TSPWG 3-250-04.05-8
25 September 2019

TRI-SERVICE PAVEMENTS WORKING GROUP (TSPWG) MANUAL

USE OF OFF-THE-SHELF CONCRETE ADMIXTURES AS COLD WEATHER ADMIXTURE SYSTEMS (CWAS)

TRI-SERVICE PAVEMENTS WORKING GROUP MANUAL (TSPWG M)

USE OF OFF-THE-SHELF CONCRETE ADMIXTURES AS COLD WEATHER ADMIXTURE SYSTEMS (CWAS)

U.S. ARMY CORPS OF ENGINEERS
NAVAL FACILITIES ENGINEERING COMMAND
AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**

This TSPWG manual supersedes Air Force Engineering Technical Letter (ETL) 05-8, dated 4 November 2005.

FOREWORD

This Tri-Service Pavements Working Group (TSPWG) manual supplements guidance found in other Unified Facilities Criteria, Unified Facilities Guide Specifications, Defense Logistics Agency specifications, and service-specific publications. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and, in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the most stringent of the TSPWG Manual, the SOFA, the HNFA, and the BIA, as applicable. This TSPWG manual provides guidance on the use of commercial off-the-shelf concrete admixtures as a part of Cold Weather Admixture Systems (CWAS) for placing concrete in below-freezing weather. The information in this TSPWG manual is referenced in technical publications found on the Whole Building Design Guide. It is not intended to take the place of service-specific doctrine, technical orders (TOs), field manuals, technical manuals, handbooks, Tactics, Techniques, and Procedures (TTPs), or contract specifications, but should be used together with these documents to help ensure pavements satisfy mission requirements.
TSPWG Manuals are living documents and will be periodically reviewed, updated, and made available to users as part of the services' responsibility for providing technical criteria for military construction, maintenance, repair, or operations. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and the Air Force Civil Engineer Center (AFCEC) are responsible for administration of this manual. Technical content of this TSPWG manual is the responsibility of the Tri-Service Pavements Working Group (TSPWG). Defense agencies should contact the preparing activity for document interpretation. Send recommended changes with supporting rationale to the respective service TSPWG member.

TSPWG Manuals are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website: http://dod.wbdg.org/

Check hard copies of TSPWG Manuals printed from electronic media against the current electronic version prior to use, to ensure they are current.

TRI-SERVICE PAVEMENTS WORKING GROUP MANUAL (TSPWG M)

NEW SUMMARY SHEET

Document: TSPWG Manual 3-250-04.05-8, *Use of Off-the-Shelf Concrete Admixtures as Cold Weather Admixture Systems (CWAS).*

Superseding: ETL 05-8, *Use of Off-the-Shelf Concrete Admixtures as Cold Weather Admixture Systems (CWAS)*, 4 November 2005.

Description: This TSPWG manual provides guidance on the design, mixing, placement, and curing of concrete in below-freezing weather. It applies to all service organizations with concrete construction, maintenance, and repair responsibility.

Reasons for Document: This Tri-Service Pavements Working Group (TSPWG) manual provides information for combining ordinary concrete admixtures into cold weather admixture systems (CWAS) that depress the freezing point of water to at least 23 °F (–5 °C) and accelerate the hydration rate of portland cement while at that lo temperature.

Impact: There is no cost impact. The following benefits should be realized:

- It allows for placement of concrete in below-freezing weather by use of commercially available, off-the-shelf concrete admixtures.
- Supplemental information on operation, construction, maintenance and repair of concrete in below-freezing weather will be available to all services.
- Maintenance and/or upgrading of this supplemental information will include inputs from all services.

Unification Issues: None.

Note: Use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this TSPWG M does not imply endorsement by the Department of Defense (DoD).

TABLE OF CONTENTS

FIGURES

TABLES

This Page Intentionally Left Blank

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

Currently, there are no commercially available admixtures that, when used alone, will prevent fresh concrete from freezing at an internal temperature of 23 °F (–5 °C). Admixtures are available that allow concrete to gain strength at air temperatures below 32 °F (0 °C), but these admixtures, when used at their recommended dosages, do not prevent freezing. They promote strength gain by accelerating cement hydration, which increases the rate of internally generated heat to help maintain concrete temperatures above freezing until enough strength is developed to resist damage from freezing.

This Tri-Service Pavements Working Group (TSPWG) manual presents the tools to design, mix, place, and cure concrete made with combinations of commercial off-the-shelf admixtures in below-freezing weather. Because standard practice places no limitations on the number of admixtures used in concrete -- just on individual dosages -- several admixtures were combined to produce the desired low-temperature effect. This TSPWG manual is based on the results of laboratory tests and field studies obtained between 1 October 2000 and 1 October 2003 under the Federal Highway Administration (FHWA) State Planning and Research Pooled Fund Study TPF-5(003), *Extending the Season for Concrete Construction and Repair: Phase I—Establishing the Technology* (Engineer Research and Development Center/Cold Regions Research and Engineering Laboratory (ERDC/CRREL) TR-04-2), and on a demonstration of the resulting technology at Grand Forks Air Force Base, North Dakota (ERDC/CRREL TR-05-9, *Placing Antifreeze Concrete at Grand Forks Air Force Base*).

1-2 PURPOSE AND SCOPE.

This TSPWG manual provides guidance for combining ordinary concrete admixtures into cold weather admixture systems (CWAS) that depress the freezing point of water to at least 23 °F (–5 °C) and accelerate the hydration rate of portland cement while at that low temperature.

1-3 APPLICABILITY.

- DoD pavement engineers.
- Air Force Base Civil Engineers (BCE), Rapid Engineers Deployable - Heavy Operations Repair Squadron Engineers (RED HORSE) squadrons, Prime BEEF (Primary Base Engineer Emergency Force), and other units responsible for design, construction, maintenance, and repair of airfield pavements.
- U.S. Army Corps of Engineers (USACE) and Navy offices responsible for Air Force design and construction.
- Designers and construction contractors building DoD airfield pavements.

1-4 BEST PRACTICES.

The best practices in Appendix A are considered to be guidance and not requirements. Best practices offer proven facility solutions, systems, and lessons learned, but may not be the only solutions to satisfy requirements.

1-5 GLOSSARY.

Appendix B contains acronyms, abbreviations, and terms.

1-6 REFERENCES.

Appendix C contains a list of references used in this manual. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 COLD WEATHER ADMIXTURE SYSTEMS (CWAS)

2-1 DEFINITION.

CWAS is defined as any commercial chemical admixture or combination of commercial chemical admixtures that depresses the freezing point of mixing water and accelerates the hydration rate of portland cement in concrete. The term *antifreeze admixture* is used interchangeably with the term *CWAS*. Concrete containing a CWAS is also referred to as *antifreeze concrete*.

2-2 FUNCTION.

The primary functions of a CWAS are to prevent fresh concrete from freezing at an internal temperature as low as 23 °F (–5.0 °C) and to promote strength gain at that temperature at least as fast as normal concrete cured at 41 °F (5.0 °C). The secondary function is to create an antifreeze concrete mixture that behaves like conventional concrete at time of placement.

This Page Intentionally Left Blank

CHAPTER 3 MATERIALS

3-1 AGGREGATE.

Aggregates, both fine and coarse, that are approved for normal concreting practice are acceptable for antifreeze concrete. The aggregates used to develop this manual were locally available, clean, and well-graded to produce workable concrete mixtures, and were known to be durable. There are no size restrictions, but the nominal maximum size coarse aggregate (NMSA) used to develop this manual was 0.75 inch [in] (19.1 millimeters [mm]) for all tests except the Rhinelander, Wisconsin, field trial (ERDC/CRREL TR-04-2), which used a 1.5 in (38.1 mm) NMSA coarse aggregate. Typically, coarse aggregates used in pavements are larger than those used in other concrete structures; the Rhinelander job was a pavement, while the other jobs were not. The fine aggregates in all cases were natural sands meeting the specifications of ASTM C33, *Standard Specification for Concrete Aggregates*.

3-2 CEMENT.

3-2.1 Portland Cement Testing.

The testing for this manual was limited to portland cement. Though blended cements such as fly ash, blast furnace slag, or silica fume combined with portland cement are common in general construction, they were not included because it was decided that the antifreeze technology should be proven on portland cement first. Now that the antifreeze properties of admixtures for winter concrete construction are proven, this technology should be expanded to include other cements.

3-2.2 Types of Cement.

Portland cements that are specified for cold weather concreting are acceptable for antifreeze concrete. Cements that conform to ASTM C150, *Standard Specification for Portland Cement*, Type I and Type III, are usually specified for winter concreting. This manual allows Type I and Type II cements, plus a combination Type I/II cement. Type III, high early strength cement, was not studied because it is not widely available. The Type II cement, though it generates less heat and at a slower rate than Type I, is permissible because the high doses of accelerating admixtures used to formulate the CWAS overcome most tendencies for slow strength development. The Type II cement has performed quite well in past studies and is recommended for use with the admixtures approved in this manual.

3-2.3 Today's Practice.

Obtaining high early age strength is advantageous in cold weather to decrease the length of time that thermal protection is necessary. This manual focuses on that concept. The usual methods of achieving high early strength are to use all Type III cement, use additional Type I cement, or use chemical accelerators. One admixture formulation, W.R. Grace & Co. (WRG) IV in the FHWA project report (ERDC/CRREL TR-04-2), used a retarding admixture expressly to slow down the slump loss characteristic of concretes made with high doses of accelerating admixtures. Unfortunately, the retarder did little to solve the early stiffening problem, but it delayed strength gain, which was viewed as a negative consequence. However, for bridge deck applications, where delayed strength gain may be desirable, a retarded mix such as WRG IV might prove useful. But, because the focus of the studies leading up to this manual was on rapid strength gain, the WRG IV formulation was not included.

3-2.4 Creating Antifreeze Concrete.

To create antifreeze concrete with high early age strength, it is recommended to use at least 612 pounds per cubic yard [lb/yd^3] (363.1 kilograms per cubic meter [kg/m^3]) of Type I, Type II, or Type I/II cement. The lowest cement factor used in this manual is 612 lb/yd^3 (363.1 kg/m^3), while the highest is 802 lb/yd^3 (475.8 kg/m^3). Also, the water/cement (w/c) ratio should be kept at or below 0.45, in accordance with current guidance for durable concrete. Lower water-to-cement (w/c) ratios, besides further increasing durability and enhancing strength gain, also lessen the amount of admixture needed for freezing point depression.

3-3 WATER.

Water approved for making normal concrete can be used as mixing water for making antifreeze concrete. Cold water, as explained later, is used to batch all antifreeze concrete mixtures to slow down slump loss. The recommended initial temperature of the concrete is 50 °F ± 9 °F (10.0 °C ± 5.0 °C).

3-4 CHEMICAL ADMIXTURES.

To avoid compatibility problems among admixtures and limit the possible combinations of admixtures to investigate, this manual concentrates on the product lines of WRG and Master Builders, Inc. (MB). (Admixtures from other sources could similarly be used, but they should be tested in laboratory and field trials to be sure they produce the desired results.) Table 3-1 shows six admixture combinations that were found to be useful for antifreeze concrete. (The FHWA project report [ERDC/CRREL TR-04-2] lists eight admixture combinations that provided antifreeze protection; however, the WRG IV and MB III combinations were not included in this manual because the former mix caused concrete to gain strength too slowly and the latter tended to disentrain air from the concrete.) The six admixture combinations were developed after numerous trials to yield concrete with the desired 23 °F (–5.0 °C) freezing point, reasonable transit life, and good job site workability. Of all the commercial admixtures marketed today, these six combinations are not the only possible antifreeze combinations, but they were chosen because they performed well. They are not even the only possibilities when using the products from the two companies chosen for this study. However, Table 3-1 serves as the basis for proportioning antifreeze concrete mixtures until more information becomes available. The admixtures in Table 3-1 were tested in laboratory concretes containing 661 lb/yd^3 (392.2 kg/m^3) cement and the w/c ratios shown.

Table 3-1 Recommended Dosages of Six Combinations of Commercial Admixtures to Protect Fresh Concrete Against Freezing

Product Name		Admixture Dosage		
		W.R. Grace & Co.		
		I†	II	III
Mira® 70	(oz/100 lb cement)	12	9	6
	(mL/100 kg cement)	780	585	390
ADVA® Flow	(oz/100 lb)	3	1.5	1
	(mL/100 kg)	195	98	65
DCI®	(gal/yd^3 concrete)	6.06	-	6.06
	(L/m^3 concrete)	30	-	30
DCI® S	(gal/yd^3)	-	6	-
	(L/m^3)	-	30	-
PolarSet®	(gal/100 lb)	0.78	0.78	0.78
	(L/100 kg)	6.52	6.52	6.52
Eclipse® Plus (percent of cement weight)		-	-	1
Darex® II AEA	(oz/100 lb)	0.9‡	0.5‡	0.3
	(mL/100 kg)	60‡	30‡	20
		Master Builders, Inc.		
		I	II	IV
Polyheed® 997	(oz/100 lb)	11.96	11.96	11.96
	(mL/100 kg)	780	780	780
Glenium 3000 NS	(oz/100 lb)	2.99	2.99	-
	(mL/100 kg)	195	195	-
Rheocrete® CNI	(gal/yd^3)	6.06	6.06	6.06
	(L/m^3)	30	30	30
Pozzutec®20	(oz/100 lb)	9.4	9.4	-
	(mL/100 kg)	5.87	5.87	-
Pozzutec® 20+	(gal/100 lb)	-	-	0.7
	(L/100 kg)	-	-	5.87
Pozzolith® 100-XR	(oz/100 lb)	-	1.0	-
	(mL/100 kg)	-	65	-
MB-VR Standard	(oz/100 lb)	0.6‡	0.3‡	0.3
	(mL/100 kg)	40‡	20‡	20
w/c ratio		0.43	0.431	0.39

*Performances received with these admixture dosages may vary from cement to cement.
†Roman numerals correspond to six admixture combinations developed for this TSPWG manual.
‡It may be necessary to redose with an air-entraining admixture (AEA) at the jobsite.

This Page Intentionally Left Blank

CHAPTER 4 PROPORTIONING ANTIFREEZE CONCRETE

4-1 RECOMMENDED APPROACH.

Until the process for formulating CWAS becomes familiar, the recommended approach to proportioning antifreeze concrete mixtures is to begin with a standard concrete used in warm-weather construction that is workable, durable, and strong. The procedure to convert a standard concrete into antifreeze concrete is to choose one of the admixture combinations from Table 3-1, verify that it can produce a 23 °F (–5.0 °C) freezing point, and conduct field trials to determine the optimum admixture dosing sequence to achieve target slump, air content, and working time.

4-2 STEP 1: SELECT STANDARD CONCRETE.

As described in paragraph 3.2.4, select a concrete mixture that contains at least 612 lb/yd^3 (363.1 kg/m^3) of cement, has a 0.45 or lower w/c ratio, and is workable. Five standard concretes were selected for field demonstration in the FHWA project (ERDC/CRREL TR-04-2) as shown in Table 4-1. Each concrete in Table 4-1 typically had a 4 in (101.6 mm) slump immediately after mixing. This manual will follow the conversion and subsequent demonstration of the Littleton, New Hampshire mix.

Table 4-1 Mixture Proportions of Five Warm-Weather Concretes Selected for Conversion to Antifreeze Concretes, and Subsequent Field Evaluation

Ingredient	Littleton, NH	Rhinelander, WI	North Woodstock, NH	West Lebanon, NH	Concord, NH
Cement lb/yd³ (kg/m³)					
Type I	–	802 (476)	–	–	–
Type I/II	–	–	–	660 (392)	–
Type II	660 (392)	–	660 (392)	–	660 (392)
Aggregate lb/yd³ (kg/m³)					
Coarse—19 mm	1756 (1042)	1601 (950)	1770 (1050)	1825 (1083)	1770 (1050)
Coarse—38 mm	–	302 (179)	–	–	–
Fine—sand	1146 (680)	1315 (780)	1178 (699)	1355 (804)	1178 (699)
AEA* oz/yd³ (mL/m³)					
DAREX® II	2.01 (78)	–	6.02 (233)	2.51 (97)	6.02 (233)
CATEXOL™ AE260	–	6.51 (252)	–	–	–
Water-reducing admixture oz/yd³ (mL/m³)					
MIRA® 70	0.013 (0.514)	–	–	0.013 (0.512)	–
CATEXOL™ 2000N	–	0.048 (1.868)	–	–	–
WRDA®-HYCOL™	–	–	0.0198 (0.766)	–	0.0198 (0.766)
w/c	0.436	0.413	0.444	0.436	0.444

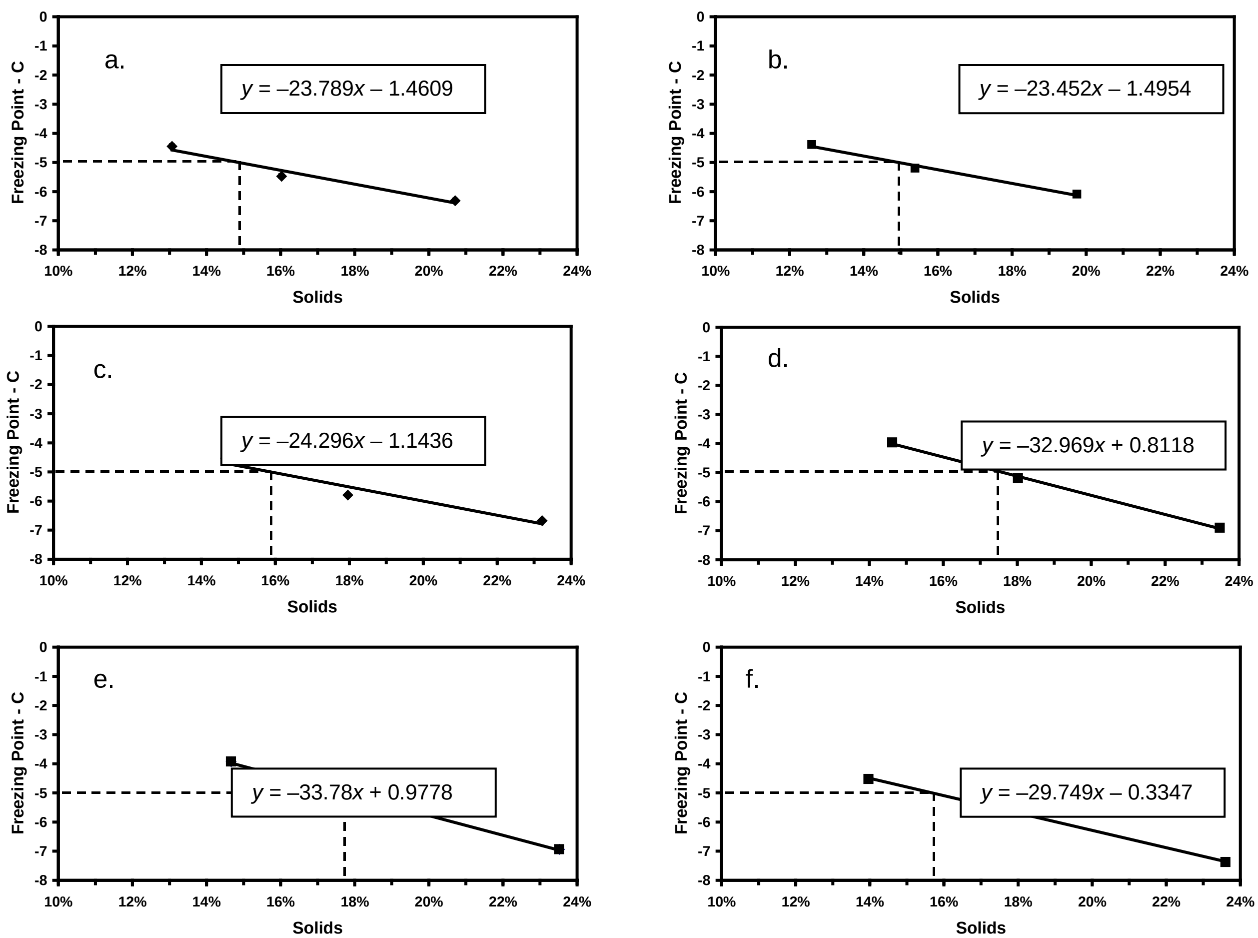
* Air-entraining admixture

4-3 STEP 2: VERIFY FREEZING POINT.

4-3.1 Establish Freezing Point.

To verify that a 23 °F (–5.0 °C) freezing point is achievable, it is necessary to calculate the percent solids from the admixtures by weight of free water in the concrete. The freezing point can then be determined from Figure 4-2, which shows the relationship between solids content and initial freezing point. These data are used to predict freezing points for antifreeze concretes made with the admixture combinations in Table 4-2. Similar curves must be developed for other admixture combinations. Each graph represents one admixture combination from Table 1: a—WRG I; b—WRG II; c—WRG III; d—MB I; e—MB II; f—MB IV.

Figure 4-1 Relationship Between Weight of Solids Contributed by Admixtures in Percent by Weight of Free Water and Initial Freezing Point of Freshly Mixed Concrete



y = freezing point
x = solids content, decimal form

4-3.2 Calculate Weight of Solids.

Equation 4-1 calculates the weight of solids contributed to the concrete when the addition rate of admixtures is based on cement content. Table 4-2 provides needed information about each admixture.

Note: The weight of water contributed by each admixture can be calculated by simply substituting [1-solids content] for the solids content.

Equation 4-1. Weight of Solids Based on Cement Content

$$Weight\,of\;solids = Dosage \times Cement\,Factor \times Sp.gr. \times Solids\,Content$$

Table 4-2 Physical Values of Individual Admixtures

Admixture	Solids Content (%)	Specific Gravity
MIRA® 70	23.5	1.1
ADVA® Flow	31.2	1.057
DCI®	33	1.273
DCI® S	32.5	1.275
PolarSet®	41.1	1.35
ECLIPSE® Plus	100	0.945
DAREX® II	12	1.005
Polyheed® 997	47.5	1.270
Glenium 3000 NS	30	1.08
Rheocrete® CNI	32.5	1.295
Pozzutec® 20	49.5	1.38
Pozzutec® 20+	40	1.35
Pozzolith® 100-XR	47	1.22
MB-VR	13	1.038

The Littleton, concrete used the WRG II admixture combination. MIRA® 70 was dosed at 8.97 ounce per 100 pounds [oz/100 lb] (586.8 milliliters per 100 kilograms [mL/100kg]) of cement (Table 3-1). Substituting this value, a specific gravity of 1.1, a solids content of 23.5% (Table 4-2), and a 660.8 lb/yd^3 (392.0 kg/m^3) cement factor (Table 4-1) into Equation 4-1 yields 1.31 pounds [lb] (0.593 kilograms [kg]) solids, 4.25 lb (1.93 kg) water, as shown below. This is the weight of solids that MIRA® 70 contributes to a cubic meter of concrete. In like manner, ADVA® Flow, PolarSet®, and DAREX® II contribute 0.28 lb (0.127 kg), 31.26 lb (14.181 kg), and 0.077 lb (0.035 kg) solids, respectively, and 0.617 lb (0.280 kg), 44.78 lb (20.321 kg), and 0.567 lb (0.257 kg) water, respectively.

Note: An extra 44 mL/100 kg of DAREX® II was added at the job site.

$$\frac{8.97\,\text{oz}}{100\text{ lb cement}} \times 866\text{ lb cement} \times 1.1 \times 0.235 = 0.999\text{ lb/yd}^3$$

$$\frac{585\,\text{mL}}{100\,\text{kg cement}} \times 392\,\text{kg cement} \times 1.1 \times 0.235 = 0.593\,\text{kg/m}^3$$

4-3.3 Calculate Admixtures.

For admixtures whose addition rates are based on concrete volume, the weight of solids is calculated by Equation 4-2. According to Table 3-1, DCI® S was dosed at a rate of 6.06 gallons per cubic yard [gal/yd^3] (30 liters per cubic meters [L/m^3]). Substituting this value, using a specific gravity of 1.275 with a solid content of 32.5% (from Table 4-2) into Equation 4-2 yields 20.95 lb/yd^3) (12.43 kg/m^3).

Equation 4-2. Weight of Solids Based on Concrete Volume

Dosage x Specific Gravity x Solids Content = Weight of Solids

$$\frac{6.06\ gal}{yd3}\ x\ 1.275\ x\ 8.344 = \frac{20.95\ lb}{yd3}$$
$$\frac{30\ L}{m^3}\ x\ 1.275\ x\ 0.325 = \frac{12.43\ kg}{m^3}$$

4-3.4 Percent Solids.

The percent solids contributed by WRG II to the Littleton concrete is equal to the weight of solids contributed by all the admixtures divided by the theoretical free water content[a] of the concrete 376.8 pounds (lb) (170.9 kilograms (kg)) = w/c ratio × cement factor [Table 4-1]. In this case, the WRG II combination was designed to contribute 16 percent solids by weight of water 60.33 lb solids/376.8 lb water (27.367 kg solids/170.9 kg water). (The amount of water the ready-mix plant would add into the mixture would be 269.6 lb [376.7 lb – 107.1 lb] (122.3 kg [170.9 kg – 48.6 kg]).

4-3.5 Freezing Point of Mixture.

Finally, the freezing point of this concrete is found to be 20.6 °F (–6.3 °C) (Figure 4-1b). In a perfect world, each admixture could be reduced to raise the freezing point to 23 °F (–5.0 °C). However, because it is difficult to accurately control moisture when batching ready-mix concrete, it is best to slightly overshoot the target freezing point.

4-4 STEP 3: TRIAL BATCHES.

4-4.1 Dosing of Admixtures.

Three approaches for dosing the admixtures into the concrete were devised to ensure an acceptable concrete could be produced. Because variations in job site conditions and concrete-making materials affect concrete performance, it is strongly recommended that trial tests be done to determine which approach works best before placing concrete on a job. Each approach is detailed in Appendix A and briefly described below. Control of workability and air content are concerns. As discussed in paragraph 7.2, the ability to measure the freezing point of the concrete needs to be refined.

4-4.1.1 First Approach.

The first approach mixes all ingredients at the ready-mix plant. The advantage of this approach is that once the truck leaves the plant, no further effort is needed to prepare the concrete. However, because the tested antifreeze concretes tended to lose slump rapidly, future antifreeze concretes should have a high initial slump to accommodate any loss during transit and still be workable during placement. In this manual, initial slump values of 5.91 to 8.86 in (150 to 225 mm) yielded acceptable results during placement. Slowly agitating the concrete while in transit was helpful for maintaining slump. Ensure the initial air content is also high to account for air lost during transit, as some admixtures tend to be harsh on entrained air. It was found that initial air contents between 8 and 10 percent produced target value air contents during placement. Re-dosing the mix at the job site with plasticizer or air-entraining admixture or both may be necessary with some mixes. This first approach is best when the haul time is no more than 45 minutes and the concrete is immediately dispensed within 20 minutes.

4-4.1.2 Second Approach.

The second approach adds half of the admixtures into the concrete at the ready-mix plant and the rest at the job site. The non-accelerating admixtures, if any, are added first. This approach requires that admixtures be transported to the job site and pumped into the truck. Though requiring extra effort, it provides more assurance that the concrete is workable, as slump loss is less of a factor until the final admixture is added into the concrete. Re-dosing the mix at the job site with an air-entraining agent may not be necessary with this approach. However, working time tends to decrease very rapidly once the last admixture is added, so dispense the concrete quickly — usually within 30 minutes. This approach allows haul times of as long as one hour.

4-4.1.3 Third Approach.

The third approach mixes all of the admixtures into the concrete at the job site. This approach requires the most effort, but the admixtures do not have to be dosed until the construction crew is ready for the concrete, and it allows 45 minutes or longer for working time. Because the concrete must leave the ready-mix plant with a very low w/c ratio to account for the water in the admixtures, the air-entraining admixture (AEA) is best added into the mix at the job site.

CHAPTER 5 FIELD DEMONSTRATIONS

5-1 INTRODUCTION.

Once trial batches prove that an acceptable antifreeze concrete can be produced, it is ready for full-scale use. The Littleton demonstration project (ERDC/CRREL TR-04-2) is used as an example.

5-2 LITTLETON EXAMPLE.

Because the estimated haul time to the Littleton project was 30 minutes, it was felt that the second approach -- adding half of the admixtures into the concrete at the ready-mix plant and the rest at the job site (paragraph 4.4.1.2) -- should be followed. Consequently, all but the PolarSet® and some of the AEA were withheld from the batch until the truck arrived at the job site (Table 5-1). Once there, a quick visual check revealed that the concrete had a slump of about 3.94 in (100.0 mm), which was higher than the expected 2.76 in (70.0 mm) determined by the trial tests. This immediately suggested that the water content of the mixture was high. However, because the solids content was designed to be higher than necessary, no adjustments were made and the PolarSet® and AEA were added into the truck. The resulting slump, measured with a slump cone, was 7.99 in (203.0 mm). Because the mix was cohesive, the concrete could have been immediately placed into its forms, but it was elected to slowly agitate it for 20 minutes at 2 to 4 revolutions per minute (rpm) until it began to lose slump. Once that happened, the concrete was placed during the next 40 minutes, dropping to the target slump of 3.94 in (100.0 mm). The freezing point of the concrete was unknown at this point.

Note: This pooled-fund project did not include as one of its goals the measurement of freezing point. However, there is no way to know that the concrete fully met expectations unless such a measurement is made. An expedient measurement method is described in paragraph 7.2 and in more detail in ERDC/CRREL TR-04-2. Our field measurements showed that the Littleton concrete's freezing point was 22.64 °F (-5.2 °C). It was fully acceptable. Appendix A shows that freezing point measurements can used to back calculate actual w/c ratios.

Table 5-1 Dosing Schemes Used in the Five Field Studies

Ingredient	Littleton, NH	Rhinelander, WI	North Woodstock, NH	West Lebanon, NH	Concord, NH
Freezing Point and Accelerating Admixture gal/yd^3 (L/m^3)					
DCI® S	6.03 (29.84)	*3.74 (18.5)*	–	–	–
DCI®	–	*2.28 (11.3)*	–	–	–
PolarSet®	*5.16 (25.56)**	*6.24 (30.9)*	–	–	–
Rheocrete® CNI	–	–	*6.02 (29.8)*	6.02 (29.8)	*6.02 (29.8)*
Pozzutec® 20+	–	–	*4.65 (23.0)*	4.65 (23.0)†	*4.65 (23.0)*
AEA‡ (mL/m^3)					
DAREX® II	23.4 *34.3* (116) *(170)*	–	–	–	–
CATEXOL™ AE260	–	94.9 *31.5* (470) *(156)*	–	–	–
MB-VR	–	–	*7.86 (38.9)*	15.75 78	*7.86 (38.9)*
Water-reducing admixture gal/yd^3 (L/m^3)					
MIRA® 70	0.463 (2.293)	*0.755 (3.74)*	–	–	–
ADVA® Flow	0.079 (0.389)	*0.189 [0.934]*	–	–	–
Polyheed® 997	–	–	*0.462 (2.289)*	0.462 2.289	*0.465 (2.304)*

* Italics denote jobsite additions; all other numbers indicate ingredients added into the concrete at the ready-mix plant.
† This admixture was pumped into the truck but not mixed into the concrete until the truck reached the job site.
‡ Air-entraining admixture.

5-3 OTHER FIELD TEST EXAMPLE.

The other field tests, except for the West Lebanon test (ERDC/CRREL TR-04-2), dosed most admixtures into the concrete at the job site. With today's admixture pumps, this was not viewed as a difficult task. This scheme provided full assurance that the load would not stiffen during transit and that the concrete could be easily adjusted on site to give the desired workability. The West Lebanon test tried an interesting variation: all admixtures were dosed at the ready-mix plant, except that one admixture was not mixed into the concrete — it was merely pumped into the truck and then mixed once the truck arrived at the job site. This scheme avoided the need for admixture pumps at the job site altogether and provided highly workable concrete.

This Page Intentionally Left Blank

CHAPTER 6 PRODUCTION AND PLACEMENT

6-1 INTRODUCTION.

Antifreeze concrete mixtures are sensitive to water content when it comes to freeze protection. They tend to lose slump very rapidly, are sticky to finish, and require close control of when admixtures are added into the mixing process. However, they show no tendency to bleed when properly batched, so the finishing operation can be started almost immediately after the concrete is consolidated and leveled. Even at very low slumps, the concretes have responded well to vibration.

6-2 READY-MIX PLANT.

6-2.1 Moisture Control.

The ready-mix plant should be within a 30-minute drive of the job site to allow time for positioning the truck and making any final adjustments to the concrete (longer drives are permissible if all admixtures are dispensed at the job site). Because of the need to create a concrete of a certain freezing point, accurate moisture control is critical. Ensure ready-mix plants have moisture meters to continuously monitor changes in the sand as it is batched. Measure the moisture content of the coarse aggregate at the start of each day and whenever the slumps start to deviate. For example, in the FHWA study (ERDC/CRREL TR-04-2), moisture contents were obtained from grab samples taken from the sand and coarse aggregate piles a few hours before batching. However, it was found that accurately measuring aggregate moisture proved difficult. In the first three field trials, the actual water content of the concretes was higher than designed. Snow in the aggregate piles was considered responsible for errors in measurement.

6-2.2 Aggregate Moisture.

In response to these difficulties, the aggregate moisture contents in the final two field trials were assumed to be somewhat greater than the grab sample measurements indicated. This led to both concretes containing lower w/c. In these instances, extra water could have been added into the mix.

6-2.3 Batch Water.

Unless better moisture control is possible, it is recommended that the ready-mix plant withhold up to 6.6 gallons [gal] (25 liters [L]) of batch water from every 1.3 cubic yards (yd^3) [1 cubic meter (m^3)] of concrete. Once all admixtures are mixed into the concrete, then the withheld water is carefully mixed into the concrete until it attains the desired slump as developed in the trial batches.

6-3 TRUCK DRIVER.

6-3.1 Wash Water.

Before batching, reverse truck drums for numerous rotations to ensure no wash water is in them. It is also recommended not to wash down the fins after loading to avoid getting extra water into the drum. If this is not possible, then withhold extra water at the ready-mix plant to account for the wash water. Demonstrate the truck driver's washing technique in several trials so the amount of wash water can be reasonably estimated. Until better data becomes available, estimate that 2.64 to 3.96 gal (10.0 to 15.0 L) of water are used to wash down fins.

6-3.2 Drivers.

Use the same driver during both the trial batches and the actual job site placement. If the truck has a resistance meter, observe its readings during several parts of the trials to know when the concrete has good slump and, more importantly, when it has begun to stiffen. Adding water at this point will loosen the mixture, but waiting too long may create problems.

6-3.3 Field Placement.

Though not experienced in the FHWA study (ERDC/CRREL TR-04-2), during field placements the last part of the load may become difficult to discharge. If this happens, reduce the batch size. Typically, it is recommended that the maximum batch size be limited to half — but no more than two-thirds — of the mixing capacity of the truck. Half-capacity is recommended for the first few loads until experience is gained with the particular concrete being used. Batch size may be increased if conditions warrant.

6-3.4 Truck Water Tank.

The concrete is made with cold water, but it is important to have hot water in the truck's water tank. The hot water will prevent the truck's hoses and nozzles from freezing up during cleanup operations.

6-4 JOB SUPERVISOR.

6-4.1 Coordination.

Successful use of antifreeze concrete requires close coordination between the ready-mix plant, the concrete truck driver, and the concrete construction crew. Hold a pre-construction meeting with these key individuals to inform them how the concrete should behave during batching, transport, and placement, particularly how quickly the concrete can stiffen.

6-4.2 Concrete not Used.

Because antifreeze concrete stiffens very rapidly, temporarily dispose of concrete that is not used at a predetermined job site location. If this is not possible, instruct the truck driver to water down the waste concrete until it has a soupy consistency; otherwise the paste may harden onto the truck's fins, requiring extra effort to clean out the drum. Alternatively, a hydration-controlling admixture could be used to prevent the concrete from hardening on the trip back to the ready-mix plant.

6-4.3 Trial Mixtures.

Trial mixing is recommended because conditions and materials vary with location. Make several 2.61 to 5.23 cubic yard [yd^3] (2 to 4 cubic meter [m^3]) trial batches to confirm mixture proportions and to give participants a feel for how the concrete will behave during each stage of the process. Use the trial batches to define the proper amounts, sequencing, and timing of the admixtures based on their response to the particular cement being used. Obtain periodic slump measurements, air content, and concrete temperature readings to verify that the concrete mixture will behave as desired throughout the time of placement. The trial batches provide the opportunity to experiment with different admixture dosing schemes for training the batch plant, truck driver, and job supervisor in working with antifreeze concrete. As with all new construction methods, there will be a learning curve.

6-4.4 Hydration Process.

Though the antifreeze concrete produced as recommended in this manual is capable of resisting freezing to 23 °F (–5.0 °C), it is not possible at this point to forecast to what outdoor temperature this translates. The thermal profile of curing concrete is a function of the mixture proportions, its geometry, the amount of wind and solar radiation, and the type of formwork. Until the hydration process is better characterized for low-temperature application, the best guidance that can be provided is that antifreeze concrete can be placed when the air temperature is at least -4 °F (–20.0 °C) and rising. The concrete was placed in sections as thin as 5.51 in (140.0 mm) on gravel when the air temperature started out at approximately –4 °F (–20.0 °C), rose to about 14 °F (–10.0 °C) over the next six hours, and then dropped to below -4 °F (–20.0 °C) that night. The concrete section was covered with a 0.98 in (25 mm)-thick insulation blanket.

6-4.5 Removing Formwork.

When removing formwork, ensure that the concrete is not exposed to a large thermal gradient. Follow guidance provided in ACI 306-R88, *Cold Weather Concreting*.

6-5 PLACING AND FINISHING.

6-5.1 Substrate.

Ensure the substrate against which fresh concrete is to be placed is free of ice and snow. It is permissible for its temperature to be below freezing, but remove all sources of excess water.

6-5.2 Finishing Concrete.

The behavior of antifreeze concrete in its plastic state is very similar to that of high-cement-content, low-w/c-ratio concrete. Like conventional concrete, it is sticky to finish but tends to lose its stickiness as slump decreases. The objective is to produce a uniformly dense cross-section that will be suitable for the service conditions. The serviceability of a concrete surface is often affected by the finishing procedures. It is important for durability and wear resistance not to overwork the surface.

6-5.3 Placing Concrete.

Continuously place the concrete within 20 to 30 minutes, or according to the working time determined during the trial batching tests. As the concrete is placed, immediately strike off excess concrete to bring the surface to proper elevation. This is done either mechanically or by hand with a straight edge. Following screeding, bull float the surface to embed aggregate and smooth the surface. Be careful not to seal the surface. Some tearing when using a magnesium float is not undesirable. Wait until the concrete can be walked upon without leaving footprints more than 0.25 in (6.35 mm) deep before floating. Floating too early is likely to cause dusting and crazing because floating tends to bring cement paste to the surface. A float finish followed by scratching the surface with a broom is often recommended for flatwork exposed to outdoor conditions. Stopping at this point provides a durable, uniform, non-skid surface and avoids problems caused by over-troweling.

6-5.4 Troweling.

If troweling is desired, a single troweling pass, rather than several, is preferred. The purpose of troweling is to produce a hard, smooth surface. Minimal troweling leaves a somewhat rough surface without creating a weakness at that level. Overworking the surface leads to a weak surface layer caused by working in too much water and a surface susceptible to frost action because of a diminished air content caused by too much mechanical action.

6-5.5 Finishing.

Once finishing is completed, protect exposed surfaces against drying out, or strength and wear resistance will suffer. Cover the surface with a sheet of plastic or a spray-on curing compound (or both) as soon as the surface is tack-free. This happens very quickly. Wrinkle-free application of the plastic sheet helps to ensure a uniformly colored surface. Cover protruding metal with insulation, since metal can act as a heat sink to freeze surrounding concrete. Be sure to insulate the ends of metal form ties.

6-5.6 Sawed Joints.

If sawed joints are necessary, saw when test cuts have sharp, clean edges.

CHAPTER 7 QUALITY VERIFICATION

7-1 STRENGTH GAIN ESTIMATES.

7-1.1 Concrete Testing.

A critical question to be answered for any concrete structure is: "*When will it be ready for use?*" There are a number of tests, both destructive and non-destructive, that are used to determine this, but the maturity method is favored. A detailed discussion of how to develop maturity curves is provided in the FHWA project report (ERDC/CRREL TR-04-2). Common practice is to develop a maturity curve from test concrete having the same mixture proportions as the intended job concrete before starting the construction project. In practice, this usually does not happen because it is difficult to plan ahead for most projects, particularly if they are small. For many projects, it is important to put the structure into service as soon as possible. Therefore, it is recommended that a maturity curve be developed from the job concrete as it is being placed.

7-1.2 Concrete Cylinders.

Before placement, position thermocouples at several locations where it is important to know what the strength is at any given time. Then, during placement, cast numerous cylinders from the fresh concrete. Typically, place about one-third of the load before cylinders are cast. Install thermocouples into several cylinders. Then allow the cylinders to cure at any convenient temperature, provided their internal temperature does not drop below 23 °F (–5.0 °C), and test them, three at a time, for compressive strength. Store the cylinders indoors. The time-temperature factor recorded from the cylinders is then plotted against cylinder strength. This plot is then used to estimate in-situ strength based on the time-temperature factor recorded from the structure. Temperature data collection continues until it is determined that the structure is safe to put into service (see the FHWA project report [ERDC/CRREL TR-04-2] for more detail).

7-2 FREEZING POINT MEASUREMENT.

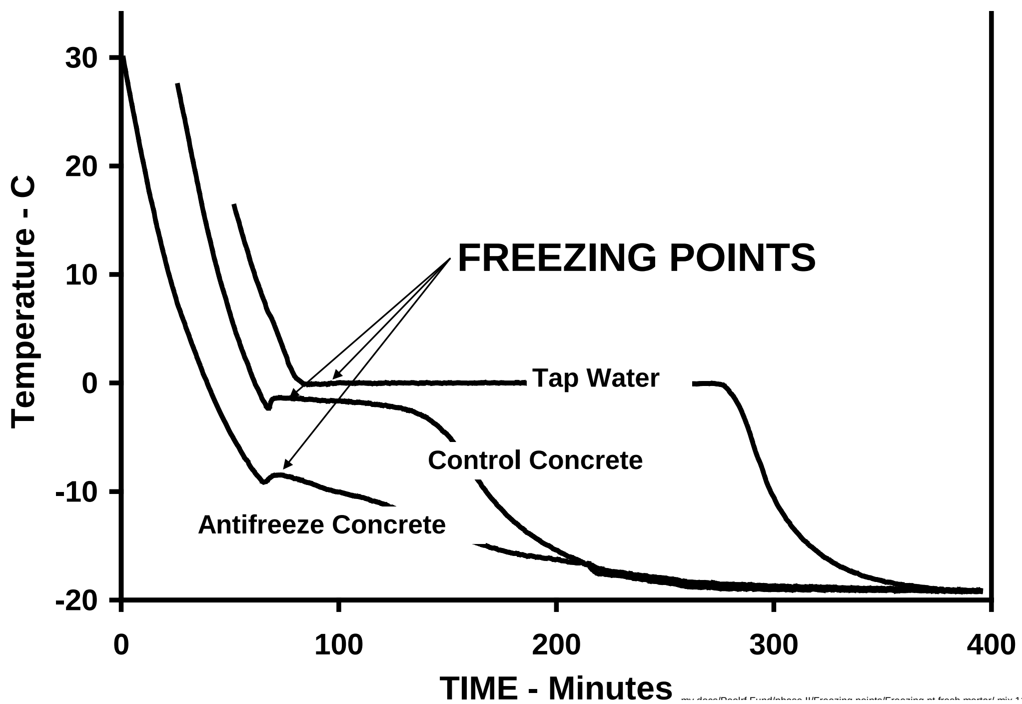
7-2.1 Concrete Freezing Point.

It is critical to know the temperature at which water in fresh concrete freezes. This temperature is affected by the type and concentration of solids dissolved in the water. This is an important parameter to know when concrete arrives at a construction site; admixtures are dosed knowing the moisture content of aggregate. However, the actual w/c ratio in ready-mix concrete can vary by several percent due to changes in aggregate moisture, measurement inaccuracies, and the tendency of contractors to add water at the site. Thus, the final freezing point of the concrete could be considerably different from desired. Unfortunately, there are no commercial devices to determine the freezing points of concrete in the field.

7-2.2 Method for Freezing PoInt.

Until a better method is developed, CRREL has developed a rudimentary way to measure the freezing point of fresh concrete in the field. Because this measurement takes about 30 minutes to complete, it is most useful when used together with the trial batch operation. It is likely that a relationship between freezing point and slump is the most useful product created for the concrete mixture selected for the job.

Figure 7-1 Cooling Curves for Water, Control Concrete, and Antifreeze Concrete



7-2.3 FHWA Freezing Point Method.

The freezing point method is described in the FWHA project report (ERDC/CRREL TR-04-2). However, in brief, it consists of making several 2.0 by 4.0 in (50.8 by 101.6 mm) cylindrical samples, installing thermocouples, and placing them in a chest containing dry ice. Experience shows that these cylinders might drop below their freezing point within 20 minutes of being placed in the chest. Having the data plotted real-time onto a laptop computer facilitates rapid determination of the freezing point. Determine freezing points at various slumps (w/c ratios). The freezing point is identified as the location on the temperature vs. time plot (Figure 7-1) from the cylinders being cooled where the initial slope of the cooling curve (the mostly linear portion above 32 °F (0 °C)) suddenly changes. The resulting relationship between freezing point and slump is then used to estimate the as-dispensed freezing point of the concrete at the job site, provided the admixtures were used in the same doses as found in the trial batches.

APPENDIX A BEST PACTICES

A-1 BEST TIMING FOR ADDING ADMIXTURES.

The trial batches will determine the best timing for adding admixtures into the concrete. To reasonably duplicate the performance of concretes batched for job site application, use a minimum batch size of 2.6 to 5.2 yd^3 (2 to 4 m^3). Use cold water for all batching operations to create an initial concrete temperature of 50°F ± 9°F (10°C ± 5°C). Higher temperatures tend to cause antifreeze mixtures to stiffen too rapidly and lower temperatures are difficult to achieve. The goal is to produce a concrete with acceptable slump and air content at the job site. Jobs with short haul times and cement content less than 10341 lb/yd^3 (400 kg/m^3) can have all admixtures added into the concrete at the ready-mix plant, whereas longer haul times or higher cement content might require that all the admixtures be added at the job site. Moisture control is critical to obtain a desired freezing point — determine moisture content of sand and coarse aggregate before the start of each day and as needed during the day. Reverse the drum on the truck to empty wash water from previous cleaning operations before making a trial batch.

A-2 DOSING ADMIXTURES INTO CONCRETE.

The three approaches developed for dosing admixtures into concrete that performed well for this manual are presented in this appendix. The times shown simulate the time spent at the ready-mix plant, in transit, and on the job site, and are based on performance requirements established at the beginning of the study: 45-minute transit time and 20- to 30-minute job site working time. All mixing and testing of trial batches can take place at the ready-mix plant.

Table A-1 Approach 1: Dose All Admixtures at the Ready-Mix Plant

Location	Operation	Time (hr:min) Start – End	Time (hr:min) Total
Ready-mix plant	Add cold mixing water into drum	0:00	15 min
	Add sand, coarse aggregate and cement into drum, with AEA* on sand	0:00‡	
	Mix for 2 minutes	0:00 – 0:02	
	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: DCI®, DCI® S, or Rheocrete® CNI†	0:02 – 0:05	
	Mix for 1 minute	0:05 – 0:06	
	Back load up to top of drum and add either MIRA® 70 or Polyheed® 997†	0:06 – 0:08	
	Mix for 1 minute	0:08 – 0:09	
	Back load up to top of drum and add either ADVA® Flow or Glenium 3000 NS†	0:09 – 0:11	
	Mix 1 minute	0:11 – 0:12	
	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: PolarSet®, Pozzutec® 20, or Pozzutec® 20+†	0:12 – 0:15	
Transit	Mix for 3 minutes, then agitate at 2–4 rpm thereafter	0:15 – 0:18	45 min
	Obtain slump and air content	0:20 – 0:30	
	Obtain slump and air content	0:35 – 0:45	
	Obtain slump and air content	0:50 – 1:00	
Job Site	Re-dose with plasticizer and AEA if needed (back up load)	1:00 – 1:20	30 min
	Obtain slump, air content, freezing point and cylinders	1:40 – 1:50	
	Immediately add water into drum and discard remaining concrete		

* Air-entraining admixture.
† Depends on the selected admixture combination.
‡ Timing starts when water hits cement.

Comments: Because all admixtures are mixed into the concrete at the ready-mix plant, the concrete may lose slump and air rapidly while in transit to the jobsite. Travel times in excess of 20 minutes may cause unacceptable slump loss with some cement, though in this study slumps could be recovered with extra plasticizer dosed into the truck after traveling up to 45 minutes. Working times of 20 to 30 minutes at the job site can be expected with this approach.

Table A-2 Approach 2: Dose Some Admixtures at the Ready-Mix Plant and the Rest at the Job Site

Location	Operation	Time (hr:min)	
		Start – End	Total
Ready-mix Plant	Add cold mixing water into drum	0:00	11 min
	Add sand, coarse aggregate and cement into drum, with AEA on sand	0:00†	
	Mix for 2 minutes	0:00 – 0:02	
	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: DCI®, DCI® S, or Rheocrete® CNI*	0:02 – 0:05	
	Mix for 1 minute	0:05 – 0:06	
	Back load up to top of drum and add either MIRA® 70 or Polyheed® 997*	0:06 – 0:08	
	Mix for 1 minute	0:08 – 0:09	
	Back load up to top of drum and add either Adva® Flow or Glenium 3000 NS*	0:09 – 0:11	
Transit	Mix for 3 minutes, then agitate at 2–4 rpm thereafter	0:11 – 0:14	45 min
	Obtain slump and air content	0:16 – 0:26	
	Obtain slump and air content	0:31 – 0:41	
	Obtain slump and air content	0:46 – 0:56	
Job Site	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: PolarSet®, Pozzutec® 20, or Pozzutec® 20+*	1:00 – 1:03	30+ min
	Mix for 3 minutes	1:03 – 1:06	
	Obtain slump and air content	1:07 – 1:17	
	Re-dose with plasticizer and AEA if needed (back up load)	1:18 – 1:21	
	Mix for 2 minutes	1:21 – 1:23	
	Obtain slump, air content, freezing point and cylinders	1:25 – 1:35	
	Immediately add water into drum and discard remaining concrete		

* Depends on the selected admixture combination.
† Timing starts when water hits cement.

Comments: Because some admixtures are withheld from the concrete at the ready-mix plant, the concrete may not lose air as rapidly during transit as in Approach 1. However, the mix may need higher doses of plasticizer to keep it mobile during transit. Transit times of 45 minutes or more should be possible with this approach, particularly if no accelerating admixtures are in the mix. Working times might still be limited to 30 minutes at the jobsite, as slump loss is very rapid once the final admixtures are mixed into the concrete.

Table A-3 Approach 3: Dose All Admixtures at the Job Site

Location	Operation	Time (hr:min) Start – End	Total
Ready-mix Plant	Add cold mixing water into drum	0:00	2 min
	Add sand, coarse aggregate and cement into drum	0:00†	
	Mix for 2 minutes	0:00 – 0:02	
Transit	Agitate at 2–4 rpm	0:02 – 0:47	45 min
Job Site	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: DCI®, DCI® S, or Rheocrete® CNI*	0:50 – 0:53	40+ min
	Mix 1 minute	0:53 – 0:54	
	Back load up to top of drum and add either MIRA® 70 or Polyheed® 997*	0:54 – 0:56	
	Mix 1 minute	0:56 – 0:57	
	Back load up to top of drum and add AEA that has been sprinkled into a bucket containing approximately 5 kg sand	0:57 – 0:59	
	Mix 2 minutes	0:59 – 1:01	
	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: PolarSet®, Pozzutec® 20, or Pozzutec® 20+*	1:01 – 1:04	
	Mix 3 minutes	1:04 – 1:07	
	Obtain slump and air content	1:08 – 1:18	
	Back load up to top of drum and add either ADVA® Flow or Glenium 3000 NS*, if needed; mix 1 minute.	1:18 – 1:21	
	Obtain slump, air content, freezing point and cylinders	1:23 – 1:30+	
	Add water into drum and discard remaining concrete		

* Depends on the selected admixture combination.
† Timing starts when water hits cement.

Comments: Because all admixtures are added at the job site, there is little concern about stiffening problems during delivery. The admixtures do not need to be added into the mix until the construction crew is ready. However, because the concrete is initially prepared with a very low w/c ratio, the AEA should be added at the job site. Transit times can easily exceed 45 minutes. There may be no need for a super-plasticizer (ADVA® Flow or Glenium). Working times at the job site can last 45 minutes or longer.

A-3 TRIAL BATCHING: DETERMINING W/C RATIO FROM FREEZING POINT MEASUREMENTS.

Because the amount of admixtures and cement in most ready-mixed concretes are more accurately known (compared to water contents), a freezing point measurement can be used to estimate the actual w/c ratio of the concrete. For example, if the MB II admixture combination was used in a concrete with a 23 °F (–5 °C) freezing point, it is immediately known from Figure 4-2.e that the water in that concrete contains 16.2 percent solids. This value, along with the amount of cement and the dosage of admixtures used to make the concrete, are all that is needed to determine the w/c. Convert dosage values to weights of solids using the procedure in paragraph 4.2. Assuming that the admixtures contributed 59.63 lb/yd^3 (35.38 kg/m^3) solids, there would be exactly 368.11 lb/yd^3 (218.39 kg/m^3) water (59.63 (35.38)/16.2 percent) in the freshly mixed concrete. If the batch ticket indicated that 836 lb/yd^3 (496 kg/m^3) cement was used in the concrete, a 0.44 w/c ratio is calculated. At this point the concrete could be rejected if its freezing point was not met, or more admixtures could be added into the concrete, or the structure could be thermally protected to prevent freezing.

APPENDIX B GLOSSARY

B-1 ACRONYMS.

°C	degrees Celsius
°F	degrees Fahrenheit
ACI	American Concrete Institute
AEA	air-entraining admixture
AFCEC	Air Force Civil Engineer Center
ASTM	American Society for Testing and Materials
BCE	Base Civil Engineer
BIA	Bilateral Infrastructure Agreement
CWAS	cold weather admixture system
DCI	
DoD	Department of Defense
ERDC/CRREL	Engineer Research and Development Center/Cold Regions Research and Engineering Laboratory
ETL	Engineering Technical Letter
FHWA	Federal Highway Administration
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Agreement
gal	gallons
gal/yd^3	gallons per cubic yard
gal/100 lb	gallons per 100 pounds
in	inch
kg	kilogram
kg/m^3	kilograms per cubic meter
L	liter
L/100 kg	liters per 100 kilograms
L/m^3	litters per cubic meter
lb	pounds
lb/yd^3	pounds per cubic yard
m^3	cubic meter
mL	milliliter
mL/100 kg	millimeter per 100 kilograms
mL/m^3	milliliter per cubic meter
mm	millimeter
MB	Master Builders, Inc.
NAVFAC	Naval Facilities Engineering Command
NMSA	nominal maximum size aggregate

oz/100 lb	ounces per 100 pounds
oz/yd^3	ounces per cubic yard
RED HORSE	Rapid Engineers Deployable - Heavy Operational Repair Squadron Engineers
rpm	revolutions per minute
SOFA	Status of Forces Agreement
TO	Technical Order
TR	Technical Report
TSPWG	Tri Services Pavement Working Group
TSPWG M	Tri Services Pavement Working Group Manual
TTP	Tactics, Techniques, and Procedures
w/c	water/cement
WRDA	water reducing admixture
WRG	W.R. Grace & Co.
yd^3	cubic yard

APPENDIX C REFERENCES

DOD

https://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476772/cold-weather-admixture-systems/

Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory Technical Report (ERDC/CRREL TR 04-2), *Extending the Season for Concrete Construction and Repair: Phase I—Establishing the Technology*

ERDC/CRREL TR-05-9, *Placing Antifreeze Concrete at Grand Forks Air Force Base*

INDUSTRY

ACI 306-R88, Cold Weather Concreting
https://www.concrete.org

ASTM C33, Standard Specification for Concrete Aggregates
http://www.astm.org

ASTM C150, Standard Specification for Portland Cement
http://www.astm.org