Brine Impact Study on Roadway Concrete
Edmonton, Alberta

PRESENTED TO
The City of Edmonton

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EXECUTIVE SUMMARY

Introduction

Tetra Tech Canada Inc. (Tetra Tech) was retained by the City of Edmonton (CoE) to conduct an investigation into the effects of sodium chloride (salt) and calcium chloride (brine) on concrete infrastructure (i.e. concrete curbs, medians, bus pads and crossings) adjacent to main arterial roadways and freeways.

The Design and Control of Concrete Mixtures, eighth Canadian edition states: "*The most destructive weathering factor is freezing and thawing while the concrete is wet, particularly in the presence of de-icing materials*". Tetra Tech undertook this research to determine if concrete deterioration was accelerated due to the use of salt and brine.

Literature Review

Tetra Tech completed an overview of research into the effects of de-icing and anti-icing agents on Portland cement concrete (concrete). This includes how sodium chloride (NaCl) salt and/or calcium chloride ($CaCl_2$) brine solutions effect concrete properties. The key findings are as follows:

- Chloride based de-icing chemicals (NaCl or $CaCl_2$) can be safely applied to concrete that is well made, well finished, well cured, of adequate strength and has an effective air void system provided that it is allowed "mature" by undergoing a short period of air drying.
- Use less chemical. Reducing solution concentrations reduces the potential for concrete distress and rate of distress. Apply de-icing/anti-icing brines with an initial concentration less than the pessimum (worst case) amount.
- Use NaCl Brines for anti-icing. The addition of small amounts of $CaCl_2$ may be a good approach provided that the amount of this salt is kept low (and below the pessimum value).
- The detrimental effects of de-icers/anti-icers on concrete exist through three main pathways: 1) physical deterioration such as "salt scaling"; 2) chemical reactions between de-icers and cement paste (especially in the presence of $CaCl_2$ and $MgCl_2$); and 3) de-icers aggravating aggregate-cement reactions.

Studies indicate to combat potential anti-icing and de-icing damage, concrete should meet all design strength, maximum water/cementing materials ratio, air void, finishing and curing specifications. Supplementary cementitious materials can be utilized in concrete mix designs to decrease chloride permeability. This can include the use of fly ash which is commonly used in City of Edmonton concrete applications. The effective use of surface sealants (siloxane and silane sealants) can also be an effective way to reduce chloride ingress into the concrete

Laboratory Testing

To determine the scaling resistance of concrete surfaces exposed to de-icing and anti-icing chemicals using mass loss, concrete panels were cast and tested in accordance with CSA A23.2-22C. The testing was completed on CoE Class 'C' concrete.

The concrete panels were exposed to different concentrations comprising of the following:

- 3% NaCl (as per CSA A23.2-22C);
- 4% $CaCl_2$ (based on total brine solids);
- 8% $CaCl_2$ (based on total brine solids); and
- Distilled water (control sample).

No significant scaling was observed (Category 0) for the control samples and the two samples exposed to brine. The concrete exposed to 3% NaCl was classified as Category 2A, which exhibits the characteristics of slight to moderate scaling of surface mortar (possibly a few popouts).

The test results indicate that, as was expected from the literature review, typical CoE Class C concrete is slightly more prone to freeze thaw damage exacerbated by salt than brine.

Roadway Survey

Tetra Tech was tasked to determine if there were differences in concrete field performance after the 2018/2019 winter season that could be related to the use of salt with sand and/or brine.

In order to document the field performance of sidewalks and curbs, photographic images of five (5) selected sites were obtained in fall of 2018 and again after street cleaning in spring of 2019.

Concrete infrastructure was surveyed along the following de-icing routes, where only salt was placed on the adjacent roadway:

- 122 Street between Whitemud Drive and Fox Drive northbound; and
- Groat Road (87 Ave to Groat Bridge), northbound and southbound.

Concrete infrastructure was also surveyed along the following anti-icing routes where a combination of brine and salt was placed on the adjacent roadway:

- 178 Street between 87 Avenue and 95 Avenue;
- 111 Avenue between 124 Street and 132 Street (Groat Road); and
- 50 Street, 82 Avenue to 101 Avenue and 106 Avenue to 109 Avenue,

Current Condition of Infrastructure

Based on the survey of five roadways where concrete was recently placed, there is little to no sign of actual or potential damage caused by freeze/thaw distress exacerbated by anti-icing and de-icing solutions. This exposure would include any salt and/or brine solutions that may have come into contact with the concrete.

The primary issue observed on the concrete infrastructure was damage from the snow removal equipment on 122 Street, 111 Avenue and 50 Street. The areas of moderate to significant damage due to snow removal are now somewhat more susceptible to freeze-thaw attack exacerbated by anti-icing and de-icing chemicals and deterioration in general.

Future Observations

Further investigation into the few distresses observed could be completed in the future. It is suggested that follow-up surveys later this year (late September/early October) and next spring might better identify locations where a detailed investigation, possibly including core sampling and laboratory analysis should be concentrated.

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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 Appendix A 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 (CoE) to conduct an investigation into the effects of sodium chloride (salt) and calcium chloride (brine) on concrete infrastructure (i.e. concrete curbs, medians, bus pads and crossings) adjacent to main arterial roadways and freeways.

The Design and Control of Concrete Mixtures, eighth Canadian edition states: "The *most destructive weathering factor is freezing and thawing while the concrete is wet, particularly in the presence of de-icing materials"*. Tetra Tech undertook this research program to determine if concrete deterioration was accelerated due to the use of salt and brine. Tetra Tech's study included the following:

- A literature review of studies that detail the effects of de-icing and ant-icing chemicals on concrete and preventative measures to mitigate the early deterioration of concrete.
- Laboratory study to determine the scaling resistance of concrete surfaces exposed to de-icing and anti-icing chemicals using mass loss.
- A roadway condition survey of concrete infrastructure on arterial roadways and freeways. The survey data would provide a record of changes in surface texture after one winter season of freeze/thaw cycles with application of de-icing and anti-icing chemicals.

2.0 CITY OF EDMONTON WINTER ROADWAY MAINTENANCE PRACTICES

The current City of Edmonton winter maintenance practices include the use of:

1. Sodium Chloride (NaCl) De-icer (typically with sand as a traction aid).
2. Calcium Chloride ($CaCl_2$) Anti-icer on arterial roads and bus routes.
3. NaCl De-icer after $CaCl_2$ Anti-icer*.

*Depending on the intensity and duration of the snowfall event and/or changes in pavement temperature, de-icers may be applied to roadways after pre-treatment with an anti-icer.

Anti-icers are applied before a snow fall event to facilitate snow clearing. De-icers are used to help melt and remove ice and snow from roadways and sidewalks. The effectiveness of salt as a de-icer decreases as the pavement temperature goes down to temperatures below about -10°C. CoE incrementally reduces the amount of salt in the sand mixture as application temperatures drop from -5°C to -25°C. At lower dosages (3%) the salt is primarily used to prevent the road sand from freezing into unmanageable lumps.

3.0 LITERATURE REVIEW

Tetra Tech completed an overview of research into the effects of de-icing and anti-icing agents on Portland cement concrete (concrete). This includes how sodium chloride (NaCl) salt and/or calcium chloride ($CaCl_2$) brine solutions effect concrete properties. The literature review focuses on the use of these de-icing and anti-icing materials during winter roadway maintenance on concrete (Attachments 1 to 8).

3.1 Key Findings

The following represents our key findings of the literature review:

- Chloride based de-icing chemicals (NaCl or $CaCl_2$) can be safely applied to concrete that is well made, well finished, well cured, of adequate strength and has an effective air void system provided that it is allowed "mature" by undergoing a short period of air drying.
- Use less chemical. Reducing solution concentrations reduces the potential for concrete distress and rate of distress. Apply de-icing/anti-icing brines with an initial concentration less than the pessimum (worst case) amount.
- Use NaCl Brines for anti-icing. The addition of small amounts of $CaCl_2$ may be a good approach provided that the amount is kept below the pessimum value.
- The detrimental effects of de-icers/anti-icers on concrete exist through three main pathways: 1) physical deterioration such as "salt scaling"; 2) chemical reactions between de-icers and cement paste (especially in the presence of $CaCl_2$ and $MgCl_2$); and 3) de-icers aggravating aggregate-cement reactions.
- Extensive research suggests that NaCl (salt) can initiate and/or accelerate alkali-silica reactivity (ASR), a chemical reaction causing swelling of concrete leading to damage, by supplying additional alkalis to the concrete.
- Anti-icing with a liquid chemical such as $CaCl_2$ brine is a good strategy when the pavement temperatures are above about -7°C (20°F) at the onset of a snowfall event.
- Field studies have shown $CaCl_2$ to be more effective than NaCl as an anti-icer, owing to its hygroscopic ability to attract moisture and stay on the road.

3.2 Discussion & Preventative Measures

Most literature indicates that lower concentrations of NaCl and $CaCl_2$ have limited effect on concrete durability while $CaCl_2$ at higher concentrations will negatively affect the long-term durability of concrete. The negative effects can include a reduction in concrete stiffness and strength. Utilizing smaller amounts of $CaCl_2$ is an effective anti-icing approach. $CaCl_2$ brine has a eutectic temperature of about -33°C but loses effectiveness as an anti-icer when pavement temperatures drop below -7°C.

NaCl is the most commonly used de-icing chemical. When applied to concrete, it also has the highest absorption rate of all de-icers. The use of NaCl can lead to reduced time to corrosion of embedded steel in concrete or supply additional alkalis to concrete initiate/accelerate ASR. The eutectic temperature of NaCl is -21°C; however, when pavement temperatures drop below -9°C, salt melts little ice and takes hours to do so.

Studies indicate to combat potential anti-icing and de-icing damage, concrete should meet all design strength, maximum water/cementing materials ratio, air void, finishing and curing specifications. Supplementary cementitious materials can be utilized in concrete mix designs to decrease chloride permeability. This can include the use of fly ash which is commonly used in City of Edmonton concrete applications. The effective use of surface sealants (siloxane and silane sealants) can also be an effective way to reduce chloride ingress into the concrete.

4.0 LABORATORY TESTING

To determine the scaling resistance of concrete surfaces exposed to de-icing and anti-icing chemicals using mass loss, concrete panels were cast and tested in accordance with CSA A23.2-22C. The testing was completed on CoE Class 'C' concrete (concrete used for roadway works including curb and gutter, sidewalks, walkways, private crossings, swales medians, New Jersey barriers and parapet walls) supplied by Inland Concrete. The concrete panels were exposed to different concentrations comprising of the following:

- 3% NaCl (as per CSA A23.2-22C);
- 4% $CaCl_2$ (based on total brine solids);
- 8% $CaCl_2$ (based on total brine solids); and
- Distilled water (control sample).

The 3% NaCl solution was identified by MTO (Ontario Ministry of Transportation) as being the most aggressive concentration for evaluating scaling resistance of concrete. ASTM C-672, which also evaluated scaling resistance, uses a 4% $CaCl_2$ solution. The 4% and 8% brine concentrations (based on total solids) applied to the test panels were selected to be aggressive concentration for evaluating scaling resistance of concrete.

The brine solution provided by the CoE contains approximately 28% $CaCl_2$ by weight, along with other minerals including sodium, magnesium and potassium. This is based on a chemical analysis performed by others. The brine concentration used for laboratory testing were based on total solids content after oven drying to a constant mass.

A summary of the testing includes the following:

- A $3m^3$ load of concrete was batched at the Inland Concrete Leduc, AB batch plant. Eight concrete panels were cast which were about 75 mm in thickness with a surface area of about ($0.064m^2$);
- About 24 hours after being cast, the specimens were demoulded from the temporary forms and placed in a 100% humidity moisture cured room for 14 days;
- After 14 days of moisture curing, the specimens were then subjected to a 38-day dry cure which comprised of the panels being subjected to 23°C at about 50% humidity;
- The concrete panel surfaces were then subjected to the salt and brine solutions and distilled water described above for 7 days;
- The test panels were then subjected to freeze and thaw cycles which included being placed in the freezer for 16 hours then thawing for 8 hours. This was completed manually 50 times; and
- The mass of the surface loss was then determined and recorded every 5 days for the 50-cycle duration. The test procedure provides a visual rating scale of the concrete surfaces.

No significant scaling was observed (Category 0) for the control samples and the two samples exposed to $CaCl_2$ brine. The concrete exposed to 3% NaCl was classified as Category 2A which exhibits the characteristics of slight to moderate scaling of surface mortar (possibly a few popouts).

It should be noted that the application of the $CaCl_2$ brine solution produced a reddish-brown surface colour.

Photos of the concrete surfaces before and after testing can be found in Photos 1 to 8. The individual report forms can be found in Attachments 9 to 12.

The test results indicate that, as was expected from the literature review, typical CoE Class C concrete is slightly more prone to freeze thaw damage exacerbated by salt than brine.

5.0 ROADWAY SURVEY

5.1 Areas of Study

Tetra Tech was tasked to determine if there were differences in concrete field performance after the 2018/2019 winter season that could be related to the use of salt with sand and/or brine.

In order to document the field performance of sidewalks, medians and curbs, photographic images of five (5) selected sites were obtained in fall of 2018 and again after street cleaning in spring of 2019. These surveys provided an effective method of documenting field performance and allowed an objective assessment of the effects of the use of salt and/or brine. The photographic surveys completed for this study included over 11,000 photographic images of the concrete surfaces obtained in the fall of 2018, and an additional 11,000 images of the same locations obtained in the spring of 2019.

Concrete infrastructure was surveyed along the following de-icing routes where only salt was used on the adjacent roadway:

- 122 Street between Whitemud Drive and Fox Drive northbound; and
- Groat Road (87 Ave to Groat Bridge), northbound and southbound.

Concrete infrastructure was also surveyed along the following anti-icing routes where a combination of brine and salt was used on the adjacent roadway:

- 178 Street between 87 Avenue and 95 Avenue;
- 111 Avenue between 124 Street and 132 Street (Groat Road); and
- 50 Street, 82 Avenue to 101 Avenue and 106 Avenue to 109 Avenue.

5.2 Concrete Photographic Survey

The sidewalks, curbs and adjacent portions of driveways were surveyed by the Pavement Surface Profiling (PSP-7000) vehicle. The PSP-7000, designed specifically to provide integrated data collection services for network level roadway condition data collection, is a state-of-the-art and highly integrated data collection platform. It combines roughness (IRI), rut, automated and semi-automated pavement distress, digital videolog, and 3D LiDAR with gap free sub-metre inertially-aided real-time differential GPS spatial referencing and high precision linear referencing systems into a single full-sized cargo van chassis. The PSP-7000's real-time inertially-aided differential GPS system provides virtually error free GPS positions, even in areas with poor or no satellite coverage.

The PSP-7000 vehicle collects all roadway information at speeds from 15 kph to 110 kph and is well suited to municipal roadway networks. Tetra Tech combines the data collection systems with integrated linear and spatial referencing to minimize referencing errors for all collected data.

The vehicle also includes a high-resolution right-of-way (ROW) digital videolog system and two separate imaging systems. All imaging systems provide permanent and fully referenced records of the roadway corridor at the time of survey. The forward-looking driver's eye view is supplemented by a high-resolution panoramic camera system used to collect continuous 360° digital videologs. The driver's eye view will be adjusted to reduce the forward-looking view in order to provide better resolution of the pavement surface texture.

Due to reduce lane widths during construction at Groat Road, the 2019 images were captured with a GoPro Hero7 Black wide screen mounted on a passenger vehicle.

This photographic survey provided a visual log of the concrete surfaces prior and after the winter season. This included over 11,000 images of the 5 locations obtained in late fall 2018 and an additional 11,000 plus images of the same locations obtained in the spring of 2019. Electronic copies of the photos along with corresponding locations have been provided under separate cover.

Once all images were visually observed by our concrete specialists, a site trip by a Tetra Tech concrete specialist was completed to confirm the extent of potential damage observed. Three sites from the photo survey were selected for field review by our concrete specialist.

6.0 CONCRETE OBSERVATIONS

6.1 Anti-Icing (Brine) Routes

6.1.1 111 Avenue, 124 Street to 132 Street

The concrete sidewalks and curbs on the south side of 111 Avenue generally appeared in good condition; however, some mortar flaking on sidewalks was observed at some locations on the north side of the roadway. Mortar flaking is the loss of surface paste over a sound coarse aggregate particle. Mortar flaking is generally attributed to surface drying caused when the coarse aggregate prevents bleed water from moving to the surface and balancing evaporation. Mortar flaking from the curb to about 1 m back could be observed in about 20 panels (Photos 9 and 10). It appears that the defect may have been exposure related as this concrete would have been subjected to more freeze thaw cycles than the south side of the road. It is also possible that the snow clearing may have been different along the curb. Two panels also exhibited spalled concrete (Photo 11). This issue seems isolated to only this portion of the sidewalk.

Significant concrete damage was observed on the curbs and sidewalks (Photos 12 and 13). The damage appears to be caused by snow clearing equipment. It appears that snow plows would place the edge of the blade to the edge/face of curb. It also appears that skid steers loaders (or equivalent equipment) may have been used to clear snow from the sidewalks. As this is completed, some of the concrete surface may have been removed. Once the concrete surface mortar is removed, the exposed interior is more prone to be damaged. This is due to the roughened/damaged surface often slower to drain and dry. This leads to an increase in moisture content of the concrete leading to an increased freeze/thaw potential resulting in a potential decrease in service life.

It should be noted that the photographs used for this section were from a study of similar scope reviewing the effects of brine on residential neighborhoods.

6.1.2 178 Street, 87 Avenue to 95 Avenue

It appears only some replacement panels were constructed in 2018 rather than full reconstruction of the sidewalks and curbs. Two panels indicate moderate scaling and cracking damage; however, the scaling and cracking may be subgrade or loading related and not from freeze/thaw damage (Photo 14). The new concrete for the sidewalk and bus pad (top of Photo 14) exhibits good concrete with no signs of freeze/thaw distress or chemical attack.

It should be noted that the photographs used for this section were from a study of similar scope reviewing the effects of brine on residential neighborhoods.

6.1.3 50 Street, 82 Avenue to 101 Avenue and 106 and 109 Avenue

It should be noted that the concrete infrastructure was at various ages constructed from 2014 to 2018. The areas were being landscaped in the spring of 2019 and some curbs were covered by mulch or topsoil. A site visit was undertaken by our concrete specialist to confirm the condition of the concrete.

The curbs and bus pad bench aprons appeared to be in good condition from the fall of 2018 to the spring of 2019. With the exception of a few curb panels that were damaged (Photo 15) and the rounded edges (Photos 16 and 17). These areas appear to be damaged by snow clearing maintenance operations. It is expected that these areas will deteriorate further due to freeze thaw cycles.

Most of the median at 101 Avenue contained a moderate amount of mortar flaking (Photo 18). This may be attributed to a construction defect. At the same location, some surface mortar was removed (Photo 19). This area was likely scraped by a skid steer during snow removal.

No obvious signs of damage caused by de-icing and anti-icing were observed.

6.2 $NaCl_2$ (Salt) Routes

6.2.1 122 Street between Whitemud and Fox Drive Northbound

The concrete observed after the winter was generally in good condition. Rust streaks (Photo 20) were observed on long stretches of the curb face indicating the snow plows/graders scraped the curb during snow removal. Areas of damaged concrete was observed (Photo 21) due to snow removal. These areas were usually located at rounded curb transitions.

The tops of some curbs exhibited darker spots (Photo 22). This is most likely from uneven application of curing compound at time of construction. This will not reduce the service life of the concrete as the acrylic base of curing compound is designed to break down off after a few months of UV exposure from sunlight. Also, the dark marks on the face of the curbs are tire marks from vehicles.

The sidewalk was also in good condition with the exception of a few panels that contained minor to moderate mortar flaking (Photo 23). This defect was not widespread and therefore appears to be a construction defect rather than a result of exposure to salt.

6.2.2 Groat Road (87 Avenue to Groat Bridge), Northbound and Southbound

The curbs appeared to be in good condition from the fall of 2018 to the spring of 2019. Some areas were photographed from a far distance due to barricades placed during construction. Additionally, some sand was on top of the curb causing a portion of the curb to be covered.

Some rust marks were observed due to the snow plows/graders scrapping the curb during snow removal. Some black tire marks were observed on the curb faces.

No signs of indication of freeze/thaw damage caused by de-icing and anti-icing chemicals were observed.

7.0 CURRENT CONDITION OF INFRASTRUCTURE

Based on the survey of five roadways with recently placed concrete, there is little to no sign of actual or potential damage caused by freeze/thaw distress exacerbated by the use of anti-icing or de-icing solutions. This exposure would include salt and/or brine solutions that may have come into contact with the concrete.

Damage to concrete caused by anti-icing and de-icing solutions would include spalling of the surface which includes removal of surface paste exposing coarse aggregate. Some mortar flaking, and minor scaling (similar to freeze/thaw distress caused by anti-icing and de-icing solutions) was observed on the north side of 111 Avenue, the median at 50 Street and 101 Avenue and the sidewalk at 122 Street but this may be attributed to construction defects or exposure to more frequent freeze/thaw cycles. The concrete containing moderate to severe mortar flaking may deteriorate at a faster rate due to the potential of water collecting in the depressions resulting in increased freeze/thaw damage.

The primary issue observed on the concrete infrastructure was damage from the snow removal equipment on 111 Avenue and 50 Street. The areas of significant damage due to snow removal are now somewhat more susceptible to /freeze-thaw attack exacerbated by anti-icing and de-icing chemicals and deterioration in general.

A large portion of the curbs observed exhibited markings from snow plow removal. Over time this process may remove the surface paste exposing the interior aggregate. Once this is completed, the exposed concrete will also be somewhat more susceptible to freeze/thaw damage.

8.0 FUTURE OBSERVATIONS

Further investigation into the few distresses observed could be completed in the future. It is suggested that follow-up surveys later this year (late September/early October) and next spring might better identify locations where a detailed investigation, possibly including core sampling, should be concentrated.

9.0 CLOSURE

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

Tetra Tech Canada Inc.

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TETRA TECH CANADA INC.
Signature
Date July 30/2019
PERMIT NUMBER: P13774
The Association of Professional Engineers and Geoscientists of Alberta

ATTACHMENTS 1 TO 12

TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Wanda Goulden, FEC, FGC, M.Sc., P.Eng., P.Geo. City of Edmonton	**Date:**	May 14, 2019
c:		**Memo No.:**	002
From:	J.D. (Dave) Robson, P.Eng.	**File:**	ENG.EMAT03571-01
Subject:	Salt and Brine Impacts on Portland Cement Concrete – Literature Review		

1.0 INTRODUCTION

This Technical Memo has been prepared by Tetra Tech Canada Inc. (Tetra Tech) as an overview of research into the effects of de-icing and anti-icing agents on Portland cement concrete (concrete). This includes how sodium chloride (NaCl) salt and/or calcium chloride ($CaCl_2$) brine solutions effect concrete properties. The literature review focuses on the use of these de-icing and anti-icing materials during winter roadway maintenance on concrete.

2.0 SCOPE OF THE WORK

The narrow scope of this literature review comprised of presenting key findings within current investigations from published academic and industry studies of chloride-based de-icers and anti-icers.

De-icers are used to help melt and remove ice and snow from roadways and sidewalks. Anti-icers are applied before a snow fall event to facilitate snow clearing.

The current City of Edmonton winter maintenance practices include the use of

1. Sodium Chloride (NaCl) De-icer (often with sand).
2. Calcium Chloride ($CaCl_2$) Anti-icer on selected bridges, arterial roads and bus routes.
3. NaCl De-icer after $CaCl_2$ Anti-icer*.

*Depending on the intensity and duration of the snow fall event, de-icers may be applied to roadways after pre-treatment with an anti-icer.

Based on the literature review, the following key areas of research have been addressed by numerous studies:

- The performance of NaCl and $CaCl_2$ as de-icers/anti-icers.
- The effects of dilute and concentrated NaCl and $CaCl_2$ solutions on concrete.

Most studies evaluated both chloride compounds, but some only considered one or the other of these materials.

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3.0 REFERENCES / INFORMATION SOURCES

The literature review for this assignment was based on the following sources:

- Dow Chemical Company, "Calcium Chloride Handbook, A Guide to Properties, Forms, Storage and Handling", 2003.
- Blackburn, Robert, et al. (Midwest Research Institute) "Snow and Ice Control: Guidelines for Methods and Material." NCHRP Report 526. 2004.
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- Nawla, Aleem, et al. (City of Edmonton) "Impacts of Salt and Brine on Concrete and Asphalt" City of Edmonton Draft Report. 2018.
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- 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 KEY FINDINGS

This review was based on the findings from academic studies and provided a synopsis of the latest research into the effects of NaCl, $CaCl_2$ or combinations of both on concrete performance compared to concrete in the absence of de-icing chemicals.

4.1 Findings from studies looking at both NaCl and $CaCl_2$ de-icers / anti-icers and the effects on concrete:

- Chloride based de-icing chemicals (NaCl or $CaCl_2$) can be safely applied to concrete that is well made, well finished, well cured, of adequate strength and has an effective air void system provided that it is allowed "mature" by undergoing a short period of air drying. (Erlin 2004).
- The Portland Cement Association notes that while dilute (weak) solutions of NaCl or $CaCl_2$ have limited effect on concrete, concentrated $CaCl_2$ solutions will disintegrate concrete (Kerkhoff 2007).
- The low temperature performance of the de-icers is determined by various factors, including the eutectic temperature (i.e., the minimum temperature at which a concentrated solution freezes) and effective temperature of the de-icer. $CaCl_2$ has low eutectic and effective temperatures, whereas sodium chloride has a higher eutectic and effective temperatures. De-icers with low eutectic and effective temperatures work well at low temperatures. (Fischel 2001).
- The detrimental effects of de-icers on concrete exist through three main pathways: 1) physical deterioration such as "salt scaling"; 2) chemical reactions between de-icers and cement paste (a cation-oriented process, especially in the presence of $CaCl_2$ and $MgCl_2$; and 3) de-icers aggravating aggregate-cement reactions (such as the anion-oriented process in the case of chlorides affecting alkali-silica reactivity (ASR) and the cation-oriented process in the case of $CaCl_2$ affecting alkali-carbonate reactivity (ACR) (Shi 2009).
- ASTM C666 testing (300 freeze/thaw cycles) of prisms in 15% $CaCl_2$ reported considerable expansion (0.18% length change) and 40% loss in dynamic modulus. The samples had extensive cracking, increased permeability and significant loss in strength. Significant evidence indicated that $CaCl_2$ chemically reacted with the hardened cement paste, as indicated by the dissolution of the cement paste and formation of oxychloride phases. In contrast, testing with prisms in 18% NaCl did not expand more than 0.04% and about 5% loss in dynamic modulus, with no noticeable chemical interaction or related distress. (Sutter 2008).
- A University of Kansas laboratory study investigated the effects of diluted and concentrated de-icers on concrete. Concrete prisms were exposed to weekly cycles of wetting and drying in distilled water and solutions of NaCl and $CaCl_2$. The solutions used the same molar ion concentration of chloride, either 6.04 molar ion concentration (A 15% solution of NaCl / 17% solution of $CaCl_2$) or 1.06 molar ion concentration (3% NaCl / 3.8% $CaCl_2$). At lower concentrations, NaCl and $CaCl_2$ showed a relatively small negative impact on the concrete properties. At high concentrations, NaCl showed a greater but still relatively small negative effect while the $CaCl_2$ caused significant loss of material and a reduction in stiffness and strength. It concluded that the application of significant quantities of $CaCl_2$, over the life of a structure or pavement will negatively impact the long-term durability of concrete. (Darwin, 2008).
- Sutter et al. (2008) also commented on mitigation strategies:
  - Use less chemicals. Regardless of the distress mechanism, reducing de-icer solution concentrations reduces the distress and distress rate. Apply de-icing chemicals with an initial concentration less than the pessimum (worst case) amount (i.e. 22% for $CaCl_2$).

- Use NaCl Brines. Small amounts of $MgCl_2$ or $CaCl_2$ may be a good approach provided that the amount of these salts is kept low (and below the pessimum values). There may also be organic freezing point depressants.
- Include Supplementary Cementitious Materials (SCMs) to decrease permeability, particularly granulated ground blast furnace slag (GGBFS) or fly ash.
- Use Sealants. Siloxane, and to a lesser extent, silane sealants were effective at significantly slowing the ingress of de-icing chemicals into concrete.

4.2 Findings from studies looking at the effects of NaCl on concrete:

- Salts (NaCl) are the most common chemicals used as de-icing materials in applications as the material is inexpensive and easy to obtain. NaCl has a eutectic temperature of -21°C (-6°F) at 23% concentration. (Ketcham 1996). The working temperature of NaCl ends at pavement temperatures of about -9.4°C (15°F). (Nixon 2015).
- NaCl has the highest absorptivity rate of all common de-icers, and this is a major concern with respect to corrosion of embedded steel in concrete (Sutter 2008).
- A study by Carlton University found that quartzite aggregate disintegrated when exposed to repeated freeze/thaw cycles while immersed in de-icer solutions. The pessimum NaCl solution was between 1% and 2% of a saturated NaCl solution (Hassan 2002). The reported mass losses after 30 freeze/thaw cycles were significantly higher than the CSA A23.1-14 maximum limit of 6% after 5 freeze/thaw cycles in a 3% NaCl solution (A23.2-24A). Further freeze/thaw testing of local concrete aggregates is suggested. It should be noted that most Edmonton area sources of construction aggregates (concrete and asphalt) contain 50% to 80% quartzite with 15% to 45% sandstone/arkose.
- Extensive research suggests that NaCl can initiate and/or accelerate ASR (alkali-silica reaction) by supplying additional alkalis to concrete (Shi 2009).

4.3 Findings from studies looking at the effects of $CaCl_2$ on concrete:

- Anti-icing with a liquid chemical such as $CaCl_2$ brine is a good strategy when the pavement temperatures are above about -7°C (20°F) at the onset of a snowfall event. (Blackburn 2004).
- De-icing is traditionally done with solid chemicals because liquid chemicals such as $CaCl_2$ brine cannot be used to effectively address thick ice or snow pack and are limited to pavement temperature 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).
- $CaCl_2$ has a eutectic temperature of -50°C (-59°F) at 29.6% concentration. (Dow 2003). It is both hygroscopic and deliquescent. Thus, solid $CaCl_2$ will absorb moisture from the air until it dissolves, and the solution will continue to absorb moisture until an equilibrium is reached between the vapor pressure of the solution and that of the air. If the humidity of the air increases, more moisture is absorbed by the solution; if it decreases, water evaporates from the solution to the air. (Dow 2003).
- Field studies have shown $CaCl_2$ to be more effective than NaCl as an anti-icer, owing to its hygroscopic ability to attract moisture and stay on the road. (Shi 2009). Blending NaCl brine with 10% $CaCl_2$ can provide a significant increase in the residual of salt on high volume roads when anti-icing and lower the effective working temperature of brine when pre-wetting. (Albers 2015).

- Research also indicated that, because of this ability to attract moisture, the application of $CaCl_2$ de-icer can cause slippery conditions at high humidity. (Tuan 2011).
- The $CaCl_2$ brine used by the City also contains about 8% to 9% $MgCl_2$. Recent research based on testing of core samples from several bridge decks indicates that cumulative exposure to $MgCl_2$ brine resulted in significantly compromised splitting tensile strength (as much as 50% reduction). It also notes that visual inspection may not be suitable for assessment of concrete exposed to $MgCl_2$. (Xie 2015, 2019).

5.0 PERTINENT ASPECTS

Pertinent aspects related to City of Edmonton Salt and Brine Laboratory Program completed by Tetra Tech include:

- The Scaling resistance of concrete surfaces exposed to de-icing chemicals using mass loss (A23.2-22C-14) test was used to assess the freeze/thaw performance of concrete subjects to distilled water, 3% NaCl, 4% brine and 8% brine.
- Scaling resistance testing by the City of Edmonton (Nawla 2018).

Based on this literature search, the in-progress City of Edmonton laboratory assessment of the effects of de-icers on concrete roadworks (sidewalks, curb and gutter) aligns well with the previous investigations undertaken by others.

The literature review identified extended freeze/thaw testing of aggregates as a potential new area of interest. This was not included in the City of Edmonton laboratory study. Although significant breakdown of quartzite aggregate was not observed in the scaling resistance testing, it is suggested that extended freeze/thaw testing be considered for a future phase of the proposed study.

6.0 DISCUSSION

Most literature indicates that lower concentrations of NaCl and $CaCl_2$ have limited effect on concrete durability while $CaCl_2$ at higher concentrations will negatively affect the long-term durability of concrete. The negative effects can include a reduction in concrete stiffness and strength. Utilizing smaller amounts of $CaCl_2$ is an effective anti-icing approach. Although $CaCl_2$ brine has a eutectic temperature of about -33°C it is not effective for anti-icing when pavement temperatures are below -7°C to -9°C.

NaCl is the most commonly used de-icing chemical. When applied to concrete, it also has the highest absorption rate of all de-icers. The use of NaCl can lead to reduced time to corrosion of embedded steel in concrete or supply additional alkalis to concrete initiate/accelerate alkali-silica reaction (reaction causing swelling of concrete leading to damage). The eutectic temperature of NaCl is -21°C; however, when pavement temperatures drop below -9°C, salt melts little ice and takes hours to do so.

Studies indicate to combat potential anti-icing and de-icing damage, concrete should meet all design strength, maximum water/cementing materials ratio, air void, finishing and curing specifications. Supplementary cementitious materials can be utilized in concrete mix designs to decrease chloride permeability. This can include the use of fly ash which is commonly used in City of Edmonton concrete applications. The effective use of sealants (siloxane and silane sealants) can also be an effective way to reduce chloride ingress into the concrete.

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 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.

FILE: 704-ENG.EMAT03571-01
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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.

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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.

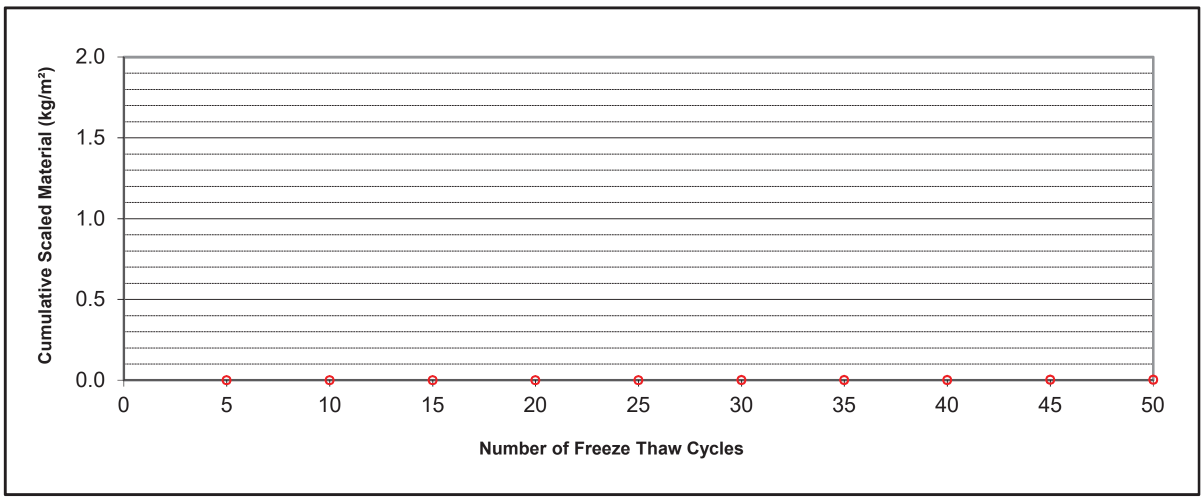
If a Geotechnical Report was prepared for the project by TETRA TECH or others, it will be referenced in the Construction Materials or Materials Design Report. The Geotechnical Report contains General Conditions that should be read in conjunction with these General Conditions for this Report.

Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

CSA A23.2-22C / ASTM C672 / MTO LS-412

Project:	Salt and Brine Impacts Study	Sample No.:	Block 9 & 10
Project No.:	ENG.EMAT03571-01	Panel 1 Cast Date:	November 16, 2018
Client:	City of Edmonton	Panel 2 Cast Date:	November 16, 2018
Attention:	Wanda Goulden	Cast By:	NAQ
Email:	wanda.goulden@edmonton.ca	Tested By:	KJF
Type of Deicer:	Distilled Water - Control	Test Start Date:	January 15, 2019
Curing Regime:	14-day moist / 38-day air dry	Test Finish Date:	March 15, 2019

Mix Design Properties		Tested Properties	
Mix designation:	30E60EM1CC06	Slump/Flow (mm):	80
Cement Type:	GU	Air Content (%):	7.8
Max. Aggregate Size:	20 mm	7-day Strength (MPa):	25.3
Admixtures:	AE	28-day Strength (MPa):	32.4
Specified Slump (mm):	60±20	56-day Strength (MPa):	N/A
Specified Air Content (%):	5.5 - 8.0	Sample 1 Area (m²):	0.0638
Spec. 28-day Strength (MPa):	30	Sample 2 Area (m²):	0.0639



Cumulative Scaling										
F/T cycles	5	10	15	20	25	30	35	40	45	50
Average (kg/m²)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rating (P1/P2)	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0

Remarks: Prep prior to testing: 14 days of moist curing,
followed by 38 days of dried curing and 7 days of distilled water saturation period.

Reviewed By: IDR P.Eng.

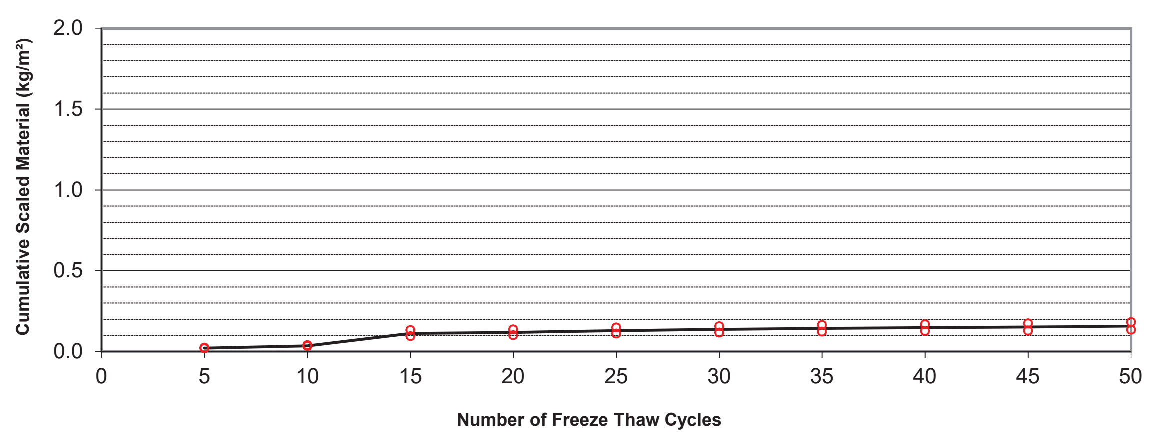
TETRA TECH

Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

CSA A23.2-22C / ASTM C672 / MTO LS-412

Project:	Salt and Brine Impacts Study	Sample No.:	Block 11 & 12
Project No.:	ENG.EMAT03571-01	Panel 1 Cast Date:	November 16, 2018
Client:	City of Edmonton	Panel 2 Cast Date:	November 16, 2018
Attention:	Wanda Goulden	Cast By:	NAQ
Email:	wanda.goulden@edmonton.ca	Tested By:	KJF
Type of Deicer:	3% NaCl	Test Start Date:	January 15, 2019
Curing Regime:	14-day moist / 38-day air dry	Test Finish Date:	March 15, 2019

Mix Design Properties		Tested Properties	
Mix designation:	30E60EM1CC06	Slump/Flow (mm):	80
Cement Type:	GU	Air Content (%):	7.8
Max. Aggregate Size:	20 mm	7-day Strength (MPa):	25.3
Admixtures:	AE	28-day Strength (MPa):	32.4
Specified Slump (mm):	60±20	56-day Strength (MPa):	N/A
Specified Air Content (%):	5.5 - 8.0	Sample 1 Area (m^2):	0.0645
Spec. 28-day Strength (MPa):	30	Sample 2 Area (m^2):	0.0644



Cumulative Scaling										
F/T cycles	5	10	15	20	25	30	35	40	45	50
Average (kg/m^2)	0.02	0.04	0.11	0.12	0.13	0.14	0.14	0.15	0.15	0.1575
Rating (P1/P2)	0/0	0/0	1/1	1/1	2A/2A	2A/2A	2A/2A	2A/2A	2A/2A	2A/2A

Remarks: Prep prior to testing: 14 days of moist curing,
followed by 38 days of dried curing and 7 days of NaCl saturation period.

Reviewed By: ____JDR____ P.Eng.

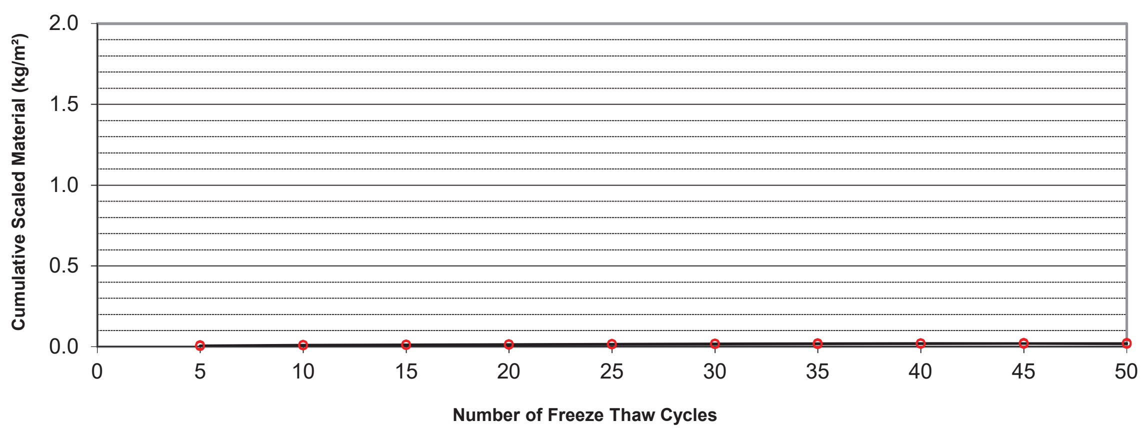
TETRA TECH

Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

CSA A23.2-22C / ASTM C672 / MTO LS-412

Project:	Salt and Brine Impacts Study	Sample No.:	Block 13 & 14
Project No.:	ENG.EMAT03571-01	Panel 1 Cast Date:	November 16, 2018
Client:	City of Edmonton	Panel 2 Cast Date:	November 16, 2018
Attention:	Wanda Goulden	Cast By:	NAQ
Email:	wanda.goulden@edmonton.ca	Tested By:	KJF
Type of Deicer:	4% CaCl2 (Brine)	Test Start Date:	January 15, 2019
Curing Regime:	14-day moist / 38-day air dry	Test Finish Date:	March 15, 2019

Mix Design Properties		Tested Properties	
Mix designation:	30E60EM1CC06	Slump/Flow (mm):	80
Cement Type:	GU	Air Content (%):	7.8
Max. Aggregate Size:	20 mm	7-day Strength (MPa):	25.3
Admixtures:	AE	28-day Strength (MPa):	32.4
Specified Slump (mm):	60±20	56-day Strength (MPa):	N/A
Specified Air Content (%):	5.5 - 8.0	Sample 1 Area (m²):	0.0645
Spec. 28-day Strength (MPa):	30	Sample 2 Area (m²):	0.0648



Cumulative Scaling										
F/T cycles	5	10	15	20	25	30	35	40	45	50
Average (kg/m²)	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
Rating (P1/P2)	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0

Remarks: Prep prior to testing: 14 days of moist storage,
followed by 38 days of dried storage and 7 days of CaCl2 saturation period.

Reviewed By: ____________________ P.Eng.

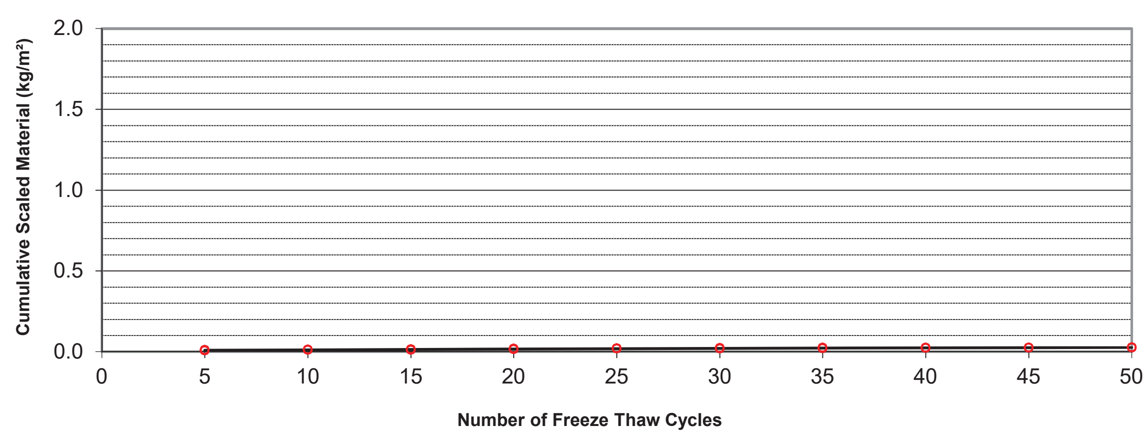
TETRA TECH

Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

CSA A23.2-22C / ASTM C672 / MTO LS-412

Project:	Salt and Brine Impacts Study	Sample No.:	Block 15 & 16
Project No.:	ENG.EMAT03571-01	Panel 1 Cast Date:	November 16, 2018
Client:	City of Edmonton	Panel 2 Cast Date:	November 16, 2018
Attention:	Wanda Goulden	Cast By:	NAQ
Email:	wanda.goulden@edmonton.ca	Tested By:	KJF
Type of Deicer:	8.0% CaCl2 (Brine)	Test Start Date:	January 15, 2019
Curing Regime:	14-day moist / 14-day air dry	Test Finish Date:	March 15, 2019

Mix Design Properties		Tested Properties	
Mix designation:	30E60EM1CC06	Slump/Flow (mm):	80
Cement Type:	GU	Air Content (%):	7.8
Max. Aggregate Size:	20 mm	7-day Strength (MPa):	25.3
Admixtures:	AE	28-day Strength (MPa):	32.4
Specified Slump (mm):	60±20	56-day Strength (MPa):	N/A
Specified Air Content (%):	5.5 - 8.0	Sample 1 Area (m²):	0.0644
Spec. 28-day Strength (MPa):	30	Sample 2 Area (m²):	0.0637



Cumulative Scaling										
F/T cycles	5	10	15	20	25	30	35	40	45	50
Average (kg/m²)	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03
Rating (P1/P2)	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0

Remarks: Prep prior to testing: 14 days of moist curing,
followed by 38 days of dried curing and 7 days of CaCl2 saturation period.

Reviewed By: ____________________ P.Eng.

TETRA TECH

PHOTOGRAPHS 1 TO 23

Photo 1: Concrete panels prior to distilled water exposure.

Photo 2: No significant scaling observed after 50 freeze thaw cycles being exposed to distilled water.

Photo 3: Concrete panels prior to 3% NaCl exposure.

Photo 4: Slight to moderate scaling of surface mortar (popouts) after 50 freeze thaw cycles being exposed to 3% NaCl.

Photo 5: Concrete panels prior to 4% $CaCl_2$ exposure.

Photo 6: No significant scaling observed after 50 freeze thaw cycles being exposed to 4% $CaCl_2$.

Photo 7: Concrete panels prior to 8% $CaCl_2$ exposure.

Photo 8: No significant scaling observed after 50 freeze thaw cycles being exposed to 8% $CaCl_2$.

Photo 9: 111 Avenue. 2018 photo on left, 2019 photo on right. 2018 photo indicating little surface damage while in 2019 some mortar flaking is visible within ~1 m of the curb.

Photo 10: 111 Avenue and 125 Street. Photo obtained in spring of 2019. Concrete with mortar flaking on surface.

Photo 11: 111 Avenue. 2018 photo on left, 2019 photo on right. Spalling of concrete observed in 2019 image on right. Significant damage observed only on a single panel.

Photo 12: 111 Avenue. Photo obtained in 2019. Surface damage on surface of curb and sidewalk likely caused during snow removal.

Photo 13: 111 Avenue. Photos obtained in 2019. Significant amount of damage to curb constructed in 2018.

Photo 14: 178 Street. 2019 photo. Appears the two replacement concrete panels were poorly constructed. Newer concrete 2 panels up appear in good condition.

Photo 15: Curb and pan damaged on 50th Street from snow clearing activities.

Photo 16: Top of rounded edge damaged on 50 Street from snow removal.

Photo 17: Rounded edge curb damage on 50 Street.

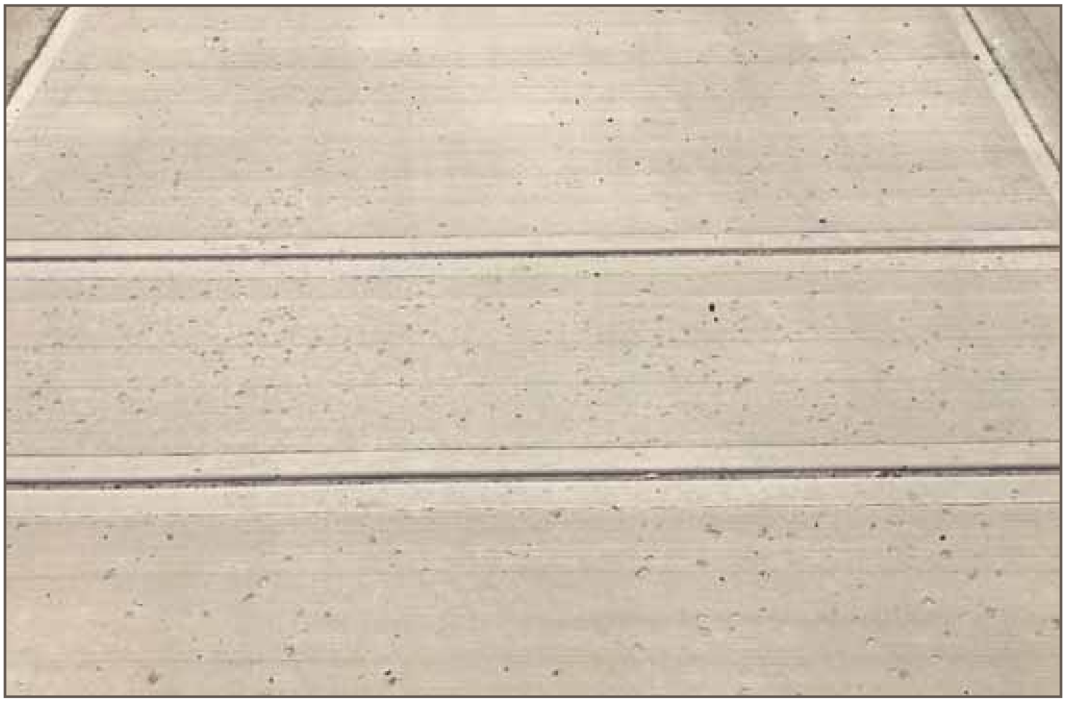


Photo 18: Mortar flaking on the median surface of 50 Street and 101 Avenue.

Photo 19: Median surface scraping at 50 Street & 101 Avenue.

Photo 20: Rust streaks and damaged curb caused by snow removal at 122 Street.

Photo 21: Curb damage and some mortar flaking on pan at 122 Street.

Photo 22: Darker spots on 122 Street curb due to uneven curing compound application.

Photo 23: Mortar flaking and scraping damage on 122 Street sidewalk. Damage to curb as well from snow removal.

APPENDIX A

TETRA TECH' LIMITATIONS ON THE USE OF THIS DOCUMENT

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.