y	Y	Y	N	N	Y	N	Y	N	Y	Y
B II	X	X	X	X	/	Y	Y	N	Y	Y	Y	Y	N	N	Y	N	Y	N	Y	Y
B III	X	X	X	X	X	/	Y	N	Y	Y	Y	N	N	N	N	N	Y	N	Y	Y
V	X	X	X	X	X	X	/	N	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	Y
V II	X	X	X	X	X	X	X	/	N	N	Y	N	Y	N	N	N	N	Y	N	N
V III	X	X	X	X	X	X	X	X	/	N	Y	N	N	N	Y	N	Y	N	Y	N
M II	X	X	X	X	X	X	X	X	X	/	Y	Y	N	Y	Y	Y	Y	N	Y	Y
M	X	X	X	X	X	X	X	X	X	X	/	Y	Y	N	Y	Y	Y	N	Y	Y
M III	X	X	X	X	X	X	X	X	X	X	X	/	Y	N	Y	Y	Y	N	Y	Y
M-1	X	X	X	X	X	X	X	X	X	X	X	X	/	Y	Y	Y	N	N	N	N
W	X	X	X	X	X	X	X	X	X	X	X	X	X	/	Y	N	N	N	N	N
W II	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/	Y	Y	N	Y	Y
W III	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/	Y	N	N	N
D II	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/	N	Y	Y
D	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/	N	N
DL	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/	Y
DL II	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/

4.3 Rutting Performance

Figure 18 shows field mix rut depth comparison with respect to percentages of RAP content, binder grade, and FAA grade for field mixes. It should be noted that the variations could be due to other variables, such as gradation, binder content, and aggregate type. Results show that for the virgin mixes PG58H-28 had the lowest rut depth of about 2mm except Minot 112, which is 50% less than 58S and 64S-28 mix. The rest of PG binders behave similarly for the virgin mix. In 10-

20% RAP mix, PG58H-28 and PG58S-34 have a rut depth of about 2.5 mm. The rut depth of PG58S-28 ranges from 2.5 mm to 4 mm for both 10-20% and 25% RAP mixes. The result also showed that FAA 43 grade mix is the most rut resistant for all virgin and RAP mixes with PG58-28S asphalt binder. Detailed results are included in the Appendix.

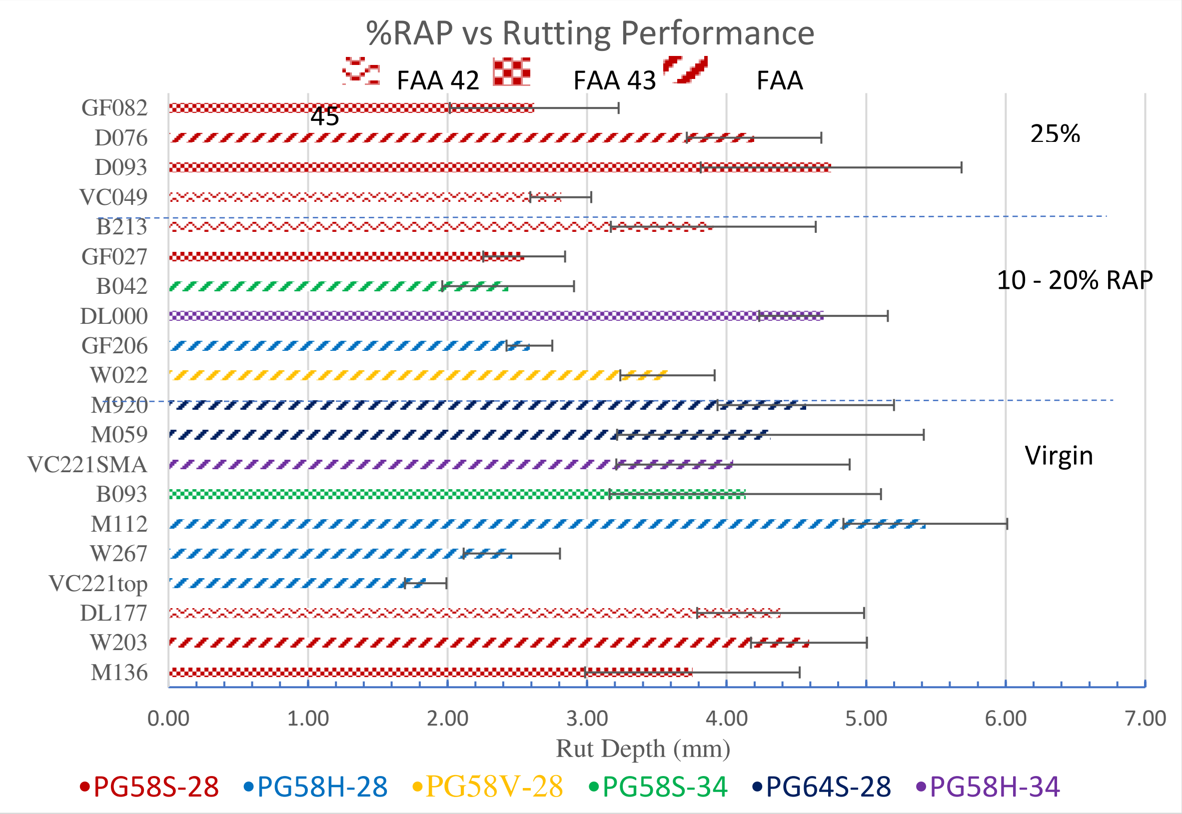

Figure 18. Field Mix Rut Depth vs % of RAP

Figure 19 shows rut depth comparison of field and lab mixes. The results are not conclusive. The lab mix performed better for the 57% of virgin mixes. For the projects with RAP lab mixes performed better than field mixes for 75% of the projects perform. Figure 20 shows typical specimens after testing.

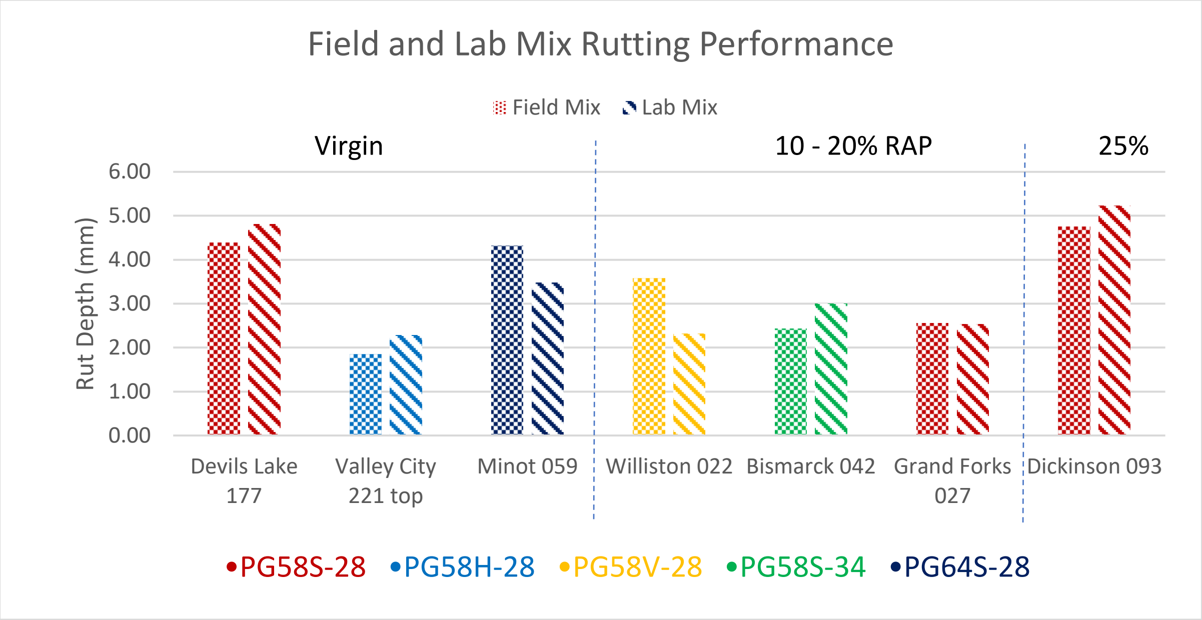

Figure 19. Field and Lab Mix Rutting Performance

Figure 20. Tested APA Specimens

Table 8 shows independent t-test results for field mixes. All t-tests were done at a 0.05 significance level. A cell with an 'N' indicates no significant difference whereas a cell with a 'Y' means there is a significant difference between each project. The statistical significance is not conclusive.

Table 8. Field Mix APA T-Test Results

	G	**B**	**M**	**W**	**V**	**D**	**DL**	**B II**	**M II**	**V II**	**D II**	**DL II**	**G II**	**W II**	**B III**	**G III**	**V III**	**M III**	**W III**	**M-1**
G	/	Y	Y	Y	Y	N	N	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	N	N
B	X	/	Y	N	Y	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	N
M	X	X	/	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	Y
W	X	X	X	/	N	N	Y	Y	Y	Y	Y	Y	N	N	Y	N	N	N	Y	Y
V	X	X	X	X	/	N	N	N	Y	N	N	N	Y	N	N	N	N	N	N	N
D	X	X	X	X	X	/	Y	Y	Y	Y	Y	Y	N	N	Y	N	N	N	Y	Y
DL	X	X	X	X	X	X	/	Y	Y	Y	Y	Y	N	N	N	N	N	N	Y	Y
B II	X	X	X	X	X	X	X	/	Y	Y	Y	Y	N	N	Y	Y	N	N	Y	Y
M II	X	X	X	X	X	X	X	X	/	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
V II	X	X	X	X	X	X	X	X	X	/	Y	Y	N	N	Y	N	N	N	Y	Y
D II	X	X	X	X	X	X	X	X	X	X	/	Y	Y	N	Y	N	N	Y	Y	Y
DL II	X	X	X	X	X	X	X	X	X	X	X	/	N	N	N	N	N	Y	N	Y
G II	X	X	X	X	X	X	X	X	X	X	X	X	/	Y	N	Y	Y	N	N	N
W II	X	X	X	X	X	X	X	X	X	X	X	X	X	/	N	Y	N	N	N	N
B III	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/	N	N	N	Y	N
G III	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/	Y	N	N	N
V III	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/	N	N	N
M III	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/	Y	Y
W III	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/	Y
M-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	/

4.4 Fatigue Cracking Performance

Table 9 to 12 illustrates field and lab mix SCB test results of all 20 projects. Results showed that all samples passed fracture energy criteria except Grand Forks 082. Bismarck 213 and Valley City 049 have low FI values of, around 2. Most projects have an FI value of 4 to 7. The field mix fracture energy of 95% confidence interval range is 1178 J/m^2 to 3035 J/m^2 The FI ranges from 6 to 9 except for the SMA and brittle mixes.

Table 9. Field Mix SCB Test Results (Fracture Energy)

Project	AC Binder	% RAP	Average Energy (J/m^2)	SD (J/m^2)	COV (%)
Grand Forks 027	PG 58S-28	20	1279.98	230.26	17.99
Grand Forks 082	PG 58S-28	25			
Grand Forks 206	PG 58H-28	15	2313.43	183.15	7.92
Bismarck 042	PG 58S-34	18	1365.99	71.78	5.25
Bismarck 093	PG 58S-34	0	1496.22	118.91	7.95
Bismarck 213	PG 58S-28	20	1178.30	0.43	0.04
Valley City 221 top	PG 58H-28	0	1982.89	265.25	13.38
Valley City 221 SMA	PG 58H-34	0	1791.92	92.51	5.16
Valley City 049	PG 58S-28	25	1630.18	235.37	14.44
Minot 059	PG 64S-28	0	1590.57	204.84	12.88
Minot 136	PG 58S-28	0	1236.73	61.16	4.95
Minot 112	PG 58H-28	0	2564.73	277.65	10.83
Minot 920	PG 64S-28	0	3053.91	347.98	11.39
Williston 022	PG 58V-28	13	2077.86	141.73	6.82
Williston 267	PG 58H-28	0	2301.98	18.29	0.79
Williston 203	PG 58S-28	0	1840.32	189.33	10.29
Dickinson 093	PG 58S-28	25	1920.32	112.34	5.85
Dickinson 076	PG 58S-28	25	2065.98	256.17	12.40
Devils Lake 177	PG 58S-28	0	1917.97	159.54	8.32
Devils Lake 000	PG 58H-34	15	1817.08	81.96	4.51

Table 10. Lab Mix SCB test results (Energy)

Project	AC Binder	% RAP	Average Energy (J/m^2)	SD (J/m^2)	COV (%)
Grand Forks 027 (Virgin)	PG 58S-28	0	2102.53	82.13	3.91
Grand Forks 027 (20% RAP)	PG 58S-28	20	1385.37	116.96	8.44
Grand Forks 027 (40% RAP)	PG 58S-28	40			
Grand Forks 027 (60% RAP)	PG 58S-28	60			
Bismarck 042	PG 58S-34	18	1771.55	140.51	7.93
Valley City 221 top	PG 58H-28	0	2231.25	154.38	6.92
Minot 059	PG 64S-28	0	2407.38	82.58	3.43
Williston 022	PG 58V-28	13	2115.64	113.81	5.38
Dickinson 093	PG 58S-28	25	1778.53	104.65	5.88
Devils Lake 177	PG 58S-28	0	2040.35	258.72	12.68

Table 11. Field Mix SCB Test Results (FI Index)

Project	AC Binder	% RAP	Average	SD	COV (%)	Status
Grand Forks 027	PG 58S-28	20	6.50	1.01	15.58	Good
Grand Forks 082	PG 58S-28	25				Poor
Grand Forks 206	PG 58H-28	15	5.23	0.77	14.72	Fair
Bismarck 042	PG 58S-34	18	10.12	1.72	17.04	Good
Bismarck 093	PG 58S-34	0	8.77	2.05	23.39	Good
Bismarck 213	PG 58S-28	20	2.21	0.16	7.03	Fair
Valley City 221 top	PG 58H-28	0	4.58	0.31	6.81	Fair
Valley City 221 SMA	PG 58H-34	0	40.11	1.60	4.00	Good
Valley City 049	PG 58S-28	25	2.70	0.26	9.56	Fair
Minot 059	PG 64S-28	0	10.18	2.26	22.16	Good
Minot 136	PG 58S-28	0	11.65	1.03	8.83	Good
Minot 112	PG 58H-28	0	8.67	0.29	3.39	Good
Minot 920	PG 64S-28	0	11.50	1.22	10.61	Good
Williston 022	PG 58V-28	13	12.98	1.59	12.23	Good
Williston 267	PG 58H-28	0	7.20	0.30	4.21	Good
Williston 203	PG 58S-28	0	10.03	0.94	9.39	Good
Dickinson 093	PG 58S-28	25	4.38	0.26	5.99	Fair
Dickinson 076	PG 58S-28	25	7.47	0.89	11.93	Good
Devils Lake 177	PG 58S-28	0	9.01	0.69	7.62	Good
Devils Lake 000	PG 58H-34	15	11.40	1.05	9.21	Good

Table 12. Lab Mix SCB Test Results (FI Index)

Project	AC Binder	% RAP	Average	SD	COV (%)	Status
Grand Forks 027 (Virgin)	PG 58S-28	virgin	1.04	0.00	0.00	Poor
Grand Forks 027 (20% RAP)	PG 58S-28	20				Poor
Grand Forks 027 (40% RAP)	PG 58S-28	40				Poor
Grand Forks 027 (60% RAP)	PG 58S-28	60				Poor
Bismarck 042	PG 58S-34	18	3.18	0.90	28.31	Fair
Valley City 221 top	PG 58H-28	0	3.58	1.31	36.69	Fair
Minot 059	PG 64S-28	0	7.66	0.64	8.40	Good
Williston 022	PG 58V-28	13	3.37	0.57	16.81	Fair
Dickinson 093	PG 58S-28	25	1.17	0.00	0.00	Poor
Devils Lake 177	PG 58S-28	0	2.14	0.07	3.09	Fair

Figure 21 shows field mix FI index vs % of RAP and binder PG grade type. It should be noted that the variations could be due to other variations such as, aggregate gradation and binder content as well. SMA mix has the strongest fatigue cracking resistance, FI number of 40. It is more than 4 times higher than regular HMA mixes. PG 58S-28 and PG 58S-34 have comparable FI numbers. PG58H-28 does perform the least. In 10-20% RAP mixes, PG58V-28 is the most fatigue cracking resistant. For the PG 58S-28 category, FAA 42 was the least fatigue cracking resistant. FAA 45 and 43 have similar FI for the virgin mixes. For the 25% RAP mixes, FAA 45 has highest FI index.

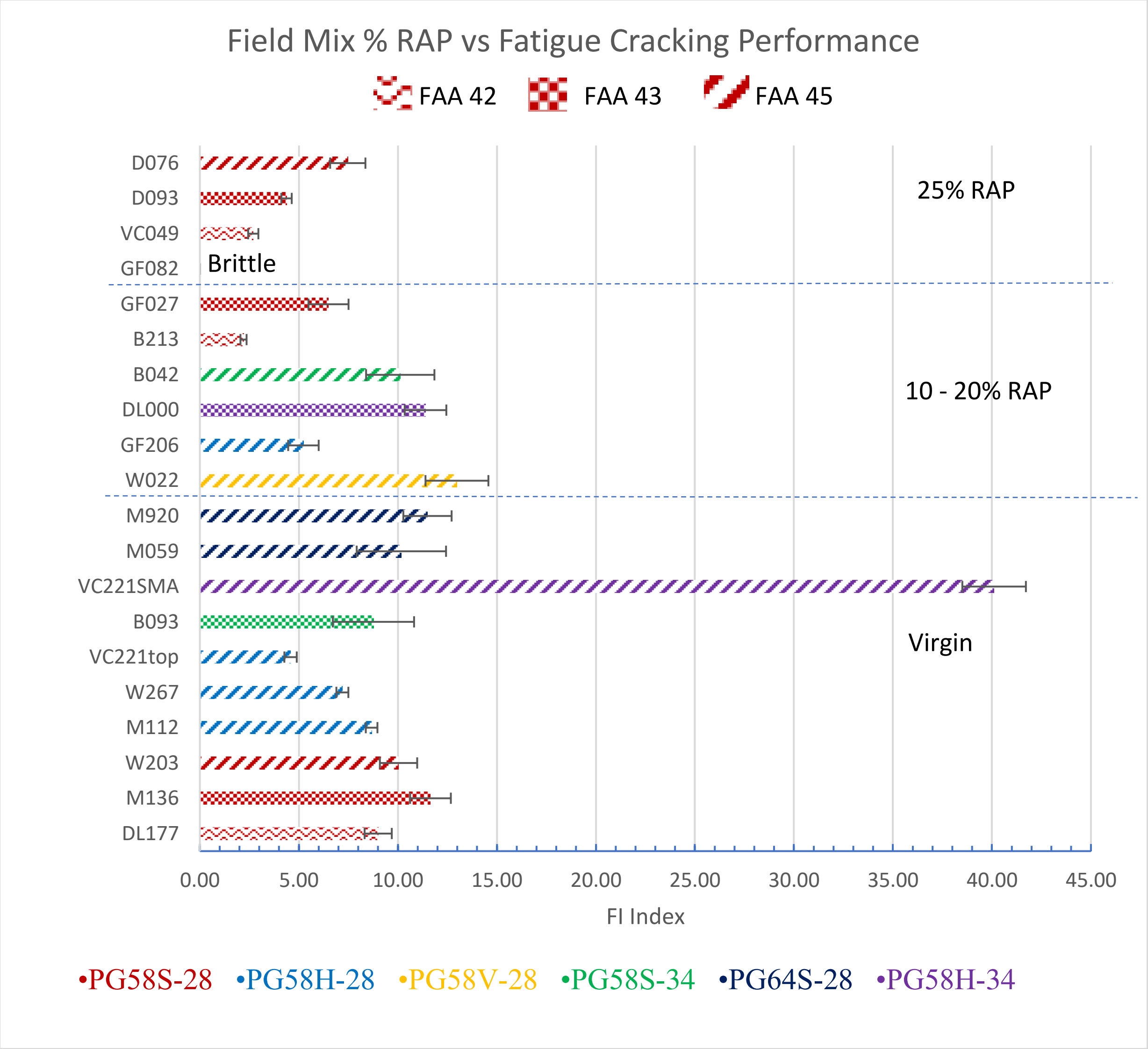

Figure 21. Field Mix Flexibility Index vs % of RAP

Figure 22 shows comparison of field and lab mix performance. Fracture energy of the lab mixes is higher than field mixes in general whereas the FI values of the lab mixes were less than the field mixes in general. This could be due to the difference in mixing type and size, mix time, aging, etc. Figure 23 shows the typical samples after SCB tests.

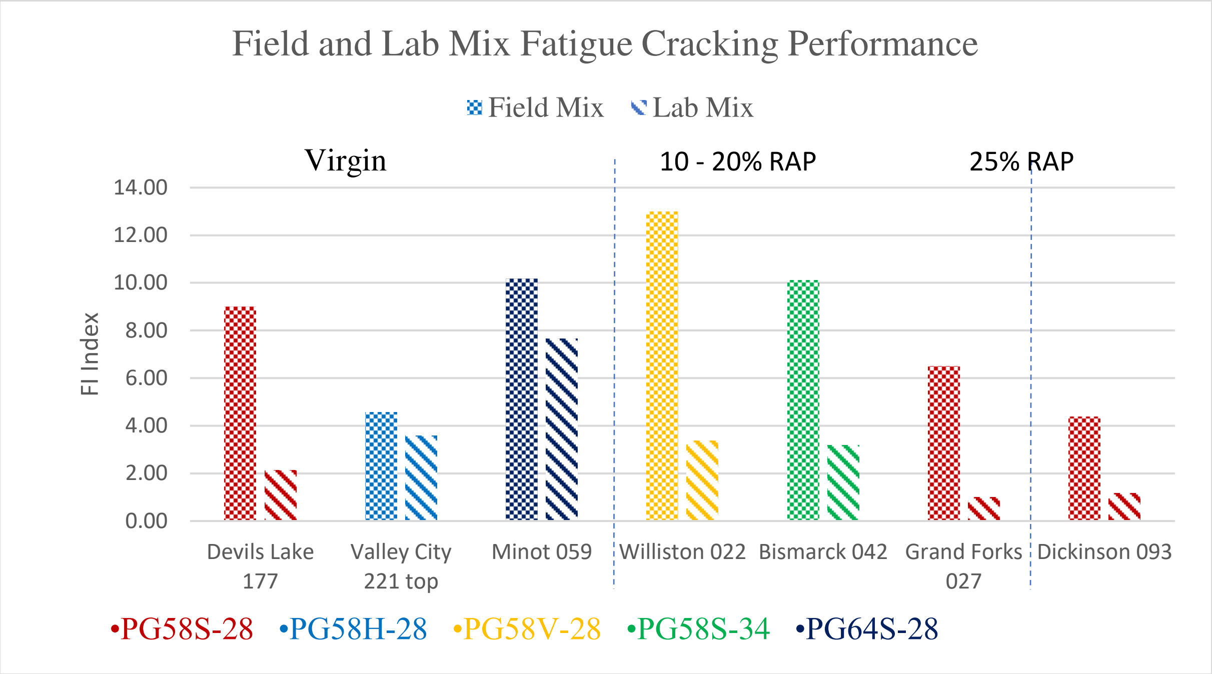

Figure 22. Comparison of Field and Lab Mix Fatigue Cracking Performance

Figure 23. Typical Samples after SCB Tests

4.5 Moisture Damage Performance

Figure 24 shows field and lab mix moisture damage performance. All of field mixes passed moisture damage test except Bismarck and Devils Lake district projects. Moisture damage resistance of lab mixes is less than field mixes in general. For the virgin mixes, PG58H-28 has performed slightly better than PG 58S-28 and PG 64S-28. For the 10-20% RAP mixes, PG 58V-28 performed slightly better than PG58S-28. The effect of RAP on lab mixes is not conclusive. This comparison is only to show the trend since other factors, such as binder content and gradation have not been controlled. Figure 25 shows typical samples after moisture damage resistance test. Detailed moisture saturation and tensile strength see Appendix.

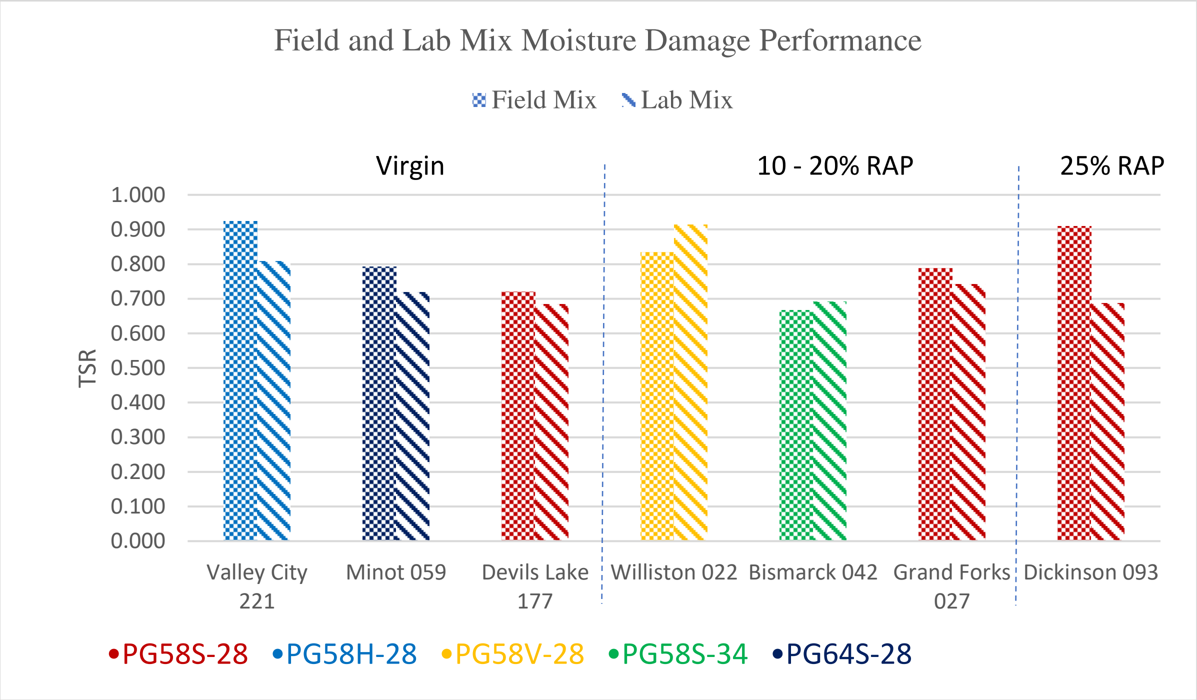

Figure 24. Field and Lab Mix Moisture Damage Performance

Figure 25. Typical Tested Moisture Damage Specimens

4.6 The Effect of RAP

- 4.6.1 The Effect of RAP in Low-Temperature Cracking Performance

Figure 26 shows the percentage of RAP vs low-temperature performance. It can be clearly seen the virgin mixes tend to have the highest fracture energy at 480 J/m^2. The fracture energy of 40% RAP was higher than that of 20% RAP but 60% RAP had the least fracture energy at 300 J/m^2.

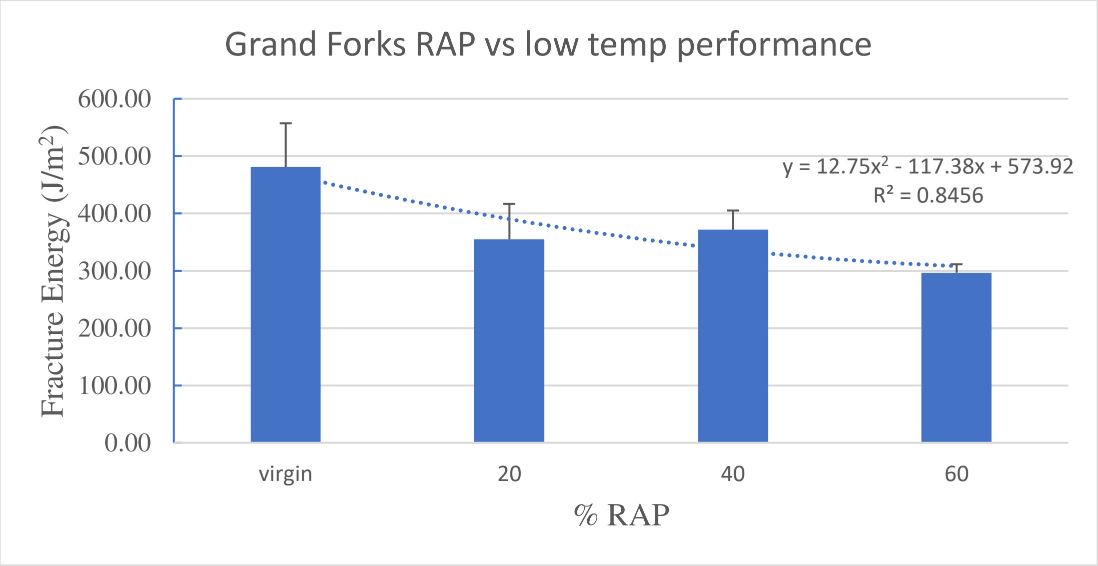

Figure 26. Effect of RAP on Low-Temperature Performance

- 4.6.2 The Effect of RAP in Rutting Performance

Figure 27 shows the % of RAP vs rut Depth. It can be seen that virgin and 20% RAP mixes have relatively high rut depth at around 1.9 mm. As percentage of RAP increases to 40%, rutting performance improved. Rutting resistance of 60% RAP is the least of all at 2.3 mm rut depth.

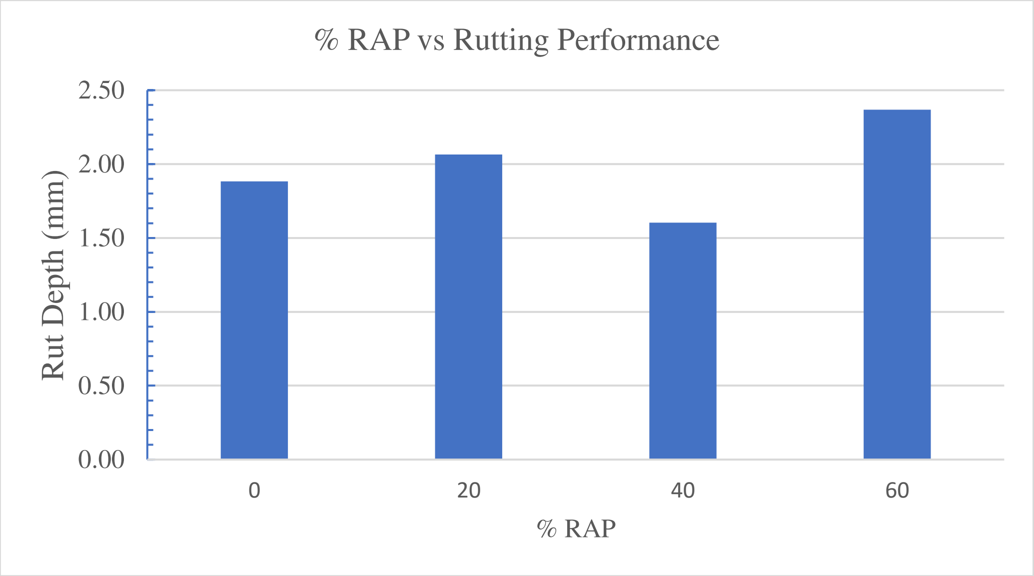

Figure 27. Effect of RAP on Rutting Performance

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made based on the result of this study.

Low- temperature cracking resistance performance:

- 75% of the field mixes satisfied the minimum fracture energy requirement of 400 J/m^2.
- The average fracture energy for 95% confidence interval ranges from 425J/m^2 to 647J/m^2 except the SMA mix which has significantly higher fracture energy.
- Lab mixes have slightly higher fracture energy than the field mixes.

Rutting resistance performance:

- All samples were well below the maximum rutting depth requirement of 7mm.
- The comparison of lab vs field mix was inconclusive.

Fatigue cracking resistance performance:

- Fracture energy of field mixes 95% confidence interval ranges from 1178 J/m^2 to 3035 J/m^2 whereas the FI ranges 6 to 9 except the SMA and brittle mixes.
- Comparison of lab vs field mixes was inconclusive.

Moisture damage

- Field mixes have higher moisture damage resistance as compared to lab mixes in general.
- Majority of the field mixes satisfied the 0.85 TSR value

Effect of RAP the performances

- The low –temperature fracture energy of 40% RAP was higher than that of 20% RAP but 60% RAP significantly reduced the low-temperature performance to 300 J/m^2.
- Rutting resistance increases as RAP content increases in general.

Appendix

Table 13. Field Mix Specimen Property Table

Field Mix										
ID	**Height (mm)**	**Rev**	**Angle**	**Pressure**	**% Gmm**	**Dry (g)**	**Wet (g)**	**SSD (g)**	**Gmb**	**% Air voids**
Grand Forks SS-2-020(017)027 Gmm = 2.466 (G)										
100(3)	99.95	25	1.29	602.93	90.7	4021.3	2287.0	4030.6	2.306	6.50
100(4)	99.75	24	1.28	601.44	90.7	3925.4	2222.4	3935.2	2.292	7.06
100(8)	99.90	27	1.27	602.44	90.8	3954.9	2250.4	3983.7	2.282	7.47
75(1)	74.78	28	1.22	603.18	89.6	2942.3	1680.7	2974.1	2.275	7.30
75(2)	74.89	31	1.26	598.96	90.4	2939.1	1670.0	2960.3	2.278	7.20
75(3)	74.94	29	1.25	602.93	89.7	2941.4	1675.3	2972.7	2.267	7.50
75(4)	74.84	31	1.25	597.47	89.7	2938.3	1689.1	2972.0	2.290	6.67
95(1)	94.70	26	1.26	603.92	90.9	3726.7	2133.0	3771.0	2.275	7.29
95(2)	94.90	22	1.27	602.44	90.9	3741.7	2136.9	3770.8	2.290	6.68
95(3)	94.65	26	1.26	603.18	90.8	3726.6	2118.4	3757.6	2.273	7.35
95(4)	94.65	25	1.26	603.92	90.9	3723.1	2120.2	3755.9	2.276	7.24
95(5)	94.70	26	1.26	602.93	90.8	3723.1	2116.6	3752.6	2.276	7.26
95(6)	94.70	33	1.13	602.44	90.7	3723.8	2118.3	3754.8	2.275	7.27
Bismarck NH-1-006(017)042 Gmm = 2.423 (B)										
100(1)	99.75	23	1.26	599.96	90.8	3926.5	2204.2	3947.0	2.253	7.02
100(2)	99.59	33	1.26	602.44	91.4	3927.4	2202.1	3947.6	2.250	7.14
100(3)	99.75	27	1.26	602.68	91.3	3929.4	2210.6	3953.3	2.254	6.94
75(1)	74.78	26	1.23	604.17	90.7	2955.9	1663.1	2966.5	2.268	6.50
75(3)	74.78	24	1.25	602.44	90.9	2933.2	1646.8	2950.3	2.250	7.13
75(4)	74.78	28	1.21	602.93	90.6	2933.0	1649.0	2949.6	2.255	6.90
75(5)	74.89	24	1.24	601.69	90.6	2936.0	1651.2	2951.8	2.250	7.00
95(1)	94.65	26	1.25	599.96	90.7	3751.5	2105.8	3764.1	2.262	6.63
95(3)	94.70	28	1.18	605.41	90.1	3716.4	2085.3	3738.1	2.249	7.20
95(4)	94.65	22	1.25	603.18	90.8	3731.2	2098.4	3748.1	2.262	6.64
95(5)	94.81	24	1.26	604.67	92.0	3723.4	2089.7	3747.9	2.245	7.30
95(6)	94.65	21	1.24	603.43	92.1	3714.3	2071.0	3730.8	2.238	7.50
95(7)	94.70	23	1.19	603.68	92.1	3719.5	2071.5	3733.3	2.238	7.50
Minot NH-4-003(015)136 Gmm = 2.442 (M)										
100(2)	99.80	41	1.10	603.18	92.7	3977.6	2251.2	3994.1	2.282	6.80
100(4)	97.53	56	1.26	600.10	91.3	3977.5	2236.3	3990.1	2.270	7.35
100(5)	99.80	22	1.28	603.68	92.4	3973.9	2243.3	3988.3	2.277	6.97
75(2)	74.89	35	1.28	600.95	90.9	2993.3	1696.4	3005.5	2.289	6.50
75(5)	74.78	33	1.27	598.71	92.8	2967.0	1673.0	2981.3	2.270	7.36
75(6)	74.89	28	1.27	602.44	92.2	2985.4	1699.9	3003.3	2.290	6.50
75(7)	74.94	27	1.28	598.71	92.2	2970.4	1676.0	2983.7	2.270	7.21

Dickinson SS-5-016(027)076 Gmm = 2.443 (D)										
100(4)	99.80	32	1.26	602.19	92.9	3993.8	2256.5	4010.4	2.277	6.80
100(7)	99.80	34	1.25	604.67	92.9	4001.5	2256.7	4008.5	2.280	6.50
100(9)	99.75	33	1.21	606.40	93.0	3988.4	2234.1	3994.5	2.266	7.26
75(2)	74.89	33	1.26	600.70	93.0	3008.5	1690.2	3013.2	2.274	6.93
75(1)	74.84	33	1.27	601.94	92.9	2997.1	1690.6	3003.1	2.284	6.52
75(6)	74.84	36	1.26	600.20	93.0	3012.0	1692.2	3016.1	2.275	6.87
75(7)	74.78	29	1.26	601.69	92.9	2999.6	1682.2	3005.5	2.267	7.21
Williston NH-NHU-7-002(156)022 Gmm = 2.490 (W)										
100(5)	99.75	39	1.22	603.92	90.6	4028.9	2302.9	4043.0	2.315	7.01
100(3)	99.80	40	1.24	600.45	91.0	4017.9	2295.8	4032.2	2.314	7.07
100(7)	99.75	38	1.24	600.45	92.0	4000.6	2287.0	4016.2	2.314	7.09
75(2)	74.78	42	1.27	603.43	91.0	3018.2	1725.4	3025.1	2.322	6.74
75(3)	74.84	41	1.28	600.70	92.0	3005.2	1718.1	3015.1	2.317	6.95
75(4)	74.84	44	1.27	599.46	92.1	2997.9	1708.2	3007.6	2.307	7.34
75(5)	74.73	37	1.25	602.19	92.1	2993.7	1704.2	3003.5	2.304	7.47
95(1)	94.75	37	1.26	602.44	91.1	3810.7	2173.4	3822.8	2.310	7.21
95(2)	94.65	40	1.22	598.71	92.1	3804.0	2171.5	3814.6	2.315	7.02
95(3)	94.70	40	1.22	600.45	92.0	3799.8	2167.8	3812.2	2.311	7.20
95(4)	94.75	40	1.25	598.71	92.0	3813.8	2169.9	3814.2	2.319	6.85
95(5)	94.70	36	1.24	600.20	92.0	3791.1	2155.2	3804.0	2.299	7.50
95(7)	94.81	43	1.22	600.20	91.2	3824.5	2175.7	3835.5	2.304	7.46
Valley City IM-2-094(156)221 Gmm = 2.510 (V)										
100(2)	99.59	28	1.26	602.68	91.8	3994.4	2309.7	4022.7	2.332	7.10
100(4)	99.85	36	1.26	602.44	90.9	4021.4	2316.2	4041.4	2.331	7.13
100(5)	99.75	32	1.25	601.44	90.9	3993.4	2284.0	4015.0	2.323	7.45
75(1)	74.73	42	1.31	604.17	91.1	3004.2	1739.5	3029.2	2.329	7.20
75(2)	74.78	35	1.29	599.96	90.5	3012.3	1730.3	3026.4	2.324	7.41
75(3)	74.78	41	1.28	603.43	91.1	2989.0	1721.2	3009.2	2.321	7.50
75(4)	74.78	35	1.27	602.68	91.1	3008.4	1733.1	3024.0	2.330	7.15
95(3)	94.70	35	1.26	605.16	91.0	3811.7	2187.4	3832.0	2.318	7.50
95(4)	94.65	31	1.25	603.92	91.1	3814.0	2192.2	3835.2	2.321	7.50
95(6)	94.75	29	1.27	603.43	91.0	3837.3	2204.6	3852.0	2.329	7.20
95(7)	94.70	38	1.25	601.44	91.5	3851.1	2217.5	3867.2	2.334	7.00
95(8)	94.75	38	1.22	602.19	91.4	3826.6	2197.7	3841.8	2.327	7.27
95(9)	94.75	37	1.26	602.44	91.4	3813.2	2188.8	3830.2	2.323	7.44
Minot NH-4-052(083)059 Gmm = 2.506 (M II)										
100(1)	99.64	34	1.25	602.68	90.6	4011.1	2323.2	4033.5	2.345	6.56
100(2)	99.70	38	1.26	603.18	90.5	4022.4	2317.8	4045.0	2.329	7.22
100(3)	99.95	32	1.26	601.94	90.5	4005.7	2322.2	4033.7	2.340	6.75
75(2)	74.89	39	1.29	603.68	90.9	3010.1	1744.1	3029.2	2.342	6.68
75(3)	74.78	39	1.30	602.19	91.0	2999.6	1738.4	3019.7	2.341	6.73

75(4)	74.89	41	1.29	602.44	90.5	3011.1	1740.8	3027.0	2.341	6.73
75(5)	74.84	39	1.28	602.44	90.5	3017.6	1747.2	3035.1	2.343	6.65
95(4)	94.75	33	1.28	603.92	90.8	3810.2	2197.4	3833.0	2.330	7.19
95(5)	94.75	40	1.28	604.17	90.9	3806.2	2194.7	3828.6	2.330	7.19
95(6)	94.70	42	1.25	602.93	90.9	3808.2	2194.5	3833.5	2.323	7.43
95(7)	94.81	31	1.28	602.19	90.8	3809.1	2193.7	3832.1	2.325	7.37
95(8)	94.70	32	1.25	602.93	90.9	3822.6	2213.1	3846.5	2.340	6.76
95(9)	94.75	29	1.21	601.20	90.8	3810.4	2188.8	3830.8	2.321	7.50
Devils Lake NH-3-003(027)177 Gmm = 2.474 (DL)										
100(2)	99.75	37	1.27	599.96	90.8	3987.2	2275.5	4007.6	2.302	6.80
100(3)	99.80	31	1.27	599.71	90.8	3964.1	2257.4	3986.5	2.293	7.18
100(4)	99.70	37	1.22	600.70	91.5	3969.7	2265.6	3992.3	2.299	6.92
75(1)	74.78	35	1.20	601.20	91.1	2968.4	1682.0	2979.4	2.288	7.37
75(3)	74.84	33	1.29	603.68	91.5	2974.3	1691.5	2991.2	2.288	7.35
75(4)	74.84	47	1.30	599.96	91.3	2972.2	1689.1	2987.1	2.290	7.29
75(5)	74.84	39	1.28	605.16	89.5	2984.5	1700.2	2998.6	2.299	6.93
95(8)	94.65	29	1.29	603.68	91.0	3736.3	2139.7	3770.3	2.291	7.23
95(9)	94.70	42	1.22	602.19	91.1	3762.0	2143.6	3787.1	2.289	7.33
95(10)	94.81	33	1.24	601.44	91.0	3764.5	2143.8	3786.0	2.292	7.20
95(11)	94.70	28	1.29	602.19	91.0	3755.3	2137.4	3779.7	2.287	7.42
95(12)	94.70	36	1.24	601.94	91.0	3752.6	2143.3	3779.7	2.293	7.16
95(14)	94.75	27	1.27	600.45	93.1	3762.5	2138.7	3785.2	2.285	7.48
95(15)	94.70	36	1.29	601.44	91.0	3752.6	2135.7	3773.9	2.291	7.41
95(16)	94.75	32	1.28	600.45	91.0	3757.9	2140.7	3778.0	2.295	7.23
95(17)	94.75	38	1.27	600.20	91.0	3761.6	2151.6	3785.3	2.303	6.93
95(18)	94.65	34	1.28	604.42	90.9	3758.6	2142.2	3777.8	2.298	7.11
95(19)	94.65	37	1.27	604.42	90.9	3764.6	2144.6	3785.3	2.295	7.26
95(20)	94.75	35	1.24	603.92	90.9	3760.4	2140.2	3780.1	2.293	7.31
Bismarck NH-1-003(049)093 Gmm = 2.492 (B II)										
100(5)	99.75	40	1.21	603.43	92.5	4008.0	2281.4	4023.7	2.300	7.48
100(3)	99.95	31	1.24	601.44	91.6	3992.5	2290.2	4009.4	2.322	6.81
100(4)	99.80	42	1.25	602.44	91.6	3976.6	2273.5	3997.7	2.306	7.45
75(2)	74.84	43	1.30	603.43	92.8	3011.0	1735.0	3028.2	2.328	6.50
75(5)	74.84	29	1.28	598.71	91.2	2996.7	1709.9	3010.0	2.305	7.50
75(6)	74.89	49	1.18	602.93	91.5	3022.1	1730.4	3033.7	2.319	6.88
75(7)	74.84	34	1.29	601.44	91.5	2982.3	1707.7	2996.7	2.317	7.08
Valley City IM-2-094(156)221 Gmm = 2.420 (V II) SMA										
100(6)	99.80	42	1.26	601.44	89.4	3801.2	2123.5	3822.4	2.237	7.50
100(7)	99.80	51	1.22	601.20	89.4	3797.2	2122.9	3821.6	2.235	7.50
100(8)	99.75	58	1.26	605.91	89.6	3835.6	2145.9	3851.3	2.249	7.06
75(15)	74.94	56	1.29	602.93	88.5	2837.8	1591.3	2859.6	2.237	7.50
75(17)	74.89	34	1.28	605.41	89.2	2857.1	1594.6	2872.9	2.235	7.50

75(18)	74.86	36	1.28	604.50	89.2	2830.6	1600.6	2868.9	2.247	7.12
75(19)	74.84	37	1.27	603.18	89.1	2855.5	1601.9	2872.0	2.248	7.10
75(1) 4%	74.89	112	1.26	602.44	94.4	2970.9	1691.4	2974.4	2.316	4.31
75(16) 4%	74.89	81	1.25	601.94	93.2	2980.9	1703.2	2985.9	2.324	3.97
95(4)	94.65	36	1.26	602.44	89.0	3616.1	2025.5	3638.2	2.242	7.35
95(6)	94.75	26	1.29	599.96	89.0	3621.9	2029.0	3645.2	2.241	7.40
95(8)	94.75	41	1.25	600.70	88.9	3625.8	2030.7	3650.4	2.239	7.50
95(9)	94.60	32	1.28	602.44	90.2	3650.7	2053.5	3669.1	2.260	6.63
95(10)	94.75	37	1.27	603.43	90.2	3626.9	2049.0	3653.3	2.261	6.58
95(11)	94.75	32	1.28	604.42	90.2	3636.8	2041.5	3656.7	2.252	6.96
Grand Forks SS-6-017(047)082 Gmm = 2.456 (G II)										
100(5)	99.80	43	1.27	603.68	91.5	3941.2	2236.5	3962.5	2.283	7.03
100(6)	99.80	48	1.25	604.42	91.5	3948.6	2242.2	3973.2	2.281	7.12
100(7)	99.80	54	1.26	601.44	91.5	3947.0	2250.9	3970.0	2.296	6.52
100(8)	99.80	47	1.25	602.19	90.6	3929.0	2226.4	3955.1	2.273	7.46
75(2)	74.78	37	1.29	602.68	91.0	2956.9	1674.3	2972.9	2.277	7.29
75(3)	74.73	41	1.30	602.93	91.0	2951.9	1671.4	2971.1	2.271	7.52
75(5)	74.73	50	1.26	601.69	91.2	2953.0	1673.7	2970.3	2.277	7.27
75(6)	74.84	44	1.27	603.43	91.2	2955.2	1672.4	2972.0	2.274	7.41
Williston SOIB-7-804(060)267 Gmm = 2.488 (W II)										
100(1)	99.70	34	1.27	600.95	91.2	4015.0	2300.8	4029.1	2.323	6.62
100(2)	99.75	33	1.25	599.96	91.6	3994.5	2282.0	4014.8	2.305	7.35
100(3)	99.70	32	1.25	600.20	91.6	3991.6	2281.9	4012.2	2.307	7.28
75(1)	74.84	46	1.26	600.70	91.6	3005.1	1716.0	3013.3	2.316	6.90
75(3)	74.78	37	1.27	601.94	91.6	3017.8	1730.3	3026.9	2.327	6.47
75(4)	74.78	41	1.26	601.94	91.6	3016.0	1726.8	3025.4	2.323	6.65
75(7)	74.89	29	1.31	603.68	91.6	2996.5	1720.0	3014.9	2.314	6.99
Dickinson SS-5-008(049)093 Gmm = 2.421 (D II)										
100(3)	99.70	26	1.23	602.19	92.7	3947.9	2214.8	3957.0	2.266	6.50
100(5)	99.75	25	1.24	601.20	92.9	3956.3	2216.1	3962.7	2.265	6.48
100(6)	99.75	34	1.22	601.20	92.7	3918.3	2187.5	3929.4	2.249	7.08
100(7)	99.75	30	1.17	602.44	91.9	3944.0	2209.6	3954.7	2.260	6.65
75(1)	74.78	32	1.28	601.94	92.3	2946.3	1643.1	2952.1	2.251	7.03
75(2)	74.78	25	1.30	599.21	92.5	2948.9	1658.2	2960.1	2.268	6.48
75(3)	74.73	27	1.26	600.45	92.5	2955.7	1654.7	2964.0	2.257	6.75
75(5)	74.84	23	1.28	602.68	92.3	2924.7	1634.5	2938.1	2.244	7.33
95(2)	94.75	33	1.19	599.96	92.1	3730.9	2089.5	3743.3	2.256	6.82
95(3)	94.75	22	1.23	601.44	92.1	3706.9	2064.3	3718.9	2.240	7.46
95(4)	94.65	24	1.24	599.96	92.2	3719.8	2076.0	3729.2	2.250	7.06
95(5)	94.65	19	1.22	598.96	92.1	3699.1	2054.3	3708.7	2.236	7.64
95(6)	94.75	30	1.18	597.72	92.1	3732.1	2092.7	3745.3	2.258	6.72

95(7)	94.70	29	1.23	602.93	91.8	3736.0	2091.6	3746.0	2.258	6.72
95(8)	94.65	23	1.24	602.19	91.9	3712.5	2069.8	3725.2	2.243	7.37
95(9)	94.75	27	1.11	603.92	91.9	3726.9	2082.8	3737.3	2.252	6.96
95(10)	94.75	54	1.27	604.92	91.9	3707.4	2063.9	3716.3	2.244	7.33
95(11)	94.81	65	1.16	603.43	91.9	3745.1	2100.3	3755.1	2.263	6.52
95(12)	94.65	21	1.31	604.17	91.9	3728.4	2096.8	3744.0	2.263	6.51
95(13)	94.70	29	1.28	600.95	91.8	3708.9	2074.3	3723.2	2.249	7.09
95(14)	94.70	29	1.28	600.95	91.8	3716.7	2081.0	3732.5	2.250	7.04
Devils Lake NH-3-057(056)000 Gmm = 2.482 (DL II)										
100(1)	99.64	17	1.17	599.21	90.4	3958.6	2257.2	3982.0	2.295	7.53
100(2)	99.70	17	1.25	604.17	91.2	3984.2	2263.2	3996.7	2.298	7.40
100(4)	99.75	18	1.26	604.42	91.2	4003.1	2283.6	4018.0	2.308	7.01
75(1)	74.73	17	1.29	602.44	90.0	2988.6	1707.0	3002.2	2.307	7.03
75(4)	74.84	18	1.26	601.94	91.5	2994.2	1698.0	3004.5	2.292	7.52
75(5)	74.68	19	1.30	604.17	90.7	3000.0	1709.0	3009.9	2.306	7.09
75(6)	74.68	15	1.29	603.18	90.8	3019.8	1724.5	3030.1	2.313	6.81
Minot SNH-4-052(073)112 Gmm = 2.492 (M III)										
100(3)	99.95	24	1.24	599.96	92.3	4056.8	2322.3	4067.7	2.324	6.73
100(4)	99.80	46	1.09	599.96	92.3	4047.6	2313.2	4058.1	2.320	6.91
100(5)	99.80	23	1.25	602.68	92.0	4032.9	2301.3	4046.8	2.310	7.28
75(1)	74.73	24	1.24	598.71	91.2	3000.8	1714.5	3015.5	2.307	7.44
75(2)	74.84	34	1.25	598.22	91.8	3014.0	1721.7	3025.8	2.311	7.26
75(3)	74.84	22	1.29	603.43	91.7	3010.5	1719.0	3021.8	2.311	7.27
75(4)	74.78	22	1.29	599.96	91.8	3017.8	1720.0	3026.7	2.309	7.32
Williston SS-7-008(032)203 Gmm = 2.492 (W III)										
100(1)	99.80	35	1.20	599.71	91.1	4006.4	2285.2	4022.1	2.307	7.43
100(2)	99.80	36	1.20	598.96	91.8	4003.8	2284.9	4020.3	2.307	7.42
100(3)	99.70	34	1.23	596.98	91.9	4024.8	2306.0	4039.3	2.322	6.82
75(1)	74.78	41	1.25	599.96	91.2	3000.0	1715.4	3010.0	2.317	7.01
75(2)	74.84	46	1.22	600.20	91.1	3017.1	1723.3	3026.1	2.316	7.07
75(3)	74.78	32	1.28	595.99	91.8	2999.4	1707.5	3009.4	2.304	7.52
75(5)	74.78	32	1.26	596.73	91.8	3001.8	1709.6	3012.7	2.304	7.53
Grand Forks NH-6-081(095)206 Gmm = 2.510 (G III)										
100(1)	99.80	35	1.29	598.71	90.7	4015.0	2310.3	4042.1	2.318	7.53
100(2)	99.80	40	1.12	600.45	91.4	4055.1	2321.9	4060.4	2.332	7.07
100(3)	99.70	33	1.29	602.19	91.4	4040.1	2320.3	4058.6	2.324	7.40
75(1)	74.84	45	1.29	599.71	90.8	3012.7	1746.3	3031.2	2.345	6.59
75(4)	74.84	42	1.27	600.20	90.8	2991.9	1727.5	3015.4	2.323	7.45
75(6)	74.84	37	1.29	602.93	90.8	3001.9	1732.8	3021.8	2.329	7.22
75(7)	74.94	39	1.30	600.95	90.8	3015.1	1741.4	3033.4	2.334	7.02
75(8)	74.94	36	1.29	599.46	90.8	3004.1	1735.4	3025.2	2.329	7.21
Valley City SS-2-032(029)049 Gmm = 2.419 (V III)										

100(4)	99.70	35	1.19	597.97	91.1	3890.3	2170.3	3911.5	2.234	7.53
100(5)	99.75	38	1.17	603.43	91.8	3911.8	2195.7	3931.5	2.254	6.84
100(6)	99.64	30	1.29	604.17	91.8	3903.0	2187.6	3922.6	2.249	7.00
75(1)	74.89	38	1.30	598.96	91.4	2927.0	1646.5	2943.5	2.257	6.71
75(2)	74.84	42	1.27	598.22	91.7	2920.9	1636.4	2935.2	2.249	7.03
75(3)	74.78	39	1.29	597.97	91.7	2929.6	1638.0	2944.1	2.243	7.27
75(4)	74.78	41	1.27	598.96	91.8	2936.0	1642.5	2948.8	2.248	7.09
Bismarck NH-1-200(074)213 Gmm = 2.463 (B III)										
100(1)	99.85	31	1.25	600.70	91.7	3971.2	2262.9	3993.1	2.295	6.81
100(2)	99.75	39	1.29	599.46	91.8	3958.0	2241.4	3980.0	2.276	7.52
100(3)	99.75	36	1.28	603.18	91.5	3969.4	2250.1	3989.4	2.282	7.34
75(2)	74.84	33	1.29	602.93	91.6	2980.8	1686.4	2993.2	2.281	7.39
75(3)	74.84	38	1.30	599.46	91.6	2962.2	1676.7	2977.8	2.277	7.56
75(5)	74.94	43	1.30	601.44	91.6	2992.6	1701.2	3005.4	2.294	6.84
75(6)	74.89	40	1.30	601.69	91.6	2980.8	1696.3	2997.6	2.291	7.00
75(7)	74.84	36	1.28	600.95	91.6	2978.3	1691.5	2994.5	2.286	7.20
Minot SOIB-CPU-TRP-4-083(130)920 Gmm = 2.506 (M-1)										
100(1)	99.75	33	1.24	598.47	90.9	4018.5	2305.7	4038.5	2.319	7.46
100(2)	99.80	35	1.23	596.23	90.8	4000.4	2302.4	4026.8	2.320	7.43
100(3)	99.70	33	1.20	600.20	91.3	4019.0	2310.4	4038.5	2.326	7.19
75(1)	74.89	36	1.29	595.49	90.9	3009.1	1730.6	3024.8	2.325	7.22
75(2)	74.78	40	1.27	598.47	91.1	3019.3	1741.5	3031.9	2.338	6.70
75(4)	74.84	35	1.29	596.48	91.1	3023.4	1737.4	3036.3	2.327	7.12
75(5)	74.89	35	1.29	600.45	91.5	3031.9	1751.4	3046.9	2.340	6.61

Table 14. Lab Mix Property Table

Lab Mix										
ID	**Height (mm)**	**Rev**	**Angle**	**Pressure**	**% Gmm**	**Dry (g)**	**Wet (g)**	**SSD (g)**	**Gmb**	**% Air voids**
Devils Lake NH-3-003(027)177 Gmm = 2.469 (DL lab)										
100(2)	99.80	30	1.28	601.69	91.3	3962.4	2264.1	3995.7	2.288	7.32
100(4)	99.70	25	1.24	597.72	91.5	3946.6	2254.0	3971.6	2.298	6.93
100(5)	99.80	39	1.27	597.63	92.2	3967.3	2267.7	3995.8	2.295	7.01
75(1)	74.89	31	1.29	599.96	91.0	2951.2	1687.4	2979.2	2.285	7.47
75(2)	74.84	51	1.29	601.94	91.0	2972.1	1702.8	2994.9	2.300	6.84
75(7)	74.84	28	1.30	602.68	91.0	2972.0	1702.2	2996.8	2.296	7.02
75(8)	74.89	32	1.30	602.19	91.0	2973.0	1698.0	2994.4	2.293	7.12
95(1)	94.70	42	1.28	598.96	91.6	3760.0	2147.0	3790.0	2.288	7.31
95(3)	94.70	36	1.27	600.95	91.3	3777.0	2168.0	3805.4	2.302	6.74
95(4)	94.60	17	1.30	600.70	91.3	3782.5	2155.3	3804.4	2.294	7.10

95(5)	94.65	20	1.30	599.71	91.3	3782.8	2160.3	3805.2	2.299	6.86
95(7)	94.75	26	1.30	598.96	91.6	3762.2	2152.5	3790.9	2.287	7.34
95(8)	94.75	32	1.29	598.71	91.5	3775.8	2150.6	3796.9	2.293	7.11
95(9)	94.75	32	1.29	597.23	91.5	3783.7	2165.8	3805.0	2.308	6.51
95(10)	94.81	32	1.29	598.96	91.5	3784.9	2160.6	3801.3	2.307	6.57
Valley City IM-2-094(156)221 Gmm = 2.500 (V lab)										
100(2)	99.75	41	1.25	597.97	90.8	4026.8	2326.0	4053.7	2.331	6.76
100(3)	99.64	29	1.23	597.47	91.2	4016.0	2309.2	4043.2	2.316	7.36
100(5)	99.80	23	1.30	599.36	92.6	4025.1	2330.1	4053.5	2.336	6.57
75(1)	74.84	42	1.29	597.47	90.9	2999.2	1729.2	3021.6	2.315	7.40
75(3)	74.89	23	1.28	594.00	90.8	3001.8	1731.3	3024.5	2.321	7.16
75(4)	74.78	27	1.28	602.44	93.4	3040.9	1756.5	3056.6	2.339	6.81
75(5)	74.54	25	1.11	596.98	92.4	3013.1	1742.3	3035.9	2.329	6.83
75(6)	74.89	39	1.28	594.99	90.8	3014.7	1733.5	3035.4	2.316	7.38
95(1)	94.75	79	1.28	596.73	91.7	3890.8	2279.7	3906.3	2.334	6.62
95(2)	94.75	45	1.25	595.49	91.7	3851.2	2230.3	3870.1	2.349	6.45
95(3)	94.70	43	1.28	600.20	90.9	3807.1	2197.9	3831.8	2.330	6.80
95(4)	94.65	26	1.29	600.70	90.9	3798.2	2191.7	3824.2	2.327	6.94
95(5)	94.65	23	1.28	596.48	90.9	3788.8	2179.0	3817.3	2.313	7.49
95(6)	94.60	27	1.29	599.46	90.9	3781.1	2168.0	3815.1	2.307	7.60
95(8)	94.65	26	1.30	598.71	90.9	3814.8	2195.0	3842.1	2.316	7.36
95(12)	94.75	66	1.26	600.45	91.1	3812.2	2210.7	3844.0	2.334	6.64
95(13)	94.81	72	1.27	599.46	91.1	3816.7	2209.2	3845.7	2.332	6.71
95(14)	94.75	65	1.28	600.70	91.1	3809.8	2210.6	3844.5	2.332	6.73
95(15)	94.75	71	1.28	598.71	91.1	3806.7	2210.3	3841.8	2.333	6.67
95(16)	94.81	60	1.28	599.21	91.1	3810.7	2220.0	3841.7	2.338	6.47
Minot NH-4-052(083)059 Gmm = 2.512 (M lab)										
100(1)	99.80	29	1.25	600.20	90.6	4037.8	2326.1	4063.5	2.324	7.48
100(3)	99.70	58	1.25	602.44	91.1	4019.2	2316.9	4039.3	2.333	7.11
100(4)	99.75	26	1.30	602.68	91.1	3996.4	2311.4	4023.7	2.334	7.09
75(1)	74.73	23	1.30	600.70	90.8	3007.2	1734.4	3027.3	2.326	7.40
75(2)	74.68	19	1.31	602.93	91.4	3022.3	1748.4	3034.7	2.350	6.46
75(3)	74.84	38	1.30	600.20	91.3	3028.4	1758.5	3047.3	2.350	6.46
75(5)	74.84	19	1.30	599.71	91.1	3024.0	1742.6	3036.1	2.338	6.93
95(1)	94.65	27	1.30	599.71	90.7	3807.3	2190.9	3828.3	2.325	7.43
95(2)	94.75	38	1.29	599.96	90.9	3835.8	2226.3	3864.0	2.342	6.76
95(4)	94.55	21	1.30	597.47	91.1	3820.6	2213.0	3847.0	2.337	6.93
95(5)	94.70	30	1.29	598.71	90.9	3813.3	2207.6	3836.0	2.342	6.78
95(6)	94.81	99	1.26	602.19	90.9	3821.3	2213.3	3840.2	2.348	6.50
95(7)	94.75	53	1.29	600.95	90.9	3812.5	2201.5	3836.7	2.332	7.18
95(8)	94.65	27	1.29	601.44	91.0	3798.3	2192.2	3828.2	2.322	7.57
95(9)	94.81	56	1.28	600.95	90.7	3820.8	2208.0	3836.1	2.347	6.58
95(10)	94.75	66	1.23	598.47	90.7	3819.3	2207.5	3843.2	2.335	7.05

95(11)	94.65	32	1.28	599.46	90.7	3811.6	2202.1	3824.6	2.349	6.53
Dickinson SS-5-008(049)093 Gmm = 2.408 (D lab)										
100(1)	99.70	18	1.29	603.43	92.0	3880.8	2177.5	3904.8	2.246	6.70
100(2)	99.49	14	1.29	604.42	91.2	3881.5	2168.2	3901.3	2.240	6.99
100(3)	99.70	15	1.24	600.95	91.1	3890.0	2184.1	3913.9	2.249	6.61
75(1)	74.73	17	1.31	602.19	91.3	2888.1	1611.9	2906.9	2.230	7.38
75(2)	74.73	12	1.32	603.18	90.6	2876.8	1611.2	2901.4	2.230	7.40
75(3)	74.73	13	1.28	602.44	90.6	2874.7	1605.7	2895.4	2.229	7.43
75(5)	74.78	18	1.31	602.44	90.6	2905.7	1622.7	2920.7	2.238	7.03
95(1)	94.75	26	1.25	601.20	91.8	3685.4	2067.3	3708.8	2.245	6.76
95(2)	94.60	18	1.26	601.69	91.4	3677.3	2051.7	3699.3	2.232	7.31
95(3)	94.65	20	1.28	602.44	91.3	3692.0	2068.6	3713.5	2.244	6.79
95(4)	94.50	15	1.28	600.70	91.6	3697.2	2080.4	3721.6	2.252	6.45
95(6)	94.50	10	1.30	604.42	91.5	3682.1	2070.2	3706.2	2.251	6.53
95(7)	94.60	22	1.27	602.44	91.5	3667.4	2054.5	3691.0	2.241	6.94
95(9)	94.65	19	1.28	601.69	91.2	3669.0	2063.4	3695.5	2.248	6.64
95(10)	94.70	17	1.22	602.19	91.1	3669.4	2053.7	3691.4	2.241	6.95
95(12)	94.70	13	1.29	601.94	91.1	3670.6	2050.5	3696.4	2.230	7.39
95(13)	94.65	13	1.24	602.44	91.1	3671.8	2064.7	3703.4	2.241	6.95
95(16)	94.60	15	1.24	605.66	91.2	3673.0	2048.2	3697.8	2.226	7.53
95(17)	94.55	15	1.27	606.16	91.2	3672.0	2058.6	3699.5	2.238	7.05
Grand Forks SS-2-020(017)027 Gmm = 2.457 (G lab) 20% RAP										
100(1)	99.80	49	1.22	601.44	91.2	3969.2	2272.1	4001.8	2.293	6.66
100(2)	99.80	44	1.27	601.20	91.5	3964.4	2264.6	3993.2	2.293	6.66
100(3)	99.85	65	1.25	601.20	91.5	3948.7	2261.3	3989.7	2.285	7.01
75(1)	74.89	33	1.30	598.96	90.9	2949.9	1679.1	2976.7	2.273	7.47
75(2)	74.89	76	1.30	599.96	91.2	2971.6	1703.9	2997.4	2.297	6.50
75(3)	74.89	71	1.31	599.46	91.2	2958.0	1698.2	2989.4	2.291	6.76
75(5)	74.89	95	1.31	598.22	91.2	2939.5	1677.5	2958.4	2.295	6.60
95(1)	94.70	49	1.29	599.96	91.3	3754.5	2145.3	3786.0	2.288	6.86
95(2)	94.70	53	1.28	599.96	91.5	3757.4	2145.5	3781.8	2.288	6.88
95(3)	94.70	45	1.27	601.44	91.2	3751.2	2142.9	3779.5	2.292	6.71
95(4)	94.81	70	1.24	598.96	91.2	3750.7	2145.2	3783.2	2.290	6.80
95(5)	94.81	55	1.29	599.21	91.2	3740.0	2141.0	3772.6	2.292	6.71
95(7)	94.75	54	1.28	598.71	91.3	3758.6	2143.0	3783.7	2.291	6.76
95(8)	94.81	68	1.27	601.20	91.2	3752.9	2148.2	3782.6	2.297	6.51
95(10)	94.75	56	1.23	599.46	91.2	3751.4	2155.5	3793.5	2.290	6.79
95(11)	94.75	68	1.28	598.96	91.3	3751.9	2152.3	3785.9	2.297	6.52
95(12)	94.75	61	1.27	598.47	91.2	3751.0	2148.2	3781.2	2.297	6.51
95(13)	94.81	72	1.27	600.70	91.0	3738.1	2136.1	3780.9	2.273	7.50
95(14)	94.75	60	1.29	600.45	91.0	3738.9	2137.3	3779.3	2.277	7.32
Grand Forks SS-2-020(017)027 Gmm = 2.495 (G virgin) No RAP										

100(1)	99.85	300	1.20	601.69	91.7	4032.0	2314.1	4052.0	2.320	7.01
100(2)	99.86	316	1.25	598.71	91.7	4030.8	2311.1	4047.0	2.322	6.93
100(3)	99.85	230	1.27	598.22	91.7	4033.4	2312.3	4055.6	2.314	7.27
75(3)	75.50	300	1.29	604.92	89.9	3012.7	1743.4	3038.7	2.326	6.78
75(4)	74.94	255	1.30	602.68	91.3	3005.7	1723.5	3025.8	2.308	7.50
Grand Forks SS-2-020(017)027 Gmm = 2.465 (G 40%) 40% RAP										
100(1)	99.75	33	1.28	601.20	91.4	3972.8	2278.6	4007.4	2.298	6.77
100(2)	99.80	29	1.26	600.45	91.4	3971.0	2278.1	4006.6	2.297	6.80
100(3)	99.80	39	1.26	599.21	91.4	3971.3	2280.5	4011.3	2.294	6.92
75(1)	74.84	39	1.30	599.21	91.2	2968.1	1698.3	2995.4	2.288	7.17
75(2)	74.94	45	1.29	597.97	91.2	2969.4	1702.6	2997.4	2.293	6.98
Grand Forks SS-2-020(017)027 Gmm = 2.403 (G 60%) 60% RAP										
100(1)	99.75	19	1.29	604.92	91.7	3877.1	2189.4	3919.3	2.241	6.73
100(2)	99.64	21	1.26	603.68	91.7	3879.3	2193.9	3925.8	2.240	6.79
100(3)	99.70	22	1.31	604.17	91.6	3879.0	2186.6	3923.5	2.233	7.06
75(1)	74.78	22	1.30	602.68	90.8	2892.2	1623.9	2920.3	2.231	7.16
75(2)	74.73	19	1.32	600.45	90.8	2887.0	1626.7	2920.7	2.231	7.15
Bismarck NH-1-006(017)042 Gmm = 2.441 (B lab)										
100(1)	99.75	44	1.28	598.96	92.5	3959.5	2247.5	3985.8	2.278	6.68
100(4)	99.75	36	1.26	601.69	91.4	3920.2	2223.9	3954.6	2.265	7.21
100(5)	99.75	45	1.25	601.20	91.4	3915.8	2222.0	3953.7	2.261	7.36
75(2)	74.84	43	1.30	600.20	91.5	2952.5	1681.6	2970.2	2.281	6.57
75(3)	74.84	33	1.31	598.96	91.5	2935.6	1669.5	2959.4	2.276	6.77
75(4)	74.78	35	1.31	600.45	91.0	2928.8	1665.7	2958.5	2.265	7.19
75(5)	74.89	45	1.27	599.96	90.9	2929.6	1664.6	2954.0	2.272	6.92
75(6)	74.78	35	1.29	600.20	90.9	2938.9	1664.4	2955.4	2.276	6.74
75(7)	74.84	49	1.29	599.71	90.9	2924.3	1657.0	2948.8	2.264	7.26
95(2)	94.65	33	1.26	598.96	91.4	3722.1	2112.9	3751.2	2.272	6.93
95(3)	94.75	52	1.25	602.68	91.3	3725.4	2113.0	3756.7	2.266	7.15
95(4)	94.81	44	1.26	601.20	91.3	3720.1	2106.3	3752.3	2.260	7.41
95(5)	94.81	49	1.25	599.71	91.3	3744.7	2129.7	3781.9	2.266	7.15
95(7)	94.70	49	1.27	601.44	91.4	3721.6	2110.2	3752.4	2.266	7.16
95(8)	94.65	44	1.29	602.68	91.4	3717.3	2102.1	3744.1	2.264	7.26
95(9)	94.65	44	1.29	602.68	91.4	3691.2	2092.1	3725.8	2.259	7.44
95(10)	94.75	47	1.27	600.95	91.4	3730.1	2117.0	3761.0	2.269	7.05
95(11)	94.70	41	1.27	600.95	91.3	3732.7	2124.9	3761.9	2.280	6.59
95(12)	94.75	44	1.26	601.69	91.4	3732.7	2123.4	3760.1	2.281	6.57
95(13)	94.75	41	1.28	599.96	91.4	3729.0	2119.6	3760.0	2.273	6.87
95(14)	94.70	48	1.28	601.94	91.4	3730.0	2122.7	3764.7	2.271	6.94
95(15)	94.86	52	1.24	602.44	91.3	3730.1	2120.5	3763.5	2.270	6.99
95(16)	94.70	38	1.27	602.44	91.4	3733.8	2120.4	3763.3	2.273	6.90
Williston NH-NHU-7-002(156)022 Gmm = 2.505 (W lab)										

100(2)	99.75	33	1.25	602.44	91.3	4042.2	2321.4	4066.8	2.316	7.55
100(5)	99.75	59	1.25	600.70	91.8	4024.9	2316.8	4053.9	2.317	7.50
100(8)	99.80	26	1.27	598.96	92.0	4066.7	2330.4	4084.5	2.318	7.45
75(1)	74.84	43	1.30	601.44	90.7	3035.0	1746.6	3051.0	2.327	7.12
75(4)	74.89	59	1.28	601.94	92.2	3033.9	1757.1	3053.4	2.340	6.57
75(6)	74.78	46	1.27	599.96	92.2	3010.0	1735.3	3033.6	2.318	7.45
75(7)	74.78	46	1.27	599.96	91.8	3048.9	1762.5	3063.9	2.343	6.48
95(2)	94.75	35	1.27	599.96	91.9	3859.5	2211.0	3876.4	2.317	7.49
95(3)	94.81	31	1.26	599.46	91.9	3854.9	2214.0	3876.4	2.319	7.43
95(4)	94.70	33	1.27	601.44	92.1	3850.8	2217.1	3873.1	2.325	7.17
95(5)	94.75	32	1.28	599.46	92.1	3850.2	2213.5	3873.8	2.319	7.43
95(6)	94.75	57	1.24	599.96	92.2	3877.3	2236.2	3896.1	2.336	6.75
95(7)	94.70	56	1.26	598.71	92.2	3887.8	2242.3	3904.8	2.339	6.64
95(8)	94.75	37	1.23	606.65	92.1	3875.2	2239.2	3896.0	2.339	6.63
95(9)	94.70	36	1.27	605.91	92.2	3876.1	2241.2	3897.9	2.340	6.60
95(12)	94.65	30	1.28	603.68	92.2	3864.7	2228.1	3885.0	2.332	6.89
95(13)	94.75	44	1.22	603.18	92.1	3864.6	2236.8	3890.3	2.337	6.70
95(14)	94.75	55	1.23	602.93	92.2	3863.9	2231.7	3881.5	2.342	6.51
95(15)	94.65	29	1.29	602.19	92.2	3860.3	2227.6	3877.4	2.340	6.59
95(16)	94.81	39	1.26	600.95	92.1	3862.4	2230.5	3884.4	2.335	6.77

Table 15. Mix Design and Gradation of Selected Projects

Project	**AC Binder**	**% RAP**	**AC %**	**Gradation**									
				5/8"	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**#200**
Grand Forks 027	PG 58S-28	20	5.5	100.0	96.4	81.1	57.0	35.8	22.6	15.8	9.3	5.7	4.4
Grand Forks 082	PG 58S-28	25	6.0	100.0	96.5	88.4	65.6	46.2	32.3	19.8	10.5	7.5	5.8
Grand Forks 206	PG 58H-28	15	5.5	100.0	97.0	80.5	50.4	36.4	27.8	16.1	9.6	6.9	5.4
Bismarck 042	PG 58S-34	18	6.0	100.0	92.7	82.4	63.7	42.6	27.2	17.6	11.3	7.3	5.4
Bismarck 093	PG 58S-34	0	5.4	100.0	96.9	85.0	60.2	42.8	31.0	20.7	11.5	7.1	5.4
Bismarck 213	PG 58S-28	20	5.7	100.0	93.8	80.4	63.2	46.4	33.7	22.9	14.0	8.2	7.7
Valley City 221 top	PG 58H-28	0	5.2	100.0	99.8	90.2	61.6	42.6	30.6	22.0	13.9	7.7	5.4
Valley City 221 SMA	PG 58H-34	0	6.6	99.8	94.0	77.0	28.8	19.8	17.4	15.7	13.0	10.9	6.7
Valley City 049	PG 58S-28	25	5.9	100.0	96.7	85.0	61.8	45.7	28.4	18.6	11.9	7.3	5.2
Minot 059	PG 64S-28	0	5.8	100.0	95.0	82.5	59.1	37.1	24.1	15.2	8.9	6.3	5.1
Minot 136	PG 58S-28	0	5.8	100.0	96.4	86.9	63.0	44.3	32.1	22.0	13.0	7.5	5.5
Minot 112	PG 58H-28	0	5.5	100.0	99.9	91.2	61.8	43.2	30.3	20.5	11.8	7.1	5.6
Minot 920	PG 64S-28	0	5.6	100.0	95.1	84.3	62.4	43.0	29.8	20.4	12.1	7.0	4.9
Williston 022	PG 58V-28	13	5.5	100.0	96.9	87.2	63.5	40.9	27.5	18.6	11.0	7.2	5.4
Williston 267	PG 58H-28	0	5.5	100.0	97.3	88.1	63.9	41.7	25.0	15.2	8.7	6.4	5.3
Williston 203	PG 58S-28	0	5.8	100.0	96.9	85.2	58.9	39.1	25.7	15.4	9.1	6.6	5.4

Dickinson 093	PG 58S-28	25	5.5	100.0	95.6	86.2	64.7	47.5	35.3	26.4	17.5	9.0	5.3
Dickinson 076	PG 58S-28	25	5.5	100.0	97.6	87.5	67.3	48.8	36.3	28.0	20.4	9.2	5.0
Devils Lake 177	PG 58S-28	0	5.7	100.0	93.9	83.8	61.1	45.4	31.5	20.5	11.8	8.3	5.6
Devils Lake 000	PG 58H-34	15	5.5	100.0	95.1	83.5	62.1	45.9	33.3	22.5	13.5	8.7	6.2

Table 16. Field Mix APA Test Results

Rev	**L top**	**L down**	**R top**	**R down**	**Mean**	**4 SD**	**4 COV**	**Final Rut**	**Final SD**
Grand Forks SS-2-020(017)027 (G) PG 58S-28 20% RAP									
2000	1.605	1.880	1.441	1.442	1.59	0.18	11.25	**2.55**	**0.29**
4000	1.988	2.472	1.785	1.805	2.01	0.28	13.76		
6000	2.416	2.842	2.064	2.071	2.35	0.32	13.57		
8000	2.764	2.911	2.254	2.267	2.55	0.29	11.51		
Bismarck NH-1-006(017)042 (B) PG58S-34 18% RAP									
2000	0.766	1.667	1.572	1.595	1.40	0.37	26.26	**2.43**	**0.47**
4000	1.459	2.031	2.121	2.142	1.94	0.28	14.43		
6000	1.644	2.269	2.456	2.473	2.21	0.34	15.22		
8000	1.618	2.661	2.717	2.741	2.43	0.47	19.39		
Minot NH-4-003(015)136 (M) PG 58S-28									
2000	2.659	1.048	2.501	2.499	2.18	0.65	30.08	**3.75**	**0.77**
4000	2.975	1.908	3.379	3.392	2.91	0.60	20.74		
6000	3.209	2.401	3.973	3.965	3.39	0.65	19.14		
8000	3.455	2.631	4.445	4.486	3.75	0.77	20.48		
Williston NH-NHU-7-002(156)022 (W) PG 58V-28 13% RAP									
2000	1.811	1.945	2.037	2.095	1.93	0.11	5.90	**3.58**	**0.34**
4000	2.278	2.194	2.685	2.769	2.39	0.26	11.00		
6000	2.710	2.820	3.364	3.422	2.96	0.35	11.81		
8000	3.239	3.575	3.915	4.032	3.58	0.34	9.45		
Valley City IM-2-094(156)221 Top (V3, V) PG 58H-28									
2000	1.017	0.854	1.328	1.304	1.07	0.24	22.61	**1.84**	**0.15**
4000	1.310	1.162	1.552	1.537	1.34	0.20	14.65		
6000	1.568	1.390	1.808	1.777	1.59	0.21	13.21		
8000	1.753	1.762	2.015	1.989	1.84	0.15	8.07		
Dickinson SS-5-016(027)076 (D) PG 58S-28 25% RAP									
2000	2.358	2.661	2.702	2.709	2.57	0.19	7.29	**4.20**	**0.48**
4000	2.983	3.379	3.623	3.595	3.33	0.32	9.70		
6000	3.326	3.840	4.224	4.184	3.80	0.45	11.85		
8000	3.715	4.195	4.679	4.637	4.20	0.48	11.49		
Devils Lake NH-3-003(027)177 (DL) PG 58S-28									

2000	3.134	2.843	3.270	3.145	3.08	0.22	7.08	**4.39**	**0.60**
4000	3.851	3.146	4.033	3.910	3.68	0.47	12.75		
6000	4.287	3.535	4.485	4.338	4.10	0.50	12.22		
8000	4.627	3.706	4.828	4.683	4.39	0.60	13.63		
Bismarck NH-1-003(049)093 (B II) PG 58S-34									
2000	2.134	2.446	3.157	3.199	2.58	0.52	20.32	**4.13**	**0.97**
4000	2.808	3.064	4.169	4.199	3.35	0.72	21.61		
6000	2.977	3.597	4.707	4.761	3.76	0.88	23.31		
8000	3.322	3.868	5.211	5.222	4.13	0.97	23.52		
Minot NH-4-052(083)059 (M II) PG 64S-28 @58									
2000	1.979	1.972	2.259	2.248	2.07	0.16	7.91	**3.36**	**0.38**
4000	2.547	2.551	2.994	2.990	2.70	0.26	9.53		
6000	3.072	2.822	3.525	3.435	3.14	0.36	11.35		
8000	3.143	3.144	3.804	3.819	3.36	0.38	11.33		
Minot NH-4-052(083)059 (M II) PG 64S-28 @64									
2000	3.114	2.316			2.72	0.56	20.77	**4.31**	**1.10**
4000	4.216	2.821			3.52	0.99	28.03		
6000	4.523	3.183			3.85	0.95	24.61		
8000	5.091	3.537			4.31	1.10	25.48		
Valley City IM-2-094(156)221 SMA (V2, V II) PG 58H-28									
2000	3.141	1.692	2.618	2.514	2.49	0.60	24.06	**4.05**	**0.84**
4000	3.773	2.185	3.506	3.391	3.21	0.70	21.91		
6000	4.237	2.547	4.070	3.960	3.70	0.78	21.05		
8000	4.606	2.803	4.442	4.331	4.05	0.84	20.67		
Dickinson SS-5-008(049)093 (D II) PG 58S-28 25% RAP									
2000	4.040	3.124	2.391	2.469	3.01	0.76	25.41	**4.75**	**0.93**
4000	5.170	3.913	3.144	3.215	3.86	0.94	24.33		
6000	5.576	4.554	3.613	3.710	4.36	0.91	20.91		
8000	6.000	4.925	3.997	4.073	4.75	0.93	19.68		
Devils Lake NH-3-057(056)000 (DL II) PG 58H-34 15% RAP									
2000	3.183	2.185	2.883	2.873	2.78	0.42	15.19	**4.69**	**0.46**
4000	3.840	2.771	3.717	3.724	3.51	0.50	14.16		
6000	4.487	3.322	4.256	4.243	4.08	0.52	12.65		
8000	5.224	4.100	4.744	4.710	4.69	0.46	9.81		
Grand Forks SS-6-017(047)082 (G II) PG 58S-28 25% RAP									
2000	1.305	0.996	2.389	1.855	1.64	0.61	37.58	**2.62**	**0.60**
4000	1.836	1.472	2.720	2.251	2.07	0.54	25.98		
6000	2.114	1.867	3.144	2.690	2.45	0.58	23.44		
8000	2.297	1.975	3.334	2.878	2.62	0.60	23.07		
Williston SOIB-7-804(060)267 (W II) PG 58H-28									

2000	1.687	1.172	1.591	1.585	1.51	0.23	15.21	**2.46**	**0.35**
4000	2.194	1.511	2.097	2.080	1.97	0.31	15.74		
6000	2.462	1.710	2.369	2.357	2.22	0.35	15.57		
8000	2.652	1.943	2.622	2.625	2.46	0.35	14.02		
Bismarck NH-1-200(074)213 (B III) PG 58S-28 20% RAP									
2000	2.445	1.764	2.685	2.723	2.40	0.44	18.48	**3.90**	**0.73**
4000	3.241	2.183	3.475	3.486	3.10	0.62	19.99		
6000	3.717	2.706	3.951	4.057	3.61	0.62	17.12		
8000	4.190	2.807	4.290	4.331	3.90	0.73	18.80		
Grand Forks NH-6-081(095)206 (G III) PG 58H-28 15% RAP									
2000	1.818	1.371	1.569	1.623	1.60	0.18	11.53	**2.59**	**0.16**
4000	2.317	2.128	2.008	2.066	2.13	0.13	6.30		
6000	2.584	2.354	2.228	2.304	2.37	0.15	6.48		
8000	2.825	2.541	2.451	2.529	2.59	0.16	6.34		
Valley City SS-2-032(029)049 (V1, V III) PG 58S-28 25% RAP									
2000	1.739	1.435	1.799	1.823	1.70	0.18	10.57	**2.81**	**0.22**
4000	2.069	2.025	2.274	2.335	2.18	0.15	6.97		
6000	2.338	2.216	2.700	2.752	2.50	0.26	10.58		
8000	2.752	2.531	2.943	3.020	2.81	0.22	7.76		
Minot SNH-4-052(073)112 (M III) PG 58H-28									
2000	2.916	2.936	3.488	3.491	3.21	0.33	10.14	**5.42**	**0.59**
4000	3.962	3.641	4.675	4.675	4.24	0.52	12.29		
6000	4.691	4.315	5.401	5.390	4.95	0.54	10.86		
8000	5.198	4.697	5.913	5.888	5.42	0.59	10.82		
Williston SS-7-008(032)203 (W III) PG 58S-28									
2000	3.435	2.434	2.704	2.738	2.83	0.43	15.11	**4.59**	**0.42**
4000	4.254	3.148	3.545	3.583	3.63	0.46	12.62		
6000	4.754	3.632	4.150	4.226	4.19	0.46	10.96		
8000	5.066	4.053	4.595	4.645	4.59	0.42	9.05		
Minot SOIB-CPU-TRP-4-083(130)920 (M-1) PG 64S-28									
2000	3.183	2.230	2.470	3.409	2.82	0.56	19.94	**4.57**	**0.63**
4000	4.090	2.975	3.355	4.217	3.66	0.59	16.22		
6000	4.675	3.343	4.078	4.251	4.09	0.56	13.60		
8000	4.992	3.719	4.453	5.103	4.57	0.63	13.84		

Table 17. Lab Mix APA test results

Rev	**L top**	**L down**	**R top**	**R down**	**Mean**	**4 SD**	**4 COV**	**Final Rut**	**Final SD**
Grand Forks SS-2-020(017)027 (G lab) PG 58S-28 20% RAP									
2000	1.534	1.052	1.831	1.865	1.57	0.38	23.97	**2.53**	**0.56**
4000	1.760	1.547	2.378	2.403	2.02	0.43	21.48		
6000	2.044	1.668	2.656	2.667	2.26	0.49	21.68		
8000	2.297	1.835	2.996	2.978	2.53	0.56	22.34		
Bismarck NH-1-006(017)042 (B lab) PG58S-34 18% RAP									
2000	1.925	1.795	2.407	2.178	2.08	0.27	13.09	**3.00**	**0.16**
4000	2.213	2.410	2.755	2.547	2.48	0.23	9.21		
6000	2.683	2.866	3.046	2.860	2.86	0.15	5.18		
8000	2.963	2.837	3.219	2.984	3.00	0.16	5.31		
Valley City IM-2-094(156)221 Top (V lab) PG 58H-28									
2000	1.456	1.434	1.746	1.671	1.58	0.16	9.85	**2.28**	**0.29**
4000	1.903	1.660	2.088	2.006	1.91	0.19	9.69		
6000	1.911	1.668	2.313	2.257	2.04	0.30	14.92		
8000	2.343	1.859	2.488	2.419	2.28	0.29	12.53		
Minot NH-4-052(083)059 (M lab) PG 64S-28									
2000	1.786	1.861	2.494	2.399	2.13	0.36	17.00	**3.47**	**0.41**
4000	2.543	2.608	3.132	3.058	2.84	0.30	10.67		
6000	2.975	2.988	3.575	3.545	3.27	0.33	10.21		
8000	3.148	3.081	3.871	3.784	3.47	0.41	11.93		
Williston NH-NHU-7-002(156)022 (W lab) PG 58V-28 13% RAP									
2000	1.444	1.242	1.631	1.670	1.50	0.20	13.12	**2.32**	**0.20**
4000	2.064	1.563	1.977	2.031	1.91	0.23	12.22		
6000	2.358	1.623	2.214	2.264	2.11	0.33	15.76		
8000	2.478	2.024	2.376	2.404	2.32	0.20	8.73		
Dickinson SS-5-008(049)093 (D lab) PG 58S-28 25% RAP									
2000	3.922	2.102	2.524	4.107	3.16	1.00	31.62	**5.23**	**1.65**
4000	5.023	2.725	3.147	5.458	4.09	1.35	33.11		
6000	5.710	3.248	3.718	6.441	4.78	1.54	32.18		
8000	6.224	3.576	4.100	7.012	5.23	1.65	31.58		
Devils Lake NH-3-003(027)177 (DL lab) PG 58S-28									
2000	3.039	2.039	3.225	3.136	2.86	0.55	19.32	**4.81**	**1.52**
4000	3.883	2.766	3.450	4.908	3.75	0.90	23.92		
6000	4.432	3.228	3.927	6.080	4.42	1.21	27.48		
8000	4.706	3.573	3.975	6.977	4.81	1.52	31.62		
Grand Forks SS-2-020(017)027 (G v) PG 58S-28 Virgin									
2000	1.119	1.152			1.14	0.02	2.09	**1.88**	**0.02**

4000	1.454	1.489			1.47	0.03	1.70		
6000	1.669	1.716			1.69	0.03	1.94		
8000	1.869	1.898			1.88	0.02	1.12		
Grand Forks SS-2-020(017)027 (G 40%) PG 58S-28 40% RAP									
2000	1.037	0.927			0.98	0.08	7.88	**1.60**	**1.96**
4000	1.311	1.200			1.26	0.08	6.27		
6000	1.415	1.606			1.51	0.14	8.94		
8000	1.580	1.625			1.60	0.03	1.96		
Grand Forks SS-2-020(017)027 (G 60%) PG 58S-28 60% RAP									
2000	1.727	1.703			1.72	0.02	1.00	**2.37**	**0.02**
4000	2.040	2.003			2.02	0.03	1.30		
6000	2.222	2.198			2.21	0.02	0.77		
8000	2.380	2.354			2.37	0.02	0.78		

Table 18. field mix moisture saturation

ID	% air (Pa)	t (cm)	D	Volume (E)	Va	A	B'	J'	S'	MS status
1st Run										
V 8	7.27	9.500	14.980	1674.31	121.72	3826.6	3913.1	86.5	71.06	Pass
V 7	7.00	9.508	15.010	1682.44	117.77	3851.1	3938.8	87.7	74.47	Pass
V 9	7.44	9.496	15.030	1684.80	125.35	3813.2	3903.2	90.0	71.80	Pass
B 3	7.20	9.502	15.010	1681.38	121.06	3716.4	3831.5	115.1	95.08	Fail
B 4	6.64	9.502	15.000	1679.14	111.50	3731.2	3836.7	105.5	94.62	Fail
B 1	6.63	9.500	14.990	1676.55	111.16	3751.5	3846.8	95.3	85.74	Fail
D II 2	6.82	9.501	15.000	1678.97	114.51	3730.9	3821.0	90.1	78.69	Pass
D II 4	7.06	9.496	15.000	1678.08	118.47	3719.8	3809.9	90.1	76.05	Pass
D II 9	6.96	9.506	15.000	1679.85	116.92	3726.9	3817.2	90.3	77.23	Pass
D II 7	6.72	9.495	14.980	1673.43	112.45	3736.0	3822.7	86.7	77.10	Pass
M II 8	6.76	9.498	15.010	1680.67	113.61	3824.0	3930.8	106.8	94.00	Fail
M II 5	7.19	9.496	15.000	1678.08	120.65	3806.2	3926.3	120.1	99.54	Fail
M II 4	7.19	9.503	15.000	1679.32	120.74	3812.5	3916.1	103.6	85.80	Fail
W 5	7.64	9.501	15.000	1678.97	128.27	3793.4	3916.3	122.9	95.81	Fail
W 7	7.46	9.506	15.010	1682.09	125.48	3826.7	3932.7	106.0	84.47	Fail
W 3	7.22	9.495	15.000	1677.91	121.14	3801.8	3916.9	115.1	95.01	Fail
DL 8	7.23	9.505	15.000	1679.67	121.44	3738.0	3858.3	120.3	99.06	Fail
DL 9	7.33	9.497	15.000	1678.26	123.02	3764.5	3869.3	104.8	85.19	Fail
DL 11	7.42	9.499	15.000	1678.61	124.55	3758.5	3876.6	118.1	94.82	Fail
G 5	7.26	9.478	15.000	1674.90	121.60	3727.1	3844.0	116.9	96.14	Fail
G 4	7.24	9.495	15.000	1677.91	121.48	3726.4	3834.9	108.5	89.31	Fail
G 1	7.29	9.503	15.000	1679.32	122.42	3739.0	3838.1	99.1	80.95	Fail
2nd Run										
DL 18	7.11	9.494	15.003	1678.40	119.33	3758.6	3847.6	89.0	74.58	Pass
DL 16	7.23	9.497	15.005	1679.38	121.42	3757.9	3845.8	87.9	72.39	Pass
DL 17	6.93	9.500	15.005	1679.91	116.42	3761.6	3845.7	84.1	72.24	Pass
D II 11	6.52	9.493	14.994	1676.21	109.29	3745.1	3829.5	84.4	77.23	Pass
D II 12	6.51	9.501	14.996	1678.07	109.24	3728.4	3806.1	77.7	71.13	Pass
DII 13	7.09	9.500	14.997	1678.12	118.98	3708.9	3793.2	84.3	70.85	Pass

Table 19. lab mix moisture saturation

ID	% air (Pa)	t (cm)	D	Volume (E)	Va	A	B'	J'	S'	MS status
1st Run										
DL lab 9	6.51	9.499	14.990	1676.37	109.13	3786.4	3872.7	86.3	79.08	Pass
DL lab 5	6.86	9.497	15.000	1678.26	115.13	3787.4	3880.2	92.8	80.61	Pass
DL lab 4	7.10	9.503	15.000	1679.32	119.23	3786.7	3885.9	99.2	83.20	Fail
DL lab 1	7.31	9.495	15.000	1677.91	122.65	3766.7	3861.3	94.6	77.13	Pass

M lab 2	6.76	9.491	15.000	1677.20	113.38	3839.6	3928.0	88.4	77.97	Pass
M lab 6	6.50	9.498	15.010	1680.67	109.24	3823.4	3903.9	80.5	73.69	Pass
M lab 7	7.18	9.486	15.010	1678.55	120.52	3816.0	3906.9	90.9	75.42	Pass
V lab 2	6.45	9.505	14.990	1677.43	108.19	3854.2	3937.0	82.8	76.53	Pass
V lab 4	6.94	9.499	14.990	1676.37	116.34	3802.1	3890.3	88.2	75.81	Pass
V lab 8	7.36	9.494	14.990	1675.49	123.32	3819.1	3910.5	91.4	74.12	Pass
W lab 3	7.43	9.502	14.990	1676.90	124.59	3861.2	3949.6	88.4	70.95	Pass
W lab 4	7.17	9.501	15.000	1678.97	120.38	3856.7	3946.8	90.1	74.85	Pass
W lab 7	6.64	9.501	14.980	1674.49	111.19	3887.8	3966.5	78.7	70.78	Pass
D lab 4	6.45	9.480	14.990	1673.02	107.91	3700.8	3786.1	85.3	79.05	Pass
D lab 6	6.53	9.477	15.000	1674.72	109.36	3686.3	3771.8	85.5	78.18	Pass
D lab 7	6.94	9.498	15.000	1678.44	116.48	3671.4	3763.5	92.1	79.07	Pass
G lab 1	6.86	9.500	15.000	1678.79	115.16	3759.8	3859.9	100.1	86.92	Fail
G lab 3	6.71	9.499	15.000	1678.61	112.63	3758.5	3853.4	94.9	84.25	Fail
G lab 4	6.80	9.501	15.000	1678.97	114.17	3757.8	3858.5	100.7	88.20	Fail
B lab 2	6.93	9.498	15.000	1678.44	116.32	3730.3	3822.9	92.6	79.61	Pass
B lab 3	7.15	9.501	15.000	1678.97	120.05	3735.7	3831.4	95.7	79.72	Pass
B lab 7	7.16	9.500	14.990	1676.55	120.04	3729.3	3818.8	89.5	74.56	Pass
B lab 8	7.26	9.506	14.990	1677.61	121.79	3722.9	3814.9	92.0	75.54	Pass
2nd Run										
V lab 12	6.64	9.500	14.935	1664.27	110.51	3819.5	3901.3	81.8	74.02	Pass
V lab 15	6.67	9.507	15.000	1680.03	112.06	3818.1	3900.5	82.4	73.53	Pass
V lab 16	6.47	9.501	15.000	1678.97	108.63	3810.7	3890.2	79.5	73.18	Pass
DL lab 10	6.57	9.505	15.001	1679.90	110.37	3790.6	3876.9	86.3	78.19	Pass
M lab 9	6.58	9.494	15.000	1677.73	110.39	3820.8	3903.3	82.5	74.73	Pass
M lab 11	6.53	9.500	14.997	1678.12	109.58	3811.6	3889.0	77.4	70.63	Pass
B lab 16	6.90	9.500	15.000	1678.79	115.84	3747.9	3835.8	87.9	75.88	Pass
B lab 11	6.59	9.500	15.001	1679.01	110.65	3732.7	3817.8	85.1	76.91	Pass
B lab 12	6.57	9.502	15.000	1679.14	110.32	3732.7	3818.5	85.8	77.77	Pass
B lab 13	6.87	9.504	15.000	1679.50	115.38	3729.0	3815.6	86.6	75.06	Pass
D lab 9	6.64	9.494	14.999	1677.50	111.39	3669.0	3754.6	85.6	76.85	Pass
D lab 10	6.95	9.493	14.997	1676.88	116.54	3669.4	3759.0	89.6	76.88	Pass
D lab 13	6.95	9.500	14.998	1678.34	116.64	3671.8	3761.2	89.4	76.64	Pass
W lab 8	6.63	9.486	15.000	1676.31	111.14	3875.2	3953.4	78.2	70.36	Pass
W lab 9	6.60	9.494	14.999	1677.50	110.72	3876.1	3955.7	79.6	71.90	Pass
W lab 14	6.51	9.502	15.000	1679.14	109.31	3863.9	3941.6	77.7	71.08	Pass
W lab 15	6.59	9.501	15.000	1678.97	110.64	3860.3	3939.2	78.9	71.31	Pass
G lab 8	6.51	9.493	15.000	1677.55	109.21	3752.9	3837.5	84.6	77.47	Pass
G lab 11	6.52	9.500	15.000	1678.79	109.46	3751.9	3835.8	83.9	76.65	Pass
G lab 12	6.51	9.500	15.000	1678.79	109.29	3751.0	3836.9	85.9	78.60	Pass

Table 20. field mix tensile strength table

ID	Condition	t (cm)	t (mm)	D (cm)	D (mm)	P (lb)	P (N)	S (kPa)
Valley City IM-2-094(156)221 (V)								
V 8	1st Wet	9.504	95.04	14.98	149.80	3284.9	14611.24	653.35
V 7	1st Wet	9.512	95.12	15.01	150.10	2373.0	10555.10	470.64
V 9	1st Wet	9.509	95.09	15.01	150.10	2400.2	10676.09	476.19
V 3	1st Dry	9.501	95.01	15.00	150.00	2686.8	11950.89	533.85
V 6	1st Dry	9.499	94.99	15.00	150.00	2943.0	13090.46	584.88
V 4	1st Dry	9.498	94.98	15.00	150.00	3080.2	13700.73	612.21
Dickinson SS-5-008(049)093 (D II)								
D II 4	1st Wet	9.520	95.20	15.00	150.00	1396.3	6210.74	276.88
D II 9	1st Wet	9.556	95.56	15.00	150.00	1458.6	6487.85	288.15
D II 7	1st Wet	9.528	95.28	14.98	149.80	1766.3	7856.50	350.43
D II 2	1st Wet	9.541	95.41	15.00	150.00	2534.2	11272.12	501.42
D II 11	2nd Wet	9.566	95.66	14.99	149.94	2653.3	11801.88	523.82
D II 12	2nd Wet	9.531	95.31	15.00	149.96	2411.9	10728.13	477.85
D II 13	2nd Wet	9.525	95.25	15.00	149.97	1957.8	8708.29	388.10
D II 8	1st Dry	9.492	94.92	14.99	149.90	2059.1	9158.88	409.79
D II 6	1st Dry	9.502	95.02	14.99	149.90	2781.8	12373.45	553.04
D II 3	1st Dry	9.499	94.99	15.00	150.00	2342.6	10419.88	465.56
D II 10	2nd Dry	9.499	94.99	15.00	149.95	4889.0	21746.27	971.94
D II 14	2nd Dry	9.502	95.02	14.99	149.86	2709.4	12051.41	538.79
D II 5	2nd Dry	9.500	95.00	14.99	149.94	2823.1	12557.15	561.22
Minot NH-4-052(083)059 (M II)								
M II 8	1st Wet	9.491	94.91	15.00	150.00	1428.3	6353.08	284.09
M II 5	1st Wet	9.503	95.03	15.00	150.00	1370.6	6096.43	272.27
M II 4	1st Wet	9.501	95.01	15.00	150.00	1656.7	7369.00	329.18
M II 9	1st Dry	9.499	94.99	15.00	150.00	1983.6	8823.05	394.21
M II 7	1st Dry	9.498	94.98	15.01	150.10	1794.9	7983.72	356.51
M II 6	1st Dry	9.498	94.98	15.00	150.00	1850.4	8230.58	367.78
Williston NH-NHU-7-002(156)022 (W)								
W 5	1st Wet	9.501	95.01	15.00	150.00	2028.8	9024.10	403.11
W 7	1st Wet	9.518	95.18	15.01	150.10	2063.0	9176.22	408.90
W 3	1st Wet	9.487	94.87	15.00	150.00	2081.7	9259.40	414.23
W 4	1st Dry	9.501	95.01	15.00	150.00	2418.1	10755.71	480.46
W 2	1st Dry	9.500	95.00	15.00	150.00	2463.3	10956.76	489.49
W 1	1st Dry	9.501	95.01	15.01	150.10	2521.7	11216.52	500.71
Devils Lake NH-3-003(027)177 (DL)								
DL 8	1st Wet	9.549	95.49	15.00	150.00	1191.5	5299.79	235.55
DL 9	1st Wet	9.538	95.38	15.00	150.00	995.3	4427.09	196.99

DL 11	1st Wet	9.531	95.31	15.00	150.00	1207.1	5369.18	239.09
DL 18	2nd Wet	9.516	95.16	15.00	150.03	901.8	4011.38	178.87
DL 16	2nd Wet	9.538	95.38	15.01	150.05	1147.1	5102.30	226.97
DL 17	2nd Wet	9.539	95.39	15.01	150.05	1302.4	5793.08	257.65
DL 10	1st Dry	9.498	94.98	15.00	150.00	1549.8	6893.51	308.03
DL 12	1st Dry	9.500	95.00	15.01	150.10	1661.9	7392.13	330.02
DL 14	1st Dry	9.491	94.91	15.01	150.10	1597.3	7104.79	317.50
DL 15	2nd Dry	9.496	94.96	15.01	150.06	1756.9	7814.69	349.12
DL 19	2nd Dry	9.500	95.00	15.00	150.02	1645.8	7320.52	327.00
DL 20	2nd Dry	9.500	95.00	15.00	150.00	2117.0	9416.42	420.68
Grand Forks SS-2-020(017)027 (G)								
G 4	1st Wet	9.502	95.02	15.00	150.00	1884.6	8382.70	374.42
G 1	1st Wet	9.496	94.96	15.00	150.00	2535.3	11277.01	504.01
G 5	1st Wet	9.479	94.79	15.00	150.00	1952.4	8684.28	388.83
G 6	1st Dry	9.507	95.07	15.00	150.00	2408.8	10714.34	478.31
G 2	1st Dry	9.484	94.84	15.02	150.20	3016.2	13416.06	599.58
G 3	1st Dry	9.483	94.83	15.02	150.20	2673.6	11892.17	531.53
Bismarck NH-1-006(017)042 (B)								
B 3	1st Wet	9.524	95.24	15.01	150.10	1120.6	4984.43	221.97
B 4	1st Wet	9.530	95.30	15.00	150.00	1538.1	6841.47	304.68
B 1	1st Wet	9.517	95.17	14.99	149.90	1437.7	6394.89	285.37
B 7	1st Dry	9.501	95.01	15.01	150.10	1857.4	8261.72	368.81
B 6	1st Dry	9.502	95.02	15.03	150.30	1953.2	8687.83	387.27
B 5	1st Dry	9.510	95.10	14.99	149.90	2323.9	10336.71	461.62

Table 21. lab mix tensile strength table

ID	Condition	t (cm)	t (mm)	D (cm)	D (mm)	P (lb)	P (N)	S (kPa)
Devils Lake NH-3-003(027)177 (DL lab)								
DL lab 9	1st Wet	9.537	95.37	14.99	149.90	1793.5	7977.49	355.25
DL lab 5	1st Wet	9.531	95.31	15.00	150.00	1623.7	7222.22	321.60
DL lab 1	1st Wet	9.550	95.50	15.00	150.00	2019.4	8982.29	399.18
DL lab 4	1st Wet	9.540	95.40	15.00	150.00	2046.6	9103.28	404.98
DL lab 10	2nd Wet	9.535	95.35	15.00	150.01	1897.8	8441.41	375.71
DL lab 3	1st Dry	9.499	94.99	15.00	150.00	2168.1	9643.71	430.88
DL lab 7	1st Dry	9.502	95.02	15.00	150.00	2685.2	11943.77	533.48
DL lab 8	1st Dry	9.498	94.98	15.00	150.00	2881.5	12816.91	572.72
Minot NH-4-052(083)059 (M lab)								
M lab 2	1st Wet	9.502	95.02	15.00	150.00	2341.0	10412.77	465.09
M lab 6	1st Wet	9.496	94.96	15.01	150.10	1713.3	7620.76	340.37
M lab 7	1st Wet	9.493	94.93	15.01	150.10	2006.9	8926.69	398.83
M lab 9	2nd Wet	9.493	94.93	15.00	150.00	1568.7	6977.58	311.95

M lab 11	2nd Wet	9.509	95.09	15.00	149.97	1950.8	8677.16	387.36
M lab 1	1st Dry	9.497	94.97	15.00	150.00	2408.8	10714.34	478.82
M lab 4	1st Dry	9.494	94.94	14.99	149.90	3095.7	13769.67	615.96
M lab 5	1st Dry	9.489	94.89	15.00	150.00	2940.7	13080.23	585.04
M lab 8	2nd Dry	9.498	94.98	15.00	150.01	2718.0	12089.66	540.18
M lab 10	2nd Dry	9.491	94.91	15.00	149.99	2280.3	10142.77	453.59
Valley City IM-2-094(156)221 (V lab)								
V lab 2	1st Wet	9.529	95.29	14.99	149.90	3274.7	14565.87	649.18
V lab 4	1st Wet	9.521	95.21	14.99	149.90	3165.4	14079.70	628.04
V lab 8	1st Wet	9.530	95.30	14.99	149.90	2855.2	12699.93	565.96
V lab 12	2nd Wet	9.531	95.31	14.94	149.35	3063.7	13627.34	609.46
V lab 15	2nd Wet	9.514	95.14	15.00	150.00	3076.2	13682.94	610.39
V lab 16	2nd Wet	9.517	95.17	15.00	150.00	3157.2	14043.23	626.26
V lab 1	1st Dry	9.508	95.08	14.99	149.90	4874.1	21680.00	968.39
V lab 3	1st Dry	9.505	95.05	14.99	149.90	4042.9	17982.82	803.50
V lab 5	1st Dry	9.500	95.00	14.99	149.90	3917.6	17425.48	779.00
V lab 6	2nd Dry	9.501	95.01	15.00	149.97	3896.9	17333.41	774.44
V lab 13	2nd Dry	9.502	95.02	15.00	149.97	4243.6	18875.53	843.26
V lab 14	2nd Dry	9.504	95.04	15.00	149.99	4510.8	20064.04	896.04
Williston NH-NHU-7-002(156)022 (W lab)								
W lab 3	1st Wet	9.491	94.91	14.99	149.90	2504.6	11140.46	498.51
W lab 4	1st Wet	9.486	94.86	15.00	150.00	2448.1	10889.15	487.19
W lab 7	1st Wet	9.477	94.77	14.98	149.80	3465.1	15412.76	691.16
W lab 8	2nd Wet	9.503	95.03	15.00	150.00	2987.4	13287.96	593.45
W lab 9	2nd Wet	9.503	95.03	15.00	149.99	3104.2	13807.48	616.70
W lab 14	2nd Wet	9.501	95.01	15.00	150.00	3192.2	14198.91	634.27
W lab 15	2nd Wet	9.505	95.05	15.00	150.00	2933.7	13049.10	582.66
W lab 2	1st Dry	9.502	95.02	15.00	150.00	3501.4	15574.23	695.63
W lab 5	1st Dry	9.502	95.02	15.00	150.00	3428.7	15250.86	681.19
W lab 6	1st Dry	9.500	95.00	14.99	149.90	3759.6	16722.70	747.59
W lab 12	2nd Dry	9.503	95.03	15.00	150.00	3249.5	14453.78	645.52
W lab 13	2nd Dry	9.503	95.03	15.00	149.98	4209.0	18721.63	836.24
W lab 16	2nd Dry	9.500	95.00	15.00	149.96	4455.7	19818.95	885.65
Dickinson SS-5-008(049)093 (D lab)								
D lab 4	1st Wet	9.502	95.02	14.99	149.90	2390.9	10634.72	475.32
D lab 6	1st Wet	9.489	94.89	15.00	150.00	2313.8	10291.78	460.32
D lab 7	1st Wet	9.499	94.99	15.00	150.00	2275.6	10121.87	452.24
D lab 9	2nd Wet	9.514	95.14	15.00	149.99	4278.8	19032.10	849.07
D lab 10	2nd Wet	9.540	95.40	15.00	149.97	2605.0	11587.04	515.58
D lab 13	2nd Wet	9.529	95.29	15.00	149.98	2731.2	12148.38	541.15
D lab 1	1st Dry	9.506	95.06	15.00	150.00	3954.4	17589.17	785.30
D lab 2	1st Dry	9.503	95.03	15.00	150.00	3887.1	17289.82	772.18

D lab 3	1st Dry	9.502	95.02	15.00	150.00	4215.7	18751.43	837.55
D lab 12	2nd Dry	9.503	95.03	15.00	150.00	6237.6	27744.84	1239.11
D lab 16	2nd Dry	9.502	95.02	15.00	149.99	3618.0	16092.86	718.85
D lab 17	2nd Dry	9.498	94.98	15.00	150.00	3707.0	16488.74	736.79
Grand Forks SS-2-020(017)027 (G lab)								
G lab 1	1st Wet	9.526	95.26	15.00	150.00	2349.6	10451.02	465.63
G lab 3	1st Wet	9.508	95.08	15.00	150.00	2234.3	9938.17	443.61
G lab 4	1st Wet	9.517	95.17	15.00	150.00	2549.7	11341.07	505.76
G lab 8	2nd Wet	9.501	95.01	15.00	150.00	2658.3	11824.12	528.19
G lab 11	2nd Wet	9.503	95.03	15.00	150.00	2732.0	12151.94	542.72
G lab 12	2nd Wet	9.495	94.95	15.00	150.00	2771.7	12328.52	551.07
G lab 2	1st Dry	9.499	94.99	15.00	150.00	3576.7	15909.16	710.82
G lab 5	1st Dry	9.502	95.02	15.00	150.00	3091.0	13748.77	614.10
G lab 7	1st Dry	9.505	95.05	15.00	150.00	4001.1	17796.89	794.66
G lab 10	2nd Dry	9.500	95.00	15.00	150.00	3556.8	15820.65	706.79
G lab 13	2nd Dry	9.498	94.98	15.00	150.00	3857.4	17157.72	766.68
G lab 14	2nd Dry	9.500	95.00	15.00	150.00	4453.6	19809.61	885.00
Bismarck NH-1-006(017)042 (B lab)								
B lab 2	1st Wet	9.523	95.23	15.00	150.00	1882.2	8372.03	373.12
B lab 3	1st Wet	9.532	95.32	15.00	150.00	1915.0	8517.92	379.26
B lab 7	1st Wet	9.524	95.24	14.99	149.90	1857.0	8259.94	368.33
B lab 8	1st Wet	9.530	95.30	14.99	149.90	2249.1	10004.00	445.82
B lab 16	2nd Wet	9.521	95.21	15.00	150.00	2263.1	10066.27	448.72
B lab 11	2nd Wet	9.520	95.20	15.00	150.01	2265.5	10076.94	449.21
B lab 12	2nd Wet	9.511	95.11	15.00	150.00	2762.7	12288.49	548.35
B lab 13	2nd Wet	9.529	95.29	15.00	150.00	2393.2	10644.95	474.12
B lab 4	1st Dry	9.508	95.08	15.00	150.00	3284.9	14611.24	652.21
B lab 5	1st Dry	9.504	95.04	15.00	150.00	3250.6	14458.67	645.67
B lab 9	1st Dry	9.502	95.02	15.00	150.00	2836.3	12615.86	563.50
B lab 10	2nd Dry	9.501	95.01	15.00	150.00	3424.8	15233.51	680.49
B lab 14	2nd Dry	9.500	95.00	15.00	149.98	3258.4	14493.36	647.58
B lab 15	2nd Dry	9.502	95.02	15.00	150.00	3053.0	13579.74	606.55

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