Proposal: SP&R Pooled-Fund Study TPF-5(075)

Start: Oct 2003
End: Oct 2005

Phase II (Continuation of TPF-5(003)

Extending the Season for Concrete Construction and Repair

Defining Engineering Parameters

By

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EXECUTIVE SUMMARY

Background

Until recently, no portland cement concrete could be placed in below-freezing weather without thermal protection. That long-held rule just changed. Under FHWA pooled-fund project TPF-5(003), Phase I, CRREL demonstrated the practicality of using commercially available admixtures as antifreeze admixtures for concrete. Admixture formulations from two manufacturers' product lines were developed and evaluated under laboratory conditions for their suitability to field application. In four field trials from New Hampshire to Wisconsin, the admixtures made the concrete easy to work with and gain strength rapidly in winter conditions. The concrete made with these admixtures was able to fully cure at internal temperatures of –5°C, was as durable as normal concrete, and was cost competitive with conventional concreting techniques because no additional heat was required to keep the concrete warm. This project is on track toward a 2003 delivery date of the first-ever tools to design, mix, place, and cure concrete in below-freezing weather.

Intriguing and interesting discoveries were made during work on TPF-5(003). One of these discoveries showed that some of our concretes became much more durable than expected, even without entrained air. If this were to be exploited, the benefit of having longer lasting concrete would be tremendous to already overburdened state maintenance budgets. Even a mere 1% increase in service life is projected to save the Nation $30 billion in repair bills over 20 years[1]—we've witnessed as much as a doubling of freeze–thaw resistance of concrete in our preliminary tests. Work now needs to be done to exploit this possibility with these new antifreeze concretes so that it can be developed and translated into practice.

Objective

The number one problem of concrete in cold climates is deterioration caused by freezing and thawing. Deicing salts only exacerbate this problem. The objective is to define the effect of chemical admixtures on the durability of concrete (as mentioned above, we just completed defining their effect on strength development at low temperature). By measuring the effect of admixtures on such things as pressure build up within fresh concrete as it freezes and on dilation of hardened concrete as it freezes, we can expect to develop a correlation of chemical type, dosage, and make up with improved freeze–thaw performance. We expect this study to lead to guidance for enhanced service life of antifreeze concrete exposed to normal and deicer salt environments.

Benefits Obtained from this Study

Participants in this study will:

- Be able to use the admixture formulations developed in Phase I for more than cold-weather concreting applications.
- Learn how various admixtures affect concrete durability
- Receive design guidelines for freeze–thaw durable concrete.
- Receive design guidelines for adjusting admixture dosage rate to specific job conditions.

How to Participate in this Study

A consortium of stakeholders will fund this study, where each stakeholder contributes between $10K and $50K per year for up to 2 years. State DoTs are encouraged to direct their 100% SP&R funds toward participation in this project. States that want to commit funds to TPF-5(075) may do so on the Transportation Pooled Fund web site [www.pooledfund.org].

[1] **Civil Engineering Research Foundation** (1993) High-Performance construction materials and systems. Executive Report 93-501l.E, CERF, 1015 15th St, N.W. Suite 600, Washington, D.C.

TPF-5(075)

[Continuation of TPF-5(003)]

Phase II

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Defining Engineering Parameters

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INTRODUCTION

Phase I, *Establishing the Technology,* of the **Extending the Season for Concrete Construction and Repair** pooled-fund study [TPF-5(003)], performed by the U.S. Army Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (CRREL), is scheduled to end in 2003. Phase I is on track toward delivering the tools to design, mix, place, and cure concrete in below-freezing weather—the goal of this project. Now Phase II, *Increasing Freeze–Thaw Durability,* needs to be investigated.

Phase I, supported by 10 northern State Departments of Transportation[2], has, thus far, demonstrated the practicality of antifreeze admixtures for concrete. The first set of antifreeze formulations, using commercial admixtures from WR Grace, was developed between October 2000 and September 2001, the first year of this project. They were subsequently field tested in December 2001 and again in February 2002, mid-way into the second year of this project. This critical stage in the project took admixtures from the laboratory to the construction site. Reports from these two field studies can be viewed at:

http://www.crrel.usace.army.mil/concrete/State_Demonstrations.htm

Between March 2002 and October 2002, work progressed from optimizing the first set of antifreeze formulations to characterizing the resulting concretes made from these, and newer formulations—made with Master Builders admixtures—to be sure that they were suitable for highway application. The newest formulations were field-tested at two sites in December 2002. Reports from the December 2002 field tests are also posted on the web site listed above.

Draft proposals, dated 10 January 2003 and 28 February 2003, of Phase II were e-mailed to state DoTs. The first draft contained suggestions for four possible studies. Feedback from the states reduced the proposal to two studies. A second draft was re-submitted for which some minor adjustments were requested to better tailor the project to states needs. This document represents the work proposed for TPF-5(075). You are now invited to join this study.

[2] Participating states: ID, NH, NY, MI, MT, PA, UT, VT, WI, WY

DEFINING ENGINEERING PARAMETERS

Based on the success of Phase I, which established the practicality of using antifreeze admixtures in concrete, it is time to expand upon this new technology. The next steps that warrant consideration include:

I. *Increasing Freeze–Thaw Durability*—Admixtures promise to minimize freeze-thaw and salt-scaling damage to concrete.
II. *Determining Thermal Safety* —Knowing the heat evolved by cement mixed with chemical admixtures will help define the proper dosage of admixtures required to allow concrete to be safely placed under expected weather conditions.

I. *Increasing Freeze–Thaw Durability*

Background: The number one problem of concrete in cold climates is deterioration caused by freezing and thawing. Several theories have been advanced to explain frost damage but it should be recognized that such damage only happens to moist concrete. The movement of water, either toward or away from the freezing front, amplifies this damage, as does a high degree of saturation coupled with rapid cooling. Air entrainment is today's only defense against frost damage. It provides empty reservoirs inside concrete into which pressurized water and ice can escape. Little attention has been devoted to possible beneficial effects of pore water chemistry on the freeze–thaw durability of concrete, though chemicals are routinely used in today's concrete.

Part of the reticence of considering chemicals to improve durability is ascribable to the widespread pavement scaling that has been attributed to de-icing salts. There is little doubt that dissolved salts lead to surface scaling of concrete pavements in northern climates and that scaling becomes progressively worse as the concentration builds up inside the concrete. Contradicting this notion are data from the former Soviet Union that suggest that concrete made with chemical concentrations as high as 20% or more result in concrete that is significantly more durable than ordinary concrete. The need exists to better understand the role chemicals play when it comes to the freeze–thaw durability of concrete.

Sources of deterioration: In northern climates, concrete's two most persistent sources of deterioration are a) freezing and thawing (Fig. 1), and b) salt scaling (Fig. 2).

Figure 1. Example of freeze–thaw damage.

Figure 2. Example of salt-scaling damage.

Freeze–thaw processes: Because concrete readily absorbs water, it is vulnerable to damage if the water within its system of pores can freeze and generate disruptive pressures. The usual approach to increasing concrete's resistance to freeze–thaw damage is to modify its microstructure, either by intentionally entraining air bubbles into the cement paste (Fig. 3) or by reducing its water-cement ratio (Fig. 4), or both.

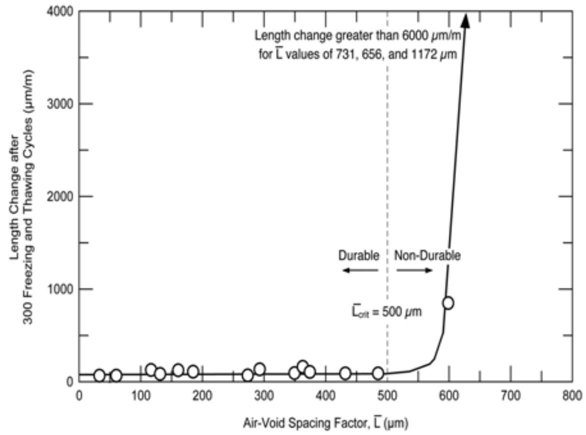

Figure 3. The benefit of closely spaced air voids. (After Pigeon[3] et al. 1986)

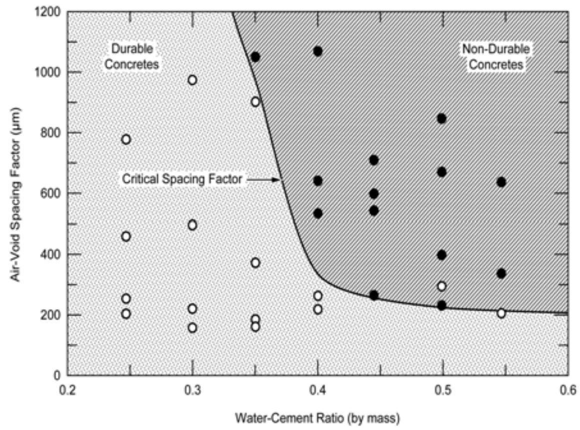

Figure 4. The effect of w/c ratio on durability. (after Okada[4] et al. 1981)

Possible effects of chemicals: For concretes made with high doses of chemical admixtures, such as those developed in TPF-5(003), the situation might change. For example, the freeze–thaw resistance of concrete could be increased because the pore water, containing more dissolved solids than ordinary concrete, might not freeze in normal winter conditions. At the very least, concrete made with high doses of chemical admixtures might experience fewer freezing cycles, thus freeze–thaw durability would be enhanced. It is also possible that chemicals might minimize the expansive pressures of pore water as it freezes. Preliminary measurements at CRREL show this to be the case. Less internal pressure should translate into more durable concrete. It is also possible that chemical admixtures inside concrete could improve its salt-scaling resistance. The operating principle behind this is that having a high concentration of chemicals inside concrete might lessen the osmotic forces produced by placing deicing salts on its surface.

Research results published by others support these contentions. Studies conducted in the former Soviet Union clearly show that chemical admixtures can positively effect the freeze–thaw durability of concrete—they also can have the opposite effect as well (Fig.5). Verbeck and Klieger[5] show that concrete is most susceptible to salt scaling at relatively low concentrations of salt but it becomes more resistant to scaling as the salt solution concentration within the concrete increases above a certain value.

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[3] **Pigeon,M.,R. Pleau, and P.C. Aitcin** (1986) Freeze-thaw durability of concrete with and without silica fume in ASTM c 666 (Procedure A, Test method: Internal cracking versus scaling). *Cement, Concrete, and Aggregates*, 8 (2): 76–85.
[4] **Okada,E., M. Hiska, Y. Kazama, and K. Hattori** (1981) Freeze-thaw resistance of superplasticized concretes. *Development in the Use of Superplasticers*, ACI SP-68, p. 215–231.
[5] **Verbeck, G.J., and P. Klieger** (1957) Studies of "salt" scaling of concrete. Highway Research Board, Bulletin 150, Washington, D.C., p. 1–13.

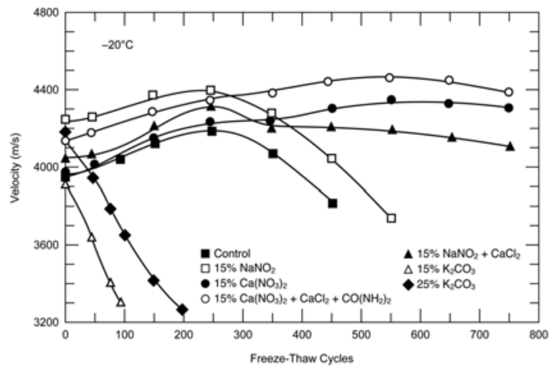


Figure 5. Effect of admixtures on durability.

Project Tasks: Research will be conducted to determine if admixtures affect the durability of concrete through a chemical or a physical process. The combination of admixtures identified in Phase I will be considered along with other possible admixture combinations for laboratory analysis and testing. A durability study, using CRREL's freeze–thaw chambers, will evaluate the chosen chemical admixtures to define if chemical type, chemical dose, or both, affect concrete's resistance to cycles of freezing and thawing. Other measurements, such as internal stresses developed in both fresh and mature concrete during freezing, will also help to define how the admixtures affect durability. Preliminary testing conducted prior to Phase I suggests that some chemicals significantly reduce the swelling of both fresh and hardened concrete during freezing. We need to understand why this happens to confidently specify more durable concrete. Evaluations will use both air entrained and non-air-entrained concrete. Laboratory findings will be demonstrated in the field. A section of concrete will be cast to compare the application and performance of the new concrete developed in this study to normal concrete.

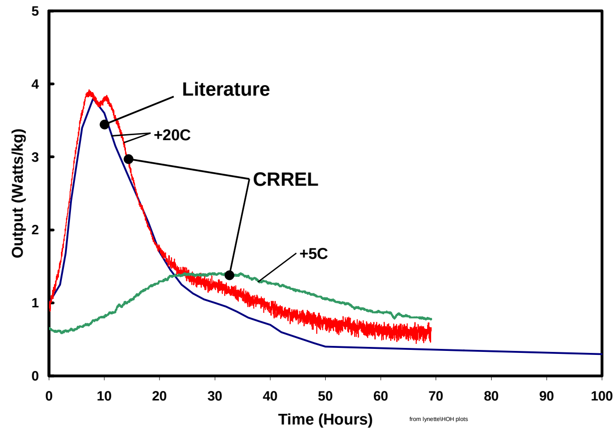
Deliverables: This project will produce guidelines for the effective use of off-the-shelf chemical admixtures to enhance the freeze–thaw durability of portland cement concrete. The guidance developed in this study will be based upon information found in the literature and on test results from this project. As a result of the laboratory and field study, subscribers will receive a technical report on the results with design guidance for longer service life concrete.

II. *Determine Thermal Safety*

Background: Phase I developed a concrete that can gain strength while its internal temperature is –5°C. Currently, we can't adjust the admixture dosage to coincide with the varying levels of protection that might be necessary for a given weather situation. We have a one-size-fits-all situation because we can't forecast an internal temperature as a function of outdoor temperature. Users of this technology need the capability to predict how a concrete mixture would perform in a particular environment, making it possible to optimize mixture design, economize material costs, and assure a desired outcome.

The thermal profile of a curing concrete structure is a function of the mix design of the concrete, its thickness and shape, the amount of wind and solar radiation, and the type of formwork. A critical element is the heat evolved from the cement as a function of temperature (Fig.6) and admixture concentration.

Figure 6. Heat of hydration data are mostly limited to room temperature environments. It is important that new data be developed for below-freezing conditions.



Past experience: The two winters of field trials[6] conducted in Phase I illustrated the difficulty of determining how the concrete would perform when subjected to the unstable outdoor conditions. In all cases, the air temperatures varied from the freezing mark down to nearly 0°F during the first few days of curing. These temperatures were low enough to freeze normal concrete but, in each instance, the antifreeze concrete was barely challenged. Easily, the work could have been conducted in more severe weather or the amount of admixtures used could have been lessened.

Project Tasks: Temperature prediction requires an accurate measurement of the heat evolved during hydration. Once this is known, it is a simple matter to use a computer model to predict thermal profiles inside a hydrating concrete structure. The model could then be extended to predict the strength of concrete as it cures. A computer model would account for heat of hydration, mix design/temperature, and various boundary conditions to predict the temperature at any location in the concrete with time. Such a model would predict:

- Whether the concrete will freeze.
- Whether thermal protection is needed.
- How rapidly the concrete will gain strength.
- How much admixture will be needed to do the job.
- How to tailor the admixture dosage for each project.

Rather than develop a program that would have to be learned and maintained by each state, this project will develop a user-guide that will allow admixture dosages to be adjusted for a specific protection level. The guide will set dosage rates for general sets of conditions to provide a conservative protection of the concrete will it cures. The dosage rates will account for the environmental conditions and for several different types of concrete elements—slabs on grade, elevated slabs, and beams—of varying thickness. The guide will allow technicians to design the correct mix and protective measures based on weather predictions for the next 3 to 5 days. Users will also estimate whether concrete has frozen, based on past temperature conditions. This could be a particularly useful decision-making tool for designing mixes and for deciding what to do with concrete that has been exposed to lower than expected temperatures. The plan is to develop a series of design tables along with laboratory evaluation followed by field validation of a few designs.

Deliverables: Heat-of-hydration measurements are unavailable for low temperatures, especially for concrete made with admixtures. This project will measure heat output from various cements, including

[6] New Hampshire in December 2001, Wisconsin in February 2002, and New Hampshire twice in December 2002.

some cement blends, made with the antifreeze admixtures developed in Phase I. These data will be incorporated into a field guide. The user will simply use the forecasted high and low temperatures for the period of interest, the cement factor and type, the type and thickness of element and then look up the required dosage of admixture to maintain the temperature of the concrete above its critical freezing point. Coupled with this the user will be able to consult the report generated in Phase I of this study to determine how soon the structure will be ready for use.

PROJECT GOVERNANCE

The project leader, Charles Korhonen, will maintain contact with all project sponsors by updating our project web site at [http://www.crrel.usace.army.mil/concrete/Durability_pooled_fund_study.htm]. Periodic progress reports will be e-mailed to each sponsor and be placed on the web site.

PROJECT SCOPE

The broad outlines of the project are described above. As issues arise during the course of experimentation, the project leader will propose and communicate any necessary amendments. As with Phase I, a web site will be maintained to facilitate dissemination of project information as it is developed.

PROJECT COSTS

This project is targeting $575K for 24-months. As with Phase I, the amount each state contributes will be left up to the discretion of each state. We will continue to accept states until the funding target is met.

PROJECT DURATION

The two studies listed above are projected to run 24 months.

QUALIFICATIONS OF THE RESEARCH STAFF

The research team assembled for this project has substantial practical experience in the laboratory and in the field in antifreeze concrete technology. The team includes individuals with thorough knowledge of and experience in the areas of analytical modeling, materials characterization, concrete materials testing, and instrumentation of field sites. Following are summaries of qualifications for key members of the research team.

Charles Korhonen

Research Civil Engineer
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Mr. Korhonen joined CRREL in 1975. He is engaged in research on the maintenance and rehabilitation of structures in the cold regions. He has evaluated radar facilities situated on the Greenland ice cap, developed methodology for non-destructive evaluation of roofing systems, conducted field and laboratory studies of external coatings for buildings, and promoted improved methods for extending construction practices into the winter. His research has led to the adoption of infrared roof warranty surveys by the Corps of Engineers to identify leaks before they become the problem of the building owner, the commercialization of a miniature vent to economically repair blistered roofs, and the patenting of an antifreeze admixture that allows concrete to be cured at below freezing temperatures.

Areas of Specialization:
- Cold weather concrete.
- Masonry construction.

Current Projects:
- Expedient cold-weather concrete admixtures for the Army.
- Off-season repairs for the transportation industry.

Notable Contributions or Highlights from Past Projects:
- Infrared roof warranty surveys.
- Commercial roof blister vent.
- Antifreeze admixture patent.

Education:
- B.S. degree in Civil Engineering in 1973, Michigan Technological University.
- M.S. degree in Arctic Engineering in 1981, University of Alaska.
- PhD in Engineering from Purdue University, pending.

Other Professional Information:
- Memberships/Professional Organizations:
  - Member ASCE.
  - Member ACI.
- International Experience:
  - Cooperative research with the Technical Research Center, Finland.
- Additional:
  - Professional Engineer, NH.
  - Serves on various technical committees.
  - Has published over 60 papers.

Peter Semen

Research Civil Engineer
Phone: 603-646-4825 E-mail: Peter.M.Semen@erdc.usace.army.mil

Mr. Semen was hired in November 2002 as a Research Civil Engineer in the Civil and Infrastructure Engineering Branch. He began his full-time work at CRREL in October 2000 as a self-employed contractor supporting the Extending the Season for Concrete Construction and Repair pooled-fund study. He previously worked at CRREL in 1997–98 as a student, contributing to the development of an expedient antifreeze concrete capability for the military.

Areas of Specialization:
- Cold weather concrete
- Concrete admixtures
- Building Structures

Current Project:
- Extending the Season for Concrete Construction and Repair for the Transportation Industry

Past Experiences:
- Development of a low-cost, low-maintenance 80-foot pedestrian footbridge design
- Structural design with engineered wood products
- GIS surveys of highway drainage structures

Education:
- A.B. Degree in Engineering Sciences, Dartmouth College, 1997
- Bachelor of Engineering Degree, concentrating in Material Science and Mechanics, Thayer School of Engineering at Dartmouth College, 1997

Awards:
- Teagle Foundation Scholarship Recipient – 1993 to 1997

Other Professional Information:
- Memberships/Professional Organizations:
  - Member, American Concrete Institute
  - Member, Dartmouth Society of Engineers
- Additional:
  - Engineer-in-Training (EIT), NH

Lynette Barna

Research Civil Engineer
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Ms. Barna has worked at CRREL since 1994. She is a Research Civil Engineer in the Civil and Infrastructure Engineering Branch.

Areas of Specialization:

- Investigating the response and performance of airfield and roadway pavement structures during freezing and thaw-weakening periods
- Antifreeze admixtures for concrete
- The use and characterization of subsurface materials
- The use of waste materials in pavement structures

Current Projects:

- Antifreeze admixtures for concrete
- Geotechnical modeling of frost heave development and spring thaw weakening

Education:

- B.S. in Recreation Resources Management, Colorado State University
- Bachelor of Engineering Degree, concentrating in Environmental Engineering, from Thayer School of Engineering at Dartmouth College

Cold Regions Research and Engineering Laboratory

CRREL is a testing and research establishment of the U.S. Army Corps of Engineers whose mission is to investigate engineering and scientific issues that pertain to regions affected by freezing and thawing. The CRREL facilities that will be used during the course of the current project are located in Hanover, New Hampshire, and include:

Facilities and Equipment Description

- Cold laboratories, which contain a 26-unit cold-room complex, where temperatures can be lowered to –35°F.
- Soils laboratory, which consists of a main soil analysis laboratory, thermal conductivity measurement area, sample preparation room, humidity storage room, controlled humidity room, and bituminous concrete testing room.
- Concrete laboratory, which contains equipment to mix concrete in laboratory batches and to test a wide range of properties and performance behaviors, including strength and durability, as affected by freeze–thaw.
- Construction materials laboratory, which includes a light microscope integrated with digital image processing and image analysis systems, a mercury intrusion porosimeter, and petrographic specimen preparation equipment.
- Resilient modulus testing system, which analyzes the resilient characteristics of concrete under simulated loading.
- In-house and field test sites, which include full-scale test sections that are constructed on-site at CRREL as well as in remote locations.
- NDT equipment:
  - Ground Penetrating Radar System.
  - Falling Weight Deflectometer (Dynatest Model 8000).