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*Installation Technology Transition Program*

# Cold Roller-Compacted Concrete for Roads and Hardstands on Army Installations in Cold Regions

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**Abstract:** Cold roller compacted concrete (Cold-RCC) is the result of merging the RCC paving technology with Cold Weather Admixture Systems (CWAS) technology. It extends the use of RCC paving beyond the traditional construction season. A laboratory investigation was conducted to produce a suitable Cold-RCC mixture capable of producing adequate strength at low temperature, have workability compatible with RCC pavers, and result in acceptable surface finishing. The 7-day average unconfined compressive strength of cylindrical Cold-RCC laboratory test specimens cured at a constant temperature of 23 °F was 3,600 psi. The Cold-RCC mixture was used in a full-scale field demonstration at Ft. Drum, New York, where the ambient air temperature was 31 °F at the time of placement. A 75 ft x 20 ft hardstand was constructed using the Cold-RCC mixture with standard RCC mixing and placing equipment and quality control procedures. The 7-day average unconfined compressive strength of the field mixture reached 4,400 psi when cured at 23 °F in the laboratory. The feasibility of building RCC pavements for military hardstands in cold weather was demonstrated by a full-scale pavement test section that sustained truck traffic within a few hours of placement in an environment near the freezing point of water.

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# Preface

This report was prepared by Dr. Edel R. Cortez and Lynette A. Barna, Force Projection and Sustainment Branch (FPSB), Charles E. Smith Jr., Engineering Resources Branch (ERB), Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Engineer Research and Development Center (ERDC), Hanover, New Hampshire, and Terry Peltz, Peltz Companies, Inc., Alliance, Nebraska.

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# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| acres | 4,046.873 | square meters |
| cubic feet | 0.02831685 | cubic meters |
| cubic yards | 0.7645549 | cubic meters |
| degrees Fahrenheit | (F-32)/1.8 | degrees Celsius |
| feet | 0.3048 | meters |
| gallons (U.S. liquid) | 3.785412 E-03 | cubic meters |
| inches | 0.393701 E-01 | millimeters |
| ounces (U.S. fluid) | 2.957353 E-05 | cubic meters |
| pounds (force) per square inch | 6.894757 | kilopascals |
| pounds (mass) | 0.45359237 | kilograms |
| pounds (mass) per cubic foot | 16.01846 | kilograms per cubic meter |
| quarts (U.S. liquid) | 9.463529 E-04 | cubic meters |

# 1 Introduction

## Overview

Roller-compacted concrete (RCC) has been shown to be a cost-effective approach for the rapid construction of large-volume concrete structures, such as roadways, hardstands, and dams, during the conventional construction season. As the air temperature turns cold, however, work usually stops as normal concrete requires ambient temperatures above 45 °F for complete curing, and to avoid irreparable damage in the event the concrete should freeze at low temperatures. At higher latitudes, this restriction renders the construction season relatively short, as cold temperatures impact the hydration rate of cement. For this reason, cold weather concrete construction practice requires freshly placed concrete to be thermally protected to maintain a favorable curing environment for strength development. Unlike vertical structures where a temporary thermal envelope is constructed and artificially heated around the project, horizontal concrete construction projects generally do not have a reasonably economical approach for keeping concrete warm.

The Cold-Weather Admixture Systems (CWAS) technology, developed by the Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL), is a new approach to cold weather concreting, providing the tools to mix, place, and cure concrete at below freezing temperatures without the need for artificial heating. Eliminating the need for artificial heat represents a significant savings of both time and money, creating a cost-competitive approach for winter concreting. CWAS ('antifreeze concrete' is a synonymous term), is a proven technology that has advanced cold weather construction operations by extending the construction season later into the fall and earlier into the spring. The CWAS approach has been used in a number of full-scale field demonstrations and, more specifically, it has shown its effectiveness for horizontal construction projects.

The RCC technology has been successfully applied during warm and hot weather, while the antifreeze concrete technology has been successfully applied when it was cold. The purpose of this study was to merge the RCC technology with the antifreeze concrete technology into Cold-RCC. The Cold-RCC approach was then applied during a full-scale demonstration project where a hardstand was constructed during a time when cold temperatures would have otherwise inhibited construction.

## Background

### Roller-Compacted Concrete

RCC has been in use over the past three decades. RCC gradually developed from a soil stabilization technique used in the northwestern region of the U.S. in the 1970s were Portland cement was added to granular soils to strengthen the working platforms at log yards. This technique came about as new environmental regulations were imposed to restrict the amount of soil contamination entering rivers from excessive soil-laden rain wash and dirty logs that were transported down rivers during logging operations. The soil-stabilized surfaces proved effective. In 1976, initial RCC laboratory and field trials were conducted at the U.S. Army Corps of Engineers in Vicksburg, MS (Pittman and Anderton 2009, ACI 1995). The Corps continues to be actively involved in RCC developments. Further refinements incorporated cleaner aggregates and higher cement contents that led to the first roller-compacted concrete pavement. For modern RCC pavements, a concrete mixture is placed with a heavy duty asphalt paver, and compacted using vibratory rollers. The quality control methods typically used include proctor density tests, originally developed for quality control for soil-stabilization.

RCC, though similar to conventional concrete, is a no-slump mixture composed of cement, coarse aggregate (stone), fine aggregate (sand) and water. Mineral fillers, such as pozzolans (flyash) or ground granulated blast-furnace slag (GGBF) (ASTM 1994), are commonly used as a partial cement replacement (USACE 2000). Due to the requirements for high production rates and a very low water-cement (w/c) ratio, most RCC pavements produced to date have employed high-volume continuous mix pugmills or central mix batch plants. Typically, for dams and other mass concrete construction, RCC is placed using standard earthmoving equipment, such as bull dozers and front end loaders. For the construction of pavements, RCC is placed using high density asphalt paving machines equipped with tamping bars, and compacted with large vibratory rollers. The pavement surface is finished with steel drum rollers, or in combination with pneumatic-tire rollers.

The stiff, no-slump characteristics of RCC, provid the ability to support compaction equipment, make this an economical and effective method for high-volume, large-quantity construction projects, such as dams and heavy duty pavements. RCC has also been successfully used in military applications, such as tank trails, and for civilian applications such as parking lots and intermodal cargo-transfer facilities.

As compared to conventional concrete paving methods, RCC is quite cost effective for the placement of large volumes of concrete material quickly, as RCC does not require placing forms, steel reinforcement, or dowel rods (ACI 1995, ACI 1999, Pittman and Anderton 2009). Additionally, conventional equipment, such as asphalt pavers and vibratory rollers are used. Fewer workers are needed to do the paving work, and finishing operations are simplified. For fixed facility applications, these features result in lower construction costs; for expeditionary military construction, the RCC technology may result in the reduction of military personnel to hazardous conditions and faster project execution.

Previous applications of RCC pavements placed during the summer indicated a savings of 35 percent or more may be realized by using RCC instead of conventional methods. Applications of antifreeze concrete in winter environments indicate that significant savings can be achieved by using this technology compared with the energy-intensive conventional alternatives, particularly for horizontal construction over cold ground. The experience obtained through this proposed technology demonstration may also be extended to contingency military operations that need to be executed in any part of the year, including cold winters. As related to infrastructure at Army installations, Cold-RCC would facilitate the building of hardstands and strategic road segments during cold times of the year when it is necessary to ensure continued operations and mobility.

A recent survey conducted by Pittman and Anderton (2009) showed that a great number of recent RCC pavement projects in the U.S. were completed in warm locations during the conventional construction season. One significant RCC pavement project was constructed during the summer seasons of 1988 and 1989 at Ft. Drum, NY (Cortez and Gerlach 1990). An area totaling 88 acres was paved, but the task was interrupted during the cold months of the year because conventional concrete needs warm ambient temperatures to develop adequate strength. Cold-RCC intends to enable RCC construction during the cold months of the year. At some locations, the new capability may allow year-round construction without winter shutdown.

## Cold-Weather Admixture Systems

CWAS, or antifreeze concrete, evolved from the need for a new approach to cold weather concreting. Current cold weather concreting practice dictates the need to artificially heat the mixture components (such as hot water and heated aggregates), as well as the substrate (ACI 2002). The need to artificially heat represents a significant cost to winter construction projects. For this reason, winter concreting operations typically cost twice as much compared with concrete construction during the summer months. Antifreeze concrete was developed to respond to the need for a concrete mixture that does not require heat, and to reduce the cost of winter concreting. More information on the development of antifreeze concrete may be found in Korhonen et al. (2004).

Antifreeze concrete uses combinations, or suites, of commercially approved off-the-shelf chemical admixtures that depress the freezing point of the mixture water and accelerate cement hydration (ASTM 2006). All of the chemical admixtures used in antifreeze concrete meet ASTM C 494 (2008b), *Standard specification for chemical admixtures for concrete*. Antifreeze concrete mixtures are capable of curing at a minimum internal concrete temperature of 23 °F. The antifreeze concrete approach is easily integrated with regular concrete mixtures. The constituents of antifreeze concrete include Type I/II Portland cement, standard coarse and fine aggregate, and normal potable water – although the use of cold water is preferred. Features of antifreeze mixtures include: a desired mixture temperature range between 23 and 50 °F, and a water-cement ratio should be less than 0.45.

Antifreeze concrete is a proven technology and has been successfully used in applications such as bridge curbs, bridge footings, pavement sections, sidewalks (Korhonen et al. 2004), as well as full-depth slab repair on an airfield (Korhonen and Seman 2005). Most recently, in March 2008, antifreeze concrete was used to construct a hardstand at Ft. Wainwright, Alaska (Barna et al. *in editing*).

It has been estimated that using antifreeze concrete may extend the concrete construction and repair season in the U.S. by as much as 60 days in the northern tier states, and 120 days in mid-continental locations

(Figure 1). At the present time, ready-mix plants at higher latitudes either significantly reduce or completely shut down their operations during the colder time of the year. An anticipated benefit of extending the concrete construction and repair season is increased productivity as equipment and personnel may be utilized more effectively. Additionally, CWAS helps to reduce traffic congestion associated with the conventional summer construction season. Typical savings of 30% are realized using antifreeze concrete compared to conventional winter concreting methods, and have ranged as high as 90% (Korhonen et al. 2004), thereby presenting a real cost advantage over traditional winter concreting methods.

Cold-RCC represents a breakthrough to rapidly place high volumes of concrete during cold weather. The goal of this project was to conduct a large-scale test merging the CWAS technology with the RCC placement approach. While the costs of deploying Cold-RCC are presumed higher compared to normal (summer) RCC costs, keep in mind that this is not a direct comparison, as there exists no conventional high-volume method of concrete placement during winter. It is also presumed that as Cold-RCC becomes more widely accepted, the costs will continue to decrease.

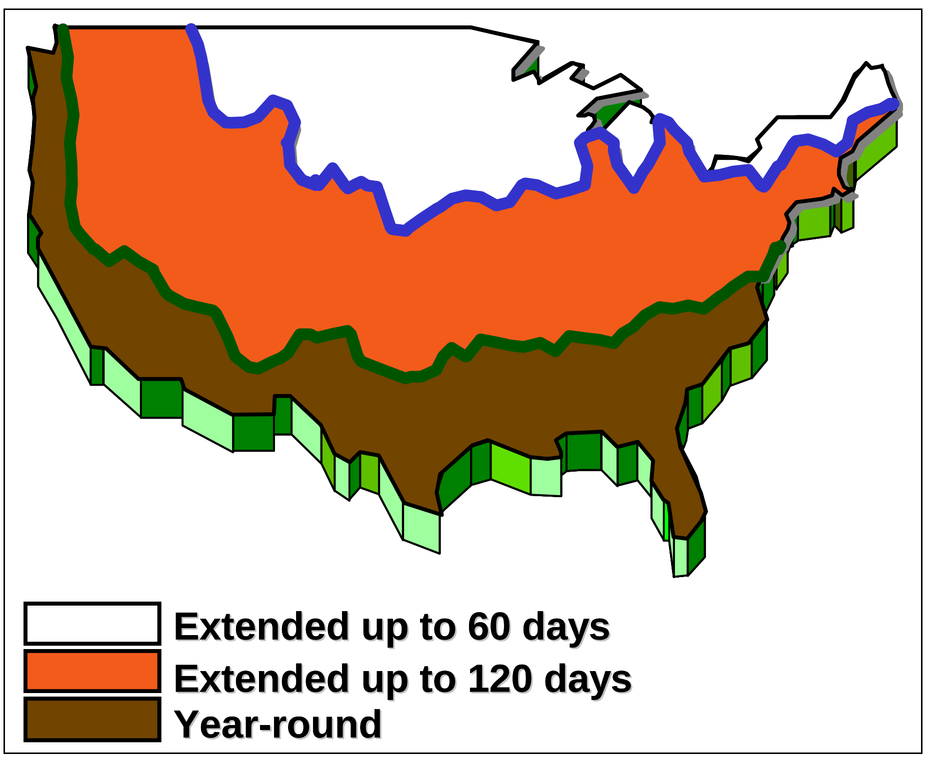



Figure 1. Estimated extension of concrete construction and repair season implementing Cold Weather Admixture Systems.

## Project objective

The objective was to merge roller compacted concrete (RCC) with the cold weather admixture systems (CWAS) technology to develop a new energy efficient method of winter paving that may benefit expeditionary and fixed Army installations, and demonstrate this in accordance with the goals of the Installation Technology Transition Program (ITTP). Many organizations, including the U.S. Army, have benefited from cost savings using RCC for paving concrete hardstands and streets. By merging the RCC technology with CWAS, the paving season could be extended.

The approach used applied the antifreeze concrete approach that developed a suitable concrete mixture and placed it with the conventional RCC method. A contractor, with a great deal of experience with RCC pavement construction under summer conditions, teamed up with ERDC-CRREL to produce concrete mixtures that will have the required strength development and workability characteristics to work well with the existing or modified RCC paving equipment. A field trial was conducted at Ft. Drum, New York during the early spring season.

This report summarizes the laboratory work conducted to prepare a RCC-suitable mixture for field use and the field demonstration where a RCC slab was constructed.

## Project Scope

The scope of the project included a laboratory investigation to verify the low-temperature characteristics of a Cold-RCC candidate mixture and using the Cold-RCC mixture during a full-scale field demonstration:

- The laboratory study determined appropriate mixture and admixture proportions;
- Cylindrical specimens were fabricate and tested to verify strength gain at low temperatures;
- A full-scale field demonstration was conducted at an Army installation by mixing, placing, and compacting a Cold-RCC mixture, incorporating the antifreeze concrete approach, during a cold time of the year;

- The hardstand was constructed using conventional RCC equipment and standard quality control/quality assurance techniques for RCC pavement construction;
- The in-place performance was monitored during warmer weather.

# 2 Laboratory Investigation

## Purpose

A laboratory investigation was conducted to develop a suitable Cold-RCC concrete mixture capable of producing adequate strength at low temperature, have suitable workability during placement with RCC pavers, and result in an acceptable surface finish. All laboratory testing was performed at ERDC-CRREL in Hanover, New Hampshire.

## Materials

The cement used for all the mixtures in the laboratory investigation was Type I-II Portland cement manufactured by Lafarge Corporation. The cement was obtained from the bulk bins of a local ready-mix plant. While typical RCC mixes incorporate supplemental cementitious material (SCM), or waste by-products to offset the quantity of cement used (such as fly ash), the mixtures developed in this laboratory investigation did not utilize SCMs as this was the first usage of antifreeze formulations with RCC. The effects of SCMs in Cold-RCC mixes should be evaluated in future investigations. The water used in these mixtures was potable water from the local municipal water company.

The aggregate materials, both fine and coarse, were obtained locally and met the specifications of ASTM C 33 (2008a). The fine aggregate was a natural, washed concrete sand. The coarse aggregate for the initial mixtures was obtained from a quarry in Lebanon, New Hampshire. The source rock type is amphibolite, a metamorphic rock (ledge) with a medium Mohs hardness and bulky shape. According to ASTM C 33 (2008a) the aggregate gradation was size 67. This material was used in the early laboratory mix during the down-selection process for a candidate mixture, since it was plentiful. Once the laboratory mixes were refined to the point of producing a candidate mixture, the local coarse aggregate was replaced with material obtained from Watertown, New York (similar material used during the field demonstration) and shipped to ERDC-CRREL. This smaller quantity was reserved for the final laboratory mixtures in order to confirm mixture consistency.

## Chemical Admixtures

The chemical admixtures used were selected from previous research efforts (Korhonen et al. 2004) that dealt with cast-in-place concrete for cold weather. Significant modifications to the admixture formulations were investigated to produce a mixture with desirable properties as indicated above, as this involved modifying antifreeze concrete formulations previously used for structural concrete projects to be used in a different application method for RCC. The chemical admixtures used in the mixes were commercial products manufactured by BASF Construction Chemicals, LLC. The admixture quantities used in the trial concrete mixtures were within the manufacturer's recommended dosage rates.

### Rheocrete® CNI

A "corrosion-inhibiting admixture for steel reinforced concrete," this admixture meets the ASTM C 494 (2008b) interim requirements for Type C accelerating admixture (BASF 2007). The admixture is sold in liquid solution containing approximately 32.5 percent of solids by weight. In our laboratory mixtures, this admixture provided freeze point depression and contributed to strength gain. Although the exact chemical composition of this admixture is protected intellectual property of the manufacturer, the manufacturer's literature indicates that its primary ingredient is calcium nitrite and it does not contain chloride ions.

### Pozzutec® 20+

An "accelerating admixture," this admixture meets the ASTM C 494 (2008b) interim requirements for Type C accelerating admixture and Type E water-reducing and accelerating admixture (BASF 2008). The admixture is sold in liquid solution containing approximately 40 percent of solids by weight. In our laboratory mixtures, this admixture contributed to early strength gain and decreased the setting times. This admixture does not contain chloride ions.

### Initial freezing point measurement

The test procedure for the initial freezing point of a fresh concrete mixture is conducted to verify that the dosage rates and chemical combinations of the admixtures used in antifreeze concrete mixtures are adequate for the designed level of temperature protection. While a mixture is still in a plastic state, cylindrical test specimens are fabricated with a temperature sensor embedded at the center of mass. The test specimens are placed into a very cold environment (a −4 °F cold chamber) to freeze the liquid water in the specimen. The internal temperature of the test specimen is monitored as heat is lost to the ambient air. Initially, similar to a typical cooling curve, the specimen cools rapidly due to the large temperature differential between the specimen and the ambient air. Over time, the cooling rate slows as the water nears the point at which it changes state from liquid to solid (ice). As water changes into ice, heat is released from the latent heat of fusion (Alexiades and Solomon 1993). This slight increase in temperature is evident in the temperature data and reflects the temperature of the initial freezing point. For this investigation, the initial freezing point of the Cold-RCC mixtures was not verified.

## Laboratory concrete mixtures

The following series of concrete mixtures were investigated in the development of a suitable mixture for the field demonstration. A revolving drum mixer was used to prepare the mixes (Figure 2). Because the initial mixtures were part of screening tests, their volumes were relatively small, approximately 0.5 $ft^3$. Future investigations should consider the use of either a rotating shaft mixer or a laboratory pan mixer to reproduce the mixing action of a full size pug mill.

In all, 10 trial mixes were batched. All mixture components were equilibrated to an ambient temperature of 72 °F, and were mixed at the same temperature. The initial three mixtures were prepared without chemical admixtures. These mixtures were used to determine the estimate the moisture content needed to obtain maximum density and testing was conducted in accordance with ASTM D 1557 (2007b) *Standard Test Methods for Laboratory Compaction of Soil Using the Modified Effort*. The basis of the test method is derived from soil-cement and cement stabilized base materials (ACI 1999). For each mixture, five test specimens were fabricated, each at an increasing moisture content from 3% to 7%. The resulting mixture was used as a starting point for the subsequent mixtures that incorporated chemical admixtures for low-temperature protection. Cylindrical test specimens (4 in. diameter by 8 in. height) were fabricated from trial mixtures 4 through 10, cured at ambient room temperature and two temperatures below freezing, and tested for unconfined compressive strength following ASTM C 39 (2005) at designated test ages. At this point, we believed a suitable mix had been achieved. This mixture had the desired workability and adequate low-temperature strength development. At this stage, an expert from Peltz Construction came into the laboratory to verify the workability of the best candidate mixtures and judge the suitability for the planned field trial. The desired mixture would flow well through the paver augers, be able to withstand the weight of the paver and the roller compactor, and gain sufficient strength to support traffic within hours of placement.

Figure 2. Laboratory mixer setup.

## Mixture 1

### *Description*

Mixture 1 (Table 1) was reproduced based on a concrete mixture from a previous RCC paving project conducted in recent years in Canada. The mixture proportions were provided by an RCC contractor, for use as a starting point. In accordance with conventional RCC mixture development procedures, the initial mixtures were screened according to maximum density. The concrete ingredients were mixed in the laboratory at room temperature (approximately 73 °F), and cylinders were fabricated according to ASTM D 1557 (2007b) *Standard Test Methods for Laboratory Compaction of Soil Using the Modified Effort*. This approach was later modified to focus on strength gain at low temperature as a starting point, followed by observations of workability and surface texture.

*Mixture proportions*

Table 1. Material proportions used in laboratory mixtures 1 through 3.

| | Units | Mix 1[A] | Mix 2[B] | Mix 3 |
|---|---|---|---|---|
| Cement | lb/ft3 | 18.71 | 22.22 | 24.37 |
| Water | lb/ft3 | 7.30 | 7.78 | 8.52 |
| Coarse Aggregate | lb/ft3 | 65.49 | 85.96 | 82.41 |
| Fine Aggregate | lb/ft3 | 60.81 | 36.96 | 40.52 |
| Fly Ash | lb/ft3 | 0 | 0 | 0 |
| Estimated water-cement ratio (w/c) | | 0.39 | 0.35 | 0.35 |
| Moisture Content at estimated w/c | % | 5.03 | 5.36 | 5.78 |
| Water for 3% (lb/ft3) | % | 4.35 | 4.35 | 4.42 |
| Water for 4% (lb/ft3) | % | 5.80 | 5.81 | 5.89 |
| Water for 5% (lb/ft3) | % | 7.25 | 7.26 | 7.36 |
| Water for 6% (lb/ft3) | % | 8.70 | 8.71 | 8.84 |
| Water for 7% (lb/ft3) | % | 10.15 | 10.16 | 10.31 |

Notes:

[A] Mix based on recent RCC Canadian paving project.

[B] Mix based on previous RCC paving project at Ft. Drum, NY (Cortez and Gerlach 1990).

The units of $lb/ft^3$ were selected to represent the proportions of mixture ingredients used for laboratory mixtures. To convert to $lb/yd^3$, multiply the $lb/ft^3$ by 27.

*Measurements and observations*

Compared to other known RCC mixtures, visual inspection of this mixture quickly revealed that it lacked sufficient coarse aggregate in proportion to the amount of cement paste and fine aggregate . This prompted a review of the material weights used in the mixture proportions. Although the unit weights initially increased with moisture content as expected, the values were clearly too low as shown in Figure 3. The mixture had too many large voids, and obviously needed some changes.

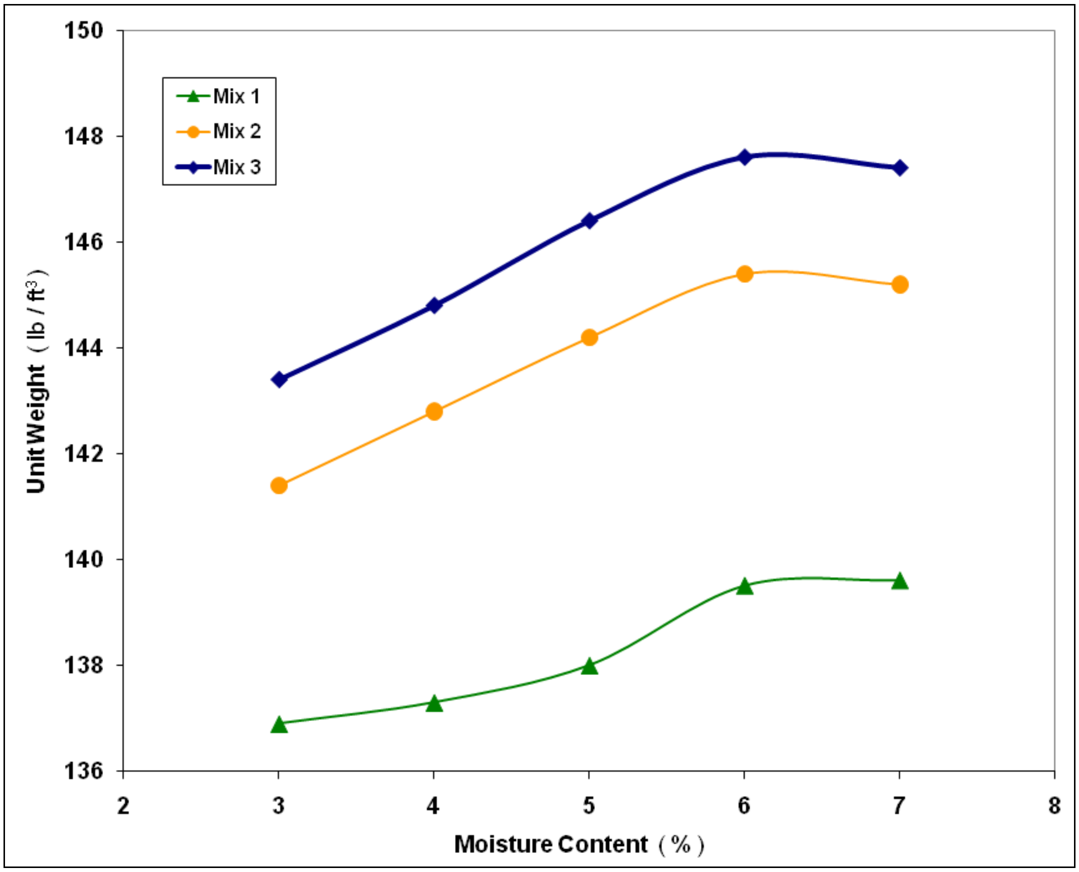


Figure 3. Unit weight-moisture content relationships for laboratory Mixtures 1 through 3.

## Mixture 2

*Description*

Mixture 2 (Table 1) was based on a concrete mixture from a previous RCC paving project conducted at Fort Drum, New York in 1988 (Cortez and Gerlach 1990) according to published project records. As with Mixture 1, Mixture 2 was used as a screening test according to maximum density. The concrete ingredients were mixed at room temperature, and cylinders were cast according to ASTM D 1557.

*Measurements and observations*

Because too little cement paste and too many large air voids were observed, it was suggested that mixture could benefit from more cement and fine aggregate to reduce air voids and increase the unit weight. Figure 3 indicates that the unit weight was maximized at a moisture content of approximately 6 percent.

### Mixture 3

*Description*

This mixture was a refinement of Mixture 2 that included increased cement and fine aggregate contents in an effort to reduce air voids and increase the unit weight. Table 1 shows the mixture proportions. As with Mixture 2, Mixture 3 was used as a screening test according to maximum density. The concrete ingredients were mixed at room temperature, and cylinders were cast according to ASTM D 1557.

*Measurements and observations*

Visual inspection of Mixture 3 indicated that this was a relatively dense mixture likely to result in good strength and workability at room temperature conditions. The mixture appeared to have relatively few large air voids. Figure 3 indicates that the unit weight was maximized at a moisture content of approximately 6 percent.

## Antifreeze RCC mixes

### Mixture 4

*Description*

Through the screening tests conducted with Mixtures 1 through 3, a baseline mixture proportion was selected. On a per cubic yard basis, the base concrete mixture used 658 lbs of cement, 2,225 lbs of coarse aggregate, and 1,094 lbs of fine aggregate (Table 2). The total amount of water in each mix, shown in Table 2 as *Total water in mix*, is the sum of mixture water added (*Water added by us)* plus the contribution of water from both of the liquid admixtures (*Water added by Rheocrete CNI*; *Water added by Pozzutec 20+*). The quantity of water in the admixtures is determined using the value of percent solids for each admixture. This calculation is detailed in Korhonen et al. (2004). The water-cement (w/c) ratio in Table 2 is shown with and without the admixtures.

The main constituents remained the same for the rest of the trial mixes. The total amount of water in the mixture ranged from 197.5 to 286.9 lbs/yd$^3$, with the total amount of mix water varying based on the chemical admixture dosage rate. As expected, the water content for the mixes varied from 4.93 to 7.16%.

Table 2. Material proportions used in laboratory mixtures 4 through 10.

| | Units | Mix 4 | Mix 5 | Mix 6 | Mix 7 | Mix 8 | Mix 9 | Mix 10 |
|---|---|---|---|---|---|---|---|---|
| Cement | lb/yd3 | 658 | 658 | 658 | 658 | 658 | 658 | 658 |
| Coarse Aggregate | lb/yd3 | 2,225 | 2,225 | 2,225 | 2,225 | 2,225 | 2,225 | 2,225 |
| Fine Aggregate | lb/yd3 | 1,094 | 1,094 | 1,094 | 1,094 | 1,094 | 1,094 | 1,094 |
| Fly Ash | lb/yd3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Water added by us | lb/yd3 | 230 | 161.5 | 201.5 | 173.5 | 174 | 143 | 155 |
| Water added by Rheocrete | lb/yd3 | 33.75 | 15.43 | 15.43 | 33.75 | 15.43 | 33.75 | 33.75 |
| Water added by Pozzutec 20+ | lb/yd3 | 23.16 | 23.16 | 23.16 | 23.16 | 31.25 | 20.83 | 20.83 |
| Total water in mix | lb/yd3 | 286.91 | 200.09 | 240.09 | 230.41 | 220.68 | 197.58 | 209.58 |
| Rheocrete CNI | lb/yd3 | 50 | 22.86 | 22.86 | 50 | 22.86 | 50 | 50 |
| Pozzutec 20+ | lb/yd3 | 38.6 | 38.6 | 38.6 | 38.6 | 52.09 | 34.72 | 34.72 |
| Solids in Rheocrete CNI (32.5%) | (%) | 16.25 | 7.43 | 7.43 | 16.25 | 7.43 | 16.25 | 16.25 |
| Solids in Pozzutec 20+ (40%) | (%) | 15.44 | 15.44 | 15.44 | 15.44 | 20.84 | 13.89 | 13.89 |
| w/c* (without admixtures) | | 0.35 | 0.25 | 0.31 | 0.26 | 0.26 | 0.22 | 0.24 |
| w/c (with admixtures) | | 0.44 | 0.30 | 0.36 | 0.35 | 0.34 | 0.30 | 0.32 |
| Moisture Content | (%) | 7.16 | 5.0 | 6.0 | 5.75 | 5.51 | 4.93 | 5.23 |

* water-cement ratio. The desired w/c ratio for typical concrete exposed to freezing and thawing should be 0.45, but not greater than 0.50 (Korhonen et al. 2004). In antifreeze concrete mixtures, the target w/c ratio should be 0.45 or less (USAF 2005).

Mixture 4 included chemical admixtures to aid the low temperature curing of concrete. Table 2 shows the mixture proportions. With this and the following mixtures, 4 x 8 in. test cylinders were fabricated at room temperature, in accordance with ASTM C 1435 (2008c) *Standard Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer* (Figure 4. Since RCC mixes are normally much stiffer, the conventional approach of rodding and tamping are not practical to fabricate cylindrical specimens in the laboratory. Therefore, a vibratory hammer was used to consolidate the fresh concrete in the cylinders. The action of a vibratory hammer appears to simulate well the action of the compaction equipment used to place RCC in the field. The RCC test cylinders were immediately sealed with protective caps, and placed in their respective curing rooms. Cylinders were cured in air in cold rooms set at 23 and 14 °F, and compared to a set of control test specimens placed in air in a curing room kept at approximately 73 °F. The curing condition at 23 °F represents the lower, internal concrete temperature limit of the antifreeze concrete technology. The curing temperature of 14 °F represented a very harsh curing condition, beyond what we would expect to encounter during the full-scale field demonstration.

Figure 4. Vibrating hammer with tamper foot (inset) used to compact laboratory test specimens for unconfined compressive strength test.

*Measurements and observations*

During mixing, some cement paste and fine aggregates stuck to the interior of the drum. This continued to be an issue with the trial batches. Later, during a meeting with the contractor to observe Mixture 10, this issue was determined to be the result of the admixture dosage. The concern was that a high admixture dosage rate used in a volumetric-type of mixer would produce a similar result. During molding of the cylinders it was observed that Mixture 4 was becoming too stiff too quickly. Cylinders were cast randomly to avoid creating a bias between the cylinders cast early and those cast later. For cylinders cast later, it was difficult to produce a good finish on the top surface. Cylinders were cast between 10 and 20 minutes of the end of mixing.

The average unconfined compressive strength values for Mixture 4 at test ages 3 and 7 days are shown in Figure 5. Note that the cylinders cured at below freezing temperatures continued to gain strength. After 7 days, the average unconfined compressive strength of the 23 °F cylinders obtained 75% of the strength of control cylinders cured at room temperature.

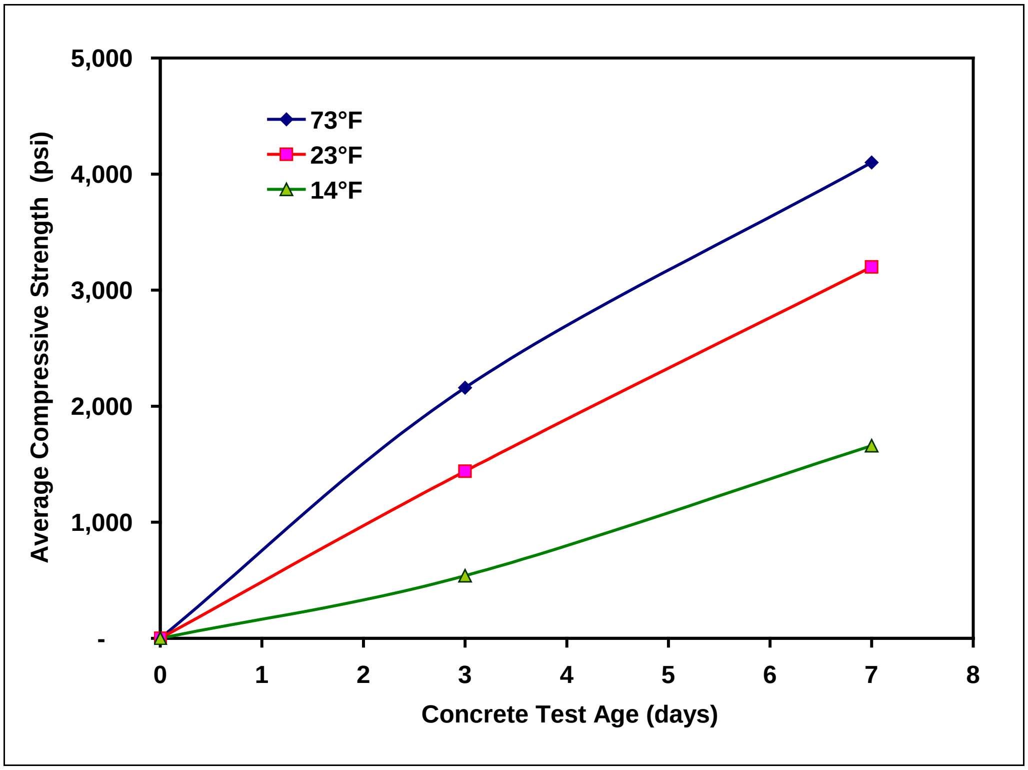



Figure 5. Early age strength development for Mixture 4 at ambient and cold curing temperatures.

## Mixture 5

*Description*

Mixture 5 was a refinement of Mixture 4 (Table 2). The quantity of both Rheocrete® CNI admixture content and the quantity of mixture water were reduced in order to produce a more workable mixture. As with Mixture 4, unconfined compression strength test cylinders were cast at room temperature and the cylinders were capped and immediately placed in the respective curing rooms at 14, 23, and 73 °F.

*Measurements and observations*

During mixing, Mixture 5 appeared too dry and some balling of the cement paste around coarse aggregate particles was observed. During molding of the cylinders it was observed that this mixture was losing workability very rapidly, becoming too stiff too quickly. To avoid bias in the test results, the cylinders selected for 3-day and 7-day unconfined compressive strength tests were selected randomly to the order of cylinder fabrication. Figure 6 illustrates the effect of curing temperature on the early age strength of Mixture 5. Compared to Mixture 4, the 7-day strength of the cylinders cured at 73 °F was slightly greater, perhaps due to the lower w/c. However, the strength of the cylinders cured at 14 °F were significantly less than those of Mixture 4, perhaps a result of the lower admixture dosage.

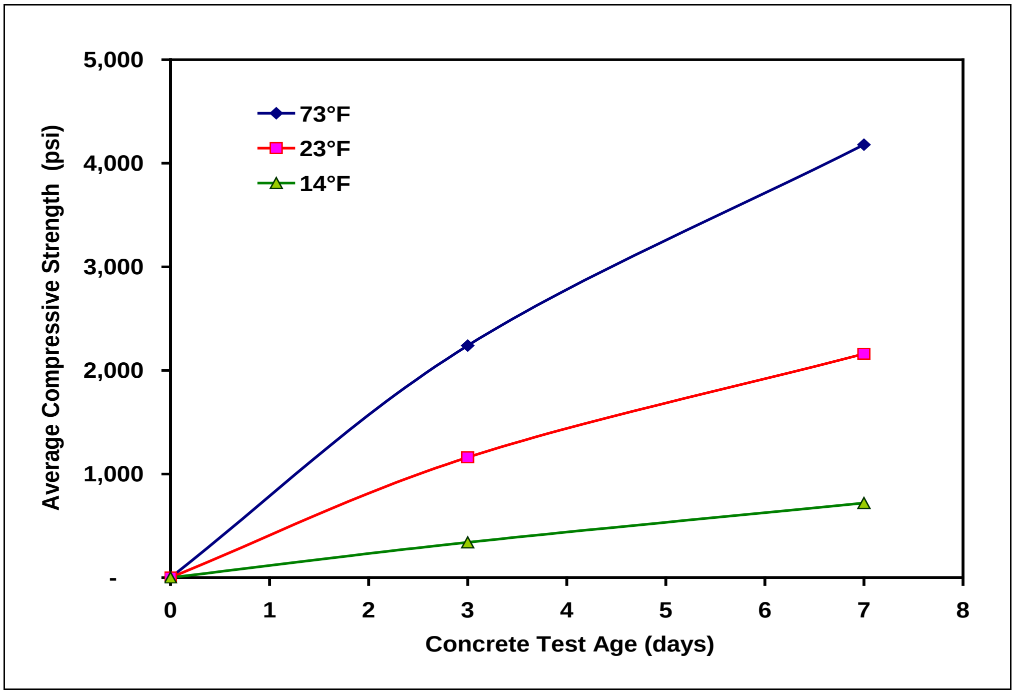



Figure 6. Early age strength development for Mixture 5 at ambient and cold curing temperatures.

## Mixture 6

*Description*

Mixture 6 was a refinement of Mixture 5 (Table 2). The Rheocrete® CNI admixture content was kept at the same dosage as that used in Mixture 5. The Pozzutec® 20+ admixture content was reduced and the moisture content was increased from 5 to 6 percent (Table 2). As with previous mixtures, unconfined compression strength test cylinders were cast at room temperature and the cylinders were immediately capped, and placed in their respective curing rooms at 14, 23, and 73 °F.

*Measurements and observations*

During fabrication of the cylinders, it was observed that an excessive amount of paste was produced, and too much moisture was rising to the top of the cylinders. Figure 7 shows the early strength development for this mixture. Relative to Mixture 5, the strength values increased slightly for all curing temperatures .

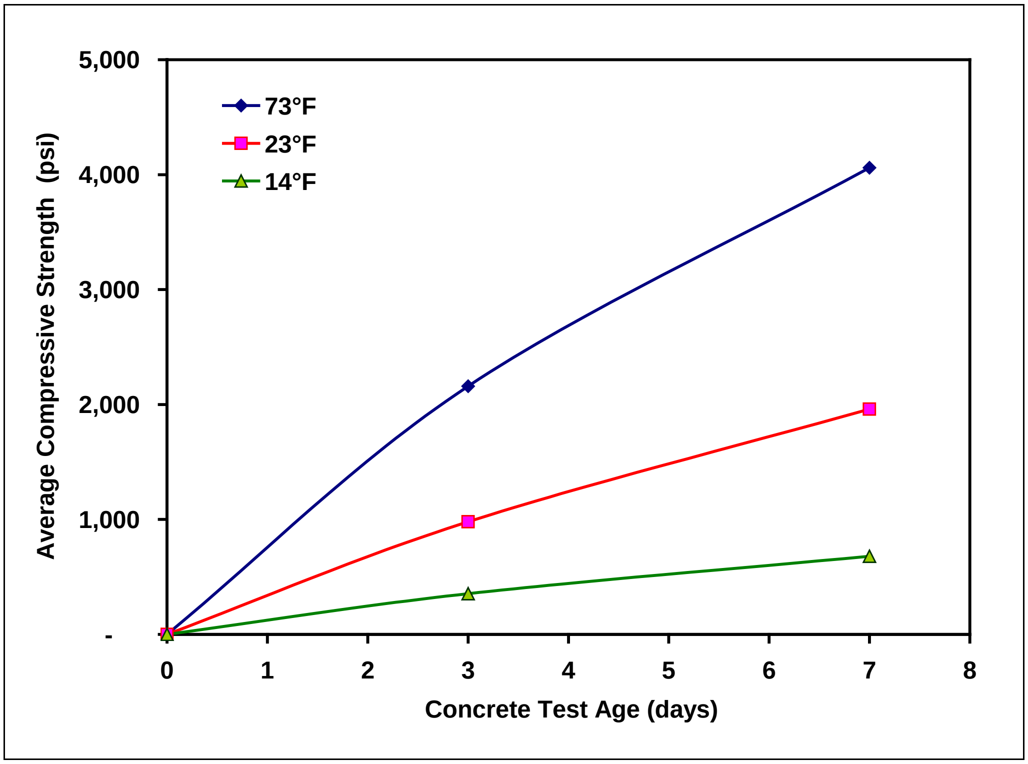



Figure 7. Early age strength development for Mixture 6 at ambient and cold curing temperatures.

### Mixture 7

*Description*

Mixture 7 was a refinement based on Mixture 6 (Table 2). The Rheocrete® CNI admixture content was increased to a similar dosage amount as used in Mixture 4, while the Pozzutec® 20+ admixture content was kept constant. The moisture content was slightly decreased (Table 2). As with previous mixtures, cylinders were cast at room temperature, and the cylinders were immediately capped, and placed in their respective curing rooms at 14, 23, and 73 °F.

*Measurements and observations*

During fabrication of the cylinders, it was observed that this mixture apparently had too high moisture content and the paste was relatively sticky. Figure 8 shows the early age strength development for this mixture. The strength values improved significantly for the room temperature specimens. Compared to Mixture 6, average unconfined compressive strength values were higher at both low temperature curing conditions: 14 °F and 23 °F.

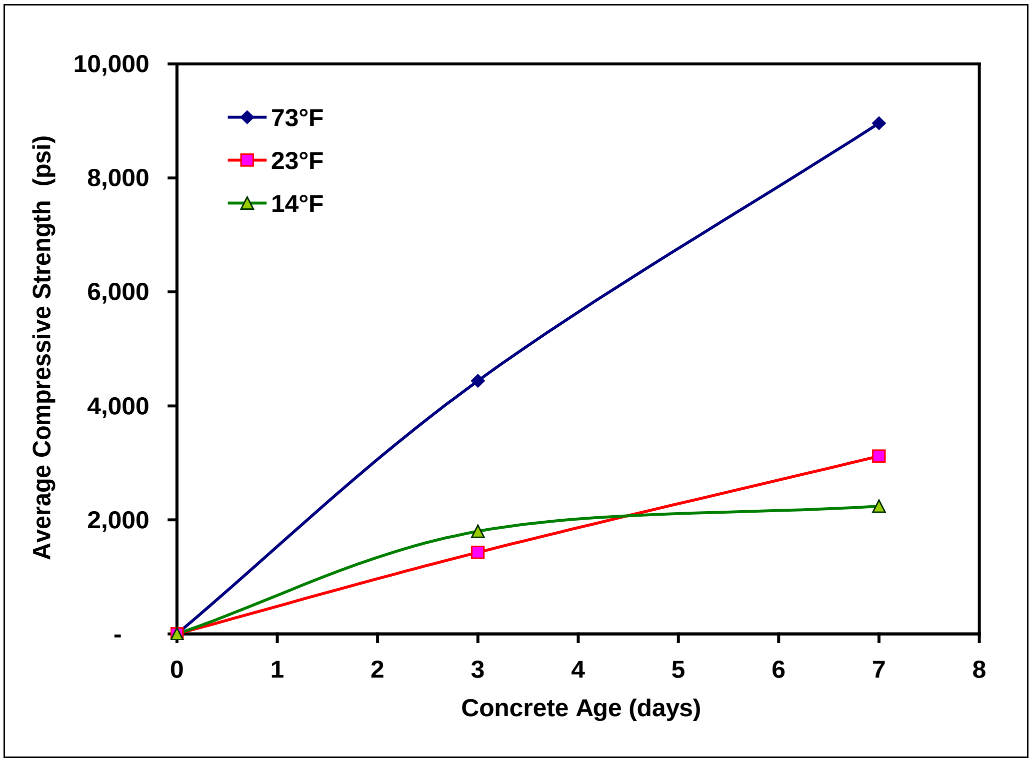



Figure 8. Early age strength development for Mixture 7 at ambient and cold curing temperatures.

## Mixture 8

*Description*

Mixture 8 was a refinement of Mixture 7 (Table 2). The Rheocrete® CNI admixture content was reduced to less than half compared to Mixture 7 (to the levels of Mixtures 5 and 6). The Pozzutec® 20+ admixture content was increased 35 percent compared to Mixture 7 (Table 2). The moisture content was slightly decreased. Cylinders were cast at room temperature and the cylinders were immediately placed in their respective curing rooms at 23, and 73 °F. Because the mixture became stiff too fast, cylinders for 14 °F curing were not cast.

*Measurements and observations*

During molding of the cylinders it was observed that this mixture was a little too sticky but the top of the cylinders finished well. Figure 9 shows the early strength development for this mixture. The strength values were substantially higher than those of Mixture 7 for the room temperature and the 14 °F specimens. Due to logistics problems, the compressive strength tests were conducted at 4 days age instead of 3 days.

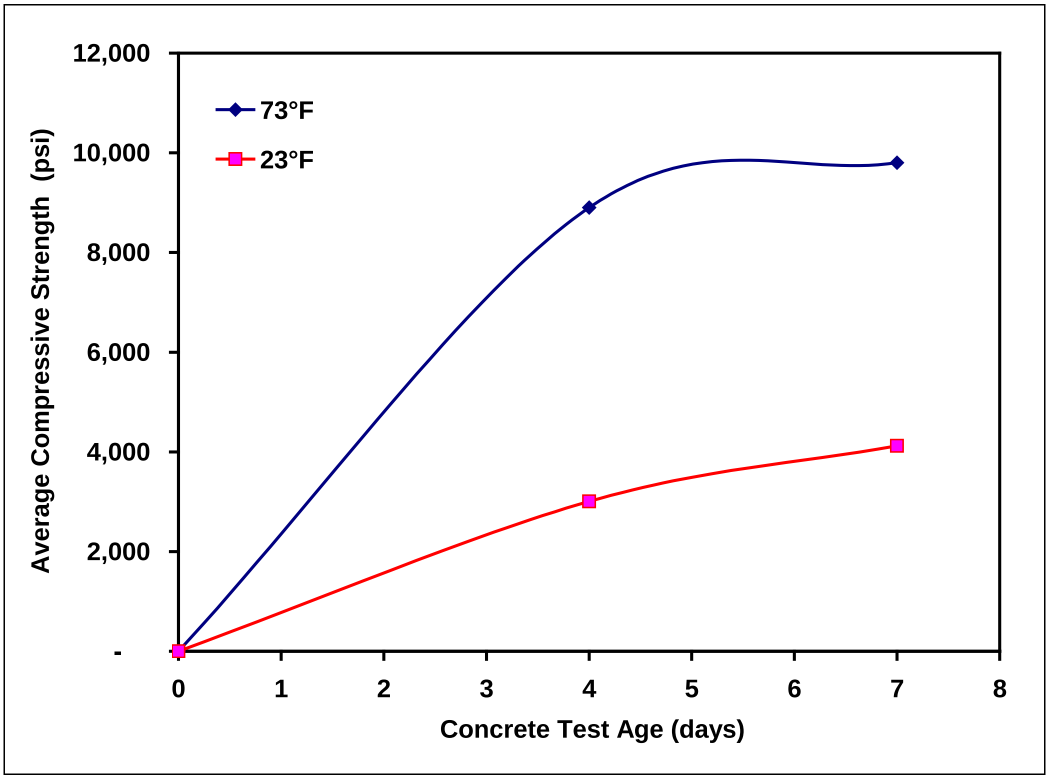



Figure 9. Early age strength development for Mixture 8 at ambient and 23 °F.

### Mixture 9

*Description*

Mixture 9 was a refinement of Mixture 8. In order to improve the mixture workability and extend the setting times, the Rheocrete® CNI admixture content was increased and the Pozzutec® 20+ admixture content was decreased compared to Mixture 7 (Table 2). The moisture content was slightly decreased.

*Measurements and observations*

During mixing it was observed that the cement paste formed very small balls, resembling ball bearings, around individual fine aggregate particles. During molding of the cylinders it was observed that the mixture appeared slightly dry but still packed well. Enough paste rose to the top of the cylinders to allow finishing with little difficulty. Mixtures 7 and 9 were very similar to each other in terms of admixture dosages, but Mixture 9 had lower moisture content. This moisture content appears to be a lower boundary for the range of moisture contents that yield mixtures suitable for RCC. Figure 10 shows the early strength development for this mixture.

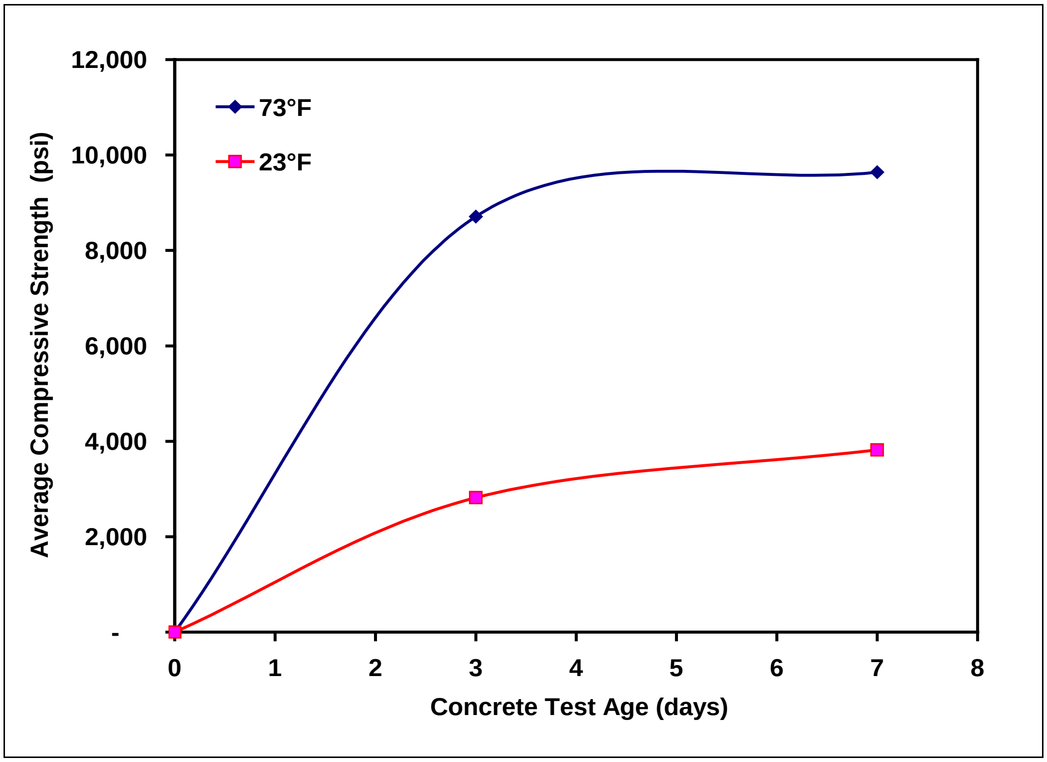



Figure 10. Early age strength development for Mixture 9 at ambient and 23 °F.

## Mixture 10

*Description*

Mixture 10 was proportioned to define the range of acceptable moisture contents that produce a suitable fresh mixture to be placed by an RCC paver (Table 2). The low temperature strengths of Mixes 9 and 10 are within acceptable values at 23°F. As with previous mixtures, cylinders were cast at room temperature and the cylinders were immediately placed in their respective curing rooms at 23 and 73 °F.

*Measurements and observations*

This mixture appeared to be suitable for placement with an RCC paver. An experienced RCC consultant was hired to observe the mixing and casting of Mixtures 9 and 10. According to his judgment, he indicated that these two mixtures defined a range of acceptable moisture contents from the standpoint of workability. The strength of the cylinders cured for 3 days at 23 °F appeared adequate and consistent with the goal of opening the RCC pavement to traffic within 24 hours after placement in an environment between 23 and 32 °F. Figure 11 shows the early strength development for this mixture.

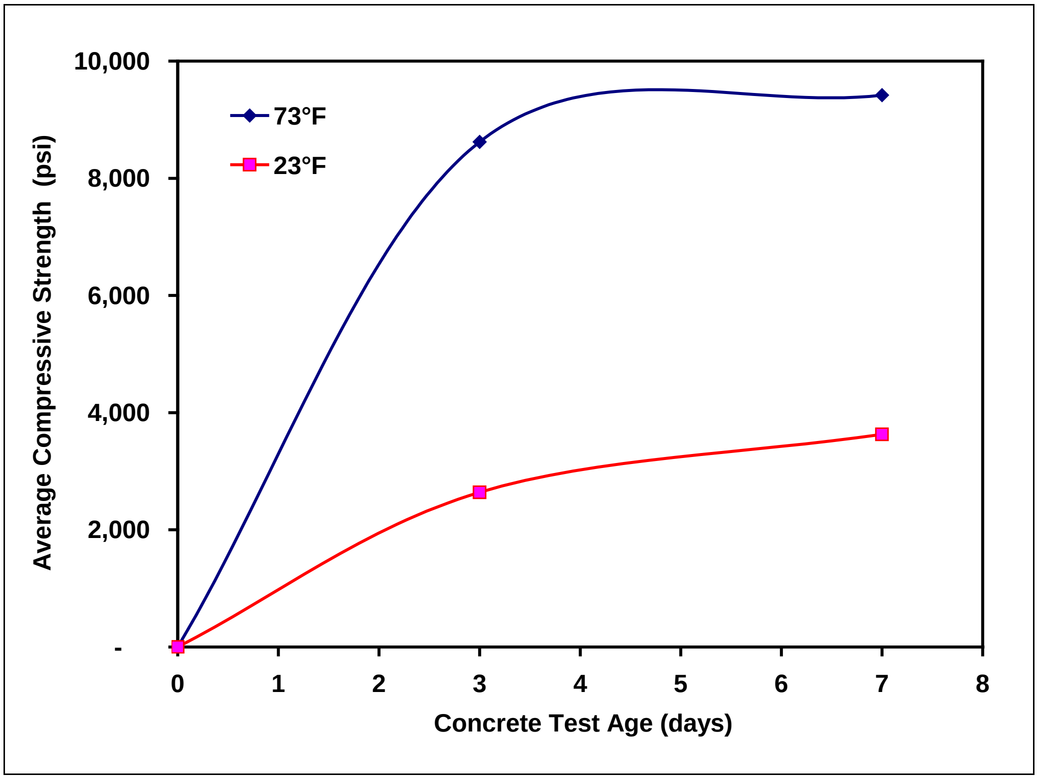



Figure 11. Early age strength development for Mixture 10 at ambient and 23 °F.

## Laboratory Summary

The laboratory investigation was conducted to develop a suitable Cold-RCC mixture for use during the field demonstration. Of importance was that the candidate mixture(s) exhibited acceptable compressive strength at low temperatures, and suitable workability and finishing characteristics for use in the paving machine. Initial mixes were first screened through a moisture-density relationship to identify a base mix. Once the base mixture was established, the chemical admixtures were added for the low temperature protection. This led to a number of refinements of the base mixture, as summarized in Table 3. The changes in the mixture ingredient proportions are shown as a percent change from Mixture 4. Reductions are shown in parentheses.

The quantities of the main constituents (cement, coarse aggregate, and fine aggregate) remained unchanged. However, the quantity of mixture water and the dosage rate of the chemical admixtures were modified to obtain the workability and finishing characteristics. The successful laboratory formulation decreased the total water in the mixture by nearly 30% by both decreasing the amount of mixing water and the dosage of the Rheocrete® CNI. This resulted in a water-cement ratio of 0.30 and 0.32 (Mix 9 and 10, respectively); and a moisture content of 4.93 and 5.23 percent, respectively (Table 2). These mixtures established the moisture content range for mixing, placing, and compaction in the field, for both quality control and quality assurance purposes.

Table 3. Summary of Cold-RCC trial mixes incorporating chemical admixtures and average unconfined compressive strength results at varying curing temperatures.

| | Mix 4 | Mix 5 | Mix 6 | Mix 7 | Mix 8 | Mix 9 | Mix 10 |
|---|---|---|---|---|---|---|---|
| Materials | | % of Mixture 4 | | | | | |
| Cement | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Coarse Aggregate | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Fine Aggregate | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Water added by us | 100 | (30) | (12) | (25) | (24) | (38) | (33) |
| Water added by Rheocrete | 100 | (54) | (54) | 0 | (54) | 0 | 0 |
| Water added by Pozzutec 20+ | 100 | 0 | 0 | 0 | 35 | (10) | (10) |
| Total water in mix | 100 | (30) | (16) | (20) | (23) | (31) | (27) |
| Rheocrete CNI | 100 | (54) | (54) | 0 | (54) | 0 | 0 |
| Pozzutec 20+ | 100 | 0 | 0 | 0 | 35 | (10) | (10) |
| Curing temperature and test age | Average Unconfined Compressive Strength (psi) | | | | | | |
| 73 °F at 3 days | 2,160 | 2,240 | 2,160 | 4,440 | 8,900 | 8,710 | 8,620 |
| 73 °F at 7 days | 4,100 | 4,180 | 4,060 | 8,960 | 9,800 | 9,640 | 9,420 |
| 23 °F at 3 days | 1,440 | 1,160 | 980 | 1,430 | 3,006 | 2,820 | 2,640 |
| 23 °F at 7 days | 3,200 | 2,160 | 1,960 | 3,120 | 4,120 | 3,820 | 3,630 |
| 14 °F at 3 days | 540 | 340 | 354 | 1,800 | Not cast | Not cast | Not cast |
| 14 °F at 7 days | 1,660 | 720 | 680 | 2,240 | Not cast | Not cast | Not cast |
| Note: Reductions in mix components are indicated with parentheses. | | | | | | | |

There was a dramatic gain in compressive strength beginning with Mixture 7 that continued with the rest of the lab mixtures. Cylinders cured at sub-freezing temperatures continued to gain strength, indicating that the low-temperature protection was working, although the initial freezing point of the mixtures was not verified. After 7 days, the average unconfined compressive strength of the cylinders cured at a constant 23 °F reached 75% of the control cylinders cured at 73 °F.

While indications of good workability and finishing were also important characteristics to observe in the laboratory, the real test would occur when the Cold-RCC mixtures were used in the equipment during the field demonstration. These issues, as well as the effect of the admixture dosage on material sticking to the mixing equipment, were monitored during the field demonstration.

# 3 Field Demonstration

## Test site location and description

The purpose of the field demonstration was to show the viability of mixing and placing concrete at cold temperatures using the Cold-RCC mixture from the laboratory investigation. The Cold-RCC material was produced using an on-site volumetric continuous mixing pugmill, and was placed with a paver equipped with a high-density screed. Both equipment items are normally specified for warmer temperature applications. During the early morning of 31 March 2009, a slab, 75 ft. x 20 ft x 10 in., was constructed near the Department of Public Works complex at Ft. Drum, New York. It was located near the sand stockpile used to treat the roadways during the winter months. Heavy equipment, such as front end loaders and plow trucks, frequently traffic this area as sand is loaded into the plow trucks (Figure 12 and Figure 13). The site location prior to construction is shown in Figure 14. The slab will be subjected to two conditions. The eastern portion of the slab (near the telephone pole) will be subjected to loading by front end loaders and plow trucks, while the western portion of the slab will be primarily subjected only to the effects of environmental conditions.

## Site preparation

About one week prior to the demonstration, the contractor visited the proposed site and met with the Chief of Roads and Grounds Branch, and an ERDC-CRREL representative. The site for the demonstration was chosen based on the previously determined size and the needs of the department, and it was anticipated a successful demonstration would take place and the finished product would be left in place.

After the demonstration site was chosen, the contractor worked with the department to determine the most feasible site for contractor mixing operations. The department was not currently using the aggregate storage areas immediately adjoining the test site (Figure 14) so it became apparent it would provide all that was needed by the contractor, namely a flat firm base in close proximity to the placement location.


Figure 12. Front end loaders are among the types of equipment that will load the slab.


Figure 13. Typical plow truck used for winter roadway maintenance.


Figure 14. Pre-construction view of test site.

The Ft. Drum Department of Public Works prepared the site by removing the remnants of prior snow falls and then excavated the area to receive the 10 in. thick Cold-RCC. Prior to excavation, the location consisted of a layer of asphalt concrete overlying a well-draining sand subgrade. From the surface, the test site was excavated to a depth of 14 in. A layer of crushed stone (4 in.) was placed and compacted over the sand subgrade to provide a stable base on which to place the Cold-RCC.

## Equipment setup and operation

The contractor began mobilizing the specialized RCC equipment from across the country. The ARAN Continuous Mix Pugmill was transported from an RCC pavement project in Mobile, Alabama. The Volvo-ABG paving machine, with high density duo-tamp screed, was shipped from the contractor's main headquarters in Alliance, Nebraska. Ancillary equipment, such as light plants, front end loaders, skid loader, water truck, and compactors were rented or hired from the local Watertown, New York area. Through precise coordination, the site was set-up by the contractor's five-man crew within forty-eight hours of the equipment's arrival at the site (Figure 15).

Figure 15. Setting up the ARAN continuous mixing pug mill.

## Materials

Cement was purchased from Essroc and was delivered from their Oswego NY terminal. The fine aggregate, was purchased from Cooke Sand & Gravel, in Brightville, NY. A grain size distribution analysis conducted by Atlantic Testing Laboratories on a sample collected from the on-site stockpile classified the material as poorly graded sand (SP) using the Unified Classification System (USCS), or A-3 under AASHTO classification system (American Association of State Highway Transportation Officials). The grain size distribution is shown in Figure 16. The coarse aggregate was purchased locally from Tughill Construction and was delivered from the Great Bend Quarry, in Champion, NY. A grain size analysis conducted on a sample collected from the on-site stockpile classified the material under USCS as poorly graded gravel (GP), or A-1-a according to AASHTO (Figure 17).

The chemical admixtures, Rheocrete® CNI and Pozzutec® 20+, were purchased from BASF and were delivered in 55-gallon barrels (Figure 18). A white membrane-forming curing compound, Kurez, meeting the specification of ASTM C 309 (2007a) *Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete*, was applied to the final surface within hours.

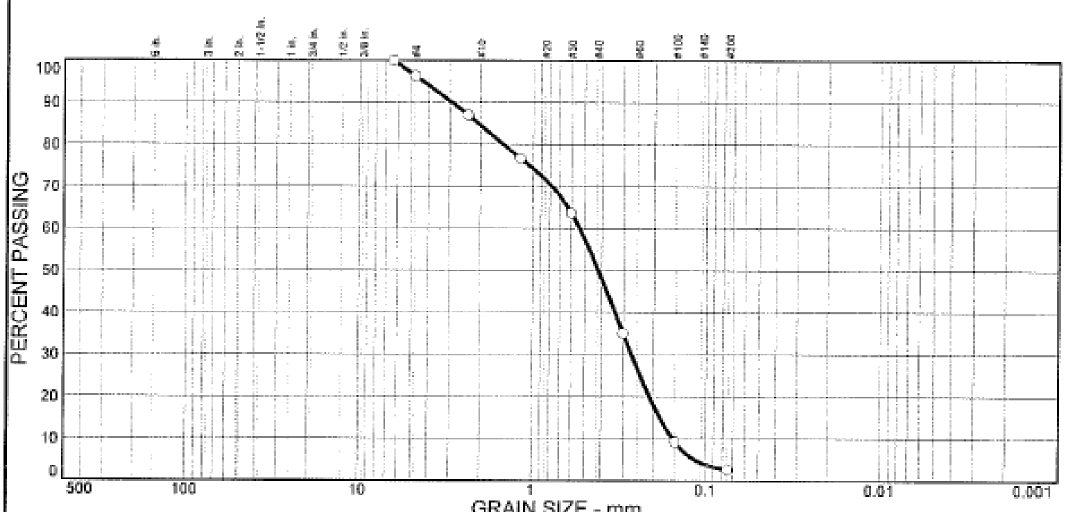
## Particle Size Distribution Report

**Project:** Roller Compacted Concrete Research **Report No.:** WT911RCL-02-03-09

**Client:** Peltz Companies, Inc. **Date:** 04/03/09

**Sample No:** WT911S1 **Source of Sample:** Unknown

**Location:** On-site Stockpile **Elev./Depth:** N/A




| % COBBLES | % GRAVEL | | % SAND | | | % FINES | |
|---|---|---|---|---|---|---|---|
| | CRS. | FINE | CRS. | MEDIUM | FINE | SILT | CLAY |
| 0 | 0 | 4 | 12 | 34 | 48 | 3 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | OUT OF SPEC. (X) |
|---|---|---|---|
| 1/4 in. | 100 | | |
| #4 | 96 | | |
| #8 | 87 | | |
| #16 | 77 | | |
| #30 | 64 | | |
| #50 | 35 | | |
| #100 | 9 | | |
| #200 | 2.7 | | |

**Soil Description**

Fine Aggregate

**Atterberg Limits**

PL= N/A LL= N/A PI= N/A

**Coefficients**

$D_{85}$= 2.06 $D_{60}$= 0.535 $D_{50}$= 0.417
$D_{30}$= 0.268 $D_{15}$= 0.183 $D_{10}$= 0.154
$C_u$= 3.46 $C_c$= 0.87

**Classification**

USCS= SP AASHTO= A-3

**Remarks**

Collected by J. Trathen on 03/31/09
ASTM C 117 & ASTM C 136
F.M.=2.32

* (no specification provided)

Figure

ATLANTIC TESTING LABORATORIES, LIMITED

Figure 16. Grain size distribution for fine aggregate.

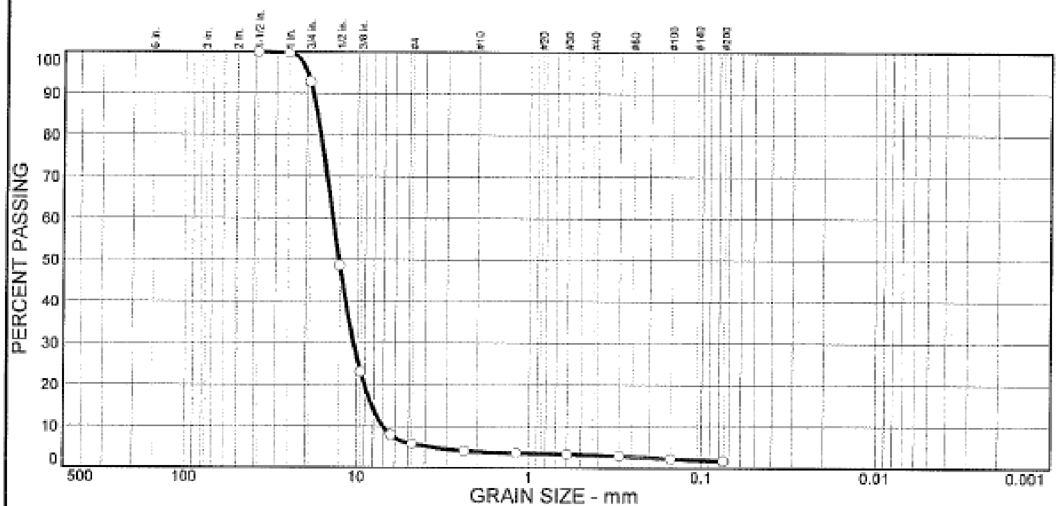
## Particle Size Distribution Report

**Project:** Roller Compacted Concrete Research  **Report No.:** WT911RCL-03-03-09

**Client:** Peltz Companies, Inc.  **Date:** 04/03/09

**Sample No:** WT911S2  **Source of Sample:** Unknown

**Location:** On-site Stockpile  **Elev./Depth:** N/A




| % COBBLES | % GRAVEL | | % SAND | | | % FINES | |
|---|---|---|---|---|---|---|---|
| | CRS. | FINE | CRS. | MEDIUM | FINE | SILT | CLAY |
| 0 | 7 | 87 | 2 | 1 | 1 | 2 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | OUT OF SPEC. (X) |
|---|---|---|---|
| 1.5 in. | 100 | | |
| 1 in. | 100 | | |
| 3/4 in. | 93 | | |
| 1/2 in. | 49 | | |
| 3/8 in. | 23 | | |
| 1/4 in. | 8 | | |
| #4 | 6 | | |
| #8 | 4 | | |
| #16 | 4 | | |
| #30 | 3 | | |
| #50 | 3 | | |
| #100 | 2 | | |
| #200 | 1.8 | | |

**Soil Description**

Coarse Aggregate

**Atterberg Limits**

PL= N/A  LL= N/A  PI= N/A

**Coefficients**

$D_{85}$= 17.3  $D_{60}$= 14.0  $D_{50}$= 12.8

$D_{30}$= 10.5  $D_{15}$= 8.18  $D_{10}$= 7.03

$C_u$= 1.99  $C_c$= 1.12

**Classification**

USCS= GP  AASHTO= A-1-a

**Remarks**

Collected by J. Trathen on 03/31/09

ASTM C 117 & ASTM C 136

* (no specification provided)

**Figure**

ATLANTIC TESTING LABORATORIES, LIMITED

Figure 17. Grain size distribution for coarse aggregate.


Figure 18. Chemical admixtures used in demonstration.

## Instrumentation

The rate of hydration of Portland cement is impacted by the curing temperature. Cold temperatures slow the hydration rate of cement, and the concrete potentially may become damaged should temperatures drop to a sufficient level that ice forms. Temperature measurements were made in the freshly placed concrete to create a thermal history, and to monitor the temperature of the structure at critical locations (center, corner, and edge). Sensors were placed at two depths at each critical location as shown in Figure 19. The measurements were made at a shallow near-surface depth (0.5 in.) and at the mid-point (5 in.) of the slab to monitor the internal temperature. The temperature sensors were installed immediately after the slab was compacted, with the sensors being installed in the eastern side first. Temperatures were recorded every 10 minutes for a total temperature history of about 26 hours of data collected.

Type-T thermocouples were used. They are composed of copper-constantan wire connected to a datalogger to record the temperature readings. The sensors were fabricated on site and installed by USAERDC-CRREL personnel. Type T thermocouples are commonly used for low temperature applications, and the thermoelement materials are non-corrosive where moisture is present. The advantages of thermocouples are that they are easy to both fabricate and read, durable, and have an accuracy of ±1°F. Figure 20 shows the datalogger setup at the eastern end of Lane 1 of the slab, with a close up view of the sensor locations in Figure 19. The datalogger system installed at the western end of the slab, Lane 2, is shown in Figure 21.

A cordless drill was used to bore a hole into the compacted concrete surface. The sensor was fed into the hole, and the hole was refilled using paste sifted from leftover mix, and recompacted using a long shaft screwdriver. Making use of the paste to refill the hole served to surround the tip of the temperature sensor with paste and reduce the possibility of the sensor being in contact with aggregate.

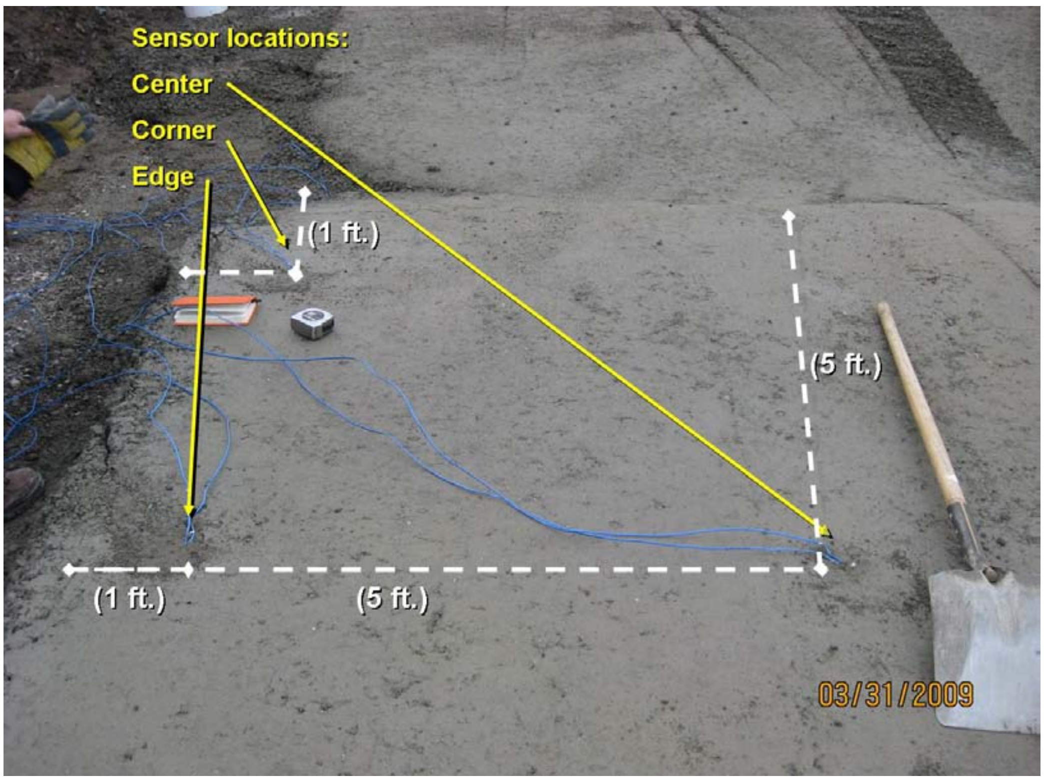



Figure 19. Center, corner, and edge locations for temperature monitoring in the eastern end of the slab.

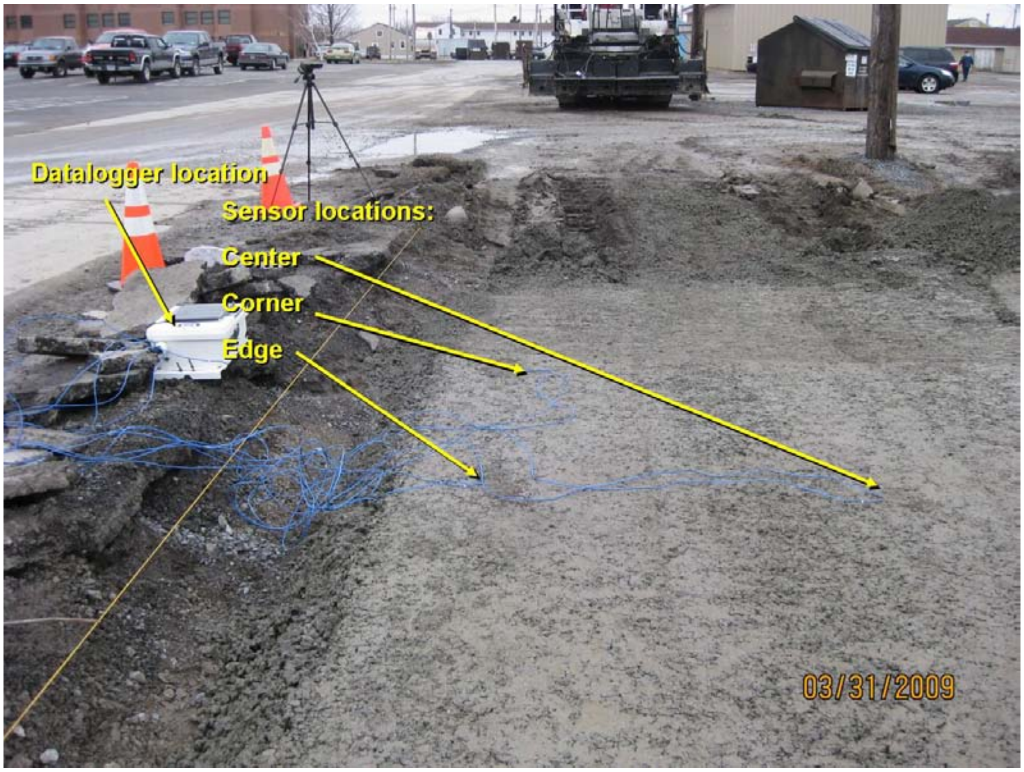



Figure 20. Instrumentation location in the northeast corner following placement and compaction of hardstand.

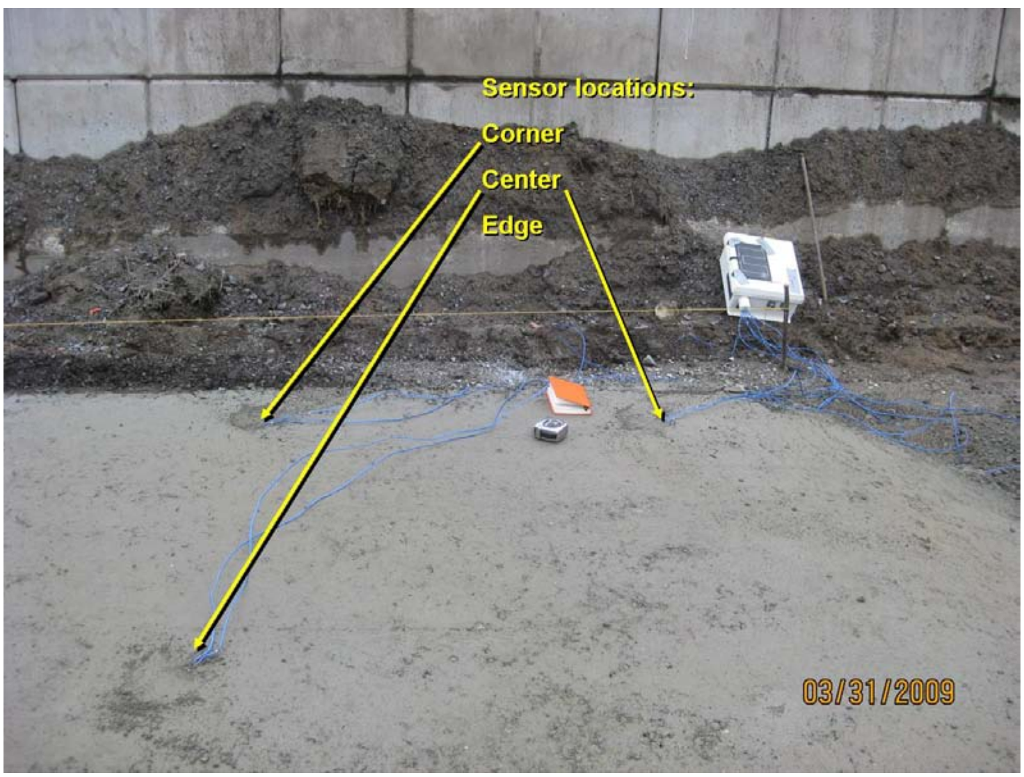



Figure 21. Instrumentation location in the southwestern corner following placement and compaction of slab.

## Pre-construction trial mixes

On the afternoon of March 30th, the contractor began loading the mixing plant with materials to calibrate and to produce trial mixes (Figure 22). The coarse and fine aggregates were volumetrically calibrated by sending controlled loads to a platform scale located a mile away on the military post. The cement was calibrated by weighing controlled samples on a digital scale provided at the Aran plant. The chemical admixtures were pre-blended with water in the onboard 2,000 gallon Aran Plant water storage tank (Figure 18).

The contractor performed preliminary mixes to determine the optimum moisture content through onsite testing with Atlantic Testing Laboratories of Watertown, New York (Figure 23). Samples collected on site for the fine and coarse aggregate, and fresh Cold-RCC mixture produced moisture content values of 5.6, 1.8, and 6.1%, respectively. Moisture content testing was done in accordance with ASTM C 566 (1997) *Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying*.


Figure 22. Calibration and trial mixes from continuous pugmill mixer.


Figure 23. Determining moisture content of trial mix with nuclear gage.

## Cold-RCC placement and compaction

The contractor began the mixing and placement operation at 0400 hrs March 31st 2009. The rationale for conducting the operation during this timeframe was that the coldest air temperatures were forecasted to occur. The air temperature reading shortly after the start of the mixing operation was 35 °F (Figure 24). The weather forecast (which was tracked from *www.weather.com*) called for air temperatures to be in the mid-30's until midnight of 31 March, then drop just below freezing by 0500 hrs.

Two continuous lanes, each 10 ft wide, were placed side by side in the test area. The northern half (Lane 1) was placed first using the ERDC-CRREL mixture design determined from the laboratory testing. For the second lane (Lane 2), the RCC mixture was modified on site. The fresh mixture was transported to the paving machine in the bucket of front end loader (Figure 25) and placed into the paving machine. Transport time was less than one minute.


Figure 24. Air temperature reading at start of cold-RCC operation.

Figure 25. Fresh cold-RCC mixture placed in paver.

The surface of the pavement showed some tearing, voids, and gouging, directly behind the screed. The contractor attributed this to the coarse aggregate, as well some sticking of the material to the screed plates and tamping bars. Following initial testing, the contractor experimented with using a rake to spread fines from the RCC mixture in an attempt to fill in some of the voids in the surface prior to compacting with several passes of the dual steel drum roller. Four passes of the roller were required to achieve the maximum density.

Following placement of Lane 1, there was a brief meeting between the Contractor, Atlantic Testing Laboratories, and ERDC-CRREL to determine changes to the mixture for Lane 2. ERDC-CRREL representatives desired a better surface appearance (Figure 26). It was agreed by all that the water content should be increased slightly either to match or be a little above the optimum moisture content. While neither the aggregate nor the cement proportions were not changed, the input rate of both the stone and sand were evened by adjusting the gate height in the proportional mixer. Static rolling of the dual drum roller provided the finish operation to both lanes of RCC pavement. As evident in Figure 26, the finished surface texture of the eastern end of the slab (Lane 1) is more coarse with larger voids between the aggregate compared with the surface of the western end (Lane 2) of the slab.


Figure 26. Finished surface of Lanes 1 and 2.

## Curing

Two curing methods were used on the completed RCC slab. Following rolling and placement of temperature sensors by ERDC-CRREL, the surface of both lanes at the eastern end were covered with the Kurez white membrane curing compound. The surface of both lanes toward the western end were covered with polyethylene sheathing to facilitate in final curing (Figure 27). Later that afternoon, the contractor sawed contraction joints spaced at twenty-foot intervals.


Figure 27. Applying curing compound and plastic sheeting to completed test lanes.

## Quality control

The contractor employed the services of Atlantic Testing Laboratories, to conduct the quality control testing for the project. Aggregate gradations, aggregate moisture contents, total mixture moisture contents, placement densities, and core thickness and unit weights were also measured.

In-place density and moisture content readings were taken with a nuclear gauge in accordance with ASTM D 2922 (2004a) *Standard test methods for density of soil and soil-aggregate in place by nuclear methods (shallow depth)*, and ASTM D 3017 (2004b) *Standard test method for* *water content of soil and rock in place by nuclear methods (shallow depth)*. Initial tests with the nuclear density gauge showed the moisture contents and density of the in-place RCC slab in Lane 1, directly behind the screed. The readings are shown in Table 4.

Table 4. In-place density and moisture readings taken of finished RCC slab (Atlantic Testing Laboratories).

**IN-PLACE FIELD DENSITY TEST RESULTS**

| Test No. | Test Location | Probe Depth (in.) | Number of Roller Passes ( in & out) | Target Wet Density (pcf) | Field Wet Density (pcf) | Field Moisture Content (%) | Field Dry Density (pcf) | Percent of Target Density (%) |
|---|---|---|---|---|---|---|---|---|
| **Lane 1, Adjacent to Railroad Street (Original Aggregate Blend)** | | | | | | | | |
| 1 | 10' South of North End | 6 | 0 | 153.9 | 149.9 | 5.5 | 142.1 | 97 |
| 2 | 30' South of North End | 6 | 0 | 153.9 | 142.4 | 6.4 | 133.8 | 93 |
| 3 | 15' North of South End | 6 | 0 | 153.9 | 146.3 | 6.6 | 137.2 | 95 |
| 4 | 20' South of North End | 6 | 2 (Static) | 153.9 | 139.8 | 5.8 | 132.1 | 91 |
| 5 | Retest of Test No. 2 | 6 | 2 (Static) | 153.9 | 147.0 | 6.6 | 137.9 | 96 |
| 6 | Retest of Test No. 3 | 6 | 2 (Static) | 153.9 | 153.1 | 7.0 | 143.1 | 100 |
| 7 | Retest of Test No. 4 | 6 | 4 (Static) | 153.9 | 144.3 | 5.7 | 136.5 | 94 |
| **Lane 2 (50/50 Aggregate Blend)** | | | | | | | | |
| 8 | 15' South of North End | 6 | 0 | 150.6 | 136.9 | 7.3 | 127.5 | 91 |
| 9 | 25' South of North End | 6 | 3 (Static) | 150.6 | 152.0 | 7.1 | 141.9 | 101 |
| 10 | 20' North of South End | 6 | 4 (Static), 1 (Vibratory) | 150.6 | 152.6 | 7.1 | 142.5 | 101 |
| 11 | Retest of Test No. 8 | 6 | 4 (Static), 1 (Vibratory) | 150.6 | 151.9 | 7.1 | 141.8 | 101 |
| 12 | Retest of Test No. 9 | 6 | 4 (Static), 1 (Vibratory) | 150.6 | 151.0 | 6.5 | 141.8 | 100 |

# 4 Results

## Slab temperatures

The reference and ambient air temperature readings throughout the recording period for both datalogger systems were plotted together (Figure 28). The sensor for the air temperature was located near the ground surface. For Logger 1, the reference and air temperatures track each other. As shown in the photograph of Figure 21, initially the datalogger (Logger 2) on the western end was temporarily located in the shade of the barrier wall next to the sand stockpile until the edge of the slab was filled in with gravel. The reference temperature spiked when the logger was moved into the sun at the center of the slab (Figure 28). With this relocation the air temperature also increased. The reference temperatures then track similar to each other, indicating comparable conditions, and the same occurs with the air temperature readings. The daytime high temperature on 31 March 2009 reached 54 °F at 1530 hrs and gradually cooled to the low temperature reading of 34 °F at 2310 hrs. The average air temperatures during this time of the year range from a high of 46 °F to a low of 37 °F (*www.weather.com*).

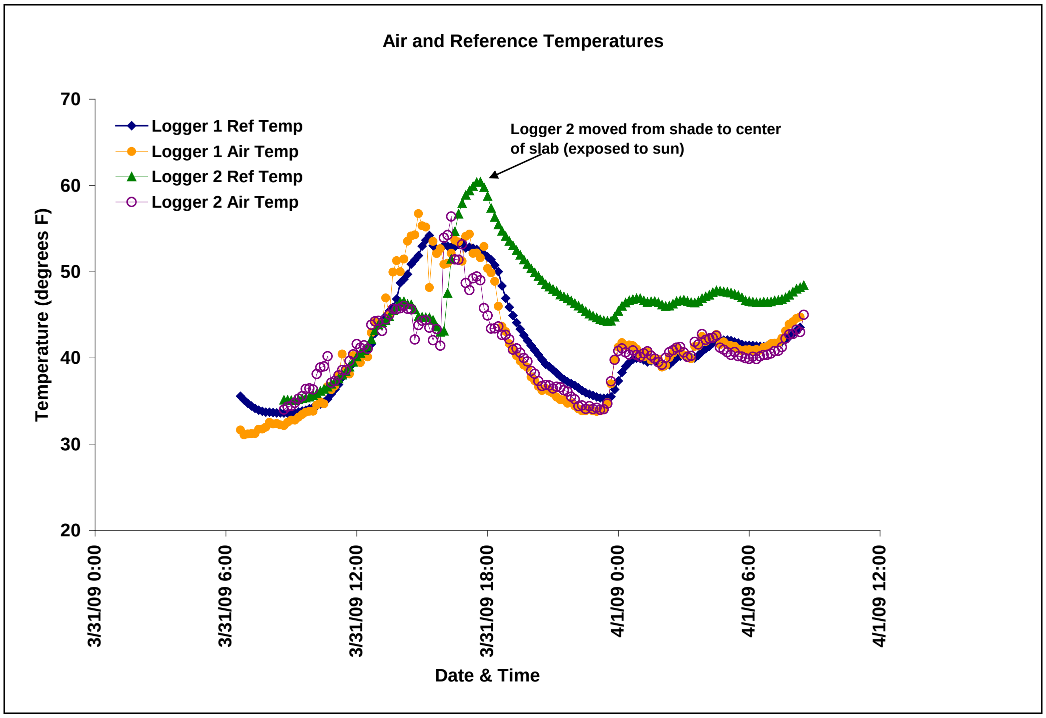



Figure 28. Air and reference temperature readings for Logger1 and Logger 2 during monitoring of temperatures in hardstand.

The increase in the slab temperature readings (Figure 29) shows that the first readings collected by the sensors in the eastern end of the slab occurred at 0640 hrs. The temperature of the concrete was roughly 54°F and the ambient air temperature was 31.6°F. Recorded maximum temperature readings at the near-surface locations peaked about the same time (1630 hrs), and similarly, the maximum mid-slab readings occurred roughly 60-90 minutes later.

Figure 30 and Figure 31 both show the slab temperature readings near the surface and at the middle of the eastern slab, respectively. The temperatures at the near-surface all reached their peak at approximately the same time at 1630 hrs. Temperatures at both the center and the edge locations followed similar trends, with the maximum temperature at the center location reaching 76.5 °F at 1630 hrs, roughly 10 hours after placement. At the mid-slab depth, the temperature peaked to 72.3 °F at 11.5 hours after placement at 1810 hrs. The temperature measurement near the top of the slab is higher due in part to the thermal gradient generated by the warmer ambient air above the slab. At the mid-slab depth (Figure 31) the maximum temperature peaks occur later than the near-surface and more gradually, then cools more slowly.

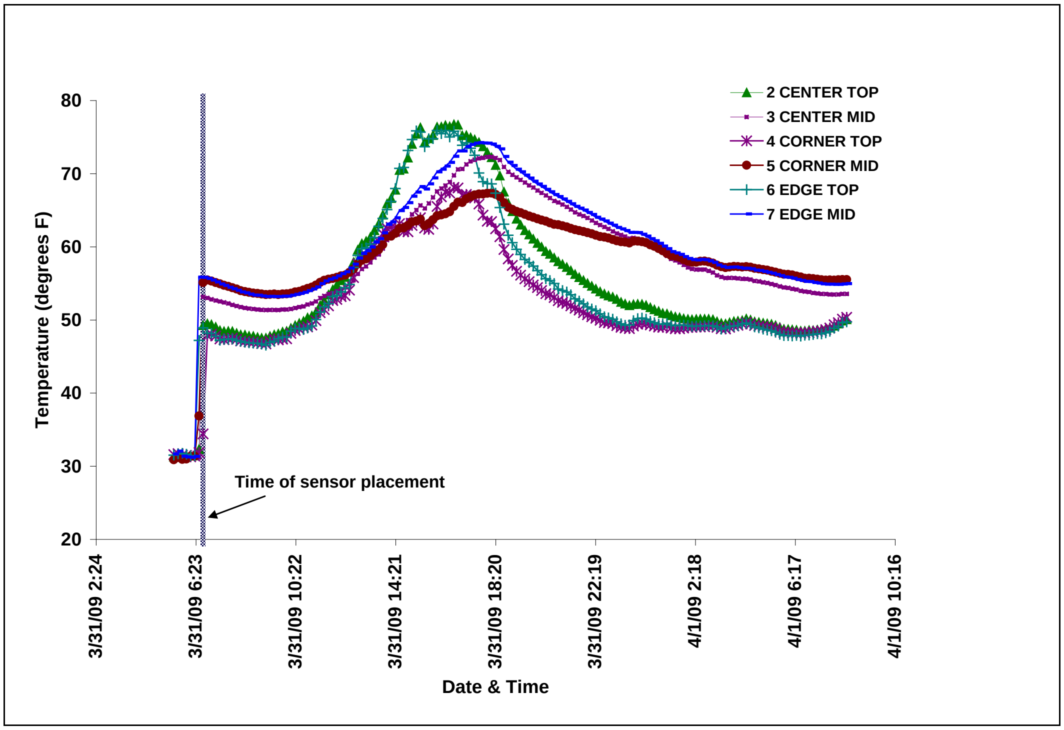



Figure 29. Temperature readings for the eastern side (Logger 1).

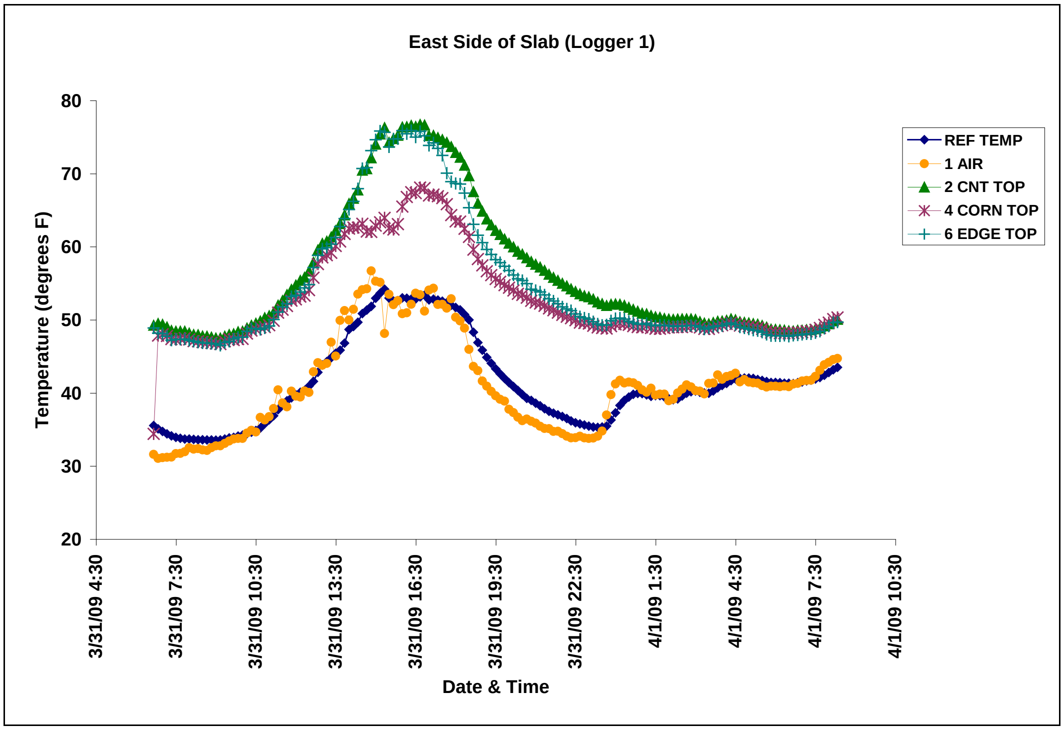



Figure 30. Temperature readings for the near surface at the center, corner, and edge at the eastern edge.

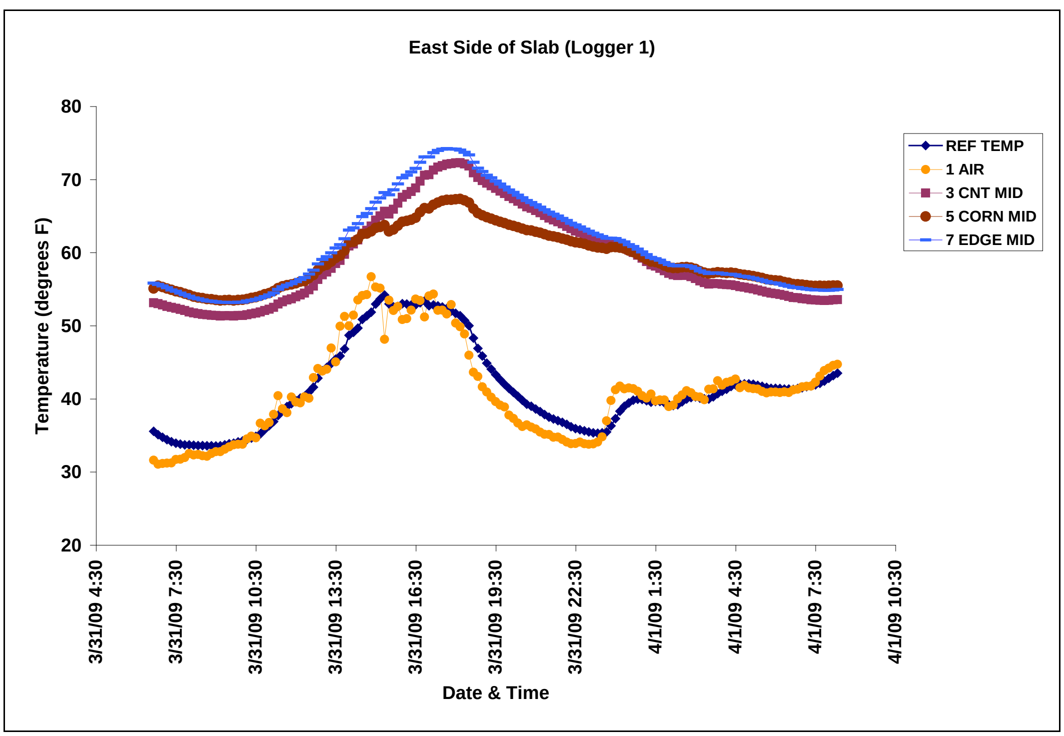



Figure 31. Temperature readings for the mid-slab at the center, corner, and edge at the eastern edge.

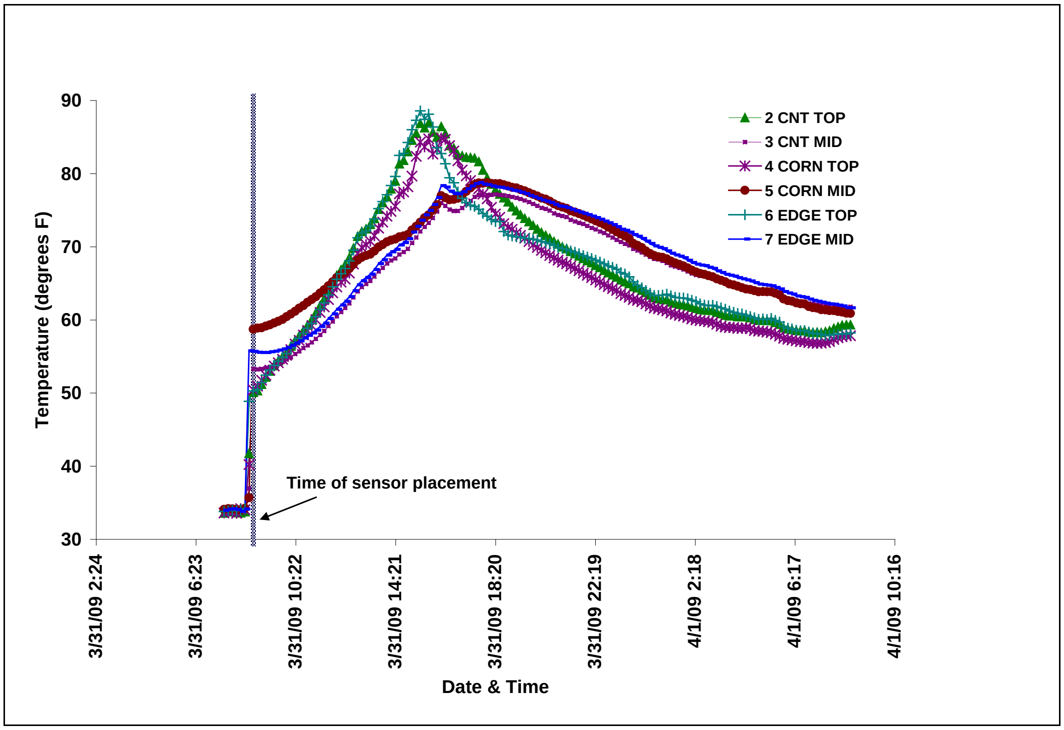



Figure 32. Temperature readings for the western side (Logger 2).

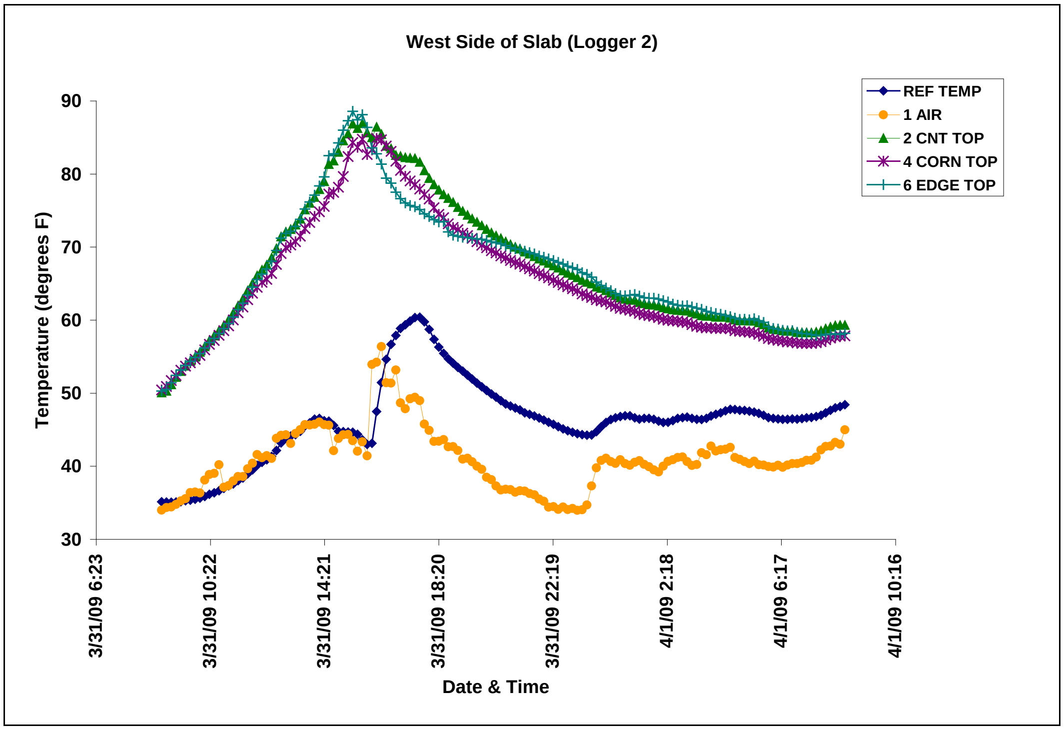



Figure 33. Temperature readings for the near surface at the center, corner, and edge at the western edge.

The southern section of the hardstand was completed and the temperature sensors installed by 0830 hrs. The sensors were installed in the western end of the slab (Figure 34). Overall, the trends of the temperature readings are similar to those from the eastern side of the slab, with the temperature readings tracking closely throughout the recording period. The near-surface temperatures at all 3 locations reached their maximum value within 20-30 minutes of each other 7.5 hours after the slab was constructed, about an hour earlier than the eastern end of the slab. The maximum temperatures were within 1-1.5 °C of each other, with the temperature of the corner recording the coolest temperature at the near-surface (Figure 35). At the mid-slab location, again the temperatures track closely, and all gradually reaching their peak around 1800 hrs with maximum temperature readings at 25 or 26 °C before tapering off (Figure 36).

## Early-age loading

Several hours after the Cold-RCC test section was completed, a high-capacity truck was parked on the early-age section (Figure 35). This illustrated that the pavement was capable of supporting the vehicle load and that there were no detrimental effects from the lower ambient temperatures on the Cold-RCC mixture.

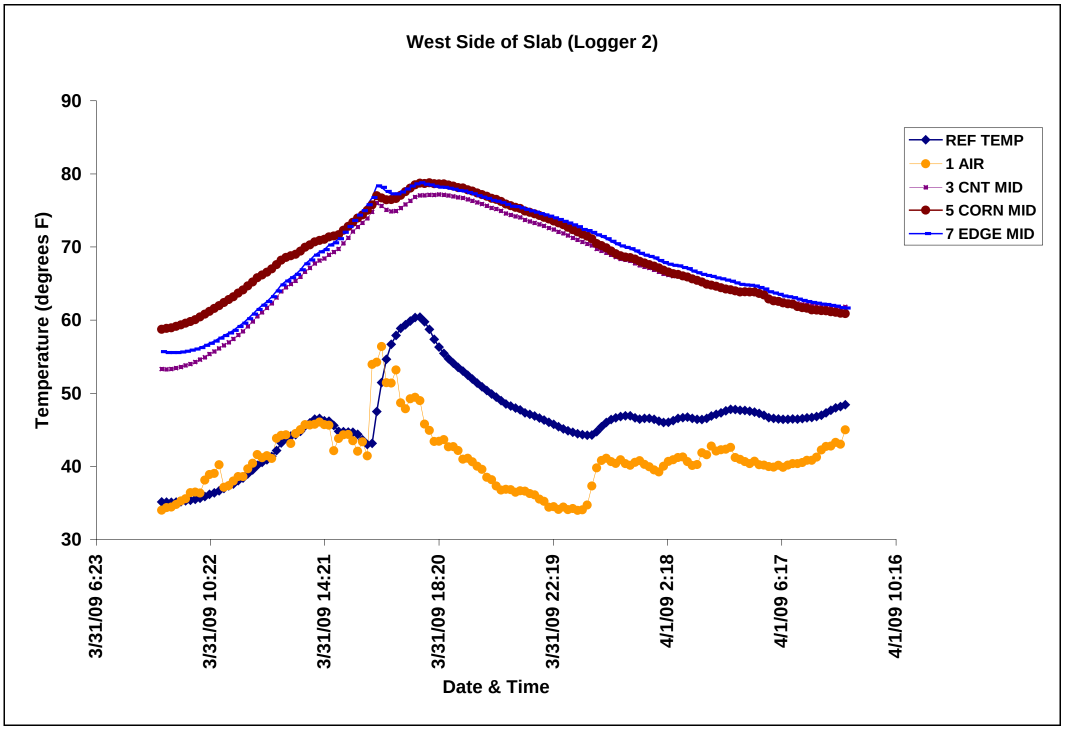



Figure 34. Temperature readings for the mid-slab at the center, corner, and edge at the western edge.


Figure 35. High-capacity truck parked on completed test section.

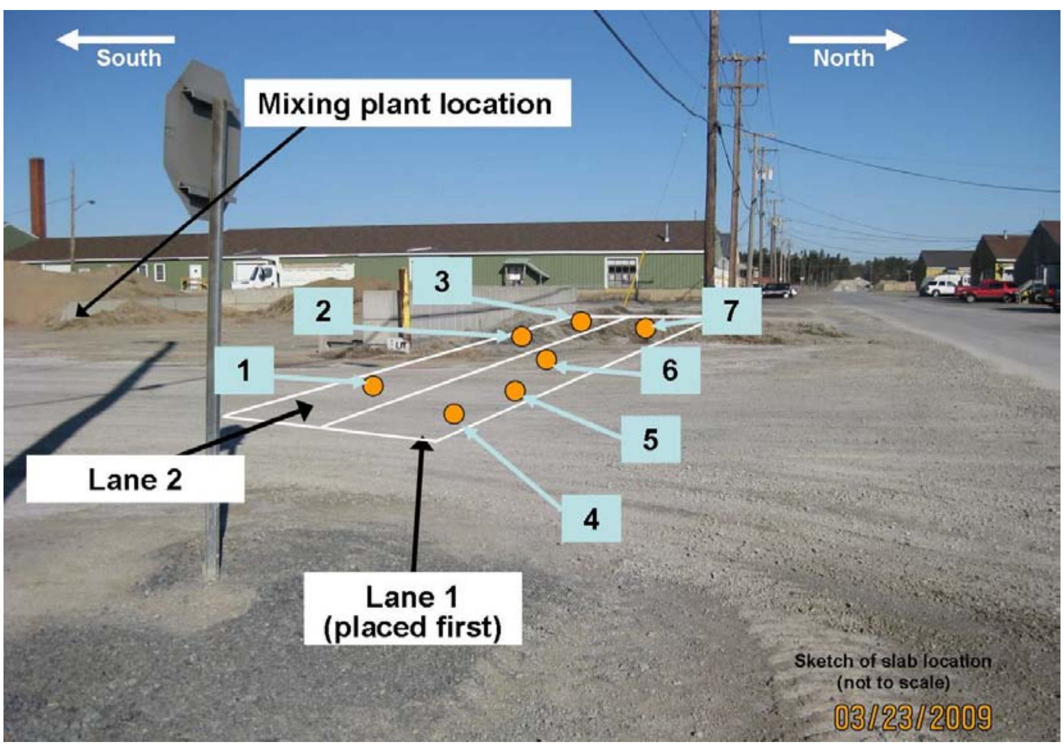



Figure 36. Approximate locations of core specimens collected from field site.

## Cold-RCC cores

Four days after the Cold-RCC concrete was placed, a total of seven core specimens were extracted from both Lanes in accordance with ASTM C 42 (2004c) *Standard test method for obtaining and testing drilled cores and sawed beams of concrete*. Atlantic Testing Laboratories obtained the cores and shipped them to ERDC-CRREL. The cores were used to verify the thickness and the consistency of the slab after placement and compaction. No testing was conducted on the cores for mechanical properties.

The length of the cores collected from Lane 1 ranged in length from 9 to 10.5 in. In Lane 2, the lengths ranged from 8.5 to 9.5 in. As shown in Figure 36, the cores were collected near the outer and internal edges, as well as close to the centerline of both slabs. Core 7 was the only specimen that did not remain intact with loose gravel and pieces below the upper 5 in. of the core. Core 7 was collected from the western end of Lane 1, and the mixture was fairly dry before the moisture content was increased for the remainder of the lane. Figure 37 through Figure 42 show photographs of the cores retrieved from Lane 2 and Lane 1. These are included to show that the Cold-RCC has the same appearance as conventional RCC pavement.


Figure 37. Core specimen from Location 1, Lane 2, length 9.5 in.


Figure 38. Core specimen from Location 2,
Lane 2, length 9.5 in.


Figure 39. Core specimen from Location 3,
Lane 1 length 8.5 in.


Figure 40. Core specimen from Location 4,
Lane 1, length 9.5 in.


Figure 41. Core specimen from Location 5,
Lane 1, length 10.5 in.


Figure 42. Core specimen from Location 6, Lane 1, length 10.5 in.

## Post-demonstration laboratory testing

Additional laboratory testing was conducted on the two Cold-RCC mixtures used during the demonstration at Ft. Drum. Table 5 lists the mixture proportions. The mixture used in Lane 1 represents the ERDC-CRREL mix, while Lane 2 is the modified mixture adapted in the field. The preparation of the mixtures followed the same procedure as presented earlier in Laboratory Investigation section. Both mixtures were mixed using a rotating drum mixer and cylindrical test specimens were cast (following ASTM C 1435 [2008c]), capped, and placed in the curing rooms.

The low-temperature curing conditions for these mixes were 23 and 32 °F. The curing temperature of 32 °F was selected as this was near the temperature the Cold-RCC was placed and initially cured at in the field. Another set of test control cylinders were cured at 73 °F. The unconfined compressive strength was tested at test ages of 1, 3, 7, and 28 days. Figure 43 and Figure 44 show the results of the unconfined compressive strength testing for Lane 1 and Lane 2 mixes, respectively.

Table 5. Material proportions used in laboratory testing to reproduce the mixes used in the field.

| | Units | Lane 1 | Lane 2 |
|---|---|---|---|
| Cement | lb/yd³ | 658 | 540 |
| Coarse Aggregate | lb/yd³ | 2,225 | 1,360 |
| Fine Aggregate | lb/yd³ | 1,094 | 1,663 |
| Water added by us | lb/yd³ | 195 | 198 |
| Rheocrete CNI | lb/yd³ | 50 | 50 |
| Pozzutec 20+ | lb/yd³ | 34.72 | 34.72 |
| Water added by Rheocrete | lb/yd³ | 33.75 | 33.75 |
| Water added by Pozzutec 20+ | lb/yd³ | 20.83 | 20.83 |
| Total water in mix | lb/yd³ | 249.58 | 252.58 |
| | | | |
| Solids in Rheocrete CNI (32.5%) | (%) | 16.25 | 16.25 |
| Solids in Pozzutec 20+ (40%) | (%) | 13.89 | 13.89 |
| Fly Ash | lb/yd³ | 0 | 0 |
| w/c (without admixtures) | | 0.30 | 0.37 |
| w/c (with admixtures) | | 0.38 | 0.47 |
| Moisture Content | (%) | 6.23 | 7.03 |

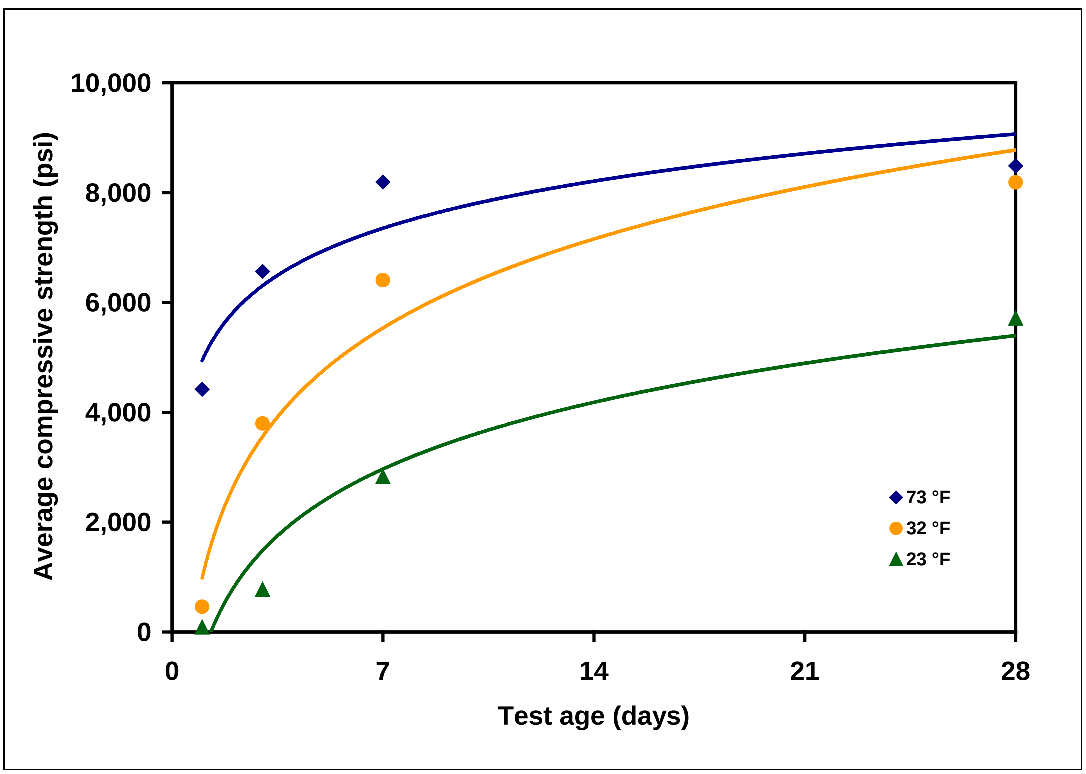



Figure 43. Average compressive strength values for Lane 1 mix at varying curing temperatures.

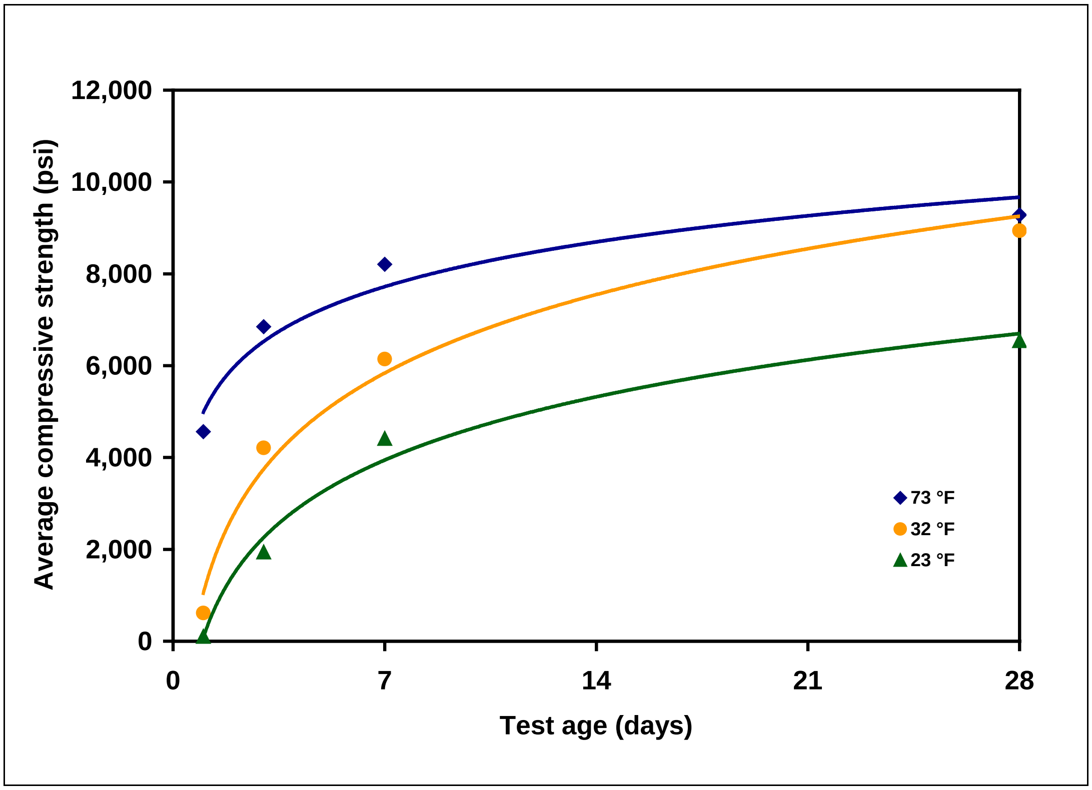



Figure 44. Average compressive strength values for Lane 2 mix at varying curing temperatures.

Compressive strengths for the curing condition at 73 °F at 7 days reached 8,000 psi. Compared to the strengths of both Mixtures 9 and 10 from the initial laboratory testing, the Lane 1 and Lane 2 mixtures reached compressive strengths exceeding 6,000 psi at the curing temperature of 32°F at a test age of 7 days. These strength values for Lane 1 and Lane 2 were lower than the earlier mixes (9,500 psi). However, the 23 °F 7-day strength for the Lane 2 mixture was roughly the same, at 4,100 psi, as Mixes 9 and 10. The 7-day strength for Lane 1 was about 30% less than the mixes in the initial laboratory investigation at 2,800 psi.

## Performance monitoring of Cold–RCC test section

As indicated earlier, one half of the test section was open to limited traffic within 8 hours of the placement of the fresh Cold-RCC pavement. The same half of the test section was opened to unrestricted traffic 24 hours after placement. The other half of the test section is located so that no traffic goes over it. This second half of the test section serves as a control to evaluate the effect of environmental factors on the durability of the Cold-RCC pavement.

Remote monitoring of the test section was conducted by observations given by installation staff in charge of roads and grounds maintenance. This was supplemented by a visit to the field site by one of the authors approximately 100 days after the Cold-RCC placement. The following observations were made during this visit:

a) Only very fine surface cracks were observed over the surface of the test section. No large shrinkage cracks were visible at this time;

b) Fine aggregate particles and some coarse aggregate particles were observed lying over the test section. These particles were brought in by traffic. It is anticipated that these particles will abrade the RCC surface over time. Removal of the lose aggregate may be only a temporary solution because the test section is next to unpaved areas that will continue to supply aggregate particles;

c) The traffic volume applied to the exposed Cold-RCC test section is relatively low, but most traffic is composed of heavy trucks traveling at low speeds;

d) The part of the test section subjected to traffic continues to perform its function as intended. It is likely that this pavement section will last many years in service.

# 5 Conclusions and Recommendations

The purpose of this project was to merge the RCC and CWAS technologies to develop a suitable mixture used in the rapid construction of a hardstand, in cold weather, using conventional RCC equipment. Cold–RCC takes advantage of the low-temperature curing capability of CWAS in a different application method for high volume projects, such as RCC, usually used in warm weather. The construction of the hardstand was accomplished using standard RCC mixing and placement equipment, and existing quality assurance/quality control methods. This application provided the preliminary step to place high volume concrete during times of cold weather without the need for thermal protection.

The following conclusions are made regarding Cold-RCC:

1. The laboratory investigation developed a candidate mixture used in the field demonstration using accepted screening and testing procedures. Mixes incorporating the admixtures exhibited good strength gain characteristics when cured at 23 °F (even at 14 °F);

2. The initial freezing point should be measured to verify the temperature limit of the Cold-RCC mix. The admixture dosage rate is decreased or increased based on the temperature protection limit needed for the job site conditions, keeping in mind that increasing the amount of mixture water reduces the freezing protection;

3. Improved workability is needed for Cold-RCC mixes by understanding the interaction between the admixture dosage and moisture content, at the laboratory level. Decreasing the admixture dosage may improve the workability of the mixture (by reducing the 'stickiness') and still provide low-temperature protection;

4. Small-scale laboratory mixing should investigate the use of rotating shaft and/or small laboratory pan mixers with Cold-RCC mixtures to better simulate field mixing action, such as that of a pug mill;

5. Mixture workability at a large-scale is difficult to determine based on the laboratory-scale, but it was observed at the full-scale field level with

surface tearing behind the screed with the initial ERDC-CRREL mixture until the mixture was modified;

6. Additional laboratory investigations on Cold-RCC formulations should look for ways to make them more conventional and economical, such as incorporating SCMs. The use of SCMs would decrease the cement content of the mixture and decrease the cost. However, their impact on strength gain at low temperature needs to be assessed;

7. The field demonstration provided an opportunity to place Cold-RCC during cold temperatures. The air temperatures at the time of placement were near freezing and rising. The ground was unfrozen, and the subsurface material was well-draining. CWAS has been used for structural concrete projects and placed on ice-free, frozen ground. Potential for frost heaving still must be considered in the design process. This was an initial step to placing high volume material during cold weather;

8. The Cold-RCC mixture developed in the laboratory needed modification during the field demonstration. Initially, additional water was added to achieve compaction in the first lane. For the second lane, there were modifications made to the aggregate proportions to improve the compaction and surface finish;

9. The use of a curing compound on the completed hardstand appeared to work well to maintain moisture for curing. At freezing temperatures, moist-curing with water would freeze at the surface. Compared to trying to secure a polyethylene sheet, a curing compound would provide ease-of-use to apply and keep in place;

10. Drilled core specimens collected after the concrete was placed showed that the Cold-RCC mixture looked similar to standard RCC mixtures.

11. Post-field laboratory testing indicated that the compressive strengths of the modified field mixes were comparable to the laboratory pre-field mixes.

## Overall project considerations

Overall, the field demonstration was completed as planned. The procedure successfully used existing methods and equipment. The only constraint during the field demonstration was the expectation for colder temperatures than what was encountered. Based on the laboratory investigation and field demonstration, observations are listed below.

### Field demonstration project size

The size of the project conducted during the field demonstration was much smaller than the typical size of a RCC project. Issues related to an increased project size need to be considered, such as maintaining operational tempo.

## Problems experienced - from the contractor's perspective:

### Design preparation

The original laboratory testing was based on RCC mixture designs from the Fort Drum hardstand paving in the latter 1980's. This design utilized approximately twice as much coarse aggregate as fine aggregate. In addition, the coarse aggregate was a 1-1/2 in. minus.

Much advancement in surface appearance and durability has been gained in the last twenty years due to using a smaller coarse aggregate and increasing the amount of fine aggregate in the total mix, thus reducing the amount of larger aggregate. Though this may be in contrast to prior RCC mixes, this change has not only improved RCC surface appearance and durability it has increased strength due to the filling of voids. Because ERDC-CRREL did not have any cold weather testing data with other aggregate gradations or mixes, the original coarse aggregate from Fort Drum was used for the demonstration project.

### Chemical admixtures

The Rheocrete® CNI and Pozzutec® 20+ used for this project were added in pre-determined amounts to the onboard storage of the ARAN mixing plant. This method proved to be very successful for this small project but could not be used on larger scale projects. In essence the system used was for "one batch of a hundred cubic yards". On larger scale projects a continuous method of adding the pre-determined admixtures to the water supply must be developed before the water enters the mixing plant. This would most likely utilize a storage system tank between the water source and the mixing plant. By using this method, the liquid in the mixing plant's system would always contain the admixture and would be prevented from freezing lines and valves.

One of the advantages of the CWAS technology when used in non-RCC concrete mixes is the ability to dose the admixture quantity on an "as needed" basis, meaning the dosage rate of the admixtures may be adjusted on-site. Maintaining the admixtures separate from the mixture water until needed would meet that feature.

### Cold weather equipment operations

#### *Mixing plant*

Pre-cautions must be maintained to keep the water cooled Caterpillar engine from freezing. This can be accomplished through adequate anti-freeze agents. Anti-freezing agents (concrete admixtures) must be maintained at proper levels throughout the mixing operations. With low temperatures of approximately 28 °F, the admixtures should be adequate to keep the plant's lines and valves from freezing during normal shut down periods. During extended cold weather periods and those periods with lower temperatures, the plant's water system should be cleaned out entirely, and bled dry with air, to prevent any possibility of line freezing. Bearings, belts, and hydraulics should work sufficiently in temperatures somewhat lower than freezing. Actual threshold limits were not determined in the demonstration due to ambient temperatures in the region during the time frame allotted for the demonstration.

#### *Paving machine*

The ABG Paver Finisher used was equipped with an air cooled engine. Some models do have water cooled engines and would require close attention to anti-freezing agents in the coolant system.

#### *Ancillary equipment*

Similar to paving machines, the contractor would not anticipate any unusual problems with the paving machine or ancillary equipment down to certain temperatures, as winter use of this type of equipment is used quite often. If possible the equipment should be stored inside enclosures, for ease in start-up and warm-up procedures.

*Equipment cleaning*

The demonstration showed the contractor potential problems with using high content additives in RCC mixes. The admixtures did cause the RCC mixture to become “sticky”. During continuous operation of the mixing plant and the paver this “sticky” material did not have any negative effects. However, temporary stoppages allowed the material to “stick” to the pugmill paddles and working parts of the compactive paver. This build-up did not adversely affect the mixing because of the short duration of the project. However, the build-up on the tamping bars and screed plates of the paver’s screed did create some minor gouging and tearing of the RCC surface. Recall that this issue was also encountered during the laboratory investigation with some of the paste material sticking to the sides of the revolving drum mixer.

On future cold weather RCC projects, special attention must be given to the cleaning of the equipment.

The first step would involve the design and layout of the project. It should be so designed to allow for a “continuous mixing and placing” as possible. If the equipment is running continuously, the material does not have the chance to build-up nearly as fast as it does when stopped.

The second step would require making allowances for cleaning during the paving days.

## Recommendations for Army implementation

The RCC construction method has been in widespread use for more than 30 years. The ability to rapidly construct heavy-duty pavements (parking areas, tank trails, hardstands, etc.) has been shown quite cost effective during the typical construction season (warm or hot conditions). Now, the ability to produce heavy-duty pavements during cold weather periods extends the construction and repair season even further. Cold-RCC is a practical, rapid construction approach applicable for horizontal infrastructure that may be used at permanent installations, remote training facilities, in-theater, and for emergency construction. It is recommended that the Cold-RCC procedure be considered for adoption into guidance documents. An example is the Unified Facilities Guide Specifications (UFGS) Section 32 13 16.16 addressing Roller Compacted Concrete (RCC) Pavement.

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# Appendix A: Thermocouple Background and Datalogger Program

## Thermocouple background

Thermocouples operate on the principle that contact between dissimilar metals creates an electrical potential. The system may be considered as a loop from the connection to the datalogger and the reference temperature to the copper-constantan measuring tip. Electromagnetic forces are not generated when the temperature remains constant. A temperature difference at the measurement junction induces a flow of electromagnetic forces that may then be measured.

The thermocouples were constructed from 24-gage duplex-insulated copper-constantan wire covered with a polyvinyl insulation, commercially available from Omega Engineering, Inc (*www.omega.com*). The heavy duty gage wire is better able to withstand the construction activities, such as heavy equipment and being stepped on, even though care is exercised to protect the sensors. The sensor was created by cutting the wire to the desired length, stripping away the insulation jacket at both ends (about the last couple of inches) and crimping the wires using a thermocouple pressure connector. The pressure connector improves the contact between the wires as opposed to just twisting the wires together. At the other end, the wires are stripped and connected into the channels of the datalogger.

Both of the datalogger systems were configured the same way and used the same computer program (Appendix A). Each system used a CR10X datalogger (Campbell Scientific, Inc., *www.campbellsci.com*). A multiplexer (AM 416) was connected to the datalogger to expand the number of recording channels. A Thermocouple Reference Thermistor (CR10XTCR) was used as the reference junction. Each logger was set up in a protective enclosure to shield against the weather and damage. Power was supplied by a 12V rechargeable battery seated within the enclosure and recharged via a solar panel attached to the exterior of the enclosure.

Prior to installation, the dataloggers were configured and allowed to collect readings for several hours. The readings collected during this time are shown in Figure 22 and Figure 23. The dataloggers were then moved outdoors at the start of construction to permit them to acclimate to the ambient air conditions. This is reflected by the steep drop shown in the readings.

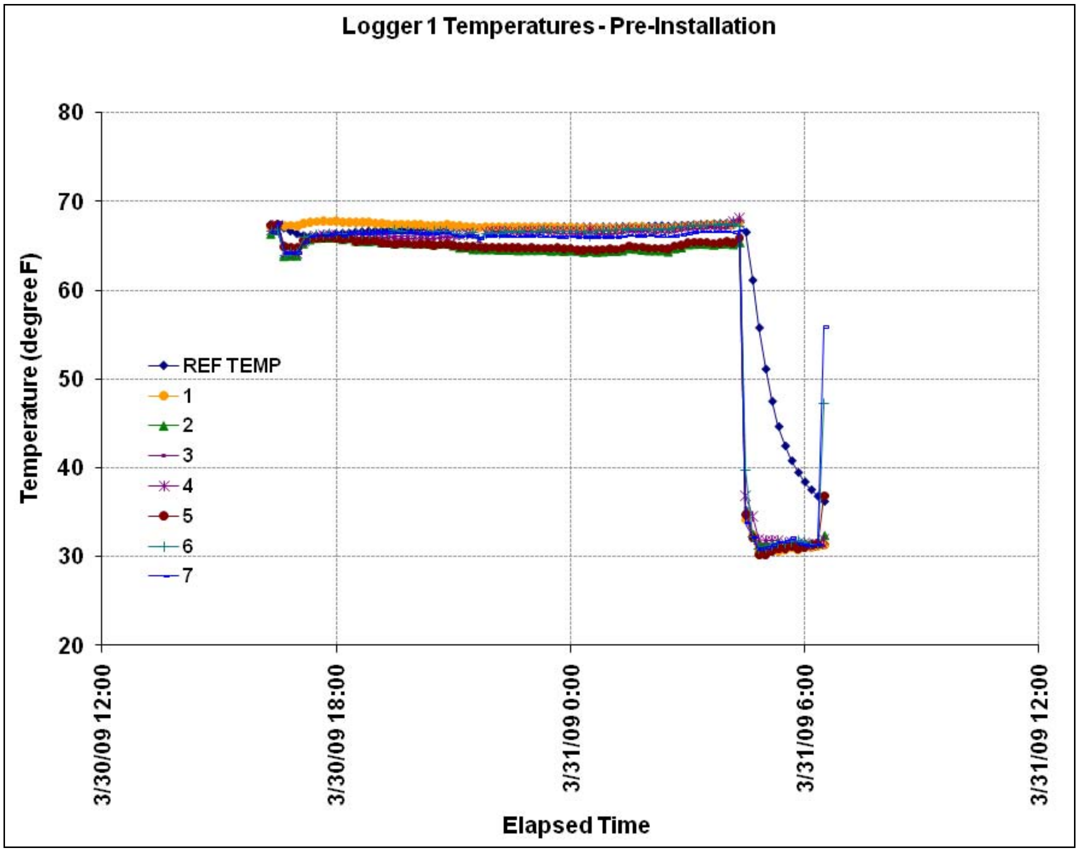


Figure A1. Temperature readings for Logger 1 prior to installation into eastern side of the hardstand.

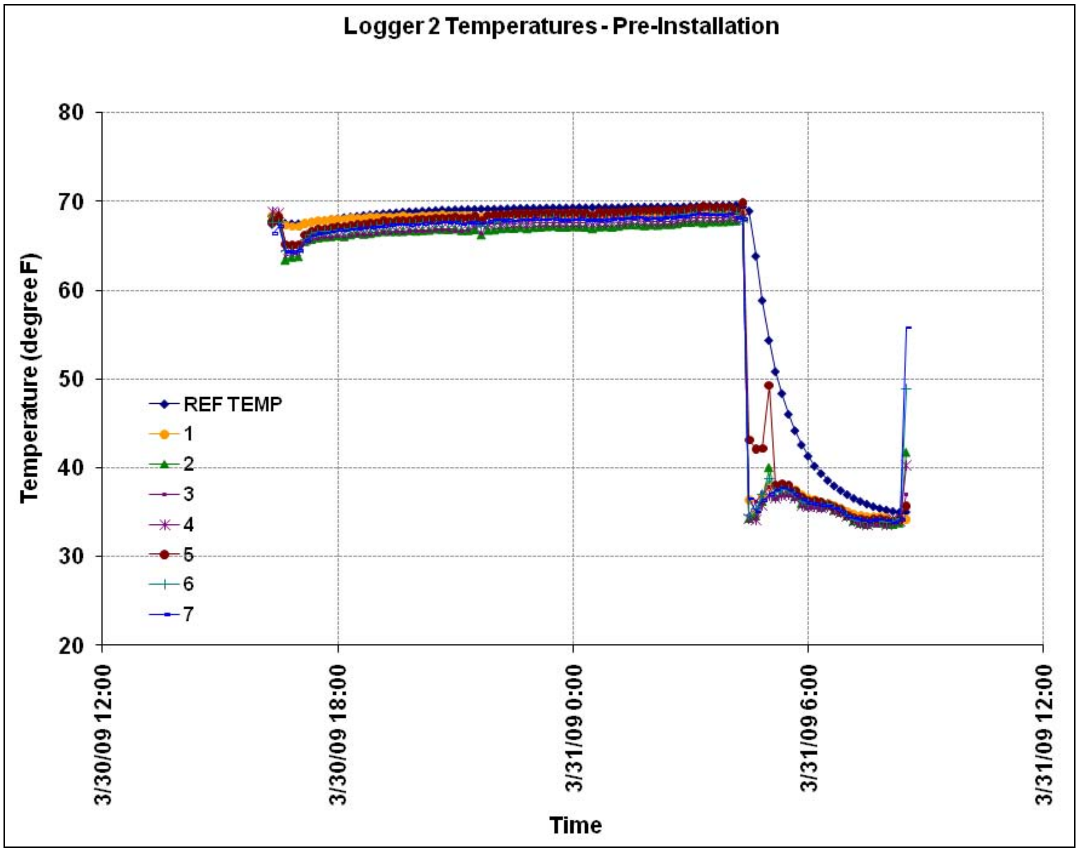


Figure A2. Temperature readings for Logger 2 prior to installation into the western end of the hardstand.

## Datalogger program

```
;{CR10X}
;
;Program - MATNWOOD.CSI
;
;PROGRAM MODIFIED 30MAR2009 BY LBA FOR ITTP FY2009 - RCC
FT DRUM
;Read 10 Channels every 10 min
;
;Program modified 18MAR2008 by LBa for ITTP - Ft. Wainwright, AK
;
;Program modified 12/12/2002 by LBa for N. Woodstock, NH
;field demo with NHDOT
;
;Program modified 5/8/2002 by L.Barna
;Modified to read 32 TCs - 16 every 30 min
;and 16 every 5 minutes
;
;Program used for freeze protection limit cylinders
;and maturity for durability II beams
;March 27, 2002
;
;Program for field lab maturity data collection of durability
;beams cured at room temperature and +5C
;Also collecting data for freeze protection limit cylinders
;PI: Chuck Korhonen
;
;Program uses 1 CR10X and 1 AM416 Mux
;Reads reference temp with 10TCRT on CR10X
;
;Read 32 channels every 10 minutes
;Output data to a 716 storage module
;
;All temperature output in degrees C
;
;Channel usage on CR10X:
;DIFF 1H Connx to COM 1H on AM416 Copper
;DIFF 1L Connx to COM 1L on AM416 Copper
;DIFF 2H Connx to COM 2H on AM416 Copper
;DIFF 2L Connx to COM 2L on AM416 Copper
;
;CS107:
;SE9 (red) CS107 (10TCRT) probe (Reference Temp)
;
;Excitation Channel
;EX3 - Reference Temp
```

```
;AG  - Grey
;
;C1 (white) Connx to RES on AM416
;C2 (green) Connx to CLK on AM416
;12V (red) Connx to 12V on AM416
;Grnd (black) Connx to GND on AM416
;
;COM1: Channel usage on AM416
;Channels 1 - 16 H Copper TCs
;Channels 1 - 16 L Constantan TCs
;
;COM2: Channel usage on AM416
;Channels 1 - 16 H Copper TCs
;Channels 1 - 16 L Constantan TCs
;
*Table 1 Program
  01: 600       Execution Interval (seconds)
;
;Read the battery voltage
;

1:  Batt Voltage (P10)
 1: 1        Loc [ BATTERY   ]
;
;Read the Reference temperature
;

2:  Temp (107) (P11)
 1: 1        Reps
 2: 9        SE Channel
 3: 3        Excite all reps w/Exchan 3
 4: 2        Loc [ REFTEMP   ]
 5: 1.0      Mult
 6: 0.0      Offset
;
;Turn on the mux
;

3:  Do (P86)
 1: 41       Set Port 1 High
;
;Loop through and read the 16 TCS on COM1
;This uses storage locations 3-18
;

4:  Beginning of Loop (P87)
 1: 0        Delay
```

```
 2: 10       Loop Count

5:  Do (P86)
 1: 72       Pulse Port 2

6:  Thermocouple Temp (DIFF) (P14)
 1: 1        Reps
 2: 22       7.5 mV 60 Hz Rejection Range
 3: 1        DIFF Channel
 4: 1        Type T (Copper-Constantan)
 5: 2        Ref Temp (Deg. C) Loc [ REFTEMP   ]
 6: 3     -- Loc [ TC_1      ]
 7: 1.0      Mult
 8: 0.0      Offset

7:  End (P95)
;
;NOT NEEDED FOR ITTP RCC PROJECT
;
;Loop through and read the 16 TCs on COM2
;Uses storage locations 19-34
;
;
;Turn Mux off
;

8:  Do (P86)
 1: 51       Set Port 1 Low
;
;Output the data
;

9:  Do (P86)
 1: 10       Set Output Flag High

10:  Real Time (P77)^30369
 1: 1220     Year,Day,Hour/Minute (midnight = 2400)

11:  Sample (P70)^447
 1: 12       Reps
 2: 1        Loc [ BATTERY   ]

12:  Serial Out (P96)
 1: 71       Storage Module

13:  Do (P86)
 1: 21       Set Flag 1 Low
```

```
*Table 2 Program
  02: 0.0000    Execution Interval (seconds)

*Table 3 Subroutines

End Program

-Input Locations-
1 BATTERY   5 1 1
2 REFTEMP   25 2 1
3 TC_1      13 1 1
4 TC_2      9 1 0
5 TC_3      9 1 0
6 TC_4      9 1 0
7 TC_5      9 1 0
8 TC_6      9 1 0
9 TC_7      9 1 0
10 TC_8      9 1 0
11 TC_9      9 1 0
12 TC_10     25 1 0
13 _________ 9 0 0
14 _________ 25 0 0
15 _________ 9 0 0
16 _________ 9 0 0
17 _________ 9 0 0
18 _________ 25 0 0
19 _________ 1 0 0
20 _________ 9 0 0
21 _________ 1 0 0
22 _________ 9 0 0
23 _________ 9 0 0
24 _________ 9 0 0
25 _________ 9 0 0
26 _________ 9 0 0
27 _________ 9 0 0
28 _________ 17 0 0
29 _________ 1 0 0
30 _________ 1 0 0
31 _________ 1 0 0
32 _________ 1 0 0
33 _________ 1 0 0
34 _________ 1 0 0
-Program Security-
0000
0000
0000
```

```
-Mode 4-
-Final Storage Area 2-
0
-CR10X ID-
0
-CR10X Power Up-
3
-CR10X Compile Setting-
3
-CR10X RS-232 Setting-
-1
-DLD File Labels-
0
-Final Storage Labels-
0,Year_RTM,30369
0,Day_RTM
0,Hour_Minute_RTM
1,BATTERY~1,447
1,REFTEMP~2
1,TC_1~3
1,TC_2~4
1,TC_3~5
1,TC_4~6
1,TC_5~7
1,TC_6~8
1,TC_7~9
1,TC_8~10
1,TC_9~11
1,TC_10~12
```

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Cold Roller-Compacted Concrete for Roads and Hardstands on Army Installations in Cold Regions

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**14. ABSTRACT**

Cold roller compacted concrete (Cold-RCC) is the result of merging the RCC paving technology with Cold Weather Admixture Systems (CWAS) technology. It extends the use of RCC paving beyond the traditional construction season. A laboratory investigation was conducted to produce a suitable Cold-RCC mixture capable of producing adequate strength at low temperature, have workability compatible with RCC pavers, and result in acceptable surface finishing. The 7-day average unconfined compressive strength of cylindrical Cold-RCC laboratory test specimens cured at a constant temperature of 23 °F was 3,600 psi. The Cold-RCC mixture was used in a full-scale field demonstration at Ft. Drum, New York, where the ambient air temperature was 31 °F at the time of placement. A 75 ft x 20 ft hardstand was constructed using the Cold-RCC mixture with standard RCC mixing and placing equipment and quality control procedures. The 7-day average unconfined compressive strength of the field mixture reached 4,400 psi when cured at 23 °F in the laboratory. The feasibility of building RCC pavements for military hardstands in cold weather was demonstrated by a full-scale pavement test section that sustained truck traffic within a few hours of placement in an environment near the freezing point of water.

**15. SUBJECT TERMS**

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Cold weather concrete
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Pavement
Roller-compacted concrete

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