IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

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RP 262

Concrete Performance in Aggressive Salt and Deicing Environments

By

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16. Abstract

Roadside concrete parapets, barriers as well as bridge decks across the State of Idaho are exposed to deicing chemicals and salt brine used for ice and snow control in the winter. As such, signs of durability damage have manifested in some of such concrete infrastructure. The main objectives of this project were to evaluate current Idaho Transportation Department (ITD) concrete mixtures' durability against freeze-thaw (F–T) and wetting–drying (W–D) cycling. Salt brine, mag bud converse, freeze guard plus, and mag chloride are four types of deicers that are currently used during winter times in the state of Idaho across the six districts. The commonly used chemical is the salt brine, made by dissolution of rock salt at 23.3% concentration. Furthermore, when possible recommended strategies were proposed to improve the durability of ITD mixtures. Eight concrete mixtures from five of ITD districts were reproduced using their local aggregates and based on the corresponding field test results obtained from the respective district. The fresh properties of unit weight, entrained air, slump and the super air meter (SAM) were measured after batching. All mixtures were tested and evaluated by surface resistivity test, deicing scaling test, rapid F-T cycling test, continuous soaking, petrographic analysis, and acid soluble chloride test when exposed to Salt brine, mag bud converse, freeze guard plus, and mag chloride. The structural mixtures with no SCMs showed severe scaling, while other mixtures showed moderate scaling, and consequently two alternative structural mixtures were proposed. The proposed mixtures containing silica fume and class C-Fly ash were evaluated under the same testing matrix used in the original mixtures. The major findings recommend modifying the ITD concrete mixtures to include SCMs in a ternary fashion, since the ternary mixtures showed outstanding durability against the high concentrations of chemical deicers. Mix design optimization is required before the ternary mixes are ready for implementation.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					LENGTH		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	In
ft	feet	0.3048	meters	m	m	meters	3.28	feet	Ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	Miles (statute)	1.61	kilometers	km	km	kilometers	0.621	Miles (statute)	mi
		AREA					AREA		
in^2	square inches	645.2	millimeters squared	cm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.0929	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	km^2	kilometers squared	0.39	square miles	mi^2
mi^2	square miles	2.59	kilometers squared	km^2	ha	hectares (10,000 m^2)	2.471	acres	ac
ac	acres	0.4046	hectares	ha					
		MASS (weight)					MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g	g	grams	0.0353	Ounces (avdp)	oz
lb	Pounds (avdp)	0.454	kilograms	kg	kg	kilograms	2.205	Pounds (avdp)	Lb
T	Short tons (2000 lb)	0.907	megagrams	mg	mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME					VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces (US)	fl oz
gal	Gallons (liq)	3.785	liters	liters	liters	liters	0.264	Gallons (liq)	gal
ft^3	cubic feet	0.0283	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
Note: Volumes greater than 1000 L shall be shown in m^3									
		TEMPERATURE (exact)					TEMPERATURE (exact)		
^oF	Fahrenheit temperature	5/9 (^oF-32)	Celsius temperature	^oC	^oC	Celsius temperature	9/5 ^oC+32	Fahrenheit temperature	^oF
		ILLUMINATION					ILLUMINATION		
fc	Foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2	cd/cm^2	candela/m^2	0.2919	foot-lamberts	Fl
		FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

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Technical Advisory Committee

This research project was overseen by a technical advisory committee (TAC), which is led by ITD as a project sponsor and Mr. Craig Wielenga as the project manager. The Technical Advisory Committee (TAC) is responsible for monitoring project progress, reviewing deliverables, ensuring that study objectives are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

Project Manager – Craig Wielenga, PE, Structural Materials Engineer

TAC Members

Clint Hoops, PE, Concrete Material Engineer (former project manager)

Ron Wright

Jeff Drager

Stuart Malley

Herbert McDowell

Greydon Wright

Ned Parrish, Research Program Manager

FHWA-Project Advisor — Kyle Holman

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List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ASR	Alkali Silica Reaction
ASTM	American Standard for Testing and Materials
CM	Cementitious materials
E_c	Concrete modulus of elasticity
f'_c	Compressive strength of PCC
f'_t	Split tensile strength of PCC
ITD	Idaho Transportation Department
M_R	Modulus of rupture of PCC
NCHRP	National Cooperative Highway Research Program
PCC	Portland Cement Concrete
RH	Relative humidity
RP	Research project
SAM	Super air meter
SCM	Supplementary cementitious materials
TCs	thermocouples
UI	University of Idaho
w/cm	Water-to-cementitious materials ratio
WSU	Washington State University

Executive Summary

Introduction

Concrete in roadside barrier rails, parapets, barriers and bridge decks across the State of Idaho are exposed to deicing chemicals and salt brine used for ice and snow control during the winter. As such, signs of durability damage have manifested in some of the concrete infrastructure. Recent studies showed that depending on the concrete mixture, deicing chemicals can chemically react with the paste and produce different forms of salt (Calcium Oxychloride) in the concrete. This chemical transformation has been shown to induce micro damage in the concrete microstructure. In addition, another deterioration mechanism develops in the concrete (or aggregate) because of exposure to freeze-thaw (F-T) cycling during the winter season. At a critical level of saturation, freezing of water inside the concrete pores forms internal osmotic pressure, which tends to damage the paste, initiate cracks and lead to concrete spalling problems. Damage due to both mechanisms result in the development of durability cracking in concrete, which increases the permeability and facilitates the migration of damaging chloride ions to the embedded reinforcing steel level. Moisture and the detrimental ions cause corrosion of the reinforcing steel and ultimately result in the failure of concrete members. Replacement of concrete members in highway applications is costly for the highway agencies and can also impose significant delays to the road users. Idaho Transportation Department (ITD)'s specifications follow industry practices developed years ago. However, concrete technology has evolved, and practices have been developed that produce more durable concrete. This research aimed at enabling ITD to change or modify current concrete mixtures specifications to improve concrete durability in aggressive environments. The goal of this study was to build on the results and recommendations of previous studies trying to increase the service life of ITD concrete mixtures against winter maintenance and deicers applications.

Project Objectives

Deicing chemicals could cause concrete to deteriorate as the result of physical and chemical effects as explained above. The two broad objectives of this project were to:

1. Evaluate current ITD concrete mixtures' durability under various exposure conditions. The proposed experimental study was focused on the evaluation of long-term mechanical degradation due to exposure to F-T cycling, W-D cycles (mass loss, scaling), and chemical (new salt formation) properties to determine the performance of existing mixes used in the State of Idaho exposed to various deicer chemicals.
2. Recommend strategies to improve durability of ITD mixtures.

The study investigated whether the addition of certain amounts of Supplementary Cementitious Materials (SCMs) such as Fly ash and silica fume to the current concrete mixture designs is necessary to alleviate the prevalent durability issues.

Overview of Experimental Work

A total of eight concrete mixtures from five districts in Idaho were reproduced as closely as possible to the mixtures used in the field. This was obtained by using each districts' local aggregates and batching mixtures based on the corresponding field test results obtained from ITD for slump and entrained air. Fresh properties of unit weight, entrained air, slump and the super air meter (SAM) were obtained. The mechanical properties testing included compressive strength (f'_c), which was evaluated and obtained from a previous research project, RP253. The eight mixtures were then evaluated for durability by performing surface resistivity, continuous soaking, deicer scaling, acid soluble chloride test, rapid F-T cycling test, and petrographic analysis. Salt brine, Mag bud converse, Freeze guard plus, and Magnesium chloride (Mag chloride) are four types of deicers that are currently used during winter times in the state of Idaho across the six districts. For instance, District 2 uses three different types of deicers, and all other districts use one deicer during the snow removal season. The commonly used chemical is the salt brine, which is made by the dissolution of rock salt (also known as sodium chloride) at 23.3 percent concentration. Due to the severe scaling that was observed in the structural original mixtures, the research team evaluated the performance and durability of two mixture alternatives for the structural mixtures being used in Districts 1, 2, and 6. The original structural mixes were sealed with epoxy sealers, which were evaluated under deicing scaling. No scaling was observed in the samples sealed with epoxy. Two new groups of mixes were evaluated for durability, the first mix contained 40 percent Class F fly ash and the second mix included 20 percent class F fly ash and 10 percent silica fume. 10 percent silica fume was selected because it is the limiting value recommended by ACI for workability.

Final Report Conclusions and Recommendations

This report summarizes the results of the performance and durability study that was performed on the current ITD paving and structural concrete mixtures, and the results of the proposed binary and ternary structural concrete mixtures for better performance under the harsh deicing environment with the following conclusions:

- The mixtures currently used by ITD perform satisfactorily under F-T cycle, as evidenced by relatively high percentage retained elastic modulus and relatively low mass losses after being subjected to a total of 300 F-T cycles.
- The structural mixture from District 1 (SH-5 Bridge crossing, Plummer) suffered a severe scaling under the salt brine deicer, while other mixtures showed mild to moderate scaling when they subjected to Mag bud converse, Freeze guard plus, and Mag chloride. The reason for the severe scaling, could be because of the absence of supplementary cementitious materials in some mixtures such as fly ash that inhibits the formation of Calcium Oxychloride (CAOXY) as reported by different studies. The scaling test was done according to the standard test method for scaling resistance of concrete exposed to deicing chemicals (ASTM C672).
- Proposed mixtures containing 40 percent class F fly ash did not have sufficient resistance to deicing scaling, even though they all performed satisfactorily in F-T cycles except the mixture for District 2 (M4-40).

- The proposed ternary mixtures containing 20 percent fly ash and 10 percent silica fume performed very well in all the performed tests with no signs of scaling.
- Salt brine deicing chemical with 23.3 percent concentration highly deteriorated the concrete samples compared to Mag bud converse, Freeze guard plus, and Mag chloride, except for ternary mixtures.
- Epoxy sealers could be used to protect concrete made with current ITD structural mixtures from deicing scaling, however the life-cycle cost should be considered. The epoxy sealer if used, should be in applied two layers or according to the manufacturer's specifications. The epoxy coated surface should be allowed to cure before exposing the concrete surface to deicing chemicals.

Recommendations

- Since the concentration of deicing chemicals used in this study is higher than the average found in literature, the possibility of using a lower concentration should be considered for existing construction built using the current ITD mixtures. Although, not tested in this report, lower deicing salt concentration (approximately 2-5 percent) were found to be non-aggressive to concrete.
- Consideration should be given to alternative deicers that are not aggressive to concrete such as the deicers based on organic materials. Before implementing such organic deicers, it is necessary to evaluate them when they used with ITD concrete mixtures.
- Ternary mixture should be considered for use in reinforced structural elements that will be exposed to high concentrations of deicing chemicals.
- Mixtures with 40 percent fly ash should not be used or implemented as suggested by authors since they do not perform satisfactorily under deicing scaling.
- Epoxy sealers used in this study can be used to seal/coat existing structures to prevent deicing scaling if it is economical to do so.

Future Studies

- Mixture design optimization for ternary mixes
- Thermogravimetric analysis to confirm the formation of calcium/magnesium oxychloride and its mitigation.
- Advanced quick chemical test to confirm the ASR observed on mixtures from district 2, when the slabs were exposed to the deicing chemicals.
- Since the ternary mixtures contained 10 percent Silica fume and 20 percent class F fly ash, it is necessary to conduct more sophisticated tests on the ternary mixtures for optimum contents of fly ash and silica fume that can be used for economy purpose.
- Determination of optimum water to binder ratio for use in ternary mixtures.

Chapter 1
Literature Review

Introduction

The state of Idaho annually receives appreciable amount of snow during the winter seasons which lasts over an average of three to four months. With this amount of snow, deicing chemicals are usually applied either before it snows of after snowing to make snow plowing easy, and to keep the roads motorable for the users. Signs of cracking, concrete spalling and damage have been reported by ITD officials on some locations on Centerline Tall Rail and Westbound Standard Rail precast concrete barriers on I-90. The damage and deterioration can reduce the life span of concrete structures exposed to deicing chemicals and lead to higher maintenance cost after winter seasons. Therefore, it is necessary to evaluate the performance of current concrete mixtures being used by ITD for deicing chemicals and develop mitigation measures.

The evaluation of ITD concrete mixtures and development of mitigation measures has been carried out by the research team at the University of Idaho in collaboration with Washington State University.

Background

The negative effects of deicers on reinforcement and concrete were investigated both in the laboratory and in the field in various research projects conducted through state department of transportation's (DOT). The studies reported the effect of deicer scaling resistance of concrete mixtures [(1)] and the evaluation of alternative anti-icing and deicing compounds using sodium and magnesium chlorides [(2)]. The goal from this study is to build on the results and recommendations of previous studies to enhance the durability of ITD concrete mixtures against winter maintenance and deicers applications.

In the United States, high amounts of chloride-based salts are annually applied on bridges and highways for snow and ice control, as reported by FWHA, 2005. The state of Idaho received substantial amount of snow in the last three years coupled with very low temperatures. This kind of harsh environment made it necessary for ITD to engage in snow control efforts using deicing/anti-icing chemicals and salts for making the highway system and local roads safe for vehicles, and to decrease the number of accidents accompanied by such harsh weather.

Most of the deicing salts in use at the state of Idaho are chloride based. The presence of chloride ions in mass concrete can be advantageous as well as harmful [(3- 6)]. It is advantageous if the chloride is bounded to the concrete matrix (bound chloride) as it helps to combat sulfate attack, especially for concrete in contact with soil; and harmful if it is free to migrate within the concrete matrix (free chloride) where it can lead to deterioration of the concrete microstructure. In any of those cases, presence of chloride in reinforced concrete structure is harmful. It is known that chloride ions react with Fe^{2+} of steel reinforcement and convert it to Fe^{3+} [(7)]. This conversion leads to corrosion, loss of strength and mass loss of the steel, as well as reduction in load carrying capacity of the whole concrete member [(8)].

The effect of deicing salts on concrete structures is a combination of both physical and chemical attacks. The physical attack is evident through scaling, salt crystallization, map cracking and/or disintegration of cement paste, during wetting/drying cycles, as well as freezing/thawing conditions. The chemical attack on the other hand results in leaching of Calcium Hydroxide- $Ca(OH)_2$ and formation of Oxychloride compounds that results in increased permeability, reduction in alkalinity, loss of integrity and strength and soundness of concrete.

It is costly to state DOTs to replace distressed concrete in structural elements as well as highway structures. The cost is interpreted in traffic delay and extended travel time to the highway road users. These mixtures' design followed the ITD's specifications, where they followed industry practices developed years ago. However, concrete technology has evolved, and new practices have been developed that tend to alter the microstructure of concrete using secondary cementitious materials.

It is therefore necessary for ITD to enhance the current specifications to improve concrete durability in such aggressive environments. The following section gives a summary of what have been reported in the literature and at the end of this report, the investigators have developed a questionnaire that has been designed to collect more information from the various districts in the State of Idaho.

Chemistry and Mechanisms of Concrete Deterioration

Many chemicals have been used and currently still in use as deicing and anti-icing based on cost per lane/mile, low effective temperature, high ice-melting capacity, ease of application and safety benefits (skid resistance). These deicers can be grouped into organic and inorganic salt. The inorganic salt includes sodium chloride (solid salt or solution), magnesium chloride, calcium chloride and agriculturally based salt, while the organic salt include Potassium Acetate, Sodium Acetate, Calcium Magnesium Acetate, and Potassium Formate. Among these inorganic chemicals, Magnesium Chloride has been reported to be the most effective in snow and ice melting because of its ability to reduce the freezing temperature of a solution to a lower temperature when compared to other deicers [9] as shown in the phase diagram, (Fig. 1). Deicers interact chemically and physically in a different way with cementitious materials [10]. It was reported that the penetrability of $CaCl_2$ deicing salt in concrete depends on the amount of C_3A in the cement and the content of portlandite available for chemical reactions in the hydrated cement paste [10]. Salt brine (NaCl) has been reported to increase freeze-thaw damage in concrete because of the formation of unexpected phases and the creation of osmotic pressures [11 - 13]. However, severe cracking has been reported in concrete exposed to Magnesium Chloride because of the formation of brucite, Friedel's salt and magnesium silicate hydrate (M-S-H), Magnesium Oxychloride, and Calcium Oxychloride, even in the absence of freezing-thawing cycles [14 - 16].

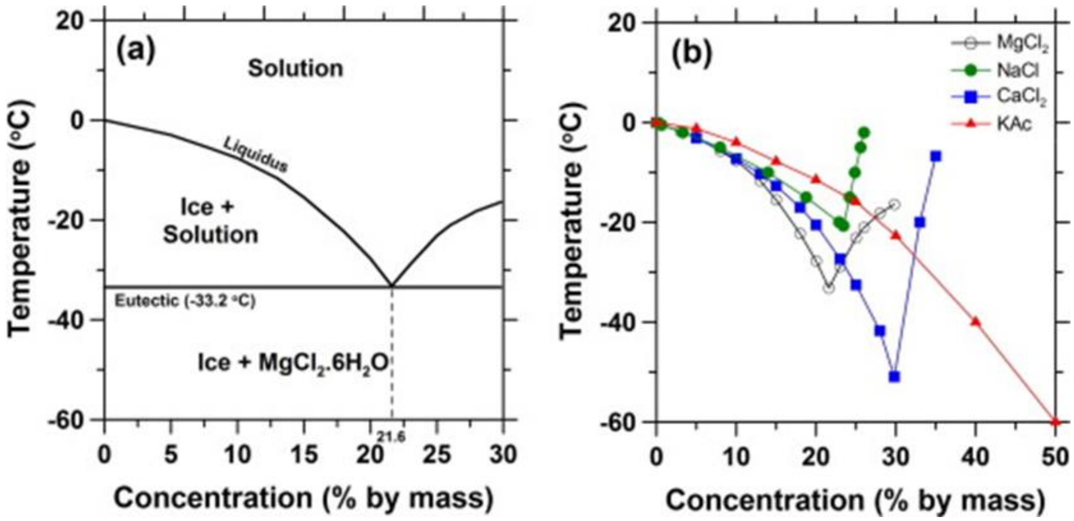


Figure 1. (a) Phase Diagram for Mgcl$_2$-H$_2$O Binary System and (b) Comparison of Freezing Temperature for Different Deicing Chemicals [9]

In the reaction of $MgCl_2$ with the main hydration products of cement (Calcium Silicate Hydrate (C-S-H) and Calcium Hydroxide ($Ca(OH)_2$)) or CH, M-S-H, brucite ($Mg(OH)_2$) and Magnesium Oxychloride (MOC) are produced. M-S-H formation results in concrete damage which appears slowly and gradually [14, 16]. Sutter et al. (2008) [15] reported brucite to be a dense and homogenous compound, that forms as an outer layer on concrete surface and slows down further deterioration caused by deicing chemicals. However, Zhang et al. (1994) [17] reported brucite to be a highly porous compound that accelerates deterioration of the hardened cement paste.

Magnesium Oxychloride (MOC) occurs in two major forms depending on the number of molecules of $Mg(OH)_2$. The two forms are termed 3-form and 5-form [18-21]. In the presence of hydraulic aluminate, the 5-form MOC can be converted into 3-form MOC [21], while due to prolonged exposure, the 5-form can change to 3-form because it is more stable [20]. It has also been reported that maximum formation of 5-form MOC is desirable because of its positive influence on the mechanical properties of concrete [22]. However, the 3-form and 5-form are highly sensitive to moisture because of their instability as they can transform to brucite by the action of water.

Over the last decades, several efforts have been geared on research to study and understand the microstructure, reaction products, strength development mechanism and deterioration mechanism of MgO-$MgCl_2$-H_2O compounds in concrete. In the secondary reaction, Calcium Oxychloride (CAOXY) can be formed since $CaCl_2$ and $Mg(OH)_2$ should be formed first. Calcium Oxychloride can also be formed if $CaCl_2$ deicer is used.

The formation of CAOXY has been reported to be highly expansive and destructive in hardened concrete because of the internal hydraulic pressure generated [16, 23]. Calcium Oxychloride is unstable at room temperature and low relative humidity, but it can be formed at temperature above water freezing point [24, 25]. MOC and CAOXY also exist in different phases depending on the molar ratios such as $CaCl_2.3Ca(OH)_2.12H_2O$, $CaCl_2.Ca(OH)_2.\ xH_2O$, and $CaCl_2.Ca(OH)_2$), but the phases can coexist and even interchange in $Ca(OH)_2$-$CaCl_2$-H_2O depending on the ambient temperature and relative humidity [24] (Brown et al. 2004). $CaCl_2.3Ca(OH)_2.12H_2O$ has been reported to be destructive because it is unstable under varying temperature and humidity [23]. Makarov and Vol'nov (1964) [26], and Vol'nov and [27] modified the $CaCl_2$-H_2O binary system phase diagram for $CaCl_2$-$Ca(OH)_2$-H_2O ternary system based on temperature and $CaCl_2$ concentration without considering the mass/molar ratio of $Ca(OH)_2$: $CaCl_2$. Farnam et al. (2015) [9] studied the influence of $CaCl_2$ deicing salt on phase changes and developed a modified ternary system-based phase diagram that accounts for different mass/molar ratio (Figure 2).

Conventionally, increasing the concentration of deicers reduce the freezing point of ice/snow as shown in Figure. 1(b). However, the addition of $Ca(OH)_2$ changes such behaviors depending on the mass/molar ratio as shown in Figure 2. At a molar ratio greater than 3, increasing the concentration of $CaCl_2$ increases the temperature (Figure. 2a), while a complex behavior is observed at a molar ratio less than 3. Changes in concrete transport properties (i.e. diffusivity and permeability) may be observed during the formation and precipitation of COC which may block the concrete pores and lead to deterioration. The rate at which CAOXY is formed within the hardened plays an important role in the concrete deterioration like freeze-thaw behavior, carbonation and diffusion behavior.

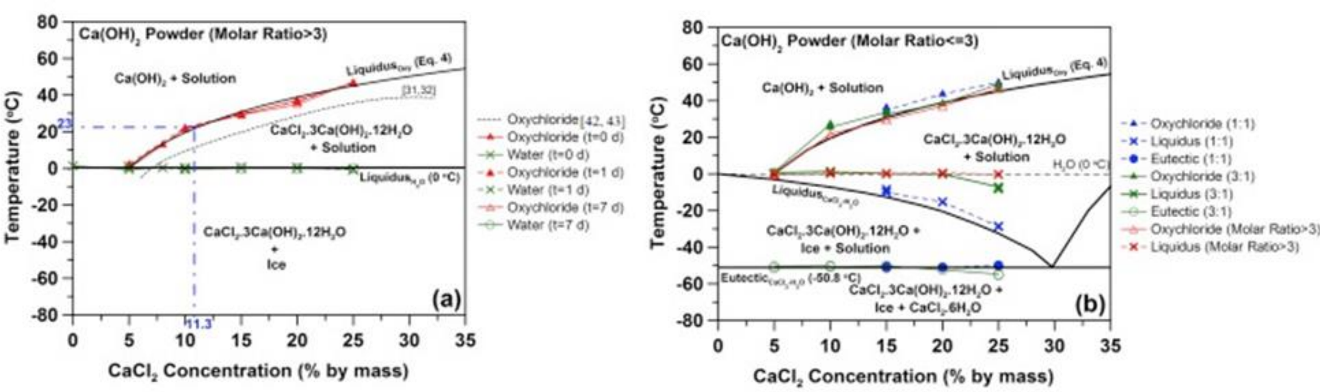


Figure 2. Phase Diagram for $CaCl_2$ Reaction (a)Molar Ratio Greater Than 3 (b)Molar Ratio ≤ 3

The use of salt brine (NaCl) as deicer has been preferred over $CaCl_2$ because of production cost and application as it is the cheapest among the deicing chemicals [28] (Wilfrid 2008). It is made from rock salt dissolution in water at a concentration of 23.3 percent by weight, which equals 2 pounds of salts per gallon of water. When salt brine is applied on the roadway as an anti-icing chemical, the moisture in the brine evaporates, the salt concentrate mix with the snow or ice to form a thin cushion layer between the road surface and the precipitation. The cushion layer prevents the snow from sticking and make snow ploughing easier. The use of salt brine has been reported to increase F-T damage in concrete because of the various phase changes that occur in the concrete and osmotic pressures. The chemical reactions between NaCl and cement paste is initiated by the adsorption of chloride ions onto the surface of C-S-H, aluminate and aluminoferrite to form Kuzel's salt ($Ca_4A_{l2}(OH)_{12}Cl(SO_4)0.5{\cdot}5H_2O$) [29] and Friedel's salt ($Ca_4A_{l2}(OH)12C_{l2}{\cdot}4H_2O$) [30]. Valenza et al. (2005) [31] and Scherer and Valenza (2005) [32] reported expansion in cement paste and concrete exposed to NaCl caused by the crystallization of Friedel's salt either through a dissolution or precipitation mechanism. The ionic exchange between the chloride and sulfate ions from hydrated monosulfoaluminate (C_3A. $CaSO_4$. $12H_2O$, AFM) can also lead to Friedel's salt formation as reported by [33]. Any form of reaction that takes place within the concrete after it has set or hardened is harmful as such reaction could lead to expansion or shrinkage within the concrete matrix.

Review of Concrete Exposed to Aggressive Environments

Numerous investigations have been conducted experimentally using accelerated approaches to study the effects of deicing salt on concrete, trying to correlate the laboratory testing with field results. Such results have been adopted by many DOTs as standards and specifications for snow fighting and/or concrete pavement maintenance guide.

Sand has been used for mobilizing high grip and friction for vehicles by many state DOTs in the past without de-freezing ice during winter seasons, but because of its fast dispersion by moving vehicles and blocking of drains, such approach has been stopped and replaced with deicing and anti-icing chemicals. Deicing chemicals are applied directly to accumulated snow to break the bond between the snow particles and the pavement/concrete surface. Anti-icing involves the application of chemicals in either aqueous or premixed granules hours before it starts snowing.

The most commonly used deicing chemicals are chloride based, which include Sodium Chloride (also known as rock salt), Calcium Chloride, and Magnesium Chloride. Each of the Chloride-based salt is known to be effective at different temperature and concentration: Sodium Chloride is efficient at temperature above 21^0F (-60 ^{0}C); Calcium Chloride at -25^0F (-320 ^{0}C); and Magnesium Chloride at 5^0F (-150 ^{0}C) [34].

Magnesium Chloride is more efficient than a mixture of Sodium Chloride and sand, it is less toxic and significantly decreases the amount of sediment entering streams and loose particles fly in the air. Thus, many state DOTs have stopped using the mixture of rock salt and sand, and they face snow fighting with liquid Magnesium Chloride [35]. In recent years, Magnesium Chloride has been reported to have greater effects on transportation infrastructure and roadside vegetation than the salt-sand mixture, which has made some local districts ban its use, and they returned to the use of Sodium Chloride-sand mixtures [35].

Organic deicers such as Potassium Acetate (KAc), and Calcium Magnesium Acetate (CMA) have recently been developed to replace mineral deicers since they are less corrosive, and lesser quantity is required as compared to mineral deicers for snow fighting. Despite this, the mineral deicers are still highly in use due to cost [15, 36]. While the organic deicers are known to be non-corrosive, it was reported to be harmful to concrete, even though the harmful effect is debatable because high water-to-cementitious materials can result in poor durability of the concrete mixtures [37, 38].

While research on the chemistry of concrete deterioration caused by deicing salt is still ongoing, the results available have shown a tremendous improvement in preventing deterioration in cold regions. Ning et al. (2016) [39] reported concentration of deicing salt; change in temperature; traffic loadings as major factors responsible for deterioration of concrete exposed to deicing salts. Farnam et al. (2015) [9]

studied the pore structure and transport properties of concrete in addition to its degree of saturation as factors responsible for concrete deterioration.

Laboratory accelerated tests usually used for studying the performance of concrete exposed to deicing salt and have been reported to exaggerate the deterioration in concrete. The accelerated laboratory testing is in contrary with concrete core samples collected from the member under exposure (15, 39). The deterioration observed from the field samples could not be completely attributed to deicing salt as was different from those observed in the laboratory.

The ingress of chloride ions from deicing salt inside concrete depends on dilution potential of the salt, surface temperature, surface condition, rate of application and removal of the deicing salt, traffic volume, average daily traffic, and the microstructure of the concrete. The microstructure of concrete is a single property that affects its intrinsic properties, such as compressive and tensile strengths, elastic modulus, permeability, porosity, diffusivity, etc. The microstructure depends on the constituent of concrete, water-to-cement ratio, degree of hydration, etc.

The source of chloride content in concrete is not only resulted from deicing salt, it can also be attributed from the surrounding environment such as mountainous and marine areas where aggregate (fine and coarse) are mined without thoroughly washing them before being used in concrete. In this case, it is very challenging to combat and address the problem. In all cases, chlorides in concrete migrate through the gel or capillary pores by different transport mechanism such as diffusion; capillary action; and convection. The transport mechanism is driven majorly by temperature and relative humidity (40).

Blended cements (mixture of ordinary Portland cement and supplementary cementitious materials) have been used in recently in concrete to produce self-consolidating concrete, high strength concrete, and ultra-high-performance concrete. Those types of concretes usually have micro to Nano-pore sizes, through the effect of extra calcium-silicate hydrate (CSH) gel. Availability of high range water reducing agent (HRWA) has also made it possible to produce good workable concrete with low water-to-cement ratio.

It is not the total chloride amount that usually leads to corrosion or deterioration. Part of the chloride is bounded or adsorbed into the Calcium-Silicate Hydrate (CSH), while the other part is free to migrate within the concrete matrix (7). It is the free chloride that leads to corrosion, by breaking the passivity protection of the steel rebars. Apart from chloride, carbonation is another attack source to concrete, where carbon dioxide (CO_2) from the surrounding atmosphere or from external sources enters the concrete and lower its pH to a value below 9. Other possible physical attacks are ASR, sulphate attack, and acid attack might lead to spalling, and concrete deterioration.

The effects of deicing salt on concrete can be broadly grouped into physical deterioration, and chemical deterioration. The physical damage is due to expansion or development of internal stress within the concrete matrix as explained by the osmotic pressure theory. This usually occurs at a temperature below the freezing point. When deicing salt is applied to concrete in aqueous form, part of the moisture is absorbed, and expands in volume at low temperature. The alternate expansion and contraction induces tensile stress in concrete, which further leads to cracks, as concrete is known to be weak in tension. Other physical damage includes salt crystallization, onion peeling (layer by layer freezing deterioration).

Chemical damage is a complex reaction between chloride ions (from the deicing salt) and hydrated CSH, or other active material within the concrete matrix. The reaction process depletes the $Ca(OH)_2$, reduces alkalinity, increases permeability, and weakens the concrete matrix. Leachate of CSH and $Ca(OH)_2$ is very disastrous in concrete, as it leads to reduction in compressive strength, elastic modulus, tensile strength, and modulus of rupture [(41)]. Concrete naturally has a high pH that ranges between 13 to 13.5. This high pH provides a passive film around steel reinforcement and prevent it from corrosion. Loss of alkalinity in concrete, make steel reinforcement highly susceptible to corrosion attack, especially pitting corrosion, and therefore results in spalling and cratering.

It is concluded from the reviewed literature that solutions exist to reduce the aggressive attack of chloride coming out of deicing salt on concrete, where one of the solutions is to reduce the parameters that could be controlled during concrete production as much as possible. Such parameters include controlling the water-cement ratio and use of SCMs to alter the pore size distribution and adjusting the pores' connectivity.

Observations from ITD Field Study

The research team has received reports of tests conducted by American Engineering Testing (AET) Inc. on hardened concrete core samples obtained from Centerline Tall Rail and Westbound Standard Rail precast concrete barriers on I-90. These barriers were cast between June 2014 and June 2015 which showed varying degrees of surface scaling and mortar flaking after winter season. The observed distress on the barriers was due to exposure of concrete to saturation and cyclic freezing and thawing, salt ingress from the snow events and spray of passing vehicles. The study concluded that the entrained air percentages in the samples were very low and did not follow the standard percentages for concrete under severe exposure. In addition, the penetration of deicers coupled with the coverage of barriers by snow, snow slushing, and the accompanied freeze and thaw cycles led to the distress observed. Figure 3 shows one of the bridge decks in District 1 experienced spalling and deterioration, while Figure 4 shows a significant spalling in a bridge rail located in the same district.

Figure 3. Large Area of Concrete Spalls with Rebar Exposed and Delamination at Midspan of the Deck

Figure 4. Concrete Spalling in a Concrete Rail (District 1)

To better understand the field deterioration caused by deicing chemicals, questionnaire for survey of practice was developed and sent to the various ITD districts within the state of Idaho. Only two responses were received (Districts 2 and 5). The questionnaire is shown in Appendix A.

In District 5, some bridges built in 1961, 1962 and 1988 were identified with different deterioration ranging from D-cracking, joint spalling, and scaling. It was reported that 23.3 percent of salt brine is commonly applied during winter seasons for easy removal of snow. There was no evident loss of friction or other negative impact of salt brine on motor vehicles, but MgCl had negative impact on vehicles which made the district adopted salt brine at 23.3 percent concentration. In District 2, some distresses were identified but no detail information was provided. The response from District 5 is shown in Appendix A-1.

Current Idaho Concrete Mixtures

The concrete mixtures design currently being used in the state of Idaho was collected and reviewed to evaluate their performance in aggressive salt and deicing environment. The mixture design for each district is shown in Appendix B and summarized in Table 1. The concrete ingredients are different from one district to the other, for example the w/cm ratios ranged from 0.38 to 0.42, the nominal maximum aggregate size range was from 0.75 to 1.5 inches. It could be observed that all the ITD mixtures contain fly ash as a SCM up to 20 percent replacement of Portland cement, except for the structural mixture (M1-SH-5) of District 1 that does not include any SCMs.

Table 1. Current Idaho Concrete Mixture Designs and Fresh Properties

District	ID	Mixture ID	Mixture Type	Coarse Agg. Content [lbs./yd^3]	Fine Agg. Content [lbs./yd^3]	Nominal Max Agg. Size [in]	w/cm	Cementitious Material Content [lbs./yd^3]	(SCMs)	Slump * [in]	SAM Number [-]
1	M1	SH-5 Bridge Crossing, Plummer	Structural	1,850	1,081	¾	0.42	611	-	3 ½	0.2
	M2	I-90 Lookout Pass Paving Mixture 2015, Mullan	Paving	1,803	1,154	1 ½	0.38	688	20% Fly Ash	1 ½	0.1
	M7	I-90 Lookout Pass Paving Mixture 2016, Mullan	Paving	1,745	1,126	1 ½	0.40	688	20% Fly Ash	1 ½	0.02
2	M3	Thain Road Paving Mixture, Lewiston	Paving	1,721	1,246	¾	0.43	611	20% Fly Ash	4 ½	0.36
	M4	US-95 Race Creek Mixture, Lewiston	Structural	1,660	1,350	¾	0.40	625	20% Fly Ash	5 ¾	0.39
3	M5	I-84 Paving Mixture, Boise	Paving	1,751	1,167	1 ½	0.40	625	20% Fly Ash	1 ¾	0.16
5	M6	US-91 Paving Mixture, Pocatello	Paving	1,720	1,043	1 ½	0.39	729	20% Fly Ash	3 ¼	0.06
6	M8	Thornton Interchange Mixture, Idaho Falls	Structural	1,762	1,005	¾	0.39	658	Fly Ash in use, but the percentage is not specified	4 ¾	0.1

*Values of slump are based on ITD' on-site tests during paving.

Deicing Chemicals

Various deicing chemicals are in use in the six (6) districts in the state of Idaho. Some of the deicing chemicals were selected by ITD personnel, which was based on experience, while some were selected based on cost as observed in the responses from the survey of practice. The commonly used chemical is the NaCl (Sodium Chloride) salt brine, made by dissolution of rock salt at 23.3 percent concentration. All the chemical deicers used in this study are summarized in Table 2.

Table 2. Summary of Deicing Chemicals

District	ID	Mixture	Application	Type of Deicer
1	M1	SH-5 Bridge Crossing, Plummer	Structural	Salt brine
	M2	I-90 Lookout Pass Paving Mixture 2015, Mullan	Paving	Salt brine
	M7	I-90 Lookout Pass Paving Mixture 2016, Mullan	Paving	Salt brine
2	M3	Thain Road Paving Mixture, Lewiston	Paving	Mag Bud Converse; Freeze Guard Plus Mag. Chloride
	M4	US-95 Race Creek Mixture, Lewiston	Structural	Mag Bud Converse; Freeze Guard plus Mag. Chloride
3	M5	I-84 Paving Mixture, Boise	Paving	Mag Bud Converse
5	M6	US-91 Paving Mixture, Pocatello	Paving	Salt brine
6	M8	Thornton Interchange Mixture, Idaho Falls	Structural	Salt brine

Chapter 2
Experimental Design

Overview of Mixes and Specimens

To evaluate the current ITD concrete mixtures' performance under aggressive salt and deicing environment, concrete specimens were made using ITD mix design. All the concrete ingredients were obtained from each district. The mixtures were mixed and reproduced in accordance with ASTM C192, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory".

Mixing Procedure

Before mixing, all the concrete constituents were brought to the temperature ranging from 68˚ to 86˚F as specified by ASTM C192. This requirement is already met for the aggregate stored inside the laboratory. The aggregate stored outside was transported to the laboratory prior to mixing with ample time to bring the aggregate to room temperature. Cement was received from Lafarge and it was stored in the laboratory under dry conditions, in closed and moisture-protected containers until mixing time.

All concrete mixtures were prepared in a rotating drum mixer. The size of the batches was designed to provide approximately 10 percent excess material after casting all the specimens. Mixing was led with flushing of the mixer with an initial concrete batch, proportioned to correspond closely to the test batch. Prior to starting the mixer, coarse aggregate was placed in the drum with a portion of the mixing water; the drum ran for a brief period to bring the aggregate to SSD condition. Fine aggregate, cement and water were added into the drum with the mixer running. Water was added into the mixture gradually, so that the predesigned slump of fresh concrete is achieved. After all ingredients were in the mixer, concrete was mixed for three minutes, then left to rest for two minutes, and finally mixed additionally for three minutes. To eliminate segregation, the mixer drum was discharged into a clean pan and then re-mixed manually by a shovel or a trowel to attain a uniform mixture and avoid segregation.

Fresh concrete tests of slump, air content and unit weight, as outlined in ASTM C143, "Standard Test Method for Slump of Hydraulic-Cement Concrete", ASTM C231, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method" ASTM C138, "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete" respectively, were performed on every concrete batch.

Specimen Preparation

According to ASTM C192, the molds for the concrete specimens should be made of non-absorbing material that does not react with cement. Molds should not undergo any shape or dimension changes under all conditions of use. Molds should be watertight. PVC and metal molds were used for casting the specimens in this project. Prior to usage, molds were lightly coated with form-release oil.

For the tests in this project, cylindrical and prismatic specimens were cast for freeze-thaw, compressive strength, wetting-and-drying, surface resistivity and soaking in deicing salt solutions testing, successively. Concrete slabs were cast to study the resistance against deicing scaling. Petrographic analysis, using Scanning Electron Microscope (SEM) and X-Ray Powder Diffraction (XRD) were conducted to study the microstructure of the concrete specimens made with current ITD mixtures. Cylindrical specimens were cast with the axis of the cylinder kept vertical, while the prismatic specimens were cast with their long axis kept horizontal. Specimens were molded close to the fog room (the mixing lab and fog room are only a few feet apart) and were transferred to be stored/cured within the first 24 hours upon casting. During casting, molds were placed on a rigid surface, and free of disturbances. Fresh concrete was placed in the molds using scoops. Material taken in each scoopful were representative of the batch. Scoop were moved around the edge of the mold as the fresh concrete was discharged to provide uniform distribution of concrete in the mold and prevent segregation. The number of lifts required for each type of specimens depended on the method of consolidation, vibration versus rodding.

For slump values less than one inch, concrete could be consolidated by vibration. Specified values of slump for all received mixture designs are given in Table 1. As seen in Table 1, specified values of slump exceed one inch, thus both consolidation methodologies may be implemented. As already stated, slump testing was performed for every concrete batch and the consolidation procedure were determined accordingly. Specified values of air content of fresh concrete are given in Table 1. As seen in Table 1, specified values of air content are between 5 and 6.5 percent for all mixture designs.

Curing of Specimens

After consolidation, specimens were finished with a trowel or a strike-off bar. To prevent excessive evaporation, freshly made specimens were covered with plastic caps or sheets of durable, impermeable plastic. Molds were removed 24 ± 8 hours after casting. After demolding, specimens were moist cured at temperature of 73.5 ± 3.5 ˚F in the fog room at relative humidity (RH) level higher than 95 percent, as defined in ASTM C511, “Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes” until the time of the designated test. According to ASTM C31, “Standard Practice for Making and Curing Concrete Test Specimens in the Field” during transportation, specimens were protected with cushioning material, to prevent the damage caused by jarring. Moisture loss was also prevented by wrapping the specimens in plastic or wet burlap.

Laboratory Testing

As outlined above, specimens were cured until the time of designated testing. The following subsections describe each of the laboratory tests conducted.

Compressive Strength

Compressive strength (f'_c) test was performed in accordance with ASTM C39, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens". The test was conducted on 6-inch on diameter cylindrical specimens, at 7-, 14-, 28- and 90-day ages. Four specimens from one batch were tested on each test day. Prior to the testing, the weight of the specimens as well as the length and diameter were recorded.

Prior to testing, all specimens were capped on both ends with gypsum caps to provide a uniform surface for load distribution. The loading rate corresponded to 35 ± 7 psi/sec as stress rate on the specimen. The compressive load was applied until the load indicator shows an abrupt decrease and the specimen presents prominent crack patterns. Compressive strength was calculated by dividing the maximum load attained during the test by the surface area of the specimen, based on the average diameter measurement.

Rapid Freeze-Thaw Cycling Test

Freeze-thaw (F-T) resistance of concrete was characterized by ASTM C666. Prism specimens of size 3 x 3 x 11 inches were unmolded and cured in the moist curing room at temperature equals 73 °F and relative humidity 98% for 14 days. Subsequently, prisms were placed in aluminum pans, positioned in the F-T cabinet (Figure 5). Water was poured at the bottom of each pan so that 3-mm water level is created around each specimen. The water level was maintained throughout the entire testing period consisting of 300 F-T cycles. The nominal F-T cycle consists of alternating the exposure temperature from 40 to 0 °F (4 to -18°C) and from 0 to 40°F (-18 to 4°C) for the periods between 2 and 5 hours. The F-T system uses a control specimen for the automatic temperature regulation in the F-T cabinet (Figure 5). A proper functioning of the cabinet was verified by four thermocouples (TCs) attached to the specimens and utilized for temperature monitoring throughout the testing. Example of temperature variation with time based on TC data is presented in Figure 6. On average, specimens were subjected to five to six F-T cycles per day. Two or three prisms per mixture design were tested on F-T resistance.

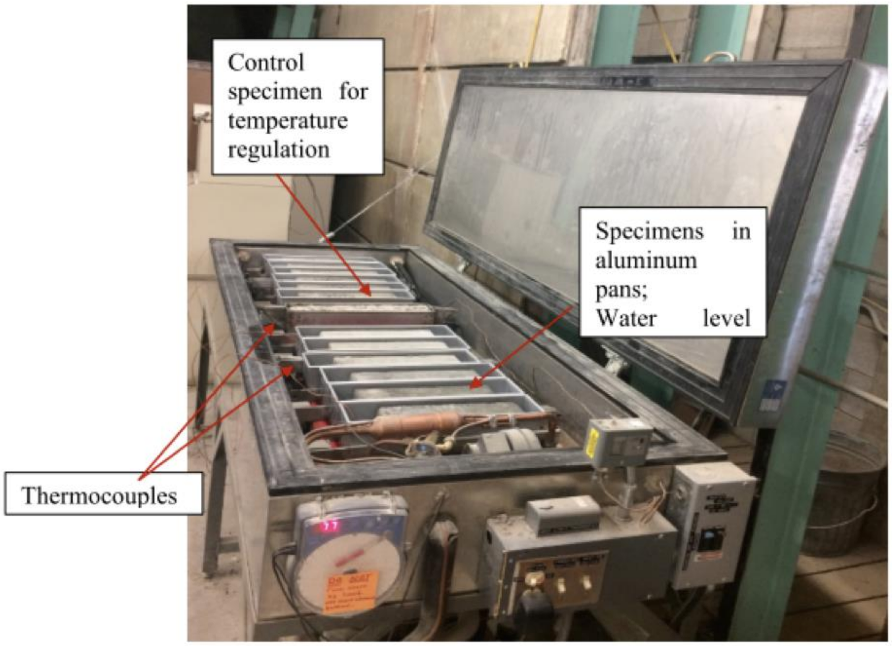


Figure 5. Freeze-Thaw (F-T) Cabinet with Concrete Prisms Subjected to F-T Testing

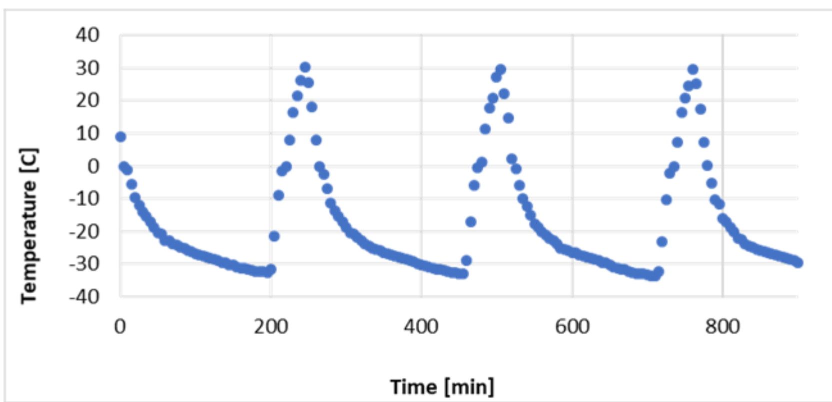


Figure 6. Example of Temperature Cycles Inside the F-T Cabinet During F-T Cycles

Resistance against Deicing Scaling

The resistance against deicing scaling test was conducted according to ASTM C 672/C 672M. The test was performed on slab specimens with dimensions 11.25 x 11.25 x 3.25 inches, after 28 days of moist air curing. According to ASTM C 672, it is suggested that other deicing chemical instead of $CaCl_2$ could be used in different concentrations instead of the 3 to 4 percent to evaluate the specific effect of the deicing chemical and its concentration. Therefore, in this study, salt brine solution was used at 23.3 percent concentration as currently being used by ITD (reported by District 5 as shown in Appendix A-1). The other deicing chemicals (Mag Bud converse; and Freeze guard plus Magnesium Chloride) were converted to the equivalent concentration of 23.3 percent using the molarity ratio calculations to ensure that the amount of chloride in each ponding height of 6 mm (0.25 inch) is 23.3 percent. Although, the concentration of the deicing salt is high, a similar test conducted by Shi et al. (2014) [42] for Oregon DOT

(SPR 742) a 15 percent concentration of $MgCl_2$ and NaCl was used for deicing scaling resistance and F/T cycle test which was like the concentration being used in the field.

The four top surface edges of the slabs were taped with aluminum tape and sealed with silicone sealers to prevent leakage when ponded with deicing chemicals as shown in Figure 7. The top surfaces of the slabs were covered with ¼ inch of deicing chemical solution and kept in a freezing environment; -18 ± 3 degrees Celsius (0 ± 5°F) (Figure 8) for 16 to 18 hours. The frozen specimens were removed from the freezing chamber and kept in laboratory air at 73.5 to 77°F, and at relative humidity of 45 to 55 percent for 6 to 8 hours. The deicing chemical was added to maintain sufficient depth of solution, while flushing the surface thoroughly after every 5 cycles. The specimens were visually inspected after 5 to 50 cycles, and rated according to their surface conditions, which ranges between 0 and 5, with 0 implying no scaling, and 5 represents severe scaling.

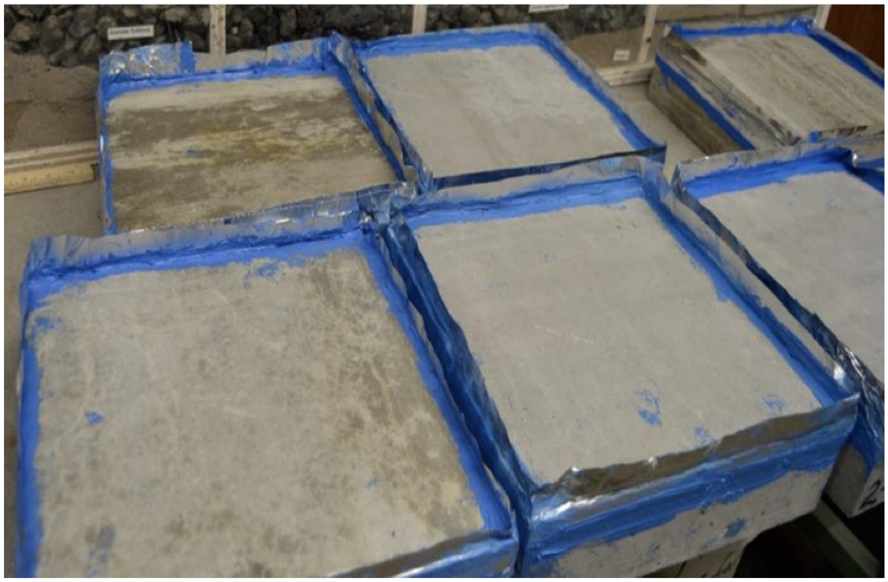


Figure 7. Slab Preparation for Surface Ponding

Figure 8. Slabs Exposed to Freezing Environment During Deicing Scaling Test

Concrete Surface Resistivity

Concrete surface resistivity is a non-destructive test conducted on cylindrical specimens according to the procedure outlined in AASHTO T358 “Standard Method of Test for Surface Resistivity Indication of Concrete’s Ability to Resist Chloride Ion Penetration”. In this project, the test was performed on 4-inch diameter cylindrical specimens using Proceq resistivity meter. The surface resistivity was conducted on 3 specimens per mix per district. Each specimen was marked at four quadrants representing 0, 90, 180 and 270 degrees, and two readings per quadrant were taken in the order of the marked angles to ensure consistency and no significant differences between the operator or the equipment. The surface resistivity measures the degree to which the concrete sample resists the flow of an electrical current. While the solid material in concrete has a relatively high resistivity, the pores are usually partially or fully saturated with a concentrated alkaline solution that has a relatively low resistivity. Thus, the flow of electrical current through the pore solution, gives an indirect measure of the quality of the microstructure of the concrete. The specimens were tested using the Wenner four-electrode test, which consists of four equally spaced, co-linear electrodes place in contact with a concrete cylinder specimen. The testing procedure involves passing alternating current to the outermost electrodes and measuring the voltage between the middle two electrodes to calculate its resistance. The specimen resistivity was then calculated using the resistance, length between the electrodes, dimensions of the cylinder specimen and necessary correction factor. The surface resistivity meter is shown in Figure. 9.

Figure 9. Surface Resistivity Testing

Scanning Electron Microscope

Fracture pieces from the slabs used for resistance against deicing scaling at different depth were observed under a scanning electron microscope to determine the depth of penetration of the deicing chemicals. The formation of chemical compounds was observed but such compounds would need further testing like thermal gravimetric analysis to accurately determine the compound form.

Continuous Soaking

This test aims to study the deterioration of concrete microstructure after 90 days of continuous submerging in deicing chemical solutions. The cylindrical specimens were soaked (Figure 10) in salt solutions obtained from Districts 1, 2, 3, 5, and 6. The cylinders were 455 days (1 year and 3 months) age before soaking because they were from RP 253 project. After 90 days, the specimens were tested under uniaxial compression to investigate the loss in strength (ASTM C39). Two reference cylinder specimens were moist cured in the humidity chamber for 90 days and tested under uniaxial compression on the same day of testing the soaked specimens.

Figure 10. Concrete Specimens under Continuous Soaking

Required Specimens for Experiment Plan

Most of the specimens required for the tests were taken from the specimens left from RP 253 research project, except for the slabs and the beams for F-T test. The remaining specimens were cast as previously described. The number of specimens for each test is summarized in Table 3.

Table 3. Summary of Number of Specimens Required for Each Test

District	Type of Deicer and Concentration	Surface Resistivity	Resistance to Deicing Scaling	Freeze-Thaw Cycling Test
1	23.3% concentration of Salt brine	9	6	2
2	Mag bud converse; Freeze guard plus Magnesium Chloride; and Compass wet Salt	6	12	2
3	Mag Bud Converse	3	2	2
5	Salt brine	3	2	2
6	Salt brine	3	2	2

Chapter 3
Experimental Results

Introduction

Correspondence with all six districts of ITD was established, except for District 4 where aggregates were not received to cast concrete samples for testing. All testing procedures were performed on the designated test dates. Surface resistivity tests, F-T cycles, resistance to surface scaling, continuous soaking have been completed for the tested mixtures. The following subsections provide the summary of the results of the completed tests.

Surface Resistivity Test Results

The results of the surface resistivity can be used to correlate the likelihood of corrosion of embedded steel in the concrete samples using the AASHTO T358. The measured results are tabulated in Table 4. The ITD field test results for I-90 shows surface resistivity of moderate to low resistance of the concrete mixture to resist chloride ion penetration. The surface resistivity meter measures up to 400 Kilo Ohms-Cm.

Table 4. Summary of Surface Resistivity Test Results

District	Mixture ID	Application	Resistivity (Kilo-Ohms Cm)	Standard Error	Remarks
1	SH-5 Bridge Crossing, Plummer	Structural	17.9	0.4	Moderate risk
	I-90 Lookout Pass Paving Mixture 2015, Mullan	Paving	75.0	1.0	Low risk
	I-90 Lookout Pass Paving Mixture 2016	Paving	73.2	0.5	Low Risk
2	Thain Road Paving Mixture, Lewiston	Paving	64.6	1.2	Low Risk
	US-95 Race Creek Lewiston	Structural	93.9	5.4	Low Risk
3	I-84 Paving Mixture, Boise	Paving	90.6	0.9	Low Risk
5	US-91 Paving, Pocatello	Paving	104.0	0.3	Negligible Risk
6	Thornton Interchange Mixture, Idaho Falls	Structural	109.8	6.9	Negligible Risk

Scaling Resistance to Deicing Chemicals

The deicer scaling tests were conducted according to ASTM C672. Figure 11 shows the specimens after the test cycles, where the results are summarized in Table 5. District 1 structural mixture specimen (SH-5 Bridge crossing, Plummer) displayed a severe scaling, with visible coarse aggregate over the entire surface. The result is in accordance with those available in literature as specimens from District 1 were made from 100 percent cement deteriorated faster when slabs were tested for scaling resistance [43].

District 2 specimens displayed slight to moderate scaling but severe Alkali-Silica-Reaction (ASR) cracks over the entire slab surface (extensive crack networks were observed). The ASR cracks extended to the edges of the slabs. Various researchers [44-49] have reported that deicing chemicals (especially NaCl) can provide extra alkalis (by producing soluble alkalis and increasing the pH due to the formation of NaOH) to react with the reactive aggregate thereby accelerating ASR. It can be observed from Table 4, that all mixtures with similar w/cm of 0.38-0.39, displayed no scaling to very light scaling except District 1 mixture which showed severe scaling. Based on the ASR observed, it is suggested to evaluate the district 2 aggregates for ASR because reports have shown that Mag. Chloride does not provide alkalis, it lowers the pH due to formation of brucite. Sodium chloride, though, increases the soluble alkalis and pH due to formation of Sodium Hydroxide. The rating index was done according to the ASTM C 672 recommendations.

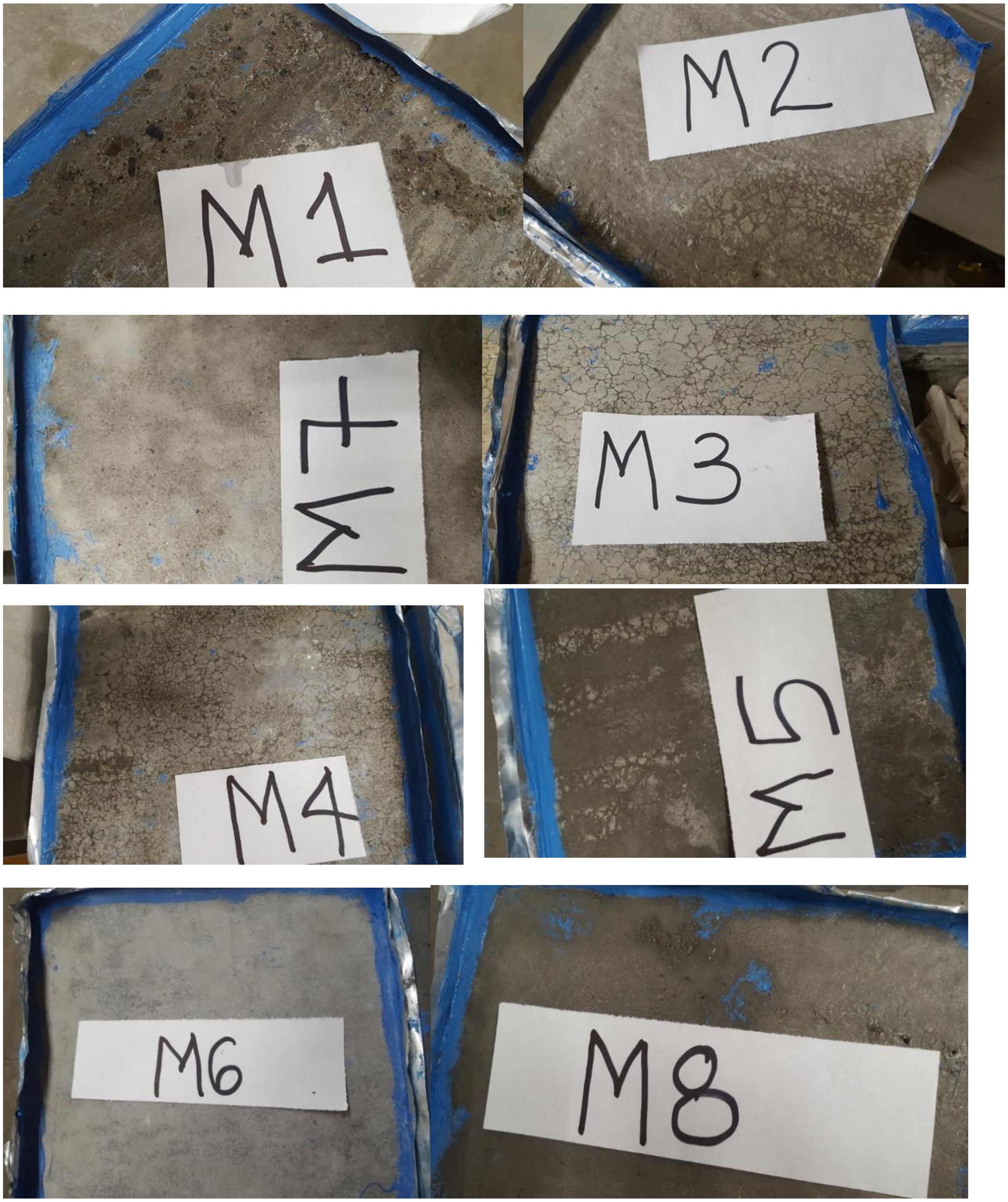


Figure 11. Slabs after Deicing Scaling Resistance Test

Table 5. Summary of Scaling Resistance Test

District	ID	Mixture	Application	Slump, (in)- Field Values	w/cm	SCMs (%)	Type of Deicer	Visual Rating
1	M1	SH-5 Bridge Crossing,	Structural	3 (3 ½)	0.42	None	Salt brine	5.0 (severe)
	M2	I-90 Lookout Paving Mixture 2015,	Paving	1 (1 ½)	0.38	20 Fly Ash	Salt brine	1.0
	M7	I-90 Lookout Paving Mixture 2016,	Paving	1 ½ (1 ½)	0.40	Not available	Salt brine	2.0
2	M3	Thain Road Paving Mixture, Lewiston	Paving	3 (4 ½)	0.43	25 Fly Ash	Mag Bud Converse; Freeze Guard plus Mag. Chloride	2.0 and Alkali Silica Reaction
	M4	US-95 Race Creek Mixture, Lewiston	Structural	5 (5 ¾)	0.40	25 Fly Ash	Mag Bud Converse; Freeze Guard plus Mag. Chloride	2.0 and Alkali Silica Reaction
3	M5	I-84 Paving Mixture,	Paving	1 ¾ (1 ¾)	0.40	25 Fly Ash	Mag Bud Converse	2.0
5	M6	US-91 Paving Mixture,	Paving	3 ¼ (4 ¼)	0.39	25 Fly Ash	Salt brine	1.0
6	M8	Thornton Interchange Mixture,	Structural	4 ½ (4 ¾)	0.39	Fly Ash (mix design did not specify %)	Salt brine	2.0

Continuous Soaking

As previously described, all the specimens were soaked continuously for 90-days in deicing chemicals at a temperature of 5°C (41°F) to promote the formation of Oxychloride compounds. As shown in Figure 12, the specimens soaked in mag-bud converse, and freeze guard plus magnesium chloride (M3, M4, and M5) displayed heavy deterioration of ASR with concrete spalling and severe cracks extended to the whole surface of the specimens with major signs of spalling, while those soaked in salt brine had mild to moderate deterioration except M2 where it showed major concrete spalling. The ASR cracked pattern observed on the concrete cylinders can be confirmed by petrographic analysis, which forms part of the suggested tests to be conducted in the future.

Figure 12. Concrete Specimens after 90 Days Continuous Soaking in Deicing Salt

Compressive Strength Test Results

The compressive strength test was conducted on the specimens used for continuous soaking. The specimens were soaked continuously for 90 days in deicing chemicals and tested under a uniaxial compression test at a standard loading rate (ASTM C39). The obtained results are summarized in Table 6. It can be observed that District 5 mixture (US-91 Paving Mixture, Pocatello) and District 6 (Thornton Interchange Mixture, Idaho Falls) suffered the highest strength loss, while the Thain road paving mixture, Lewiston showed negligible strength loss. Minimum of two specimens were soaked for 90 days and after 90 days, the specimens were tested under axial compression. The results were compared to two un-soaked reference specimens that were moist cured in the curing room till the day of testing. The compressive strength of the referenced specimens at ages beyond 28-days was predicted using ACI 209.2R-08 Equations given by:

$$f_{cmt} = \left[\frac{t}{a+bt}\right] f_{cm28} \qquad (1)$$

Where,

f_{cmt} is the compressive strength at any time *t*, in days;

f_{cm28} is the compressive strength at 28 days;

a, b are constants depending on the type of cement used and method of curing; and

t is the age of the concrete in days.

F-T Cycle Test Results

Results of the fresh properties of the concrete specimens and comparisons with ITD standard field tests (in parenthesis) are shown in Table 1. All specimens were fully thawed, tested for mass loss and characterized in terms of modulus of elasticity (*E*), as showed in Figures 13 and 14. E-testing was performed by a non-destructive (ND) sonic pulse velocity characterization, using Metriguard 239, a stress wave timer.

Results in Figure 14 show that the residual elastic moduli after 300 cycles range from 76.0 to 83.3 percent of the initial moduli for all tested mixtures. Considering the requirements of ASTM C666, which specify 60 percent of initial *E* as a failure criterion, it can be concluded that all tested mixtures exhibited satisfactory F-T resistance. Mixtures M1 and M2 from District 1, demonstrated the highest percentage in residual *E* among tested mixtures (83.3 and 80.0 percent, respectively), while the mixture M8 from District 6 showed the lowest percentage of initial E (76.0 percent). The differences in percentage of retained stiffness are not substantial among mixtures, therefore it was not possible to draw clear trends of the impact of air content or SAM number on the mixtures durability. Recommended values for SAM (Tanesi et al., 2016) number equal or lower than 0.2 were attained by all mixtures except M3 and M4 (Table 1). Nevertheless, these two mixtures demonstrated adequate F-T resistance based on results in Figure 14.

Mass loss due to freezing and thawing presented in Figure 13, reveals that the tested specimens exhibited mass losses below 0.6 percent. The two mixtures with highest mass losses are the two structural mixes from District 2 (M3 and M4). Severe surface scaling in the bottom of the tested prims seen in Figure 15 (c) and (d), which contributes to relatively high mass losses of these mixtures. Specimens cast out of M3 and M4 retained 79.7 and 76.9 percent of the initial *E*, which indicates that structural integrity of these specimens is not substantially compromised as the effect of F-T cycles. Nonetheless, surface scaling, particularly in the presence of deicing chemicals can impair the serviceability and service lives of structures cast out of these mixtures. Mixture M5 from District 3 is characterized by lowest mass loss, at 1.61 percent after 300 cycles. Comparison with fresh concrete test results (Table 1) suggests that mixtures with higher SAM number also exhibited higher mass loss, while the prominent correlation between mass loss and air content cannot be established.

Table 6. Summary of Compressive Strength Test Results

District	ID	Mixture	Application	f'_c-28 days (Psi) (Standard deviation [psi])	f'_c- 548 days (control- without soaking) (Psi) (Standard deviation [psi])	f'_c- 548 days after soaking (Standard deviation [psi])	Type of Deicer	Percent Loss
1	M1	SH-5 Bridge Crossing, Plummer	Structural	4870 (160)	6885 (20)	6230 (35)	Salt brine	10.52
	M2	I-90 Lookout Pass Paving Mixture 2015, Mullan	Paving	5510 (240)	7790 (35)	6740 (55)	Salt brine	15.58
	M7	I-90 Lookout Pass Paving Mixture 2016, Mullan	Paving	4640 (210)	6380 (25)	5600 (25)	Salt brine	13.92
2	M3	Thain Road Paving Mixture, Lewiston	Paving	5160 (260)	7095 (50)	6970 (25)	Mag Bud Converse;	1.79
	M3	Thain Road Paving Mixture, Lewiston	Paving	5160 (260)	7095 (65)	7140 (35)	Freeze Guard plus Mag. Chloride	0.63
	M4	US-95 Race Creek Mixture, Lewiston	Structural	6900 (130)	9487 (45)	8170 (55)	Freeze Guard plus Mag. Chloride	16.12
	M4	US-95 Race Creek Mixture, Lewiston	Structural	6900 (130)	9487 (55)	7310 (60)	Salt brine	29.78
3	M5	I-84 Paving Mixture, Boise	Paving	5590 (220)	7686 (65)	4500 (45)	Mag Bud Converse	70.80
5	M6	US-91 Paving Mixture,	Paving	5080	6985	5430	Salt brine	

		Pocatello		(120)	(55)	(30)		28.63
6	M8	Thornton Interchange Mixture, Idaho Falls	Structural	4310 (150)	5545 (75)	3620 (55)	Salt brine	53.17

Excluding mixtures M3 and M4 [see Figure 15 (c) and (d)], Figure 15 shows that the tested specimens after the entire F-T test exhibited some calcium leaching on the surface due to the prolonged contact with the water, minor damage on the surface, and overall good structural integrity, consistent with a satisfactory F-T performance elaborated above.

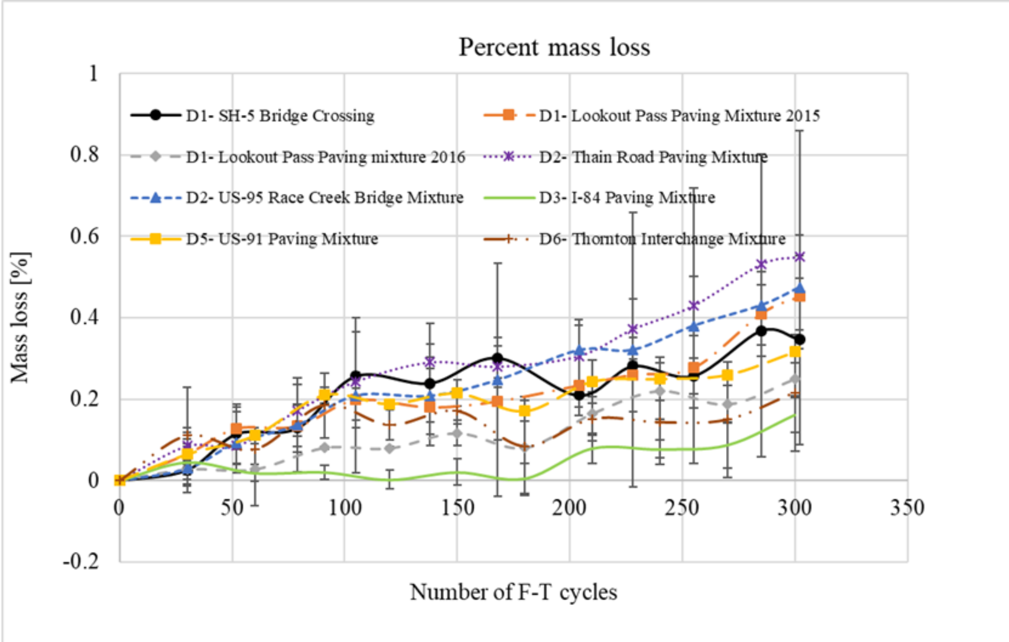


Figure 13. Specimens Mass Loss under F-T Cycle Tests

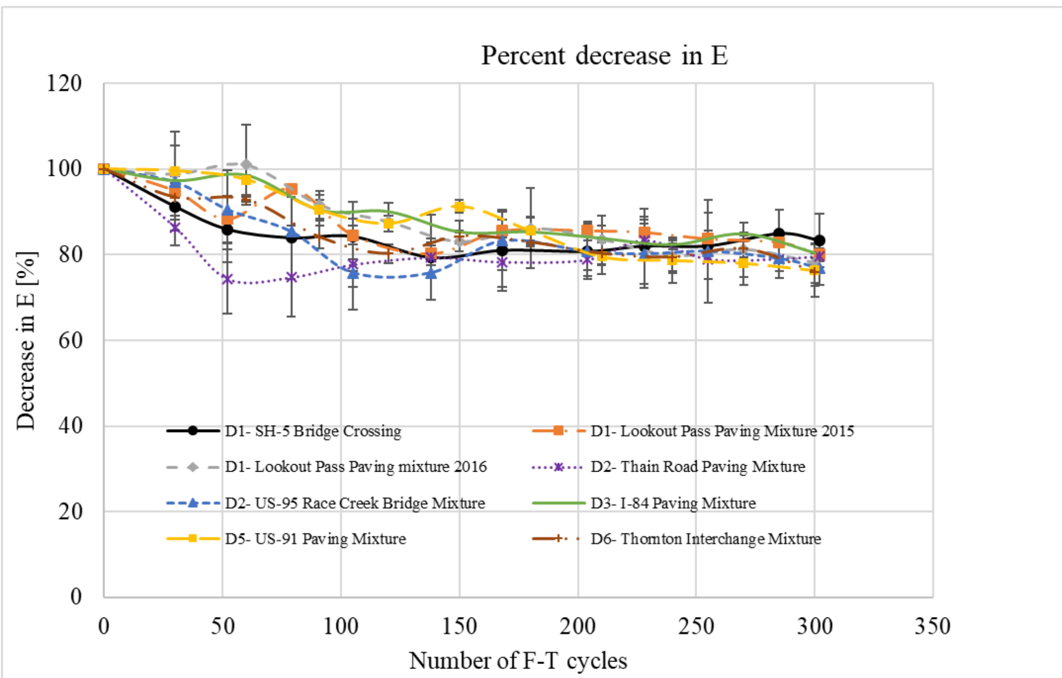
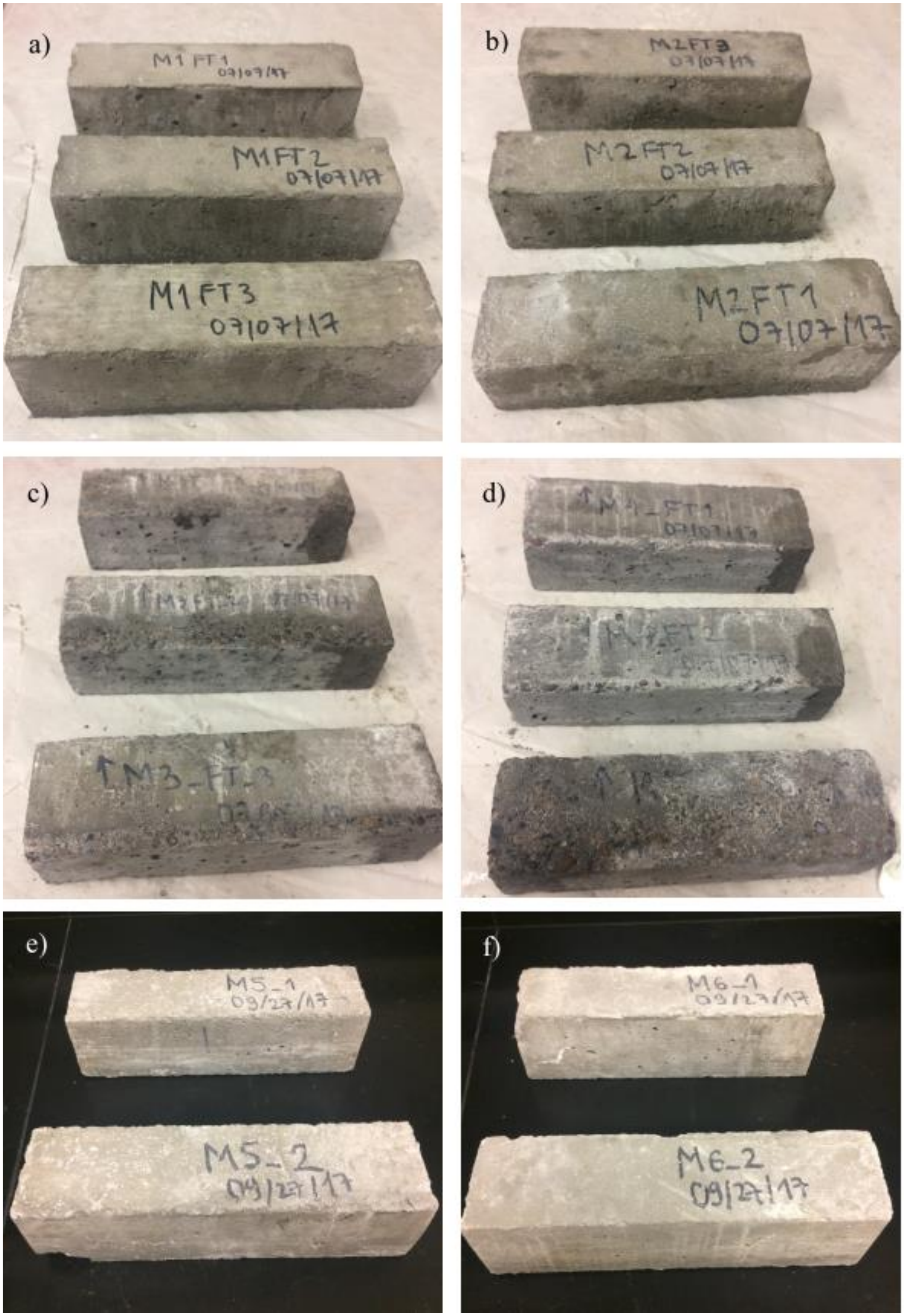


Figure 14. Variation in Elastic Modulus in F-T Cycle Test


a)
M1 FT1
07/07/17
M1FT2
07/07/17
M1FT3
07/07/17
b)
M2FT3
07/07/17
M2FT2
07/07/17
M2FT1
07/07/17
c)
d)
e)
M5_1
09/27/17
M5_2
09/27/17
f)
M6_1
09/27/17
M6_2
09/27/17

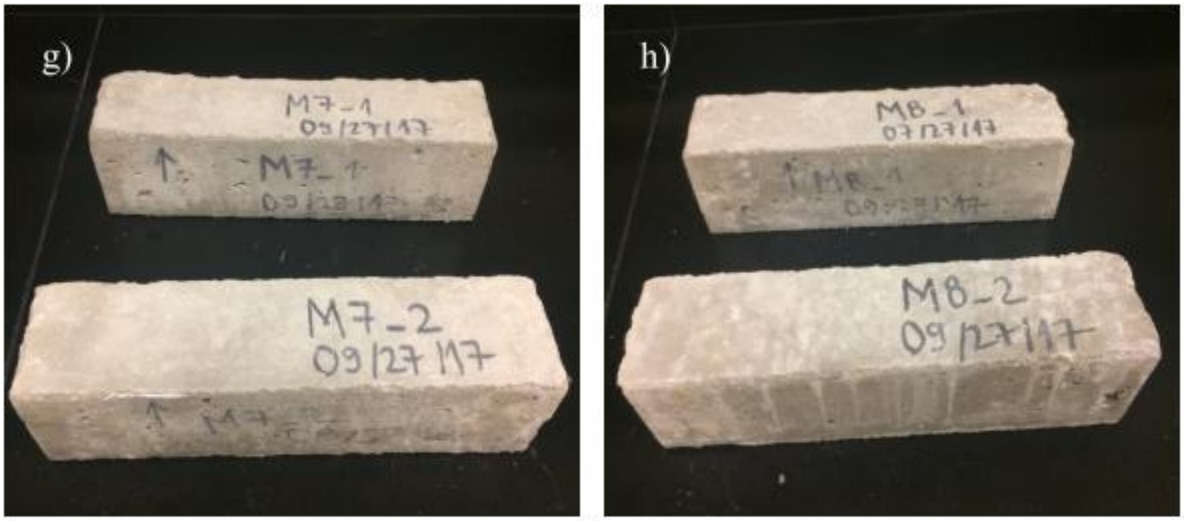
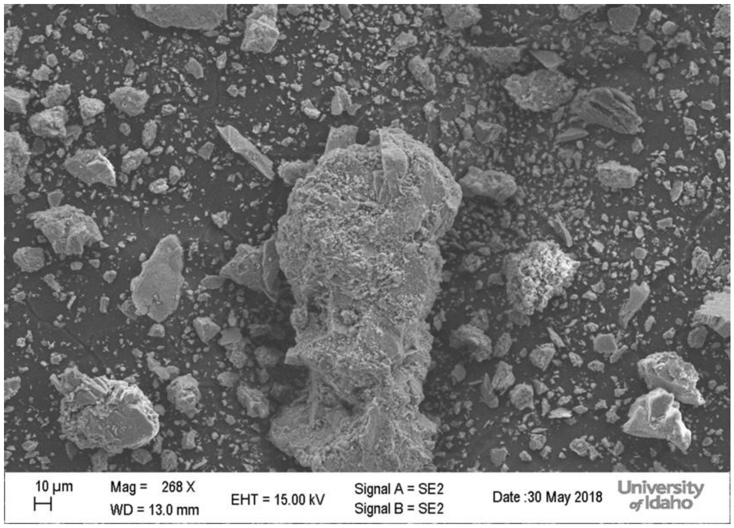


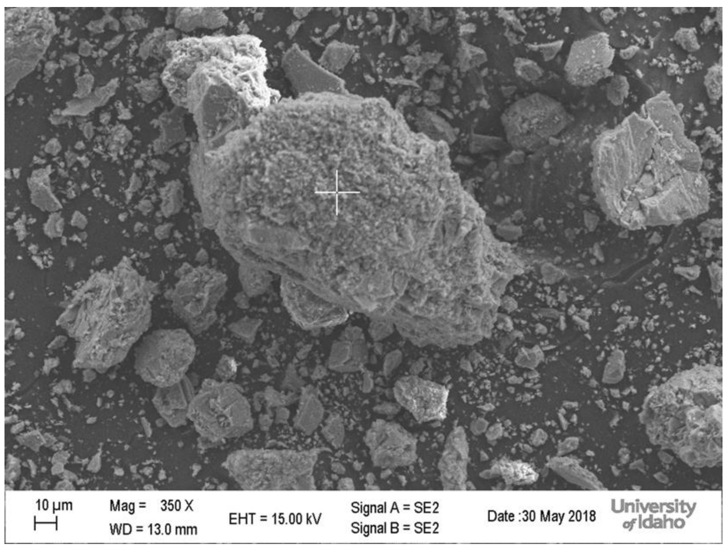
Figure 15. 300 F-T Cycles Results: a) M1, b) M2, c) M3, d) M4, e) M5, f) M6, g) M7, h) M8

Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Analysis (EDX)

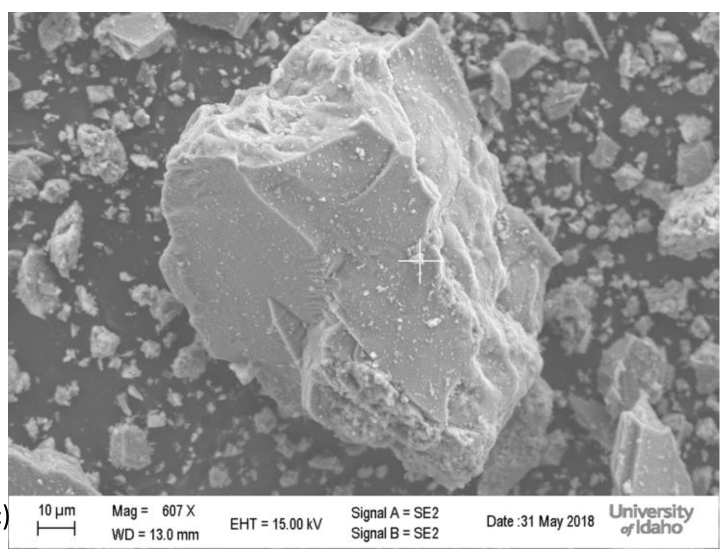
Concrete samples (powders) were taken from the slabs used for resistance against deicing and viewed under scanning electron microscopy to detect the likelihood of the formation of new chemical compounds in the concrete microstructure, and at different depths. The concrete samples were used for the energy dispersive x-ray test (EDX) to evaluate the chemical analysis of the constituent of the concrete. The concrete samples exposed to salt brine displayed high content of chloride at a depth up to 1 inch. Although, new chemical compounds were suspected in the concrete based on the SEM images (Figure 16), but the actual compound could not be determined without performing the thermal gravimetric test (out of this project’s scope) or detailed chemical analysis. Of notable interest is the EDX shown in Figure 17, which displays presence of chloride in the mixture at certain depth. The concentration of the chloride could not be determined, therefore, acid soluble chloride would be done to determine chloride concentration and comparing same with values prescribed by American Concrete Institute (ACI 222).


10 µm
Mag = 268 X
WD = 13.0 mm
EHT = 15.00 kV
Signal A = SE2
Signal B = SE2
Date :30 May 2018
University of Idaho

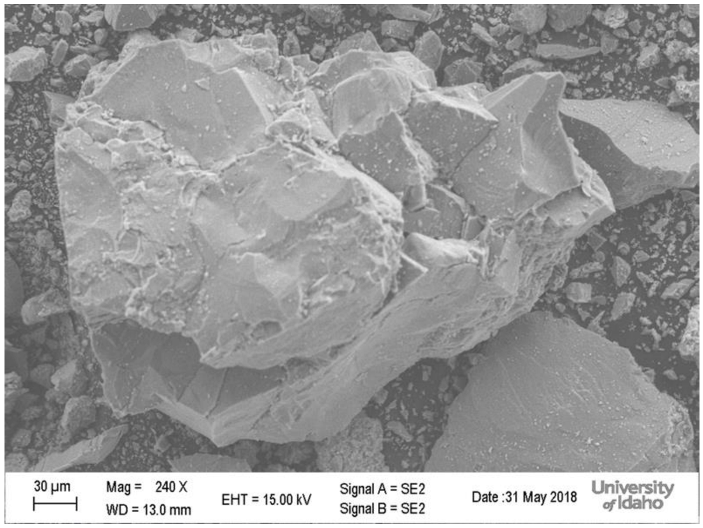
a)


10 µm
Mag = 350 X
WD = 13.0 mm
EHT = 15.00 kV
Signal A = SE2
Signal B = SE2
Date :30 May 2018
University of Idaho

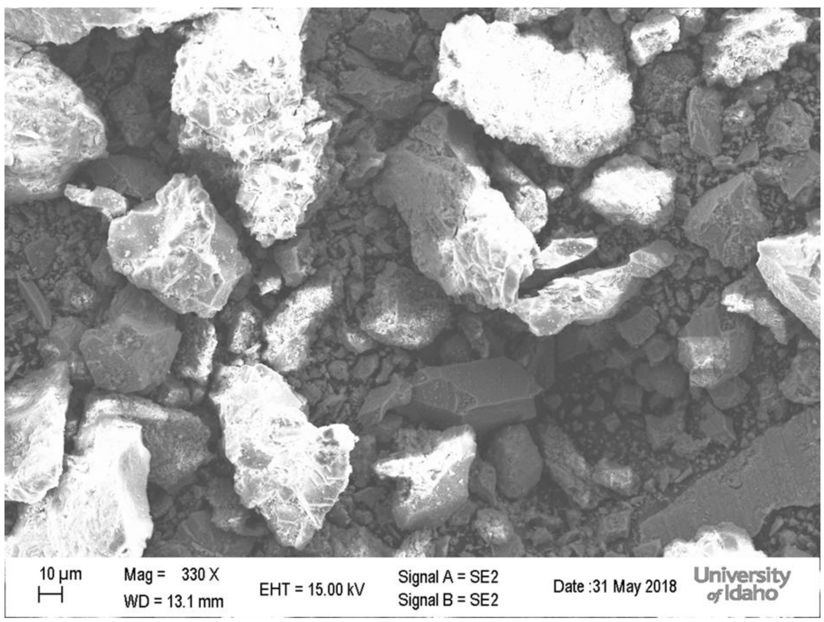
b)


10 µm
Mag = 607 X
WD = 13.0 mm
EHT = 15.00 kV
Signal A = SE2
Signal B = SE2
Date :31 May 2018
University of Idaho

c)


30 µm
Mag = 240 X
WD = 13.0 mm
EHT = 15.00 kV
Signal A = SE2
Signal B = SE2
Date :31 May 2018
University of Idaho

d)


10 µm
Mag = 330 X
WD = 13.1 mm
EHT = 15.00 kV
Signal A = SE2
Signal B = SE2
Date :31 May 2018
University of Idaho

e)

f)

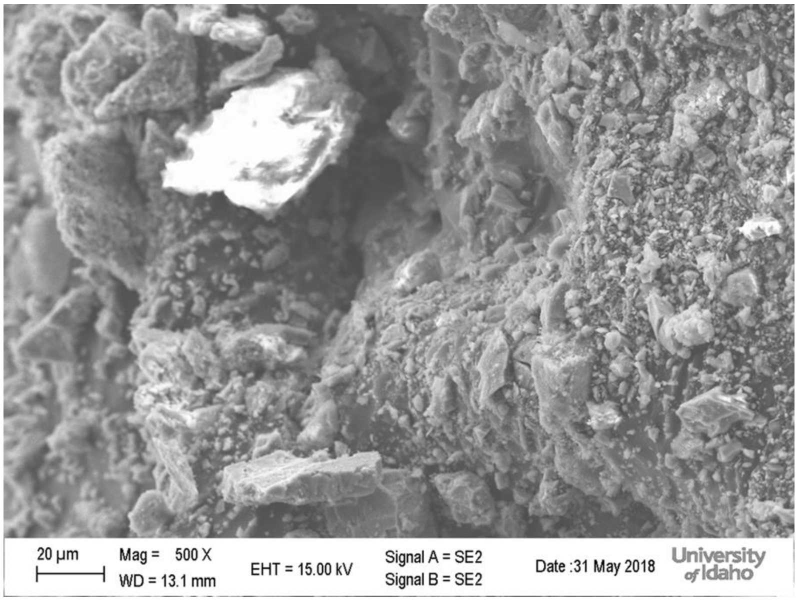
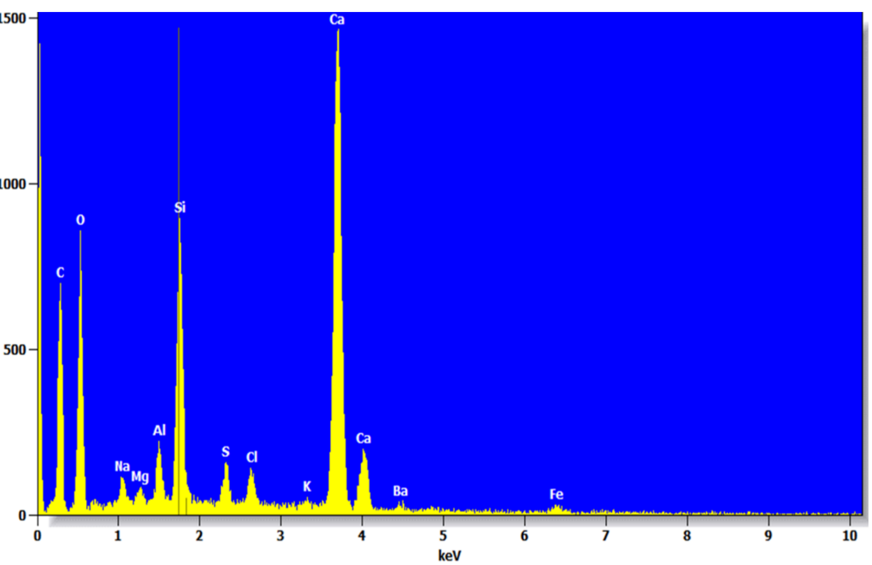
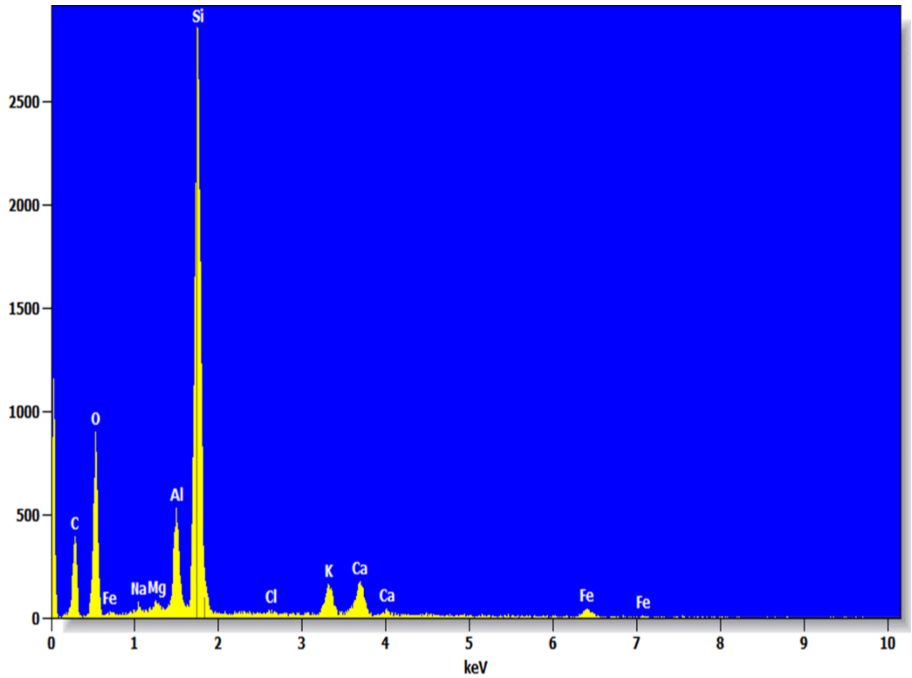


Figure 16. SEM Images for: a) M1 at 0-0-5'' b) M1 at 0.5-1.0''c) M8 at 0-0-5'' d) M8 at 0.5-1.0'' e) M4 at 0-0-5'' f) M4 at 0.5-1.0''

a)



b)

Si
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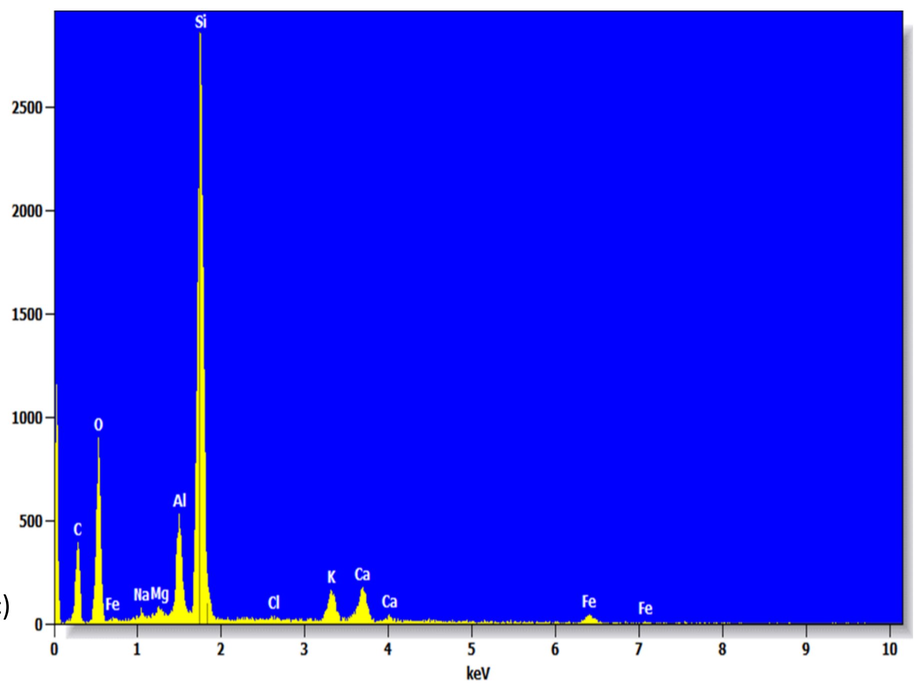
c)

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keV

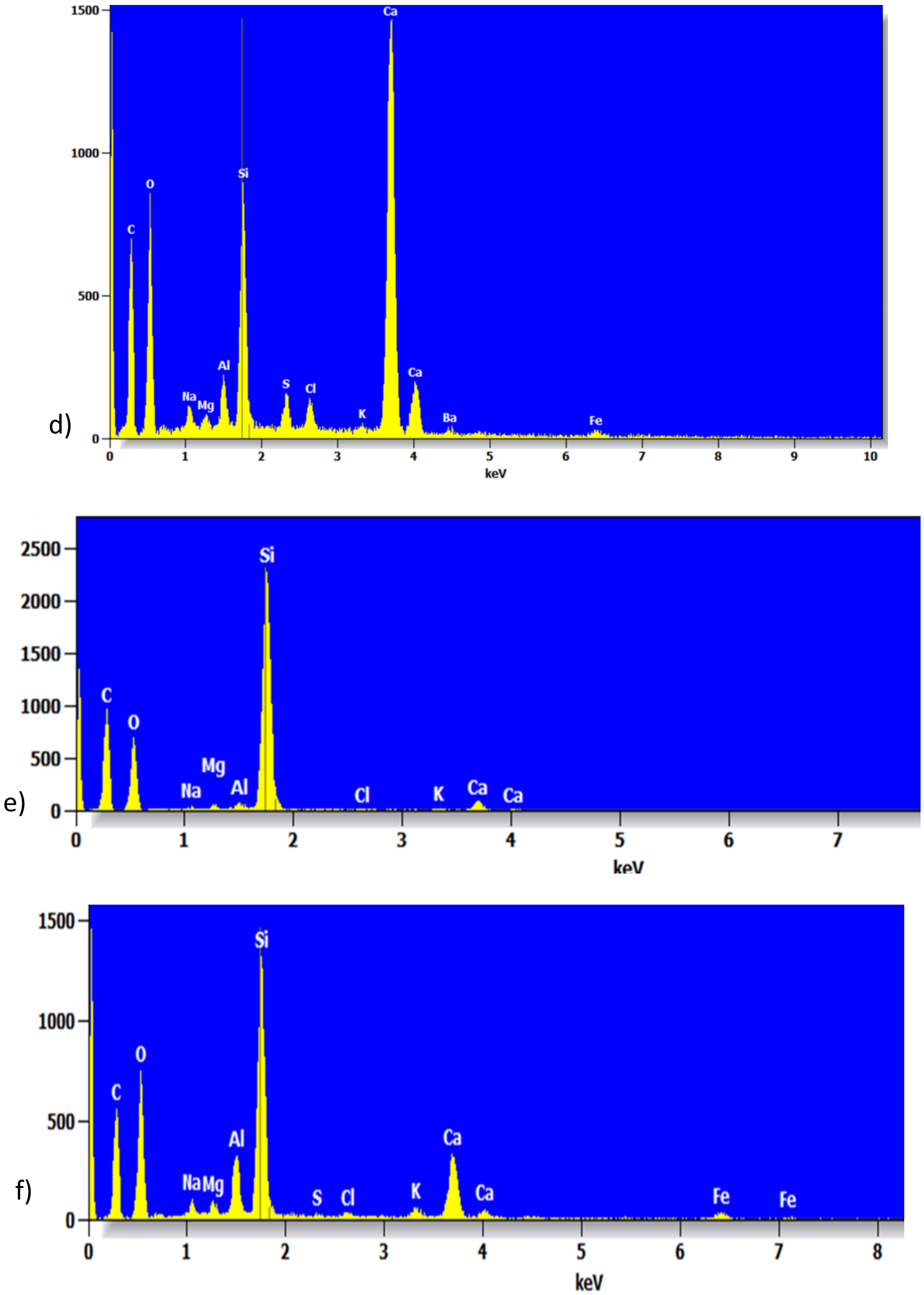


Figure 17. EDX Images a) M1 0-0-5'' b) 0.5-1.0'' c) M8 0-0.5'' d) 0.5-1.0'' e) M4 0-0.5'' f) 0.5-1.0''

Acid Soluble Chloride Test

The acid soluble chloride test was conducted according to ASTM C 1152-04. The test provides procedures for determining the concentration of acid soluble chloride in mortar and concrete. This test was done on the structural mixtures (District 1-M1; District 2-M4; and District 6-M8) because of the importance of the mixes in reinforced concrete members such as bridge barriers and decks. If the free chloride concentration at level of the rebar exceeds the threshold value prescribed by ACI 222, the chances of corrosion will be higher which could lead to loss of load carting capacity of the member. Powdered concrete samples were taken at different depths and titrated against 0.05 N Silver Nitrate ($AgNO_3$). The chloride concentrations are summarized in Table 7. It should be noted from the Table that District 1 concrete mixture had the highest chloride transport properties as visible in the concentration of the chloride that has diffused through the concrete within a short period of exposure to deicing chemical (90 days). Concentration above the threshold value was visible at a depth up to 1 inch. This same mixture displayed the highest scaling in the scaling resistance test. Similar result was observed in District 6-M8 mixture. It could be stated that the salt brine penetrates deeper than the Mag bud converse deicing chemical being used in District 2 (M4-US 95 race creek mixture, Lewiston).

Table 7. Summary of Acid Soluble Chloride Test

District	Basic Mixture ID	Depth (in)	Acid Soluble Chloride	ACI 222 (Table 3.1-Threshold)
1	(M1) SH-5 Bridge Crossing, Plummer	0.0-0.5	0.1240	0.1000
		0.5-1.0	0.1050	
		1.0-1.5	0.0850	
		1.5-2.5	0.0628	
		2.5-3.0	0.0587	
2	(M4) US-95 Race Creek Mixture, Lewiston	0.0-0.5	0.0754	0.1000
		0.5-1.0	0.0563	
		1.0-1.5	0.0432	
		1.5-2.5	0.0382	
		2.5-3.0	0.0105	
6	(M8) Thornton Interchange Mixture, Idaho Falls	0.0-0.5	0.1109	0.1000
		0.5-1.0	0.1010	
		1.0-1.5	0.0795	
		1.5-2.5	0.0653	
		2.5-3.0	0.0553	

Summary of the Results

The results of the surface resistivity, continuous soaking, resistance to scaling and freeze-thaw testing that have been conducted on the concrete mixtures from six districts in the state of Idaho were presented above. The goal from this project was to evaluate the performance of the pavement and structural concrete mixtures currently used in the state of Idaho.

From the test results, district 1 structural mixture (SH-5 Bridge crossing, Plummer) suffered a severe scaling, while other specimens showed mild to moderate scaling. The reason for the severe scaling in the structural mix for District 1, could be attributed to the absence of supplementary cementitious materials such as fly ash that inhibits the formation of Calcium Oxychloride (CAOXY) as stated by (Suraneni et al. 2016) [(50)]. District 2 structural and paving mixtures (M3 and M4) showed some evidence of Alkali Silica Reaction because of the reactive aggregate and that was evidence when district 2 specimens were exposed to Magnesium Chloride under several cycles of deicing chemical conforms with the results available in [(50)] (Suraneni et al. 2016).

The surface resistivity results showed that district 1 structural mixture has a moderate resistivity which match what has been found from the scaling test. Moderate risk of corrosion and that confirms what has been observed in the field study that previous performed by ITD in terms of concrete spalling in some places and the existence of corrosion signs.

Similarly, it was observed that all the concrete mixtures currently in use by ITD districts perform satisfactorily under F-T cycle, as evidenced by relatively high percentage retained elastic modulus and relatively low mass losses after being subjected to a total of 300 F-T cycles. The differences in percentage of retained stiffness are not substantial among all the concrete mixtures, therefore it is not possible to draw clear trends of impact or air content or SAM number on this parameter.

In the next phase, alternative concrete mixtures were proposed and evaluated under the same testing matrix that has been done to the current mixtures. The proposed mixtures were suggested and agreed by ITD personnel to focus on structural mixtures (District 1- SH-5 Bridge crossing (M1), Plummer; District 2-US-95 Race Creek Mixture (M4), Lewiston and District 6structural mixture (M8)-Thornton Interchange, Idaho Falls).

Chapter 4
Alternative Concrete Mixtures

Introduction

In this section, alternative concrete mixtures were proposed, batched and tested as previously done for the original ITD concrete mixtures. The mixtures in focus for these alternative mixes are the structural mixtures. The alternative mixtures were based on the reviewed literature and were made by replacing Portland cement with supplementary cementitious materials at a higher percentage (especially for Fly Ash). The following sections describe the new mixtures and the results obtained after the laboratory testing.

Design and Casting of Concrete Mixtures

Additional replicates of the three structural mixes (M1, M4, and M8) were batched to investigate the effectiveness of using SCMs in ITD mixtures. The replicate mixtures were batched following the same exact mixture design received from ITD but varied in cementitious materials' contents as described below:

- Plain replicates of ITD original mixtures which contained fly ash, with the original mass of cementitious materials replaced by the equal mass of cement,
- Ternary replicates of ITD original mixtures, with partial cement replacement of cement with 20 percent fly ash and 10 percent silica fume by mass,
- Fly ash mixtures, with increased partial cement replacement from 20 to 40 percent fly ash.
- Sealing the original structural mixtures with epoxy sealers and testing them for deicing scaling.

In the case of M1, the original mixture design did not contain any fly ash, therefore the plain mixture was not batched as a separate replicate. For mixture M4, the original aggregate was from Salmon river, which was not available during the winter months when the replicate mixtures were batched. Therefore, ITD provided a new mixture design as shown in Table 1 with the correspondent river aggregate. Mixture M8 was reproduced with 40 percent fly ash, however, the available amount of material was not enough to cast the specimens for F-T testing.

As previously described, the alternative concrete mixtures focused on the structural mixtures for districts 1, 2 and 6. Tables 8, 9, and 10 summarize the concrete mixture design.

Table 8. Alternative Concrete Mixture for District 1 (Structural Mix)

Material Type	Amount (lb./yd^3)		
	Original Mix (M1_original)	Ternary Mix (M1_ternary)	40 percent Fly Ash (M1_40FA)
Coarse aggregate	1850	1850	1850
Fine aggregate	702.65	702.65	702.65
Water	258	258	258
Cement Type I/II from Lafarge	378.35	378.35	378.35
Fly ash Sundance	258	258	258
Silica fume BASF	611	427.7	366.6
Air entrainer MasterAir AE 90	5 (oz/yd^3)	5 (oz/yd^3)	5 (oz/yd^3)
Water reducer Pozz 80	45(oz/yd^3)	45(oz/yd^3)	45(oz/yd^3)

Table 9. Alternative Concrete Mixture for District 2 (Structural mix)

Material Type	Amount (lb./yd^3)			
	Original Mix (M4_original)	Plain Mix (M4_plain)	Ternary Mix (M4_ternary)	40 percent Fly Ash (M4_40FA)
Coarse aggregate	1552	1582	1541	1522
Fine aggregate	1502	1532	1491	1472
Water	224	224	224	224
Cement Type I/II from Ash Grove	500	640	448	384
Fly ash ENX Genesee	96	0	128	256
Silica fume BASF	44	0	1541	0
Air entrainer MasterAir AE 90, BASF	1.6 (oz/yd^3)	1.6 (oz/yd^3)	1.6 (oz/yd^3)	1.6 (oz/yd^3)
Superplasticizer BASF, Z60	26 (oz/yd^3)	26 (oz/yd^3)	26 (oz/yd^3)	26 (oz/yd^3)
Superplasticizer BASF, Glenium 3030	58 (oz/yd^3)	58 (oz/yd^3)	58 (oz/yd^3)	58 (oz/yd^3)
Hydration Stabilizer Delvo	13 (oz/yd^3)	13 (oz/yd^3)	13 (oz/yd^3)	13 (oz/yd^3)

Table 10. Alternative Concrete Mixture for District 6 (Structural Mix)

Material Type		**Amount (lb./yd^3)**		
	Original Mix (M8_original)	**Plain Mix (M8_plain)**	**Ternary Mix (M8_ternary)**	**40 percent Fly Ash (M8_40FA)**
Coarse aggregate	1762	1762	1762	1762
Fine aggregate	1005.3	1005.3	1005.3	1005.3
Water	258.85	258.85	258.85	258.85
Cement Type I/II from Lafarge	494	658	460.6	394.8
Fly ash Navajo	164	0	131.6	263.2
Silica fume BASF	0	0	65.8	0
Air entrainer MasterAir AE 90	20 (oz/yd^3)	20 (oz/yd^3)	20 (oz/yd^3)	20 (oz/yd^3)
Water reducer Master Pozzolith P-200 N	5 (oz/cwt)	5 (oz/cwt)	5 (oz/cwt)	5 (oz/cwt)
Hydration stabilizer Delvo	25 (oz/yd^3)	25 (oz/yd^3)	25 (oz/yd^3)	25 (oz/yd^3)
High-range water reducer PS-1466	3.5 (oz/yd^3)	3.5 (oz/yd^3)	3.5 (oz/yd^3)	3.5 (oz/yd^3)
Accelerator MS-AC534	20 (fl oz/cwt)	20 (fl oz/cwt)	20 (fl oz/cwt)	20 (fl oz/cwt)

Results of Experimental Testing

After the concrete mixtures were cast, they were cured in a similar manner like the original ITD mixtures. For the mixtures having 40 percent fly ash of cement replacement, extra two weeks (14 days) were allowed before testing so that sufficient strength and maturity could be achieved. The following sub-sections provide detailed analysis and description of the results.

Concrete Fresh Properties

The original, plain and ternary mixtures from the same group generally exhibited comparable fresh properties. In all the three mixture groups, 40 percent fly ash replicates were characterized by the highest slump. Therefore, for M1 and M4 slump was not measured for the fly ash replicate. Additionally, M4_40FA mixture is characterized by substantially lower air content compared to the other M4 replicates (2 percent for M4_40FA versus 4.3 to 5.6 percent for other M4 replicates). The values of SAM number for all mixtures ranged from 0.25 to 0.54. The influence of SCM on SAM number varies among the tested mixtures and unique trend cannot be clearly identified. The fresh properties and visual rating to resistance against deicing scaling is summarized in Tables 11 and 12.

Table 11. Summary of Fresh Properties and Deicing Scaling Resistance Visual Rating

District	Basic Mixture ID	Description	Slump (in)	Air Content (%)	Unit Weight (lbs./ft^3)	SAM Number [-]	Type of Deicer	Visual Rating
1	(M1) SH-5 Bridge Crossing, Plummer	Original mix (M1_original)	1 1/2	Not measured	Not measured	Not measured	Salt brine	5.0 (Severe)
		Ternary mix (M1_ternary)	2	3.25	143.0	0.43	Salt brine	0 (No scaling)
		40% fly ash (M1_40FA)	Not measured	3.5	142.8	0.54	Salt brine	5.0 (Severe)
2	(M4) US-95 Race Creek Mixture, Lewiston	Original mix (M4_original)	6 ¾	5.3	148.4	0.47	Mag Bud Converse	2.0 and ASR
		Plain mix (M4_plain)	6.5	4.3	151.5	0.47	Mag Bud Converse	4.0 (severe scaling) and ASR
		Ternary mix (M4_ternary)	6 ¾	5.6	150.5	0.25	Mag Bud Converse	0 (No scaling)
		40% fly ash (M4_40FA)	Not measured	2	145.1	0.4	Mag Bud Converse	1.0 (very slight scaling) and ASR
6	(M8) Thornton Interchange Mixture, Idaho Falls	Plain mix (M8_plain)	2	5.2	143.5	0.27	Salt brine	4.0 (Moderate to severe scaling)
		Ternary mix (M8_ternary)	1 ¾	5.2	139.9	0.41	Salt brine	0 (No Scaling)
		40% fly ash (M8_40FA)	6 ¾	4.9	142.4	0.26	Salt brine	5.0 (Severe)

Table 12. Summary of Fresh Properties and Deicing Scaling Resistance for Epoxy Coated Samples

District	Basic Mixture ID	Description	Slump (in)	Air Content (%)	Unit Weight (lbs./ft^3)	SAM Number [-]	Type of Deicer	Visual Rating
1	(M1) SH-5 Bridge Crossing, Plummer	M1_original sealed with Epoxy Proxy FS sealer	1 1/2	Not measured	Not measured	Not measured	Salt brine	0 (No scaling)
		M1_original sealed with Epoxy Proxy 40 LV/LM sealer	1 1/2	Not measured	Not measured	Not measured	Salt brine	0 (No scaling)
2	(M4) US-95 Race Creek Mixture, Lewiston	M4_original sealed with Epoxy Proxy FS sealer	6 ¾	5.3	148.4	0.47	Mag Bud Converse	0 (No scaling nor ASR)
		M4_original sealed with Epoxy Proxy 40 LV/LM sealer	6 ¾	5.3	148.4	0.47	Mag Bud Converse	0 (No scaling nor ASR)
6	(M8) Thornton Interchange Mixture, Idaho Falls	M8_plain sealed with Epoxy Proxy FS sealer	2	5.2	143.5	0.27	Salt brine	0 (No scaling)
		M8_plain sealed with Epoxy proxy 40 LV/LM	2	5.2	143.5	0.27	Salt brine	0 (No scaling)

Surface Resistivity Test

The surface resistivity test for the new alternative mixtures was performed like the original mix as summarized in Table 12. From table 13, it can be observed that all the ternary mixtures displayed negligible risks of chloride penetrability (corrosion risk), while those with 40 percent fly ash displayed low risk.

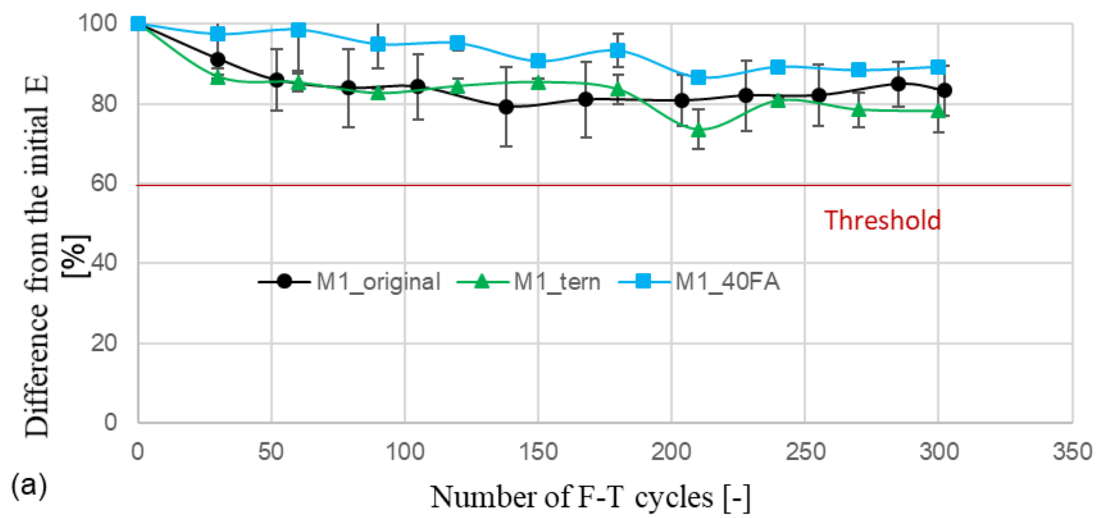
Freeze-Thaw Test

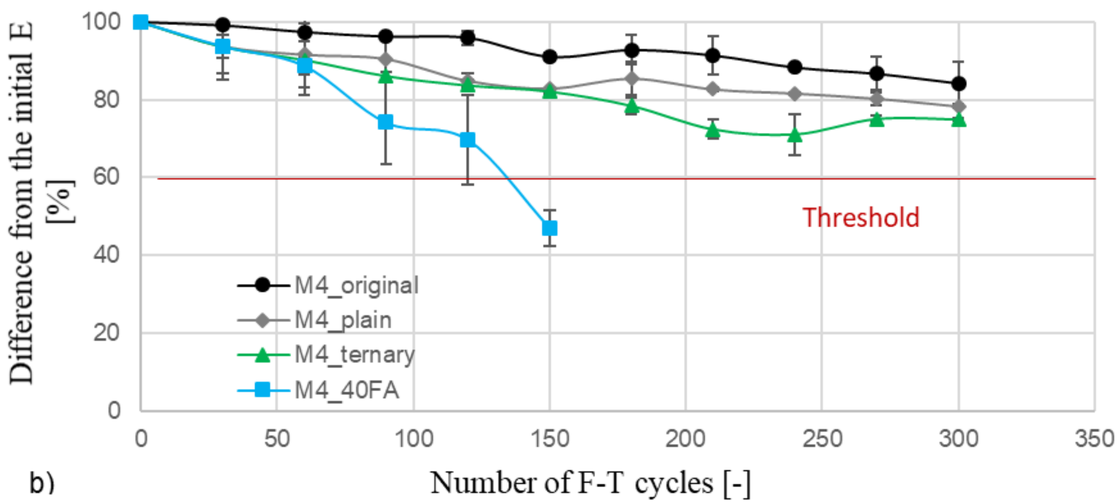
Freeze-thaw (F-T) test was evaluated based on the requirements of ASTM C666. Specimens were subjected to a total of 300 F-T cycles. After every 30 cycles, specimens were tested for mass loss and the residual elastic modulus using the sonic pulse velocity method as done for the original mixes. The relative loss in elastic modulus (*E*) during the F-T test for the replicate mixtures of M1, M4, and M8 was established by is presented in Figure 18. The corresponding mass losses are shown in Figure 19.

As seen in Figure 18, the residual *E* of all tested mixtures are above 60 percent of the original *E* after the 300-cycle marker defined in ASTM C666. The only exception is the replicate of mixture M4 with 40 percent fly ash, which exhibited more than a 60-percent drop in *E* after 150 cycles. Replicates of M1 maintain between 78 to 89 percent of their original E after 300 cycles, with mixture M1_40FA exhibiting the highest residual *E*. In the case of M4, the replicates that met the specifications, retained from 74 to 84 percent of their E. Mixture M4_original had the highest residual *E* in its group. Replicates of M8 retained 76-81 percent of their E after 300 cycles, with ternary mixture showing the best performance.

Table 13. Summary of Surface Resistivity Test Results for the Alternative Concrete Mixtures

District	Basic Mixture ID	Description	Resistivity (Kilo-Ohms-cm)	Standard Error	Remarks (Chloride Penetrability)
1	(M1) SH-5 Bridge Crossing, Plummer	Original mix (M1_original)	17.9	0.4	Moderate risk
		Ternary mix (M1_ternary)	145.0	2.5	Negligible
		40% fly ash (M1_40FA)	63.0	1.5	Low risk
2	(M4) US-95 Race Creek Mixture, Lewiston	Original mix (M4_original)	93.9	5.4	Low risk
		Plain mix (M4_plain)	45.8	4.3	Moderate risk
		Ternary mix (M4_ternary)	163.5	4.8	Negligible
		40% fly ash (M4_40FA)	65.4	2.6	Low risk
6	(M8) Thornton Interchange Mixture, Idaho Falls	Original mix (M8_original)	109.8	6.9	Negligible
		Plain mix (M8_plain)	58.7	1.5	Low risk
		Ternary mix (M8_ternary)	178	6.5	Negligible
		40% fly ash (M8_40FA)	79	2.7	Low risk


Difference from the initial E [%]
Threshold
M1_original
M1_tern
M1_40FA
Number of F-T cycles [-]
(a)


Difference from the initial E [%]
Threshold
M4_original
M4_plain
M4_ternary
M4_40FA
Number of F-T cycles [-]
b)

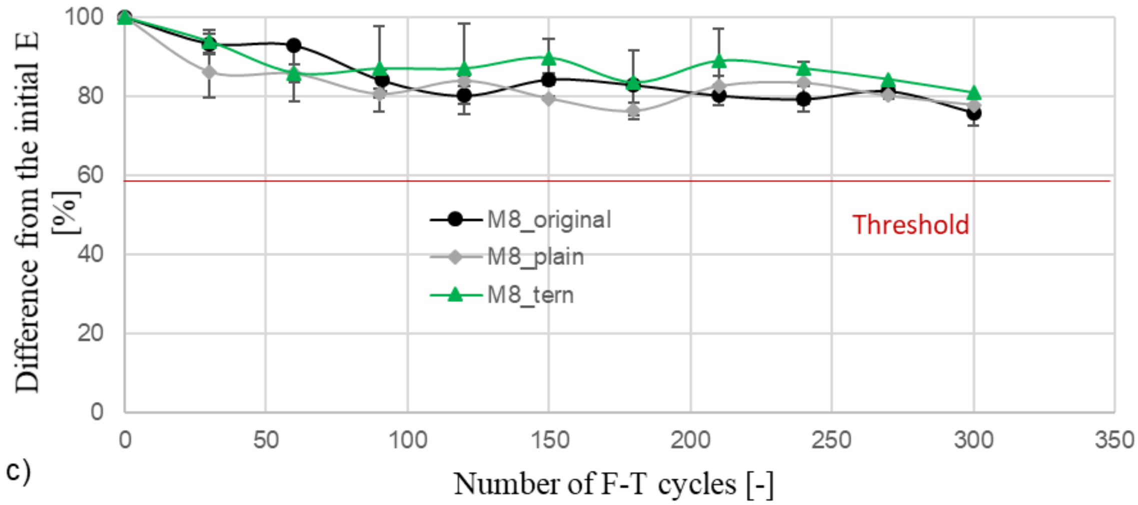


Figure 18. Variation in Elastic Modulus in F-T Test for Specimens of a) M1, b) M4, and c) M8

Mass loss was taken after each 30-cycle prior to *E* testing. As evident in Figure 19, all tested mixtures presented mass losses below 1.0 percent after 300 cycles. The mixture with the highest mass loss was the M1 replicate with 40 percent fly ash. The same mixture also retained approximately 90 percent of *E* after 300 F-T cycles. The mix M4_40, which did not meet the 60-pecent *E* requirement, shows a relatively low mass loss (less than 0.2 percent after 150 cycles). These results indicate that mass loss alone may not be a good predictor of degradation of mechanical properties on F-T test.

All the tested mixtures presented SAM numbers higher than the recommended value of 0.20 (Tanesi et al. 2016). Mix M4_40 had a low entrained air content (2 percent), which might be the reason for its poor performance in the F-T test. It is likely that the air void system of that mixture could not adequately accommodate the expansion of the water upon the phase change. The differences in percentage of retained *E* were not substantial for mixtures that meet the requirements of ASTM C666 (more than 60 percent *E* after 300 cycles), therefore it is not possible to draw clear trends of impact or air content or SAM number on this parameter. Among the same group of mixes, higher mass loss percentage is seen for mixes with lower air content. Strong correlations between SAM number and mass loss percentage cannot be identified.

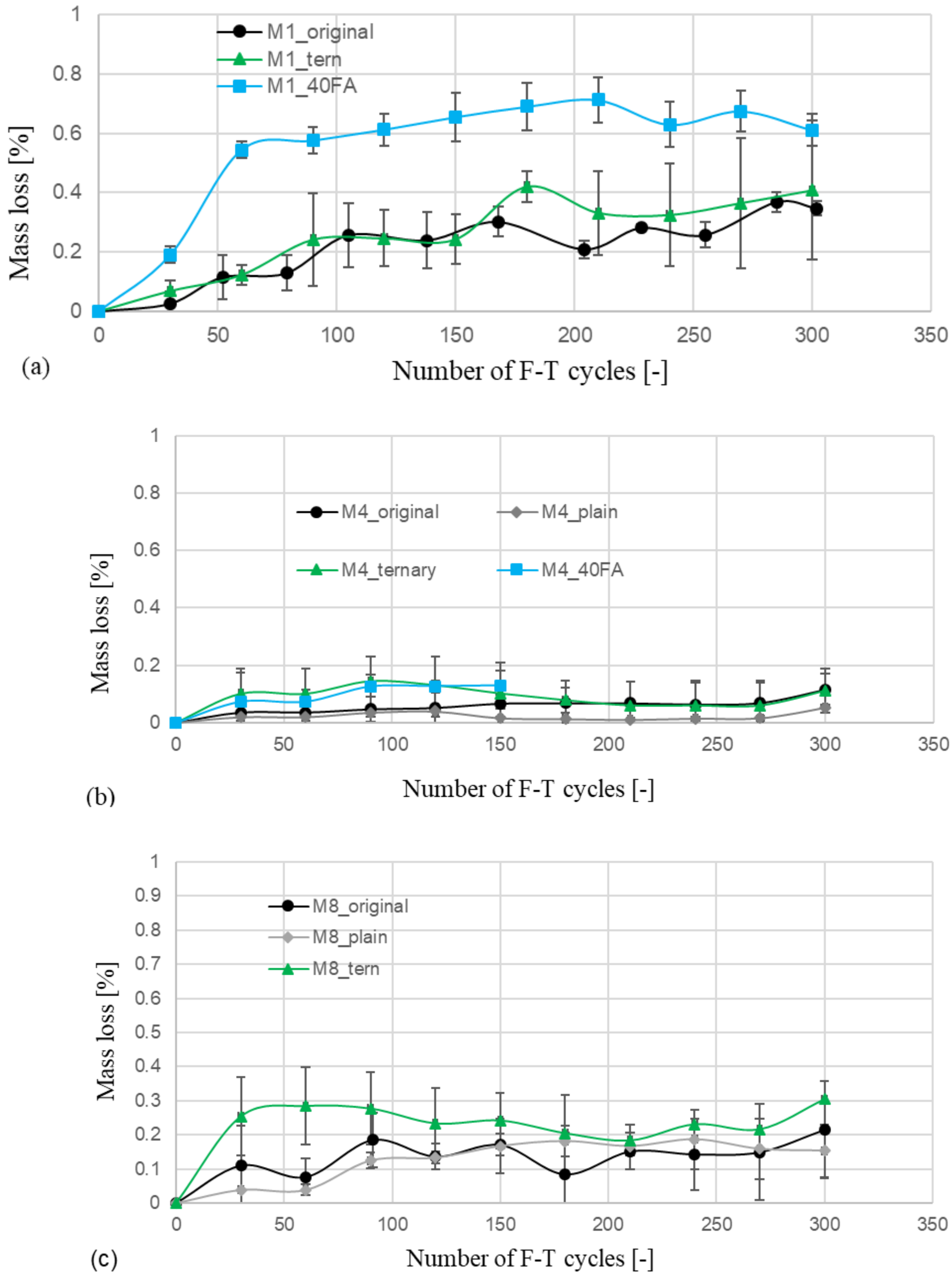


Figure 19. Mass Loss in F-T Tests for Specimens Cast from a) M1, b) M4, and c) M8

Figure 20 shows the tested specimens after 300 F-T cycles for the replicates of M1, M4, and M8, respectively. As seen in the figures, besides small scaling at the surface, specimens generally exhibited satisfactory structural integrity. Specimens from mixture M4_FA40 are captured after 150 cycles; similarly, no apparent visual damage can be identified for these specimens.

Altogether, the analysis of different mixture replicates in F-T suggests that plain and ternary mixtures generally exhibit satisfactory performance. Different mixtures with 40 percent fly ash may showed an outstanding performance, as well as the poor performance on F-T test. The difference in the performance may be due to a chemical composition or pozzolanicity of a specific fly ash. A relatively short curing period of 14 days before the F-T test may be insufficient for an adequate pore system development in mixtures with 40 percent fly ash because of the delayed hydration. If 40 percent fly ash replacement is selected, it is suggested to alter mixture design (water content, admixtures) and apply prolonged curing to attain the desired performance.

Figure 20. Results of F-T Cycles a) M1_ternary b) M1_FA40 c) M4_original d) M4_plain e) M4_ternary f) M4_FA40 g) M8_plain h) M8_ternary

Resistance Against Deicing Scaling

The resistance against deicing scaling was performed using the same procedures in the original mixtures. Interesting results were observed in the mixtures containing 40 percent Fly Ash for both

District 1 and 6. Severe scaling (visual rating of 5) was observed as shown in Figure 21 and 22. A 35-40 percent cement replacement with fly ash was reported to reduce Calcium-Oxychloride (CAOXY) formation which resulted in no scaling [(50)] (Suraneni, et al. 2016). However, other authors [(51-54)] reported that increasing fly ash content in concrete with water-to-cementitious ratio above 0.4 will increase scaling damage in concrete. on the contrary, very slight scaling was observed in the specimens with 40 percent fly ash for district 2 as shown in Figure 23, while the ternary mixture showed no scaling (Figure 24).

The original structural mixtures specimens when coated with epoxy sealers showed no scaling as shown in Figures 25 and 26 and summarized in Table 12. Therefore, it is important to state that bridges and concrete pavement made with current ITD concrete mixtures can be protected from deicing scaling by applying epoxy sealers, if the cost is economical.

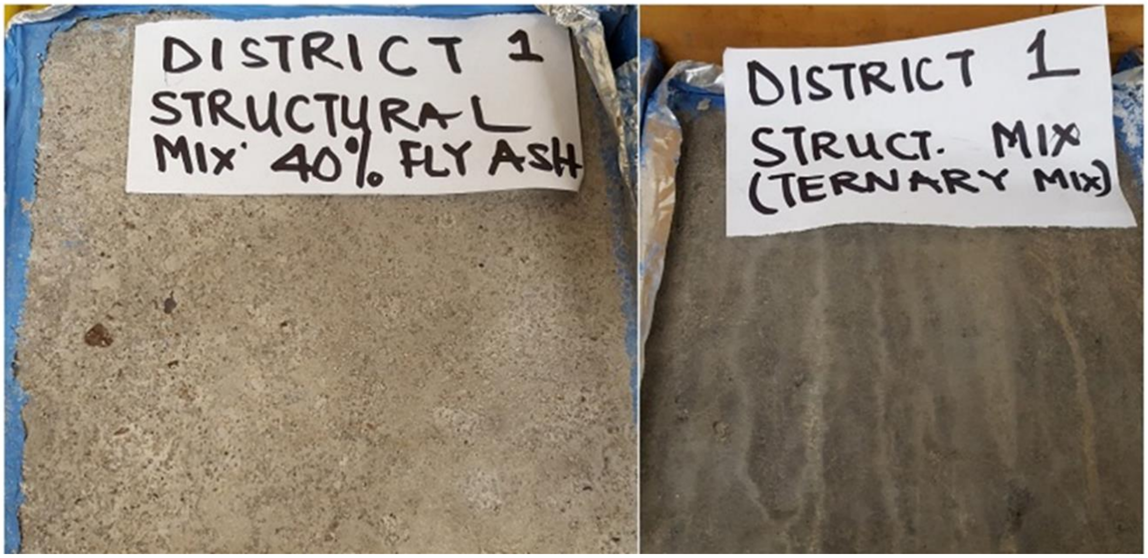


Figure 21. Specimens Tested for Deicing Scaling (District 1)

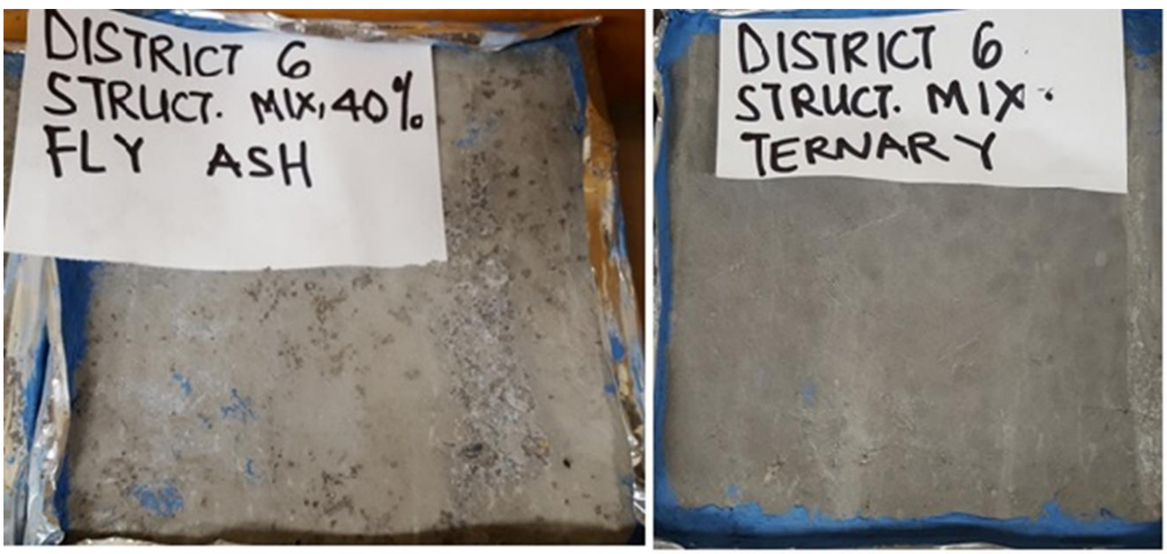


Figure 22. Specimens Tested for Deicing Scaling (District 6)

Figure 23. Specimens Tested for Deicing Scaling (District 2)

Figure 24. Specimens Tested for Deicing Scaling (District 2)

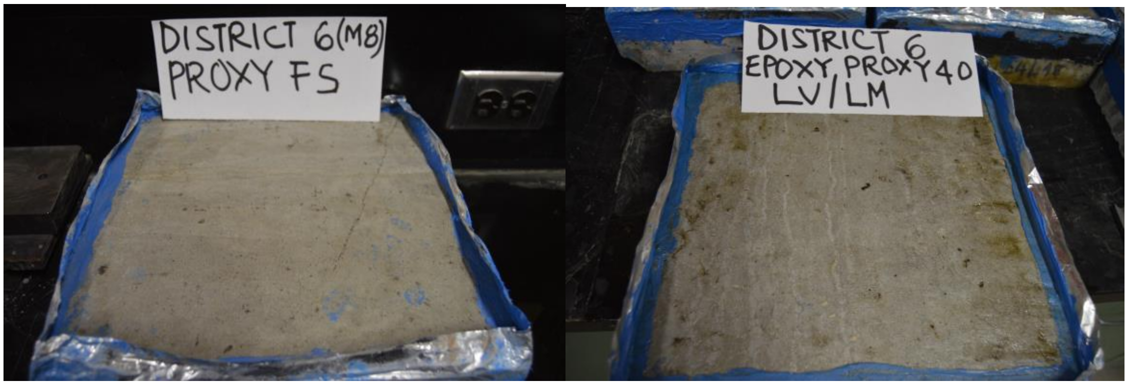


Figure 25. Epoxy Coated Specimens Tested for Deicing Scaling (District 6)

Figure 26. Epoxy coated Specimens Tested for Deicing Scaling (District 1)

From all the observed results, the ternary mixtures showed satisfactorily performance under deicing scaling using salt brine. It should be noted that salt brine is the most aggressive deicing chemical based on its penetrability and negative effect on concrete.

Chapter 5
Conclusions and Recommendations

Introduction

Concrete in barrier rails, parapets, barriers and bridge decks throughout the State of Idaho are exposed to deicing chemicals and salt brine. As such, signs of durability damage have manifested in some of the concrete infrastructure. Recent studies have shown that depending on the concrete mixture, deicing chemicals can chemically react with the paste and produce different forms of salt or Calcium Oxychloride in the concrete. This chemical transformation has been shown to induce micro damage in the concrete. In addition, another deterioration mechanism develops in the concrete (or aggregate) because of exposure to freeze-thaw (F-T) cycling during the winter season. At a certain level of saturation, freezing of water inside the concrete pores forms internal osmotic pressure, which tends to damage the paste, initiate cracks and lead to concrete spalling problems. Damage due to both mechanisms result in the development of durability cracking in concrete, which increases its permeability and facilitates the migration of damaging chloride ions to the embedded reinforcing steel level. Moisture and the detrimental ions cause corrosion of the reinforcing steel and ultimately result in the failure of concrete members. Replacement of concrete members in highway applications is not only costly for the highway agencies but can also impose significant delays to the road users. Idaho Transportation Department (ITD's) specifications follow industry practices developed years ago. However, concrete technology has evolved, and practices have been developed that produce more durable concrete. This research aimed at enabling ITD to change or modify the current specifications to improve concrete durability in aggressive environments. The goal of this study is to build on the results and recommendations of previous studies trying to increase the durability of ITD concrete mixtures against winter maintenance and deicers applications.

Conclusions

From the results presented in this report the following conclusions can be made:

- The mixtures currently used by ITD perform satisfactorily under F-T cycle, as evidenced by relatively high percentage retained elastic modulus and relatively low mass losses after being subjected to a total of 300 F-T cycles.
- The structural mixture (SH-5 Bridge crossing, Plummer) suffered a severe scaling, while other mixtures showed mild to moderate scaling. The reason for the severe scaling, could be because of the absence of supplementary cementitious materials- Fly Ash that inhibits the penetrability of deicing chemicals as observed by different studies.
- Mixture M5 from District 3 is characterized by lowest mass loss, at 1.61 percent after 300 cycles.
- The original District 2 mixtures (M3 and M4) showed that SAM numbers exceeded the threshold value.
- The SAM number in all the proposed mixtures exceeded the threshold value.

- District 2 mixtures (M3 and M4) showed some visual evidence of Alkali Silica Reaction because of the reactive aggregate and that was observed when samples were exposed to Magnesium chloride under several cycles of deicing chemical.
- Mixtures with 40 percent Fly Ash do not have sufficient resistant for deicing scaling, even though they all performed satisfactorily well in F/T cycles except mixture for District 2 (M4-40).
- The mixtures containing fly ash and silica fume (ternary mixtures) performed very well in all durability tests.
- As observed in the results of District 1 and District 6 structural mixtures, it can be stated that salt brine deicing chemical made with 23.3 percent concentration, highly deteriorates the concrete samples (both the original mixtures and the binary mixtures with 40 percent fly ash), except for ternary mixtures.

Recommendations

The results of this project opened various venues of research ideas to be conducted on ITD concrete mixtures when they exposed to very high concentration of deicing chemicals. The results presented in this report, are concluded based on a comprehensive durability evaluation of the ITD concrete mixtures currently used in Idaho infrastructure. While conducting all the durability testing, it was found other concrete degradation issues that was not expected such as the signs of the ASR when concrete exposed to Magnesium chloride. In addition, the researchers have proposed ternary mixtures with the recommended highest percentage of silica fume, which showed more gaps need to be covered as future studies. The following recommendations are suggested to enhance the performance of concrete mixtures exposed to heavy concentrations of chemical deicers:

- Since the concentration of deicing chemicals used in this study is higher than the average found in literature, the possibility of using a lower concentration should be considered for existing construction built using the current ITD mixtures. Although, not tested in this report, lower deicing salt concentration (approximately 2-5 percent) were found to be non-aggressive to concrete.
- Consideration should be given to alternative deicers that are not aggressive to concrete such as the deicers based on organic materials. Before implementing such organic deicers, it is necessary to evaluate them when they used with ITD concrete mixtures.
- Ternary mixture should be considered for use in reinforced structural elements that will be exposed to high concentrations of deicing chemicals.
- Mixtures with 40 percent fly ash should not be used or implemented as suggested by authors since they do not perform satisfactorily under deicing scaling.
- Epoxy sealers used in this study can be used to seal/coat existing structures to prevent deicing scaling if it is economical to do so.

Suggested Further Investigations

- Mixture design optimization for ternary mixes
- Thermogravimetric analysis to confirm the formation of Calcium/Magnesium Oxychloride and its mitigation.
- Advanced quick chemical test to confirm the ASR observed on mixtures from district 2, when the slabs were exposed to the deicing chemicals.
- Since the ternary mixtures contained 10 percent Silica fume and 20 percent fly ash, it is necessary to conduct more sophisticated tests on the ternary mixtures for optimum contents of fly ash and silica fume that can be used for economy purpose.
- Determination of optimum water to binder ratio for use in ternary mixtures.

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Appendix A
Questionnaire

ITD DEICER SURVEY: IDENTIFICATION OF POTENTIAL DURABILITY-RELATED DISTRESSES ACROSS THE STATE

This survey is designed to gather information from winter maintenance professionals and ITD engineers/personnel to evaluate the effect of deicers on concrete structures/pavements structures.

District no. (Please specify):

A. GENERAL INFORMATION

1. Type(s) and age of the structure(s)

2. What is the repair/rehabilitation history of the structure, if any?

3. What are the geographical locations of the distressed structures?

4. What are the signs of distress observed in inspected concrete members?

5. Specify the types of distresses e.g., D-cracks, joint spalling, scaling, other types of cracking.;

6. Which area/part of the structures are these deteriorations visible?

7. How are the identified distresses repaired commonly?

8. What is the condition rating of the distressed structures by visual inspection?

B. <u>CONCRETE MATERIALS AND TEST RESULTS</u>

9. What type of concrete was used for the structures identified in Section A (e.g., ready mix, precast, etc.)

10. What w/cm ratio was used in the mixture?

11. What was the air entrained content?

12. What type of aggregate was used in the mixture?

13. Provide the 28th day compressive strength of the concrete or any other test results such as surface resistivity.

14. Were any cores extracted from the structure?

If yes, please kindly state.........

21. Do you have any record of negative impact of deicing salts on concretes, such as slipperiness, loss of friction, impacts on motor vehicle types, etc.?

Please email it back to: aibrahim@uidaho.edu

Appendix B
Responses to Questionnaire

ITD DEICER SURVEY: IDENTIFICATION OF POTENTIAL DURABILITY-RELATED DISTRESSES ACROSS THE STATE

This survey is designed to gather information from winter maintenance professionals and ITD engineers/personnel to evaluate the effect of deicers on concrete structures/pavements structures.

District no. (Please specify): 5

A. <u>GENERAL INFORMATION</u>

1. Type(s) and age of the structure(s)

I-15B; UPRR; S Blackfoot IC – Built in 1961

W. Bridge St GS UPRR OP I-15 NB and SB – Built in 1962

UPRR: Soda Springs OP - 1988

2. What is the repair/rehabilitation history of the structure, if any?

General Maintenance activities – ie. Patches, deck sealing, and joint repairs

3. What are the geographical locations of the distressed structures?

The I-15 structures are located on I-15 in the Blackfoot area on the Snake River Plain.

The US-30 Structure is located just South of Soda Springs on US-30.

4. What are the signs of distress observed in inspected concrete members?

See Bridge Inspection Reports included with this document

5. Specify the types of distresses e.g., D-cracks, joint spalling, scaling, other types of cracking.;

See Bridge Inspection Reports included with this document

6. Which area/part of the structures are these deteriorations visible?

See Bridge Inspection Reports included with this document

7. How are the identified distresses repaired commonly?

Patches

8. What is the condition rating of the distressed structures by visual inspection?

95.1 and 96.1 for the W Bridge Street Bridges and a 65.8 for the UPRR Bridge.

100.0 for the Soda Springs structure.

B. <u>CONCRETE MATERIALS AND TEST RESULTS</u>

9. What type of concrete was used for the structures identified in Section A (e.g., ready mix, precast, etc.)

   Ready Mix

10. What w/cm ratio was used in the mixture?

    Due to the age of the structures and files available not sure.

11. What was the air entrained content?

    Due to the age of the structures and files available not sure.

12. What type of aggregate was used in the mixture?

Due to the age of the structures and files available not sure.

13. Provide the 28th day compressive strength of the concrete or any other test results such as surface resistivity.

Not available

14. Were any cores extracted from the structure?

No

If yes, what tests were conducted on the cores? List test results if possible.

No

If no, is it possible to extract cores from the deteriorated area for this project?

The interstate bridges, this could prove to be difficult to get. Especially during the summer time. It might be possible to get cores from the US-30 bridge

C. <u>DEICING/ANTI-ICINGSALT AND CHEMICAL AGENTS</u>

15. What type of deicing salt is being used in the district? Please list all.

8b salt for roadway application, 8a salt is used for making brine in Soda Springs, 8b salt is used for making brine in Pocatello

16. Does the deicing salt contain corrosion inhibitors?

No

If no, do you add inhibitors to the deicers before its application on roads/bridges/rails?

No

17. Do you use organic deicers such as Potassium Acetate (KAc); Potassium-Magnesium Acetate (KMA), etc.?

No

18. How much of deicing salt do you apply (amount of salt/Mile length of roadway)?

We use the Clear Roads application Matrix, the amount of salt varies on the roadway temperature and precipitation amount. The rate will also vary for what the application is for de-icing or anti-icing

19. What is the concentration of the deicer solution?

23.3% salt brine

20. Have you had any reported case of deicing salt affecting roadside vegetation and vehicles?

No

If yes, please kindly state.........

21. Do you have any record of negative impact of deicing salts on concretes, such as slipperiness, loss of friction, impacts on motor vehicle types, etc.?

Salt brine, no.

MagCl, yes, before our current Maintenance or Operations Engineer started, salt brine has been the only liquid we have used in this district, we did experiment with some Boost once.

Appendix C
Current ITD Concrete Mixtures

District 1

I-90 Lookout Pass 2015 Paving Mixture Design

CONCRETE MIX CALCULATION

DATE: 24-Jul-15

FOR: ACME PROJECT: i-90 Paving

MIX: Centralia Mix - Adj #1

W/C RATIO		0.38
WT.CU.FT.		144.55

	SSD WT.	VOLUME	BATCH WT.	Revised Mix for Moisture CUBIC FEET 2.00			MATERIAL SOURCE	S.S.D. SP.G
Type I	550	2.80	550	40.74	pounds		Type I	3.15
Fly Ash	138	0.85	138	10.22		20%	Fly Ash	2.59
Silca Fume	0	0.00	0	0.00	pounds	0%	Silica Fume	2.20
Slag	0	0.00	0	0.00	pounds	0%	Slag	2.87
Coarse SAND	808	4.85	823	60.96	pounds	27%	C Sand	2.67
1 1/2	541	3.28	539	39.91	pounds	18%	1 1/2	2.64
3/4	1262	7.66	1250	92.57		43%	3/4	2.64
Fine Sand	346	2.06	345	25.54	pounds	12%	3/8	2.69
WATER	31.0	4.14	31.1	19.21	pounds		WATER	1.00
AIR%	5.0%	1.35	5.0%				AIR ENTRAINED	
AIROZ/100	1.00		6.9	15.02	mL			AE-90
WROZ/100	5.00	---	34	75.08	mL		WATER REDUCER	POZZ 80
SWR/100	0.00	---	0	0.00	mL		SUPER PLASTICIZER	
	----	VOLUME						
TOTAL WT	3903	27.00						

c/a ratio	60.98%		
% MORTAR	50%	PASS #8	90.0%

TARGET VOLUME	27.00
Total Moisture - Sand	5.25%
Total Moisture - 1 3/8"	1.00%
Total Moisture - 3/4"	0.50%
	0.50%

SH-5 Bridge Crossing Mixture

INTERSTATE
CONCRETE & ASPHALT

CONCRETE MIX DESIGN

PROJECT:	SH-5 RAILROAD BR, PLUMMER	DATE:	03/24/15
CONTRACTOR:	RALPH L. WADSWORTH CONSTRUCTION	SLUMP:	3.5"
MIX DESIGN:	320006 ITD CLASS 40 A	w/ Super P:	8.5" MAX
PLANT LOCATION:	INTERSTATE	W/C:	.44 MAX
CEMENT TYPE:	LAFARGE I-II	AIR:	5.0%-8.0%
PRODUCT USE:	CLASS 40 A		

DISPATCH:
208-712-2030

AGGREGATE	SPECIFIC GRAVITY
3/4" ROCK	2.62
ITD FINE AGG	2.59

DESCRIPTION	VOLUME	WEIGHTS
CEMENT	3.11	611
FLYASH	0.00	0
OTHER	0.00	0
WATER	4.13	258
3/4" ROCK	11.32	1850
ITD FINE AGGREGATE	6.69	1081
AIR PERCENT	1.76	6.5%
TOTAL	27.00	3800

ADMIXTURES: AIR ENTRAINMENT ADMIXTURE, WATER REDUCING ADMIXTURE.

REMARKS: MAY BE PLACED BY CHUTE OR PUMP.

Edward Benson
QUALITY CONTROL

I-90 Lookout Pass 2016 Paving Mixture Design

CONCRETE MIX CALCULATION

DATE: 5-Jul-16

FOR: ACME
Look Out Pass

PROJECT:

MIX: Ritchey Sand
4000psi 5" Max Slump

W/C RATIO 0.40
WT.CU.FT. 142.01

	SSD WT.	VOLUME	BATCH WT.	Revised Mix for Moisture CUBIC FEET 1.00	
MaxCem	550	2.80	550	20.37	pounds
Fly Ash	138	0.97	138	5.11	
Silca Fume	0	0.00	0	0.00	pounds
Slag	0	0.00	0	0.00	pounds
Coarse SAND***	619	3.72	639	23.66	pounds
Fine Sand	507	3.02	499	18.50	pounds
1 1/2	615	3.73	612	22.66	
3/4	1130	6.86	1124	41.62	pounds
WATER	33.0	4.41	32.6	10.13	pounds
AIR%	5.5%	1.49	5.5%		
AIROZ/100	1.00		6.9	7.51	mL
WROZ/100	5.00	---	34	37.54	mL
SWR/100	4.00	---	28	30.03	mL
	----	VOLUME			
TOTAL WT	3834	27.00			
c/a ratio	61%				
% MORTAR	48%	PASS #8	90.0%		

	MATERIAL SOURCE	S.S.D. SP.G	Absorption
	Type ISM	3.15	
20%	Fly Ash	2.27	
0%	Silica Fume	2.20	
0%	Slag	2.87	
22%	C Sand	2.67	2.21%
18%	F Sand	2.69	2.52%
21%	1.5	2.64	1.00%
39%	3/4	2.64	1.05%
	WATER	1.00	
	AIR ENTRAINED	AE-90	
	WATER REDUCER	pozz 80	
	SUPER PLASTICIZER	matrix 33	
			-0.566

TARGET VOLUME	27.00
Total Moisture - Sand	5.25%
Total Moisture - 1 3/8"	1.00%
Total Moisture - 3/4"	0.50%
Total Moisture - 3/8"	0.50%

This concrete mix design is only a suggested starting point, based upon materials meeting ASTM requirements. LAFARGE NORTH AMERICA MAKES NO WARRANTY OR REPRESENTATION WITH RESPECT TO THIS MIX DESIGN AND WILL ACCEPT NO LIABILITY FOR ITS USE.

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SUBMITTED BY:

DATE:

District 2

Thain Road Paving Mixture

Atlas Concrete
4341 Snake River Ave.
Lewiston , Idaho , 83501
208-746-9985

Concrete Mix Design
Mix 8
Strength Compressive: 4,000 psi

Contractor : Stillwater Electric
Project : Thain And Grelle Intersection
Source of Concrete : Atlas Concrete
Construction Type : Class 40
Placement : Tailgate/Pump

Weights per Cubic Yard	(Saturated, Surface-Dry)		
	Quantity	Density	Yield, ft^3
ASTM C-150 Type I/II Cement, lb	489	3.150	2.49
ASTM C-618 Class F Fly Ash, lb	122	2.600	0.75
Well Water , lb	265	1.000	4.25
ASTM C-33 Coarse Aggregate , lb	1,721	2.720	10.14
ASTM C-33 Fine Aggregate , lb	1,246	2.640	7.57
ASTM C-494 Type A Water Reducer , oz (US)	45.0	1.000	0.05
ASTM C-260 Air Entrainment , oz (US)	5.0	1.000	0.01
Total Air, %	6.5 ± 1.5		1.76
		TOTAL	27.00

Water/Cement Ratio, lbs/lb	0.43
Slump, High, in	5.00
Low, in	3.00
Super Plasticizer High, in	8.00
Super Plasticizer Low, in	5.00
Concrete Unit Weight, pcf	142.47
Yield, %	100.0

Exposure Condition : Moderate exposure

ACTUAL BATCH WEIGHTS WILL VARY DEPENDING ON THE MOISTURE CONTENT OF THE CONCRETE AGGREGATES. ACCEPTANCE OF THIS MIX CARRIES WITH IT THE INCLUSION OF ATLAS CONCRETE ON THE DISTRIBUTION LIST OF ALL TEST REPORTS PLASTISIZER, STABILIZER ON REQUEST

Prepared by :

Dennis Anderson

US95 Race Creek Bridge Mixture

Accumix

CONCRETE MIX DESIGN

Mix ID Number:	40 Class A	Date:	26-Aug-15
Design Strength:	4000 psi	Plant:	Grangeville
	28 MPa	Designed By:	Accumix

MIX DESIGN QUANTITIES:

			English Units		Metric Units	
Material	Product/Source	Spec Grav	Weight	Volume (ft3)	Mass	Volume (m3)
Cement	Ash Grove Durkee, Type I-II	3.15	500 lb	2.54	297 kg	0.094
Fly Ash	ENX Genesee Class F	2.03	125 lb	0.99	74 kg	0.036
Silica Fume	Basf	2.20	0 lb	0.00	0 kg	0.000
Water (Total)	City Source	1.00	250 lb	4.01	148 kg	0.148
3/4-#4	Salmon River Pit	2.76 *	1660 lb*	9.64	985 kg*	0.357
Ground Limestone	John Day Cr. Pit	2.68 *	0 lb*	0.00	0 kg*	0.000
		2.60 *	0 lb*	0.00	0 kg*	0.000
Fine Aggregate	Salmon River Pit	2.68 *	1350 lb*	8.07	804 kg*	0.300
	Total Mix Weight:		3885 lb		2308 kg	
	Air (Entrap/Entrain)	6.5 %		1.76		0.065
	Total Mix Volume:			27.01		1.000

ADMIXTURES:

Product	Product Name/Type	Dosage Rate	Dosage (English)	Dosage (Metric)
Air Entrainment	Basf AE-90	0.28 oz/cwt**	1.8 oz/cy**	70 mL/m3**
Water Reducer	322N	4.0 oz/cwt**	25.0 oz/cy**	968 mL/m3**
Superplasticizer	Basf Z60	4.0 oz/cwt**	25.0 oz/cy**	968 mL/m3**
Superplasticizer	Basf Glenium 3030	2.0 oz/cwt**	13.0 oz/cy**	503 mL/m3**
Hydration Stabilizer	Basf Delvo	0.0 oz/cwt**	0.0 oz/cy**	0 mL/m3**
Accelerator	Basf NC534	0.0 oz/cwt**	0.0 oz/cy**	0 mL/m3**
Fibers		0.0 lb/cy**	0.0 lb/cy**	0.0 kg/m3**

MIX DESIGN PROPERTIES:

Aggregate Properties:	SG	Abs	FM	Dry Rodded Unit Wt	
3/4-#4	2.76	1.3%	n/a	101.0 pcf	1618 kg/m3
Ground Limestone	2.68	0.2%	n/a	pcf	kg/m3
	2.60	3.1%	n/a	pcf	kg/m3
Fine Aggregate	2.68	1.6%	2.90	n/a	n/a

Plastic Properties:	Slump:	6.0 ± 2.0 inch		150 ± 50 mm
	Air Content:	6.5 ± 1.5 %		
	Unit Weight:	143.8 pcf		2308 kg/m3
Design Properties:	Total Cementitious:	625 lb		371 kg
	Fly Ash Replacement:	20.0 %	W/C Ratio:	0.40 (incl Admix)

Project:

Contractor:

Comments: W/C ratio can be increased to but not exceed .42

Usage:

Footnotes: * SSD Weights and Spec Gravities. **Admixture dosage rates will be adjusted according to manufacturer's recommendations to accommodate varying field conditions.

This mix design is predicated on the specific information and/or materials provided by the customer and therefore. Change in design components or proportions, materials gradations and/or field placement and curing practices will all strongly affect the ultimate quality of concrete. User should confirm each laboratory design with concrete batched on site and then routinely run quality control checks to verify yield, air content and compressive strength because the physical and chemical characteristics of materials may vary.

District 3

I-84 Paving Mixture

Concrete Placing Company
6451 West Gowen Road
Boise, Idaho 83709
Phone: 208.362.2100 Fax: 208.362.2220

CONCRETE MIX DESIGN REPORT BIC/MIC_500_125 Mix#2014_001
Compressive Strength: 5600

Contractor: Concrete Placing Company
Project: Broadway IC A009(081), A012(029) & A012(379)
Source of Concrete: Portable Wet Batch
Project Type: 4500 PSI Paving
Placement Type: Slipform

Material / Source or Designation / Blend[1]	Quantity (SSD)	S.G.	Yield, ft^3
Type I/II Cement / Ash Grove Cement / 80%	500 lb	3.15	2.54
Type F Ash (Bridger) / Head Waters / 20%	125 lb	2.36	0.85
Water / Boise City Water	248 lb	1.00	3.97
1 1/2" / 1.5" / 17.96%	524 lb	2.61	3.22
3/4" / .75" / 42.05%	1227 lb	2.61	7.54
Sand / Sand / 39.99%	1167 lb	2.59	7.23
Total Air, percent	6%		1.62
AE 90 / BASF	5 fl oz (US)	1.01	0.00
Pozz 80 / BASF	30 fl oz (US)	1.20	0.03
			27.00

[1] The blend percentage indicated (by weight) is listed separately for cementitious materials and aggregates.

Total Water Content (including water in admixtures), lb			250		
Water / Cementitious Material Ratio:			0.4		
Concrete Unit Weight, pcf			140.5		
Target Slump, in.			1.5 ± 0.5		
Paste Content, percent			27.39%		
Workability Factor (WF)	Target:	35.0		Actual:	36.8
Coarseness Factor (CF)	Target:	60.2		Actual:	58.5
Prepared On:			7/10/14 3:17 PM		

Prepared By:

District 5

US-91 Paving Mixture

4500 ITD Paving

	#	Material	Description	Amount		Based On
1 >>	0	~~BRIG-SND~~ Pokey Sand	FINE AGG	1,043.000	lb	0.000
2	1	POC-#57	COARSE AGG	1,260.000	lb	0.000
3	2	BRIG-#4 1.5 Rock	BRIG-#4	460.000	lb	0.000
4	3	DUR-I/II	CEMENT	584.000	lb	0.000
5	4	NAVAJO	FLYASH	145.000	lb	0.000
6	5	WATER	COLD WATER	34.000	gl	0.000
7	6	MICRO-AE	AIR	20.000	oz	0.000
8	7	P-200N	MR-WATER REDUCER	22.000	oz	0.000
9	8	DELVO	HYDRATION STABILIZER	25.000	oz	0.000
*						

District 6

Thornton Interchange Mixture

WALTERS Ready Mix, Inc.

342 West 4th North • P.O. Box 390 • Rexburg, Idaho 83440
PHONE (208) 356-5491 • FAX (208) 356-5553 • EMAIL: wrm@ida.net

Mix# 500F- Class 40F
Project: ITD-NH-6470(129)Thornton Interchange
Slump-4" Date: 1/29/16
Slump-With HRWR-8"
Contractor: Cannon Bldrs.

MATERIALS			*VOL.*					*WEIGHT*
% Air:	6.5		1.76					
Gal water:	31.0		4.14					258.54
Lbs Cement:	494		2.51	Holcim I-II				494.00
LbsFly Ash:	164		1.14	Navajo class F				164.00
Silica Fume:				S.F. 100				
Sub Total:	9.55		17.45					
S/A Ratio:	38.00	Source		*SPEC.GRAV.*				
Sand:	6.63	MA-22	6.63		2.43	62.40	151.63	1005.32
% Split:		MA-68			2.51	62.40	156.62	
3/4" Rock:	10.82	MA-68	10.82		2.61	62.40	162.86	1762.18
3/8"% Split:		MA-22			2.47	62.40	154.12	
W/C Ratio:	0.393		27.00				*lbs/cuyd*	3684.04
							lbs/c.f.:	136.45

Moisture	*Wet*	*Dry*	*Total*	*Moisture %*		*Absorption*	Total Moisture
Sand				0		3.15	
3/4 "Rock		Dry	0		0.00	0.8	
					0.00	0.8	
						0.8	

Free Water

Sand		Per Yard
3/4" Rock		Per Yard
		Per Yard

POZ AIR

Admixtures:	Product:	Dose:
Air Entrainme	MA-AE90	To meet spec
Water Reducer	MP-322N	5 oz./cwt
Set Control	MS-Delvo	To meet spec
HRWR	PS-1466	To meet spec
Accelerator	MS-AC534	To meet spec

Quality Assurance Record
Walters Ready Mix Inc.