ERDC/CRREL Letter Report 10-07

Cold Regions Research and Engineering Laboratory

Extending the Season for Concrete Construction and Repair:

Phase III: Guidance for Optimizing Admixture Dosage Rates

Data Review and Project Framework Development

Lynette A. Barna

January 2010

Approved for public release; distribution is unlimited.

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Unit Conversion Factors

Symbol	When You Know	Multiply By	To Find	Symbol
		Length		
mm	millimeters	3.93701×10^{-2}	inches	in.
cm	centimeters	3.93701×10^{-1}	inches	in.
m	meters	3.28084	feet	ft
m	meters	1.09361	yards	yd
km	kilometers	6.21371×10^{-1}	miles (statute)	mi
		Area		
mm^2	square millimeters	1.55000×10^{-3}	square inches	$In.^2$
m^2	square meters	1.07639×10^{1}	square feet	ft^2
m^2	square meters	1.19599	square yards	yd^2
		Volume		
mL	milliliters	3.38140×10^{-2}	fluid ounces	fl oz
L	liters	2.64172×10^{-1}	gallons	gal
m^3	cubic meters	3.53147×10^{1}	cubic feet	ft^3
m^3	cubic meters	1.30795	cubic yards	yd^3
		Mass		
kg	kilograms	2.20462	pound-mass, avoirdupois (avdp)	lbm
g	grams	3.52740×10^{-2}	ounces (avdp)	oz
		Density		
kg/m^3	kilograms per cubic meter	1.68555	pound-mass (avdp) per cubic yard	lbm/yd^3
kg/m^3	kilograms per cubic meter	6.24280×10^{-2}	pound-mass (avdp) per cubic foot	lbm/ft^3
		Temperature (exact)		
°C	degrees Centigrade	1.8 × (°C) + 32	degrees Fahrenheit	°F
°C days	degrees Centigrade days		degrees Fahrenheit days	°F days
		Pressure or Stress		
MPa	megapascals	1.45038×10^{2}	pound-force per square inch	psi

Acronyms and Terms

Abbreviations

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
COTS	commercial off-the-shelf
CWAS	Cold-Weather Admixture Systems
DOT	Department of Transportation
ETL	Engineering Technical Letter
FHWA	Federal Highway Administration
OSFA	one-size-fits-all

Phase III: Guidance for Optimizing Admixture Dosage Rates Data Review and Project Framework Development

Lynette A. Barna

Introduction

Conventional cold weather concreting methods needing thermal protection has met a new challenge. Two previous pooled-fund studies sponsored by the Federal Highway Administration (FHWA) and contributing State Departments of Transportation (DOTs), showed the practicality of using commercially available off-the-shelf chemical admixtures to produce antifreeze concrete formulations capable of curing at below freezing temperatures – without the need for external heat. Cold weather admixture systems (CWAS), or antifreeze concrete, is defined as an admixture or group of admixtures that depress the freezing point of mixing water and increases the hydration rate of Portland cement in concrete (ASTM 2006).

The first study (Phase I) developed eight antifreeze concrete mixtures in the laboratory and demonstrated these formulations in five full-scale field projects using standard construction equipment, mixing, and placement operations. The details of this study may be found in Korhonen et al. (2004a). Building on the success of the first study, the second study (Phase II) investigated the benefits of using high concentrations of chemical admixtures in concrete as related to freeze-thaw durability. Higher dosages of chemical admixtures were found to be beneficial against the damaging effect of freeze-thaw cycling (Korhonen 2006). Since then, the antifreeze concrete technology has been used in several additional field applications outside of the FHWA pooled-fund program, to include airfield pavement repair (Korhonen and Seman 2005), and precast concrete work (Barna et al. draft). Most recently, the antifreeze concrete technology was demonstrated at Ft. Wainwright, Alaska in March 2008 (Barna et al. draft).

Technical specifications have been developed to transfer the antifreeze concrete technology to both the civilian and military practitioners, and include: ASTM C1622, *Standard specification for Cold-Weather Admixture Systems* (2006), *A Guide to the Field Production and Use of Off-the-Shelf Concrete Admixtures as Antifreeze Admixtures* (Korhonen et al. 2004b), and *Use of Off-the-Shelf Concrete Admixtures as Cold Weather Admixture Systems (CWAS)* (U.S. Air Force 2005). The current specifications facilitate integrating the antifreeze concrete technology into standard practice. However, a gap exists to tailor the chemical admixture dosage for specific job-site conditions.

The problem

Current antifreeze concrete formulations resist freezing down to 23 °F. However, not all conditions require this level of freeze protection. The ability to tailor the admixture dosage to conditions specific to the intended job site would provide much needed flexibility for using antifreeze formulations, as well as achieving a more economical mixture.

Project objective

The purpose of the this study is to develop the tools and guidance needed to specify admixture dosage levels for antifreeze concrete mixtures corresponding to the varying weather conditions experienced at any job location.

Project scope

This report identifies and summarizes the data inputs needed in the design process to tailor antifreeze concrete mixtures for job specific conditions. Data collected from previous field sites was reviewed to identify the critical parameters needed and existing knowledge gaps. This information was then used to build the framework for the remainder of the project.

Portland cement, acceptable for cold weather concreting, will be considered in this study. This includes Type I or Type II cements that conform to ASTM C 150 and have been used in previous phases of this program. While the use of blended cements and supplementary cementitious materials (SCMs) are commonly used in practice, they are not considered in this study. Given their widespread use in the industry, the use of blended cements and SCMs should be considered for use in antifreeze concrete formulations in future investigations.

Technical approach

The project is divided into three parts: 1) data review and project framework development, 2) develop design guidance, and 3) develop soft-ware-based design tool. The first part, data review and project framework development, serves to review the current collection of data and identify the critical parameters for tailoring the design of antifreeze concrete mixtures. The data review also identifies existing knowledge gaps that may play a role in achieving the project's objectives. The first part also takes an initial

look at existing thermal models for their potential use with antifreeze concrete formulations.

Part two, develop design guidance, is anticipated to encompass the bulk of the project. This includes analyzing the previous data sets to determine the interactions between the critical parameters (such as weather, geometry, and admixture formulations, etc.) and develop relationships between these factors and varying dosage levels in antifreeze concrete formulations. Small-scale, controlled laboratory testing may be needed to further investigate the knowledge gaps. Currently, the antifreeze concrete approach is limited by its "one-size-fits-all" (OSFA). This portion of the study will further refine OSFA to establish temperature ranges where antifreeze concrete dosages would be successful. The product of this part of the study is seen to be guidance, in the form of tables or charts to provide the end user the capability to design for specific project needs. This portion of the project also lays the foundation to develop a software-based design tool, which is the focus of Part Three in the project.

The third part of the project is to develop a software-based design tool. The principle idea of this part of the project is to provide a design tool that offers an easy-to-use format for designers and practitioners to incorporate antifreeze admixture technology into their construction operations, and thus "putting it into practice." A software-based design tool, such as in a spreadsheet format, is useful in the design process to evaluate multiple scenarios, based on anticipated weather conditions. At the job site, such a design tool allows for real-time modifications to the mix based on actual job-site conditions. At this time, this part of the study is unfunded. Existing thermal models were surveyed for their potential use with antifreeze concrete mixtures.

PART 1: DATA REVIEW

The antifreeze concrete technology has been proven in a number of successful full-scale field applications. Table 1 summarizes the date, location, and application of several field applications. The listing illustrates the range of applications, which used antifreeze concrete. Five of the field sites listed in Table 1 were conducted during the Phase I study (Korhonen et al. 2004a). The most recent field demonstrations were conducted after the Phase I study had concluded.

Table 1. Summary of field trials incorporating CWAS technology.

Date	Location	Member
17-18 February 1994	Hanover, NH	Slab and Wall
15-17 March 1994	Sault Ste. Marie, MI	Pavement
10 December 2001	Littleton, NH[1]	Bridge curbing
27 February 2002	Rhinelander, WI[1]	Pavement
12 December 2002	North Woodstock, NH[1]	Bridge footing
18 December 2002	West Lebanon, NH[1]	Bridge curbing
14 February 2003	Concord, NH[1]	Sidewalk
23 February 2004	Grand Forks AFB, ND[2]	Airfield pavement
7 February 2007	Juneau, AK[3]	Precast work
27 March 2007	Fairbanks, AK[4]	Slabs on grade
25-27 March 2008	Ft. Wainwright, AK[5]	Communications hardstand

Varying site conditions were encountered at each job site. To illustrate this, air temperature readings collected from four New Hampshire field site locations, and Ft. Wainwright, Alaska, are shown in Figure 1. The graph shows the range of measured air temperature readings from near freezing to -4°F during the initial 72 hr from the time of concrete placement. The solid red line in the figure indicates the freezing temperature,

[1] Korhonen et al. (2004a).

[2] Korhonen and Seman (2005).

[3] Barna and Korhonen (draft).

[4] Barna et al. (draft).

[5] Barna et al. (draft).

32 °F. As expected, the air temperature decreased overnight, where the coldest reading of −4 °F occurred at Concord, NH. The use of the conventional winter concreting methods at any of these sites would have required protective measures for normal concrete. While the antifreeze concrete formulations did not freeze, these conditions did not test their full capability. The air temperature data support the need to optimize the admixture dosage levels in antifreeze concrete formulations to the level needed at the job site.

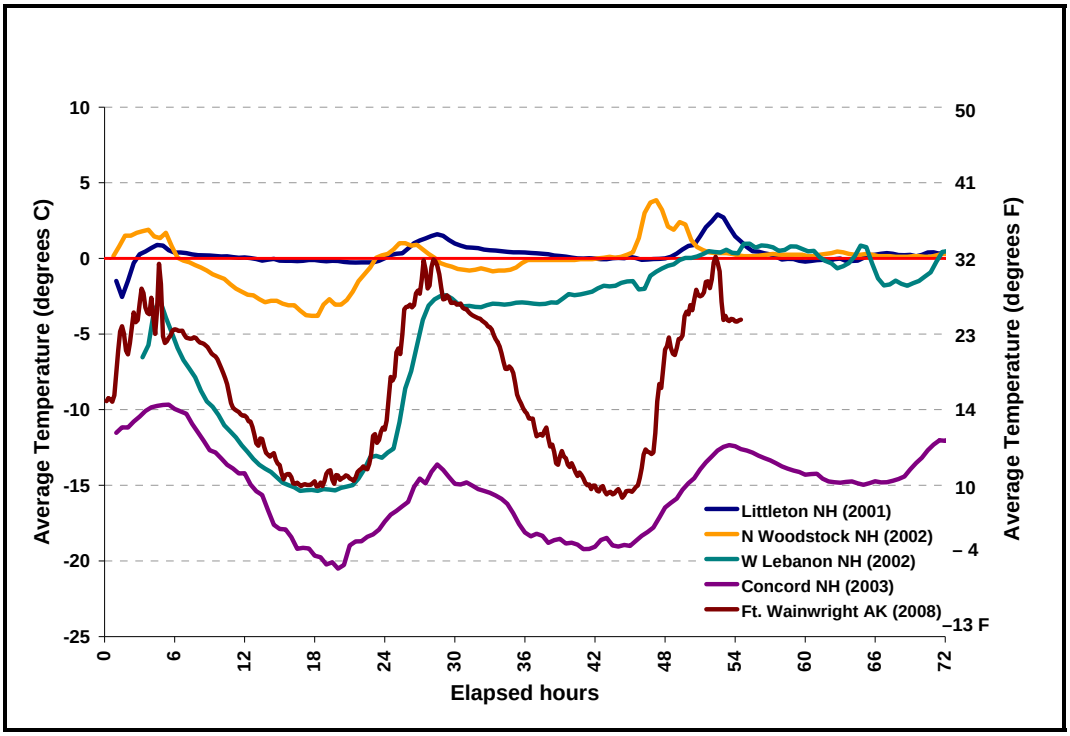

Figure 1. Air temperature measurements collected from previous full-scale field sites.

Critical parameters

Review of the previous field studies identified the following parameters when planning a specific job and optimizing the chemical admixture dosage in antifreeze concrete mixtures. While some of these parameters are typical considerations for any job, they also impact antifreeze concrete mixtures.

Geometry

The geometry of the proposed structure is needed as part of the design procedure to determine the quantity of material needed. The layout of the structure determines the critical locations for monitoring the temperature and subsequently, where temperature sensors should be located. Furthermore, the geometry determines the thermal regime, such as a pavement application where a concrete slab placed on the grade, or a bridge member, to understand the flow of heat from the concrete structure to the surroundings.

Structural layers and material thermal properties

The composition and thickness of each of the supporting substrate materials, such as for a slab on grade, are necessary to understand the transfer of heat through different materials, particularly when placing fresh antifreeze concrete on cold ground, including vapor barriers or insulation placed on the concrete surface. Heat transfer plays a significant role in how the environment interacts with the structure and vice versa. For each material layer, the thermal properties are needed including the thermal conductivity and specific heat. Insulation and soil properties are also needed.

Initial temperatures

Initial temperatures at the time of concrete placement are needed for ambient air temperature, fresh concrete, and substrate. These are needed to describe the initial conditions. These values will be necessary inputs for a software-based program.

Concrete mix

Material properties for each of the mixture components, as well as the proportioning of each material are needed as their combined interaction, while complex, are key to developing relationships for cement hydration and strength gain. For example, the components of the base mixture used in the Phase I study for the laboratory investigation are given in Table 2 (from Korhonen et al. 2004). Previously investigated antifreeze mixtures, as well as mixtures used in this study, will be representative of a winter mixture design and meet the guidance stated in ACI 211.1 (1991).

Table 2. Base concrete mixture components used in Phase I study (Korhonen et al. 2004).

Mixture Component	Product Type	Quantity
Cement (lb/yd^3)	Lafarge Type I-II	660
¾ in. aggregate, ssd (lb/yd^3)	ASTM C 33 #67	1,819
Sand, ssd (lb/yd^3)	ASTM C 33, fine aggregate	1,350
Batch water ‡ (gal/yd^3)	Regular tap water	34.7
Air-entraining admixture (floz/cwt)	Darex® II AEA*	1.49-
Water-reducer (floz/cwt)	Mira™ 70 (mid-range)*	7.78
Final water-cement ratio		0.436

* Darex II and Mira 70 were W.R. Grace products.

Cement

Portland cement, acceptable for cold weather concreting, should be considered. Type I/II cements, conforming to ASTM C 150, have been used in previous phases of this program and shown to be effective. To date, this program has only tested non-blended cements and has not incorporated supplemental cementitious materials (SCMs), such as fly ash, blast furnace slag, or silica fume. While the use of SCMs is common in general practice for concrete production, they have not yet been tested with antifreeze concrete mixtures and should be a topic for future research.

The cement content in the mixture is important as it relates to the generation of heat during hydration (Mindess and Young 1981). Moreover, the quantity of cement ties into the water-cement ratio (w/c), which has a bearing on the strength development of concrete.

Water

Potable water suitable for normal concrete mixes should be used in antifreeze concrete mixtures. Cold water is used and the initial temperature is recommended to be 50 ± 9 °F. In the laboratory and the field, the use of cold water aids in slowing down the slump loss.

The quantity of water present plays an important role in antifreeze concrete mixtures. The total quantity of water in the mix is closely monitored from all sources (fine and coarse aggregates, and chemical admixtures). As antifreeze concrete mixtures serve to depress the freezing point of the water, more water added into the mix reduces the freeze protection temperature limit of the mix.

Aggregates

Fine and coarse aggregates used in normal concrete are also used in antifreeze concrete formulations. In the previous phases of this program, locally available materials were used to produce antifreeze concrete mixes. The aggregates should be clean, durable, and well graded (Korhonen et al. 2004b, U.S. Air Force 2005). Both the fine and coarse aggregates should conform to ASTM C 33.

As a constituent with the concrete mix, the composition of the aggregates will play a role in the exchange of heat with the environment (Schindler et al. 2002).

Chemical admixtures

The quantity of each chemical admixture used in the antifreeze mix is needed to understand the effect on the set time, as well as the hydration.

Construction

This includes information related to the construction activities, such as when the finished surface was covered with a vapor barrier, formwork, inclusion of reinforcing steel, etc.

Weather forecast

In addition, the forecasted air temperatures for the first 72 hr following placement of the antifreeze concrete are needed. These values will be used to develop design guidance.

Ft. Wainwright, Alaska, field demonstration project

Recently, a full-scale field demonstration was conducted in March 2008 at Ft. Wainwright, Alaska. This was the first full-scale field demonstration that used varying admixture dosage rates in the concrete mixtures. A communications hardstand was constructed incorporating the CWAS approach. The total size of the test area was 25 x 75 ft, and it was partitioned into five test sections of equal size of 15 x 25 ft. The overall slab thickness was 6 in., requiring roughly 10 yd^3 of concrete to complete each test section. The concrete was placed over a two-day period, with test section 1, 3, and 5 completed on the first day, and test section 2 and 4 completed on the second day. The chemical admixture dosage rate was

varied in each of the five slabs, as shown in Table 3. Test section 5, located on the southern-most end of the test area, used the lowest dosage of admixtures. The proportion of the base concrete mix components (cement, sand, and stone) remained the same.

The concrete specifications called for a 28-day compressive strength of 4,000 psi, with 5% to 7% entrained air. The base antifreeze concrete mix used 658 lbs per cubic yard of Type I/II cement. Commercially available chemical admixtures from BASF were used to formulate the antifreeze mixes. Glenium® 3000 NS, Rheocrete® CNI, and Pozzutec® 20+, were added into the mixes, and all admixture dosages were within the maximum allowable dosage levels recommended by the manufacturer.

The Glenium® 3000 NS is a polycarboxylate-based high-range water reducer (HRWR) that meets ASTM C 494 Type A and F (BASF 2007a). In antifreeze mixes, this type of admixture reduces the total amount of mix water needed. The manufacturer's maximum recommended dosage is 12 fl oz per hundred weight of cement. In the Ft. Wainwright mixtures, the dosage ranged from 4.9- to 8.0-fl oz/cwt.

The Pozzutec® 20+ is a non-chloride accelerating admixture that meets ASTM C 494 Type C and E (BASF 2008). As it is non-chloride, it should inhibit corrosion with steel reinforcement. The manufacturer's maximum recommended dosage is 90-fl oz per hundred weight of cement. In the Ft. Wainwright mixtures, the dosage ranged from 22- to 68-fl oz/cwt.

Rheocrete® CNI is a corrosion inhibiting admixture that meets ASTM C 494 for Type C (BASF 2007b). The Rheocrete® CNI aids in freezing point depression. The manufacture's maximum recommended dosage is 6.0 gal per cubic yard. In the Ft. Wainwright mixtures the dosage rate ranged from 1.5 to 4.0 gal per cubic yard.

Temperature sensors were installed at similar locations in each test section to monitor the thermal history of the concrete from the time of placement through a 28-day curing period. The layout of the test area and the locations of the temperature sensors are shown in Figure 2.

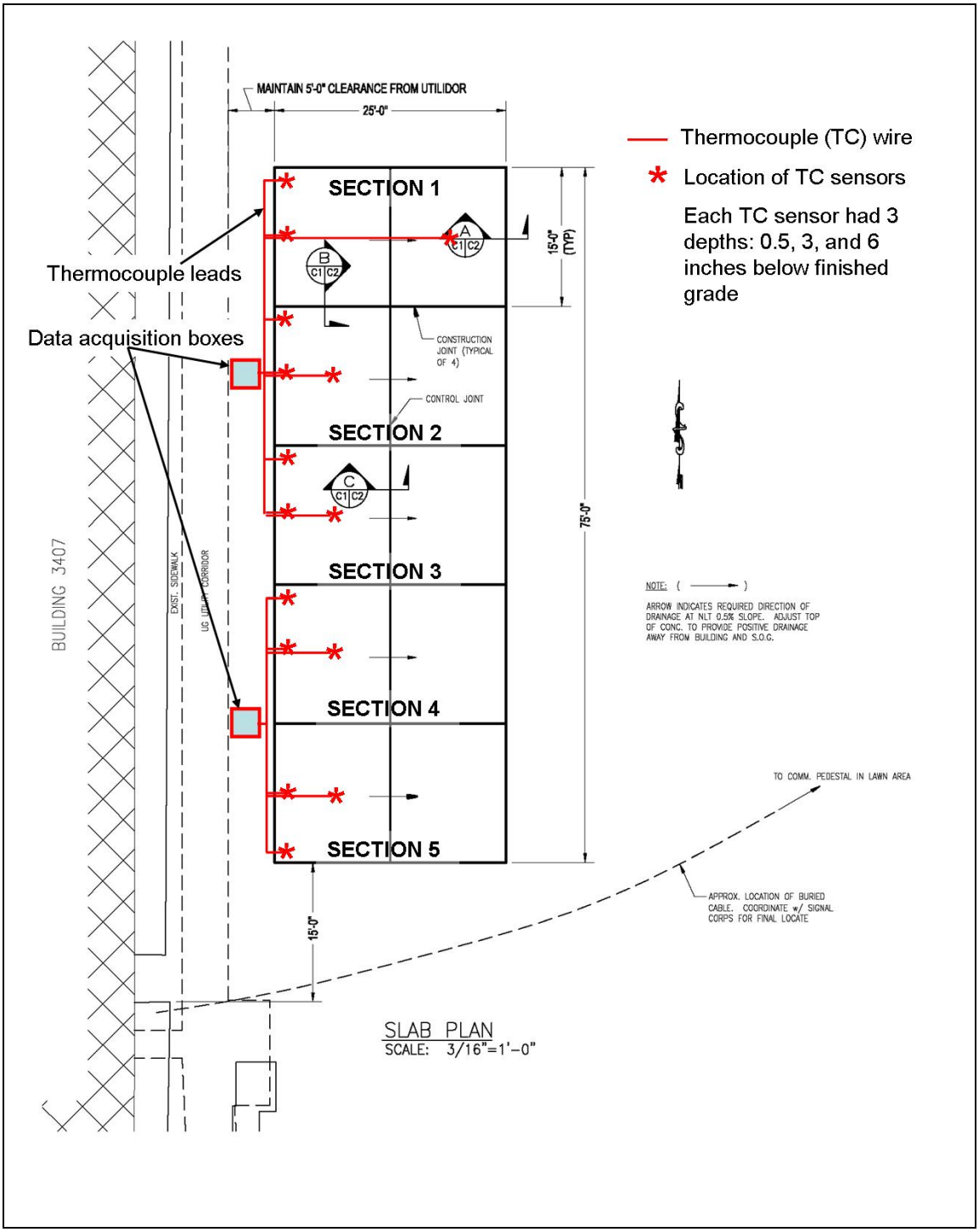

Figure 2. Test area layout indicating location of instrumentation.

Table 3. Material proportions used in demonstration concrete mixes.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
	Test Section 1	Test Section 3	Test Section 5	Test Section 2	Test Section 4
Date Batched	26 March	26 March	26 March	27 March	27 March
Placement Location	Section 1	Section 3	Section 5	Section 2	Section 4
Cement (lb/yd^3)	658	659	660	658	656
¾ in. aggregate, ssd (lb/yd^3)	1,762	1,776	1,766	1,762	1,758
Sand, ssd (lb/yd^3)	1,350	1,383	1,352	1,365	1,375
Batch water‡ (gal/yd^3)	19.0	20.1	24.0	20.4	24.5
Glenium® 3000NS (floz/cwt)	8.0	7.0	4.9	6.0	--
Rheomac® VMA (floz/cwt)	--	--	--	--	4.0†
Pozzutec 20+ (floz/cwt)	68.0	45.0	22.0	34.0	34.1
Rheocrete CNI (gal/yd^3)	4.0	3.0	1.5	2.3	2.3
Extra water added at batch plant (gal/yd^3)	3.8	5.0	3.0	5.9	8.7
Water added at jobsite (gal/yd^3)	1.6	1.2	0.4	--	--
Final water-cement ratio	0.39	0.39	0.38	0.38	0.47
Percent total solids (%)	11.8	8.3	4.4	6.6	5.3

† Mix 5, Test Section 4 used Rheomac® VMA instead of the Glenium® 3000 NS.

Table 3 gives the admixture dosage rate for each of the antifreeze concrete mixtures as a percentage of the manufacturer's recommended maximum dosage. This is also shown graphically in Figure 3. Varying the chemical admixture dosages resulted in different initial freezing point temperatures, or the freeze protection limit (Figure 4). There is a relationship between the initial freezing point and the percentage of solids in the mixture. This relationship correlates the total amount of water to the non-water components of the mixture and is discussed in detail in Korhonen et al. (2004a). Reducing the admixture dosage subsequently reduces the freezing point, as shown in both Table 3 and Figure 4. Mixture 1, used in Test section 1, had the coldest initial freezing point, or the lowest freeze protection tem-

perature, at 25.3 °F as this mix contained the highest dosage of admixtures.

Table 4. Admixture dosage level, indicated as a percentage of the manufacturer's recommended maximum dosage rate, and freezing point temperatures for the field demonstration antifreeze concrete mixtures.

	Mixture 1 Test Section 1	Mixture 2 Test Section 3	Mixture 3 Test Section 5	Mixture 4 Test Section 2
Admixture Dosage Level (percentage of maximum)				
Glenium	67	58	41	50
Rheocrete CNI	67	50	26	38
Pozzutec 20+	76	50	24	38
Initial Freezing Point Temperature (˚F)				
Average	25.3	29.8	30.6	29.3

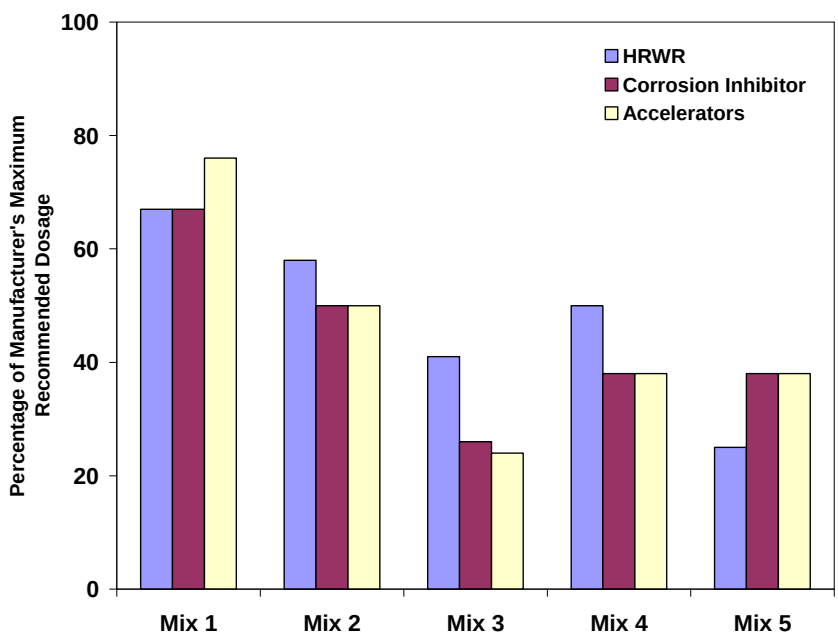

Figure 3. Relationship of initial freezing point to percent solids in antifreeze concrete mixtures used at Ft. Wainwright, Alaska, demonstration.

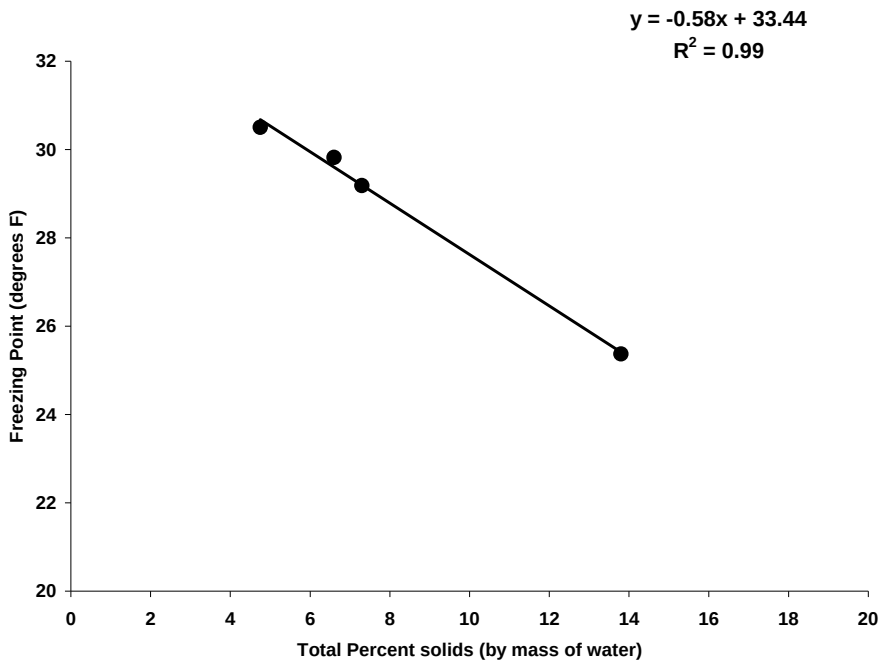

Figure 4. Relationship of initial freezing point to percent solids in antifreeze concrete mixtures used at Ft. Wainwright, Alaska, demonstration (based on procedure for calculating concentrations in Korhonen et al. (2004a).

The temperature data provided a thermal history for each section as the concrete hardened and gained early strength. Figures 5 and 6 show the temperature data for the two mixes containing the highest and lowest admixture content; Mix 1 (Test Section 1) and Mix 3 (Test Section 5), respectively.

To estimate the strength gain in each test section the maturity method was used. The maturity method was used to estimate the strength gain for each test section. This approach uses the temperature data with the compressive strength data from test cylinders cast onsite and tested by a local materials laboratory. The estimated strength gain for Mix 1 and Mix 3 are given in Figures 7 and 8, respectively.

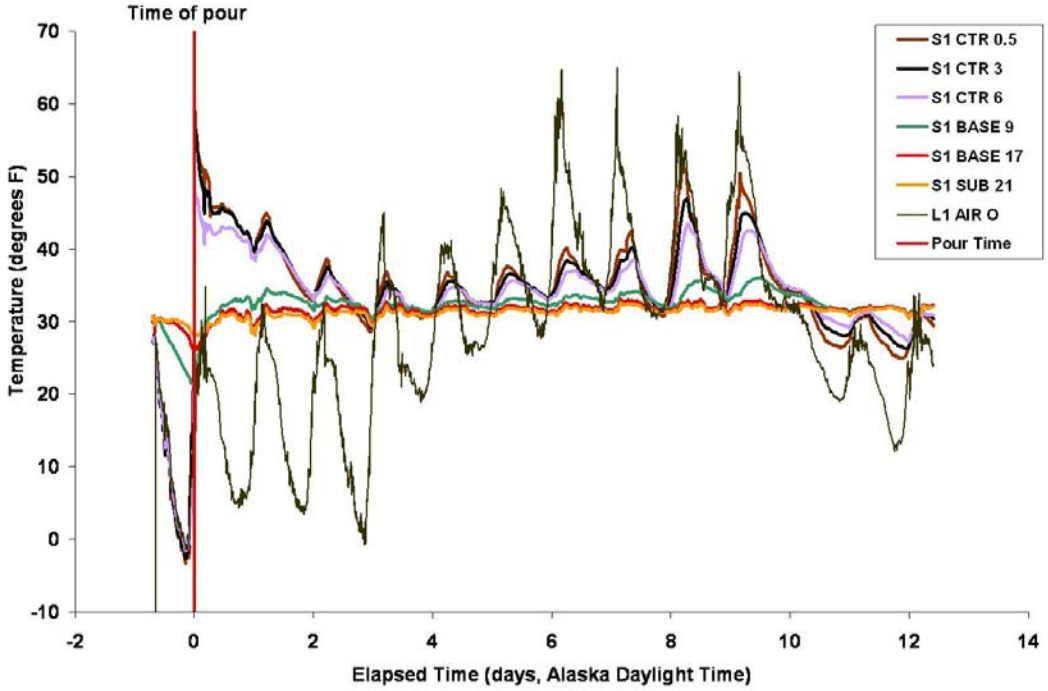

Figure 5. Temperature history readings for Mix 1 Test Section 1 at center of mass and within the substrate.

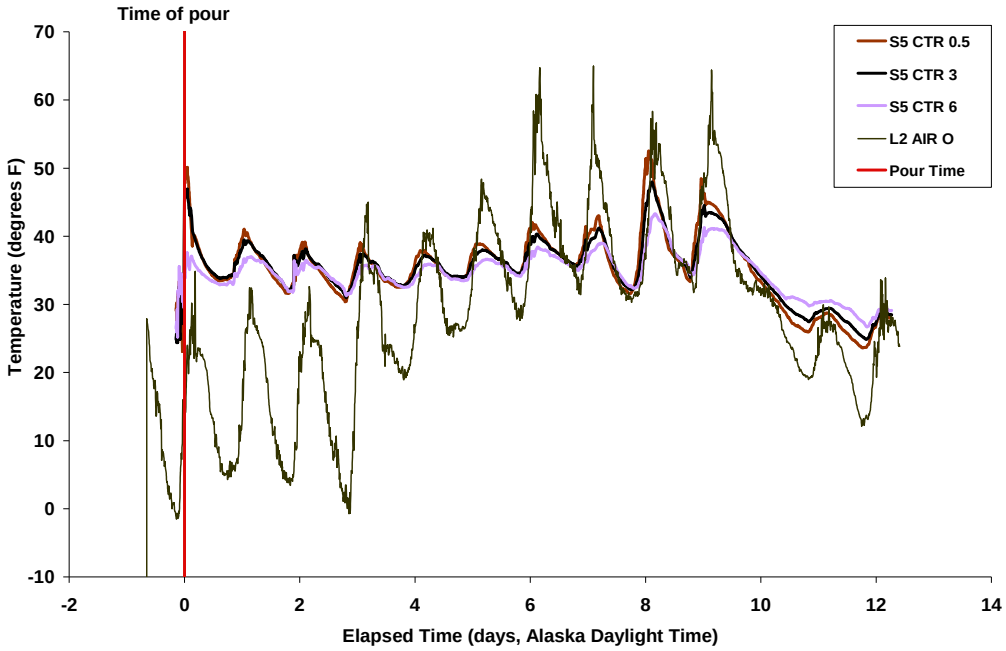

Figure 6. Temperature history readings for Mix 3 Test Section 5 at center of mass.

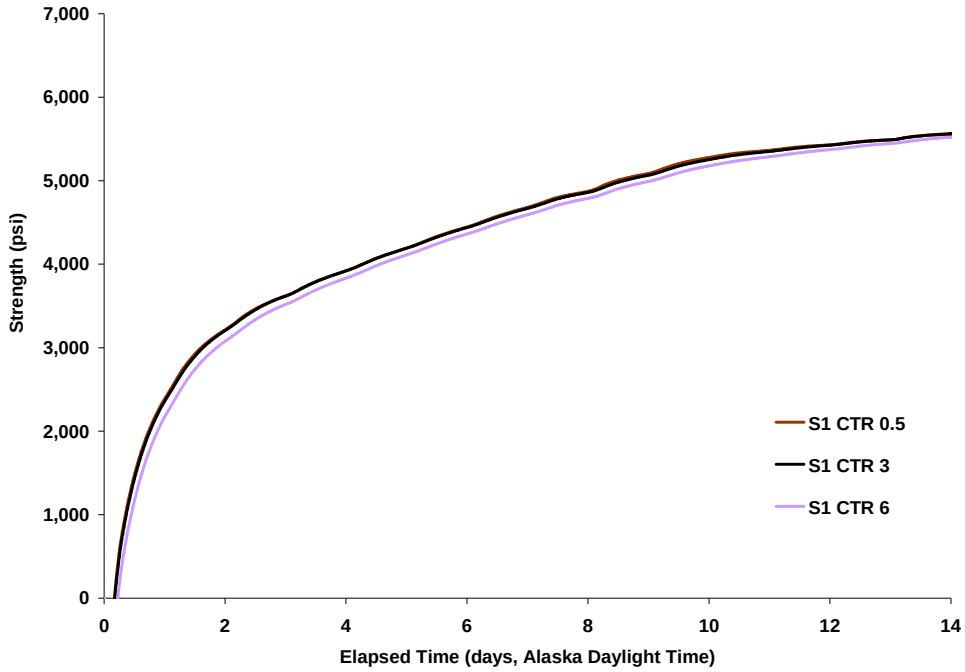

Figure 7. Estimated strength gain for Mix 1 Test Section 1.

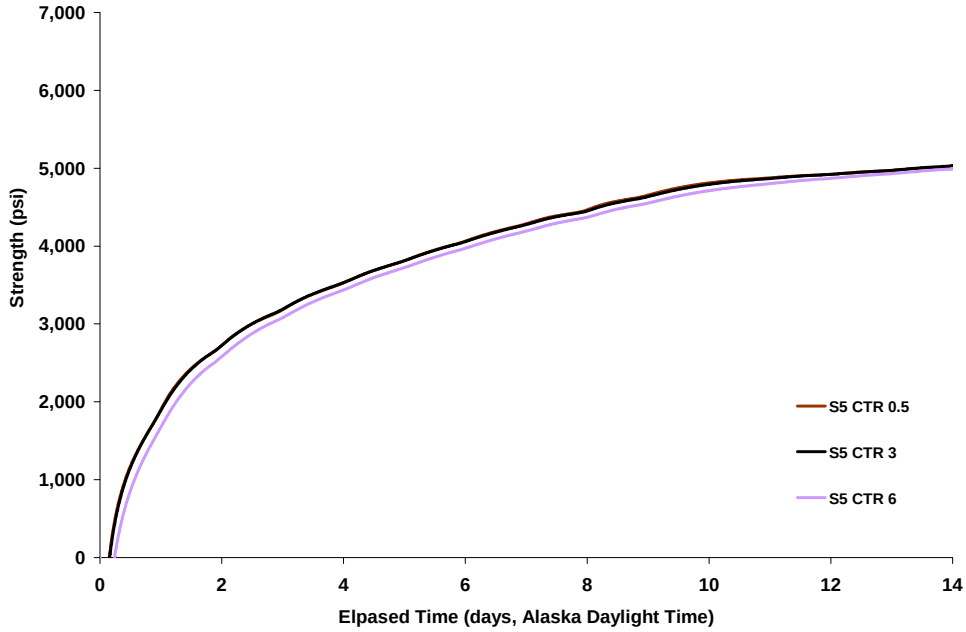

Figure 8. Estimated strength gain for Mix 3 Test Section 5.

The estimated strength results from the Ft. Wainwright field-demonstration data show that Mix 1 and Mix 3 reached the target strength of 4,000 psi within 30 hr (Figures 7 and 8). As expected, Mix 1 reached the target strength sooner as it contained a higher admixture dosage than Mix 3 in Test Section 5. These results suggest that the conditions at the jobsite were favorable for using a lower admixture dosage in the concrete mix.

Eventually, the measured temperatures from the Ft. Wainwright field test will also be useful as input in computer models to compare the predicted and measured temperatures in the slab.

PART 2: Develop Design Guidance

This part of the project uses the data obtained from previous field site to establish the relationships that will lead to tailoring the admixture dosage rates for antifreeze mixtures. Adjusting the amount of admixtures used in the mixes makes them more economical. Currently, CWAS has developed guidance on how to use this approach. The next step is to divide the "one-size-fits-all" method into smaller portions to further an effort to optimize the admixtures. This step will evaluate the parameters identified in Part 1 to develop relationships between these variables for conditions that are suitable for antifreeze concrete formulations. For the user, practical guidance has been developed for the user to design, mix, place, and cure antifreeze concrete. It is anticipated that experience with antifreeze formulations will still be needed until the user becomes familiar with this approach. A final report will be prepared, in an easy-to-use format providing direction on designing and modifying admixture dosage rates for the anticipated conditions.

Job site information, including the geographic location, material types and thicknesses of the supporting subgrade, temperatures, etc., will be needed. The use of climate databases to retrieve historical weather data may be useful in developing expected air temperature ranges, such as maximum and minimums. One example of a climate database is WorldIndex (version 99.1), developed by the Corps of Engineers, which is used in the design of horizontal projects such as pavements and utilities located in cold regions. WorldIndex contains summary data for over 4,000 stations world wide and includes information related to the duration of the freezing season, as well as expected air temperatures. An example of the summary for Lebanon, NH is shown in Figure 9.

The state of the ground, related to the frost or thaw depth, may be estimated using the ModBerg computer program (version 99.2), based on Modified Berggren equation. ModBerg is a one-dimensional heat flow program that uses the freezing index, a measure of the duration and intensity of the freezing season, as an input. Figure 10 illustrates the distribution of the design freezing index for North America (U.S. Army Corps of Engineers 1992).

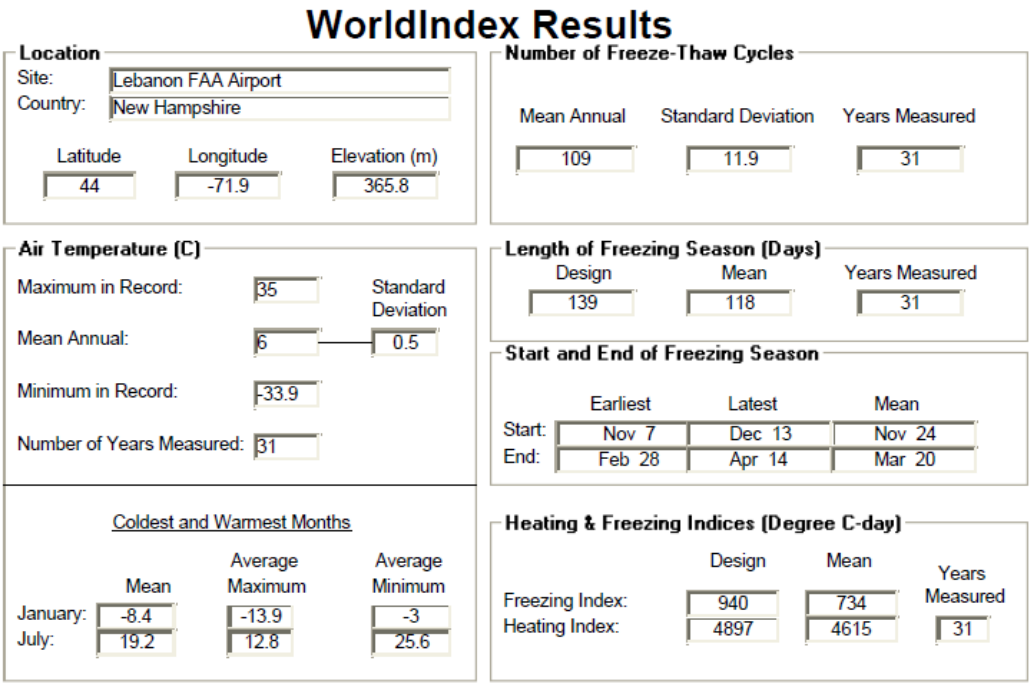

Figure 9. Example of climate data available from WorldIndex (version 99.1). Note: WorldIndex displays information in SI units. Use the Unit Conversion Table in the front of this report to convert from SI to U.S. units.

Figure 10. North American Design Freezing Indexes (U.S. Army Corps of Engineers 2001).

An understanding of the interactions between the environmental conditions and the antifreeze concrete formulations will be developed. It is anticipated that data collected from the previous field sites will be used to establish this. If needed, controlled laboratory experiment(s) may be conducted to fill in gaps in knowledge. This will be documented in a final project technical report.

The relationships developed between the geometry, site conditions, antifreeze concrete mix dosage, etc., will provide the foundation for establishing a computer-based design tool.

COMPUTER MODELS

Eventually, developing a computer-based design tool would serve as an easy-to-use interface for practitioners to design, and even modify in real-time, the antifreeze mixtures used for cold weather construction. An initial survey of existing computer models identified three that may be favorable for use with antifreeze concrete formulations. Existing computer models for consideration include HIPERPAV II from TransTec, PavePro from the University of Texas at Austin, and an ERDC-CRREL one-dimensional thermal model from Dr. Paul Richmond.

HIPERPAV® II

The Windows-based software program HIPERPAV® II, which stands for High PERformance PAVing, was initially released in 1996 and was developed by the TransTec Group and sponsored by the U.S. Department of Transportation, Federal Highway Administration. The software program considers the concrete mixture materials and climate conditions to plan, design, and monitor concrete pavements, especially during the early age time period. Currently, the HIPERPAV® II software output is given in terms of the thermal stress condition and strength gain. Details about the HIPERPAV® II software, along with a user's guide are provided in Ruiz et al. (2005).

PavePro

The software program PavePro was developed by the Center for Transportation Research at the University of Texas at Austin. PavePro is a Microsoft Windows Excel spreadsheet-based tool useful for Portland cement concrete pavements. Input information on geometry, geography, environmental conditions, and construction criteria are considered in the algorithms to predict the temperatures within the slab and in the subbase layer below. The average concrete temperatures within the slab are estimated during the initial 48 hr following placement, while the average temperatures in the subbase layer are estimated during the initial 36 hr. Details of the development of the mathematical models used in PavePro are given in Schindler et al. (2002).

Richmond model

The Richmond model is a one-dimensional model that simulates the thermal regime of curing concrete. The model is applicable for structural concrete members, such as horizontal structures on soil foundations or bridge decks. The 1-D thermal model is based on fundamental principles of heat transfer (conduction, convection, and radiation) and the interaction of the concrete structure within the environment that it is placed, particularly in environments where freezing temperatures occur. Varying scenarios may be constructed and simulated using the model to include the use of insulation layers when ambient temperatures are forecasted to be very cold.

The model interface for the use is set up in a spreadsheet format for ease of use. Model inputs needed include the material layers for each (including the supporting substrate layers), material thermal properties, initial temperatures to establish boundary conditions, forecasted air temperature data, etc. The model output consists of calculated temperatures at designated node locations at the interface (upper and lower surfaces) and interior of the structure (Richmond draft).

These potential computer models, and perhaps others, will need to be fully assessed for use with antifreeze concrete mixtures to evaluate how well they may predict the thermal evolution in a given structure. This may be accomplished through the use of previous field data as input into the computer programs. The predicted values may be compared to actual field measurements.

PROJECT FRAMEWORK

The purpose of this project is to develop the tools and guidance needed to specify admixture dosage levels for antifreeze concrete mixtures adapted to site-specific conditions. Up to this point, antifreeze concrete mixtures have followed a 'one-size-fits-all approach' to achieve a freeze protection temperature of 23 °F. The result of this temperature limit may be over-designing antifreeze concrete mixtures in most cases, and has prompted the need to tailor the admixture dosage rates. The dataset from Ft. Wainwright, Alaska, provided the first full-scale field demonstration to use varying admixture dosage levels during the construction of five separate slabs. The temperature data collected at Ft. Wainwright was used in two computer models to compare the calculated temperatures against the measured temperatures. The results from the computer models emphasized the necessary input and output values needed, and that the early-age behavior of antifreeze concrete is not well understood.

The information gained in this portion of the study will be used in the next part, *Developing Design Guidance*. Two important parts in developing the design guidance includes understanding the interactions between the cement and chemical admixtures, and developing relationships between the varying admixture dosage levels in antifreeze concrete, the geometry, and environmental conditions.

The need exists to better understand the interactions between the chemical admixtures in the concrete mixtures and the effect on curing at low temperatures. In the Phase I study (Korhonen et al. 2004a) the maturity method was investigated for use with antifreeze concrete formulations. The results indicated that the time-temperature factor (Nurse-Saul method) was valid with antifreeze concrete mixtures. However, the results with the equivalent age (Arrhenius function) were not as clear. Determining the activation energy of antifreeze concrete formulations needs to be revisited.

The heat of hydration generated by the mixture during early age is another important consideration in understanding antifreeze concrete curing. Targeted laboratory studies may serve to gain a better understanding of the interaction issues related to antifreeze concrete.

CONCLUSIONS

This project is the third phase in support of the program *Extending the Season for Concrete Construction and Repair*. This program has developed the concept of antifreeze concrete from the laboratory to full-scale field use. Previous portions of this program have established the practical feasibility and benefits of using antifreeze concrete, as compared to conventional cold weather concreting methods. A number of field demonstrations have been conducted, firmly confirming the feasibility of this approach. The objective of this project is to develop the tools and guidance to tailor dosage rates of chemical admixtures based on the features of the jobsite.

Data collected from previous field sites highlights the varying conditions encountered, and show that the current 'one-size-fits-all' approach may be further economized. A survey of existing computer models identified three that may be applicable for use with antifreeze concrete formulations. Temperature data, geometry, and other particulars from the most recent field project at Ft. Wainwright, Alaska, were input into two of the models to obtain computed concrete temperatures. The computed concrete temperatures were compared to the actual temperatures measured in the field. The results from one model over-predicted the temperatures, while the other under-predicted temperatures. These results indicate the need for understanding the effects of high doses of chemical admixtures used within concrete mixtures and their impacts as antifreeze concrete cures at low temperatures.

The information gathered in this first portion of the project will be useful in the next step to develop design guidance. Anticipated products to aid in the design of antifreeze concrete formulations may include charts and tables. Fully funded project, a computer-based design tool would provide the most ease-of-use to the end user; and permit the consideration of varying scenarios. Finally, a final project report will be prepared.

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