Salt and Brine Impacts on Asphalt Concrete Pavement
An Investigation for the City of Edmonton



PRESENTED TO
The City of Edmonton

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EXECUTIVE SUMMARY

Introduction

Agencies responsible for constructing and maintaining roadway infrastructure are tasked with balancing public safety and the potential for the harmful effects of anti-icing and de-icing chemical applications. Historically, the effects of anti-icing and de-icing materials have been primarily from an environmental perspective. More recently, attention has shifted to the potential impacts these anti-icing and de-icing materials have on the physical roadway infrastructure, specifically asphalt and concrete materials.

In support of the City of Edmonton's (the City) ongoing investigations into the evaluation of anti-icing and de-icing chemicals on roadway infrastructure, Tetra Tech Canada Inc. (Tetra Tech) was retained to investigate the potential impacts of sodium chloride (NaCl) (salt) and calcium chloride ($CaCl_2$) (brine) on asphalt concrete pavement (ACP). The overall premise of the study was to gain an understanding of the effects that salt and brine may have on asphalt pavements under local Edmonton conditions.

The scope of this investigation focused on three key areas: 1) A literature review of the current "state-of-the-industry practices" for the use of salt and brine, as well as an academic study review of evaluations previously completed by others; 2) A laboratory investigation evaluating the potential impacts salt and brine have on ACP; and 3) A supplemental field review, where a comparison of pavement surface condition pre and post 2018/2019 winter maintenance activities was completed.

Literature Review

The current state-of-the-industry practice review included forty agencies – thirty-two Provincial Agencies/US State DoTs and eight municipalities. This review is based primarily on the works published in the Clear Road Survey (Blackburn and Associates, 2013 and 2014) and the C-SHRP 1999/2000 Lead State Survey (C-SHRP 2000).

Sodium Chloride is the most common chemical used in winter maintenance operations as a de-icing agent as the material is inexpensive and easy to obtain. Some agencies also use solid rock salt as an anti-icing agent, however the dry salt is typically pre-wetted before the spreading operation. Salt solution is used in thirty-two states/provinces as an anti-icing agent and $CaCl_2$ brine is used as an anti-icing agent in fourteen states/provinces. Some agencies mix the $CaCl_2$ brine with an organic corrosion inhibitor in solution. Nine agencies use magnesium chloride solution and six states use potassium acetate solution as anti-icing agents in their winter maintenance operations.

In summary, current City winter maintenance practices are generally consistent with industry practice.

Review of recent academic studies into the impacts of anti-icing and de-icing chemicals on asphalt concrete pavements is limited. Of the eleven academic publications reviewed, consensus indicated that exposure to salt and $CaCl_2$ solutions can have a negative influence on some mix properties which could result in a reduced pavement service life. These observations should be qualified because the research reviewed was based on laboratory testing and not field studies.

Laboratory Investigation

The laboratory program was broken into two distinct phases:

- <u>Phase 1:</u> Exposure of the asphalt concrete samples to a selection of anti-icing and de-icing chemicals at different concentrations, and
- <u>Phase 2:</u> Assessment of five key asphalt concrete properties following the chemical exposure.

Phase 1 of the laboratory testing program was developed to mimic actual field conditions as closely as possible. Specimens were prepared with a ±7.0% air void content to reflect typical field conditions. Specimens were then exposed to each anti-icing and/or de-icing material for several cycles, where each cycle was intended to represent one season of exposure in the field. Each exposure cycle would consist of three days submerged in one of the anti-icing and/or de-icing solutions, plus one control sample in distilled water. At the end of each cycle, each specimen was air-dried for one day before the next cycle was started.

Following completion of the chemical exposure completed under Phase 1, Phase 2 of the laboratory program focused on evaluating the potential impact on five key asphalt concrete mix properties:

1. Durability: Assessed with the Cantabro Abrasion Test
2. Moisture Susceptibility: Assessed with the Tensile Strength Ratio (TSR) Test
3. Cohesion (Strength): Assessed with the Dry Tensile Strength
4. Rutting Performance: Assessed with the Hamburg Wheel-Track Test
5. Asphalt Binder Properties: Assessed with Asphalt Binder Characterization Testing

Discussion on the results obtained from the laboratory testing program are as follows:

- Mix durability: There is no indication that the anti-icing or de-icing chemicals investigated have any negative impact on asphalt concrete durability and performance.
- Mix strength (cohesion): It appears that long term exposure to anti-icing and de-icing chemicals may result in some decrease in mix strength, but it is not likely significant enough to have a negative impact on asphalt concrete performance.
- Moisture susceptibility: Although there was a noted decrease in moisture susceptibility for the anti-icing and de-icing chemicals, it is not likely to have an impact on asphalt concrete performance.
- Rutting potential: Anti-icing and de-icing chemical exposure had no influence on rutting potential.
- Asphalt Binder Characteristics: Although it was clear that exposure to liquid (any anti-icing/de-icing chemical solutions or distilled water) significantly increased binder stiffness, there was no difference between anti-icing/de-icing chemical exposure and water exposure.

Supplemental Field Review

Supplemental to the laboratory investigation, Tetra Tech completed a field review of select City roadways pre and post the 2018/2019 winter maintenance season. The purpose of this field review was to evaluate the potential in-situ impact anti-icing and de-icing chemicals have under Edmonton winter conditions.

Five roadway sections were surveyed with Tetra Tech's Pavement Surface Profiler (PSP-7000) pre-winter season in October 2018, and post-winter season in May 2019. The PSP surveys provided high resolution right-of-way (ROW) images, as well as Laser Crack Mapping System (LCMS) pavement surface images along each travel lane, for each roadway. Both the ROW and LCMS photologs collected pre and post the 2018/2019 winter maintenance season were included as part of this field review.

In general, no discernible differences in roadway surface condition or performance were observed for roadway sections related to the application of anti-icing and/or de-icing chemicals through the 2018/2019 winter maintenance season. This observation is expected and is reasonably consistent with laboratory observations, given the field review captured only a single season of anti-icing and/or de-icing chemical application and the laboratory program attempted to simulate several seasons of winter maintenance operations.

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LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the City of Edmonton and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than the City of Edmonton, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on the Use of this Document attached in the Appendix G or Contractual Terms and Conditions executed by both parties.

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by the City of Edmonton (the City) to investigate the potential impacts of sodium chloride (NaCl) (salt) and calcium chloride ($CaCl_2$) (brine) on asphalt concrete pavement (ACP).

The scope of this investigation was provided in Tetra Tech's proposal "Salt and Brine Impacts on Concrete and Asphalt – Rev 02", dated October 19, 2019 (Tetra Tech File: 704-PENG.EMAT03571-01), and generally included the following tasks:

- Complete a literature review to investigate both the latest research and current industry practice on the use of salt and brine de-icing/anti-icing chemicals,
- Develop and complete a laboratory testing program investigating the potential impacts these de-icing/anti-icing solutions have on ACP mix characteristics, and
- Complete a field investigation evaluating the potential in-situ impacts these de-icing solutions have under Edmonton winter conditions.

This report provides summary of Tetra Tech's approach, methodology, and findings following the completion of these tasks.

This investigation was completed in parallel with a similar concrete sidewalk and curb impact study, completed by Tetra Tech's concrete specialists, and delivered to the City independent of this report.

Authorization to proceed with the completion of this assignment was provided by Ms. Wanda Goulden on or around October 20, 2019.

2.0 BACKGROUND

2.1 Premise for this Investigation

Agencies responsible for constructing and maintaining roadway infrastructure are tasked with balancing public safety and the potential for the harmful effects of anti-icing and de-icing chemical applications. Historically, the effects of anti-icing and de-icing materials have been primarily from an environmental perspective. Much of the concerns with these chemicals is potential run-off, potential passage into water courses, and the best practices for chemical storage.

More recently, attention has shifted to the potential impacts these anti-icing and de-icing materials have on the physical roadway infrastructure (i.e., asphalt and concrete materials). Early indications from recent research suggest that some negative effects due to chemical exposure may potentially influence asphalt and concrete properties.

The overall premise of the study was to gain an understanding of the effects that anti-icing and de-icing chemicals may have on asphalt pavements under local Edmonton conditions.

The first step was to gain an understanding of research and experience in the industry as reported by others. A comprehensive description of this literature review was provided under a separate memo and is summarized in this report. The literature review information was also used, in part, to validate the planned laboratory assessment for this project.

The second step included the selection and sampling of a typical City asphalt concrete mix type for the laboratory study. The mix type selected was a “City of Edmonton 10 mm – High Traffic (HT) with a PG 58-28 asphalt binder. Due to the size of the planned laboratory program asphalt mix requirements, a total of approximately 700 kg of HT-10 mix was obtained from a local hot-mix asphalt plant in Edmonton. The mix was produced by Lafarge Canada Inc. at their Winterburn Asphalt facility and was sampled by Tetra Tech on October 17, 2018.

The third step involved the development of an appropriate laboratory program. The laboratory program was broken into two distinct phases: 1) exposure of the asphalt concrete samples to a selection of anti-icing and de-icing chemicals at different concentrations, and 2) an assessment of five key asphalt concrete properties following the chemical exposure.

Five laboratory tests were selected for the assessment which focused on: 1) mix durability, 2) mix strength (cohesion), 3) mix susceptibility to moisture induced damage, 4) pavement rutting potential, and 5) potential impacts on the asphalt binder properties. A “control” was established where specimens were exposed to only distilled water. Further details regarding the testing and the chemical exposure protocols are provided in subsequent sections of this report.

The test data was reviewed and analyzed to determine evidence of trends or other findings. The premise was that if there was detrimental (or beneficial) effects, these could be qualified. The results could then be used by the City to better understand these chemicals and their effects on roadway infrastructure. This information could serve the City in optimizing their de-icing processes in the future.

The overarching goal of the assessment described in this report is to attempt to identify (and quantify, if possible) the effects these materials have on asphalt concrete. The assessment undertaken, the results and the findings represent the contents of this report.

2.2 Current City of Edmonton Practices

The following provides our understanding of the current City practices for the usage of anti-icing and de-icing chemicals. For clarity of terminology, throughout this report “anti-icing” refers to the process of applying a chemical solution (typically brine) prior to a snow fall event, and “de-icing” refers to the process of applying a chemical (typically rock salt) during or after a snow fall event when snow and/or ice has begun to accumulate on the roadway surface.

It is understood that the City of Edmonton current winter maintenance practices include the use of:

- Calcium Chloride ($CaCl_2$) brine as an anti-icing agent,
- Sodium Chloride (NaCl) as a de-icing agent which is often rock salt mixed with sand (a traction aid), and distributed at various application rates dependent on ambient temperature, and
- A combined application of $CaCl_2$ brine anti-icing pre-treatment, followed by a NaCl treatment during the snow fall event.

The City currently uses Road Guard Plus ($CaCl_2$ brine with corrosion inhibitors) for anti-icing. This product, supplied by Tiger Calcium Services Inc., contains a chemical composition of 25 to 27% $CaCl_2$, 2 to 4% Magnesium Chloride ($MgCl_2$), and 3 to 5% other chlorides. For this investigation, Road Guard Plus is referred to as $CaCl_2$ brine and/or anti-icing brine. Standard practice is to apply a thin film of anti-icer (to avoid pooling) prior to a snow fall event. Typical application rates are 100 L/lane-km distributed at 40 km/hr. Streets that are anti-iced also receive standard snowstorm plowing, NaCl salt and sand applications.

The City uses a combination of NaCl rock salt and sand for roadway ice control. Salt and sand application rates are a function of ambient temperature, where warmer temperature (e.g., -1 to -5°C) receive a higher ratio of salt to sand (typically 25%) than at colder temperatures. For ambient temperatures below -19°C, salt it no longer applied, and only sand is distributed as a traction aid. For the purpose of this investigation, NaCl rock salt is referred to salt, NaCl, and/or de-icing chemical.

Discussions with the City indicates that although these are the current standard practices, they are currently under review and subject to change.

3.0 LITERATURE REVIEW

A literature review was completed and included a review of the current state-of-the-industry agency practices and investigations from published academic studies on the use of chloride-based anti-icing and de-icing chemicals and their potential impact on asphalt pavements. The literature review focused on the use of anti-icing and de-icing materials in similar geographic locations, primarily in the prairie provinces of Canada, and the mid-western United States.

Detailed findings from the literature review were provided to the City separately on May 28, 2019. A synopsis of Tetra Tech's findings is summarized in the following sections of this report. The literature review Technical Memo is provided in Appendix A.

3.1 Current State-of-the-Industry Agency Practices

The current state-of-the-industry practice review included forty agencies – thirty-two Provincial Agencies/US State DoTs and eight municipalities. This review is based primarily on the works published in the Clear Road Survey (Blackburn and Associates, 2013 and 2014) and the C-SHRP 1999/2000 Lead State Survey (C-SHRP 2000).

Sodium Chloride is the most common chemical used in winter maintenance operations because the material is inexpensive and easy to obtain. Most of the surveyed agencies use rock salt as their primary de-icing agent, however some agencies also use solid rock salt as an anti-icing agent. The dry salt is typically pre-wetted before the spreading operation as solid salt particles are subject to "bounce and scatter". The pre-wetting agent is typically water or a 10% $CaCl_2$ solution.

De-icing is traditionally done with solid chemicals because liquid chemicals cannot be used effectively to address thick ice or snow pack and they are limited to pavement temperatures typically above -7°C. Salt solution is used in thirty-two states/provinces as an anti-icing agent and $CaCl_2$ brine is used as an anti-icing agent in fourteen states/provinces. Some agencies mix the $CaCl_2$ brine with an organic corrosion inhibitor in solution.

Nine agencies use magnesium chloride solution and six states use potassium acetate solution as anti-icing agents in their winter maintenance operations.

3.2 Review of Academic Studies

The review was based on the findings from academic studies and the following provides a synopsis of the latest research into the impacts of salt or $CaCl_2$ brine on asphalt cement (asphalt binder) properties and/or asphalt concrete (combination of asphalt binder and aggregate) mix characteristics.

- The "strength" of asphalt mix increases and the susceptibility to moisture damage is greater with increased exposure time to salt and $CaCl_2$ solutions.
- The durability of asphalt mixtures exposed to salt and $CaCl_2$ solution was similar to mixtures exposed only to water.
- Indications are that the asphalt binder in a mix hardens with increased exposure to salt and $CaCl_2$, which could result in accelerated aging and an overall reduction in service life.
- The "flexibility" of asphalt pavements decreased when samples were exposed to salt solution and numerous freeze/thaw cycles, which could relate to a higher potential for cracking.
- Asphalt samples subjected to salt solution showed lower resistance to particle loss compared to unconditioned samples, indicating increased potential for loss of surface material and/or potholes.
- Higher salt solution concentration correlated to increased softening of the asphalt binder and reduced strength.

In general, the research reviewed indicated that exposure to salt and $CaCl_2$ solutions can have a negative influence on some mix properties, which may result in a reduced pavement service life. These observations should be qualified given that the research reviewed was based on laboratory testing and not field studies.

4.0 LABORATORY PROGRAM

4.1 Laboratory Program Development

The laboratory program was broken into two distinct phases:

- Phase 1: Exposure of the asphalt concrete samples to a selection of anti-icing and de-icing chemicals at different concentrations, and
- Phase 2: Assessment of five key asphalt concrete properties following the chemical exposure.

Phase 1 of the laboratory testing program was developed to represent actual field conditions as closely as possible. Specimens were prepared with a ±7.0% air void content to reflect typical field conditions. Specimens were then exposed to each de-icing material for several cycles, where each cycle was intended to represent one season of exposure in the field. Each exposure cycle consisted of three days submerged in one of the anti-icing and/or de-icing solutions, in addition to one control sample in distilled water. At the end of each cycle, each specimen was air-dried for one day before the next cycle was started.

Three exposure cycle conditions were included in the laboratory program:

- 3-cycles (representing three years of exposure in the field),
- 5-cycles (representing five years of exposure in the field), and
- 10-cycles (representing the typical total number of years service of an asphalt concrete surface treatment).

Following completion of the chemical exposure completed under Phase 1, Phase 2 of the laboratory program focused on evaluating the potential impact on five key asphalt concrete mix properties:

1. Durability: Assessed with the Cantabro Abrasion Test
2. Moisture Susceptibility: Assessed with the Tensile Strength Ratio (TSR) Test

3. Cohesion (Strength): Assessed with the Dry Tensile Strength
4. Rutting Performance: Assessed with the Hamburg Wheel Tracker Test
5. Asphalt Binder Properties: Assessed with Asphalt Binder Characterization Testing

The intention of the laboratory testing approach is to provide a means for assessing the potential influence that these de-icing solutions have on asphalt concrete mix properties and performance matching as closely as possible to actual conditions in the field.

Additional details pertaining to the laboratory testing program is provided in the following sections of this report.

4.2 Mixture Characterization

The first step of the laboratory program was to characterize the plant-produced mixture in terms of asphalt binder content, aggregate gradation, and volumetric properties (air voids, Voids in Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA).

It was considered very important that the plant mix sampled was not only compliant with the City's asphalt mix specification but was consistent with the mix design Job Mix Formula (JMF). This would better validate the results of the remainder of the laboratory program.

4.3 Establishing Required Compaction Effort

As part of the specimen preparation, a set of "calibration" briquettes was compacted to establish the necessary compactive effort required to achieve 7% air voids. A target 7% air voids was selected to represent the in-situ condition of compacted ACP in the field.

The calibration process consisted of compacting three briquettes, each at a different targeted compactive effort. For example, three manually compacted Marshall specimens were compacted at 15, 25 and 35 blows, and the percent air voids was measured for each briquette. A line of best fit was used to interpolate the necessary number of blows to target a briquette with 7% air voids. Figure A below demonstrates this process.

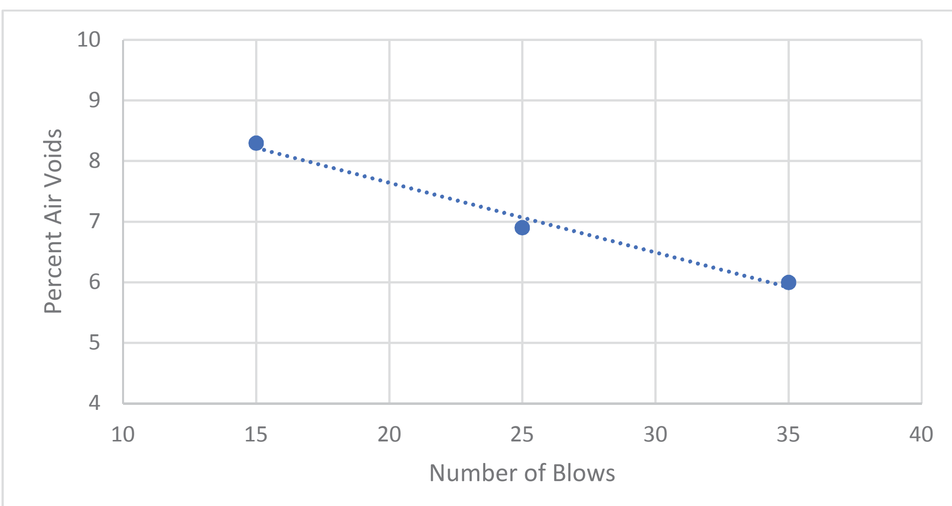

Figure A: Example of Establishing Number of Marshall Blows for 7% Air Voids

The same process was completed for 1) mechanically compacted Marshall briquettes, and 2) gyratory compacted briquettes. A summary of the resultant compactive effort used for specimen preparation is as follows:

- Manually compacted Marshall briquettes: 25 blows,
- Mechanically compacted Marshall briquettes: 45 blows, and
- Gyratory compacted briquetted: 23 gyrations.

4.4 Specimen Preparation

All specimens were prepared at the Tetra Tech laboratory facilities in Edmonton. Both Marshall briquettes and gyratory briquettes were compacted to a target 7% air voids, +/- 0.5%. Marshall briquettes were compacted both by hand and mechanical compaction. Following the completion of specimen production, the Marshall briquettes were sorted by % air voids and then combined into groups of three with the objective of targeting as close to 7% air voids for all groupings. Gyratory briquettes were combined into groups of two with the same targeted average air voids of 7%.

In total, 124 Marshall briquettes and eight gyratory briquettes were produced. A summary of the number of briquettes produced for each test procedure is provided in Table 4-1.

Table 4-1: Specimen Preparation Summary

Laboratory Test Procedure	Chemical Exposure	Number of Marshall Briquettes Produced			Number of Gyratory Briquettes Produced
		3-Cycle Exposure	5-Cycle Exposure	10-Cycle Exposure	10-Cycle Exposure
Cantabro Abrasion Testing	NaCl	3	3	3	-
	NaCl/CaCl2 Blend 1	3	3	3	-
	NaCl/CaCl2 Blend 2	3	3	3	-
	Distilled Water	3	3	3	-
Tensile Strength Ratio Testing	NaCl	6	6	6	-
	NaCl/CaCl2 Blend 1	6	6	6	-
	NaCl/CaCl2 Blend 2	6	6	6	-
	Distilled Water	6	6	6	-
Binder Characterization Testing	NaCl	-	-	4	-
	NaCl/CaCl2 Blend 1	-	-	4	-
	NaCl/CaCl2 Blend 2	-	-	4	-
	Distilled Water	-	-	4	-
	NaCl	-	-	-	2

Laboratory Test Procedure	Chemical Exposure	Number of Marshall Briquettes Produced			Number of Gyratory Briquettes Produced
		3-Cycle Exposure	5-Cycle Exposure	10-Cycle Exposure	10-Cycle Exposure
Hamburg Wheel Tracer Testing	NaCl/CaCl2 Blend 1	-	-	-	2
	NaCl/CaCl2 Blend 2	-	-	-	2
	Distilled Water	-	-	-	2
Totals		**36**	**36**	**52**	**8**

4.5 Determining Chemical Concentration for Exposure

Three chemical solutions were prepared for the laboratory program:

1. NaCl solution,
2. NaCl-$CaCl_2$ Blend 1 solution – chemical concentration “1”, and
6. NaCl-$CaCl_2$ Blend 2 solution – chemical concentration “2”.

Establishing the percent concentration of each chemical solution was based on the following general principles:

- Select a percent concentration that within reason, represented the general concentration (or range of concentrations) that could be experienced in the field.
- Select a percent concentration that could withstand sub-0°C temperatures without freezing.
- Select a percent concentration that could be produced and managed safely in the laboratory.

To assist with this process, phase diagrams for NaCl-water and $CaCl_2$-water were referenced, and the percent concentrations selected for each chemical solution were selected. A summary of these percent concentrations is provided in Table 4-2.

Table 4-2: Summary of Chemical Solution Concentrations

Chemical Solution	% Concentration	Rationale
NaCl	▪ 24% NaCl	▪ Selected the percent concentration for the eutectic temperature of the solution (approximately -21°C).
NaCl/CaCl2 - 1	▪ 24% NaCl ▪ 27% CaCl2	▪ NaCl: Selected the percent concentration for the eutectic temperature of the solution (approximately -21°C). ▪ CaCl2: The percent concentration provided by the manufacturer. The same concentration that would be applied to the roadway.
NaCl/CaCl2 - 2	▪ 12% NaCl ▪ 14% CaCl2	▪ NaCl: Selected the percent concentration at the solution-solution+ice phase boundary (approximately -8°C). Represents a solution diluted to 50% the chemical concentration for “NaCl/CaCl2 – 1”. ▪ CaCl2: Selected the percent concentration at the solution-solution+ice phase boundary (approximately -8°C). Represents a solution diluted to 50% the chemical concentration for “NaCl/CaCl2 – 1”.

Figure B shows the NaCl and $CaCl_2$ phase diagrams used for determining the solution concentrations (source: Federal Highway Administration "Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel – June 1996").

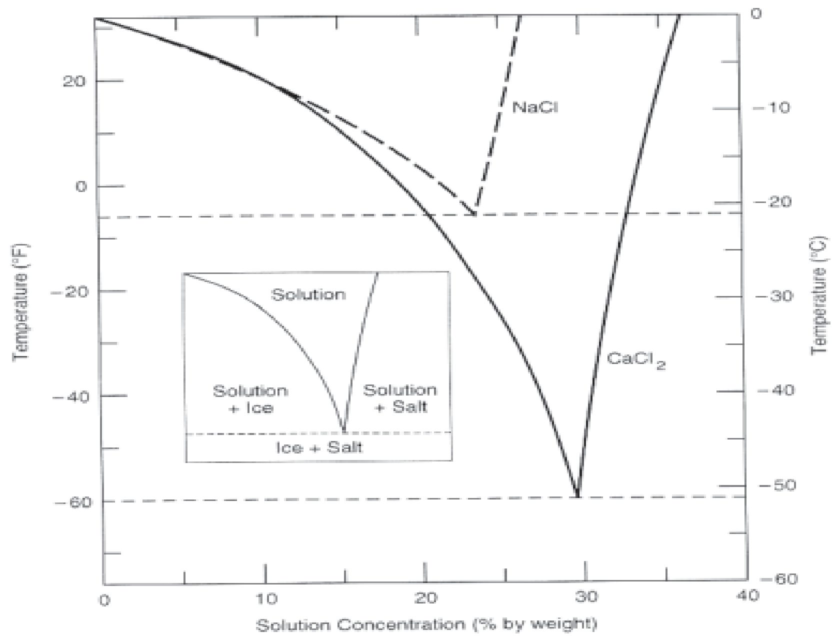

Figure B: NaCl and $CaCl_2$ Phase Diagrams

Prior to starting the laboratory program, small batch samples of each chemical solution were produced and exposed to temperatures around -10°C for approximately 72 hours to test for slush production or freezing. All three chemical solutions remained in the "solution" phase after the 72-hour test, and therefore no modifications to the percent concentrations selected were deemed necessary.

4.6 Specimen Chemical Exposure

The chemical exposure laboratory program was completed at Tetra Tech's laboratory facilities in Edmonton.

For all chemical solutions, inert plastic bins and/or pails were used for completing the chemical exposure cycles. Bins were selected with sufficient depth to allow for complete submersion of each compacted briquette. A wire mesh "drying" rack was installed at the bottom of the bin to allow for full surface area penetration of the chemical solution into each briquette. The same chemical solution was used for each set of briquettes throughout the entire length of the exposure period. Photographs 1 and 2 below show the general configuration of the exposure apparatus.

Photographs 1 and 2: General Configuration of the Chemical Exposure Apparatus

Each "Cycle-Exposure" consisted of three consecutive days in a walk-in freezer held at a constant temperature of -8°C. Following the three days in the freezer, each specimen was removed from the chemical solution and allowed to dry for one full day at ambient temperature (approximately 21°C). After one day of drying at ambient temperature, each specimen was re-submerged into the respective chemical solution and placed back into the walk-in freezer for another three days, or another "Cycle". This procedure was followed for $NaCl$, $NaCl/CaCL_2$-1 and $NaCl/CaCl_2$-2 solutions.

The distilled water control samples were exposed at the same days-in days-out solution interval as the other chemical solutions. However, to prevent freezing and the introduction of unwanted potential freeze/thaw damage, distilled water samples were exposed at ambient temperature of approximately 21°C.

Photographs 3 and 4 below show the specimens submerged in the chemical solutions.

Photographs 3 and 4: Example of Submerged Specimens in Chemical Solution

Photographs 5 and 6 below show the drying apparatus used between exposure cycles.

Photographs 5 and 6: Drying Apparatus Used Between Exposure Cycles

In summary:

- 3-Cycle Exposure specimens took a total of twelve days to complete: nine days in the chemical solution and three days of drying at ambient temperature.
- 5-Cycle Exposure specimens took a total of twenty days to complete: fifteen days in the chemical solution and five days of drying at ambient temperature.
- 10-Cycle Exposure specimens took a total of forty days to complete: thirty days in the chemical solution and ten days of drying at ambient temperature.

4.7 Description of Laboratory Test Procedures

4.7.1 Cantabro Abrasion Testing

The Cantabro test was completed in accordance with Appendix X2 of ASTM D7064 “Standard Practice for Open-Graded Friction Course (OGFC) Mix Design”. The Cantabro test was originally developed in Spain, and as the test procedure name indicates, it is commonly used in the design of OGFC surfacing designs. The test is relatively simple, and it provides an indication of the relative durability of asphalt mixtures by abrasion while “tumbling” in a rotating drum (as used for the LA Abrasion Test). The test specimens were prepared to ± 7.0% air voids to simulate typical in-service pavement void content. The mass loss during the test, due to dislodgment of particles is the measure of relative durability.

All Cantabro Abrasion testing was completed by Tetra Tech.

4.7.2 Tensile Strength Ratio Testing

The tensile strength testing was conducted in accordance with AASHTO T283, “Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage”. This is a relatively standard test in the industry, most often used for mix design. The test compares the Indirect Tensile Strength (ITS) of two subsets of specimens; one subset that is conditioned both by freezing and then soaking in a hot water bath, which is then compared to a subset that is not conditioned. The test requires the specimens to be prepared to ± 7.0% air voids, again to simulate in-service conditions. The test provides information on the ITS of each subset (a measure of cohesion). The ratio of the conditioned subset to the unconditioned is known as the Tensile Strength Ratio (TSR), which is a measure of the relative potential for moisture induced damage of an asphalt mixture.

All TSR testing was completed by Tetra Tech.

4.7.3 Hamburg Wheel Track Testing

The Hamburg Wheel-Track rut testing was conducted in accordance AASHTO T324, “Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures”. The Hamburg test was originally developed in Europe and is a relatively specialized test where a pair of specimens is submerged in a temperature-controlled water bath at a temperature selected for the climate. The specimens are subjected to wheel loading and the deformation is measured after 20,000 cycles. Again, the specimens are prepared to ± 7.0% air voids to simulate actual in-service conditions. The test is primarily used to assess the potential for mixture rutting, but because the specimens are submerged, it also provides an indication of the potential for moisture-induced damage (e.g., stripping).

All Hamburg Wheel Track testing was undertaken by the University of Alberta.

4.7.4 Binder Characterization Testing

Asphalt binder characterisation was done in accordance with AASHTO M 320 “Standard Specification for Performance-Graded Asphalt Binder”. This processed involved solvent extraction of the asphalt binder from compacted specimens. The asphalt binder is then “recovered” from the solvent/binder effluent using the Roto-vap process. The recovered binder is characterized using several test methods and conditioning procedures to determine both the relative high temperature and low temperature properties and resulting performance grade. For example, the binder used for the mixture subject of this study was PG 58-28. The “PG” stands for Performance Grade, the “58” represents the high temperature grade and the “-28” represents the low temperature characteristic of the binder. The results where then compared between the samples exposed to the various chemicals.

For the Asphalt Binder Testing, the asphalt cement extraction was completed by Tetra Tech in Calgary, and the binder characterization completed by GECAN in Acheson, AB.

5.0 LABORATORY TEST RESULTS

5.1 Mix Characterization

5.1.1 Mix Characterization Results

To characterize the plant-produced mixture, three random samples were taken from the plant sample. The samples where tested for asphalt content and gradation as well as volumetric properties. Table 5-1 summarizes this testing. The results are compared with the Mix Design Job Mix Formula (JMF) and the City of Edmonton (C of E) Specifications.

Table 5-1: Mixture Characterization Results

Mix Property		Tetra Tech Sample ID				Lafarge JMF	C of E Spec
		001	002	003	Average		
Asphalt Content (%, by mix)		**5.36**	**5.43**	**5.46**	**5.42**	**5.5**	**-**
Percent Passing Sieve Size	12.5 mm	100	100	100	100	100	100
	10 mm	98	97	98	97.7	97.7	97-100
	8 mm	85	86	86	85.7	87.1	70-94
	6.3 mm	71	72	71	71.3	73.9	45-85
	5 mm	64	65	63	64.0	65.1	32-75
	2.5 mm	47	48	46	47.0	49.8	23-55
	1.25 mm	37	38	37	37.3	38.7	16-45
	0.630 mm	31	31	31	31.0	31.2	11-36
	0.315 mm	21	21	20	20.7	21	8-26
	0.160 mm	10	9	9	9.3	10.7	7-16
	0.080 mm	5.1	4.4	4.8	4.8	5.2	4-9

Mix Property	Tetra Tech Sample ID				Lafarge JMF	C of E Spec
	001	002	003	Average		
Bulk Relative Density	2.349	2.344	2.348	2.347	2.338	-
Maximum Relative Density	2.427	2.427	2.428	2.427	2.435	-
Air Voids (%)	3.2	3.4	3.3	3.3	4.0	3.6-4.4
VMA (%)	14.6	15.1	14.7	14.8	15.1	13 min.
VFA (%)	78.1	77.4	77.5	77.7	73.5	70-80
Film Thickness (µm)	8.2	8.6	8.4	8.4	7.6	7.5 min.

The Lafarge Mix Design, dated May 16, 2017, is provided in Appendix B. The individual Tetra Tech Mix Characterization Reports are provided in Appendix C.

5.1.2 Mix Characterization Discussion

As shown in Table 5-1 the three samples were consistent in the properties tested. Generally, the sampled mix corresponded well to the mix design JMF and satisfied the City's specifications. The single exception was air voids which were below the JMF and marginally lower than the specification. Given the specimens for this laboratory assessment would all be prepared to ± 7.0% air voids, the air void deviation was not considered significant.

Based on this characterization, the mix sampled was an appropriate representation of the mix type and typical for mixtures used in the City. This would enable a legitimate basis for the other testing conducted as part of this assessment.

5.2 Cantabro Abrasion Testing

5.2.1 Cantabro Abrasion Testing Results

A summary of the Cantabro abrasion test results for 3-Cycle, 5-Cycle, and 10-Cycle exposures is presented in Table 5-2.

Table 5-2: Summary of Cantabro Abrasion Test Results

Chemical Exposure	3 Cycle % Loss	5 Cycles % Loss	10 Cycles % Loss
NaCl[1]	6.5	8.0	6.7
$NaCl/CaCl_2$-1[2]	6.2	7.1	8.7
$NaCl/CaCl_2$-2[3]	5.4	4.7	5.8
Distilled Water	6.1	4.9	7.0

[1] – NaCl @ 24% Concentration
[2] – $NaCl/CaCl_2$-1 @ 24% NaCl Concentration and 27% $CaCl_2$ Concentration
[3] – $NaCl/CaCl_2$-2 @ 12% NaCl Concentration and 14% $CaCl_2$ Concentration

A graphical summary of the results presented in Table 5-2 is provided in Figure C.

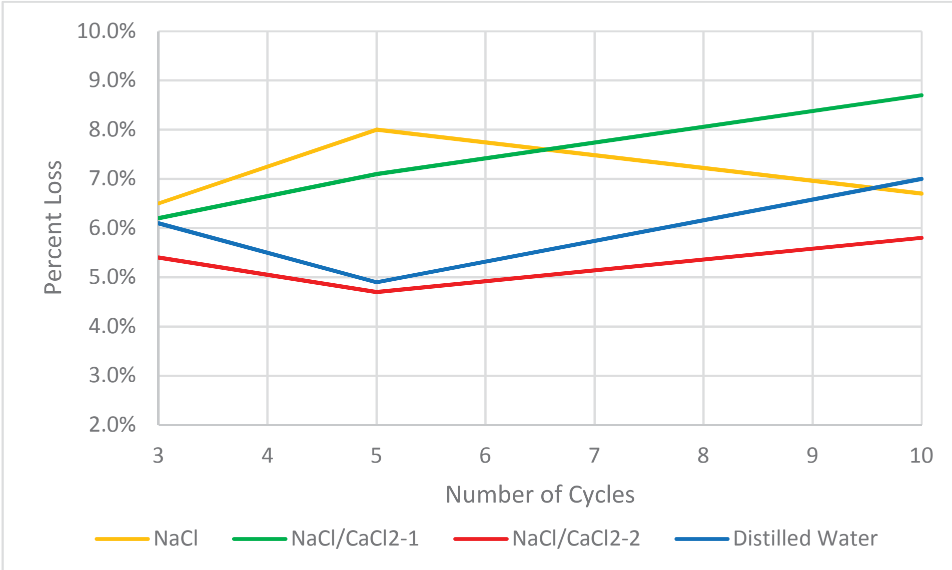

Figure C: Cantabro Abrasion Test Results

The full collection of laboratory test results for the Cantabro abrasion tests are provided in Appendix D.

5.2.2 Cantabro Abrasion Testing Discussion

Comparison of the mix durability properties from the Cantabro Abrasion testing shows generally increasing material loss from 3-Cycles to 10-Cycles for all chemical solutions, except for the NaCl chemical exposure, which shows little change in material loss from 3-Cycles to 10-Cycles. Variability in reported material loss was reported at the 5-Cycle exposure. NaCl exposed specimens showed an initial increase in material loss from 3-Cycles to 5-Cycles, followed by a decrease at 10-Cycles. NaCl/$CaCl_2$-2 and distilled water exposed specimens showed a decrease in material loss between 3-Cyles and 5-Cylces, followed by an increase at 10-Cycles. NaCl/$CaCl_2$-1 exposed specimens showed a continual increase in material loss across all three Cycles. The reason for this noted variability is not specifically known, and the reported values at 5-Cycles does not correlate with the observed 3-Cycle to 10-Cycle trend. Based on these observations, and for this summary, a comparison of 3-Cycle and 10-Cycle results is considered appropriate.

In summary, comparing 3-Cycle and 10-Cycle results:

- NaCl does not show a significant difference in material loss – relative change of 3.1%,
- NaCl/$CaCl_2$-1 shows relatively significant increase in material loss - relative change of 40.3%,
- NaCl/$CaCl_2$-2 shows a marginal increase in material loss - relative change of 7.4%, and
- Distilled Water shows a marginal increase in material loss – relative change of 14.8%

Key Findings

- NaCl chemical exposure does not appear to influence mix durability.
- $NaCl/CaCl_2$-2 and Distilled Water resulted in only a marginal decrease in mix durability.
- Of the four chemical exposures, $NaCl/CaCl_2$-1 showed the greatest reduction in mix durability. ($NaCl/CaCl_2$-1 contained the highest concentration of NaCl and $CaCl_2$.)
- The NaCl concentration does not appear to have a significant negative influence on mixture durability, regardless of whether it is mixed with $CaCl_2$, or in solution on its own.
- Increasing the $CaCl_2$ concentration appears to have the most significant influence on mixture durability.
- The reported percent material loss across all four chemical solutions at 10-Cycles ranges between 5.8% loss ($NaCl/CaCl_2$-2) and 8.7% loss ($NaCl/CaCl_2$-1), with an average 7.1% loss. Therefore, despite the differences in laboratory test results observed, the comparative percent loss, and the range of percent loss across chemical solutions differences in field performance, would not be expected between the three anti-icing/de-icing chemicals.

5.3 Moisture Susceptibility Testing

5.3.1 Moisture Susceptibility Testing Results

A summary of the Moisture Susceptibility (TSR) test results 3-Cycle, 5-Cycle, and 10-Cycle exposures is presented in Table 5-3.

Table 5-3: Tensile Strength Ratio Test Results

Chemical Exposure	3-Cycles			5-Cycles			10-Cycles		
	Wet Strength (kPa)	Dry Strength (kPa)	TSR (%)	Wet Strength (kPa)	Dry Strength (kPa)	TSR (%)	Wet Strength (kPa)	Dry Strength (kPa)	TSR (%)
NaCl[1]	1045	1189	87.9	972	1363	71.3	1060	1155	91.8
NaCl / CaCl2-1[2]	1065	1260	84.5	1087	1197	90.9	1014	1053	96.3
NaCl / CaCl2-2[3]	964	1116	86.3	957	1126	84.9	1004	1065	94.3
Distilled Water	1040	1172	88.8	966	1251	77.2	818	1221	67.0

[1] – NaCl @ 24% Concentration
[2] – $NaCl/CaCl_2$-1 @ 24% NaCl Concentration and 27% $CaCl_2$ Concentration
[3] – $NaCl/CaCl_2$-2 @ 12% NaCl Concentration and 14% $CaCl_2$ Concentration

A graphical summary of the wet and dry strength results is presented in Figure D.

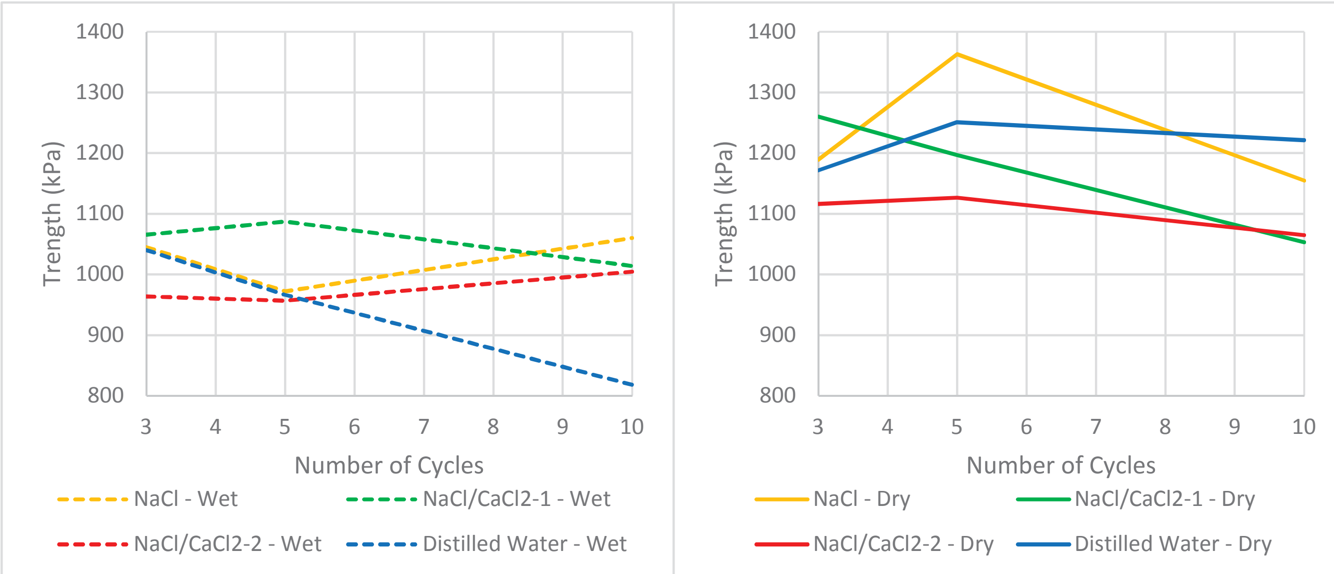

Figure D: Wet and Dry Strength Summary

A graphical summary of the TSR results is presented in Figure E.

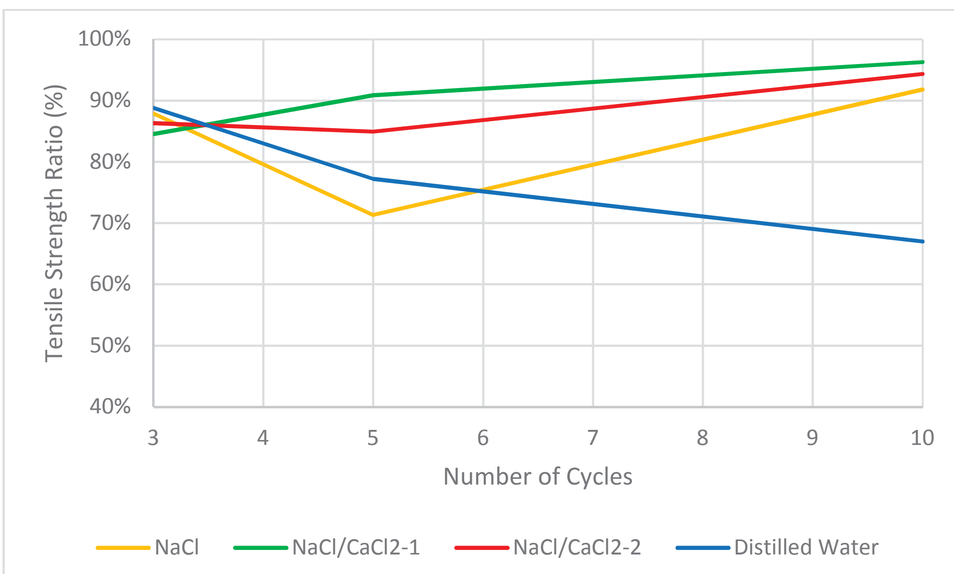

Figure E: TSR Results Summary

The full collection of laboratory test results for the Tensile Strength Ratio tests are provided in Appendix E.

5.3.2 Moisture Susceptibility Testing Discussion

Results from the TSR testing can be categorized into two distinct areas: 1) mix cohesion properties, and 2) mix moisture susceptibility.

Cohesion (mix strength) properties are best correlated to specimen dry strength values (unconditioned specimens). Comparison of the dry strength values at 3-Cycles, 5-Cycles, and 10-Cycles generally shows a consistent reduction in material strength for both NaCl/$CaCl_2$-1 and NaCl/$CaCl_2$-2 chemical solutions: 16.4% and 4.6% decrease respectively. However, the same comparison for NaCl and Distilled Water shows a slight increase or stable material strength: 2.8% decrease and 4.2% increase respectively. This observation suggests that $CaCl_2$ has an overall negative effect of mix strength. Conversely, NaCl and Distilled Water have a less (if any at all) effect on mix strength.

While both NaCl/$CaCl_2$-1 and NaCl/$CaCl_2$-2 chemical solutions showed an apparent decrease in material strength, both chemical solutions showed an increase in TSR from 3-Cycles to 5-Cycles to 10-Cycles: 13.0% and 9.3% improvement respectively. A higher TSR indicates less moisture susceptibility and therefore reduced stripping potential and better resistance to moisture-related damage (i.e., ravelling, potholes). NaCl chemical solution also shows an improvement in TSR from 3-Cycles to 10-Cycles (4.6% improvement), although less significant than NaCl/$CaCl_2$-1 and NaCl/$CaCl_2$-2. Interestingly, unlike all three other chemical solutions, the Distilled Water (the "control") specimens showed a continual decrease in TSR (32.8% decrease) when comparing 3-Cycles to 10-Cycles.

Key Findings

- The presence of $CaCl_2$ appears to have an overall negative effect on mix cohesion properties, resulting in an apparent loss of strength of the mix. Increased concentration on $CaCl_2$ has a more significant impact on loss of strength.
- NaCl and Distilled Water do not appear to have a significant impact on mix strength.
- The presence of $CaCl_2$ appears to have an overall positive effect on mix moisture susceptibility, with increased TSR values from 3-Cycles to 10-Cycles for both NaCl/$CaCl_2$-1 and NaCl/$CaCl_2$-2.
- The presence of NaCl appears to have a modest positive effect on mix moisture susceptibility, with increased TSR values from 3-Cycles to 10-Cycles.
- Distilled Water specimens show a continual and significant decrease in moisture susceptibility properties. This is a significant difference to the test results from all three other chemical solutions, where the moisture susceptibility properties improved.
- Although there were observed differences between the reported cohesion and moisture susceptibility results among the NaCl, NaCl/$CaCl_2$-1 and NaCl/$CaCl_2$-2 chemical solutions, the overall reported dry strengths and TSR values exceeded 1,000 kPa and 90% respectively. Therefore, differences in field performance would not be expected between the three anti-icing/de-icing chemicals.

5.4 Hamburg Wheel-Track Testing

5.4.1 Hamburg Wheel-Track Test Results

A summary of the Hamburg Wheel-track test results for 10-Cycle exposure is presented in Table 5-4.

Table 5-4: Hamburg Wheel-Track Test Results

Chemical Exposure	Stripping Inflection Point	Rut at 20,000 Passes (mm)
NaCl[1]	19,999	3.11
$NaCl/CaCl_2$-1[2]	19,999	2.90
$NaCl/CaCl_2$-2[3]	19,999	3.73
Distilled Water	19,999	3.08

[1] – NaCl @ 24% Concentration
[2] – $NaCl/CaCl_2$-1 @ 24% NaCl Concentration and 27% $CaCl_2$ Concentration
[3] – $NaCl/CaCl_2$-2 @ 12% NaCl Concentration and 14% $CaCl_2$ Concentration

A graphical summary of the results presented in Table 5-4 are provided in Figure F.

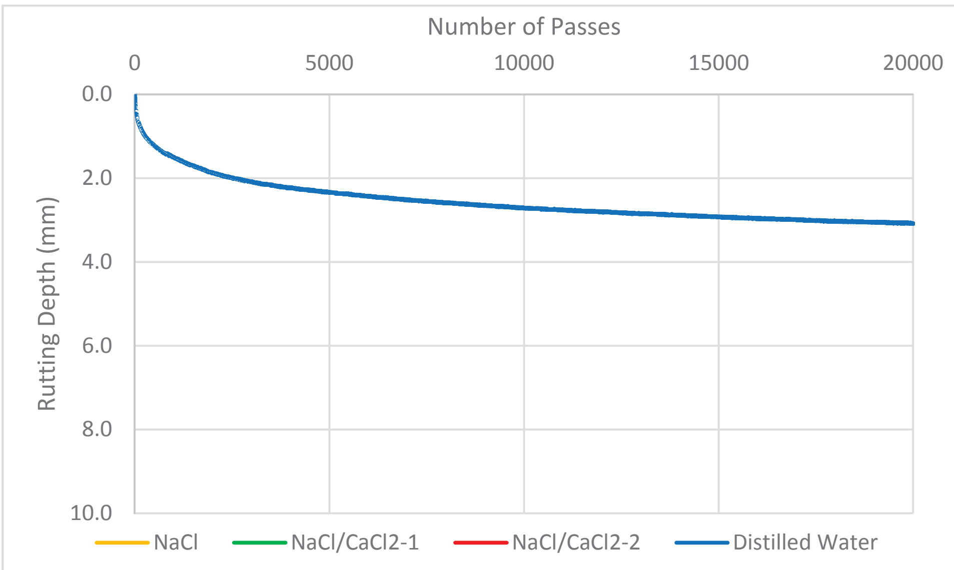

Figure F: Hamburg Wheel-Track Test Results

A report containing the full collection of laboratory test results for the Hamburg Wheel-Track test results is provided in Appendix F.

5.4.2 Hamburg Wheel-Track Test Discussion

The results of the Hamburg Wheel-Trac testing were similar in nature for all four sets of specimens. The results ranged from 2.90 mm to 3.71 mm. The differences in measured rut between the various chemical exposures are not considered significant. The testing for all the mixes provided excellent results, reflecting very little potential for pavement rutting. For reference, agencies that have specifications for rutting in the Hamburg Wheel-Track test typically limit rutting to 8 mm or 10 mm when accepting mix design submissions.

In addition, the Hamburg Wheel-track test specimens showed no visible signs of moisture induced damage.

Key Findings

- The testing indicates excellent rutting performance of this mixture, irrespective of the 10-cycle exposure solution.
- The specific type of de-icing or anti-icing solution has no influence on rutting potential.
- None of the Hamburg Wheel-track test specimens showed visible signs of moisture induced damage.
- There was no significant difference in the test data for any type of exposure. Therefore, differences in field performance would not be expected between the three anti-icing/de-icing chemicals.

5.5 Binder Characterization Testing

5.5.1 Binder Characterization Test Results

A summary of the Binder Characterization test results for 10-Cycle exposure is presented in Table 5-5.

Table 5-5: Binder Characterization Test Results

Chemical Exposure	Mix Design PG Grade	"True" High Temperature Grade	"True" Low Temperature Grade
Mix Design	58-28	60.0	-33.1
NaCl[1]	58-28	78.9	-25.4
$NaCl/CaCl_2$-1[2]	58-28	77.4	-26.4
$NaCl/CaCl_2$-2[3]	58-28	73.1	-27.2
Distilled Water	58-28	76.4	-27.6

[1] – NaCl @ 24% Concentration
[2] – $NaCl/CaCl_2$-1 @ 24% NaCl Concentration and 27% $CaCl_2$ Concentration
[3] – $NaCl/CaCl_2$-2 @ 12% NaCl Concentration and 14% $CaCl_2$ Concentration

A graphical summary of the results presented in Table 5-5 are provided in Figure G.

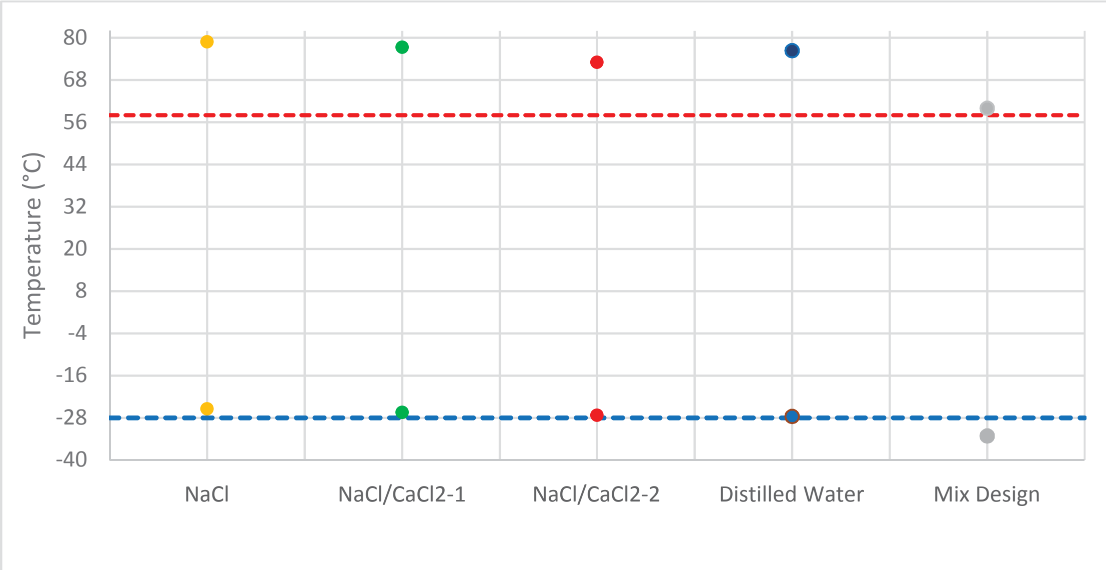

Figure G: Binder Characterization Test Results

The full collection of laboratory test results for the binder characterisation tests is provided in Appendix G.

5.5.2 Binder Characterization Test Discussion

With respect to the test data in Table 5-5, significant hardening occurred in the samples subjected to chemical exposure, compared to the mix design binder analysis. The increase in high temperature ranged from 13.1°C (for the NaCl/$CaCl_2$ – 2 exposure) to 18.9°C (for the NaCl exposure). For the low temperature grade, the increase in temperature ranged from 5.5°C to 7.7°C. Also, in terms of low temperature, the 10-Cycles of exposure resulted in non-compliance with the PG 58-28 binder specified.

Interestingly, this asphalt binder hardening was as much the case for the distilled water exposure as for the de-icing and de-icing solutions.

Key Findings

- Significant hardening of the binder was demonstrated by the analysis of recovered binder after 10 exposure cycles for all chemical solutions. Although, this hardening would suggest better rutting performance, it could also indicate a more brittle mix with a higher potential for cracking.
- The binder hardening appears to be a function of exposure to liquid, irrespective if it is anti-icing and de-icing solution or distilled water.
- Based on the low temperature grading of the recovered binder, multiple liquid exposure cycles could result in an increase in the potential for low temperature induced cracking.

6.0 SUMMARY OF LABORATORY FINDINGS

Upon review of the laboratory test results, a summary of findings as they relate to pavement performance based on the five key pavement characteristics includes:

- **Mix durability:** There is no indication that the anti-icing or de-icing chemicals investigated have any negative impact on asphalt concrete durability and performance.
- **Mix strength (cohesion):** It appears that long term exposure to anti-icing and de-icing chemicals may result in some decrease in mix strength, but it is not likely significant enough to have a negative impact on asphalt concrete performance.
- **Moisture susceptibility:** Although there was a noted decrease in moisture susceptibility for the anti-icing and de-icing chemicals, it is not likely to have an impact on asphalt concrete performance.
- **Rutting potential**: Anti-icing and de-icing chemical exposure had no influence on rutting potential.
- **Asphalt Binder characteristics:** Although it was clear that exposure to liquid (any anti-icing/de-icing chemical solutions or distilled water) significantly increased binder stiffness, there was no difference between anti-icing/de-icing chemical exposure and water exposure.

7.0 SUPPLEMENTAL FIELD REVIEW

7.1 Supplemental Field Review Overview

In addition to the laboratory investigation, Tetra Tech completed a field review of select City roadways pre and post the 2018/2019 winter maintenance season. The purpose of this field review was to evaluate the potential in-situ impact anti-icing and de-icing chemicals have under Edmonton winter conditions. The general approach to this field review included the following:

- The selection of a roadway, or roadways that have been recently paved and ideally have not experienced a winter season.
- The selected roadway, or roadways would have been constructed of similar asphalt mix type used for the laboratory testing.
- The roadway, or roadways will be in service and be exposed to a reasonable amount of traffic loading (residential or local road at minimum, bus route preferred).
- The roadway, or roadways would be subjected to both anti-icing and de-icing operations.

Based on the above, and through consultation with the City, the following roadways were selected for the field review:

NaCl and Sand De-icing Maintenance Routes

- 122nd Street: Between Whitemud Drive and Fox Drive – Northbound Direction only.
- Groat Road: From 87th Avenue to Groat Road Bridge – Northbound and Southbound Directions.

Anti-icing Routes

- 178th Street: From 87th Avenue to and 95th Avenue.
- 111th Avenue: From 124th Street to 132nd Street.
- 97th Street: From 137th Avenue to 167th Avenue.

All five roadway sections were surveyed with Tetra Tech's Pavement Surface Profiler (PSP-7000) pre-winter season in October 2018, and post-winter season in May 2019. The PSP surveys provided high resolution right-of-way (ROW) images, as well as Laser Crack Mapping System (LCMS) pavement surface images along each travel lane for each roadway. Both the ROW and LCMS photologs collected both pre and post the 2018/2019 winter maintenance season were included as part of this field review.

Differences and/or changes in roadway surface condition were noted as part of this review. Specific attention was focused on potential changes in asphalt concrete weathering and ravelling (pavement durability and/or moisture susceptibility) and surfacing cracking (pavement strength and/or asphalt binder stiffness). Where possible, changes in surface rutting were also reviewed.

7.2 Photolog Review and Observations

7.2.1 122nd Street: Between Whitemud Drive and Fox Drive

The section of 122nd Street reviewed was treated with NaCl and sand de-icing maintenance activities during the 2018/2019 winter season.

Based on review of the 2018 and 2019 photologs, this section of 122nd Street appears to have been recently paved. This observation was confirmed by the City, indicating that the roadway was paved in 2018 with a HT asphalt concrete mix.

A general observation of the 2018 and 2019 photologs indicates no significant change in the overall roadway surface condition or performance pre and post the winter maintenance season.

7.2.2 Groat Road: From 87th Avenue to Groat Road Bridge

The section of Groat reviewed was treated with NaCl and sand de-icing maintenance activities during the 2018/2019 winter season.

Significant distress of the roadway surface was observed of the 2018 photologs. However, 2019 photologs were not collected. Therefore, the comparison in the road surface condition pre and post the 2018/2019 winter maintenance season could not be carried out.

7.2.3 178th Street: From 87th Avenue to and 95th Avenue

The section of 178th Street reviewed was treated with anti-icing maintenance activities during the 2018/2019 winter season.

Based on review of the 2018 photologs, severe distresses (weathering, fatigue cracking, longitudinal cracking, and transverse cracking) were observed along this section. However, no further damage in the road surface condition post winter maintenance season was observed from the 2019 photologs.

7.2.4 111th Avenue: From 124th Street to 132nd Street.

The section of 111th Street reviewed was treated with anti-icing maintenance activities during the 2018/2019 winter season.

Based on review of the 2018 and 2019 photologs, this section of 122nd Street appears to have been recently paved. The overall observation of the 2018 and 2019 photologs shows no discernible change in the overall roadway surface condition or performance pre and post the winter maintenance season. However, a slight weathering in the roadway surface was spotted at a different location of this section of 111th street; yet, this weathering does not appear to be salt/brine related.

7.2.5 97th Street: From 137th Avenue to 167th Avenue

The section of 97th Street reviewed was treated with anti-icing maintenance activities during the 2018/2019 winter season.

The roadway surface of the section observed generally appeared in good condition. No significant change in the overall surface condition was noted along this section post the 2019 winter maintenance season. Nonetheless, 2019 photologs indicate a non-related salt/brine weathering at different locations of this section.

7.3 Field Review Discussion and Next Steps

In general, no discernible differences in roadway surface condition or performance were observed for roadway sections related to the application of anti-icing and/or de-icing chemicals through the 2018/2019 winter maintenance season. This observation is expected and reasonably consistent with laboratory observations, given the field review captured only a single season of anti-icing and/or de-icing chemical application, and where the laboratory program attempted to simulate several seasons of winter maintenance operations.

The roadway condition data does provide a valuable base-line condition for future comparisons, particularly after multiple years of application. Given the high-resolution surface textural information provided by the LCMS, a more intensive analysis of the LCMS images in future years could provide a better indication of minute changes in asphalt concrete distress as they relate to anti-icing and/or de-icing chemical application.

8.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully Submitted,
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PERMIT TO PRACTICE
TETRA TECH CANADA INC.
Signature ______
Date JULY 31/19
PERMIT NUMBER: P13774
The Association of Professional Engineers and Geoscientists of Alberta

/JP

APPENDIX A

LITERATURE REVIEW

TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Wanda Goulden, FEC, FGC, M.Sc., P.Eng., P.Geo. City of Edmonton	**Date:**	May 28, 2019
c:		**Memo No.:**	001
From:	Cong Luo, M.A.Sc., P.Eng. Art Johnston, C.E.T.	**File:**	704-ENG.EMAT03571-01
Subject:	Salt and Brine Impacts on Asphalt Pavements – Literature Review		

1.0 INTRODUCTION

This Technical Memo has been prepared by Tetra Tech Canada Inc. (Tetra Tech) as an overview of a literature review investigating the potential effects of anti-icing and de-icing agents on asphalt concrete pavements (ACP). This literature review focused primarily on how Sodium Chloride (salt) and/or Calcium Chloride F solutions potentially impact ACP properties. The literature review focuses on the use of these anti-icing and de-icing chemicals during winter roadway maintenance.

2.0 SCOPE OF THE WORK

The narrow scope literature research included the review of the current state-of-the-industry agency practices and investigations from published academic studies on the use of chloride-based anti-icing and de-icing chemicals.

For clarity of terminology, throughout this Technical Memo “anti-icing” refers to the process of applying a chemical solution (typically brine) prior to a snow fall event, and “de-icing” refers to the process of applying a chemical (typically rock salt) during or after a snow fall event when snow and/or ice has begun to accumulate on the roadway surface.

It is understood that the City of Edmonton current winter maintenance practices include the use of:

- Calcium Chloride ($CaCl_2$) brine as an anti-icing agent,
- Sodium Chloride (NaCl) as a de-icing agent which is often mixed rock salt with sand, and distributed as various application rates dependent on ambient temperature, and
- A combined application of $CaCl_2$ brine anti-icing pre-treatment, followed by a NaCl treatment during the snow fall event.

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The objective of the literature review was effectively two-fold:

1. Compile and summarize the i) current state-of-the-industry agency practices, and ii) published academic studies for the use of anti-icing and de-icing chemicals, and
2. Use the information compiled and summarized to support the proposed City of Edmonton laboratory program for the salt/brine impact study for ACP.

Therefore, the following "guiding principles" were developed and followed while completing this literature review:

- **Investigate the Current State-of-the-Industry Agency (in North America) Practices, specifically:**
  - How many agencies allow the use of $CaCl_2$ brine and/or salt in their anti-icing and/or de-icing operations?
  - In what format (brine solution, solid/crystalline, etc.) are these chemicals applied?
  - For the application of chemical solutions, what potential blends of $CaCl_2$, NaCl, and/or other chemicals are applied?
  - Which agencies have recommendations and/or best practices for minimum pavement temperatures recommended for liquid and solid chemicals?
- **Investigate Published Academic Studies on the Effect Anti-icing and/or De-icing Chemicals have on ACP Properties, specifically:**
  - What potential impact(s) do $CaCl_2$ brine and salt have on asphalt binder properties and asphalt mix characteristics (durability, moisture susceptibility, and stability)?

3.0 REFERENCES / INFORMATION SOURCES

The literature research reviewed for this assignment were based on the following sources:

- **Current Agency/Industry Practice Surveys**
  - Blackburn and Associates (MnDOT contract), "Clear Roads Study – Establishing Effective Salt and Anti-icing Application Rates." http://clearroads.org/project/12-02/ 2013 and 2014.
  - Canadian Strategic Highway Research Program (C-SHRP), "Anti-Icing and RWIS Technology in Canada." C-SHRP Technical Brief #20, 2000.
- **Academic Studies**
  - Albers, Tregan. (University of Nebraska) "Best Practices for Winter Maintenance Roadway De-icer Applications in The State of Nebraska." 2015.
  - Amsler, D. E. (Cornell University) "Snow and Ice Control. Cornell Local Roads Program." CLRP-06-7, 2006.
  - Anastasio, Sara, et al. (Norwegian University of Science and Technology) "Effect of Freeze-thaw Cycles and Deicing Fluids on Pavements." Proceedings of the International Conference on the Bearing Capacity of Roads, Railways and Airfields. 2013.
  - Flintsch, Gerardo W, et al. (Virginia Polytechnic Institute & State University) "Assessment of the Performance of Several Roadway Mixes under Rain, Snow, and Winter Maintenance Activities." Virginia Center for Transportation Innovation and Research, 2004.

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- Ketcham, Stephen, et al. (Federal Highway Administration) “Manual of Practice for an Effective Anti-Icing Program: A Guide for Highway Winter Maintenance Personnel.” No. FHWA-RD-95-202, 1996.
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- Shi, Xianming, et al. (Montana State University) "De-icer Impacts on Pavement Materials: Introduction and Recent Developments." Open Civil Engineering Journal 3. 2009.
- Takeshi, Toshiya, et al. (Administrative Agency of Public Works Research Institute, Japan) "Development and Evaluation of Non-chloride Antifreeze Admixture." Sixth International Symposium on Snow Removal and Ice Control Technology. 2004.
- Tuan, Christopher Y, et al. (University of Nebraska-Lincoln) "Improving the Freight Transportation Roadway System during Snow Events: A Performance Evaluation of Deicing Chemicals." 2011.

4.0 SUMMARY OF CURRENT STATE-OF-THE-INDUSTRY AGENCY PRACTICE

The following summary of current state-of-the-industry agency practices are based primarily on two independent surveys previously completed by others. Each survey focused primarily on the standard practice of Canadian Provincial Agencies, and United State Department of Transportations (DoTs). Limited investigation into the practices of municipalities was also included.

Between the Clear Road Survey (Blackburn and Associates, 2013 and 2014) and the C-SHRP 1999/2000 Lead State Survey (C-SHRP 2000), a total of forty agencies were included in the surveys – thirty-two Provincial Agencies/US State DoTs and eight municipalities.

Salts are the most common chemicals used in winter maintenance operations as the material is inexpensive and easy to obtain. The surveyed agencies use rock salt as their primary de-icing agent. The solid rock salt is also used as anti-icing agent. When the solid salt is used as an anti-icing agent, dry salt is pre-wetted before spreading operation as solid salt particles are subject to “bounce and scatter” during spreading operation, which cause problems distributing the salt uniformly on the pavement surface. The pre-wetting agent is typically water or 10% concentration $CaCl_2$ brine which showed a significant increase in the residual of salt on high volume roads and lowered the effective working temperature (Albers 2015). Solid $CaCl_2$ is also considered as both an anti-icing and as de-icing in seven states.

De-icing is traditionally done with solid chemicals because liquid chemicals cannot be used effectively to address thick ice or snow pack and are limited to pavement temperatures typically above -7°C. Liquid de-icers will become diluted (and may refreeze) more quickly than solid salt during heavy snow and ice storms. (Amsler 2006). Salt solution is used in thirty-two states/provinces and $CaCl_2$ brine is used as an anti-icing agent in fourteen states/provinces. The brine is usually mixed with an organic corrosion inhibitor in solution.

Furthermore, nine states use magnesium chloride solution and six states use potassium acetate solution as anti-icing agents in their winter maintenance operations.

In general, liquid chemical solutions are not recommended for use in weather events including sleet or freezing rain as they lose both their anti-icing and de-icing effectiveness.

This study mainly focused on the two common chemicals used for ice control: salt and $CaCl_2$. A summary of the Provincial Agencies/US State DoTs included in the review are shown on the map in Figure 4-1. Municipalities included in the review are shown in Table 4-1. Detailed information on the use of the chemicals for all surveyed agencies can be found in Table A-1 in the Appendix.

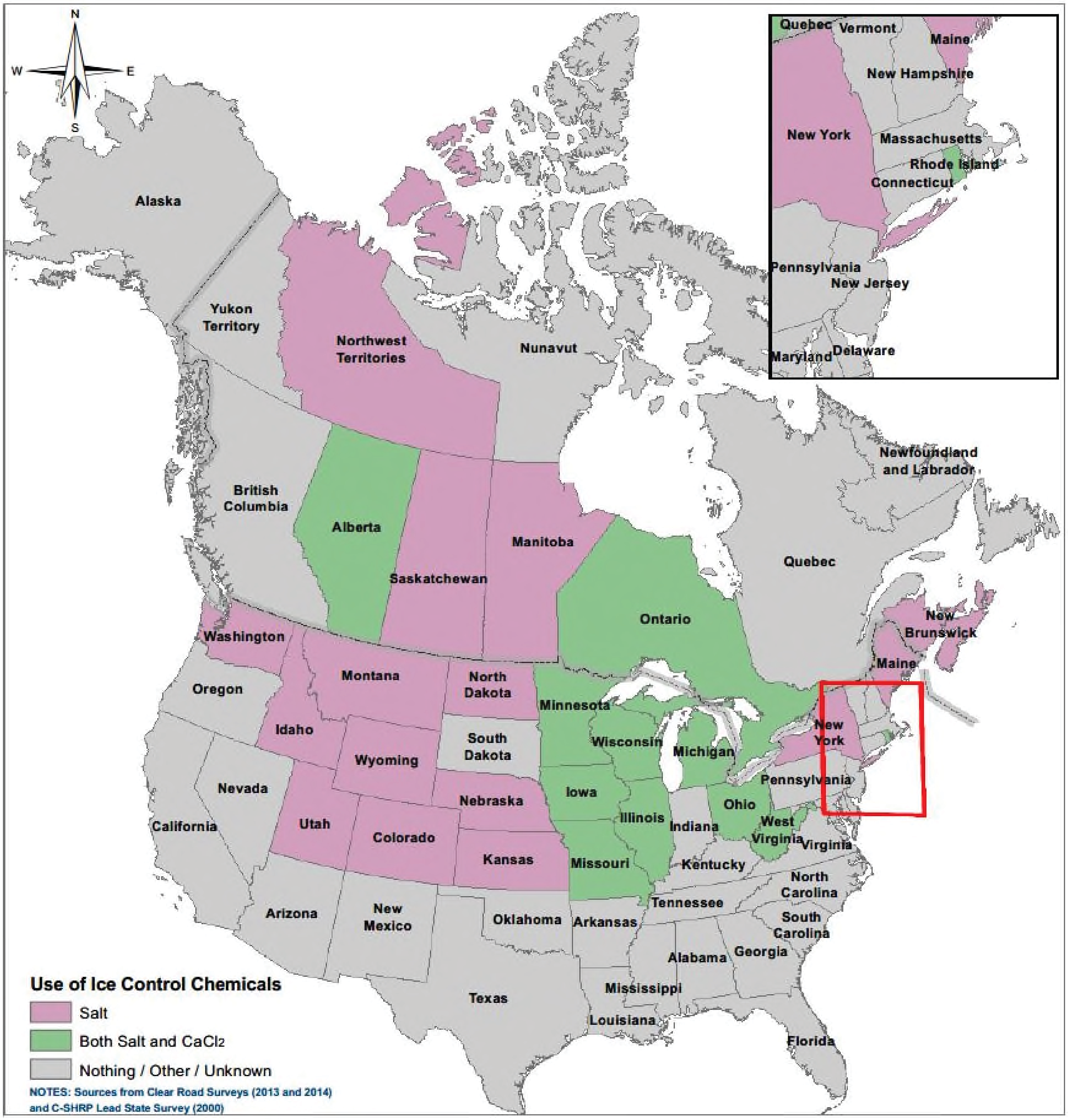

Figure 4-1: North America Provincial/State Agencies included in Review

Table 4-1: The Use of Ice Control Chemicals by Surveyed Municipalities

Agency	Salt Solution (anti-icing)	Rock Salt (de-icing)	$CaCl_2$ brine (anti-icing)
City of Calgary	Yes	Yes	Yes
City of Denver	Unknown	Unknown	Unknown
City of Toronto	Yes	Yes	No
Lake St. Louis	Yes	Yes	No
McHenry Co, IL	Yes	Unknown	Yes
NY Throughway Auth.	Yes	Yes	No
West Des Moines	Yes	Yes	Yes
City of Vancouver	Yes	Yes	No

A summary of the survey findings for the use of anti-icing and/or de-icing chemicals during winter maintenance includes:

- Thirty-five agencies reviewed use salt as their primary de-icing chemical – as shown in pink in Figure 4-1. It was not clear if the Massachusetts DoT, Vermont DoT, Virginia DoT, Quebec and City of Denver use salt as a de-icing agent.
- Thirty-two agencies use salt solution (typical 23% concentration) and thirteen agencies apply $CaCl_2$ brine (typical 32% concentration) as an anti-icing agent.
- Illinois DoT, Iowa DoT, Missouri DoT, Ohio DoT and West Virginia DoT use both solid $CaCl_2$ and $CaCl_2$ brine as anti-icing agent; Minnesota DoT, Wisconsin DoT, Alberta Transportation, and Ministry of Transportation Ontario, City of Calgary, McHenry Co and NY Throughway Auth. only use $CaCl_2$ brine as anti-icing agent; Michigan DoT only uses solid $CaCl_2$ as anti-icing agent.
- Ohio and Minnesota DoTs blend salt with $CaCl_2$ brine and apply it as a pre-treatment or anti-icing agent.
- Salt has a eutectic temperature of -6°F (-21°C) at 23% concentration and $CaCl_2$ brine has a eutectic temperature of -60°F (-51°C) at 30% concentration. (Ketcham 1996). These temperatures are important when establishing the percent concentration of each chemical for use under a variety of ambient temperatures.
- The surveyed agencies also provide the minimum pavement temperature recommended for use of the chemicals. In general, these minimum temperatures are:
  - Solid salt used as anti-icing: -11°C on the wet pavement and -9°C on the dry pavement;
  - Solid salt used as de-icing: -9°C to -7°C;
  - Solid $CaCl_2$ used as anti-icing: -14°C to -11°C;
  - Solid $CaCl_2$ used as de-icing: -9°C to -3°C;
  - Liquid 23% salt solution used as anti-icing: -9°C to -6°C; and
  - Liquid 32% $CaCl_2$ brine as de-icing: -9°C to -6°C.

5.0 SUMMARY OF ACADEMIC STUDY REVIEW

This review was based on the findings from a review of published academic studies and provides a synopsis of the latest research into the impacts of salt or $CaCl_2$ brine on asphalt cement (asphalt binder) properties and/or asphalt concrete (combination of asphalt binder and aggregate) mix characteristics.

A summary of findings for salt and $CaCl_2$ brine with similar impact on asphalt cement properties and/or asphalt concrete mix characteristics includes:

- The Tensile Strength Ratio (TSR) test was used to determine the moisture susceptibility of the asphalt concrete mixes. The test results were found to be similar for the asphalt concrete mixes soaked in salt and $CaCl_2$ solutions, where the TSR increased as the soaking time increased. In other words, the strength of asphalt mix increases and moisture susceptibility decreases with increased exposure time to salt and $CaCl_2$ solutions. (Nawla 2018)

- The salt and $CaCl_2$ solution conditioned asphalt concrete mix samples and unconditioned samples (the samples exposed to distilled water) have similar mass loss values, but the conditioned samples are more brittle compared to the unconditioned ones. (Nawla 2018)

- Hassan (2002) did an extraction test on the condition and unconditioned asphalt concrete mix samples which had been obtained from the field coring program. The samples were then subjected to 25 and 50 freeze-thaw cycles using the same equipment. The study found that the penetration values of recovered asphalt cement were generally higher for the unconditioned samples than the conditioned ones; the penetration increases with an increasing number of freeze-thaw cycles. In the other words, salt and $CaCl_2$ cause hardening of asphalt cement and freeze-thaw causes softening of asphalt cement.

A summary of findings from the studies investigating the impact the application of salt and $CaCl_2$ brine have on asphalt cement properties and/or asphalt concrete mix characteristics includes:

- The salt solution conditioned asphalt concrete mix samples had higher Indirect Tensile Strength (ITS) than unconditioned samples. The elastic modulus of asphalt concrete mixes decreased after they were subjected to salt solution after 25 and 50 freeze-thaw cycles (Hassan 2002).The conditioned samples had higher ITS than unconditioned samples. The elastic modulus of asphalt mixes decreased after they were subjected to NaCl solution after freeze-thaw cycles. (Hassan 2002)

- Cantabro tests were used to test the particle loss of the asphalt concrete mix samples after eight freeze-thaw cycles. From the tests, the asphalt binder is softer after being immersed in water and in the 25% NaCl solution, and conversely stiffer after conditioning in the 12.5% NaCl solution. The assessment was based on the Standard Specification for Performance-Graded Asphalt Binder. (Anastasio 2013)

- The samples subjected to salt solution showed lower resistance to particle loss compared to the unconditioned ones and there is a negative relationship between the concentration of the salt solution and asphalt concrete mix durability. (Anastasio 2013)

- Dynamic Shear Rheometer testing (DSR) was conducted on the extracted binder from the asphalt concrete mixes that had been subjected to eight freeze-thaw cycles in salt solution with different concentrations. The test was to evaluate the stiffness of the asphalt binder and the test results show variations in the asphalt binder stiffness as a result of exposure to salt solutions. The asphalt binder extracted from unconditioned samples and samples subjected to 25% salt solution was softer than the samples conditioned in the 12.5% salt solution. (Anastasio 2013)

- The skid resistance of the pavement was not significantly changed after the application of the NaCl solution for different types of surface mix, including Open Graded Friction Course (OGFC) and dense-graded mixes. (Flintsch 2004). The pavement friction coefficient was also related to the pavement temperature. A study showed that salt solution or $CaCl_2$ brine applied at 70.5 L/lane-kilometer at -9°C pavement temperature with high humidity reduced pavement friction. (Shi 2009) The salt solution application could cause the road to become more slippery than with $CaCl_2$ brine application. (Takeshi 2004)

6.0 PERTINENT ASPECTS

6.1 Validation of Laboratory Testing Program

Pertinent aspects related to the City of Edmonton Salt and Brine Laboratory Program include:

- The Cantabro test was used to assess the de-icer conditioned asphalt mix durability by comparing the particle loss after freeze-thaw cycles – study completed by Norwegian University of Science and Technology;
- Tensile strength was tested to determine the moisture susceptibility of asphalt mix – studies completed by Carleton University and the City of Edmonton;
- Binder characterization was assessed based on Standard Specification for Performance-Graded Asphalt Binder – studies completed by Carleton University and Norwegian University of Science and Technology;
- The Hamburg Wheel Test, which is used to evaluate the rutting susceptibility, was not conducted in any studies in the literature review except for the City of Edmonton study which conducted Asphalt Pavement Analyser (APA) testing in 2018;
- Friction testing was used to evaluate the effect of de-icers on skid resistance – studies completed in Japan, but this was not considered pertinent to the City of Edmonton study; and
- Although elastic modulus was not considered in the current plan for the City of Edmonton Salt and Brine Laboratory Program, the elasticity modulus of the anti-icing and de-icing agent conditioned asphalt mixtures was tested through an Indirect Tensile Strength (ITS) Test – study completed by Carleton University.

Based on this literature search, the planned City of Edmonton laboratory assessment of the effects of de-icers on asphalt pavement aligns well with the previous investigations undertaken by others. In particular, the Cantabro test (to assess durability), tensile strength ratio (to assess moisture susceptibility), and binder characterization (to evaluate the influence of de-icers on asphalt binder) have all been included in the City of Edmonton laboratory program. In addition, the Hamburg Wheel Test will provide further information on rutting resistance and moisture susceptibility.

Although elastic modulus and friction have not been included in the City of Edmonton laboratory study, this is not considered significant with respect to the proposed study.

6.2 Summary Comments

Additional general comments/observations relating to the impacts of salt or $CaCl_2$ brine on asphalt pavements include:

- The “strength” of asphalt mix increases and the susceptibility to moisture damage is greater with increased exposure time to salt and CaCl2 solutions;
- The durability of asphalt mixtures exposed to salt and CaCl2 solution was similar to mixtures exposed only to water;
- Indications are that the asphalt binder in a mix hardens with increased exposure to salt and CaCl2 which could result in accelerated aging and an overall reduction in service life;
- Asphalt pavements are intended to by flexible by design. Asphalt concrete samples exposed to salt solution and numerous freeze/thaw cycles showed a tendency to stiffen, reducing pavement flexibility, and therefore leading to a higher potential for cracking;
- Asphalt samples subjected to salt solution showed lower resistance to particle loss compared to unconditioned samples, indicating increased potential for loss of surface material and/or potholes; and
- The higher the salt solution concentration correlated to increased softening of the asphalt binder and reduced strength.

In general, the research reviewed indicates that exposure to salt and CaCl2 solutions can have a negative influence on some mix properties which could result in a reduced pavement service life. These observations should be qualified in that the research reviewed was based on laboratory testing and not field studies.

7.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the City of Edmonton and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than City of Edmonton, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on the Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

8.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully Submitted,
Tetra Tech Canada Inc.

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PROFESSIONAL ENGINEER
BRYAN D. PALSAT
ALBERTA

PERMIT TO PRACTICE
TETRA TECH CANADA INC.
Signature
Date May 28/2019
PERMIT NUMBER: P13774
The Association of Professional Engineers and Geoscientists of Alberta

Reviewed by:
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Transportation Practice
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Attachments: Tetra Tech's Limitations on the use of this Document
Figure 1 – North America Agencies included in Review
Table 1 – List of America Agencies included in Review

ATTACHMENTS

LIMITATIONS ON USE OF THIS DOCUMENT

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If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

1.4 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by third parties other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary exploration, investigation, and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless so stipulated in the Design Report, TETRA TECH was not retained to explore, address or consider, and has not explored, addressed or considered any environmental or regulatory issues associated with the project specific design.

1.8 CALCULATIONS AND DESIGNS

TETRA TECH may have undertaken design calculations and prepared project specific designs in accordance with terms of reference that were previously set out in consultation with, and agreement of, TETRA TECH's client. These designs have been prepared to a standard that is consistent with current industry practice. Notwithstanding, if any error or omission is detected by TETRA TECH's Client or any party that is authorized to use the Design Report, the error or omission should be immediately drawn to the attention of TETRA TECH.

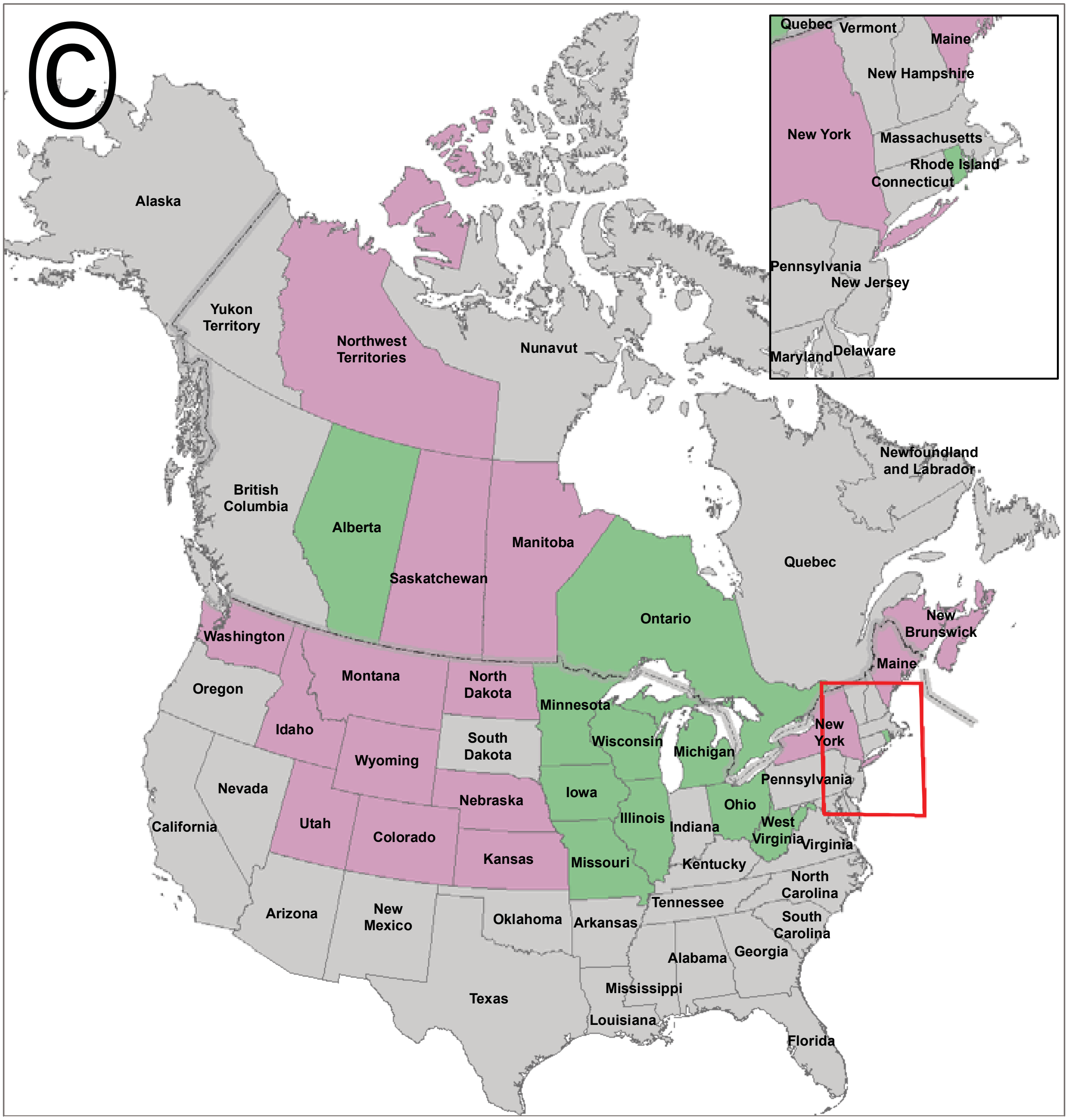
1.9 GEOTECHNICAL CONDITIONS

A Geotechnical Report is commonly the basis upon which the specific project design has been completed. It is incumbent upon TETRA TECH's Client, and any other authorized party, to be knowledgeable of the level of risk that has been incorporated into the project design, in consideration of the level of the geotechnical information that was reasonably acquired to facilitate completion of the design.

If a Geotechnical Report was prepared for the project by TETRA TECH, it may be included in the Design Report as appropriate. The Geotechnical Report contains Limitations that should be read in conjunction with these Limitations for the Design Report.

1.10 APPLICABLE CODES, STANDARDS, GUIDELINES & BEST PRACTICE

This report has been prepared based on the applicable codes, standards, guidelines or best practice as identified in the report. Some mandated codes, standards and guidelines (such as ASTM, AASHTO Bridge Design/Construction Codes, Canadian Highway Bridge Design Code, National/Provincial Building Codes) are routinely updated and corrections made. TETRA TECH cannot predict nor be held liable for any such future changes, amendments, errors or omissions in these documents that may have a bearing on the assessment, design or analyses included in this report.



LEGEND

Use of Ice Control Chemicals

- Salt
- Both Salt and $CaCl_2$
- Nothing / Other / Unknown

NOTES

Sources from Clear Road Surveys (2013 and 2014) and C-SHRP Lead State Survey (2000)

STATUS
ISSUED FOR REVIEW

CITY OF EDMONTON SALT AND BRINE STUDY

Roadway Anti-icing/De-icing Practices Across North America

PROJECTION	DATUM	CLIENT
Canadian Lambert Conf. Conic	NAD83	Edmonton

Scale: 1:35,000,000
400 200 0 400
Kilometres

TETRA TECH

FILE NO.				
EMAT03571-01_CoE_Figure1.mxd				
OFFICE	DWN	CKD	APVD	REV
Tt-VANC	DL	CL	BP	0
DATE	PROJECT NO.			
January 24, 2019	ENG.EMAT03571-01			

Figure 1

H:\2019Projects\Salt\EMAT03571-01_CoE_Figure1.mxd modified 1/24/2019 by Dennis.Luo

Table 1: List of American Agencies included in Review (Sources from Clear Road 2013 and 2014 Surveys and C-SHRP 2000 Lead State Survey)

Agency	Common Snow and Ice Control Chemicals				
	Liquid		Solid		
	NaCl	$CaCl_2$	Rock Salt[1]	Solar Salt[2]	$CaCl_2$
Colorado DOT	x		x	x	
Idaho DOT	x		x		
Illinois DOT	x	x	x		x
Iowa DOT	x	x	x		x
Kansas DOT	x		x		
Maine DOT	x		x		
Massachusetts DOT					
Michigan DOT	x		x		x
Minnesota DOT	x	x	x		
Missouri DOT	x	x	x		x
Montana DOT	x				
Nebraska DOT	x		x		
New York DOT	x		x		
North Dakota DOT	x		x		
Ohio DOT	x	x	x		x
Rhode Island DOT	x	x	x		x
Utah DOT	x		x	x	
Vermont DOT					
Virginia DOT					
Washington State DOT			x	x	
West Virginia DOT	x	x	x		x
Wisconsin DOT	x	x	x		
Wyoming DOT	x		x		
Alberta, AT	x	x	x		
Manitoba MIT	x		x		
New Brunswick DOT	x		x		
Nova Scotia TIR	x		x		
Ontario MTO	x	x	x		
Quebec MTQ					

Table 1: List of American Agencies included in Review (Sources from Clear Road 2013 and 2014 Surveys and C-SHRP 2000 Lead State Survey)

Agency	Common Snow and Ice Control Chemicals				
	Liquid		Solid		
	NaCl	$CaCl_2$	Rock Salt[1]	Solar Salt[2]	$CaCl_2$
Saskatchewan MHI	x		x		
Northwest Territories DOT			x		
Prince Edward Island DOT			x		
City of Calgary	x	x	x		
City of Denver					
City of Toronto	x		x		
Lake St. Louis	x		x		
McHenry Co, IL	x	x			
NY Throughway Auth.	x		x		
West Des Moines	x	x	x		
City of Vancouver	x		x		

[1] – Rock Salt is typically mined from underground salt mines.
[2] – Solar Salt is typically extracted through the evaporation of saline solutions (i.e. sea water).

APPENDIX B

CITY OF EDMONTON 10 MM HT MIX DESIGN

May 16, 2017

Mr. Kyle Poulson C.E.T.,
Lafarge Canada Inc.
1140 Ellwood Road SW,
Edmonton, Alberta
T6X 0B2

Dear Sir:

Re: <u>City of Edmonton 10mm – High Traffic (HT) 10% RAP Asphalt Mix Design Superpave Gyratory Compactor (SGC) - 100 Gyrations</u>

Lafarge Canada Inc. (LCI) has prepared a 100 gyration compactive effort SGC mix design in accordance with the City of Edmonton specifications for Designation 1, Class 10.0, Asphalt Concrete Surface Course. This mix incorporates Lafarge Asphalt Technologies (LAT) PG58-28 Asphalt Cement and 10% Reclaimed Asphalt Pavement (RAP).

Preparation of this mix design was done in accordance with the latest edition of the Asphalt Institute Manual Series MS-2 "Asphalt Mix Design Methods", and the City of Edmonton 2015 Roadways Design and Construction specifications; Section 02066 "SGC Hot-Mix Asphalt Concrete" and Section 02966 "Recycled Asphalt Paving". Laboratory testing was conducted by LCI to determine the physical properties of the various aggregates used in the mix design, as well as the SGC mix design properties. The Rut Resistance Testing using the Asphalt Pavement Analyzer (APA) was conducted by the City of Edmonton Engineering Services Section. The Performance Grade (PG) testing was conducted by LAT. A detailed report of the mix design properties is attached; the contents are outlined on Page 3.

Representative samples of the 10.0mm RAP were tested to establish aggregate gradation and fracture, recovered binder content, and binder rheology. The average recovered asphalt cement content of the 10.0mm RAP was determined to be 5.32% by mass of dry aggregate (5.05% by mix). This 10% RAP mix meets the City of Edmonton HT specification of 10% maximum recycle content. At the recommended AC content of 5.82% by mass of dry aggregate (5.50% by mix) the amount of virgin binder to total binder was determined to be 90.8% for this mix, which meets the City of Edmonton specification of 80% minimum for a surface mixture.

A stock binder grade of PG58-28 (true grade PG58.9-32.7) was combined with a representative sample of the recovered binder from the recycle material, RAP (PG70.1-31.9) at the calculated binder replacement ratio. The blended sample was then tested to establish its Performance Grade and critical cracking temperature. The actual Performance Grade of this blend was determined to be PG60.0-32.5, which meets the PG58-28 Specification. The critical cracking temperature of this blend was determined to be -33.1°C, which meets the -28°C specification.

With regards to the Bailey Method Volume Blending Sheet parameters, the chosen Coarse Aggregate Loose Unit Weight (CA-LUW) was determined to be 71.4, in accordance with the City of Edmonton Specification of 60-85 for a fine graded mix. The Old CA ratio can provide an indication of segregation susceptibility in fine graded mix, with a ratio of 0.438 this should not be an issue. For a fine graded blend the Old FA_c ratio of 0.627 provides an indication of the coarseness or fineness of the material passing the original PCS, in this case it should react fine graded. The Old FA_f ratio of 0.324 generally indicates that the new fine fraction portion of the material passing the original PCS may react coarse graded. The new CA ratio of 0.676 is within the suggested parameters. The new FA_c ratio of 0.324 is below the minimum suggested parameter which could lead to compaction issues in the field if combined with a low new FA_f ratio. Since there is no new FA_f ratio for a 9.5mm NMAS blend, compaction should not be an issue.

Past experience has indicated that the properties of plant produced hot mix asphalt concrete may vary from the mix properties obtained with laboratory hot mix samples prepared during the mix design phase. If this should occur during initial plant production, the asphalt content and/or aggregate gradation should be adjusted to obtain the desired mix properties. Small adjustments should not require additional design data, however quality control testing should be conducted to confirm the mix properties.

We trust that this information will meet the requirements of The City of Edmonton. Should you have any questions or comments, please contact the undersigned.

Respectfully submitted on behalf of Lafarge Canada Inc.,

Bradley Maguire, P.Eng., M.A.Sc.
Quality Manager, Lafarge GEA Asphalt
APEGA Permit to Practice # P08987

Reviewed by R.W. Forfylow, P.Eng.
Director of Quality - Asphalt & Paving

2017 10mm HT RAP PG58-28
Asphalt Concrete Mix Design

Contents Page

City of Edmonton ~ 10mm High Traffic (HT) with RAP

1.0 AGGREGATE INFORMATION

1.1 Sources:

SUPPLIER / DESCRIPTION	%
10.0mm Berrymoor NW12-50-06-W5M	33.0%
MF Berrymoor NW12-50-06-W5M	21.0%
WMF Berrymoor NW12-50-06-W5M	22.0%
Onoway Sand NW06-54-01-W5M	7.0%
Cornerstone Sand W13-54-2-W5	6.0%
BHF	1.0%
10.0mm RAP (Petroway) NW08-53-23-W4M	10.0%

* Individual Product and Combined Product Gradations tabulated in SECTION 4.0

2.0 SGC PROPERTIES

		DESIGN DATA				
A.C., % of Total Mix		4.50	5.00	5.50	6.00	6.50
A.C., % of Dry Aggregate		4.71	5.26	5.82	6.38	6.95

M.T.D.	(kg/m³)	2471	2453	2435	2418	2401
Density	(kg/m³)	2289	2315	2338	2358	2374
Air Voids	(%)	7.4	5.6	4.0	2.5	1.1
V.M.A.	(%)	16.0	15.5	15.1	14.8	14.7
V.F.A.	(%)	53.8	63.9	73.5	83.1	92.5
%Gmm@Nini	(%)	85.9	87.4	88.7	90.1	91.7
%Gmm@Ndes	(%)	92.6	94.4	96.0	97.5	98.9
%Gmm@Nmax	(%)			96.9		
Film Thickness	(µm)	6.0	6.8	7.6	8.5	9.3
Asphalt Absorption	(%)	0.62	0.62	0.61	0.62	0.62
Dust / AC		1.3	1.2	1.1	1.0	0.9
TSR	(%)			85.6		

3.0 COMBINED AGGREGATE PROPERTIES

PROPERTIES	RESULT	SPECIFICATION
Combined Gsb	2.603	-
LA Abrasion - B Grading	25.9%	30% max.
LA Abrasion - C Grading	28.5%	30% max.
Plasticity Index	Non-Plastic	Non-Plastic
Soundness (MgS04)-Coarse	1.3%	16% max.
Soundness (MgS04)-Fine	13.9%	16% max.
Detrimental Matter	0.47%	2% max.
Manufactured Fines	76.0%	75% min.
-25 to +12.5mm (1F/2F)	-	-
-12.5 to +10mm (1F/2F)	97.9% / 97.6%	92% / 88%
-10 to +5mm (1F/2F)	99.0% / 98.9%	95% / 93%
Total Fracture (2F)	98.8%	90%

4.0 GRADATION INFORMATION

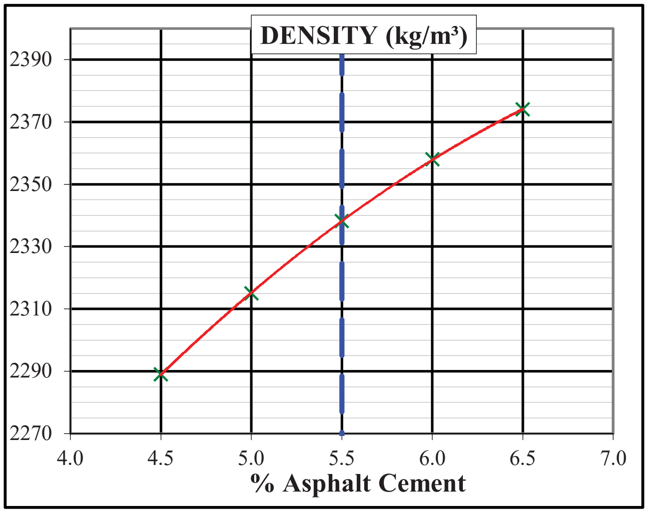
4.1 INDIVIDUAL PRODUCT GRADATION (ASTM C136, C117)

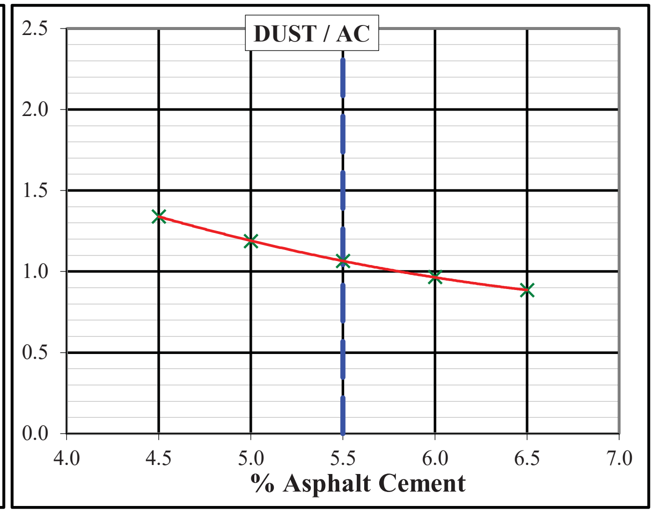
SCREEN SIZE (mm)	PERCENT PASSING BY MASS										
	10.0mm Berrymo	MF Berrymo	WMF Berrymo	Onoway Sand	Cornerstone Sand		BHF		10.0mm RAP		
	33.0%	21.0%	22.0%	7.0%	6.0%		1.0%		10.0%		
25.0	100.0	100.0	100.0	100.0	100.0		100.0		100.0		
20.0	100.0	100.0	100.0	100.0	100.0		100.0		100.0		
16.0	100.0	100.0	100.0	100.0	100.0		100.0		100.0		
12.5	100.0	100.0	100.0	100.0	100.0		100.0		100.0		
10.0	94.9	100.0	100.0	100.0	100.0		100.0		94.1		
8.0	65.7	100.0	100.0	100.0	100.0		100.0		84.3		
6.3	27.6	100.0	100.0	100.0	100.0		100.0		77.5		
5.0	7.0	97.6	97.4	97.7	100.0		100.0		70.9		
2.50	2.3	72.9	70.8	79.1	99.5		100.0		56.4		
1.25	1.8	54.1	48.4	63.8	99.1		100.0		46.8		
0.630	1.6	41.4	33.8	52.8	98.1		100.0		39.9		
0.315	1.4	29.6	18.9	30.1	69.7		99.8		28.4		
0.160	1.2	17.9	8.0	9.9	14.2		97.8		16.9		
0.080	0.9	10.6	2.9	2.1	2.4		76.4		9.7		

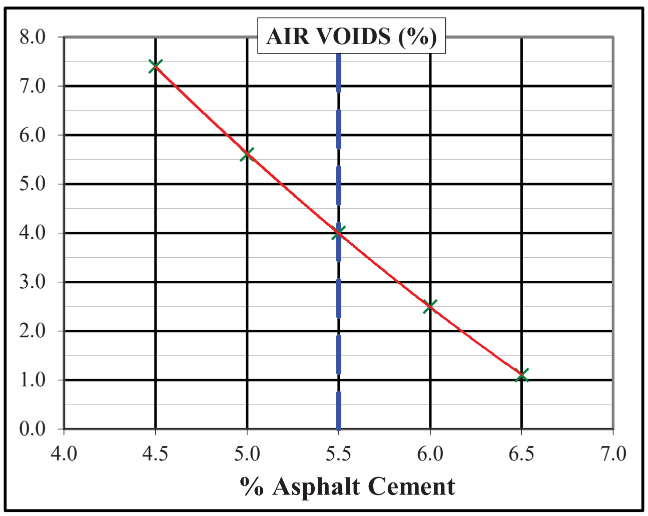
4.2 COMBINED DESIGN GRADATION

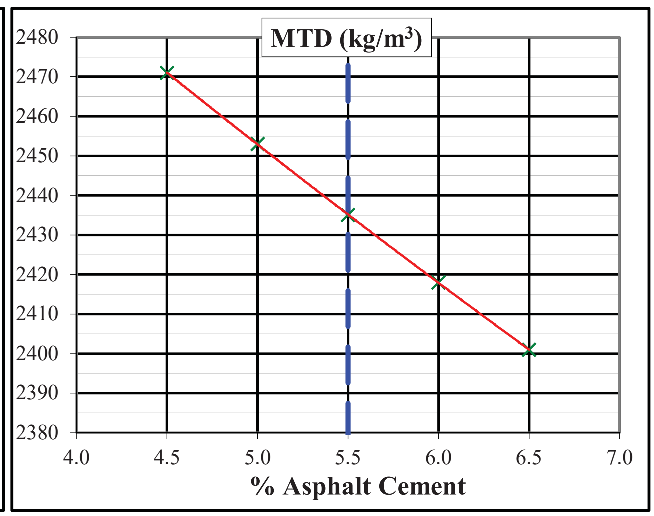
SCREEN SIZE (mm)	PERCENT PASSING BY MASS	JMF GRADATION LIMITS	
	COMBINED GRADATION	LOWER	UPPER
25.0	100.0	100	100
20.0	100.0	100	100
16.0	100.0	100	100
12.5	100.0	100	100
10.0	97.7	97	100
8.0	87.1	70	94
6.30	73.9	45	85
5.00	65.1	32	75
2.50	49.8	23	55
1.25	38.7	16	45
0.630	31.2	11	36
0.315	21.0	8	26
0.160	10.1	7	16
0.080	5.2	4	9

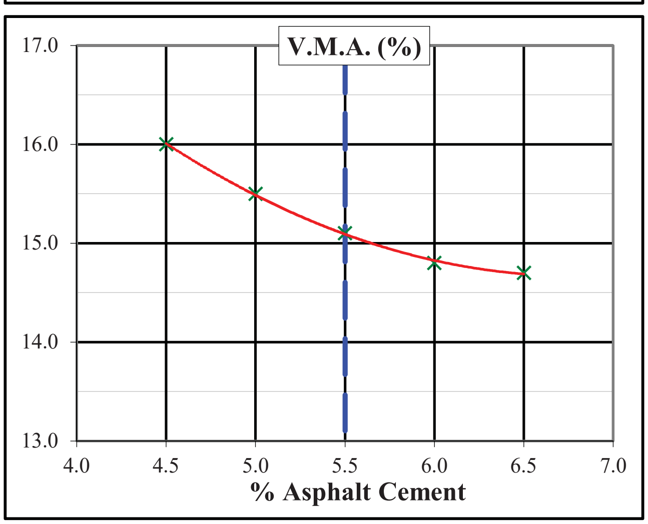
5.0 DESIGN PROPERTIES CHARTS

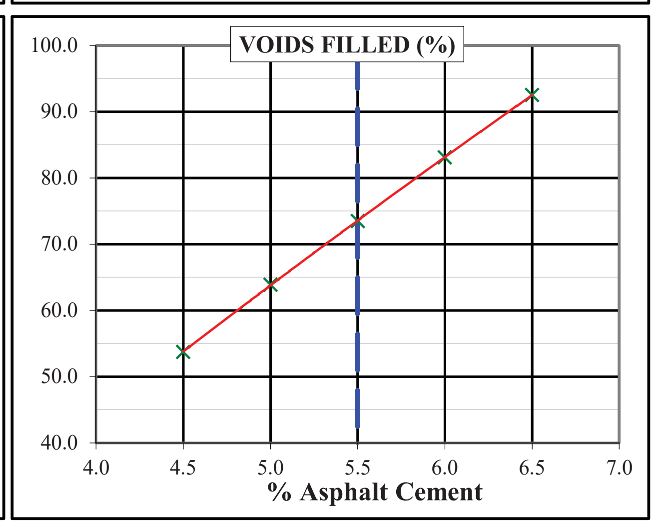












City of Edmonton ~ 10mm High Traffic (HT) with RAP

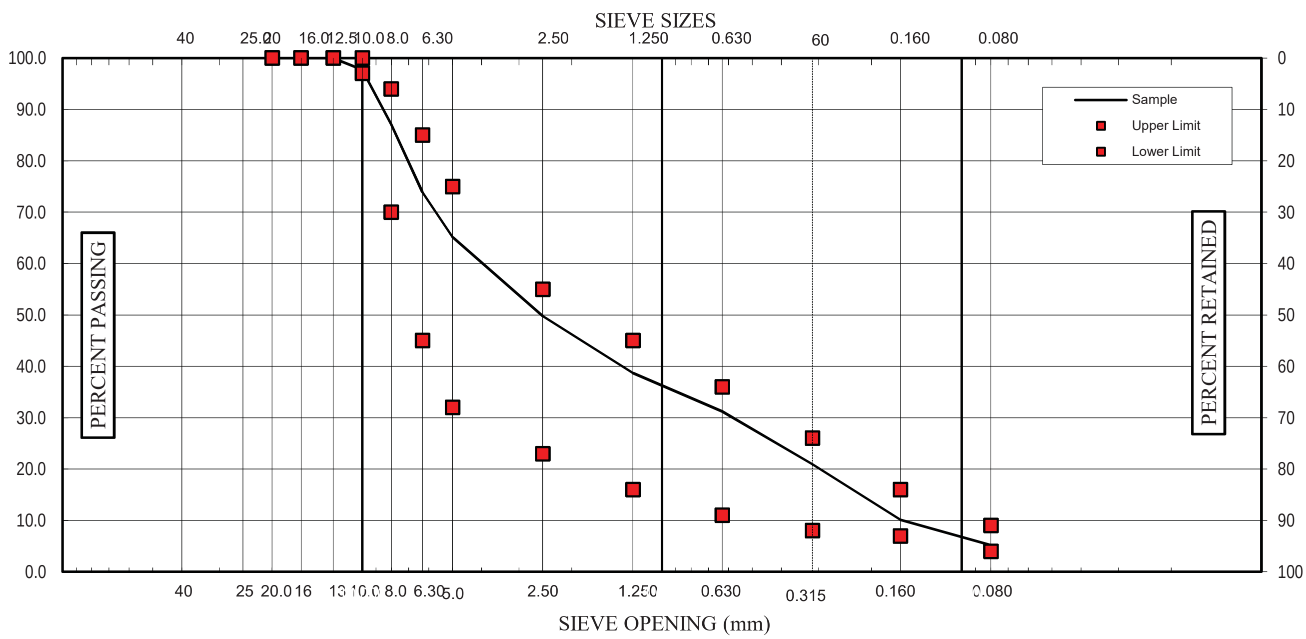
6.0 JOB MIX FORMULA SUMMARY PAGE

PREPARED FOR: Lafarge Canada
SOURCE PLANT: Greater Edmonton
DESIGN NUMBER: 2017-2

MIX DESIGN PROPERTIES		ACTUAL	SPEC
Number of gyrations		100	100
A.C., % of Total Mix	(%)	5.50	-
M.T.D	(kg/m³)	2435	
Density	(kg/m³)	2338	
Air Voids	(%)	4.0	3.6 - 4.4
V.M.A.	(%)	15.1	13 min.
V.F.A.	(%)	73.5	70 - 80
%Gmm@Nmax	(%)	96.9	98.0 max.
Dust/AC	(%)	1.1	-
Film Thickness	(µm)	7.6	7.5 min.
TSR	(%)	85.6	80 min.
Combined Aggregate Gsb		2.603	
Asphalt Absorption	(%)	0.62	
AC Supplier		LAT	
AC Grade		PG58-28	
AC Specific Gravity at 15.6°C		1.033	
Mixing Temperature	°C	142-148	
Compaction Temperature	°C	132-136	

SIEVE SIZE (mm)	COMBINED GRADATION	SPEC. LIMITS	
		LOWER	UPPER
25.0	100.0	100	100
20.0	100.0	100	100
16.0	100.0	100	100
12.5	100.0	100	100
10.0	97.7	97	100
8.0	87.1	70	94
6.3	73.9	45	85
5.0	65.1	32	75
2.5	49.8	23	55
1.25	38.7	16	45
0.630	31.2	11	36
0.315	21.0	8	26
0.160	10.1	7	16
0.080	5.2	4	9

0.3% AD-here 77-00 (BL) Liquid anti-strip was added to the mix by weight of binder.



City of Edmonton ~ 10mm High Traffic (HT) with RAP

7.0 MIX DESIGN PARAMETERS SUMMARY PAGE

7.1 INDIVIDUAL AGGREGATE PROPERTIES

		10.0mm Berrymoor NW12-50-	MF Berrymoor NW12-50-	WMF Berrymoor NW12-50-	Onoway Sand NW06-54-	Cornersto ne Sand		BHF
Water Absorption	(%)	0.88	0.72	0.92	1.01	0.99		
Specific Gravity		2.603	2.612	2.592	2.567	2.601		2.658
Bailey LUW	(kg/m^3)	1367	1553	1532	1636	1381		
Bailey RUW	(kg/m^3)	1520	1837	1738	1788	1561		
-25.0 +12.5 (1F/2F)	(%)	-	-	-	-	-		
-12.5+10.0 (1F/2F)	(%)	99.1/99.1	-	-	-	-		
-10.0 +5.5 (1F/2F)	(%)	99.3/99.3	100.0/100.0	100.0/100.0	73.0/73.0	-		
Total Crushed (2F)	(%)	99.3	100.0	100.0	73.0	-		

7.2 RECYCLE AGGREGATE PROPERTIES

			10.0mm RAP (Petroway
Asphalt Absorption	(%)		0.65
Specific Gravity (Gse)			2.632
MTD	(kg/m^3)		2447
Binder content (total mix)	(%)		5.05%
S.G. of Binder			1.055
Source			GEA
-12.5+10.0 (1F/2F)	(%)		93.4/92.3
-10.0 +5.5 (1F/2F)	(%)		96.9/95.7
Total Crushed (2F)	(%)		95.0

7.3 MIX DESIGN PARAMETERS

		Result	Specification
Combined aggregate water absorption	(%)	0.86	-
Bailey CUW	(%)	71.4	60 - 85
N_{design} Number of Gyrations in SGC		100	100
$N_{maximum}$ Number of Gyrations in SGC		160	160
Ignition Oven Correction Factor (total mix)		-0.38	-
Ignition Oven Correction Factor (dry aggregate)		-0.42	-
Anti-Stripping Agent Supplier		Road Science	-
Anti-Stripping Agent Product Name		AD-here 77-00 (BL)	-
Anti-Stripping Agent Application Rate		0.30%	-
APA (mm, 52°C, 8000 cycles)	(mm)	3.6	5.0 max.

8: Bailey Method Volume Blending Sheet

Heritage Research Group
7901 W. Morris Street • Indianapolis, IN 46231 U.S.A.
317-243-0811 • 486-2985 (FAX)

Design Number:	2017-2
Design Date:	2017
Mix Producer Name:	Lafarge Canada Inc.
Mixture Name/Code:	10mm HT with RAP

Clear All Data

Units

Show or Hide FINE-Graded Info

Aggregate	#1-CA	#2-CA	#3-CA	#4-CA	#1-FA	#2-FA	#3-FA	#4-FA	MF	Hyd Lime	RAP1	RAP2	RAP3	AC
Code														
Source id														
Name	10mm				MF	WMF	Sand	Sand	BHF		10mm RAP			
Location	Berrymoor				Berrymoor	Berrymoor	Onoway	Cornerstone	Petroway		Petroway			
Virgin %'s	35.7	0.0	0.0	0.0	23.7	24.9	7.9	6.8	1.0	0.0				100.0
%'s with RAP	33.0				21.0	22.0	7.0	6.0	1.0		10.0			100.0

Sieve	#1-CA	#2-CA	#3-CA	#4-CA	#1-FA	#2-FA	#3-FA	#4-FA	MF	Hyd Lime	RAP1	RAP2	RAP3	Virgin	With RAP
19.0	100.0				100.0	100.0	100.0	100.0	100.0		100.0			100.0	100.0
12.5	100.0				100.0	100.0	100.0	100.0	100.0		100.0			100.0	100.0
9.5	94.9				100.0	100.0	100.0	100.0	100.0		94.1			98.2	97.7
4.75	7.0				97.6	97.4	97.7	100.0	100.0		70.9			65.4	65.1
2.36	2.3				72.9	70.8	79.1	99.5	100.0		56.4			49.8	49.8
1.18	1.8				54.1	48.4	63.8	99.1	100.0		46.8			38.3	38.7
0.600	1.6				41.4	33.8	52.8	98.1	100.0		39.9			30.6	31.2
0.300	1.4				29.6	18.9	30.1	69.7	99.8		28.4			20.3	21.0
0.150	1.2				17.9	8.0	9.9	14.2	97.8		16.9			9.4	10.1
0.075	0.9				10.6	2.9	2.1	2.4	76.4		9.7			4.7	5.2

	Virgin	W/ RAP
CA	0.451	0.438
FA_c	0.614	0.627
FA_f	0.307	0.324

% CA LUW 71.4 | UW Factor 1000.0 | % FA RUW 100.0

	#1-CA	#2-CA	#3-CA	#4-CA	#1-FA	#2-FA	#3-FA	#4-FA	MF	Hyd Lime	RAP1
LUW	1367.2				1553.0	1532.1	1635.9	1381.2		RAP AC →	5.1
CHOSEN UW	975.5	0.0	0.0	0.0	1837.3	1738.2	1787.5	1560.9		RAP Gmm →	2.447
RUW	1519.9				1837.3	1738.2	1787.5	1560.9		RAP Gb →	1.055
Bulk Spec Gr	2.603				2.612	2.592	2.567	2.601	2.658		2.632
Apparent Gr	2.665				2.662	2.655	2.636	2.670	2.658		2.732
% Absptn.	0.9				0.7	0.9	1.0	1.0	0.9	1.0	0.7
Loose Voids	47.5				40.5	40.9	36.3	46.9			
Rodded Voids	41.6				29.7	32.9	30.4	40.0			

For Fine-Graded mixes, where the % CA LUW is ≤ 90.0%

New		
CA	0.670	0.676
FA_c	0.307	0.324

	#1-FA	#2-FA	#3-FA	#4-FA	Total
Virgin - FA Blend by MASS (Cells G18:J18)	37.4	39.3	12.5	10.7	99.9
RAP - FA Blend by MASS (Cells G20:J20)	37.5	39.3	12.5	10.7	100.0

Desired Blends by VOLUME of VIRGIN Aggregates									Total Volume %'s
Coarse Agg's	100.0			100.0 ← MUST TOTAL 100.0%					37.5
Fine Agg's	MUST TOTAL 100.0% →			100.0	34.9	37.9	12.5	14.8	62.5

	Virgin	RAP
Combined Water Absorption	0.87	0.85
Pba as % of Water Absorption	65%	
Estimated Pba	0.57	0.55

Virgin Blend		
% AC	Gmb	VCAmix

RAP Blend		
% AC	Gmb	VCAmix
5.5	2.338	57.4

Enter the percent passing the 0.075mm sieve desired in the VIRGIN Blend	4.75
Combined Bulk Specific Gravity of the VIRGIN Aggregates (Gsb)	2.600
Combined Bulk Specific Gravity of ALL Aggregates (Gsb)	2.603

9: Mix Design PG Results

Laboratory Report

Cloverbar Asphalt Binder Laboratory
12221 17st NE
Edmonton, AB T6S 1A7
Phone (780)472-9435 Fax (780)472-9451

Project:	GEA HT RAP	Batch:	
Lab ID:	1703019	Batch Size:	
Date Received:	16-Mar-17	Tested by:	Krystle Lynk
Date Tested:	27-Mar-17	Verified By:	Alissa Sinclair
Comments:	LAT 58-28 + 10% RAP		

	Test	Units	AASHTO Standard	Test Temperature (°C)	Results	Pass/Fail	Spec.
Original Binder	Flash Point (COC)	°C	T48			PASS	>230°C
	Penetration	0.1mm	T49	25	141.7		
	Specific Gravity		T228	15.6	1.033		
	Absolute Viscosity	Pa-s	T202	60	100.5		
	Rotational Viscosity	cP	T316	135	265	PASS	≤ 3000 cP
	DSR		T315				
	G*/sin(δ)	kPa		58	1.269	PASS	≥ 1.00 kPa @ 10 rad/s
				64	0.61	FAIL	
	Predicted Fail Temperature	°C			59.95		
RTFO Aged Binder	RTFO mass change	%	T240	163	-0.37	PASS	≤ 1.00%
	DSR:		T315				
	G*/sin(δ), kPa			58	3.082	PASS	≥ 2.20 kPa @ 10 rad/s
				64	1.448	FAIL	
	Predicted Fail Temperature	°C			60.68		
PAV Aged Binder	PAV Aging Temperature	°C	R28		100		
	DSR:		T315				
	G* x sin(δ), kPa			16	4649	PASS	≤ 5000 kPa @ 10 rad/s
				13	6758	FAIL	
	Predicted Fail Temperature	°C			15.38		
	BBR:		T313				
	Creep Stiffness (S)	Mpa		-18	183	PASS	≤300 Mpa @ 60s
				-24	352.5	FAIL	
	Predicted Fail Temperature	°C			-32.52		
	Slope (m)			-18	0.3505	PASS	≥ 0.30 @ 60s
				-24	0.2955	FAIL	
	Predicted Fail Temperature	°C			-33.51		

Target Grade	58-28
True Performance Grade	60.0-32.5
Performance Grade	58-28

AASHTO R18

Lafarge Asphalt Technologies, a division of Lafarge Canada Inc. is nationally accredited by AASHTO/AAP

Laboratory Report

Cloverbar Asphalt Binder Laboratory
12221 17st NE
Edmonton, AB T6S 1A7
Phone (780)472-9435 Fax (780)472-9451

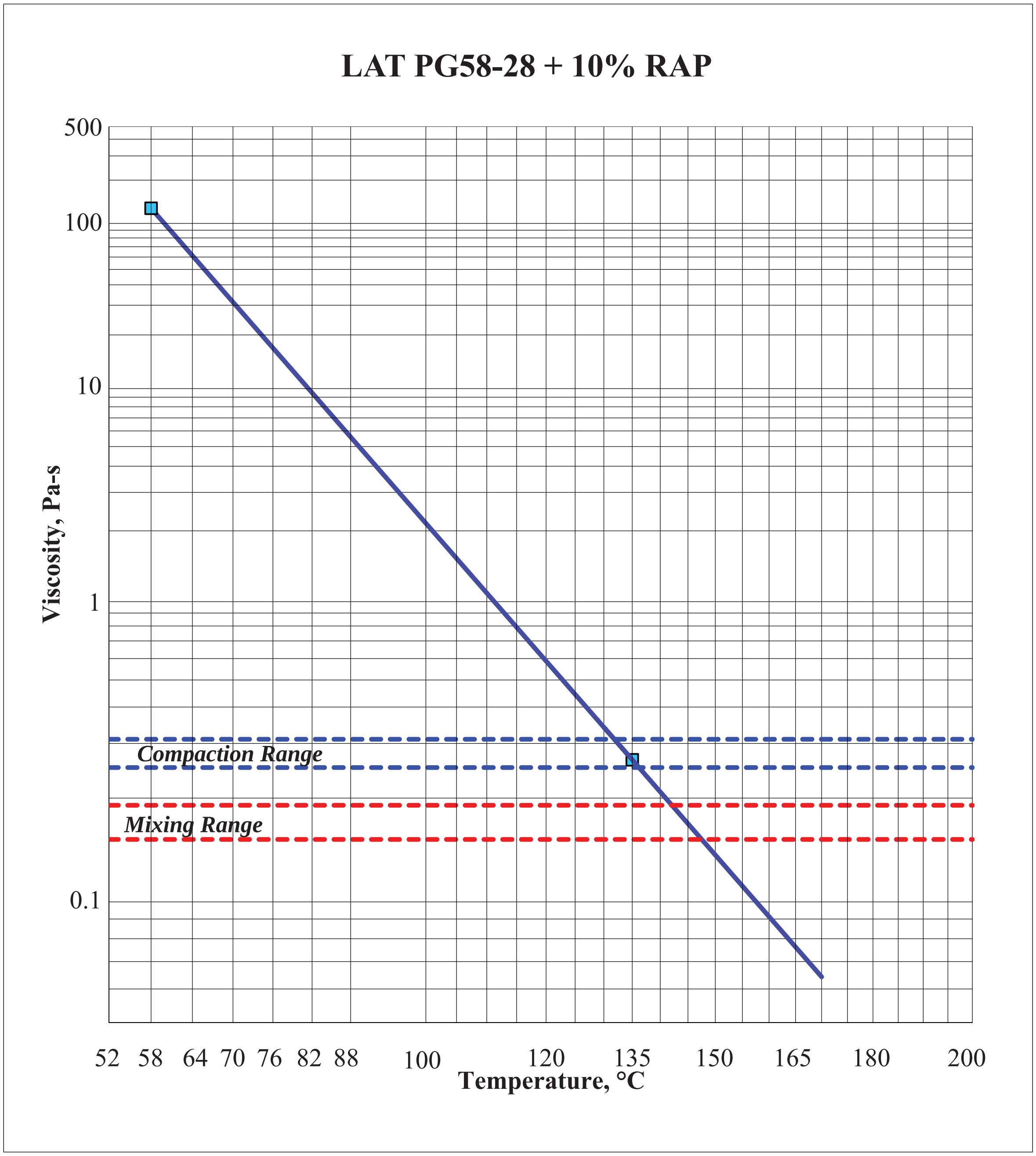
Project:	GEA HT RAP	Batch:	
Lab ID:	1703019	Batch Size:	
Date Received:	3/16/2017	Tested by:	Krystle Lynk
Date Tested:	3/27/2017	Verified By:	Alissa Sinclair
Comments:	LAT 58-28 + 10% RAP		

	Test	Units	AASHTO Standard	Test Temperature (°C)	Results	Pass/Fail	Spec.
RTFO Aged Binder	MSCR		TP 70	58			
	R100	%			5.768		
	R3200	%			1.34	PASS	≥ 40%
	Rdiff	%			76.77		
	Jnr0.1	kPa^{-1}			2.776		
	Jnr3.2	kPa^{-1}			3.141	PASS	≤ 4.5 kPa-1: S
	Jnrdiff	%			13.16		
PAV Aged Binder	DTT:		T314				
	Failure Strain	%		-18	0.67		≥ 1.00%
				-24	1.41		
	Failure Stress	MPa		-18	2.18		
				-24	6.12		
	Critical Cracking Temperature	°C			-33.10		

Target Grade	58-28
True Performance Grade (Table 1)	60.0-32.5
True Performance Grade (Table 2)	60.0-33.1
True Performance Grade (T 350)	58S-28
Performance Grade	58-28

Lafarge Asphalt Technologies, a division of Lafarge Canada Inc. is nationally accredited by AASHTO/AAP

Lafarge Ashalt Technologies
12221 17 St NE
Edmonton, AB T6S 1A7
Phone: (780) 472-9434 Fax: (780) 472-9451



Mixing Temperature Range	142°C	-	148°C
Compaction Temperature Range	132°C	-	136°C

INTEGRATED INFRASTRUCTURE SERVICES
Business Planning & Support
Engineering Services Section

City of Edmonton
11004 - 190 Street NW
Edmonton, AB T5S 0G9

edmonton.ca

March 21, 2017

Our File # 200.00.05

Mr. Bradley Maguire, E.I.T.
Lafarge Canada Inc.
11255 17 Street,
Edmonton, AB T6S 0A3

10mm- HT RAP Asphalt Mix
Rut Resistance Testing Using Asphalt Pavement Analyzer

Dear Mr. Maguire:

At the request of Lafarge Canada Inc., City of Edmonton, Engineering Services Section has prepared this report for permanent deformation (rutting) resistance testing using the Asphalt Pavement Analyzer (APA) for 10mm-HT RAP Asphalt Mix. Three sets of two asphalt concrete lab specimens were prepared by Lafarge Canada Inc. and delivered to City of Edmonton, Engineering Services Section Lab for rut resistance testing as per AASHTO T340 – 10.

TEST PROCEDURE AND RESULTS

Asphalt Pavement Analyzer

The Asphalt Pavement Analyzer (APA) is a multifunctional Loaded Wheel Tester (LWT) used for accelerated performance testing of asphalt concrete mixes. The APA features controllable wheel loads up to 1113 N and variable contact pressure. Pneumatic cylinders apply a repetitive load through a pressurized rubber hose to generate contact pressures up to 1378 kPa that are representative of actual field loading conditions. Calibration of the applied load, contact pressure and deformation measurement are built into the APA system and are computer controlled.

Triplicate beam samples or six cylindrical samples can be tested under controllable high temperatures and in dry or submerged (in water or other liquid) environments. Testing is completed in a microprocessor-controlled temperature chamber having a temperature range of 5°C to 71°C.

The Automated Data Acquisition System features software for measuring permanent deformation and fatigue and displaying the results in both numerical and graphical format. The APA includes a preconditioning chamber used to bring samples to the desired testing temperature.

Permanent Deformation (Rutting) Resistance Testing

The 150 mm diameter specimens were placed in the APA permanent deformation test moulds, and the testing of these specimen were carried out in accordance with the AASHTO T340-10 Standard Test Method. After placing three sets of test samples (six specimens) in the test chamber, the temperature of the chamber was adjusted to the test temperature of 52°C for 06 hours and then subjecting the specimens to repetitive wheel loads and measuring the amount of permanent deformation under the loaded wheel path. As specified, a test temperature of 52°C was adopted for this project as it is considered to be representative of the high temperature environment to which the paving mixtures will be subjected. In the APA, the vehicle loading (contact pressure) was simulated by rolling a concave metal wheel over a rubber hose pressurized at 690 kPa which is considered to be a typical heavy truck tire pressure. A load of 445 N was applied to the metal wheel. The sample was then subjected to 8,000 cycles (strokes) of loading, creating a rut (permanent deformation) in the sample. The rut depth was constantly monitored by a computer and displayed in both numerical and graphical format. A summary of the test results (the average deformation for each set of two sample) is provided in Table 1 and shown graphically in Figure 1

TABLE 1: SUMMARY OF APA RUTTING TEST RESULTS AND PHYSICAL PROPERTIES

Set #	Lab Sample ID	Bulk Relative Density (kg/m^3)	Air Voids (%)	Permanent Deformation (mm)
1	Lab Sample # 1 Lab Sample # 2	2275 2268	6.5 6.8	3.45
2	Lab Sample # 3 Lab Sample # 4	2272 2271	6.6 6.7	3.74
3	Lab Sample # 5 Lab Sample # 6	2275 2272	6.5 6.6	3.57

The overall average permanent deformation (rutting) measured in the APA for these samples are 3.6 mm. The current Standard Specifications of the City of Edmonton Roadways Construction requires that the average rut depth for the specimens tested using the APA shall not exceed 5.0 mm.

The results stated in Table 1 meet or exceed the requirements, as stated in the Contract Specifications of the City of Edmonton Roadways Construction Specifications

We trust that this report is satisfactory for your purposes. Please do not hesitate to contact me if you have any questions or require more information.

Faizal Kanji, P.Eng
Senior Research Engineer

Reviewed By: Hugh Donovan, P.Eng

Road Science™
Division of ArrMaz Custom Chemicals

AD-here® 77-00 BL

Description:
AD-here® 77-00 BL is an amine-based liquid anti-strip additive that is formulated to enhance asphalt-aggregate adhesion and significantly reduce moisture damage in hot and warm mix asphalt.

Product Attributes:
AD-here 77-00 BL is formulated to provide adhesion promotion with a broad range of asphalt and aggregate chemistries. In many mix designs, AD-here 77-00 BL is effective in increasing retained tensile strength ratio (TSR) and reducing moisture damage at dosage levels of 0.25-1.00% by weight of asphalt. The optimum dosage level for mix design is dependent on asphalt and aggregate properties and should be determined in laboratory trials.

Physical Properties:

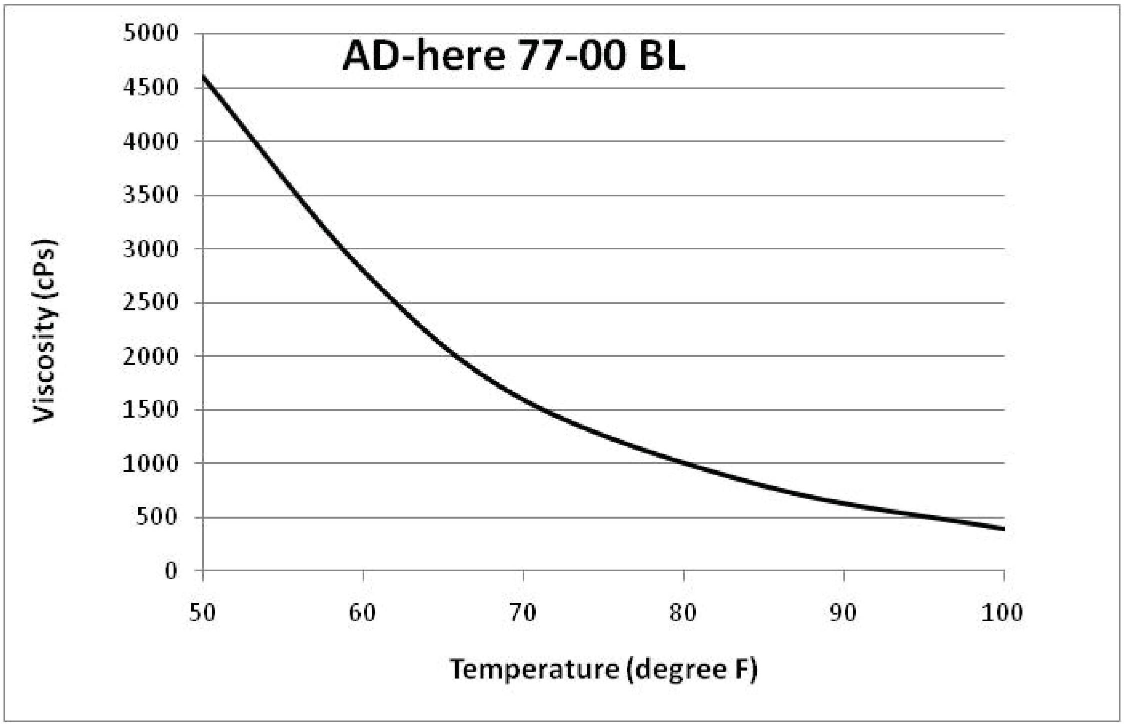
Appearance at 77°F	Brown Fluid
Viscosity at 77°F*	1200 cps
Specific Gravity at 77°F*	1.08

Availability:
AD-here 77-00 BL is available for immediate shipment in bulk, tote, or drum quantities.

Handling:
Always handle AD-here 77-00 BL in accordance with Materials Safety Data Sheet (MSDS) and proper safety procedures. Avoid product contamination with other materials.

**The data reported in this document are typical and not specifications. Typical ranges for specific gravity and viscosity values are ± 2 and ± 20%, respectively.*

AD-here® 77-00 BL



Additional Information:

To request additional product technical information or samples, contact a Road Science Representative at 877 354 1851.

ZA71770– July 2012

LAFARGE

Laboratory Report

Cloverbar Asphalt Binder Laboratory
12221 17st NE
Edmonton, AB T6S 1A7
Phone (780)472-9435 Fax (780)472-9451

Project:	LAT 58-28	Batch:	170108
Lab ID:	1701030	Batch Size:	
Date Received:	16-Jan-17	Tested by:	Krystle Lynk
Date Tested:	16-Jan-17	Verified By:	Alissa Sinclair
Comments:	Tank 3		

	Test	Units	AASHTO Standard	Test Temperature (°C)	Results	Pass/Fail	Spec.
Original Binder	Flash Point (COC)	°C	T48			PASS	>230°C
	Penetration	0.1mm	T49	25	164.9		
	Specific Gravity		T228	15.6	1.032		
	Absolute Viscosity	Pa-s	T202	60	104		
	Rotational Viscosity	cP	T316	135	264.6	PASS	≤ 3000 cP
	DSR		T315				
	G*/sin(δ)	kPa		58	1.121	PASS	≥ 1.00 kPa @ 10 rad/s
				64	0.5428	FAIL	
	Predicted Fail Temperature	°C			58.94		
RTFO Aged Binder	RTFO mass change	%	T240	163	-0.249	PASS	≤ 1.00%
	DSR:		T315				
	G*/sin(δ), kPa			58	2.487	PASS	≥ 2.20 kPa @ 10 rad/s
				64	1.173	FAIL	
	Predicted Fail Temperature	°C			58.98		
PAV Aged Binder	PAV Aging Temperature	°C	R28		100		
	DSR:		T315				
	G* x sin(δ), kPa				4158	PASS	≤ 5000 kPa @ 10 rad/s
					6024	FAIL	
	Predicted Fail Temperature	°C			14.49		
	BBR:		T313				
	Creep Stiffness (S)	Mpa		-18	163	PASS	≤300 Mpa @ 60s
				-24	358	FAIL	
	Predicted Fail Temperature	°C			-32.65		
	Slope (m)			-18	0.357	PASS	≥ 0.30 @ 60s
				-24	0.3015	FAIL	
	Predicted Fail Temperature	°C			-34.16		

Target Grade	58-28
True Performance Grade	58.9-32.7
Performance Grade	58-28

AAP® AASHTO R18

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Laboratory Report

Cloverbar Asphalt Binder Laboratory
12221 17st NE
Edmonton, AB T6S 1A7
Phone (780)472-9435 Fax (780)472-9451

Project:	LAT 58-28	Batch:	
Lab ID:	1701030	Batch Size:	
Date Received:	1/16/2017	Tested by:	Krystle Lynk
Date Tested:	1/16/2017	Verified By:	Alissa Sinclair
Comments:	Tank 3		

	Test	Units	AASHTO Standard	Test Temperature (°C)	Results	Pass/Fail	Spec.
RTFO Aged Binder	MSCR		TP 70	58			
	R100	%			3.264		
	R3200	%			0.8299	PASS	≥ 40%
	Rdiff	%			74.57		
	Jnr0.1	kPa^{-1}			3.609		
	Jnr3.2	kPa^{-1}			4.006	PASS	≤ 4.5 kPa-1: S
	Jnrdiff	%			10.99		
PAV Aged Binder	DTT:		T314				
	Failure Strain	%			2.90		≥ 1.00%
					1.34		
	Failure Stress	MPa			3.60		
					5.98		
	Critical Cracking Temperature	°C			-33.70		

Target Grade	58-28
True Performance Grade (Table 1)	58.9-32.7
True Performance Grade (Table 2)	58.9-33.7
True Performance Grade (T 350)	58S-28
Performance Grade	58-28

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14: RAP PG Results

Laboratory Report

Cloverbar Asphalt Binder Laboratory
12221 17st NE
Edmonton, AB T6S 1A7
Phone (780)472-9435 Fax (780)472-9451

Project:	GEA RAP	Batch:	170218
Lab ID:	1703031	Batch Size:	
Date Received:	24-Mar-17	Tested by:	Krystle Lynk
Date Tested:	27-Mar-17	Verified By:	Alissa Sinclair
Comments:			

	Test	Units	AASHTO Standard	Test Temperature (°C)	Results	Pass/Fail	Spec.
Original Binder	Flash Point (COC)	°C	T48			PASS	>230°C
	Penetration	0.1mm	T49	25	54.5		
	Specific Gravity		T228	15.6	1.055		
	Absolute Viscosity	Pa-s	T202	60	553		
	Rotational Viscosity	cP	T316	135	612.5	PASS	≤ 3000 cP
	DSR		T315				
	G*/sin(δ)	kPa		64	1.334	PASS	≥ 1.00 kPa @ 10 rad/s
				70	0.6669	FAIL	
	Predicted Fail Temperature	°C			72.49		
RTFO Aged Binder	RTFO mass change	%	T240	163	-0.842	PASS	≤ 1.00%
	DSR:		T315				
	G*/sin(δ), kPa			64	2.231	PASS	≥ 2.20 kPa @ 10 rad/s
				70	1.102	FAIL	
	Predicted Fail Temperature	°C			70.12		
PAV Aged Binder	PAV Aging Temperature	°C	R28		100		
	DSR:		T315				
	G* x sin(δ), kPa						≤ 5000 kPa @ 10 rad/s
	Predicted Fail Temperature	°C					
	BBR:		T313				
	Creep Stiffness (S)	Mpa		-18	160	PASS	≤300 Mpa @ 60s
				-24	385	FAIL	
	Predicted Fail Temperature	°C			-32.30		
	Slope (m)			-18	0.371	PASS	≥ 0.30 @ 60s
				-24	0.3025	FAIL	
	Predicted Fail Temperature	°C			-34.22		

Target Grade	N/A
True Performance Grade	70.1-32.3
Performance Grade	70-28

AASHTO R18

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Laboratory Report

Cloverbar Asphalt Binder Laboratory
12221 17st NE
Edmonton, AB T6S 1A7
Phone (780)472-9435 Fax (780)472-9451

Project:	GEA RAP	Batch:	
Lab ID:	1703031	Batch Size:	
Date Received:	3/24/2017	Tested by:	Krystle Lynk
Date Tested:	3/27/2017	Verified By:	Alissa Sinclair
Comments:	0		

	Test	Units	AASHTO Standard	Test Temperature (°C)	Results	Pass/Fail	Spec.
RTFO Aged Binder	MSCR		TP 70	58			
	R100	%			20.29		
	R3200	%			12.33		
	Rdiff	%			39.24		
	Jnr0.1	kPa^{-1}			0.6169		
	Jnr3.2	kPa^{-1}			0.6979	PASS	≤ 1.0 kPa-1: V
	Jnrdiff	%			13.14		
PAV Aged Binder	DTT:		T314				
	Failure Strain	%		-18	2.09		≥ 1.00%
				-24	1.17		
	Failure Stress	MPa		-18	3.89		
				-24	5.44		
	Critical Cracking Temperature	°C			-31.90		

Target Grade	N/A
True Performance Grade (Table 1)	70.1-32.3
True Performance Grade (Table 2)	70.1-31.9
True Performance Grade (T 350)	58V-28
Performance Grade	70-28

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APPENDIX C

TETRA TECH MIX CHARACTERIZATION

SUPERPAVE ASPHALT MIXTURE ANALYSIS REPORT

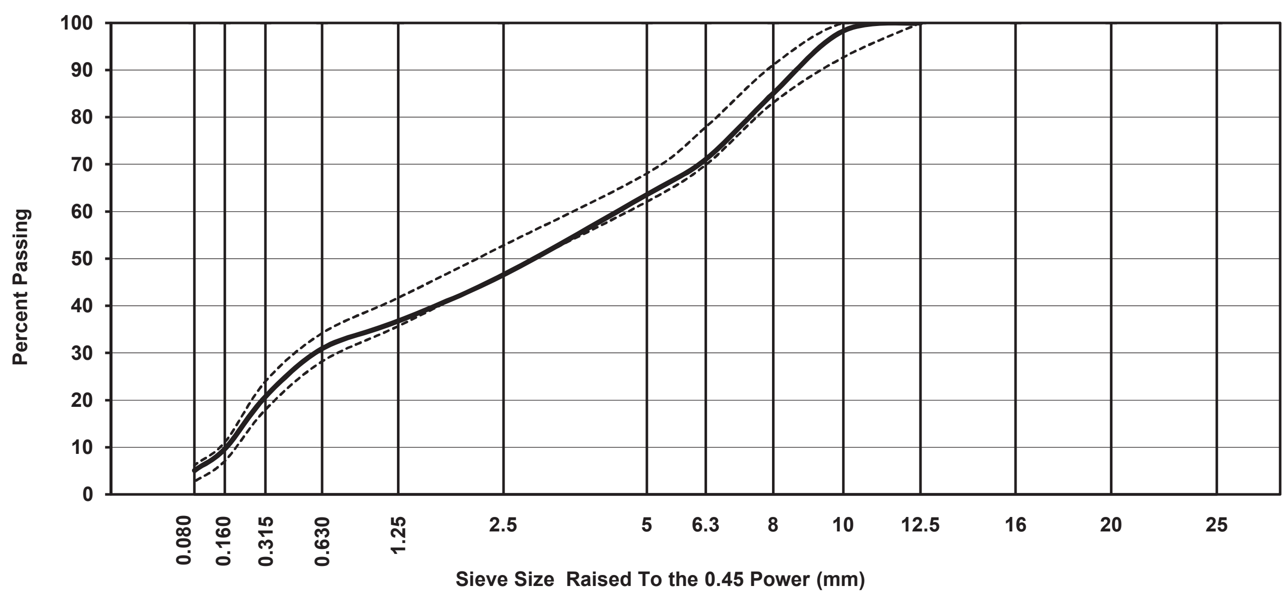
ASTM D6307, & C117, C136, D5821, D2726, D2041, D3203 & AASHTO T-312

Project:	Salt and Brine Impacts Study	Sample No.:	001
Project No.:	ENG.EMAT03571-01	Description:	City of Edmonton - 10 mm HT
Client:	City of Edmonton	Date Sampled:	17-Oct-18 09:05 AM
Supplier:	Lafarge Canada Inc.	Date Tested:	27-Nov-18
Contractor.:	N/A	Tested By:	SG
Sampled By:	R3	Mix Temp. (°C):	N/A
Location:	N/A	SGC Effort:	100 Gyrations

Property	Test Value	Specified Tolerance	Property	Test Value	Specified Tolerance
Asphalt Content (%, by mix):	5.36	5.20 - 5.80	Air Voids (%)	3.2	3.5 - 4.5
Fracture (%, 2+ faces):	100	90 min	V.M.A. (%)	14.6	
Bulk Relative Density	2.349	-	V.F.A. (%)	78.1	70 - 80
Maximum Relative Density:	2.427	-	Film Thickness (μm):	8.2	7.5 min

Percent Passing

Sieve Size (mm)	25	20	16	12.5	10	8	6.3	5	2.5	1.25	0.630	0.315	0.160	0.080
Job Mix Formula	100	100	100	100	98	87	74	65	50	39	31	21	10.1	5.2
Upper Tolerance Limit	100	100	100	100	100	91	78	68	53	42	34	24	11.1	6.2
Lower Tolerance Limit	100	100	100	100	93	83	70	62	47	36	28	18	7.1	2.7
Test Result	**100**	**100**	**100**	**100**	**98**	**85**	**71**	**64**	**47**	**37**	**31**	**21**	**10**	**5.1**



Remarks:

Testing Lab: 14940 - 123 Avenue, Edmonton, AB

Reviewed By: P.L.(Eng.)

TETRA TECH

SUPERPAVE ASPHALT MIXTURE ANALYSIS REPORT

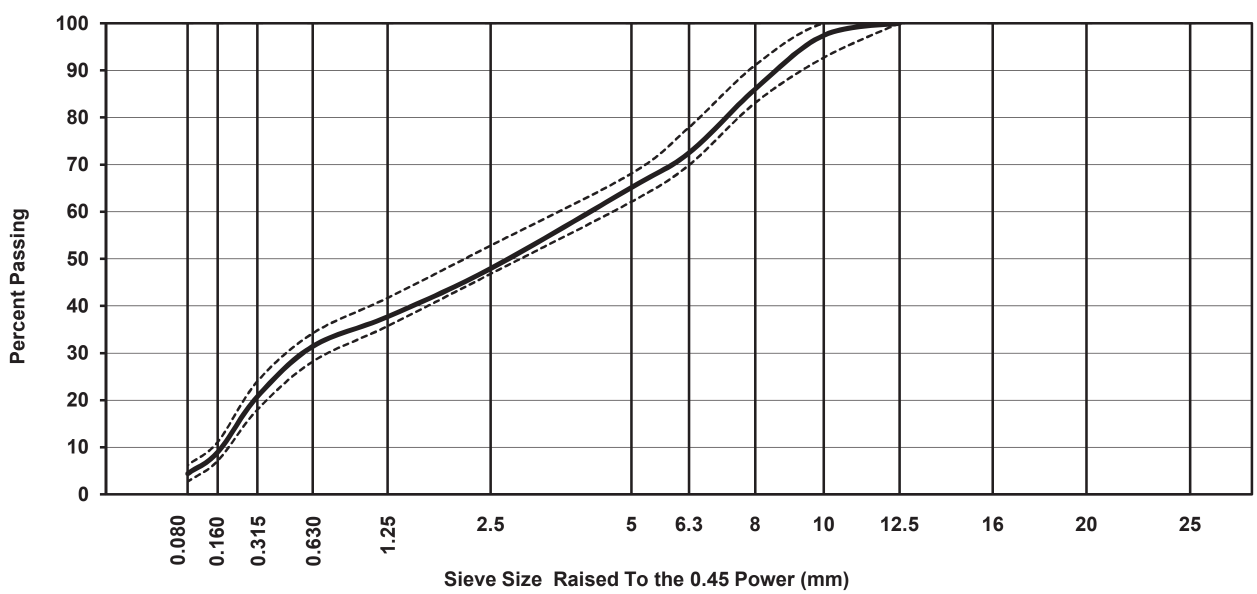
ASTM D6307, & C117, C136, D5821, D2726, D2041, D3203 & AASHTO T-312

Project:	Salt and Brine Impacts Study	Sample No.:	002
Project No.:	ENG.EMAT03571-01	Description:	City of Edmonton - 10 mm HT
Client:	City of Edmonton	Date Sampled:	17-Oct-18 09:05 AM
Supplier:	Lafarge Canada Inc.	Date Tested:	3-Dec-18
Contractor.:	N/A	Tested By:	SG, JG
Sampled By:	R3	Mix Temp. (°C):	N/A
Location:	N/A	SGC Effort:	100 Gyrations

Property	Test Value	Specified Tolerance	Property	Test Value	Specified Tolerance
Asphalt Content (%, by mix):	5.43	5.20 - 5.80	Air Voids (%)	3.4	3.5 - 4.5
Fracture (%, 2+ faces):	98	90 min	V.M.A. (%)	14.8	
Bulk Relative Density	2.344	-	V.F.A. (%)	77.1	70 - 80
Maximum Relative Density:	2.427	-	Film Thickness (μm):	8.6	7.5 min

Percent Passing

Sieve Size (mm)	25	20	16	12.5	10	8	6.3	5	2.5	1.25	0.630	0.315	0.160	0.080
Job Mix Formula	100	100	100	100	98	87	74	65	50	39	31	21	10.1	5.2
Upper Tolerance Limit	100	100	100	100	100	91	78	68	53	42	34	24	11.1	6.2
Lower Tolerance Limit	100	100	100	100	93	83	70	62	47	36	28	18	7.1	2.7
Test Result	**100**	**100**	**100**	**100**	**97**	**86**	**72**	**65**	**48**	**38**	**31**	**21**	**9**	**4.4**



Remarks:		Testing Lab:	14940 - 123 Avenue, Edmonton, AB
		Reviewed By:	P.L.(Eng.)

TETRA TECH

SUPERPAVE ASPHALT MIXTURE ANALYSIS REPORT

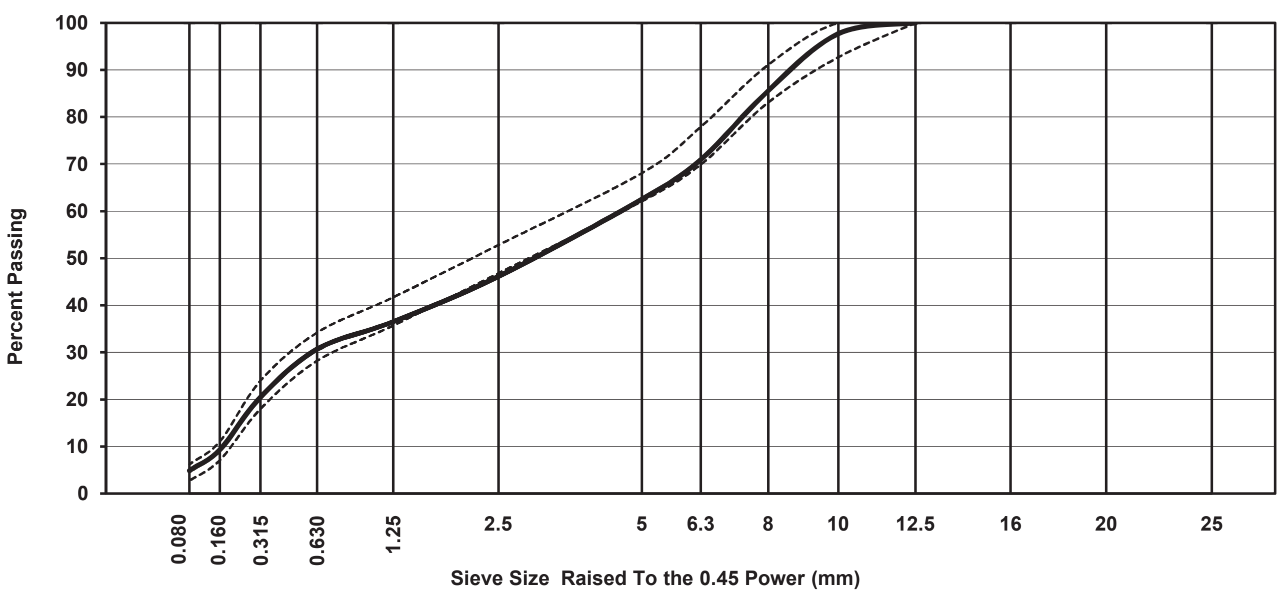
ASTM D6307, & C117, C136, D5821, D2726, D2041, D3203 & AASHTO T-312

Project:	Salt and Brine Impacts Study	Sample No.:	003
Project No.:	ENG.EMAT03571-01	Description:	City of Edmonton - 10 mm HT
Client:	City of Edmonton	Date Sampled:	17-Oct-18 09:05 AM
Supplier:	Lafarge Canada Inc.	Date Tested:	3-Dec-18
Contractor.:	N/A	Tested By:	SG, JG
Sampled By:	R3	Mix Temp. (°C):	N/A
Location:	N/A	SGC Effort:	100 Gyrations

Property	Test Value	Specified Tolerance	Property	Test Value	Specified Tolerance
Asphalt Content (%, by mix):	5.46	5.20 - 5.80	Air Voids (%)	3.3	3.5 - 4.5
Fracture (%, 2+ faces):	100	90 min	V.M.A. (%)	14.7	
Bulk Relative Density	2.348	-	V.F.A. (%)	77.5	70 - 80
Maximum Relative Density:	2.428	-	Film Thickness (µm):	8.4	7.5 min

Percent Passing

Sieve Size (mm)	25	20	16	12.5	10	8	6.3	5	2.5	1.25	0.630	0.315	0.160	0.080
Job Mix Formula	100	100	100	100	98	87	74	65	50	39	31	21	10.1	5.2
Upper Tolerance Limit	100	100	100	100	100	91	78	68	53	42	34	24	11.1	6.2
Lower Tolerance Limit	100	100	100	100	93	83	70	62	47	36	28	18	7.1	2.7
Test Result	**100**	**100**	**100**	**100**	**98**	**86**	**71**	**63**	**46**	**37**	**31**	**20**	**9**	**4.8**



Remarks:

Testing Lab: 14940 - 123 Avenue, Edmonton, AB

Reviewed By: ____________ P.L.(Eng.)

TETRA TECH

APPENDIX D

CANTABRO ABRASION TEST RESULTS

Cantabro Abrasion Test

ASTM D7064/D7064 - X2

Project:	City of Edmonton Brine Study	**Sample No.:**	NA
Client:	City of Edmonton	**Date Sampled:**	October 17, 2018
Project No.:	704-ENG.EMAT03571-01	**Sampled By:**	R3
Supplier:	Lafarge Canada Inc.	**Date Tested:**	Spring 2019
Mix Type:	10 mm - HT	**Lab Location:**	Edmonton, AB

Exposure	3 Cycles % Loss	5 Cycles % Loss	10 Cycles % Loss
NaCl	**6.5**	**8.0**	**6.7**
NaCl/$CaCl_2$ - 1	**6.2**	**7.1**	**8.7**
NaCl/$CaCl_2$ - 2	**5.4**	**4.7**	**5.8**
Distilled Water	**6.1**	**4.9**	**7.0**

Remarks: **NaCl** @ 24% concentration **NaCl/$CaCl_2$ - 1** - NaCl@ 24% concentration, $CaCl_2$ @ 27% concentration
NaCl/$CaCl_2$ - 2 - NaCl @ 12% concentration, $CaCl_2$ @ 14% concentration

Reviewed By: ____________________ P.L.(Eng.)

Table D-1: Cantabro Abrasion Test Results

Exposure	3 Cycle				5 Cycle				10 Cycle			
	Sample #	Weight Before (g)	Weight After (g)	Weight Loss (%)	Sample #	Weight Before (g)	Weight After (g)	Weight Loss (%)	Sample #	Weight Before (g)	Weight After (g)	Weight Loss (%)
NaCl	18	1200.1	1108.0	7.7	630	1208.8	1130.6	6.5	562	1206	1116.8	7.4
	2	1206.9	1142.6	5.3	627	1206.9	1099.2	8.9	540	1201.9	1128.8	6.1
	649	1205.5	1038.4	13.9	589	1205.9	1102.6	8.6	574	1209	1129.1	6.6
$NaCl/CaCl_2$ - 1	629	1212.7	1126.8	7.1	635	1212.1	1107.3	8.6	642	1218.9	1109	9.0
	575	1208.4	1149.9	4.8	505	1212.8	1130.9	6.8	637	1212.5	1098	9.4
	512	1209.0	1129.4	6.6	611	1215.0	1144.9	5.8	622	1213.5	1120	7.7
$NaCl/CaCl_2$ - 2	539	1196.6	1131	5.5	19	1204.2	1135.7	5.7	530	1206.8	1150.9	4.6
	529	1201.7	1142.4	4.9	563	1206.8	1144.1	5.2	536	1202.9	1120.4	6.9
	502	1202.7	1132.1	5.9	511	1205.9	1166	3.3	581	1210.6	1137.9	6.0
Distilled Water	564	1207.4	1145.8	5.1	549	1203.7	1150.3	4.4	547	1203.6	1141.7	5.1
	607	1202.1	1124.2	6.5	579	1204.6	1136.5	5.7	628	1211.3	1102.7	9.0
	527	1204.2	1121.8	6.8	514	1204.6	1147.4	4.7	516	1205.6	1123.5	6.8

NaCl @ 24% Concentration

$NaCl/CaCl_2$-1 @ 24% NaCl Concentration and 27% $CaCl_2$ Concentration

$NaCl/CaCl_2$-2 @ 12% NaCl Concentration and 14% $CaCl_2$ Concentration

Photo 1: Cantabro Test
Test results/samples for 3, 5, and 10 cycle exposure in NaCl solution

Photo 2: Cantabro Test
Test results/samples for 3, 5, and 10 cycle exposure in $NaCl/CaCl_2$-1 solution

Photo 3: Cantabro Test
Test results/samples for 3, 5, and 10 cycle exposure in NaCl/$CaCl_2$-2 solution

Photo 4: Cantabro Test
Test results/samples for 3, 5, and 10 cycle exposure in water solution

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Photo 5: Cantabro Test
Test results/samples in NaCl, NaCl/$CaCl_2$-1, NaCl/$CaCl_2$-2, and water solutions for 3-cycle exposure

Photo 6: Cantabro Test
Test results/samples in NaCl, NaCl/$CaCl_2$-1, NaCl/$CaCl_2$-2, and water solutions for 5-cycle exposure

Photo 7: Cantabro Test
Test results/samples in NaCl, NaCl/$CaCl_2$-1, NaCl/$CaCl_2$-2, and water solutions for 10-cycle exposure

APPENDIX E

MOISTURE SUSCEPTABILTY TEST RESULTS

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	April 10, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		610	524	16	506	507	585
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**66**	**64**	**66**	**67**	**66**	**66**
Dry Mass in Air, g	A	**1204.9**	**1197.6**	**1201.4**	**1203.4**	**1205.7**	**1198.9**
SSD Mass, g	B	**1210.9**	**1202.6**	**1208.9**	**1210.8**	**1212.4**	**1206.5**
Mass in Water, g	C	**678.1**	**675.1**	**673.9**	**678.5**	**681.3**	**672.8**
Volume, cc **(B-C)**	E	532.8	527.5	535.0	532.3	531.1	533.7
Bulk SG **(A ÷ E)**	F	2.261	2.270	2.246	2.261	2.270	2.246
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.86	6.49	7.51	6.89	6.50	7.48
Volume Air Voids **(HE/100)**	I	36.55	34.25	40.19	36.67	34.52	39.92
Average Air Voids, %			6.96			6.96	

Saturated Subset **					**Unconditioned (UCS)**		
SSD MASS, g	B'	**1233.2**	**1222.6**	**1229.9**	Cracked/Broken Aggregate?	< 5.0 mm	
Mass in Water, g	C'					> 5.0 mm	
Volume, cc (B'-C')	E'	1233.2	1222.6	1229.9	Notes:	506 - 1	
Vol Abs Water, cc **(B'-A)**	J'	28.3	25.0	28.5		507 - 1	
% Saturation **(100J'/I)**		77.43	72.98	70.91		585 - 1	
% Swell **(100(E'-E)÷E)**		131.46	131.77	129.89	Visual Moisture Damage (Stripping)	Coarse	1.0
Average Saturation, %			73.8			Fine	0.0
Average Swell, %			131.04		Rating (0 to 5) "5" being the most stripped		

Conditioned Subset					**Conditioned (CS)**		
Thickness, mm	t"	**66**	**64**	**66**	Cracked/Broken Aggregate?	< 5.0 mm	1.0%
SSD Mass, g	B"					> 5.0 mm	2.5%
Mass in Water, g	C"				Notes:		
Volume, cc **(B" - C")**	E"					610 - 0	
Vol Abs Water, cc **(B"- A)**	J"					524 - 1	
% Saturation **(100J"÷I)**						16 - 1	
% Swell **(100(E" - E)÷E)**					Visual Moisture Damage (Stripping)	Coarse	1.0
Average Saturation, %						Fine	0.0
Average Swell, %					Rating (0 to 5) "5" being the most stripped		

Tensile Strength

Load, N	P	**11008**	**10506**	**10966**	**11050**	**12761**	**13691**
Dry Strength **(2000P/(t*D*3.14)**	Std				1040.1	1219.3	1308.2
Wet Strength **(2000P/(t"*D*3.14)**	Stm	1051.8	1035.2	1047.8			

Average Dry Strength (kPa): **1189.2** **Average Wet Strength** (kPa): **1045.0** **TSR, %:** **87.9**

Remarks: NaCl Conditioned - 3 Cycle

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	April 10, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		522	1	513	640	653	9
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**66**	**65**	**66**	**66**	**65**	**65**
Dry Mass in Air, g	A	**1198.9**	**1202.8**	**1207.6**	**1201.9**	**1199.9**	**1197.9**
SSD Mass, g	B	**1205.5**	**1206.0**	**1215.1**	**1208.6**	**1205.9**	**1198.7**
Mass in Water, g	C	**675.5**	**675.9**	**677.9**	**677.0**	**677.4**	**665.6**
Volume, cc **(B-C)**	E	530.0	530.1	537.2	531.6	528.5	533.1
Bulk SG **(A ÷ E)**	F	2.262	2.269	2.248	2.261	2.270	2.247
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.83	6.55	7.42	6.88	6.49	7.45
Volume Air Voids **(HE/100)**	I	36.22	34.71	39.84	36.58	34.31	39.73
Average Air Voids, %			6.93			6.94	

Saturated Subset **				
SSD MASS, g	B'	**1227.5**	**1229.4**	**1236.1**
Mass in Water, g	C'			
Volume, cc (B'-C')	E'	1227.5	1229.4	1236.1
Vol Abs Water, cc **(B'-A)**	J'	28.6	26.6	28.5
% Saturation **(100J'/I)**		78.96	76.63	71.54
% Swell **(100(E'-E)÷E)**		131.60	131.92	130.10
Average Saturation, %			75.7	
Average Swell, %			131.21	

Unconditioned (UCS)		
Cracked/Broken Aggregate?	< 5.0 mm	1.0%
	> 5.0 mm	2.0%
Notes:	640 - 1	
	653 - 1	
	9 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Conditioned Subset				
Thickness, mm	t"	**66**	**65**	**66**
SSD Mass, g	B"			
Mass in Water, g	C"			
Volume, cc **(B" - C")**	E"			
Vol Abs Water, cc **(B"- A)**	J"			
% Saturation **(100J"÷I)**				
% Swell **(100(E" - E)÷E)**				
Average Saturation, %				
Average Swell, %			#DIV/0!	

Conditioned (CS)		
Cracked/Broken Aggregate?	< 5.0 mm	1.0%
	> 5.0 mm	2.5%
Notes:		
	522 - 1	
	1 - 1	
	513 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Tensile Strength							
Load, N	P	**11050**	**11343**	**10882**	**15058**	**12133**	**12009**
Dry Strength **(2000P/(t*D*3.14)**	Std				1438.8	1177.2	1165.1
Wet Strength **(2000P/(t"*D*3.14)**	Stm	1055.8	1100.5	1039.8			

Average Dry Strength (kPa): **1260.4** **Average Wet Strength** (kPa): **1065.4** **TSR, %:** **84.5**

Remarks: NaCl/CaCl_2 - 1 Conditioned - 3 Cycle

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	April 10, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		**561**	**596**	**526**	**543**	**568**	**29**
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**66**	**65**	**66**	**65**	**65**	**66**
Dry Mass in Air, g	A	**1198.1**	**1199.0**	**1199.6**	**1196.3**	**1202.3**	**1191.0**
SSD Mass, g	B	**1204.5**	**1204.9**	**1206.6**	**1200.7**	**1207.3**	**1206.3**
Mass in Water, g	C	**674.9**	**676.5**	**673.1**	**671.9**	**677.4**	**676.5**
Volume, cc **(B-C)**	E	529.6	528.4	533.5	528.8	529.9	529.8
Bulk SG **(A ÷ E)**	F	2.262	2.269	2.249	2.262	2.269	2.248
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.83	6.54	7.39	6.82	6.55	7.41
Volume Air Voids **(HE/100)**	I	36.15	34.58	39.43	36.09	34.72	39.27
Average Air Voids, %			6.92			6.93	

Saturated Subset **				
SSD MASS, g	B'	**1224.7**	**1223.3**	**1229.7**
Mass in Water, g	C'			
Volume, cc (B'-C')	E'	1224.7	1223.3	1229.7
Vol Abs Water, cc **(B'-A)**	J'	26.6	24.3	30.1
% Saturation **(100J'/I)**		73.59	70.28	76.34
% Swell **(100(E'-E)÷E)**		131.25	131.51	130.50
Average Saturation, %			73.4	
Average Swell, %			131.09	

Unconditioned (UCS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:	543 - 1	
	568 - 1	
	29 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Conditioned Subset				
Thickness, mm	t"	**66**	**65**	**66**
SSD Mass, g	B"			
Mass in Water, g	C"			
Volume, cc **(B" - C")**	E"			
Vol Abs Water, cc **(B"- A)**	J"			
% Saturation **(100J"÷I)**				
% Swell **(100(E" - E)÷E)**				
Average Saturation, %				
Average Swell, %				

Conditioned (CS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:		
	561 - 1	
	596 - 1	
	526 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Tensile Strength							
Load, N	P	**9793**	**10924**	**10380**	**12383**	**11175**	**11133**
Dry Strength **(2000P/(t*D*3.14)**	Std				1201.4	1084.2	1063.8
Wet Strength **(2000P/(t"*D*3.14)**	Stm	935.7	~~1059.9~~	991.8			

Average Dry Strength (kPa): **1116.5** **Average Wet Strength** (kPa): **963.8** **TSR, %:** **86.3**

Remarks: NaCl/CaCl$_2$ -2 Conditioned - 3 Cycle
Sample #596 with the outlier value of 1059.9 kPa was excluded in the TSR calculation, the final TSR was calculated using 2 conditioned and 3 unconditioned samples.

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	April 10, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		**597**	**644**	**623**	**571**	**609**	**523**
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**66**	**65**	**66**	**67**	**66**	**65**
Dry Mass in Air, g	A	**1197.7**	**1202.7**	**1199.4**	**1202.3**	**1198.5**	**1195.8**
SSD Mass, g	B	**1205.7**	**1210.1**	**1203.7**	**1208.9**	**1204.7**	**1201.9**
Mass in Water, g	C	**676.1**	**680.0**	**670.9**	**677.4**	**676.4**	**670.5**
Volume, cc **(B-C)**	E	529.6	530.1	532.8	531.5	528.3	531.4
Bulk SG **(A ÷ E)**	F	2.262	2.269	2.251	2.262	2.269	2.250
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.86	6.56	7.28	6.83	6.57	7.32
Volume Air Voids **(HE/100)**	I	36.31	34.75	38.81	36.32	34.68	38.90
Average Air Voids, %			6.90			6.91	

Saturated Subset **				
SSD MASS, g	B'	**1225.0**	**1228.5**	**1227.9**
Mass in Water, g	C'			
Volume, cc (B'-C')	E'	1225.0	1228.5	1227.9
Vol Abs Water, cc **(B'-A)**	J'	27.3	25.8	28.5
% Saturation **(100J'/I)**		75.18	74.24	73.43
% Swell **(100(E'-E)÷E)**		131.31	131.75	130.46
Average Saturation, %			74.3	
Average Swell, %			131.17	

Unconditioned (UCS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:	571 - 1	
	609 - 1	
	523 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Conditioned Subset				
Thickness, mm	t"	**66**	**65**	**66**
SSD Mass, g	B"			
Mass in Water, g	C"			
Volume, cc **(B" - C")**	E"			
Vol Abs Water, cc **(B"- A)**	J"			
% Saturation **(100J"÷I)**				
% Swell **(100(E" - E)÷E)**				
Average Saturation, %				
Average Swell, %				

Conditioned (CS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:		
	597 - 1	
	644 - 1	
	623 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Tensile Strength							
Load, N	P	**10924**	**11676**	**9877**	**11967**	**12973**	**11843**
Dry Strength **(2000P/(t*D*3.14)**	Std				1126.4	1239.6	1149.0
Wet Strength **(2000P/(t"*D*3.14)**	Stm	1043.8	1132.8	943.8			

Average Dry Strength (kPa): **1171.7** **Average Wet Strength** (kPa): **1040.1** **TSR, %:** **88.8**

Remarks: Water Conditioned - 3 Cycle

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	April 20, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		634	652	7	632	638	587
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**66**	**65**	**65**	**66**	**66**	**66**
Dry Mass in Air, g	A	**1197.6**	**1200.7**	**1197.4**	**1196.2**	**1205.7**	**1198.9**
SSD Mass, g	B	**1203.8**	**1206.6**	**1200.7**	**1203.3**	**1212.4**	**1206.5**
Mass in Water, g	C	**674.3**	**676.8**	**668.8**	**674.4**	**681.3**	**672.8**
Volume, cc **(B-C)**	E	529.5	529.8	531.9	528.9	531.1	533.7
Bulk SG **(A ÷ E)**	F	2.262	2.266	2.251	2.262	2.270	2.246
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.85	6.66	7.28	6.85	6.50	7.48
Volume Air Voids **(HE/100)**	I	36.25	35.28	38.74	36.23	34.52	39.92
Average Air Voids, %			6.93			6.94	
Saturated Subset **					**Unconditioned (UCS)**		
SSD MASS, g	B'	**1224.0**	**1228.7**	**1224.8**	Cracked/Broken Aggregate?	< 5.0 mm	
Mass in Water, g	C'					> 5.0 mm	
Volume, cc (B'-C')	E'	1224.0	1228.7	1224.8	Notes:	632 - 1	
Vol Abs Water, cc **(B'-A)**	J'	26.4	28.0	27.4		638 - 1	
% Saturation **(100J'/I)**		72.82	79.37	70.73		587 - 1	
% Swell **(100(E'-E)÷E)**		131.16	131.92	130.27	Visual Moisture Damage (Stripping)	Coarse	1.0
Average Saturation, %			74.3			Fine	0.0
Average Swell, %			131.12		Rating (0 to 5) "5" being the most stripped		
Conditioned Subset					**Conditioned (CS)**		
Thickness, mm	t"	**66**	**65**	**65**	Cracked/Broken Aggregate?	< 5.0 mm	
SSD Mass, g	B"					> 5.0 mm	
Mass in Water, g	C"				Notes:		
Volume, cc **(B" - C")**	E"					634 - 1	
Vol Abs Water, cc **(B"- A)**	J"					652 - 1	
% Saturation **(100J"÷I)**						7 - 1	
% Swell **(100(E" - E)÷E)**					Visual Moisture Damage (Stripping)	Coarse	1.0
Average Saturation, %						Fine	0.0
Average Swell, %					Rating (0 to 5) "5" being the most stripped		
Tensile Strength							
Load, N	P	**10464**	**9835**	**9919**	**13355**	**14512**	**14931**
Dry Strength **(2000P/(t*D*3.14)**	Std				1276.1	1386.6	1426.7
Wet Strength **(2000P/(t"*D*3.14)**	Stm	999.8	954.2	962.4			

Average Dry Strength (kPa): **1363.1** **Average Wet Strength** (kPa): **972.1** **TSR, %:** **71.3**

Remarks: NaCl Conditioned - 5 Cycle

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	April 20, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		641	556	521	636	525	554
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**67**	**64**	**67**	**65**	**67**	**67**
Dry Mass in Air, g	A	**1199.9**	**1197.2**	**1200.9**	**1201.6**	**1199.0**	**1199.7**
SSD Mass, g	B	**1208.6**	**1202.3**	**1207.3**	**1208.0**	**1206.8**	**1205.9**
Mass in Water, g	C	**678.1**	**674.4**	**674.0**	**676.9**	**678.1**	**673.2**
Volume, cc **(B-C)**	E	530.5	527.9	533.3	531.1	528.7	532.7
Bulk SG **(A ÷ E)**	F	2.262	2.268	2.252	2.262	2.268	2.252
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.84	6.60	7.26	6.82	6.60	7.24
Volume Air Voids **(HE/100)**	I	36.31	34.82	38.70	36.21	34.88	38.59
Average Air Voids, %			6.90			6.89	

Saturated Subset **				
SSD MASS, g	B'	**1228.8**	**1223.8**	**1230.1**
Mass in Water, g	C'			
Volume, cc (B'-C')	E'	1228.8	1223.8	1230.1
Vol Abs Water, cc **(B'-A)**	J'	28.9	26.6	29.2
% Saturation **(100J'/I)**		79.60	76.39	75.46
% Swell **(100(E'-E)÷E)**		131.63	131.82	130.66
Average Saturation, %			77.2	
Average Swell, %			131.37	

Unconditioned (UCS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:	636 - 1	
	525 - 1	
	554 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Conditioned Subset				
Thickness, mm	t"	**67**	**64**	**67**
SSD Mass, g	B"			
Mass in Water, g	C"			
Volume, cc **(B" - C")**	E"			
Vol Abs Water, cc **(B"- A)**	J"			
% Saturation **(100J"÷I)**				
% Swell **(100(E" - E)÷E)**				
Average Saturation, %				
Average Swell, %				

Conditioned (CS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:		
	641 - 1	
	556 - 1	
	521 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Tensile Strength		641	556	521	636	525	554
Load, N	P	**12761**	**9877**	**7447**	**14348**	**12217**	**11133**
Dry Strength **(2000P/(t*D*3.14)**	Std				1392.1	1149.9	1047.9
Wet Strength **(2000P/(t"*D*3.14)**	Stm	1201.1	973.2	~~700.9~~			

Average Dry Strength (kPa): **1196.6** **Average Wet Strength** (kPa): **1087.2** **TSR, %:** **90.9**

Remarks: $NaCl/CaCl_2$ - 1 Conditioned - 5 Cycle
Sample #521 with the outlier value of 700.9 kPa was excluded in the TSR calculation, the final TSR was calculated using 2 conditioned and 3 unconditioned samples.

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	April 20, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		**537**	**573**	**570**	**510**	**567**	**639**
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**65**	**66**	**66**	**65**	**67**	**65**
Dry Mass in Air, g	A	**1197.2**	**1203.4**	**1200.6**	**1202.1**	**1224.7**	**1202.9**
SSD Mass, g	B	**1202.8**	**1207.7**	**1206.6**	**1208.8**	**1229.6**	**1210.8**
Mass in Water, g	C	**673.1**	**677.0**	**673.7**	**677.0**	**689.6**	**676.9**
Volume, cc **(B-C)**	E	529.7	530.7	532.9	531.8	540.0	533.9
Bulk SG **(A ÷ E)**	F	2.260	2.268	2.253	2.260	2.268	2.253
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.91	6.61	7.21	6.90	6.59	7.21
Volume Air Voids **(HE/100)**	I	36.62	35.07	38.42	36.70	35.59	38.47
Average Air Voids, %			6.91			6.90	

Saturated Subset **				
SSD MASS, g	B'	**1223.3**	**1231.2**	**1228.4**
Mass in Water, g	C'			
Volume, cc (B'-C')	E'	1223.3	1231.2	1228.4
Vol Abs Water, cc **(B'-A)**	J'	26.1	27.8	27.8
% Saturation **(100J'/I)**		71.27	79.28	72.36
% Swell **(100(E'-E)÷E)**		130.94	132.00	130.51
Average Saturation, %			74.3	
Average Swell, %			131.15	

Unconditioned (UCS)		
Cracked/Broken Aggregate?	< 5.0 mm	0.0%
	> 5.0 mm	2.0%
Notes:	510 - 1	
	567 - 1	
	639 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Conditioned Subset				
Thickness, mm	t"	**65**	**66**	**66**
SSD Mass, g	B"			
Mass in Water, g	C"			
Volume, cc **(B" - C")**	E"			
Vol Abs Water, cc **(B"- A)**	J"			
% Saturation **(100J"÷I)**				
% Swell **(100(E" - E)÷E)**				
Average Saturation, %				
Average Swell, %				

Conditioned (CS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:		
	537 - 1	
	573 - 1	
	570 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Tensile Strength							
Load, N	P	**10128**	**9919**	**9835**	**12175**	**11385**	**13691**
Dry Strength **(2000P/(t*D*3.14)**	Std				1181.2	1071.6	~~1328.3~~
Wet Strength **(2000P/(t"*D*3.14)**	Stm	982.6	947.8	939.7			

Average Dry Strength (kPa): **1126.4** **Average Wet Strength** (kPa): **956.7** **TSR, %:** **84.9**

Remarks: NaCl/$CaCl_2$ - 2 Conditioned - 5 Cycle
Sample #639 with the outlier value of 1328.3 kPa was excluded in the TSR calculation, the final TSR was calculated using 3 conditioned and 2 unconditioned samples.

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	April 20, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		559	519	584	557	583	503
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**65**	**67**	**66**	**66**	**65**	**67**
Dry Mass in Air, g	A	**1200.4**	**1199.8**	**1199.1**	**1202.9**	**1200.8**	**1204.9**
SSD Mass, g	B	**1205.6**	**1205.2**	**1206.8**	**1209.2**	**1207.9**	**1215.3**
Mass in Water, g	C	**674.4**	**675.9**	**674.8**	**677.0**	**678.4**	**680.6**
Volume, cc **(B-C)**	E	531.2	529.3	532.0	532.2	529.5	534.7
Bulk SG **(A ÷ E)**	F	2.260	2.267	2.254	2.260	2.268	2.253
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.93	6.64	7.17	6.91	6.60	7.19
Volume Air Voids **(HE/100)**	I	36.80	35.15	38.14	36.77	34.94	38.45
Average Air Voids, %			6.91			6.90	

Saturated Subset **					Unconditioned (UCS)		
SSD MASS, g	B'	**1226.2**	**1225.3**	**1226.0**	Cracked/Broken Aggregate?	< 5.0 mm	
Mass in Water, g	C'					> 5.0 mm	
Volume, cc (B'-C')	E'	1226.2	1225.3	1226.0	Notes:	557 - 1	
Vol Abs Water, cc **(B'-A)**	J'	25.8	25.5	26.9		583 - 1	
% Saturation **(100J'/I)**		70.11	72.55	70.54		503 - 1	
% Swell **(100(E'-E)÷E)**		130.84	131.49	130.45	Visual Moisture Damage (Stripping)	Coarse	1.0
Average Saturation, %			71.1			Fine	0.0
Average Swell, %			130.93		Rating (0 to 5) "5" being the most stripped		

Conditioned Subset					Conditioned (CS)		
Thickness, mm	t"	**65**	**67**	**66**	Cracked/Broken Aggregate?	< 5.0 mm	0.0%
SSD Mass, g	B"					> 5.0 mm	2.5%
Mass in Water, g	C"				Notes:		
Volume, cc **(B" - C")**	E"					559 - 1	
Vol Abs Water, cc **(B"- A)**	J"					519 - 1	
% Saturation **(100J"÷I)**						584 - 1	
% Swell **(100(E" - E)÷E)**					Visual Moisture Damage (Stripping)	Coarse	1.0
Average Saturation, %						Fine	0.0
Average Swell, %					Rating (0 to 5) "5" being the most stripped		

Tensile Strength							
Load, N	P	**9499**	**10464**	**10380**	**12676**	**14266**	**12300**
Dry Strength **(2000P/(t*D*3.14)**	Std				1211.2	1384.1	1157.7
Wet Strength **(2000P/(t"*D*3.14)**	Stm	921.6	984.9	991.8			

Average Dry Strength (kPa): **1251.0** **Average Wet Strength** (kPa): **966.1** **TSR, %:** **77.2**

Remarks: Water - Conditioned - 5 Cycle

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	May 8, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		633	612	3	626	572	552
Diameter, mm	D	101	101	101	101	101	101
Thickness, mm	t	66	67	64	65	64	65
Dry Mass in Air, g	A	1200.7	1199.3	1200.0	1198.1	1201.3	1200.7
SSD Mass, g	B	1208.4	1205.0	1202.7	1204.8	1205.2	1206.6
Mass in Water, g	C	677.1	675.6	670.2	674.7	675.4	673.8
Volume, cc **(B-C)**	E	531.3	529.4	532.5	530.1	529.8	532.8
Bulk SG **(A ÷ E)**	F	2.260	2.265	2.254	2.260	2.267	2.254
Maximum SG	G	2.428	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.92	6.70	7.19	6.91	6.61	7.18
Volume Air Voids **(HE/100)**	I	36.78	35.45	38.27	36.65	35.03	38.28
Average Air Voids, %			6.94			6.90	

Saturated Subset **				
SSD MASS, g	B'	1228.9	1226.5	1230.0
Mass in Water, g	C'			
Volume, cc (B'-C')	E'	1228.9	1226.5	1230.0
Vol Abs Water, cc **(B'-A)**	J'	28.2	27.2	30.0
% Saturation **(100J'/I)**		76.68	76.72	78.40
% Swell **(100(E'-E)÷E)**		131.30	131.68	130.99
Average Saturation, %			77.3	
Average Swell, %			131.32	

Unconditioned (UCS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:	626 - 1	
	572 - 1	
	552 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Conditioned Subset				
Thickness, mm	t"	66	65	65
SSD Mass, g	B"			
Mass in Water, g	C"			
Volume, cc **(B" - C")**	E"			
Vol Abs Water, cc **(B"- A)**	J"			
% Saturation **(100J"÷I)**				
% Swell **(100(E" - E)÷E)**				
Average Saturation, %				
Average Swell, %				

Conditioned (CS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:		
	633 - 1	
	612 - 1	
	3 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Tensile Strength		633	612	3	626	572	552
Load, N	P	10757	11259	7575	12133	11593	11801
Dry Strength **(2000P/(t*D*3.14)**	Std				1177.2	1142.3	1144.9
Wet Strength **(2000P/(t"*D*3.14)**	Stm	1027.8	1092.4	~~734.9~~			

Average Dry Strength (kPa): 1154.8 **Average Wet Strength** (kPa): 1060.1 **TSR, %:** 91.8

Remarks: NaCl Conditioned - 10 Cycle
Sample #3 with the outlier value of 734.9 kPa was excluded from the TSR calculation.
the final TSR was calculated using 2 conditioned and 3 unconditioned samples.

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	May 8, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		535	595	545	17	531	621
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**66**	**66**	**66**	**66**	**66**	**66**
Dry Mass in Air, g	A	**1201.2**	**1198.5**	**1196.6**	**1195.8**	**1199.9**	**1199.2**
SSD Mass, g	B	**1204.9**	**1204.5**	**1201.7**	**1203.3**	**1205.4**	**1204.3**
Mass in Water, g	C	**674.1**	**675.6**	**671.1**	**674.8**	**675.9**	**672.5**
Volume, cc **(B-C)**	E	530.8	528.9	530.6	528.5	529.5	531.8
Bulk SG **(A ÷ E)**	F	2.263	2.266	2.255	2.263	2.266	2.255
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.80	6.67	7.12	6.81	6.67	7.13
Volume Air Voids **(HE/100)**	I	36.07	35.28	37.77	36.00	35.31	37.90
Average Air Voids, %			6.86			6.87	

Saturated Subset **				
SSD MASS, g	B'	**1228.2**	**1226.1**	**1224.4**
Mass in Water, g	C'			
Volume, cc (B'-C')	E'	1228.2	1226.1	1224.4
Vol Abs Water, cc **(B'-A)**	J'	27.0	27.6	27.8
% Saturation **(100J'/I)**		74.85	78.22	73.61
% Swell **(100(E'-E)÷E)**		131.39	131.82	130.76
Average Saturation, %			75.6	
Average Swell, %			131.32	

Unconditioned (UCS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:	17 - 1	
	531 - 1	
	621 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Conditioned Subset				
Thickness, mm	t"	**67**	**64**	**67**
SSD Mass, g	B"			
Mass in Water, g	C"			
Volume, cc **(B" - C")**	E"			
Vol Abs Water, cc **(B"- A)**	J"			
% Saturation **(100J"÷I)**				
% Swell **(100(E" - E)÷E)**				
Average Saturation, %				
Average Swell, %				

Conditioned (CS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:		
	535 - 1	
	595 - 1	
	545 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Tensile Strength							
Load, N	P	**9330**	**11884**	**10547**	**9961**	**9919**	**13185**
Dry Strength **(2000P/(t*D*3.14)**	Std				951.8	947.8	1259.8
Wet Strength **(2000P/(t"*D*3.14)**	Stm	878.2	1171.0	992.7			

Average Dry Strength (kPa): **1053.1** **Average Wet Strength** (kPa): **1014.0** **TSR, %:** **96.3**

Remarks: NaCl/$CaCl_2$ - 1 Conditioned - 10 Cycle

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	May 8, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		624	533	620	569	501	504
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**66**	**65**	**66**	**66**	**66**	**65**
Dry Mass in Air, g	A	**1200.1**	**1195.9**	**1199.9**	**1203.3**	**1199.7**	**1203.6**
SSD Mass, g	B	**1207.4**	**1201.4**	**1205.6**	**1209.9**	**1204.2**	**1211.1**
Mass in Water, g	C	**677.1**	**673.4**	**673.7**	**678.1**	**674.6**	**677.4**
Volume, cc **(B-C)**	E	530.3	528.0	531.9	531.8	529.6	533.7
Bulk SG **(A ÷ E)**	F	2.263	2.265	2.256	2.263	2.265	2.255
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.79	6.71	7.09	6.81	6.70	7.12
Volume Air Voids **(HE/100)**	I	36.02	35.45	37.71	36.21	35.49	37.98
Average Air Voids, %			6.87			6.88	

Saturated Subset **				
SSD MASS, g	B'	**1228.6**	**1222.4**	**1227.7**
Mass in Water, g	C'			
Volume, cc (B'-C')	E'	1228.6	1222.4	1227.7
Vol Abs Water, cc **(B'-A)**	J'	28.5	26.5	27.8
% Saturation **(100J'/I)**		79.11	74.74	73.73
% Swell **(100(E'-E)÷E)**		131.68	131.52	130.81
Average Saturation, %			75.9	
Average Swell, %			131.34	

Conditioned Subset				
Thickness, mm	t"	**66**	**65**	**66**
SSD Mass, g	B"			
Mass in Water, g	C"			
Volume, cc **(B" - C")**	E"			
Vol Abs Water, cc **(B"- A)**	J"			
% Saturation **(100J"÷I)**				
% Swell **(100(E" - E)÷E)**				
Average Saturation, %				
Average Swell, %				

Unconditioned (UCS)		
Cracked/Broken Aggregate?	< 5.0 mm	0.0%
	> 5.0 mm	2.0%
Notes:	569 - 1	
	501 - 1	
	504 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Conditioned (CS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
Notes:		
	624 - 1	
	533 - 1	
	620 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Tensile Strength							
Load, N	P	**11217**	**9625**	**10547**	**13228**	**8987**	**11050**
Dry Strength **(2000P/(t*D*3.14)**	Std				1263.9	858.7	1072.1
Wet Strength **(2000P/(t"*D*3.14)**	Stm	1071.8	933.8	1007.8			

Average Dry Strength (kPa): 1064.9 **Average Wet Strength** (kPa): 1004.5 **TSR, %:** 94.3

Remarks: NaCl/$CaCl_2$ - 2 Conditioned - 10 Cycle

RESISTANCE OF COMPACTED ASPHALT MIXTURES to MOISTURE-INDUCED DAMAGE

AASHTO Designation T 283, Tensile Strength Ratio (TSR)

Project:	Brine Study	Mix Type:	10 mm HT
Project No.:	ENG.EMAT03571-01	Date Tested:	May 8, 2019
Client:	City of Edmonton	Tested By:	Tetra Tech Edmonton

Sample		565	560	551	544	541	565
Diameter, mm	D	**101**	**101**	**101**	**101**	**101**	**101**
Thickness, mm	t	**66**	**67**	**65**	**67**	**65**	**66**
Dry Mass in Air, g	A	**1200.1**	**1200.1**	**1203.4**	**1197.6**	**1195.9**	**1200.1**
SSD Mass, g	B	**1206.2**	**1207.0**	**1208.3**	**1202.1**	**1201.6**	**1206.2**
Mass in Water, g	C	**675.0**	**677.1**	**674.9**	**671.9**	**673.6**	**675.0**
Volume, cc **(B-C)**	E	531.2	529.9	533.4	530.2	528.0	531.2
Bulk SG **(A ÷ E)**	F	2.259	2.265	2.256	2.259	2.265	2.259
Maximum SG	G	**2.428**	2.428	2.428	2.428	2.428	2.428
% Air Voids **(100(G - F)÷G)**	H	6.95	6.72	7.08	6.97	6.71	6.95
Volume Air Voids **(HE/100)**	I	36.92	35.62	37.77	36.95	35.45	36.92
Average Air Voids, %			6.92			6.88	

Saturated Subset **				
SSD MASS, g	B'	**1226.4**	**1227.6**	**1231.5**
Mass in Water, g	C'			
Volume, cc (B'-C')	E'	1226.4	1227.6	1231.5
Vol Abs Water, cc **(B'-A)**	J'	26.3	27.5	28.1
% Saturation **(100J'/I)**		71.23	77.19	74.41
% Swell **(100(E'-E)÷E)**		130.87	131.67	130.88
Average Saturation, %			74.3	
Average Swell, %			131.14	

Unconditioned (UCS)		
Cracked/Broken Aggregate?	< 5.0 mm	
	> 5.0 mm	
	544 - 1	
	541 - 1	
	565 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Conditioned Subset				
Thickness, mm	t"	**65**	**67**	**66**
SSD Mass, g	B"			
Mass in Water, g	C"			
Volume, cc **(B" - C")**	E"			
Vol Abs Water, cc **(B"- A)**	J"			
% Saturation **(100J"÷I)**				
% Swell **(100(E" - E)÷E)**				
Average Saturation, %				
Average Swell, %				

Conditioned (CS)		
Cracked/Broken Aggregate?	< 5.0 mm	0.0%
	> 5.0 mm	2.5%
Notes:		
	565 - 1	
	560 - 1	
	551 - 1	
Visual Moisture Damage (Stripping)	Coarse	1.0
	Fine	0.0
Rating (0 to 5) "5" being the most stripped		

Tensile Strength							
Load, N	P	**8816**	**8388**	**8473**	**12973**	**12931**	**12424**
Dry Strength **(2000P/(t*D*3.14)**	Std				1221.1	1254.6	1187.1
Wet Strength **(2000P/(t"*D*3.14)**	Stm	855.3	789.5	809.6			

Average Dry Strength (kPa): **1220.9** **Average Wet Strength** (kPa): **818.2** **TSR, %:** **67.0**

Remarks: Water Conditioned - 10 Cycle

Photo 1: TSR Test
Test results of conditioned samples for 3, 5, and 10-Cycle exposure in NaCl solution

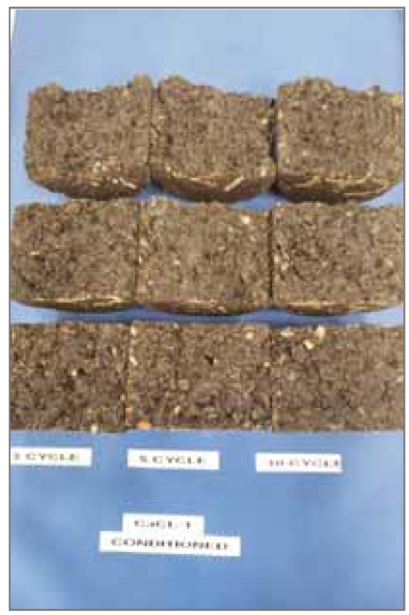


Photo 2: TSR Test
Test results of conditioned samples for 3, 5, and 10-Cycle exposure in NaCl/$CaCl_2$-1 solution

Photo 3: TSR Test
Test results of conditioned samples for 3, 5, and 10-Cycle exposure in NaCl/$CaCl_2$-2 solution

Photo 4: TSR Test
Test results of conditioned samples for 3, 5, and 10-Cycle exposure in water solution

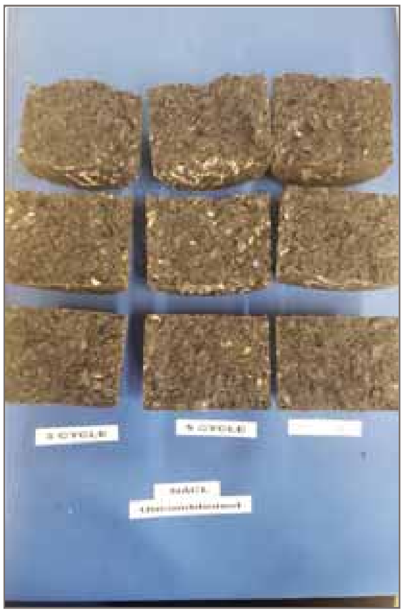


Photo 5: TSR Test
Test results of unconditioned samples for 3, 5, and 10-Cycle exposure in NaCl solution

Photo 6: TSR Test
Test results of unconditioned samples for 3, 5, and 10-Cycle exposure in NaCl/$CaCl_2$-1 solution

Photo 7: TSR Test
Test results of unconditioned samples for 3, 5, and 10-Cycle exposure in NaCl/$CaCl_2$-2 solution

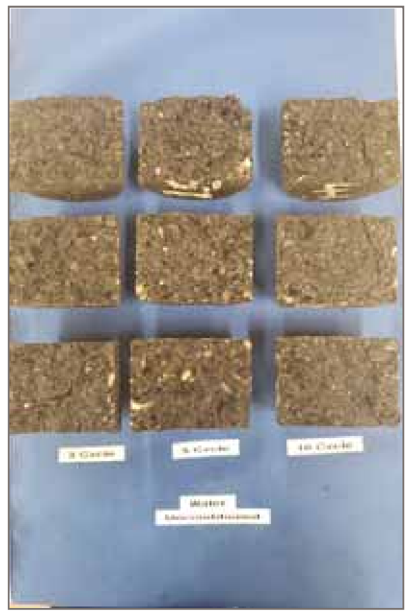


Photo 8: TSR Test
Test results of unconditioned samples for 3, 5, and 10-Cycle exposure in water solution

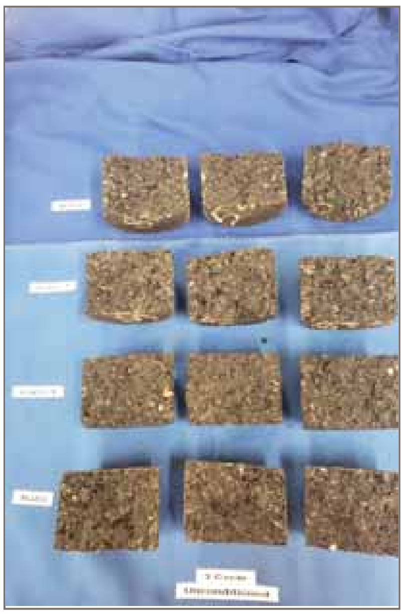


Photo 9: TSR Test
Test results of unconditioned samples in NaCl, $NaCl/CaCl_2$-1, $NaCl/CaCl_2$-2, and water solutions for 3-Cycle exposure

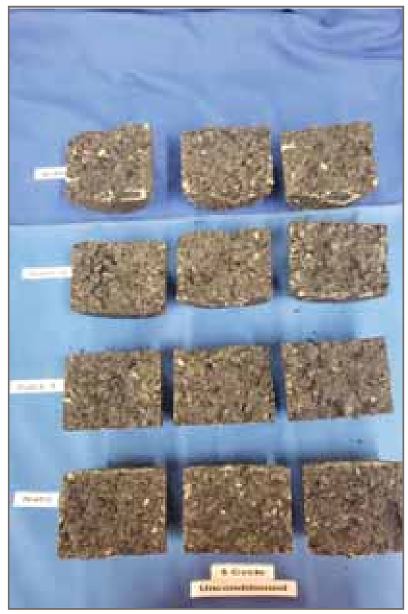


Photo 10: TSR Test
Test results of unconditioned samples in NaCl, $NaCl/CaCl_2$-1, $NaCl/CaCl_2$-2, and water solutions for 5-Cycle exposure

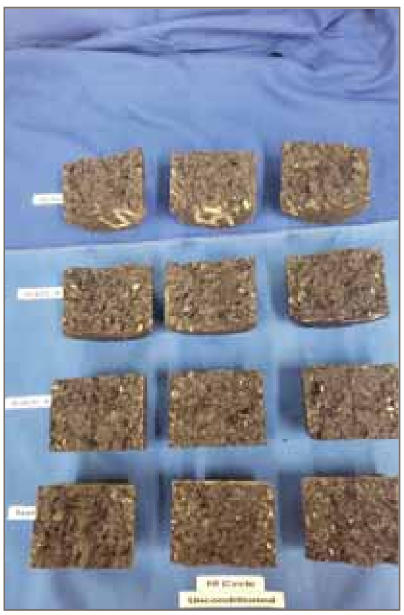


Photo 11: TSR Test
Test results of unconditioned samples in NaCl, $NaCl/CaCl_2$-1, $NaCl/CaCl_2$-2, and water solutions for 10-Cycle exposure

APPENDIX F

HAMBURG WHEEL-TRACK TEST RESULTS

IRRF INTEGRATED ROAD RESEARCH FACILITY

Hamburg Wheel Tracking Test Results

July 26, 2019

INTRODUCTION

The Integrated Road Research Facility (IRRF), University of Alberta conducted Hamburg Wheel Tracking test on asphalt samples prepared by TetraTech EBA, Canada. The test was conducted on four pairs of 12 cm by 15 cm (i.e. height by diameter), already compacted, hot mix asphalt cylindrical specimens. All the samples were prepared using PG 58-28 asphalt cement and were received with the description below.

Table 1: Sample Description

Test Pairing	Chemical Exposure	Specimen Number	Approx. Height (cm)	Diameter (cm)
1	NaCl	22	12	15
		6		
2	NaCl/$CaCl_2$-1	9		
		2		
3	NaCl/$CaCl_2$-2	31		
		1		
4	Water Control	30		
		16		

METHODOLOGY

Hamburg wheel-track device (HWTD) was used to evaluate the 4 pairs of HMA samples for rutting potential and moisture susceptibility by tracking a 705±4.5N, 47mm-wide steel wheel across a water submerged HMA sample (cylindrical or slab) at a frequency of 52±2 passes per minute and a maximum speed of 0.305m/s at midpoint) for 20,000 passes, or until 12 mm rut depth, was achieved (whichever was earlier).

Each specimen in the pair was first saw-cut to a height of 6±0.1 cm (Figure 1) and then saw-cut along a secant line such that when joined to another in the high-density polyethylene (HDPE) molds, a maximum gap of 7.5 mm was achieved between the molds (Figure 2).

The water bath of the Hamburg wheel tracking device was filled with water and preheated to the test temperature of 45°C [1]. The test specimens were then preconditioned in the water bath at the test temperature for 30 minutes, after which the test began. The depth of rutting was plotted against the number of passes to provide valuable information about the asphalt concrete mix susceptibility to plastic deformation and moisture damage [2]. Moisture damage begins to take effect at the stripping inflection point (SIP) and accelerates the deformation, which is evident by a change in the concavity of the graph. An HMA with SIP occurring at several load cycles less than 10,000 passes may be susceptible to moisture damage [3].

Figure 1: Specimens saw-cut to the height of 6±0.1 cm

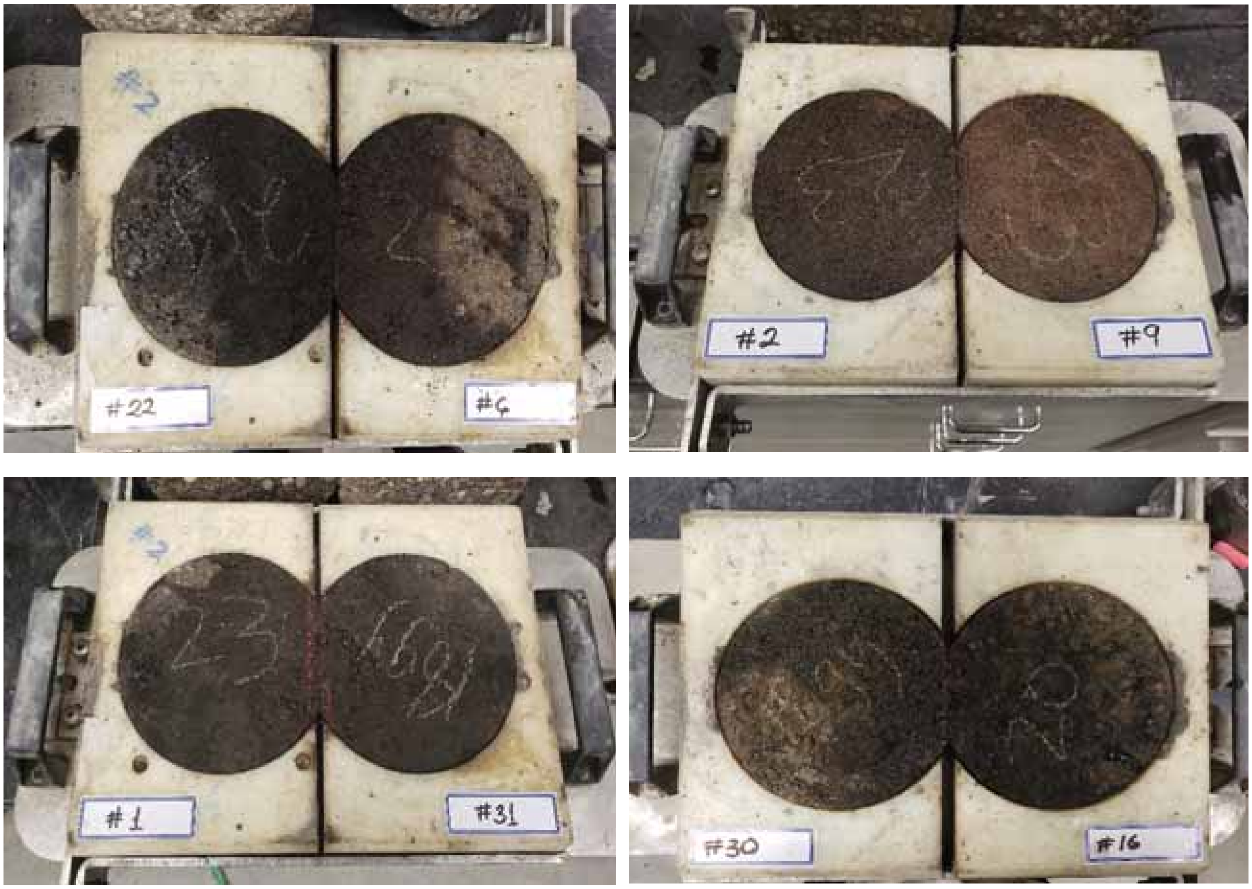


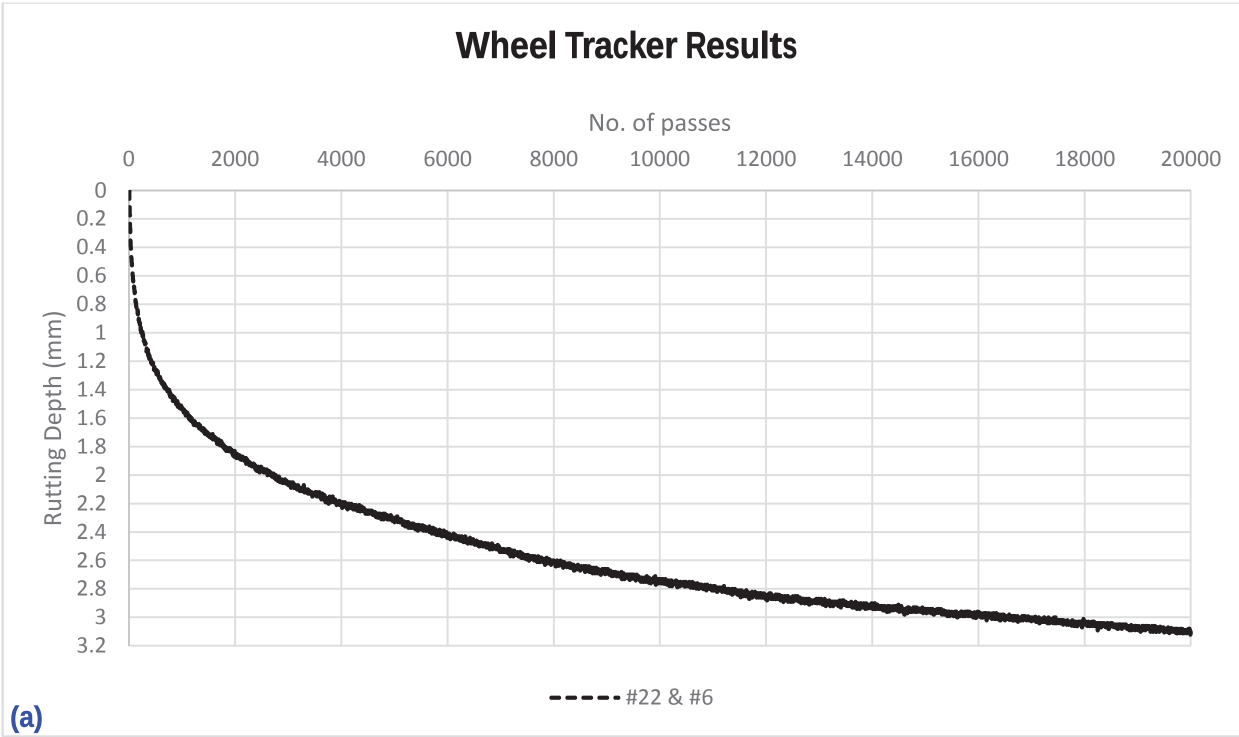
Figure 2: Specimens saw-cut along a secant line (ready for testing)

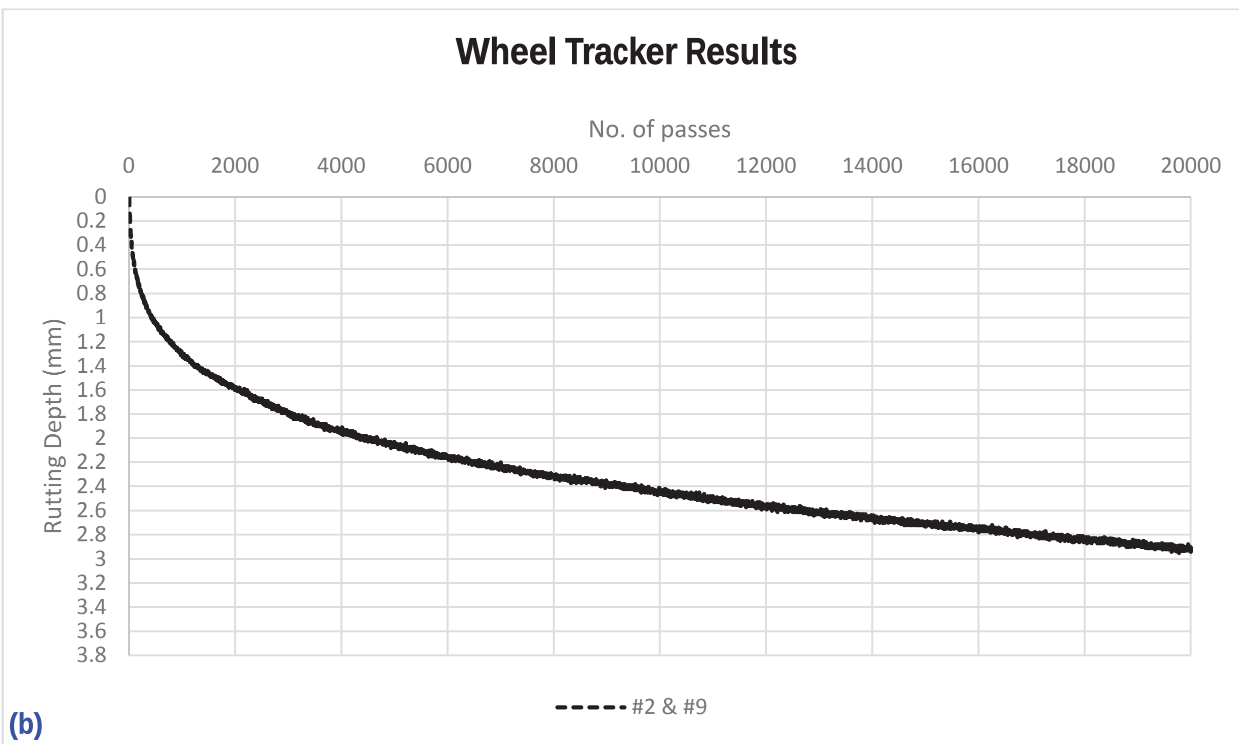
TEST RESULTS

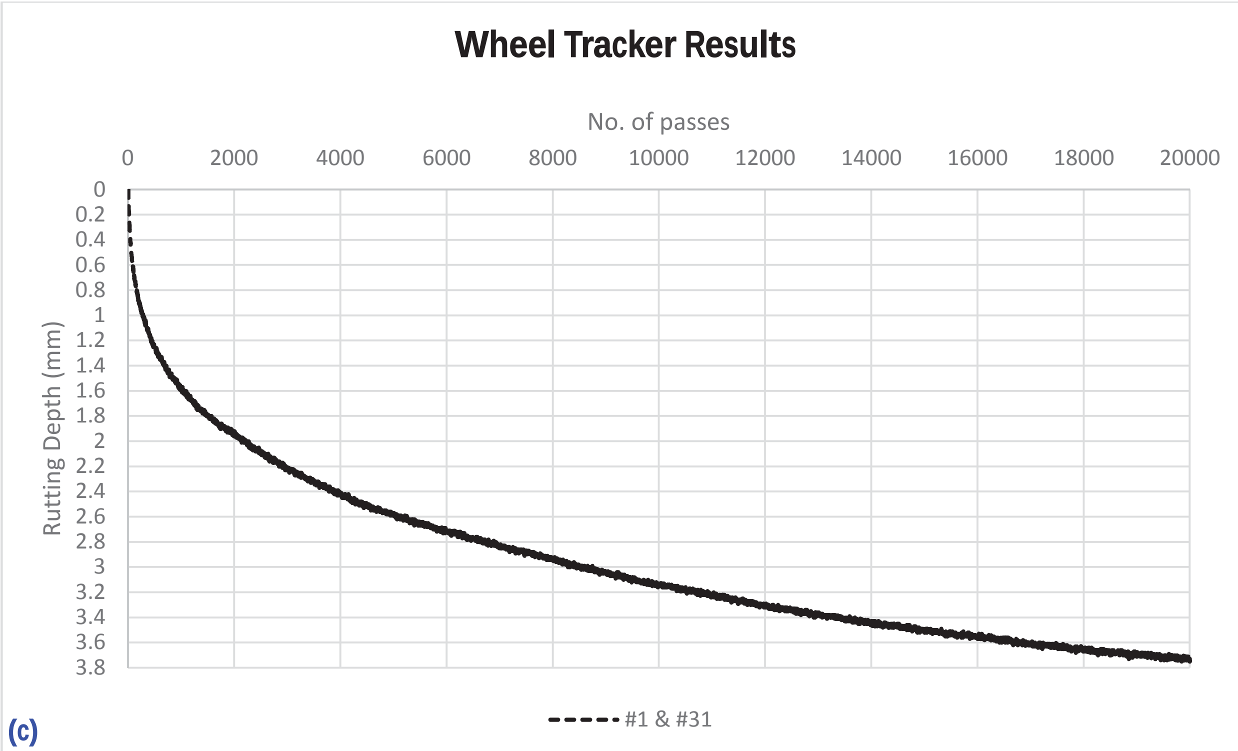
Figures 3 and 4 present the results of the wheel tracking test and the rutted samples after the test. The rut depths at 20,000 passes of all samples were less than 4 mm, and no stripping was observed which indicates that the samples are not moisture susceptible.

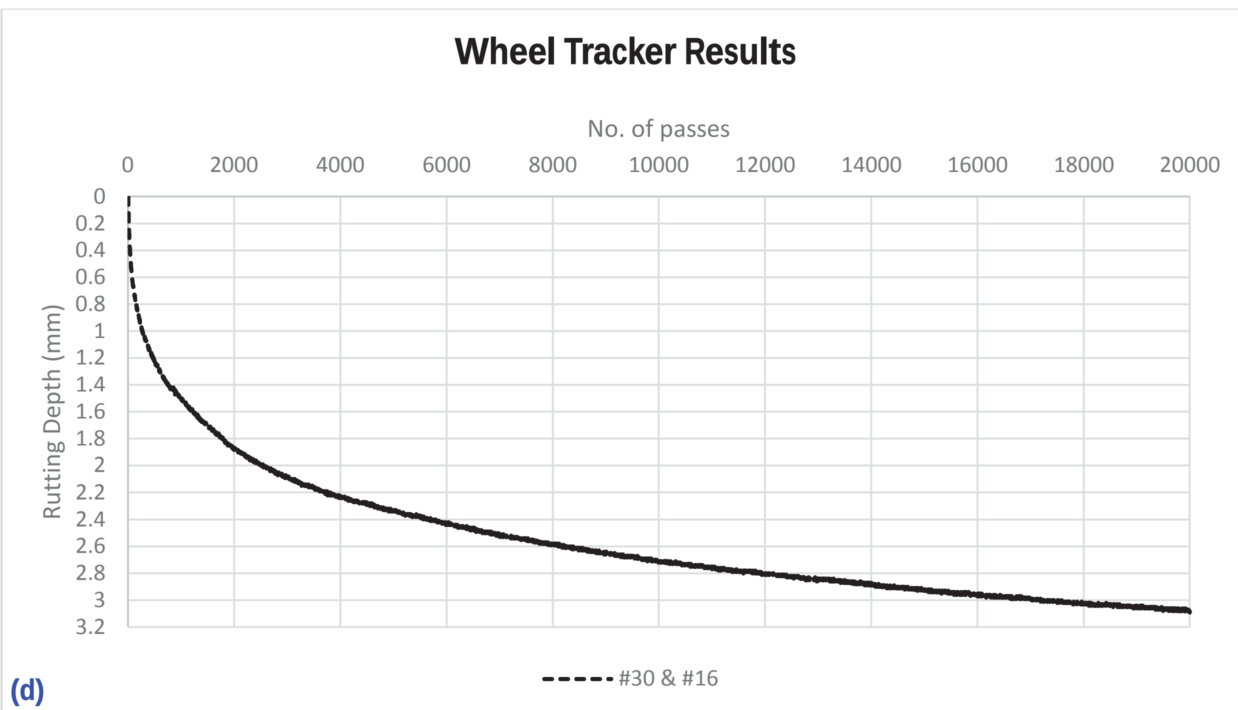
Table 2: Hamburg wheel tracker results

Test Pairing	Chemical Exposure	Specimen Number	SIP	Rut @ 20,000 Passes (mm)
1	NaCl	22	19,999	3.11
		6		
2	$NaCl/CaCl_2$-1	9	19,999	2.90
		2		
3	$NaCl/CaCl_2$-2	31	19,999	3.73
		1		
4	Water Control	30	19,999	3.08
		16		


Wheel Tracker Results
No. of passes
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Rutting Depth (mm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
#22 & #6
(a)


Wheel Tracker Results
No. of passes
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Rutting Depth (mm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
#2 & #9
(b)


Wheel Tracker Results
No. of passes
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Rutting Depth (mm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
#1 & #31
(c)


Wheel Tracker Results
No. of passes
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Rutting Depth (mm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
#30 & #16
(d)

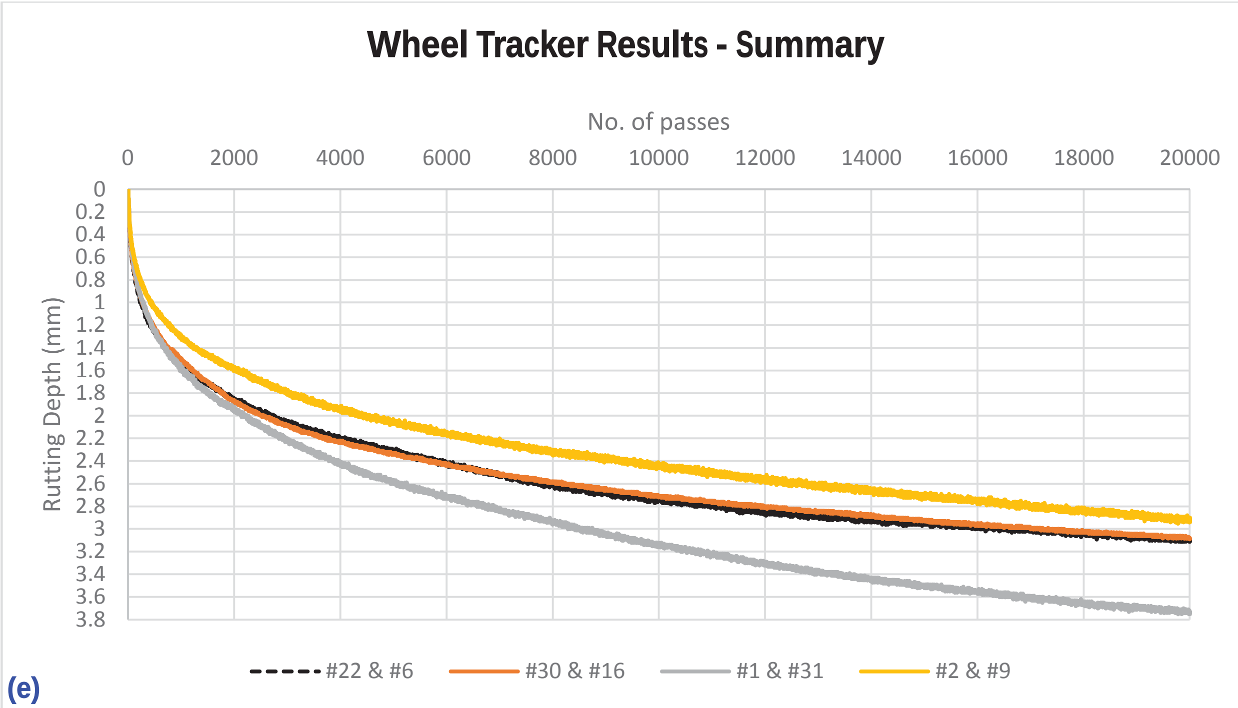


Figure 3: Wheel tracker results (a) – (d) plot of rut depth vs number of passes (d) Summary of all results

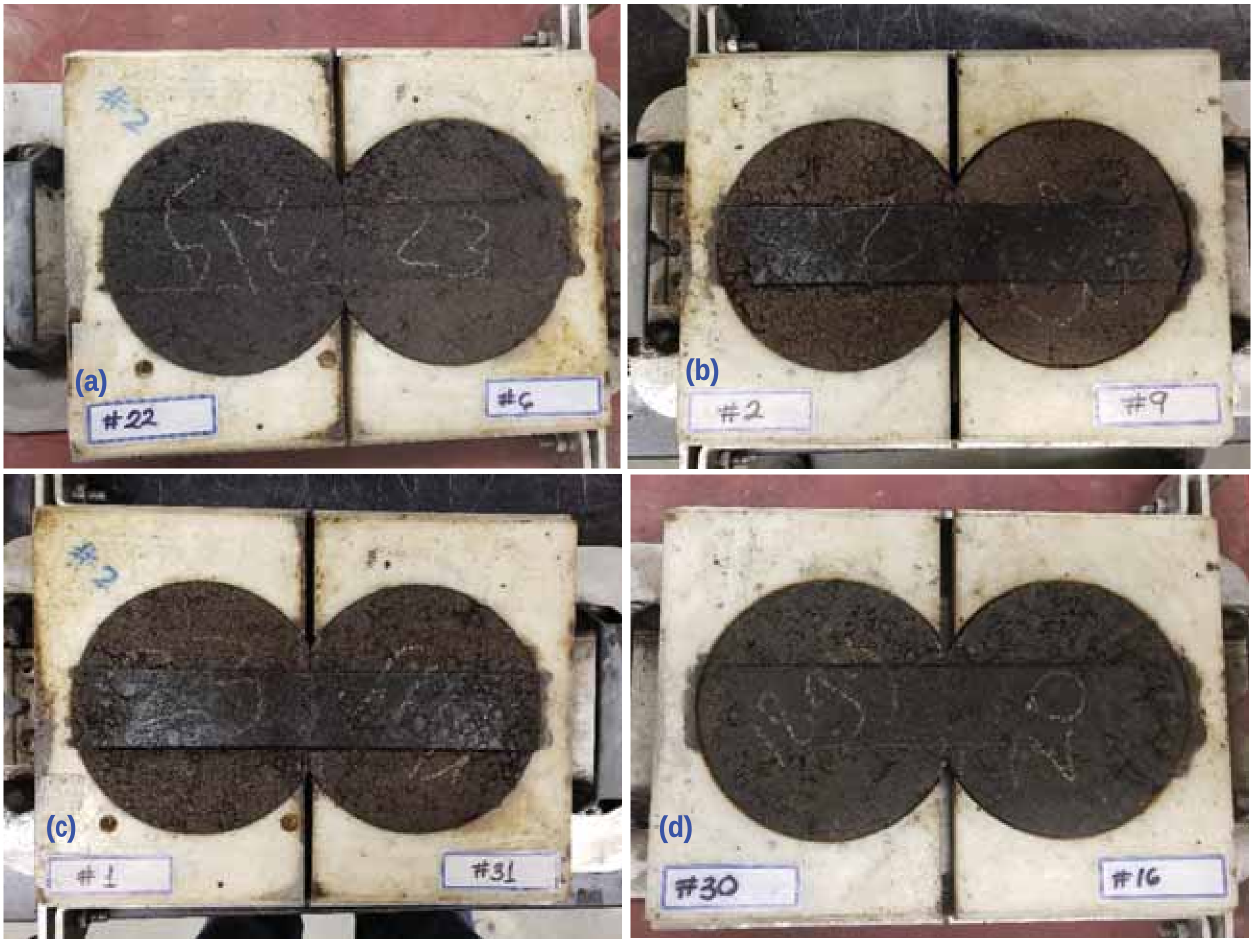


Figure 4: Samples after wheel tracking test

CONCLUSIONS

1. Specimens performed almost similarly in rutting. Lowest rutting value of 2.9 mm after 20,000 passes were achieved for NaCl/CaCl2-1 samples and the highest value of 3.73 mm for NaCl/CaCl2-2 samples.
2. Specimens were not susceptible to moisture damage

REFERENCES

1. G. L. Fitts, Hamburg Wheel Tracking (HWT) Test.
2. AASHTO, AASHTO T 324-16: Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA), (American Association of State Highway and Transportation Officials), 2016.
3. T. Aschenbrener, "Evaluation of Hamburg Wheel-Tracking Device to Predict Moisture Damage in Hot Mix-Asphalt.," Transportation Research Record, vol. 1492, pp. 193-201, 1995

APPENDIX G

BINDER CHARACTERIZATIONS TEST RESULTS

Laboratory Report

26120 Acheson Road
Acheson, AB
T7X 6B3
TEL (780) 960-6475 FAX (780) 960-6476

Customer	Tetra Tech Canada Inc. - Calgary
Customer Address	Riverbend Atrium One #115 200 Rivercrest Drive SE Calgary, AB T2C 2X5
AC Sample Identification	P#ENG. EMAT03571-01 NaCl
AC Sample Grade	TBD
Date Received	July 3, 2019
Sample Lab Number	7418

Test Name	AASHTO	ASTM	Test Temp(°C)	Test Result	Unit	Pass/Fail
Original Binder						
Brookfield Viscosity	T316	D4402	135		cP	
Flash COC	T48	D92			°C	
Original Dynamic Shear Rheometer	T315	D7175			kPa	
					kPa	
Predicted Failure Temp					°C	
Specific Gravity	T228	D70	25	1.0605		
			15	1.0646		
Penetration	T49	D5	25		mm/10	
RTFO Residue						
Mass Change	T240	D2872	163		%	
RTFO Dynamic Shear Rheometer	T315	D7175	76	3.050	kPa	PASS
			82	1.560	kPa	FAIL
Predicted Failure Temp				78.92	°C	
PAV Residue						
Aging Temperature	R28	D6521		100	°C	
PAV Dynamic Shear Rheometer	T315	D7175	31	2150	kPa	PASS
			28	3000	kPa	PASS
Predicted Failure Temp				23.40	°C	
Bending Beam Rheometer Creep Stiffness @ 60 sec	T313	D6648	-12	116	MPa	PASS
			-18	222	MPa	PASS
Predicted Failure Temp				-30.81	°C	
Bending Beam Rheometer Slope (m) @ 60 sec	T313	D6648	-12	0.317		PASS
			-18	0.287		FAIL
Predicted Failure Temp				-25.40	°C	
Performance Grade M320						PG 76-22
Performance Grade M320 "True Grade"						PG 78.9-25.4

Comments:

Tested by	Melissa Corrigan
Verified by:	Jeff Jarvis AI#76
Date	July 8, 2019

Laboratory Report

26120 Acheson Road
Acheson, AB
T7X 6B3
TEL (780) 960-6475 FAX (780) 960-6476

Customer	Tetra Tech Canada Inc. - Calgary
Customer Address	Riverbend Atrium One #115 200 Rivercrest Drive SE Calgary, AB T2C 2X5
AC Sample Identification	P#ENG. EMAT03571-01 NaCl/CaCl2-1
AC Sample Grade	TBD
Date Received	July 3, 2019
Sample Lab Number	7419

Test Name	AASHTO	ASTM	Test Temp(°C)	Test Result	Unit	Pass/Fail
Original Binder						
Brookfield Viscosity	T316	D4402	135		cP	
Flash COC	T48	D92			°C	
Original Dynamic Shear Rheometer	T315	D7175			kPa	
					kPa	
Predicted Failure Temp					°C	
Specific Gravity	T228	D70	25	1.0628		
			15	1.0670		
Penetration	T49	D5	25		mm/10	
RTFO Residue						
Mass Change	T240	D2872	163		%	
RTFO Dynamic Shear Rheometer	T315	D7175	76	2.590	kPa	PASS
			82	1.290	kPa	FAIL
Predicted Failure Temp				77.40	°C	
PAV Residue						
Aging Temperature	R28	D6521		100	°C	
PAV Dynamic Shear Rheometer	T315	D7175	31	1950	kPa	PASS
			28	2730	kPa	PASS
Predicted Failure Temp				22.60	°C	
Bending Beam Rheometer Creep Stiffness @ 60 sec	T313	D6648	-12	107	MPa	PASS
			-18	213	MPa	PASS
Predicted Failure Temp				-30.96	°C	
Bending Beam Rheometer Slope (m) @ 60 sec	T313	D6648	-12	0.317		PASS
			-18	0.294		FAIL
Predicted Failure Temp				-26.43	°C	
Performance Grade M320						PG 76-22
Performance Grade M320 "True Grade"						PG 77.4-26.4

Comments:

Tested by	Melissa Corrigan
Verified by:	Jeff Jarvis AI#76
Date	July 8, 2019

Laboratory Report

26120 Acheson Road
Acheson, AB
T7X 6B3
TEL (780) 960-6475 FAX (780) 960-6476

Customer	Tetra Tech Canada Inc. - Calgary
Customer Address	Riverbend Atrium One #115 200 Rivercrest Drive SE Calgary, AB T2C 2X5
AC Sample Identification	P#ENG. EMAT03571-01 NaCl/CaCl2-2
AC Sample Grade	TBD
Date Received	July 3, 2019
Sample Lab Number	7420

Test Name	AASHTO	ASTM	Test Temp(°C)	Test Result	Unit	Pass/Fail
Original Binder						
Brookfield Viscosity	T316	D4402	135		cP	
Flash COC	T48	D92			°C	
Original Dynamic Shear Rheometer	T315	D7175			kPa	
					kPa	
Predicted Failure Temp					°C	
Specific Gravity	T228	D70	25	1.0582		
			15	1.0623		
Penetration	T49	D5	25		mm/10	
RTFO Residue						
Mass Change	T240	D2872	163		%	
RTFO Dynamic Shear Rheometer	T315	D7175	70	3.210	kPa	PASS
			76	1.560	kPa	FAIL
Predicted Failure Temp				73.14	°C	
PAV Residue						
Aging Temperature	R28	D6521		100	°C	
PAV Dynamic Shear Rheometer	T315	D7175	28	2340	kPa	PASS
			25	3340	kPa	PASS
Predicted Failure Temp				21.60	°C	
Bending Beam Rheometer Creep Stiffness @ 60 sec	T313	D6648	-12	106	MPa	PASS
			-18	211	MPa	PASS
Predicted Failure Temp				-31.05	°C	
Bending Beam Rheometer Slope (m) @ 60 sec	T313	D6648	-12	0.333		PASS
			-18	0.295		FAIL
Predicted Failure Temp				-27.21	°C	
Performance Grade M320						PG 70-22
Performance Grade M320 "True Grade"						PG 73.1-27.2

Comments:

Tested by	Melissa Corrigan
Verified by:	Jeff Jarvis AI#76
Date	July 8, 2019

Laboratory Report

26120 Acheson Road
Acheson, AB
T7X 6B3
TEL (780) 960-6475 FAX (780) 960-6476

Customer	Tetra Tech Canada Inc. - Calgary
Customer Address	Riverbend Atrium One #115 200 Rivercrest Drive SE Calgary, AB T2C 2X5
AC Sample Identification	P#ENG. EMAT03571-01 Pure Water
AC Sample Grade	TBD
Date Received	July 3, 2019
Sample Lab Number	7417

Test Name	AASHTO	ASTM	Test Temp(°C)	Test Result	Unit	Pass/Fail
Original Binder						
Brookfield Viscosity	T316	D4402	135		cP	
Flash COC	T48	D92			°C	
Original Dynamic Shear Rheometer	T315	D7175			kPa	
					kPa	
Predicted Failure Temp					°C	
Specific Gravity	T228	D70	25	1.0499		
			15	1.0541		
Penetration	T49	D5	25		mm/10	
RTFO Residue						
Mass Change	T240	D2872	163		%	
RTFO Dynamic Shear Rheometer	T315	D7175	76	2.300	kPa	PASS
			82	1.160	kPa	FAIL
Predicted Failure Temp				76.39	°C	
PAV Residue						
Aging Temperature	R28	D6521		100	°C	
PAV Dynamic Shear Rheometer	T315	D7175	31	1760	kPa	PASS
			28	2490	kPa	PASS
Predicted Failure Temp				21.97	°C	
Bending Beam Rheometer Creep Stiffness @ 60 sec	T313	D6648	-12	107	MPa	PASS
			-18	213	MPa	PASS
Predicted Failure Temp				-30.98	°C	
Bending Beam Rheometer Slope (m) @ 60 sec	T313	D6648	-12	0.328		PASS
			-18	0.298		FAIL
Predicted Failure Temp				-27.60	°C	
Performance Grade M320						PG 76-22
Performance Grade M320 "True Grade"						PG 76.4-27.6

Comments:

Tested by	Melissa Corrigan
Verified by:	Jeff Jarvis AI#76
Date	July 8, 2019

APPENDIX H

LIMITATIONS OF USE

LIMITATIONS ON USE OF THIS DOCUMENT

CONSTRUCTION MATERIALS ENGINEERING AND TESTING

1.1 USE OF DOCUMENT AND OWNERSHIP

This document pertains to a specific site, a specific development, and a specific scope of work. The document may include plans, drawings, profiles and other supporting documents that collectively constitute the document (the "Professional Document").

The Professional Document is intended for the sole use of TETRA TECH's Client (the "Client") as specifically identified in the TETRA TECH Services Agreement or other Contractual Agreement entered into with the Client (either of which is termed the "Contract" herein). TETRA TECH does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Professional Document when it is used or relied upon by any party other than the Client, unless authorized in writing by TETRA TECH.

Any unauthorized use of the Professional Document is at the sole risk of the user. TETRA TECH accepts no responsibility whatsoever for any loss or damage where such loss or damage is alleged to be or, is in fact, caused by the unauthorized use of the Professional Document.

Where TETRA TECH has expressly authorized the use of the Professional Document by a third party (an "Authorized Party"), consideration for such authorization is the Authorized Party's acceptance of these Limitations on Use of this Document as well as any limitations on liability contained in the Contract with the Client (all of which is collectively termed the "Limitations on Liability"). The Authorized Party should carefully review both these Limitations on Use of this Document and the Contract prior to making any use of the Professional Document. Any use made of the Professional Document by an Authorized Party constitutes the Authorized Party's express acceptance of, and agreement to, the Limitations on Liability.

The Professional Document and any other form or type of data or documents generated by TETRA TECH during the performance of the work are TETRA TECH's professional work product and shall remain the copyright property of TETRA TECH.

The Professional Document is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of TETRA TECH. Additional copies of the Document, if required, may be obtained upon request.

1.2 ALTERNATIVE DOCUMENT FORMAT

Where TETRA TECH submits electronic file and/or hard copy versions of the Professional Document or any drawings or other project-related documents and deliverables (collectively termed TETRA TECH's "Instruments of Professional Service"), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed electronic file and/or hard copy version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive a protected digital copy of the original signed and/or sealed version for a period of 10 years.

Both electronic file and/or hard copy versions of TETRA TECH's Instruments of Professional Service shall not, under any circumstances, be altered by any party except TETRA TECH. TETRA TECH's Instruments of Professional Service will be used only and exactly as submitted by TETRA TECH.

Electronic files submitted by TETRA TECH have been prepared and submitted using specific software and hardware systems. TETRA TECH makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Professional Document have been conducted in accordance with the Contract, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Professional Document. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Professional Document.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

1.4 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by persons other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary investigation and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental, regulatory, or sediment and erosion issues associated with construction on the subject site.

1.8 VARIATION OF MATERIAL CHARACTERISTICS AND CONDITIONS

Observations and standardized sampling, inspection and testing procedures employed by TETRA TECH will indicate conditions of materials and construction activities only at the precise location and time where and when Services were performed. The Client recognizes that conditions of materials and construction activities at other locations may vary from those measured or observed, and that conditions at one location and time do not necessarily indicate the conditions of apparently identical material(s) at other locations and/or times.

Services of TETRA TECH, even if performed on a continuous basis, should not be interpreted to mean that TETRA TECH is observing, verifying, testing or inspecting all materials on the Project. TETRA TECH is responsible only for those data, interpretations, and recommendations regarding the actual materials and construction activities observed, sampled, inspected or tested, and is not responsible for other parties' interpretations or use of the information developed. TETRA TECH may make certain inferences based upon the information derived from these procedures to formulate professional opinions regarding conditions in other areas.

1.9 SAMPLING, OBSERVATION & TEST LOCATIONS

Unless specifically stated otherwise, the Scope of Services does not include surveying the Site or precisely identifying sampling, observation or test locations, depths or elevations. Sampling, observation and test locations, depths and elevations will be based on field estimates and information furnished by the Client and its representatives. Unless stated otherwise in the report, such locations, depths and elevations provided are approximate.

1.10 CONTRACTOR'S PERFORMANCE

TETRA TECH is not responsible for Contractor's means, methods, techniques or sequences during the performance of its Work. TETRA TECH will not supervise or direct Contractor's Work, nor be liable for any failure of Contractor to complete its Work in accordance with the Project's plans, specifications and applicable codes, laws and regulations. The Client understands and agrees that Contractor, not TETRA TECH, has sole responsibility for the safety of persons and property at the Project Site.

1.11 NOTIFICATION AND LEVEL OF SERVICE

Unless the Client requests or the building code requires full-time services, the Client understands that services provided by TETRA TECH are on an "On-Call" basis. The Client shall assume responsibility for adequate notification and scheduling of TETRA TECH services. TETRA TECH will make every reasonable effort to meet the Client's schedule, but will not guarantee service availability without direct confirmation from with the Client or their agent.

1.12 CERTIFICATIONS

The Client will not require TETRA TECH to execute any certification regarding Services performed or the Work tested or observed unless: 1) TETRA TECH believes that it has performed sufficient Services to provide a sufficient basis to issue the certification; 2) TETRA TECH believes that the Services performed and Work tested or observed meet the criteria of the certification; and 3) TETRA TECH has reviewed and approved in writing the exact form of such certification prior to execution of the Service Agreement. Any certification by TETRA TECH is limited to the expression of a professional opinion based upon the Services performed by TETRA TECH, and does not constitute a warranty or guarantee, either express or implied.

1.13 WEATHER AND PROTECTION OF MATERIALS

Performance of the Services by TETRA TECH and/or its designated subcontractor may be delayed or excused when such performance is commercially impossible or impracticable as a result of weather events, strikes, shortages or other causes beyond their reasonable control which may also impact cost estimates.

Excavation and construction operations expose materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations, and stockpiles, must be protected from the elements, particularly moisture, desiccation, frost action and construction activities.

1.14 CALCULATIONS AND DESIGN

Where TETRA TECH has undertaken design calculations and has prepared project specific designs in accordance with terms of reference that were previously set out in consultation with, and agreement of, TETRA TECH's client. These designs have been prepared to a standard that is consistent with industry practice. Notwithstanding, if any error or omission is detected by TETRA TECH's Client or any party that is authorized to use the Design Report, the error or omission should be immediately drawn to the attention of TETRA TECH.

1.15 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

1.16 SAMPLES

The Client will provide samples for testing (at the Client's expense). TETRA TECH will retain unused portions of samples only until such time as internal review is accomplished for intended purpose. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded. The duration of sample retention must be discussed in advance.

1.17 GEOTECHNICAL CONDITIONS

A Geotechnical Report is commonly the basis upon which the specific project design or testing has been completed. It is incumbent upon TETRA TECH's Client, and any other authorized party, to be knowledgeable of the level of risk that has been incorporated into the project design, in consideration of the level of the geotechnical information that was reasonably acquired to facilitate completion of the design.

If a Geotechnical Report was prepared for the project by TETRA TECH or others, it will be referenced in the Construction Materials or Materials Design Report. The Geotechnical Report contains General Conditions that should be read in conjunction with these General Conditions for this Report.