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Mechanical Behavior of High Performance Concretes, Volume 2

Production of High Performance Concrete

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Preface

The strategic Highway Research Program (SHRP) is a 5-year, nationally coordinated research effort initiated in 1987 at a cost of $150 million. This highly focused and mission oriented program originated from a thorough and probing study* to address the serious problems of deterioration of the nation's highway and bridge infrastructure. The study documented the need for a concerted research effort to produce major innovations for increasing the productivity and safety of the nation's highway system. Further, it recommended that the research effort be focused on six critical areas in which the nation spends most of the $50 billion used for roads annually and thus technical innovations could lead to substantial payoffs. The six critical research areas were as follows:

- Asphalt Characteristics
- Long-Term Pavement Performance
- Maintenance Cost-Effectiveness
- Concrete Bridge Component Protection
- Cement and Concrete
- Snow and Ice Control

When SHRP was initiated, the two research areas of Concrete Bridge Component Protection and Cement and Concrete were combined under a single program directorate of Concrete and Structures. Likewise, the two research areas of Maintenance Cost-Effectiveness and Snow and Ice Control were also combined under another program directorate of Highway Operations.

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* *America's Highways: Accelerating the Search for Innovation.* Special Report 202, Transportation Research Board, National Research Council, Washington, D. C. 1984.

Abstract

This report details the laboratory developmental work on producing high performance concrete for highway applications. High performance concrete is defined as concrete with much higher early strength and greatly enhanced durability against freezing and thawing in comparison with conventional concrete. The objective was to explore the feasibility of developing appropriate mixture proportions for three different categories of high performance concrete *with only locally available, conventional constituent materials and normal production and curing procedures*.

The constituent materials are described in detail in terms of their physical, chemical, and mineral properties. The method of proportioning and the selection of materials are discussed, and the mixing and curing procedures are summarized.

A total of 360 trial batches were mixed from which 21 different mixture proportions were selected for in-depth study and evaluation of the mechanical behavior of the concrete. The mixture proportions and the plastic and strength properties of each trial batch are summarized in two appendixes.

The results of the laboratory work and field trials indicated that concrete with high performance requirements can be successfully produced, and several precautionary steps are suggested for quality assurance in the production of such concrete.

Executive Summary

This report documents the laboratory developmental work on producing high performance concrete for highway applications. The objective was to explore the feasibility of developing appropriate mixture proportions for high performance concrete *with only locally available, conventional constituent materials and normal production and curing procedures*.

For the purpose of this research program, high performance concrete is defined in terms of certain *target* strength and durability requirements as shown below:

Category of High Performance Concrete	Minimum Compressive Strength	Maximum Water/ Cement Ratio	Minimum Frost Durability Factor
Very early strength (VES)			
Option A (with Type III cement)	2,000 psi (14 MPa) in 6 hours	0.40	80%
Option B (with Pyrament PBC-XT cement)	2,500 psi (17.5 MPa) in 4 hours	0.29	80%
High early strength (HES) (with Type III cement)	5,000 psi (35 MPa) in 24 hours	0.35	80%
Very high strength (VHS) (with Type I cement)	10,000 psi (70 MPa) in 28 days	0.35	80%

In the above definition, the target minimum strength should be achieved in the specified time after water is added to the concrete mixture. The compressive strength is determined from 4 x 8-in. (100 x 200-mm) cylinders tested with neoprene caps. The water/cement ratio is based on all cementitious materials. The minimum durability factor should be achieved after 300 cycles of freezing and thawing according to ASTM C 666 (procedure A).

In comparison with conventional concrete, the high performance concrete defined above has much higher early strength and greatly enhanced durability against freezing and thawing. The various types of high performance concrete are envisioned to have many potential applications:

Potential Applications	Concrete Type VES (A)	VES (B)	HES	VHS
New pavement	X		X	
Full-depth pavement patch	X	X	X	
Pavement overlay	X	X	X	
New bridge deck			X	X
Full bridge deck replacement			X	X
Bridge deck overlay	X	X	X	
Bridge girders			X	X
Precast elements		X	X	X
Prestressed piles		X	X	X
Columns and piers			X	X

VES concrete is especially useful in situations in which the construction time is critical and the cost of materials is only marginally important in comparison with the costs of closing a bridge or a section of pavement to traffic. HES concrete is clearly the most versatile material in terms of potential applications. It is useful in situations in which the speed of construction is important but not critical, even though the cost of materials may be relatively more expensive. VHS concrete is useful primarily for structural members, for which the construction time is not a critical factor but structural efficiency and economy are important.

So that the research results would be applicable to different geographical regions, four different types of coarse aggregates were selected for the experimental program: crushed granite and marine marl from North Carolina, dense crushed limestone from Arkansas, and washed rounded gravel from Tennessee. These aggregates were used with the local sand from the three states. All constituent materials used for the concrete mixtures are described in detail in terms of their physical, chemical, and mineral properties.

The normal laboratory mixing and batching procedures (ASTM C 192) were modified slightly to represent more closely typical concrete dry-batch plant operations.

Curing procedures were developed to simulate more closely the conditions in the field and were considerably different from the normal laboratory curing procedure (ASTM C 192). For VES concrete, whether made with Type III portland cement or PBC-XT cement, insulation was used to achieve rapid strength gain in the first few hours. For HES and VHS concretes, the demand for early strength gain was not as critical; therefore it was not necessary to use insulation.

A total of 360 trial batches were produced. Their mixture proportions and the plastic and strength properties are summarized in appendixes A and B. Each trial batch was evaluated successively for four basic characteristics: good workability, adequate air content, sufficient design strength, and acceptable durability. If a trial batch failed to develop any one of these four characteristics, it was excluded from further consideration. By means of such a screening procedure, 21 different mixture proportions were selected from the trial batches for in-depth evaluation. Each of these mixtures was reproduced several times in the laboratory for studies of its mechanical behaviors in both plastic and hardened states. Certain VES and HES mixtures, and the batching, mixing, and accelerated curing methods developed in the laboratory, were confirmed in large-scale productions for five field trials, which are discussed in detail in *Volume 4: High Early Strength (HES) Concrete* of this report series.

From the experience of laboratory experiments and field trials, it is concluded that the three categories of high performance concrete considered in this investigation can be successfully produced in the field. For VES and HES mixtures, because of the rapid hydration, higher variation in slump and air content of the concrete can be expected in comparison with conventional concrete.

To produce high performance concrete in the field, it is important to take several precautionary steps for quality assurance:

1. Using the mixture proportions developed in this investigation as a guide, conduct trial batches in the laboratory, before field placement, with the specific raw materials to be used. Trials allow refinement of the batch weights before further adjustments needed in the field and reduce confusion during initial practice placements.

2. Before concrete placement, conduct preconstruction meetings with all key personnel involved, including construction managers, batch plant operators, and finishing crew foremen.

3. Include at least one practice placement of the concrete, and expect a significant learning experience. Generally, one full day should be allowed for the practice placement.

4. Pay attention to truck load size and batching sequence. Be especially sensitive to truck condition and mixing efficiency. Keep the load to no more than two-thirds of the maximum rated mixing capacity of the truck. In some cases, it may be advisable to reduce the truck load to no more than half of the rated mixing capacity.

5. Discharge the concrete quickly at the job site. If the concrete is to be insulated, minimize the time before the insulation is placed. Sawing of the pavement joints should be scheduled for no later than 8 hours after concrete placement or immediately after removal of insulation.

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Introduction

SHRP's research on the mechanical behavior of high performance concretes had three general objectives:

1. To obtain needed information to fill gaps in the present knowledge;
2. To develop new, significantly improved engineering criteria for the mechanical properties and behavior of high performance concretes; and
3. To provide recommendations and guidelines for using these concretes in highway applications according to the intended use, required properties, environment, and service.

Both plain and fiber-reinforced concretes were included in the study. The research findings are presented in a series of six project reports:

Volume 1 *Summary Report*

Volume 2 *Production of High Performance Concrete*

Volume 3 *Very Early Strength (VES) Concrete*

Volume 4 *High Early Strength (HES) Concrete*

Volume 5 *Very High Strength (VHS) Concrete*

Volume 6 *High Early Strength Fiber-Reinforced Concrete (HESFRC)*

This volume is the second of these reports. The readers will notice a certain uniformity in format and similarity in many general statements in these reports. This feature is adopted intentionally so that each volume of the reports can be read independently without the need to cross-reference to other reports in the series.

1.1 Definition of High Performance Concrete (HPC)

In general terms, HPC may be defined as any concrete that provides enhanced performance characteristics for a given application. For example, concretes that provide substantially improved durability under severe service conditions, extraordinary properties at earlier ages, or substantially enhanced mechanical properties are potential HPCs. These concretes may contain materials such as fly ash, ground granulated slags, silica fume, fibers, chemical admixtures, and other materials, individually or in various combinations.

Engineers are making increasing use of HPC for a variety of highway applications, including new construction, repairs, and rehabilitation. Higher-strength concrete will provide more structural design options. Improved early age properties of concrete will facilitate construction and rehabilitation tasks and improve quality. Higher durability will increase the service life, which may reduce life-cycle cost.

For the purpose of this research program, HPC is defined in terms of certain *target* strength and durability criteria as specified in Table 1.1.

Table 1.1 Criteria for HPC

Category of HPC	Minimum Compressive Strength	Maximum Water/ Cement Ratio	Minimum Frost Durability Factor
Very early strength (VES)			
Option A (with Type III cement)	2,000 psi (14 MPa) in 6 hours	0.40	80%
Option B (with PBC-XT cement)	2,500 psi (17.5 MPa) in 4 hours	0.29	80%
High early strength (HES) (with Type III cement)	5,000 psi (35 MPa) in 24 hours	0.35	80%
Very high strength (VHS) (with Type I cement)	10,000 psi (70 MPa) in 28 days	0.35	80%

In the above definition, the target minimum strength should be achieved in the specified time after water is added to the concrete mixture. The compressive strength is determined from 4 x 8-in. (100 x 200-mm) cylinders tested with neoprene caps. The water/cement ratio (W/C) is based on all cementitious materials. The minimum durability factor should be achieved after 300 cycles of freezing and thawing, according to ASTM C 666 (procedure A).

These working definitions of HPC were adopted after several important factors were considered with respect to the construction and design of highway pavements and structures. The rationale for the selection of the various limits is discussed below.

1.1.1 Time Constraint

The choice of an appropriate time constraint for VES concrete depends on typical construction limitations on heavily traveled roads and highways, especially in urban locations. To minimize restrictions to rush hour traffic, typical work periods would be available for a daytime window of 6 hours between 9:30 A.M. and 3:30 P.M., for example, or for a nighttime window of 9 hours between 8:00 P.M. and 5:00 A.M. With VES concrete being used for small, full-depth patches, after allowing time for preparation and placement, the available time for concrete to harden would be only 4 to 6 hours. Therefore, a time constraint of 4 or 6 hours is imposed on VES concrete.

The use of a time constraint of 24 hours for HES concrete is intended for projects with accelerated construction schedules but without such critical conditions as congested traffic in urban areas.

The choice of a time requirement of 28 days for VHS concrete is based on conventional construction practice, in which time would not be a critical factor. However, it is considered unnecessary to extend this time requirement to a longer period, such as 56 days, as in many previous construction projects using moderately high strength concrete (Zia et al. 1991).

1.1.2 Strength Requirement

The minimum strength level of 2,000 psi (14 MPa) for VES concrete is based on the need to carry normal design traffic. It is recognized that for some locations heavy trucks might be required to use alternate lanes for a short period of time.

A strength requirement of 5,000 psi (35 MPa) is selected for HES concrete to provide a class of concrete that would meet the need for accelerated construction of pavements and bridges.

The choice of 10,000 psi (70 MPa) as the strength criterion for VHS concrete is based in part on the results of previous research (Jobse and Moustafa 1984, Zia et al. 1989), which indicates that concrete strength of 8,000 to 10,000 psi (56 to 70 MPa) is optimal for the current American Association of State Highway and Transportation Officials (AASHTO) standard bridge girders, and in part on cost considerations indicating that cost of concrete increases substantially when its strength level exceeds 10,000 psi (70 MPa).

1.1.3 W/C Limit

The ratios of water to cementitious materials selected for the three categories of HPC are relatively low. With a low W/C, concrete durability may be improved in all exposure conditions. Since the HPCs are intended for highway applications where exposure to frost must be expected, HPCs are required to be frost resistant. The maximum W/C of 0.40 and 0.35 are selected for VES (A) concrete and HES concrete, respectively, after considering the short curing time for both concretes. Since both concretes are intended to be in service in one day or less, the W/C selected might provide a discontinous capillary pore system at about that age as suggested by Powers's work (1959). Their workability as enhanced by the use of high-range water reducers is another consideration.

The maximum W/C of 0.29 is specified for VES (B) concrete, as recommended by the manufacturer of PBC-XT cement. The cement is very sensitive to water, and its strength development would be greatly delayed if higher W/C is used.

For VHS concrete, a low W/C of 0.35 is needed to meet the high strength requirement.

1.1.4 Frost Durability Requirement

The choice of an appropriate measure for frost durability is debatable and subjective. It is recognized that ASTM C 666 (procedure A), which involves freezing and thawing in water, is already a severe test; therefore, durability criterion need not be unduly conservative. On the other hand, if HPC is to provide enhanced durability, it may be argued that higher standards are required. Since frost durability of concrete as measured by ASTM C 666 (procedure A) is highly dependent on the air void system, and since freezing low-permeability concrete at the very high rate required in the test procedure would tend to discriminate against concrete with low W/C, the selected durability factor of 80% at 300 cycles of freezing and thawing is considered appropriate. This is in contrast to a durability factor of 60% commonly expected of quality conventional concrete according to ASTM C 666.

1.2 Potential Applications of High Performance Concrete

Potential applications of VES concrete are for situations in which construction time is critical and the cost of materials is only marginally important in comparison with the costs of closing a bridge or a section of pavement to traffic. The use of this concrete would be limited to full-depth pavement patches, short stretches of new pavement, bridge deck, and pavement overlays. VES concrete would probably be inappropriate for most structural applications. Since either hand or machine finishing is possible, a moderate slump of 3 to 4 in. (75 to 100 mm) would be required.

HES concrete is probably the most universal material in terms of potential applications. With its enhanced performance characteristics, it would be useful for structural members, full-depth pavement patches, or new pavement construction and overlays -- situations where the speed of construction is important but not critical, even though the cost of materials may be relatively more expensive. As with VES concrete, hand or machine finishing is possible with pavements, and conventional concrete placement practices would be used in structural applications. Although machine placement is likely for overlays or larger pavement sections, a slump of 3 to 4 in. (75 to 100 mm) would more commonly be needed.

VHS concrete would be useful primarily for structural members, for which the construction time is not a critical factor. Little, if any, direct application of its very high strength characteristics to pavement is anticipated for VHS concrete. However, if including a mineral admixture such as silica fume or fly ash would improve abrasion resistance or prevent deleterious alkali-silica reactivity, VHS concrete might be chosen for application in a pavement. Since conventional practices of concrete placement would be used for VHS concrete, a slump of 3 to 4 in. (75 to 100 mm) would again be needed.

Table 1.2 summarizes the potential applications of the three categories of HPC.

Table 1.2 Potential applications of HPC

Potential Applications	Concrete Type			
	VES (A)	VES (B)	HES	VHS
New pavement	X		X	
Full-depth pavement patch	X	X	X	
Pavement overlay	X	X	X	
New bridge deck			X	X
Full bridge deck replacement			X	X
Bridge deck overlay	X	X	X	
Bridge girders			X	X
Precast elements		X	X	X
Prestressed piles		X	X	X
Columns and piers			X	X

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Objective and Scope

The objective of the research reported herein was to explore the feasibility of developing appropriate mixture proportions for the various categories of HPC as defined in section 1.1, *with only locally available, conventional constituent materials and normal production and curing procedures*. Therefore, the study included seven different paste compositions, with four different types of coarse aggregates and three kinds of sand, as summarized in Tables 2.1 and 2.2. The materials were chosen as being representative from a wide geographical area.

The studies using crushed granite, marine marl, and washed rounded gravel were conducted at North Carolina State University (NCSU) whereas the studies using dense crushed limestone were carried out at the University of Arkansas. Lillington sand was used for the concretes made with either crushed granite or marine marl, but for the concrete made with washed rounded gravel, Memphis sand was used. Furthermore, Arkansas River sand was used for the concrete made with dense crushed limestone.

Table 2.1 Types of pastes

Type	Symbol	Principal Paste Components
1	VES (A)	Type III + calcium nitrite
2	VES (B)	Pyrament PBC-XT
3	HES	Type III + calcium nitrite
4	HES (L)	HES + latex
5	HES (S)	HES (standard cure)
6	VHS (P)	Type I + HRWR + fly ash (class F or C)
7	VHS (R)	Type I + HRWR + silica fume

HRWR = high-range water reducer, L = latex, S = standard cure, P = fly ash, R = silica fume.

Table 2.2 Types of coarse and fine aggregates

Type	Symbol	Source
Marine marl	MM	Castle Hayne, N.C.
Crushed granite	CG	Garner, N.C.
Dense crushed limestone	DL	West Fork, Ark.
Washed rounded gravel	RG	Memphis, Tenn.
Sand		Lillington, N.C.
Sand		Memphis, Tenn.
Sand		Van Buren, Ark.

3

Characterizations of Constituent Materials

3.1 Cements

As indicated in Table 2.1, three different types of cement were used for the various categories of HPC. Type III cement was used for VES (A) and HES concretes, Type I for VHS concrete, and Pyrament PBC-XT cement for VES (B) concrete.

Type I and Type III cements used at NCSU were of low alkali content and met the requirements of ASTM C 150 specifications. They were supplied by Blue Circle Cement, Inc., from its plant in Harleyville, South Carolina. The cements used at Arkansas were supplied also by the same manufacturer, but from its plant in Tulsa, Oklahoma.

Pyrament PBC-XT cement is a proprietary product that was supplied by Lone Star Industries from its Greencastle, Indiana plant. It may be classified as an alkali-activated system composed of about 60% portland cement meeting ASTM C 150 specifications for Type III, and 35% fly ash meeting ASTM C 618 class C specifications for use as a mineral admixture in portland cement concrete. The remaining 5% is essentially a proprietary functional addition consisting of high-range water reducers (HRWR), citric acid, and potassium carbonate. No chloride compounds are used. The cement is manufactured under U.S. patent 4,842,649.

The material is very sensitive to moisture and is packaged in plastic-lined bags. It should be stored in a dry environment. According to the manufacturer, the cement stored under normal conditions should be used within 6 months of date of manufacture. If the cement is stored in a room with relatively high humidity, its shelf life may be greatly reduced.

The results of physical and chemical analyses of the various types of cement are summarized in Tables 3.1 through 3.3, along with the requirements of relevant ASTM specifications for comparison.

It is important to note that although ASTM C 595 does not specify a limit, the total equivalent alkali content of PBC-XT is typically as much as three times the limit specified by ASTM C 150 for Type I and Type III cements. This high alkali content of PBC-XT poses a potential for alkali-silica reactivity when the cement is used with deleteriously reactive aggregates. Investigation of this phenomenon is outside the scope of this research.

Table 3.1 Results of physical and chemical analyses of Type I cement compared with ASTM C 150

	ASTM C 150 Type I	Type I* NCSU	Type I+ Arkansas
Fineness			
Specific surface (Blaine)	2,800 cm^2/g	3,200 cm^2/g	3,970 cm^2/g
Soundness			
Autoclave expansion	0.80%	-0.01%	0.02%
Time of setting (Gillmore)			
Initial	[illegible] hr	--	3 hr 2 min
Final	10 hr	--	4 hr 10 min
Water required			
1 : 2.75 mortar cubes	--	48.5%	--
Air temperature	--	73°F	--
Relative humidity	--	70%	--
Compressive strength, 2 in.mortar cubes			
1 day	--	--	2,208 psi
3 days	1,800 psi	3,150 psi	3,692 psi
7 days	2,800 psi	5,060 psi	4,583 psi
Silicon dioxide (SiO_2), %	--	20.8	19.4
Aluminum oxide (Al_2O_3), %	--	5.3	5.6
Ferric oxide (Fe_2O_3), %	--	3.6	2.2
Calcium oxide (CaO), %	--	64.8	64.7
Magnesium oxide (MgO), %	6.0	0.9	2.3
Sulfur trioxide (SO_3), %	3.5	2.7	2.9
Loss on ignition, %	3.0	1.3	1.4
Sodium oxide (Na_2O),%	--		0.3
Potassium oxide (K_2O), %	--	--	0.6
Total equivalent alkali content, %	0.60	0.21	0.66
Tricalcium silicate, %	--	57.5	67.3
Dicalcium silicate, %	--	16.3	4.7
Tricalcium aluminate, %	--	7.8	11.0
Tetracalcium aluminoferrite, %	--	11.0	6.8
Insoluble residue, %	0.75	0.11	0.25

Note: 1 MPa = 145 psi
* Tests performed by the Materials and Tests Unit of North Carolina Department of Transportation (DOT)
+ Tests performed by the Materials Division of Arkansas DOT

Table 3.2 Results of physical and chemical analyses of Type III cement compared with ASTM C 150

	ASTM C 150 Type III	Type III* NCSU	Type III+ Arkansas
Fineness			
Specific surface (Blaine)	--	4,575 cm2/g	5,590 cm2/g
Soundness			
Autoclave expansion	0.80%	-0.03%	0.02%
Time of setting (Gillmore)			
Initial	1 hr	3 hr	1 hr 48 min
Final	10 hr	6 hr	2 hr 43 min
Water required			
1 : 2.75 mortar cubes	--	48.5%	--
Air temperature	--	73^{o}F	--
Relative humidity	--	70%	--
Compressive strength, 2 in. mortar cubes			
1 day	1,800 psi	3,400 psi	3,717 psi
3 days	3,500 psi	4,450 psi	5,258 psi
7 days	--	--	5,725 psi
Silicon dioxide (SiO_2), %	--	20.4	20.1
Aluminum oxide (Al_2O_3), %	--	5.1	5.6
Ferric oxide (Fe_2O_3), %	--	3.8	2.1
Calcium oxide (CaO), %	--	65.2	64.1
Magnesium oxide (MgO), %	6.0	1.0	2.4
Sulfur trioxide (SO_3), %	3.5	2.9	3.7
Loss on ignition, %	3.0	1.2	1.1
Sodium oxide (Na_2O),%	--	--	0.2
Potassium oxide (K_2O), %	--	--	0.7
Total equivalent alkali content, %	0.60	0.18	0.66
Tricalcium silicate, %	--	62.6	58.6
Dicalcium silicate, %	--	11.2	13.3
Tricalcium aluminate, %	15	7.2	11.4
Tetracalcium aluminoferrite, %	--	11.5	6.4
Insoluble residue, %	0.75	0.03	0.15

Note: 1 MPa = 145 psi

* Tests performed by the Materials and Tests Unit of North Carolina DOT

\+ Tests performed by the Materials Division of Arkansas DOT

Table 3.3 Results of physical and chemical analyses of PBC-XT cement compared with ASTM C 595

	ASTM C 595 Type IP	Typical Value* PBC-XT	PBC-XT+ NCSU
Fineness			
Specifics surface (Blaine)	--	5,000 cm^2/g	3,200 cm^2/g
Soundness			
Autoclave expansion	0.50%	0.07%	--
Time of setting (Vicat)			
Initial	45 min	32 min	--
Final	7 hr	--	--
Water required			
1 : 2.75 mortar cubes	--	--	32.7%
Air temperature	--	--	73°F
Relative humidity	--	--	70%
Compressive strength, 2 in. mortar cubes			
1 day	--	--	1,800 psi
3 days	1,800 psi	4,470 psi	4,200 psi
7 days	2,800 psi	6,150 psi	4,500 psi
28 days	3,500 psi	7,700 psi	--
Silicon dioxide (SiO_2), %	--	23.6	23.5
Aluminum oxide (Al_2O_3), %	--	9.6	12.5
Ferric oxide (Fe_2O_3), %	--	3.5	3.8
Calcium oxide (CaO), %	--	48.1	48.5
Magnesium oxide (MgO), %	5.0	3.0	3.1
Sulfur trioxide (SO_3), %	4.0	2.9	2.0
Loss on ignition, %	5.0	4.6	3.7
Sodium oxide (Na_2O),%	--	0.2	0.6
Potassium oxide (K_2O), %	--	2.6	1.8
Total equivalent alkali content, %	--	1.9	1.8
Tricalcium silicate, %	--	--	--
Dicalcium silicate, %	--	--	--
Tricalcium aluminate, %	--	--	--
Tetracalcium aluminoferrite, %	--	--	--
Insoluble residue, %	--	--	8.2

Note: 1 MPa = 145 psi
* Provided by Pyrament/Lone Star Industries, Inc.
+ Tests performed by the Materials and Tests Unit of North Carolina DOT

3.2 Coarse Aggregates

Four different types of coarse aggregates were used in this test program. They were chosen as representative aggregates from a wide geographical area. CG is a strong, durable aggregate locally available in North Carolina; it was supplied by Martin Marietta Company from its quarry in Garner. MM is a weaker and more absorptive aggregate available in the coastal area of North Carolina; it was also supplied by Martin Marietta Company from its quarry in Castle Hayne. RG was provided by Memphis Stone and Gravel Company from its Pit 558 in Shelby County, Tennessee. DL was supplied by McClinton-Anchor from its West Fork quarry just outside Fayetteville, Arkansas.

The coarse aggregates used in North Carolina met ASTM C 33 size #57 specifications, with most of the material passing the 25-mm (1-in.) sieve. The CG was a hard, angular aggregate of low absorption (0.6%). The MM was a cubical to subangular, relatively porous, and highly absorptive (typically over 4.5%) shell limestone. The RG, drawn from a river, was primarily silicious and contained some crushed faces, but most of them were worn. The absorption was moderate (just under 3%), and hard chert particles were present. The maximum size of the coarse aggregate used at Arkansas was slightly smaller and met ASTM C 33 size #67 specifications.

Mineralogically, the CG consisted of approximately 35% quartz, 30% potassium feldspar, 25% sodium-rich plagioclase feldspar, and 10% biotite. The MM was a sandy fossiliferous limestone with about 60% calcite, 35% quartz, and 5% other oxide and hydroxide minerals. The RG consisted of 25% quartz, 10% quartzite, 60% chert, and 5% sandstone. The DL contained about 97% limestone and 3% clay minerals. It should be noted that the RG contained a large amount of chert, which could be a cause for alkali-silica reaction.

Physical analyses of the coarse aggregates were performed according to ASTM C 33, and the results are shown in Table 3.4.

3.3 Fine Aggregates

Three different kinds of sand were used in this test program. The sand used with CG and MM was obtained from Lillington, North Carolina. The sand used with RG was shipped from Memphis, Tennessee, and Arkansas River sand was used with DL.

The Lillington sand contained 75% quartz, 22% feldspar, and 3% epidote. The finer material (passing #10 sieve) of the Memphis sand consisted of 95% quartz, 4% opaque minerals (oxide and hydroxide minerals), and 1% other miscellaneous minerals; whereas the coarser material (retained on #10 sieve) of the sand consisted of 20% chert, 30% sandstone and shale fragments, and 50% quartz. The finer material of the Arkansas River sand consisted of 85% quartz, 4% chert, 11% microcline, and less than 1% rock fragments and heavy minerals; whereas the coarser material of the Arkansas River sand consisted of 62% quartz, 16% chert, 11% microcline, and 5% rock fragments. The characteristics of the three kinds of sand are shown in Table 3.5.

Table 3.4 Properties of coarse aggregates

	CG	MM	RG	DL
Specific gravity (SSD)	2.64	2.48	2.55	2.72
% absorption	0.6	6.1	2.8	0.69
DRUW (pcf)	93.6	78.4	94.8	99.0
Fineness modulus	6.95	6.92	6.99	6.43
% Passing				
1 in.	100	98	95	100
3/4 in.	90	85	72	100
1/2 in.	31	43	56	82
3/8 in.	13	19	26	48
#4	2	4	1	6
#8	0	0	2	3
L.A. abrasion, %				
Grading A			17.6	
Grading B	39.6	43.7		24
Sodium sulfate soundness, %	1.3	9.6	2.8	3
Less than 200 by washing, %	0.6	0.4	--	--

Table 3.5 Properties of fine aggregates

	Lillington Sand	Memphis Sand	Arkansas River Sand
Specific gravity (SSD)	2.57	2.62	2.62
% absorption	1.1	1.2	0.6
Fineness modulus	2.66	2.60	2.72
% passing			
#4	100	100	96
#8	97	93	88
#16	80	82	75
#30	47	55	55
#50	9	9	13
#100	1	1	0.4

3.4 Mineral Admixtures

Mineral admixtures used in this test program included fly ash (classes F and C) and silica fume. The fly ash (class F) used for the tests in North Carolina was supplied by Monex Resources, Inc., from its plant at Belews Creek, North Carolina. The fly ash (class C) used for the tests in Arkansas was supplied by Fly Ash Products in Pine Bluff, Arkansas. Class F fly ash typically contains much less calcium than class C fly ash. Therefore, although both are pozzolanic, class C fly ash usually has cementitious properties. The results of physical and chemical analyses of the fly ash are given in Table 3.6, along with the requirements of ASTM C 618 for comparison.

The silica fume used for the tests in North Carolina was EMSAC, Type F-100, supplied by Elkem Chemicals, Pittsburgh, Pennsylvania (now a subsidiary of Cormix). It was in slurry form, containing approximately 50% solids of silica fume and a water reducer. However, the silica fume used for the tests in Arkansas was in powder form supplied by Cormix.

Table 3.6 Results of physical and chemical analyses of fly ash compared with ASTM C 618

	ASTM C 618 Class F	Class F* NCSU	ASTM C 618 Class C	Class C+ Arkansas
Fineness: Retained on no. 325 sieve, %	34	26.5	34	12.06
Soundness: Autoclave expansion, %	0.8	--	0.8	--
Specific gravity	--	2.20	--	2.58
Silicon dioxide plus iron and aluminum oxides, %	70	96.0	50	63.3
Calcium oxide, %	--	--	--	29.7
Magnesium oxide, %	--	--	--	5.1
Sulfur trioxide, %	5	0.5	5	1.9
Moisture content, %	3	0.4	3	0.05
Loss on ignition, %	6	1.1	6	0.1

* Analyses performed by the Materials and Tests Unit of North Carolina DOT
+ Analyses performed by the Materials Division of Arkansas DOT

3.5 Chemical Admixtures

Chemical admixtures used in the various concrete mixtures of this test program included an accelerator, two types of HRWR, an air-entraining agent (AEA), and a retarder. Their brand names, suppliers, and reference specifications are identified in Table 3.7.

Table 3.7 Chemical admixtures used in the test program

Admixture	Brand Name	Supplier	Reference Specifications
Accelerator	DCI (calcium nitrite), 30% solution	W. R. Grace	ASTM C 494, Type C
HRWR	Melment 33% (melamine base)	Cormix	ASTM C 494, Type F
HRWR	PSI Super (naphthalene base)	Cormix	ASTM C 494, Type F
AEA	Daravair (neutral vinsol resin), 17% solids	W. R. Grace	ASTM C 260
Retarder	PSI 400R (lignin base)	Cormix	ASTM C 494, Type D

DCI = Darex Corrosion Inhibitor

3.6 Other Admixtures

Other admixtures used in this research included latex and calcium chloride. Latex was used in one test series of HES, and calcium chloride was used as accelerator for several trial batches of VES at the early stage of the development work. The latex used in the tests was a styrene butadiene, Mod A (lot MM 90102303) supplied by Dow Chemical. Calcium chloride was a commercial product in flake form, containing 77% calcium chloride (ASTM D 98, Type S, Grade 1, Class A flake) which was obtained from a local building materials supply firm. An appropriate amount of the product was dissolved in water so that the solution contained 1% calcium chloride by weight of cement in the concrete mixture.

4

Mixture Proportions

4.1 Development Phase

During the development phase, numerous trial batches of HPCwere produced with different combinations of paste proportions and aggregates. Due considerations were given to the selection of materials, and the modifications of mixing and curing procedures. The concrete produced from each of these trial batches was evaluated for its air content, workability, consistency, and uniformity before it was selected for further study.

4.1.1 General Guidelines

As noted in section 1, the overall purpose of this project was to investigate the mechanical behavior of concretes with enhanced performance characteristics useful for such highway applications as bridges and pavements. In the development of mixture proportions for such concretes, several important factors were considered as general guidelines, which are summarized as follows:

1. The concrete must be robust and reliable. The engineer must have confidence in the performance of the concrete outside a laboratory environment. The performance of the concrete mixture must be reasonably predictable and reproducible under field conditions. Therefore, the data developed from the laboratory should be immediately transferable to the field.

2. Practicality was of utmost importance. Materials, proportions, and production controls should be selected based on attainable goals that would meet the needs of the engineer. Materials and methods should be routinely available or obtainable without special effort. Mixing, curing, and testing procedures used should be such that will avoid unrealistic results.

3. The research scope should be of sufficient breadth. The research should investigate the three kinds of HPC with a variety of constituent materials rather than exhaustively investigate a single class of concrete. Original or innovative mixtures would be developed to avoid unnecessary duplication of existing data.

4. Simplicity of material constituents in the selection of mixture proportions should be maintained for both economy and flexibility. The number of different materials in each concrete mixture was kept to a minimum, and the minimum amount of material was used, in most cases, consistent with achieving the desired performance level.

5. Versatility was also important. It was considered highly desirable to have a series of concrete mixtures from which the engineer could make an appropriate choice for a given application with certain performance requirements. For example, the criteria for HES mixtures could often be met by VHS mixtures as well. Therefore, a VHS mixture might be chosen for an HES application, depending on the situation.

4.1.2 Method of Proportioning

Proportioning the HPC mixtures developed in this research program was based on the methods in ACI 211 (1993a). Selections of W/C, workability, and air content requirements were made first, and incorporation of these constraints was accomplished in accordance with the ACI 211 guidelines, as was selection of aggregate quantities. For mixtures containing mineral admixtures, trial batches were formulated for several different percentages of mineral admixture with several different amounts of portland cement.

For the coarse aggregate, a nominal maximum size of 1 in. (25 mm) was selected as the most appropriate for a variety of applications. This aggregate size could be used for many structural members or pavements, although larger aggregates might be better for pavement concrete in some locations.

The quantity of coarse aggregate (volume of coarse aggregate per unit volume of concrete) was selected initially at or near the recommended value in ACI 211, although for pavement applications it could have been increased by about 10%. These values were adjusted slightly in subsequent trial batches. The purpose of selecting a less coarse mixture was to provide a more general-purpose mixture. A less coarse mixture would be easier to use in small, hand-placed and finished applications.

4.1.3 Selection of Materials

4.1.3.1 Cements

The choice of appropriate cementitious materials was governed by considerations of cost; availability; evidence of satisfactory performance; the engineer's confidence in specifying the material; and the contractor's ability to produce, handle, and place concrete containing the product. In light of these considerations, many materials were excluded from active consideration early in the investigation. For example, regulated set cement was not considered because it sets too quickly and has questionable sulfate durability. Nor was calcium aluminate cement considered because of the high porosity that accompanies the inevitable conversion. Extra-fine portland cement was not selected because it was not generally available. Proprietary, bagged patching materials were not considered since they were not suitable for large-scale work, and their cost was relatively high.

For VES concrete, which involves only limited time for curing, Type III portland cement was not regarded as the best choice. To meet the need for very early strength development, it would be necessary to use higher cement contents, accelerating admixtures, elevated temperatures, or a combination of these. Such measures could easily result in conflicts with the delivery and placement limitations for cast-in-place construction. Although higher mixing temperatures and curing with insulation to take advantage of the heat of hydration could increase concrete strengths at very early ages (4 to 6 hours), performance of the concrete mixture would be more variable.

Pyrament blended cement PBC-XT was initially considered to be the primary cementitious material for VES applications based on its strength and durability characteristics at very early ages as reported in the literature (Zia et al. 1991). After some preliminary work with Pyrament cement, questions were raised about the long-term availability, cost, and some field performance records of the material (Carter 1991, Lee 1991). So, the use of Pyrament cement was suspended in the early stage of the investigation. However, when more positive information was obtained on the various issues and concerns regarding the material (Barnes 1992, Wakeley and Husbands 1991a, 1991b) and when it became evident that the early strength characteristics of Pyrament concrete could not be matched by portland-cement-based concrete, Pyrament cement was reinstated as an alternative to Type III portland cement for VES applications. Accordingly, two options were established for VES concrete, as indicated in section 1.1. It should be cautioned again that the issue of how well Pyrament cement would perform with alkali-sensitive aggregates remains to be fully investigated.

For HES applications in which concrete can be cured for 24 hours, Type III portland cement was the obvious choice because of its strength development characteristics, general availability, and relative cost. Where early strength was not required (e.g., VHS), Type I portland cement was selected as the primary cementitious material.

The portland cement used for experiments at NCSU contained an extremely low equivalent alkali content of less than 0.6% as optionally specified by ASTM C 150. This created two significant effects. First, the required amount of air-entraining agent was higher than typically expected (Greening 1967). Second, mineral admixtures such as class F fly ash or silica fume will not be as reactive with this cement as with other, higher alkali cements, especially at earlier ages (ACI 1993c, 1987). In addition, it was found that the strengths of VES and HES concretes produced with this cement were lower than with other cements that were finer and had higher alkali and tricalcium aluminate contents.

4.1.3.2 Aggregates

To provide sufficient breadth for this research program, four different coarse aggregates were selected for investigation, including both silicious and carbonate aggregates, as outlined in section 3.2. Both crushed and rounded particle shapes were included for the silicious aggregates. Further, the selection also included both a limestone and a silicious aggregate with low absorption and high strength, plus a relatively porous, high-absorption, moderate-strength carbonate marl.

The fine aggregate selected was natural silicious sand, which was reasonably available and generally used with the specific coarse aggregates at a given locality.

4.1.3.3 Mineral Admixtures

Pozzolanic materials will enhance concrete durability to certain exposure conditions and have been used frequently to enhance strength characteristics of high-strength concrete. Therefore, the use of fly ash; ground granulated iron blast-furnace slag; and silica fume was considered.

Since slag and fly ash do not contribute significantly to concrete strength at 1 day or less, these materials were not included in the mixtures for VES and HES concretes. On the other hand, silica fume is more reactive at early ages, so its use in the mixture for HES concrete was considered.

However, the decision was made not to use silica fume in the HES mixture for two reasons. First, the contribution of silica fume to the 1-day strength of HES concrete was found to be minimal when silica fume was used with Type III portland cement. Second, since it was desired to keep the concrete mixtures both as simple and as economical as possible, silica fume would have been used only if it substantially improved performance.

For the VHS mixtures, it was decided that silica fume should be included. Not only was the 28-day performance expected to be improved, but the mixture containing silica fume with Type I portland cement was also expected to provide 1-day strength performance comparable to that of

HES concrete. Silica fume was used in a slurry form, which was found to be relatively easy to store, handle, and mix.

Given the availability of product in different regions of the country, class F fly ash was selected for VHS mixtures with CG, RG, and MM, while class C fly ash was used for VHS mixture with DL. Since the use of these two types of fly ash is fairly common in comparison with slag, slag was not included in this investigation.

4.1.3.4 Chemical Admixtures

To enhance the strength development at early ages of VES (A) and HES, it was necessary to include a set accelerator. Although calcium chloride is widely used as an accelerator, it was excluded from consideration for at least two reasons. First, much research on the contributions of chlorides to the performance of concrete was already available. Second, the addition of calcium chloride to HPC is difficult to justify from the standpoint of concrete durability. However, at the early stage of investigation, several mixtures containing calcium chloride were partially investigated (see Tables A.1 through A.4 in appendix A).

In lieu of calcium chloride, a 30% solution of calcium nitrite, $Ca(NO_2)_2$, in the amount of 4 or 6 gallons per cubic yard (gcy) (19.8 to 29.7 L/m^3) of concrete was selected as an accelerator for VES (A) and HES mixtures. The amount used was in accordance with the recommendations of the manufacturer. The calcium nitrite solution used is produced by W. R. Grace Company under the trade name of Darex Corrosion Inhibitor (DCI). Even though the product is intended to enhance concrete performance against corrosion of reinforcing steel, it is also an effective set accelerator. As a nonchloride accelerator, DCI would also improve long-term durability of reinforced structures such as bridge decks.

Some nonstandard tests conducted by the Virginia Transportation Research Council have been reported (Ozyildirim 1992a, 1992b) to show that using DCI in some concretes might reduce its frost durability. The tests were conducted by subjecting specimens to freezing and thawing in salt solution. The specimens were conditioned before testing by moist curing for 14 days, followed by 7 days of air curing.

There are several implications in using DCI. Since it is a fast-acting accelerator, it can not be added to the concrete mixtures at the time of batching unless the delivery time for concrete is very short. The addition of a retarding admixture to help control slump loss was not advisable, since the retarder would also delay early strength development. Because of the large quantity of DCI used, the high water content of the DCI solution, and the necessity of adding the DCI at the end of the mixing process, the amount of water that could be added initially at the time of batching was much less than needed for adequate mixing.

Experience with trial batches indicated that to prevent excessive stickiness, promote better workability, reduce slump loss, and still provide an acceptable base for generation of a stable air void system, a minimum initial water content in the mixture was required.

Because of the initial low water content of the VES(A) and HES mixtures and the low W/C for all the HPCs, the use of a HRWR or superplasticizer was required for adequate workability. Two generic types of HRWR are commonly available: those based on naphthalene and those based on melamine. Typically, naphthalene-based HRWRs have a higher water reducing capacity but a greater tendency to retard set than melamine-based HRWRs. The HES mixtures used a naphthalene-based HRWR, and the VES(A) mixtures used a melamine-based HRWR.

4.1.4 Batching and Mixing Sequences

A rotating-drum mixer was used for all laboratory batches. *In order for the concrete mixtures to be easily transferred to plant production, the normal laboratory mixing procedures were modified.* Since the combination of HRWR and large cement content in a mixture could lead to fairly rapid slump loss, an extended period of mixing or agitating was used for VES and HES mixtures. Extended mixing times were also used for a few VHS mixtures, but it was found over time that the loss of slump of the VHS mixtures was not difficult to control with retarding admixtures.

The batching sequence was also modified slightly to more closely resemble typical concrete dry-batch plant operations. Mixing was initiated after charging the mixer with the initial mixing water, air-entraining admixture, and most of the aggregate. After a few minutes of mixing, the cement, remaining aggregate, and HRWR were added (with the mixer stopped for safety). Mixing was then continued for an additional time appropriate for the delivery of the concrete. Then the nonchloride set accelerator (DCI) was added and the concrete mixed for an additional 5 minutes before being discharged for testing and fabrication of specimens. For the VES (A), VES (B), and HES mixtures, a total of 30 minutes elapsed from the time water and cement were first mixed to the time concrete was discharged.

As noted above, because the DCI solution contains a large amount of the required mixing water and the DCI cannot be added to the mixtures until just before the concrete is discharged, the use of a HRWR at the beginning of batching is a practical necessity. Although modern HRWRs may have improved performance, earlier research by Smutzer and Zander (1985) indicated that delayed additions of HRWR can cause some reduction in frost durability. Therefore, redosing of HRWR was not permitted. The addition of the DCI increased the slump, because of the high dosage used, although slump loss was very rapid thereafter.

The dosage of AEA required for a given air content was increased due to the higher content of fines in the mixtures (ACI 1993b). However, the dosage of AEA necessary to create an adequate total air content was much higher than anticipated.

In addition, the air content was more difficult to control than normal because of the extended mixing, the delayed addition of the DCI, and the relatively rapid slump loss of the mixtures. The addition of the DCI resulted in a significant increase in slump with a concomitant increase in the air content in most cases. However, the response was very sensitive to the slump of the batch just before addition of the DCI. Having a higher initial water content helped to reduce these problems.

Also, trial batching in both summer and winter months led to changes in proportions or the use of warm water. In addition, aggregates were brought inside to stabilize their temperature before mixing. All these changes had an effect on fresh and hardened properties of the trial batches.

4.1.5 Screening of Trial Batches

During the developmental stage, most of the trial batches tested were limited in scope, and many were of limited utility because of inadequate slump or insufficient air content, particularly those in the early stages of development. Some of the trial batches were mixed to confirm or determine the influences of various mixture components, mixing requirements, or curing conditions. Other trial batches were conducted to refine mixture proportions to provide preliminary results for strength or frost durability.

In principle, the screening of trial batches for later, in-depth investigation followed a simple hierarchy of criteria. In the first place, if slump and air content were not acceptable, the mixture was clearly of limited value and would be discarded (see appendix B). If the slump and the air content were acceptable, the next criterion examined was strength, since it was easy to determine, especially for VES and HES mixtures. If the strength was acceptable, tests on frost durability would then be conducted. In some cases, preliminary frost durability studies were conducted; but in later trial batches, when minimum acceptable air contents had been established, full-scale testings were often started without waiting for the results of durability tests. In addition to these screening criteria, engineering judgment was also exercised by considering such aspects as workability, deliverability, and variability.

4.1.6 Modifications of the Definition of VES Concrete

During the developmental stage, several significant steps were taken that resulted in a series of modifications of the definition of VES concrete until the present definitions were adopted as given in section 1.1. This refinement is reflected in the large number of trial batches shown in appendix A for the VES concrete.

The strength criterion for the VES concrete was set initially at 3,000 psi (21 MPa) at 4 hours *after concrete placement,* with an extra 30 minutes being allowed for the batching and mixing sequence described previously. The maximum W/C was set at 0.35. This strength-time criterion was chosen after a review of published data on the performance of Pyrament blended cement.

cement. After consultations with the Expert Task Group of the project, two critical decisions were made. The first decision was that portland cement should be used in lieu of Pyrament blended cement because of questions about the long-term availability and technical performance of Pyrament cement. The second decision was to measure the time limit of 4 hours from *when water was first added to concrete* rather than from *concrete placement*. This change in time reference was intended to provide a less arbitrary definition and one that was more reproducible. Since the change amounted to only 30 minutes' reduction in hydration time, it made virtually no difference to the criteria for the HES and VHS concretes. However, the change affected the strength requirement for the VES concrete substantially.

When these two decisions were made, a considerable number of trial batches had been conducted for the development of HES mixture proportions based on Type III portland cement. The data obtained on the HES mixtures were used as guides to conduct additional trial batches involving different proportions with increased cement content, higher batching temperatures, and curing accelerated by insulating the concrete. Data from these additional tests indicated that strengths of 2,000 to 3,000 psi (14 to 21 MPa) were attainable within 6 hours by using 870 pounds per cubic yard (pcy) (516 kg/m^3) of Type III cement and 4 (gcy) (19.8 L/m^3) of DCI, maintaining the batch temperature at no less than 80°F (26.7°C), and insulating the concrete. So, the strength criterion for the VES concrete became 3,000 psi (21 MPa) at 6 hours.

Shortly thereafter, this criterion was modified to 2,000 psi (14 MPa) at 6 hours for several reasons. First, additional work indicated that the 3,000 psi (21 MPa) target was overly optimistic with some materials. Second, since the VES concrete was primarily intended for pavement work, a strength of 2,000 psi (14 MPa) was a more realistic requirement. Third, the temperature sensitivity of the mixture was somewhat reduced. With this revised criterion for the VES concrete, it was possible to use the same mixture proportion for both the VES and HES concretes, making insulation for the VES concrete the only difference between the two. This approach worked reasonably well for the field trials in North Carolina, Illinois, Arkansas, and Nebraska.

After the field trials, many attempts were made to change the definition of the VES concrete back to 3,000 psi (21 MPa) within 4 hours. More leeway was given, such as increasing the W/C limit, in the development of a portland-cement-based VES mixture that met the more restrictive strength-time criterion. After repeated trials, there was no success in producing a portland-cement-based VES concrete with the desired strength at 4 hours that would have performance characteristics acceptable in practice and did not contain calcium chloride.

By examining time-temperature curves for many of the trial batches, it was found that delays in concrete setting time accounted for much of the delay in early strength gain. Since the amount of HRWR required to maintain the low W/C was found to retard the setting time of the concrete mixture, and thus hurt the very early strength development, the limitation on W/C was then relaxed. This provided more flexibility, but the strengths attained at 4 hours were still low. After reviewing the results of this final phase of the research, it was decided to create two categories of VES concrete, as outlined in section 1.1, one based on portland cement and the other based on Pyrament blended cement.

4.2 Production Phase

From the extensive series of trial batches summarized in appendix A, 21 different mixture proportions were selected for in-depth study and evaluation of the mechanical behavior of the different categories of HPC as defined in section 1.1. The 21 mixture proportions are detailed in Tables 4.1 through 4.6.

Laboratory production of concrete based on these mixture proportions for testing and evaluation of mechanical behavior was limited to small batch sizes, large enough to yield enough material for the specimens required in a given test series. The batch size was dictated partly by the capacity of the drum mixer in the laboratory and partly by the *very tight testing schedule.* Since small variations in time would have a significant impact on the properties of VES mixtures and a not inconsequential effect on the properties of HES mixtures, it was necessary to keep the time for specimen preparation and testing very short.

However, it should be noted that the selected mixture proportions and batching, mixing, and accelerated curing methods developed in the laboratory were largely confirmed in large-scale productions for five field trials, even though there were larger strength variations from the target values, as one would expect under the production conditions in the field. Detailed discussions of the five field trials are given in *Volume 4: High Early Strength (HES) Concrete* of this report series.

Table 4.1 Mixture proportions of VES (A) concrete with four different aggregate types

Coarse aggregate type: **Source of sand:**	**CG** **Lillington**	**MM** **Lillington**	**RG** **Memphis**	**DL** **Van Buren**
Cement (Type III), pcy	870	870	870	870
Coarse aggregate, pcy	1,720	1,570	1,650	1,680
Sand, pcy	820	800	760	920
HRWR (melamine based), oz/cwt	5.0	5.0	10	4.0
Calcium nitrite (DCI), gcy	6.0	6.0	6.0	6.0
AEA, oz/cwt	3.0	2.5	4.0	2.5
Water, pcy	350	350	350	340
W/C	0.40	0.40	0.40	0.39
Slump, in.	5	7	6	5.75
Air, %	6.5	6.4	7.5	4.40
Strength at 6 hr, psi (insulated)	2,090	2,000	2,360	3,090
Concrete temperature at placement, ^{O}F	71	75	79	78

Note: 1 MPa = 145 psi

Table 4.2 Mixture proportions of VES (B) concrete with four different aggregate types

Aggregate type: Source of sand:	CG Lillington	MM Lillington	RG Memphis	DL Van Buren
Cement (Pyrament), pcy	850	850	850	855
Coarse aggregate, pcy	1,510	1,500	1,510	1,680
Sand, pcy	1,440	1,460	1,400	1,560
HRWR (Melamine Based), oz/cwt	0	0	0	0
Calcium nitrite (DCI), gcy	0	0	0	0
AEA, oz/cwt	0	0	0	0
Water, pcy	195	145	183	200
W/C	0.23	0.17	0.22	0.23
Slump, in.	6.5	4	3.5	7.0
Air, %	6.0	7.0	3.7	7.6
Strength at 4 hr, psi (insulated)	2,510	2,270	3,060	2,890
Concrete temperature at placement, ^{O}F	72	72	75	77

Note: 1 MPa = 145 psi

Table 4.3 Mixture proportions of HES concrete with four different aggregate types

Aggregate type: Source of sand:	CG Lillington	MM Lillington	RG Memphis	DL Van Buren
Cement (Type III), pcy	870	870	870	870
Coarse aggregate, pcy	1,720	1,570	1,650	1,680
Sand, pcy	960	980	900	1,030
HRWR (Naphthalene Based), oz/cwt	26	26	26	16
Calcium nitrite (DCI), gcy	4.0	4.0	4.0	4.0
AEA, oz/cwt	9	1.0	1.0	4.0
Water, pcy	280	280	300	300
W/C	0.32	0.32	0.34	0.34
Slump, in.	1.0	6.75	7.0	3.5
Air, %	5.3	5.6	6.6	5.4
Strength at 1 day, psi	5,410	5,610	5,690	5,300
Concrete temperature at placement, ^{O}F	80	73	84	78

Note: 1 MPa = 145 psi

Table 4.4 Mixture proportion of HES concrete with latex

Aggregate type	MM
Cement (Type III), pcy	870
Coarse aggregate, pcy	1,570
Sand (Lillington), pcy	930
Latex (48% solids), pcy	231
HRWR (naphthalene based), oz/cwt	0
Calcium nitrite (DCI), gcy	0
AEA, oz/cwt	0
Water, pcy	300
W/C	0.34
Slump, in	--
Air, %	2.1
Strength at 1 day, psi	4,225
Concrete temperature at placement, ^{O}F	65

Note: 1 MPa = 145 psi

Table 4.5 Mixture proportions of VHS concrete with fly ash

Aggregate type: Source of sand: Type of fly ash:	CG Lillington F	MM Lillington F	RG Memphis F	DL Van Buren C
Cement (Type I), pcy	830	830	830	830
Fly ash, pcy	200	200	200	200
Coarse aggregate, pcy	1,720	1,570	1,650	1,680
Sand, pcy	937	900	860	1,020
HRWR (Naphthalene Based), oz/cwt	26	20	20	18
Retarder, oz/cwt	3.0	3.0	3.0	3.0
AEA, oz/cwt	3.5	1.3	1.2	2.5
Water, pcy	240	240	240	240
W/(C+FA)	0.23	0.23	0.23	0.23
Slump, in.	3.5	10	7.0	3.75
Air, %	5.5	8.0	2.0	4.8
Strength at 28 days, psi	12,200	7,620	8,970	9,833
Concrete temperature at placement, ^{O}F	80	72	69	76

Note: 1 MPa = 145 psi
W/(C+FA) = ratio of weight of water to combined weight of cement and fly ash

Table 4.6 Mixture proportions of VHS concrete with silica fume

Aggregate type: Source of sand:	CG Lillington	MM Lillington	RG Memphis	DL Van Buren
Cement (Type I), pcy	760	760	760	770
Silica fume, pcy	35	35	35	35
Coarse aggregate, pcy	1,720	1,570	1,650	1,680
Sand, pcy	1,205	1,140	1,150	1,250
HRWR (naphthalene based), oz/cwt	14	12	14	17
Retarder, oz/cwt	2.0	2.0	3.0	3.0
AEA, oz/cwt	0.9	0.6	0.9	1.5
Water, pcy	230	240	240	230
W/(C+SF)	0.29	0.30	0.30	0.29
Slump, in.	2.75	4.25	3.0	2.75
Air, %	5.0	5.6	7.3	5.1
Strength at 28 days, psi	11,780	8,460	9,120	10,010
Concrete temperature at placement, ^{O}F	80	77	80	75

Note: 1 MPa = 145 psi
W/(C+SF) = ratio of weight of water to combined weight of cement and silica fume

5

Mixing Procedures

Concretes made with CG, MM, or RG were produced in the Concrete Materials Laboratory at NCSU using a tilt-drum mixer with a rated capacity of 3.5 ft^3 (0.1 m^3). Concretes using DL were produced also with an identical mixer in the Concrete Laboratory at Arkansas. The normal laboratory mixing and batching procedures (ASTM C 192) were modified slightly to represent more closely typical concrete dry-batch plant operations. Whether the concrete was produced at NCSU or Arkansas, generally the same mixing procedures as described below were followed.

5.1 VES (A) and HES Concretes

Both VES (A) and HES concretes used Type III portland cement, with calcium nitrite (DCI) as an accelerator. The mixing procedures used for these two types of HPC were the same and are as follows:

1. Butter the mixer with a representative sample of mortar composed of approximately 3 lb (1.36 kg) of cement, 6 lb (2.73 kg) of sand, and 2 lb (0.91 kg) of water. Turn on the mixer to coat the inside of the mixer completely. (Only water was used to butter the mixer at Arkansas.) Empty the mixer and drain it for 1 minute.

2. Charge the mixer successively with approximately 25% of coarse aggregate, 100% of sand, 50% of water, and 100% of AEA added with the sand. Mix for 1 minute to generate air bubbles. (At Arkansas, the mixer was charged with 50% of coarse aggregate, 67% of sand, and 67% of water.)

3. Stop the mixer and add remaining coarse aggregate and water. Mix for 1 minute (if needed) to equalize the temperature of the materials. Otherwise mix 10 seconds and then add the entire amount of cement. Record the time as the beginning of the total mixing time. After mixing for 1 minute, stop the mixer; add the HRWR and continue mixing for 5 minutes. During all mixing, cover the mixer with a lid to minimize evaporation.

4. Mix continuously for 20 minutes to simulate travel time for a ready-mix truck. Then stop the mixer and add DCI. Mix for an additional 5 minutes. (Total mixing time beginning with the addition of cement is approximately 30 minutes.)

5. Discharge the concrete into a wheelbarrow; measure unit weight, air content, slump, and temperature; and fabricate test specimens.

5.2 VES (B) Concrete

VES (B) concrete used PBC-XT cement, and the mixing procedures are as follows:

1. Butter the mixer with a representative sample of mortar composed of approximately 3 lb (1.36 kg) of cement, 6 lb (2.73 kg) of sand, and 2 lb (0.91 kg) of water. Turn on the mixer to coat the inside of the mixer completely. (At Arkansas, only water was used to butter the mixer.) Empty the mixer and drain it for 1 minute.

2. Charge the mixer successively with the entire amount of coarse aggregate, sand, and water. Mix for 10 seconds (1 minute at Arkansas) to coat the rock and sand with water. Ensure that the materials are of the same temperature.

3. Stop the mixer and add the entire amount of PBC-XT cement. Record the time as the beginning of the total mixing time. During all mixing, cover the mixer with a lid to minimize evaporation.

4. Mix continuously for 30 minutes to simulate travel time for a ready-mix truck. (The concrete may appear dry initially; resist the temptation to add water. Workability will gradually improve with continued mixing. The total mixing time, beginning with the addition of PBC-XT cement, is 30 minutes.)

5. Discharge the concrete into a wheelbarrow; measure unit weight, air content, slump, and temperature; and fabricate test specimens.

5.3 VHS Concrete

VHS concretes used Type I portland cement and either fly ash or silica fume as pozzolan. The mixing procedures are as follows:

1. Butter the mixer with a representative sample of mortar composed of approximately 3 lb (1.36 kg) of cement, 6 lb (2.73 kg) of sand, and 2 lb (0.91 kg) of water. Turn on the mixer to coat the inside of the mixer completely. (At Arkansas, only water was used to butter the mixer.) Empty the mixer and drain it for 1 minute.

2. Charge the mixer successively with approximately 25% of coarse aggregate, 67% of sand, 50% of water, and 100% of AEA added with the sand. Mix for 1 minute to generate air bubbles. The amount of water may be varied slightly to obtain a thick slurry. (At Arkansas, the mixer was charged with 0.33% of coarse aggregate, 50% of sand, and 67% of water.)

3. Stop the mixer and add the remaining coarse aggregate, sand, water, and retarder. Mix for 10 seconds to coat sand and rock with water. If silica fume is used, add it with the sand.

4. Add cement (and fly ash, if used). Record the time as the beginning of the total mixing time. Mix for 1 minute. Stop the mixer and add the HRWR. Mix for a minimum of 10 minutes, until a homogeneous mass of acceptable workability has been achieved. During all mixing, cover the mixer with a lid to minimize evaporation.

5. Discharge the concrete into a wheelbarrow; measure unit weight, air content, slump, and temperature; and fabricate test specimens.

6

Curing Procedures

Curing procedures were developed to simulate more closely the conditions in the field, and were considerably different from the normal laboratory curing procedure (ASTM C 192). The procedures differed for different categories of HPC. For VES concrete, whether using Type III portland cement or PBC-XT cement, insulation was used to achieve rapid strength gain in the first few hours. For HES and VHS concretes, the demand for early strength gain was not as critical; thus, it was not necessary to use insulation. The detailed procedures used for the three categories of HPC are described below.

6.1 VES Concrete

For each batch of concrete produced, an appropriate number of control cylinders were cast in 4 x 8-in. (100 x 200-mm) plastic molds. The cylinders were placed immediately in a Styrofoam block serving as an insulating jacket.

At NCSU, the Styrofoam block was made by gluing together a stack of eight sheets of 1-in. (25-mm) thick Styrofoam board. Through the 8-in. (200-mm) thickness of this block, several 4.25-in. (108-mm) holes were bored. This block was then glued to a base sheet of 1-in. (25-mm) thick Styrofoam that was, in turn, backed by a 0.5-in. (13-mm) sheet of plywood. Each control cylinder, together with its plastic mold, was then stored in the bored hole in the Styrofoam block. The block was then covered with a top Styrofoam sheet made in the same way as the base sheet. Figure 6.1 shows a view of the Styrofoam block used at NCSU. The block used at Arkansas was constructed of six sheets of 2-in. (50-mm) Styrofoam board glued together as shown in Figure 6.2.

After the cylinders were stored in the Styrofoam block for 6 hours for VES (A) or 4 hours for VES (B), they were removed from the insulation block and stripped from their molds. Several of the cylinders were tested immediately for compressive strength, and the remaining cylinders were stored in sealed plastic bags under the normal laboratory conditions until they were tested at later ages.

The purpose of placing the cylinders in the plastic bags was not so much to ensure continued curing as to control the rate of evaporation of the specimens. Although the concrete at the job site would be covered with curing compound, opening a pavement structure to traffic at 4 or 6 hours would probably result in loss of the compound fairly soon. The concrete would, therefore, be exposed to evaporation of internal water soon after the design age. However, evaporation would be somewhat slowed, since only one face of the pavement would be exposed. The plastic bag would reduce evaporation compared to exposure of the specimen to laboratory air (50% relatlive humidity [RH]) but would not prevent it. Such curing would not provide unrealistically optimistic strength values nor reproduce unrealistic strength-gain characteristics.

Although any proposed curing method would be arguable, clearly standard (100% RH) curing methods are so unrealistic for the applications of this type of material that they should be rejected immediately.

In addition to the 4 x 8-in. (100 x 200-mm) cylinders, three 6 x 12-in. (150 cm x 300-mm) cylinders were also cast for each batch of concrete These larger cylinders were cured inside an

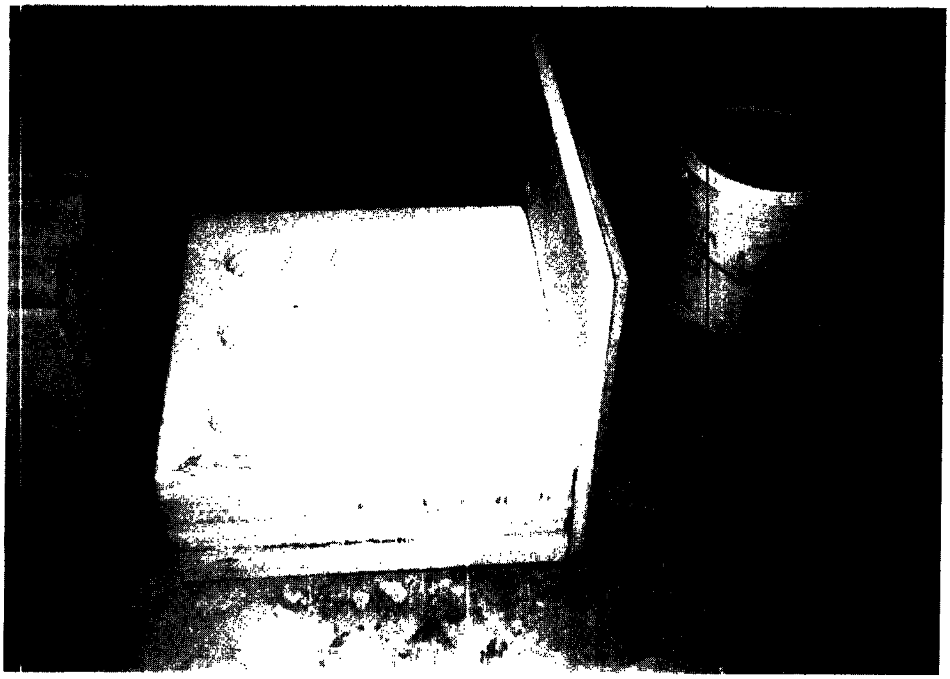

Figure 6.1 Styrofoam insulation block used for curing concrete cylinders at NCSU

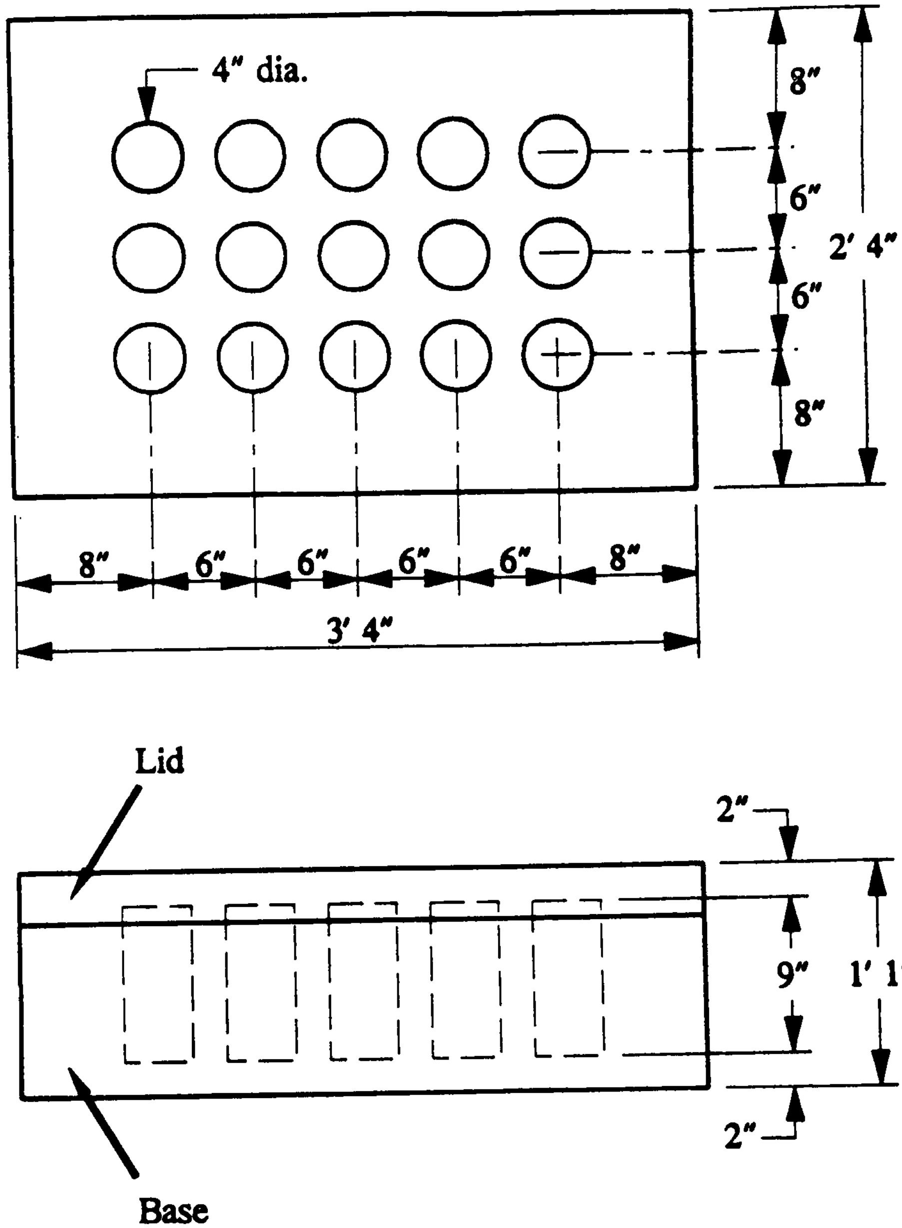

Figure 6.2 Styrofoam insulation block used for curing concrete cylinders at Arkansas

insulation block similarly to the small cylinders and were also tested for compressive strength at 6 hours or 4 hours, as appropriate, for comparison with the results from the smaller cylinders. The comparison was used to investigate possible size effects.

Beam specimens for flexure or freeze-thaw tests were cast in steel forms, as were their companion cylinders. After they were cast, these specimens and cylinders were kept in an insulation box for 6 or 4 hours. Once removed from the insulation box and stripped from their forms, some were tested immediately and others were stored in sealed plastic bags to be tested at later ages.

The inside dimensions of the insulation box are 40-in. (100-cm) wide, 43-in. (108-cm) long, and 21-in. (53-cm) deep. The side walls of the box are made of 1.5-in. (38-mm) Styrofoam insulation sandwiched between two sheets of 0.75-in. (19-mm) plywood. The base and the cover of the box are also made of 1.5-in. (38-mm) Styrofoam insulation, but sandwiched between two sheets of 0.5-in. (13-mm) plywood. Figure 6.3 shows a view of the insulation box.

Interestingly, during early testing of HES mixtures, cylinders made in steel molds were found to give lower average strengths at 1 day, compared with those made in plastic molds. This lower strength was found to be due to more rapid heat loss of the concrete during fabrication with steel molds.

6.2 HES Concrete

Cylinders of HES concrete were cast in 4 x 8-in. (100 x 200-mm) plastic molds, and beam specimens were cast in steel forms. These specimens were maintained at 60 to 80°F (15.6 to 26.7°C), protected from evaporation until an age of 20 to 24 hours, at which time they were removed from molds and either tested immediately or placed in sealed plastic bags to be tested at later ages.

6.3 VHS Concrete

VHS concrete specimens were cast in steel molds (but in plastic molds at Arkansas) and maintained for the first 20 to 24 hours at 60 to 80°F (15.6 to 26.7°C), protected from evaporation, at which time they were removed from their molds and placed in an atmosphere with 100% RH at 71 to 75°F (21.7 to 23.9°C) until testing. Some of the specimens with dense limestone were soaked in limewater. After the specimens were removed from the moist curing room or limewater bath, they were allowed to dry in the laboratory for at least 1 hour before they were tested for strength. The drying was necessary to permit adhesion of linear voltage differential transducer connections during testing.

Figure 6.3 Insulated curing box for concrete specimens

7

Test Results

Based on the general guidelines and various considerations regarding the formulation of mixture proportions discussed in section 4, an extensive development work was conducted in search of appropriate mixture proportions for the various types of HPC considered in this research program. A total of 360 trial batches of concrete were mixed and their properties evaluated. A major effort was devoted to the formulation and experimentation of VES concrete in view of its stringent performance requirements. Table 7.1 is an overview of the development work.

Table 7.1 Overview of the development work

Concrete Type	Aggregate Type	No. of Trial Batches
VES	CG	99
VES	MM	35
VES	RG	27
VES	DL	42
HES	CG	21
HES	MM	11
HES	RG	9
HES	DL	40
VHS	CG	27
VHS	MM	16
VHS	RG	12
VHS	DL	21

The details of the mix proportions of all trial batches are presented in appendix A. They are summarized in a series of 12 tables (see Tables A.1 through A.12), one for each concrete-aggregate combination. The first column in each table provides a unique reference number for a specific trial batch so that it can be used easily for cross reference to the corresponding entry in appendix B.

After each trial batch was mixed, the temperature, slump, air content, and unit weight of the plastic concrete were measured. The trial batch was then evaluated successively against four basic characteristics: good workability, adequate air content, sufficient design strength, and acceptable durability. If the trial batch failed to develop any one of these four characteristics, it was excluded from further consideration. It is obvious that to make such an evaluation, one must exercise certain judgment. Initially, a 4-in. (100-mm) slump as a target value was used as a measure for good workability, and a target value of 6% air content (applied to portland cement mixtures only) as a measure for some assurance of acceptable durability. Because of extended mixing times, rapid hydration, and warm initial temperatures, slumps after 30 to 45 minutes often became somewhat lower. However, even with lower slumps, the concrete responded well to vibration, and it was not difficult to obtain an adequate finish because of the higher content of fines in the concrete.

The concrete properties measured for each trial batch are presented in appendix B. They are summarized in a series of 12 tables (see Tables B.1 through B.12). By using the reference number in the first column of each table, each entry can be cross-referenced to the same trial batch given in appendix A to obtain the data on mixture proportion for the specific trial batch. The number in the last column of each table refers to one of the footnotes that explains the reason for rejection of the particular trial batch. For example, the trial batch with reference number 20 in Table B.1 is identified with note 1 in the last column of the table. This note indicates that the trial batch was rejected because of inadequate initial slump of 1.5 in. (38 mm). Similarly, a trial batch might be rejected because of inadequate air content (note 2), inadequate design strength (note 3), inadequate freezing-thawing resistance (note 4), or other inadequate performance such as rapid change in workability, deliverability, or lack of reproduceability (note 5).

The trial batches that satisfied the four basic characteristics were identified as the potential HPC for reproduction and further study. These trial batches are identified by an asterisk in the left-hand margin of the tables in appendixes A and B.

It should be pointed out that even though a very large number of trial batches were prepared and evaluated in this research program, not enough test replications were carried out, because of the breadth of the program and the large number of parameters involved. Therefore, it is not statistically meaningful to analyze the large amount of data contained in appendixes A and B.

8

Conclusions

An extensive test program was conducted to develop mixture proportions of three categories of HPC intended primarily for highway applications. The test program included 360 trial batches, covering VES concrete for pavement repairs, HES concrete for bridge structures and pavements, and VHS concrete for structural applications. For each category of HPC, four different types of aggregates with different chemical and mineral admixtures were investigated. In view of its stringent performance requirements, a major effort was devoted to the formulation and experimentation of VES concrete.

In the development of the various mixture proportions, several critical factors were considered. First and foremost is that the concrete's performance must be reasonably predictable and reproducible under field conditions. Conventional materials that are readily available should be used, and the concrete should be produced with standard equipment and routine mixing, placing, and curing procedures.

Through this development program, 21 mixture proportions of HPC were produced successfully, as summarized in Tables 4.1 through 4.6. Each of these mixtures was reproduced several times in the laboratory for studies of its mechanical behaviors in both plastic and hardened states. Certain VES and HES mixtures and the batching, mixing, and accelerated curing methods developed in the laboratory were confirmed in large-scale productions for five field trials, which are discussed in detail in *Volume 4: High Early Strength (HES) Concrete* of this report series.

From the experience of laboratory experiments and field trials, it is concluded that the three categories of HPC considered in this investigation can be successfully produced in the field. For VES and HES mixtures, because of the rapid hydration, higher variation in slump and air content of the concrete can be expected when compared with conventional concrete.

To produce the HPC in the field, it is important to take several precautionary steps for quality assurance:

1. Using the mixture proportions developed in this investigation as a guide, conduct trial batches in the laboratory, before field placement, with the specific raw materials to be

used. Trials allow refinement of the batch weights before further adjustments needed in the field and reduces confusion during initial practice placements.

2. Before concrete placement, conduct preconstruction meetings with all key personnel involved, including construction managers, batch plant operators, and finishing crew foremen.

3. Include at least one practice placement of the concrete, and expect a significant learning experience. Generally, one full day should be allowed for the practice placement.

4. Pay attention to truck load size and batching sequence. Be especially sensitive to truck condition and mixing efficiency. Keep the load to no more than two thirds of the maximum rated mixing capacity of the truck. In some cases, it may be advisable to reduce the truck load to no more than half the rated mixing capacity.

5. Discharge the concrete quickly at the job site. If the concrete is to be insulated, minimize the time before the insulation is placed. Sawing of the pavement joints should be scheduled for no later than 8 hours after concrete placement or immediately after removal of insulation.

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Appendix A

Mixture Proportions of Trial Batches of High Performance Concrete

Abbreviations Used in Tables

AEA	=	air-entraining agent
CMT	=	cement
DCI	=	Darex Corrosion Inhibitor (calcium nitrite)
FA	=	fly ash
gcy	=	gallons per cubic yard
HRWR	=	high-range water reducer
pcy	=	pounds per cubic yard
RTDR	=	retarder
SF	=	silica fume
W/C	=	water to cementitious materias (by weight)

Table A.1 Mixture proportions for the trial batches of VES (CG) concrete

Ref.	Mixing	Batch	Cementitious Material				Aggregate		Water	W/C	Admixtures						
			CMT	CMT	FA	SF	Coarse	Fine			HRWR		Latex	DCI	RTDR	CaCl	AEA
No.	Date	ID	Type	pcy	pcy	pcy	pcy	pcy	pcy		Type	oz/cwt	gcy	gcy	oz/cwt	% CMT	oz/cwt
1	10/13/90	CVALT1	III	820	0	0	1720	1140	302	0.36	N	9	0	6	0	0	0.5
2	10/19/90	CVALT2	III	800	0	0	1720	1170	286	0.36	N	10	0	6.5	0	0	0.6
3	10/25/90	C/VE(C)/1	III	830	0	0	1720	1080	311	0.38	M	12	0	6.3	0	0	0.8
4	10/31/90	CVALT3	III	830	0	0	1720	1080	326	0.39	M	12	0	6.3	0	0	0.9
5	10/31/90	CVALT4	III	830	0	0	1720	1080	305	0.36	N	8	0	6.3	0	0	0.8
6	10/31/90	CVALT5	III	830	0	0	1720	1080	305	0.36	N	8	0	6.3	0	0	0.8
7	11/09/90	CVALT6	III	830	0	0	1720	1080	304	0.36	N	8	0	6.3	0	0	0.8
8	11/21/90	CVALT7	III	830	0	0	1720	1040	310	0.37	N	10	0	6.3	0	0	1.8
9	01/15/91	CVALT8	III	860	0	0	1720	990	311	0.36	–	0	0	6	0	0	3.5
10	01/15/91	CVALT9	III	860	0	21.5	1730	970	309	0.35	–	0	0	6	0	0	3.5
11	03/23/91	CVALT10	III	850	0	0	1720	1000	312	0.37	M	12	0	6	0	0	3.5
12	03/23/91	CVALT11	III	850	0	25.5	1720	960	315	0.36	M	12	0	6	0	0	3.5
13	03/23/91	CVALT12	III	850	0	25.5	1720	960	314	0.36	M	12	0	6	0	0	3.5
14	03/26/91	CVALT13	III	950	0	0	1720	910	319	0.33	M	12	0	6	0	0	4
15	03/26/91	CVALT14	III	850	0	0	1720	1000	319	0.36	M	12	0	4.5	0	1	4
16	03/26/91	CVALT15	III	850	0	0	1720	1000	312	0.36	M	12	0	4.5	0	2	4
17	04/02/91	CVALT16	III	850	0	0	1720	1000	304	0.37	M	14	0	4.5	0	0.5	4
18	04/02/91	CVALT17	III	850	0	0	1720	1000	327	0.36	M	14	0	0	0	0.5	4
19	04/04/91	CVALT18	III	850	0	0	1720	1000	321	0.37	M	14	0	0	0	1	4
20	04/04/91	CVALT19	III	850	0	0	1720	1000	309	0.36	M	14	0	0	0	1	4
21	04/09/91	CVALT20	III	870	0	0	1720	970	322	0.37	M	16	0	5	0	1	4
22	04/16/91	CVALT21	III	940	0	0	1720	870	320	0.34	M	18	0	5	0	1	4
23	04/30/91	C/VE(CC)/3	III	940	0	0	1720	860	320	0.34	M	18	0	5	0	1	4
24	06/18/91	C/VE(CC)/1	III	940	0	0	1720	860	320	0.34	M	18	0	5	0	1	5
25	06/28/91	CVALT22	III	940	0	0	1720	863	320	0.34	M	18	0	5	0	1	5
26	07/09/91	CVALT23	III	940	0	0	1720	863	320	0.34	M	28	0	5	0	0	10
27	07/15/91	CVALT24	III	940	0	0	1720	858	305	0.32	M	28	0	5	0	0	9
28	08/29/91	CVALT25	III	870	0	0	1720	909	300	0.34	M	30	0	4	0	0	10

Continued on next page

Table A.1 Mixture proportions for the trial batches of VES (CG) concrete -- Continued

Ref.	Mixing	Batch	Cementitious Material				Aggregate		Water	W/C	Admixtures								
			CMT	CMT	FA	SF	Coarse	Fine			HRWR		Latex	DCI	RTDR	CaCl	AEA	
No.	Date	ID	Type	pcy	pcy	pcy	pcy	pcy	pcy		Type	oz/cwt	gcy	gcy	oz/cwt	% CMT	oz/cwt	
29	09/25/91	CVALT26	XT	940	0	0	1720	1009	255	0.27	–	0	0	0	0	0	0	
30	09/25/91	CVALT27	XXT	940	0	0	1720	1009	255	0.27	–	0	0	0	0	0	0	
31	09/30/91	CVALT28	XT	940	0	0	1680	1100	235	0.25	–	0	0	0	0	0	0	
32	09/30/91	CVALT29	XXT	940	0	0	1680	1100	235	0.25	–	0	0	0	0	0	0	
33	11/20/91	CVALT30	XT	750	0	0	1720	1390	175	0.23	–	0	0	0	0	0	0	
34	12/17/91	CVALT31	III	870	0	0	1720	910	300	0.34	M	26	0	6	0	0	1	
35	12/18/91	CVALT32	III	950	0	0	1720	800	315	0.33	M	26	0	6	0	0	1.1	
36	12/19/91	CVALT33	III	870	0	0	1720	910	300	0.34	M	30	0	8	0	0	1.5	
37	12/20/91	CVALT34	III	920	0	0	1720	690	370	0.40	–	0	0	6	0	0	1.1	
38	12/21/91	CVALT35	III	920	0	0	1720	690	370	0.40	–	0	0	6	0	0	1.2	
39	12/21/91	CVALT36	III	950	0	0	1720	800	315	0.33	M	30	0	8	0	0	1.3	
40	12/23/91	CVALT37	III	920	0	0	1720	690	370	0.40	–	0	0	6	0	0	1.4	
41	12/23/91	CVALT38	III	950	0	0	1720	790	320	0.34	M	12	0	6	0	0	1.4	
42	01/04/92	CVALT39	III	940	0	0	1720	800	320	0.34	M	12	0	6	0	0	3	
43	01/04/92	CVALT40	III	940	0	0	1720	650	380	0.40	–	0	0	6	0	0	1.9	
44	01/06/92	CVALT41	III	940	0	0	1720	800	320	0.34	M	12	0	6	0	0	4	
45	01/07/92	C/VE(C)/3	III	940	0	0	1720	650	380	0.40	–	0	0	6	0	0	1.8	
46	01/10/92	C/VE(C)/.34	III	940	0	0	1720	800	320	0.34	M	12	0	6	0	0	5	
47	01/22/92	CVALT42	III	940	0	0	1720	650	380	0.40	M	0	0	6	0	0	1.7	(a)
48	02/05/92	CVALT43	SLAG	940	0	0	1720	1130	190	0.20	–	0	0	0	0	0	0	(b)
49	02/26/92	CVALT44	III	870	0	0	1720	910	300	0.34	M	26	0	6	0	0	1.2	
50	02/28/92	CVALT45	III	870	0	0	1720	910	300	0.34	M	26	0	6	0	0	1.4	
51	03/04/92	CVALT46	III	870	0	0	1720	910	350	0.40	–	0	0	6	0	0	1.8	
52	03/04/92	CVALT47	III	870	0	0	1720	910	350	0.40	M	5	0	6	0	0	3	
53	03/05/92	CVALT48	III	870	0	0	1720	780	350	0.40	M	10	0	6	0	0	4	
54	03/05/92	CVALT49	III	870	0	0	1720	780	350	0.40	M	20	0	6	0	0	0	
55	03/05/92	CVALT50	III	870	0	0	1720	780	350	0.40	M	20	0	6	0	0	4.5	
56	03/05/92	CVALT51	XT	850	0	0	1720	1220	210	0.25	–	0	0	0	0	0	0	

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Table A.1 Mixture proportions for the trial batches of VES (CG) concrete -- Continued

Ref. No.	Mixing Date	Batch ID	Cementitious Material: CMT Type	Cementitious Material: CMT pcy	Cementitious Material: FA pcy	Cementitious Material: SF pcy	Aggregate: Coarse pcy	Aggregate: Fine pcy	Water pcy	W/C	Admixtures: HRWR Type	Admixtures: HRWR oz/cwt	Admixtures: Latex gcy	Admixtures: DCI gcy	Admixtures: RTDR oz/cwt	Admixtures: CaCl % CMT	Admixtures: AEA oz/cwt
57	03/09/92	CVALT52	III	870	0	0	1720	780	350	0.40	–	0	0	4	0	0	5
58	03/09/92	CVALT53	III	870	0	0	1720	780	350	0.40	M	8	0	4	0	0	10
* 59	03/09/92	CVALT54	XT	850	0	0	1720	1260	195	0.23	–	0	0	0	0	0	0
60	03/11/92	C/VE(PYR)/3	XT	850	0	0	1720	1290	180	0.21	–	0	0	0	0	0	0
61	03/11/92	CVALT55	III	870	0	0	1720	780	350	0.40	M	8	0	5	0	0	8
62	03/11/92	CVALT56	III	870	0	0	1720	780	350	0.40	M	8	0	5	0	0	7
63	03/13/92	CVALT57	XT	850	0	0	1720	1160	190	0.22	–	0	0	0	0	0	0
64	03/13/92	C/VE(C)/3R5	III	870	0	0	1720	820	350	0.40	M	7.5	0	6	0	0	3.5
* 65	03/20/92	CVALT58	XT	850	0	0	1720	1440	195	0.23	–	0	0	0	0	0	0
* 66	03/20/92	CVALT59	III	870	0	0	1720	820	350	0.40	M	5	0	6	0	0	3
* 67	03/23/92	C/VE(C)/3R6	III	870	0	0	1720	820	350	0.40	M	5	0	6	0	0	3
* 68	03/25/92	C/VE(PYR)/3	XT	850	0	0	1510	1440	195	0.23	–	0	0	0	0	0	0
* 69	04/08/92	C/VE(C)/1	III	870	0	0	1720	820	350	0.40	M	5	0	6	0	0	3
70	04/20/92	C/VE(PYR)/1	XT	850	0	0	1510	1440	195	0.23	–	0	0	0	0	0	0
* 71	05/08/92	C/VE(C*)/3	III	870	0	0	1720	780	350	0.40	M	5	0	6	0	0	2.5
72	05/13/92	C/VE(C)/2	III	870	0	0	1720	780	350	0.40	M	5	0	6	0	0	2.2
73	05/19/92	C/VE(CS)/3N	III	870	0	21.8	1720	910	360	0.40	M	10	0	6	0	0	0
74	05/27/92	C/VE(PYR)/2	XT	850	0	0	1510	1440	195	0.23	–	0	0	0	0	0	0
* 75	05/27/92	CVALT59	III	870	0	0	1720	780	350	0.40	M	5	0	6	0	0	2
76	05/27/92	CVALT60	III	870	0	0	1720	780	350	0.40	M	5	0	4	0	0	2
77	05/28/92	CVALT61	III	870	0	0	1720	780	350	0.40	M	5	0	2	0	0	2
78	05/29/92	CVALT62	III	870	0	0	1720	780	350	0.40	M	5	0	0	0	0	2
79	06/10/92	CVALT63	III	870	0	0	1720	780	350	0.40	M	5	0	6	0	0	2
80	06/10/92	CVALT64	III	870	0	9.65	1720	770	350	0.40	M	5	0	6	0	0	2
81	06/11/92	CVALT65	III	870	0	19.3	1720	750	355	0.40	M	5	0	6	0	0	2
82	06/11/92	CVALT66	III	870	0	29	1720	740	355	0.40	M	5	0	6	0	0	2
83	06/16/92	CVALT67	III	870	0	38.7	1720	720	360	0.40	M	5	0	6	0	0	2
84	06/16/92	CVALT68	III	870	0	48.3	1720	690	365	0.40	M	5	0	6	0	0	2

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Table A.1 Mixture proportions for the trial batches of VES (CG) concrete -- Continued

Ref.	Mixing	Batch	Cementitious Material				Aggregate		Water	W/C	Admixtures							
			CMT	CMT	FA	SF	Coarse	Fine			HRWR		Latex	DCI	RTDR	CaCl	AEA
No.	Date	ID	Type	pcy	pcy	pcy	pcy	pcy	pcy		Type	oz/cwt	gcy	gcy	oz/cwt	% CMT	oz/cwt
85	06/23/92	C/VE(C)/J	III	870	0	0	1720	780	350	0.40	M	5	0	6	0	0	2
86	07/16/92	CVALT69	I	870	0	0	1720	920	295	0.34	M	5	0	6	0	0	1.8
87	07/17/92	CVALT70	I	870	0	0	1720	920	295	0.34	M	5	0	6	0	0	1.8
88	07/21/92	CVALT71	III	870	0	0	1720	780	350	0.40	M	5	0	6	15	0	2
89	07/21/92	CVALT72	III	870	0	0	1720	780	350	0.40	M	5	0	4	15	0	2
90	07/22/92	CVALT73	III	870	0	0	1720	780	350	0.40	M	5	0	2	3	0	2
91	07/22/92	CVALT74	III	870	0	0	1720	780	350	0.40	M	5	0	0	3	0	2
92	07/23/92	CVALT77	III	870	0	0	1720	780	350	0.40	M	5	0	6	3	0	2
93	07/23/92	CVALT78	III	870	0	0	1720	780	350	0.40	M	5	0	4	3	0	2
94	07/29/92	CVALT79	III	870	0	0	1720	780	350	0.40	M	5	0	6	6	0	1.8
95	07/29/92	CVALT80	III	870	0	0	1720	780	350	0.40	M	5	0	4	6	0	1.8
96	07/29/92	CVALT81	III	870	0	0	1720	780	350	0.40	M	5	0	2	6	0	1.8
97	07/29/92	CVALT82	III	870	0	0	1720	780	350	0.40	M	5	0	0	6	0	1.8
98	07/30/92	CVALT83	III	870	0	0	1720	910	300	0.34	M	5	0	6	0	0	1.9
99	08/11/92	CVALT84	III	870	0	0	1720	780	350	0.40	M	5	0	6	0	0	1.9

(a) 3% Na(SiO4)
(b) 7% Na(SiO4)

Table A.2 Mixture proportions for the trial batches of VES (MM) concrete

Ref.	Mixing	Batch	Cementitious Material				Aggregate		Water	W/C	Admixtures						
			CMT	CMT	FA	SF	Coarse	Fine			HRWR		Latex	DCI	RTDR	CaCl	AEA
No.	Date	ID	Type	pcy	pcy	pcy	pcy	pcy	pcy		Type	oz/cwt	gcy	gcy	oz/cwt	% CMT	oz/cwt
150	09/19/90	MVALT1	III	800	0	0	1620	1180	296	0.37	N	10	0	6.5	0	0	0.6
151	04/25/91	MVALT2	III	940	0	0	1570	920	329	0.38	M	18	0	5.0	0	1	4.0
152	05/03/91	MVALT3	III	940	0	0	1570	870	335	0.36	M	18	0	5.0	0	1	2.0
153	05/07/91	MVALT4	III	940	0	0	1570	970	290	0.30	M	22	0	5.0	0	1	2.0
154	06/07/91	M/VE(CC)/3	III	940	0	0	1570	957	280	0.30	M	33	0	5.0	0	1	5.4
155	06/07/91	MVE(CC)1F3	III	940	0	0	1570	957	280	0.30	M	44	0	5.0	0	1	5.4
156	06/19/91	MVE(CC)1F2	III	940	0	0	1570	957	280	0.30	M	44	0	5.0	0	1	6.0
157	06/21/91	MVE(CC)1F1	III	940	0	0	1570	961	280	0.30	M	22	0	5.0	0	1	2.0
158	06/02/91	M/VE(CC)/1	III	940	0	0	1570	961	280	0.30	M	22	0	5.0	0	1	2.0
159	11/15/91	M/VE(C)/2	III	870	0	0	1570	930	300	0.34	M	26	0	4.0	0	0	1.0
160	11/20/91	MVALT5	XT	750	0	0	1570	1410	175	0.23	–	0	0	0.0	0	0	0.0
161	11/27/91	MVALT6	XT	750	0	0	1570	1450	160	0.21	–	0	0	0.0	0	0	0.0
162	11/27/91	MVALT7	XT	750	0	0	1570	1450	160	0.21	–	0	0	0.0	0	0	0.0
163	11/29/91	MVALT8	XT	750	0	0	1570	1450	160	0.21	–	0	0	0.0	0	0	0.0
164	11/29/91	MVALT9	XT	750	0	0	1570	1450	160	0.21	–	0	0	0.0	0	0	0.0
165	01/29/92	M/VE(PYR)/1	XT	750	0	0	1570	1450	160	0.21	–	0	0	0.0	0	0	0.0
166	01/31/92	MVE(PYR)2F	XT	750	0	0	1570	1450	160	0.21	–	0	0	0.0	0	0	0.0
167	02/05/92	MVE(PYR)1R	XT	750	0	0	1570	1390	185	0.25	–	0	0	0.0	0	0	0.0
168	03/25/92	MVALT10	III	870	0	0	1570	800	350	0.40	M	5	0	6.0	0	0	2.5
169	03/25/92	MVALT11	III	870	0	0	1570	800	350	0.40	M	5	0	6.0	0	0	2.5
170	04/13/92	M/VE(C)/1	III	870	0	0	1570	800	350	0.40	M	5	0	6.0	0	0	2.5
171	04/22/92	MVALT12	XT	850	0	0	1480	1350	195	0.23	–	0	0	0.0	0	0	0.0
172	04/24/92	MVALT13	XT	850	0	0	1500	1380	175	0.21	–	0	0	0.0	0	0	0.0
173	04/24/92	MVALT14	XT	850	0	0	1500	1400	166	0.20	–	0	0	0.0	0	0	0.0
174	04/28/92	MVALT15	XT	850	0	0	1500	1400	166	0.20	–	0	0	0.0	0	0	0.0
175	04/28/92	MVALT16	XT	850	0	0	1500	1420	158	0.19	–	0	0	0.0	0	0	0.0
176	05/06/92	M/VE(C)/3	III	870	0	0	1570	800	350	0.40	M	5	0	6.0	0	0	2.4
177	05/07/92	MVALT17	XT	850	0	0	1500	1440	150	0.18	–	0	0	0.0	0	0	0.0

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Table A.2 Mixture proportions for the trial batches of VES (MM) concrete -- Continued

Ref. No.	Mixing Date	Batch ID	Cementitious Material				Aggregate		Water	W/C	Admixtures							
			CMT Type	CMT pcy	FA pcy	SF pcy	Coarse pcy	Fine pcy	pcy		HRWR Type	HRWR oz/cwt	Latex gcy	DCI gcy	RTDR oz/cwt	CaCl % CMT	AEA oz/cwt
* 178	05/07/92	MVALT18	XT	850	0	0	1500	1460	145	0.17	–	0	0	0.0	0	0	0.0
179	05/28/92	M/VE(C)/2	III	870	0	0	1570	800	350	0.40	M	5	0	6.0	0	0	2.3
180	05/29/92	M/VE(PYR)/1	XT	850	0	0	1500	1460	145	0.17	–	0	0	0.0	0	0	0.0
181	06/18/92	M/VE(PYR)/2	XT	850	0	0	1500	1460	145	0.17	–	0	0	0.0	0	0	0.0
182	06/23/92	M/VE(PYR)/3	XT	850	0	0	1500	1460	145	0.17	–	0	0	0.0	0	0	0.0
183	08/24/92	MVALT IB	XT	850	0	0	1500	1460	145	0.17	–	0	0	0.0	0	0	0.0
184	08/26/92	MVALT IA	XT	850	0	0	1500	1460	145	0.17	–	0	0	0.0	0	0	0.0

Table A.3 Mixture proportions for the trial batches of VES (RG) concrete

Ref. No.	Mixing Date	Batch ID	Cementitious Material CMT Type	CMT pcy	FA pcy	SF pcy	Aggregate Coarse pcy	Fine pcy	Water pcy	W/C	Admixtures HRWR Type	HRWR oz/cwt	Latex gcy	DCI gcy	RTDR oz/cwt	CaCl % CMT	AEA oz/cwt
200	10/04/90	RVALT1	III	820	0	0	1850	950	232	0.28	N	10	0	6.5	0	0	0.7
201	10/10/90	RVALT2	III	820	0	0	1690	1070	331	0.40	N	10	0	6.5	0	0	0.5
202	10/16/90	RVALT3	III	830	0	0	1650	1090	337	0.42	N	10	0	6.3	0	0	1
203	04/25/91	RVALT4	III	940	0	0	1650	880	340	0.36	M	18	0	5	0	1	4
204	05/03/91	RVALT5	III	940	0	0	1650	880	358	0.39	M	18	0	5	0	1	4
205	05/07/91	RVALT6	III	940	0	0	1650	990	280	0.30	M	22	0	5	0	1	4
206	06/24/91	R/VE(CC)/1	III	940	0	0	1650	938	280	0.30	M	26	0	5	0	1	5
207	01/22/92	R/VE(C)/.34	III	940	0	0	1650	790	320	0.34		12	0	6	0	0	5
208	03/27/92	RVALT7	III	870	0	0	1650	770	350	0.40	M	48	0	6	0	0	2.5
209	03/27/92	RVALT8	III	870	0	0	1650	770	350	0.40	M	5	0	6	0	0	2.9
210	03/27/92	RVALT9	XT	850	0	0	1500	1390	195	0.23	–	0	0	0	0	0	0
211	04/01/92	RVALT10	III	870	0	0	1650	770	350	0.40	M	10	0	6	0	0	3.5
212	04/01/92	RVALT11	III	870	0	0	1650	770	350	0.40	M	5	0	6	0	0	5
213	04/03/92	RVALT12	III	870	0	0	1650	760	350	0.40	M	10	0	6	0	0	8
214	04/03/92	RVALT13	III	870	0	0	1650	760	350	0.40	M	10	0	6	0	0	6
215	04/03/92	RVALT14	III	870	0	0	1650	760	350	0.40	M	10	0	6	0	0	5
216	04/08/92	RVALT15	III	870	0	0	1650	760	350	0.40	M	10	0	6	0	0	5
217	04/08/92	RVALT16	III	870	0	0	1650	760	350	0.40	M	10	0	6	0	0	5
* 218	04/10/92	RVALT17	III	870	0	0	1650	760	350	0.40	M	10	0	6	0	0	4
219	04/15/92	R/VE(C)/32	III	870	0	0	1650	760	350	0.40	M	10	0	6	0	0	4
220	04/15/92	R/VE(C)/1	III	870	0	0	1650	760	350	0.40	M	10	0	6	0	0	3.5
221	04/22/92	RVALT18	XT	850	0	0	1510	1370	195	0.23	–	0	0	0	0	0	0
222	04/24/92	RVALT19	XT	850	0	0	1510	1400	183	0.22	–	0	0	0	0	0	0
223	05/07/92	R/VE(PYR)/1	XT	850	0	0	1510	1400	183	0.22	–	0	0	0	0	0	0
224	06/01/92	R/VE(C)/2	III	870	0	0	1650	760	350	0.40	M	10	0	6	0	0	3
* 225	06/02/92	R/VE(PYR)/2	XT	850	0	0	1510	1400	183	0.22	–	0	0	0	0	0	0
226	06/16/92	R/VE(PYR)/3	XT	850	0	0	1510	1410	183	0.22	–	0	0	0	0	0	0

Table A.4 Mixture proportions for the trial batches of VES (DL) concrete

Ref.	Mixing	Batch	Cementitious Material				Aggregate		Water	W/C	Admixtures						
			CMT	CMT	FA	SF	Coarse	Fine			HRWR		Latex	DCI	RTDR	CaCl	AEA
No.	Date	ID	Type	pcy	pcy	pcy	pcy	pcy	pcy		Type	oz/cwt	gcy	gcy	oz/cwt	% CMT	oz/cwt
250	05/28/91		III	958	0	0	1754	892	325	0.34	M	18	0	5.1	0	1	4
251	05/29/91		III	958	0	0	1754	829	325	0.34	M	18	0	5.1	0	1	4
252	06/03/91		III	958	0	0	1754	892	325	0.34	M	18	0	5.1	0	1	4
253	06/04/91		III	958	0	0	1754	892	325	0.34	M	18	0	5.1	0	1	4
254	06/05/91		III	958	0	0	1754	892	310	0.32	M	19	0	5.1	0	1	4
255	06/06/91		III	958	0	0	1754	892	310	0.32	M	19	0	5.1	0	1	4
256	06/12/91		III	958	0	0	1754	892	325	0.34	M	18	0	5.1	0	1.5	4
257	06/13/91		III	958	0	0	1754	892	325	0.34	M	18	0	5.1	0	1.75	4
258	06/17/91		III	958	0	0	1754	892	325	0.34	M	18	0	5.1	0	1.75	4
259	06/19/91		III	958	0	0	1754	892	325	0.34	M	18	0	5.1	0	1.75	4
260	07/03/91		III	958	0	0	1754	892	325	0.34	M	18	0	5.1	0	1.75	4
261	07/18/91		III	958	0	0	1754	892	325	0.34	M	18	0	5.1	0	1.75	4
262	10/10/91		III	870	0	0	1684	1028	299	0.34	M	18	0	4	0	0	3.5
263	11/01/91		III	870	0	0	1684	1041	294	0.34	M	18	0	4	0	0	4
264	11/13/91		III	870	0	0	1684	1041	294	0.34	M	18	0	4	0	0	5
265	11/14/91		III	870	0	0	1684	1041	294	0.34	M	16	0	4	0	0	4
266	11/15/91		III	870	0	0	1684	1041	294	0.34	M	16	0	4	0	0	5
267	11/15/91		III	870	0	0	1684	1041	294	0.34	M	18	0	4	0	0	4.5
268	11/18/91		III	870	0	0	1684	1041	294	0.34	M	18	0	4	0	0	5
269	11/20/91		III	870	0	0	1684	1041	289	0.33	M	20	0	4	0	0	6
270	11/21/91		III	870	0	0	1684	1041	289	0.33	M	22	0	4	0	0	7
271	11/28/91		III	870	0	0	1684	1041	289	0.33	M	17	0	4	0	0	6
272	11/27/91		III	870	0	0	1684	1041	289	0.33	M	20	0	4	0	0	7
273	12/04/91		III	870	0	0	1684	1041	294	0.34	M	17	0	4	0	0	5
274	12/04/91		III	870	0	0	1684	1041	294	0.34	M	17	0	4	0	0	5.5
275	12/05/91		III	870	0	0	1684	1041	294	0.34	M	16	0	4	0	0	6
276	12/09/91		III	870	0	0	1684	1041	294	0.34	M	18	0	4	0	0	4.5
277	12/11/91		III	870	0	0	1684	1041	294	0.34	M	17	0	4	0	0	5.5

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Table A.4 Mixture proportions for the trial batches of VES (DL) concrete -- Continued

	Ref. No.	Mixing Date	Batch ID	Cementitious Material: CMT Type	CMT pcy	FA pcy	SF pcy	Aggregate: Coarse pcy	Fine pcy	Water pcy	W/C	Admixtures: HRWR Type	HRWR oz/cwt	Latex gcy	DCI gcy	RTDR oz/cwt	CaCl % CMT	AEA oz/cwt
	278	12/17/91		III	870	0	0	1684	1041	299	0.34	M	16	0	4	0	0	3.5
	279	12/18/91		III	870	0	0	1684	1041	294	0.34	M	18	0	5	0	0	5
*	280	05/13/92	VET01	III	870	0	0	1684	919	340	0.39	M	5	0	6	0	0	2
	281	05/14/92	VET02	III	870	0	0	1684	919	340	0.39	M	4.5	0	6	0	0	2.5
*	282	05/15/92	VET03	III	870	0	0	1684	919	340	0.39	M	4	0	6	0	0	2.5
*	283	05/20/92	VET04	III	870	0	0	1684	919	340	0.39	M	4	0	6	0	0	2.5
*	284	06/01/92	VET05	III	870	0	0	1684	919	340	0.39	M	4	0	6	0	0	2.5
	285	06/12/92	VEPT01	XT	850	0	0	1684	1577	195	0.23	–	0	0	0	0	0	0
	286	06/17/92	VEPT02	XT	855	0	0	1684	1567	197	0.23	–	0	0	0	0	0	0
	287	06/26/92	VEPT03	XT	855	0	0	1684	1567	197	0.23	–	0	0	0	0	0	1.0
*	288	07/01/92	VEPT04	XT	855	0	0	1684	1553	202	0.24	–	0	0	0	0	0	0
*	289	07/20/92	VEPT05	XT	855	0	0	1684	1557	201	0.24	–	0	0	0	0	0	0
	290	07/31/92	VEPT06	XT	855	0	0	1684	1557	201	0.24	–	0	0	0	0	0	0
*	291	08/12/92	VEPT07	XT	855	0	0	1684	1557	201	0.24	–	0	0	0	0	0	0

Table A.5 Mixture proportions for the trial batches of HES (CG) concrete

Ref. No.	Mixing Date	Batch ID	Cementitious Materials				Aggregate		Water	W/C	Admixtures						
			CMT Type	CMT pcy	FA pcy	SF pcy	Coarse pcy	Fine pcy	pcy		HRWR Type	HRWR oz/cwt	Latex gcy	DCI gcy	RTDR oz/cwt	CaCl % CMT	AEA oz/cwt
300	10/25/90	C/HE(C)/1	III	810	0	0	1720	1100	286	0.36	N	10	0	6	0	0	0.8
301	11/14/90	CHALT1	III	810	0	0	1720	1030	283	0.35	N	10	0	0	0	0	1
302	11/21/90	CHALT2	III	810	0	0	1720	1030	293	0.35	N	10	0	0	0	0	2.1
303	04/09/91	CHALT3	III	810	0	0	1720	1070	295	0.37	M	12	0	6	0	0	4
304	04/16/91	CHALT4	III	810	0	0	1720	1070	285	0.34	W	16	0	6	0	0	4
305	06/04/91	C/HE(C)/1	III	810	0	0	1720	1086	275	0.34	N	12	0	6	0	0	0.8
306	06/04/91	C/HE(C)/3F1	III	810	0	0	1720	1086	275	0.34	N	10	0	6	0	0	0.8
307	06/11/91	C/HE(C)/3F	III	810	0	0	1720	1086	275	0.34	N	18	0	6	0	0	5
308	06/13/91	C/HE(C)/1	III	810	0	0	1720	1086	275	0.34	N	18	0	6	0	0	5
309	06/26/91	C/HE(C*)/3	III	810	0	0	1720	1090	275	0.34	N	22	0	6	0	0	6
310	07/08/91	CHALT5	III	810	0	0	1720	1090	275	0.34	M	22	0	6	0	0	6.5
311	07/08/91	CHALT6	III	810	0	0	1720	1090	275	0.34	M	22	0	6	2	0	6.5
312	07/09/91	CHALT7	III	810	0	0	1720	1090	275	0.34	N	28	0	6	0	0	10
313	07/16/91	CHALT8	III	870	0	0	1720	982	280	0.32	N	28	0	4	0	0	10
314	07/16/91	CHALT9	III	870	0	0	1720	982	280	0.32	M	28	0	4	0	0	10
315	08/26/91	CHALT10	III	870	0	0	1720	960	280	0.32	N	24	0	4	0	0	8
316	08/27/91	CHALT11	III	870	0	0	1720	960	280	0.32	N	26	0	4	0	0	9
317	09/04/91	CHALT12	III	810	0	0	1720	1022	275	0.34	N	30	0	4	0	0	10
* 318	11/12/91	C/HE(C)/2	III	870	0	0	1720	910	300	0.34	N	26	0	4	0	0	1.5
319	11/14/91	C/HE(C)/3	III	870	0	0	1720	910	300	0.34	N	26	0	4	0	0	1.3
320	02/17/92	CHALT13	III	870	0	0	1720	910	300	0.34	N	26	0	4	0	0	1.1

Table A.6 Mixture proportions for the trial batches of HES (MM) concrete

Ref.	Mixing	Batch	Cementitious Material				Aggregate		Water	W/C	Admixtures						
			CMT	CMT	FA	SF	Coarse	Fine			HRWR		Latex	DCI	RTDR	CaCl	AEA
No.	Date	ID	Type	pcy	pcy	pcy	pcy	pcy	pcy		Type	oz/cwt	gcy	gcy	oz/cwt	% CMT	oz/cwt
350	11/09/90	M/HE(C)/1F	III	810	0	0	1570	1150	249	0.36	N	10	0.0	6	0	0	0.8
351	11/29/90	M/HE(C)/1R	III	810	0	0	1570	1100	252	0.31	N	10	0.0	6	0	0	2.4
352	12/07/90	M/HE(L)/1	III	810	0	0	1570	1100	296	0.38	–	0	25.9	0	0	0	0.0
353	12/20/90	M/HE(L)/1R1	III	810	0	0	1570	1120	296	0.38	–	0	25.9	0	0	0	0.0
354	06/26/91	M/HE(C)/1	III	810	0	0	1570	1082	275	0.34	N	10	0.0	6	0	0	3.0
355	06/28/91	MHALT1	III	810	0	0	1570	1082	275	0.34	–	0	25.9	0	0	0	0.0
356	06/09/91	M/HE(L)/1R2	III	810	0	0	1570	1082	275	0.34	–	0	0.0	0	0	0	0.0
* 357	11/04/91	M/HE(C)/2	III	870	0	0	1570	980	280	0.32	N	26	0.0	4	0	0	1.0
358	11/08/91	M/HE(L)/2	III	870	0	0	1570	930	300	0.34	–	0	27.7	0	0	0	0.0
359	12/16/91	M/HE(C)/3	III	870	0	0	1570	980	280	0.32	N	26	0.0	4	0	0	1.1
360	12/17/91	M/HE(L)/3	III	870	0	0	1570	930	300	0.34	–	0	27.7	0	0	0	0.0

Table A.7 Mixture proportions for the trial batches of HES (RG) concrete

Ref. No.	Mixing Date	Batch ID	Cementitious Material: CMT Type	Cementitious Material: CMT pcy	Cementitious Material: FA pcy	Cementitious Material: SF pcy	Aggregate: Coarse pcy	Aggregate: Fine pcy	Water pcy	W/C	Admixtures: HRWR Type	Admixtures: HRWR oz/cwt	Admixtures: Latex gcy	Admixtures: DCI gcy	Admixtures: RTDR oz/cwt	Admixtures: CaCl % cmt	Admixtures: AEA oz/cwt
400	11/14/90	R/HE(C)/1F	III	810	0	0	1650	1060	155	0.25	N	10	0	6	0	0	1.0
401	11/29/90	R/HE(C)/1R	III	810	0	0	1650	1060	315	0.39	N	10	0	6	0	0	2.4
402	12/07/90	R/HE(C*)/1F	III	810	0	0	1650	1060	256	0.37	N	14	0	6	0	0	2.4
403	12/20/90	R/HE(C*)/1R	III	810	0	0	1650	1060	274	0.34	N	14	0	6	0	0	2.4
404	07/01/91	R/HE(C)/1	III	810	0	0	1650	1056	275	0.34	N	27	0	6	0	0	5.0
405	07/05/91	R/HE(C*)/1	III	810	0	0	1650	1056	275	0.34	N	28	0	7	0	0	6.0
* 406	11/01/91	R/HE(C*)/2	III	870	0	0	1650	900	300	0.34	N	26	0	4	0	0	10.0
407	11/05/91	R/HE(C)/2	III	870	0	0	1650	900	300	0.34	N	26	0	4	0	0	1.0
408	12/19/91	R/HE(C)/3	III	870	0	0	1650	900	300	0.34	N	25	0	4	0	0	1.3

Table A.8 Mixture proportions for the trial batches of HES (DL) concrete

Ref. No.	Mixing Date	Batch ID	Cementitious Material: CMT Type	Cementitious Material: CMT pcy	Cementitious Material: FA pcy	Cementitious Material: SF pcy	Aggregate: Coarse pcy	Aggregate: Fine pcy	Water pcy	W/C	Admixtures: HRWR Type	Admixtures: HRWR oz/cwt	Admixtures: Latex gcy	Admixtures: DCI gcy	Admixtures: RTDR oz/cwt	Admixtures: CaCl % CMT	Admixtures: AEA oz/cwt
450	01/31/91		III	810	0	0	1720	1100	270	0.33	N	10	0	6	0	0	0.8
451	02/12/91		III	810	0	0	1720	1100	270	0.33	N	10	0	6	0	0	0.8
452	02/19/91		III	810	0	0	1720	1100	270	0.33	N	10	0	6	0	0	0.8
453	02/26/91		III	810	0	0	1720	1100	270	0.33	N	13.5	0	6	0	0	0.8
454	03/04/91		III	810	0	0	1720	1100	270	0.33	N	12	0	6	0	0	0.8
455	03/05/91		III	810	0	0	1720	1100	270	0.33	N	14	0	6	0	0	0.8
* 456	03/11/91		III	810	0	0	1720	1100	270	0.33	N	14	0	6	0	0	1
* 457	03/12/91		III	810	0	0	1720	1100	270	0.33	N	14	0	6	0	0	2
458	04/16/91		III	810	0	0	1720	1100	275	0.34	N	14	0	6	0	0	1.8
459	04/16/91		III	810	0	0	1720	1100	275	0.34	N	14	0	6	0	0	1.8
460	04/18/91		III	810	0	0	1720	1100	275	0.34	N	14	0	6	0	0	1.8
* 461	04/18/91		III	810	0	0	1720	1100	275	0.34	N	14	0	6	0	0	1.8
462	08/28/91	HET01	III	870	0	0	1684	1015	304	0.35	N	24	0	4	0	0	10
463	08/29/91	HET02	III	870	0	0	1684	1015	304	0.35	N	20	0	4	0	0	5
464	08/30/91	HET03	III	870	0	0	1684	1015	304	0.35	N	14	0	4	0	0	2
465	09/03/91	HET04	III	870	0	0	1684	1015	304	0.35	N	16	0	4	0	0	2.5
466	09/04/91	HET05	III	870	0	0	1684	1015	304	0.35	N	16	0	4	0	0	3.5
467	09/05/91	HET06	III	870	0	0	1684	1015	304	0.35	N	15	0	4	0	0	3.5
468	09/09/91	HET07	III	870	0	0	1684	1015	304	0.35	N	16	0	4	0	0	3.5
469	09/10/91	HET08	III	870	0	0	1684	1015	304	0.35	N	16	0	4	0	0	3
470	09/17/91	HET09	III	870	0	0	1684	1015	304	0.35	N	16	0	4	0	0	3.2
471	09/23/91	HET10	III	870	0	0	1684	1015	299	0.34	N	18	0	4	0	0	3.5
472	09/30/91	HET12	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	3.5
* 473	10/01/91	HET13	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	3.5
474	01/09/92	HET14	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	3.5
475	01/24/92	HET15	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	3.5
476	01/27/92	HET16	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4
477	01/28/92	HET17	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4

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Table A.8 Mixture proportions for the trial batches of HES (DL) concrete -- Continued

Ref. No.	Mixing Date	Batch ID	Cementitious Material: CMT Type	CMT pcy	FA pcy	SF pcy	Aggregate: Coarse pcy	Fine pcy	Water pcy	W/C	Admixtures: HRWR Type	HRWR oz/cwt	Latex gcy	DCI gcy	RTDR oz/cwt	CaCl % CMT	AEA oz/cwt
478	01/29/92	HET18	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4
479	02/05/92	HET19	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4.5
480	02/11/92	HET20	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4
481	05/12/92	HET21	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4.5
* 482	05/15/92	HET22	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4.2
483	06/01/92	HET23	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4.2
484	06/03/92	HET24	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4.2
485	06/05/92	HET25	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4.2
486	06/10/92	HESG3B1	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4.2
487	07/06/92	HESG3B2	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4.2
* 488	07/22/92	HESG3B3	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4.2
489	09/03/92	HESG3B4	III	870	0	0	1684	1015	299	0.34	N	16	0	4	0	0	4.2

Table A.9 Mixture proportions for the trial batches of VHS (CG) concrete

Ref. No.	Mixing Date	Batch ID	Cementitious Material: CMT Type	Cementitious Material: CMT pcy	Cementitious Material: FA pcy	Cementitious Material: SF pcy	Aggregate: Coarse pcy	Aggregate: Fine pcy	Water pcy	W/C	Admixtures: HRWR Type	Admixtures: HRWR oz/cwt	Admixtures: Latex gcy	Admixtures: DCI gcy	Admixtures: RTDR oz/cwt	Admixtures: CaCl % CMT	Admixtures: AEA oz/cwt
500	09/13/90	CSALT1	I	750	0	32.5	1720	1220	258	0.33	N	12	0	0	2	0	0.7
501	10/16/90	CSALT2	I	760	0	35	1720	1190	250	0.33	N	12	0	0	2	0	0.8
502	12/28/90	CSALT3	I	780	90	0	1720	1070	255	0.31	N	12	0	0	2	0	1
503	12/28/90	CSALT4	I	760	0	35	1720	1150	250	0.33	N	14	0	0	2	0	1.2
504	01/19/91	CSALT5	I	760	100	0	1720	1070	245	0.3	N	12	0	0	2	0	3.5
505	01/19/91	CSALT6	I	760	150	0	1720	1010	251	0.29	N	12	0	0	2	0	3.5
506	01/19/91	CSALT7	I	760	200	0	1720	950	258	0.27	N	12	0	0	2	0	3.5
507	01/24/91	C/VH(S*)/1	I	760	0	35	1720	1150	242	0.31	N	12	0	0	2	0	1
508	01/29/91	CSALT8	I	830	100	0	1720	1020	261	0.29	N	12	0	0	2	0	3
509	01/29/91	CSALT9	I	830	150	0	1720	960	256	0.27	N	12	0	0	2	0	3.5
510	01/29/91	CSALT10	I	830	200	0	1720	900	262	0.26	N	12	0	0	2	0	3.5
511	05/09/91	CSALT11	I	830	100	0	1720	1060	240	0.26	M	18	0	0	2	0	3.5
512	05/09/91	CSALT12	I	830	150	0	1720	1000	235	0.24	M	22	0	0	2	0	3.5
513	05/09/91	CSALT13	I	830	200	0	1720	940	240	0.23	M	26	0	0	2	0	3.5
514	05/14/91	CSALT14F1	I	760	0	35	1720	1206	240	0.3	N	12	0	0	2	0	0.8
515	05/16/91	CSALT14F2	I	760	0	35	1720	1206	240	0.3	N	12	0	0	2	0	0.8
516	05/21/91	CSALT14	I	760	0	35	1720	1206	240	0.3	N	12	0	0	2	0	0.8
517	07/02/91	C/VH(S)/3F	I	760	0	35	1720	1206	230	0.29	N	12	0	0	2	0	0.9
518	07/03/91	C/VH(S)/3	I	760	0	35	1720	1206	230	0.3	N	14	0	0	2	0	0.9
* 519	07/10/91	C/VH(F)/1	I	830	200	0	1720	937	240	0.23	N	26	0	0	3	0	3.5
520	08/26/91	C/VH(S)/1	I	760	0	35	1720	1135	230	0.29	N	15	0	0	3	0	0.9
* 521	10/10/91	C/VH(F)/2	I	830	200	0	1720	872	240	0.23	N	26	0	0	3	0	3.5
522	10/14/91	C/VH(S)/2	I	760	0	35	1720	1120	240	0.3	N	15	0	0	2	0	1
523	10/17/91	C/VH(F)/3	I	830	200	0	1720	870	240	0.23	N	30	0	0	3	0	2.9
524	02/19/92	C/VH(F)/3	I	830	200	0	1720	870	240	0.23	N	20	0	0	3	0	2.8
525	02/21/92	C/VH(S)/3CF	I	760	0	35	1720	1120	240	0.3	N	15	0	0	2	0	1
526	04/16/92	C/VH(S)/3C	I	760	0	35	1720	1120	240	0.3	N	15	0	0	2	0	1

Table A.10 Mixture proportions for the trial batches of VHS (MM) concrete

Ref. No.	Mixing Date	Batch ID	Cementitious Material				Aggregate		Water	W/C	Admixtures						
			CMT Type	CMT pcy	FA pcy	SF pcy	Coarse pcy	Fine pcy	pcy		HRWR Type	HRWR oz/cwt	Latex gcy	DCI gcy	RTDR oz/cwt	CaCl % CMT	AEA oz/cwt
550	01/29/91	M/VH(S*)/1	I	760	0	35	1570	1200	178	0.24	N	12	0	0	2	0	3.5
551	05/23/91	MSALT1	I	760	0	35	1570	1198	240	0.30	N	12	0	0	2	0	0.8
552	05/28/91	MSALT2	I	760	0	35	1570	1211	230	0.29	N	12	0	0	2	0	0.5
553	08/27/91	M/VH(S)/1	I	760	0	35	1570	1155	230	0.29	N	12	0	0	2	0	0.7
554	09/05/91	M/VH(F)/1F	I	830	200	0	1570	892	240	0.23	N	26	0	0	3	0	4.0
555	10/04/91	M/VH(F)/1	I	830	200	0	1570	892	240	0.23	N	30	0	0	3	0	4.0
556	10/21/91	M/VH(S)/3	I	760	0	35	1570	1140	240	0.30	N	12	0	0	2	0	0.6
557	10/24/91	M/VH(F)/2F1	I	830	200	0	1570	900	240	0.23	N	35	0	0	3	0	4.0
558	10/25/91	M/VH(F)/2F2	I	830	200	0	1570	900	240	0.23	N	35	0	0	3	0	3.0
559	10/26/91	M/VH(F)/2F3	I	830	200	0	1570	900	240	0.23	N	35	0	0	3	0	2.0
560	10/29/91	M/VH(S)/2	I	760	0	35	1570	1140	240	0.30	N	12	0	0	2	0	0.6
561	11/02/91	M/VH(F)/2F4	I	830	200	0	1570	900	240	0.23	N	35	0	0	3	0	1.0
562	11/17/91	M/VH(F)/2	I	830	200	0	1570	900	240	0.23	N	30	0	0	3	0	1.1
563	12/18/91	M/VH(F)/3F1	I	830	200	0	1570	900	240	0.23	N	25	0	0	3	0	1.2
564	02/26/92	M/VH(F)/3F2	I	830	200	0	1570	900	240	0.21	N	20	0	0	3	0	1.2
565	03/06/92	M/VH(F)/3	I	830	200	0	1570	900	240	0.23	N	20	0	0	3	0	1.3

Table A.11 Mixture proportions for the trial batches of VHS (RG) concrete

Ref. No.	Mixing Date	Batch ID	Cementitious Material				Aggregate		Water	W/C	Admixtures						
			CMT	CMT	FA	SF	Coarse	Fine			HRWR		Latex	DCI	RTDR	CaCl	AEA
			Type	pcy	pcy	pcy	pcy	pcy	pcy		Type	oz/cwt	gcy	gcy	oz/cwt	% CMT	oz/cwt
600	01/24/91	R/VH(S*)/1	I	760	0	35	1650	1160	200	0.25	N	12	0	0	2.0	0	1.0
601	05/16/91	RSALT1	I	760	0	35	1650	1176	240	0.30	N	12	0	0	0.8	0	0.0
602	05/21/91	RSALT2	I	760	0	35	1650	1176	240	0.30	N	12	0	0	2.0	0	0.8
603	05/28/91	RSALT3	I	760	0	35	1650	1189	230	0.29	N	12	0	0	2.0	0	0.7
604	07/15/91	R/VH(F)/1	I	810	200	0	1650	920	240	0.24	N	26	0	0	3.0	0	3.5
605	07/17/91	R/VH(S)/1	I	760	0	35	1650	1185	225	0.25	N	12	0	0	2.5	0	0.7
606	10/24/91	R/VH(F)/2	I	830	200	0	1650	860	240	0.23	N	26	0	0	3.0	0	3.0
607	10/25/91	R/VH(S)/2	I	760	0	35	1650	1150	240	0.30	N	14	0	0	3.0	0	0.9
608	11/06/91	R/VH(S)/3	I	760	0	35	1650	1160	220	0.28	N	14	0	0	3.0	0	0.9
609	12/20/91	R/VH(F)/3	I	830	200	0	1650	860	240	0.23	N	20	0	0	3.0	0	1.2
610	04/20/92	R/VH(F)/3C	I	830	200	0	1650	860	240	0.23	N	20	0	0	2.0	0	2.0
611	05/21/92	R/VH(S)/3R	I	760	0	35	1650	1160	220	0.28	N	14	0	0	3.0	0	0.8

Table A.12 Mixture proportions for the trial batches of VHS (DL) concrete

Ref. No.	Mixing Date	Batch ID	Cementitious Material: CMT Type	Cementitious Material: CMT pcy	Cementitious Material: FA pcy	Cementitious Material: SF pcy	Aggregate: Coarse pcy	Aggregate: Fine pcy	Water pcy	W/C	Admixtures: HRWR Type	Admixtures: HRWR oz/cwt	Admixtures: Latex gcy	Admixtures: DCI gcy	Admixtures: RTDR oz/cwt	Admixtures: CaCl % CMT	Admixtures: AEA oz/cwt
650	02/14/92	VHFAT01	I	830	200	0	1684	1018	240	0.29	N	26	0	0	3	0	3.5
651	02/17/92	VHFAT02	I	830	200	0	1684	1018	240	0.29	N	26	0	0	3	0	3.5
652	02/19/92	VHFAT03	I	830	200	0	1684	1018	240	0.29	N	18	0	0	3	0	3.5
653	02/24/92	VHFAT04	I	830	200	0	1684	1018	240	0.29	N	18	0	0	3	0	2.5
654	03/23/92	VHFAT05	I	830	225	0	1684	1018	240	0.29	N	18	0	0	3	0	2.5
* 655	04/27/92	VHFAT06	I	830	200	0	1684	1018	240	0.29	N	18	0	0	3	0	2.5
656	06/08/92	VHFAT07	I	830	200	0	1684	1018	240	0.29	N	18	0	0	3	0	2.5
* 657	06/10/92	VHFAG3B1	I	830	200	0	1684	1018	240	0.29	N	18	0	0	3	0	2.5
658	07/08/92	VHFAG3B2	I	830	200	0	1684	1018	240	0.29	N	18	0	0	3	0	2.5
659	07/22/92	VHFAG3B3	I	830	200	0	1684	1018	240	0.29	N	18	0	0	3	0	2.5
660	02/21/92	VHSFT01	I	760	0	35	1684	1260	230	0.30	N	14	0	0	2	0	1
661	02/26/91	VHSFT02	I	760	0	35	1684	1260	230	0.30	N	16	0	0	2	0	2
662	03/03/92	VHSFT03	I	760	0	35	1684	1260	230	0.30	N	18	0	0	3	0	1.5
663	03/09/92	VHSFT04	I	760	0	35	1684	1260	230	0.30	N	18	0	0	3	0	1.5
664	03/11/92	VHSFT05	I	760	0	35	1684	1260	230	0.30	N	17	0	0	3	0	1.5
665	04/13/92	VHSFT06	I	760	0	35	1684	1260	230	0.30	N	16.5	0	0	3	0	1.5
666	04/20/92	VHSFT07	I	760	0	35	1684	1260	230	0.30	N	17	0	0	3	0	1.5
* 667	05/27/92	VHSFT08	I	770	0	35	1684	1260	230	0.30	N	17	0	0	3	0	2
668	06/10/92	VHSFG3B1	I	770	0	35	1684	1260	230	0.30	N	17	0	0	3	0	2
669	07/22/92	VHSFG3B2	I	770	0	35	1684	1260	230	0.30	N	17	0	0	3	0	2
670	07/27/92	VHSFG3B3	I	770	0	35	1684	1260	230	0.30	N	17	0	0	3	0	2

Appendix B

Properties of Trial Batches of High Performance Concrete

Table B.1 Properties of VES (CG) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at Design		Note
								4 hr	6 hr	
1	10/13/90	CVALT1	2.5	150.2	2.50	83	Box		3040	1
2	10/19/90	CVALT2	2.4	148.6	3.75	77	"		2360	2
3	10/25/90	C/VE(C)/1	2.8		4.00	77	"			2
4	10/31/90	CVALT3	3.4	149.0	4.00	82	"	1680	2900	2
5	10/31/90	CVALT4	1.9	148.2	4.00	82	"	1700		3
6	10/31/90	CVALT5		148.2	5.00	85	"	640		1
7	11/09/90	CVALT6	2.0	149.2	0.50	83	"	1220		2
8	11/21/90	CVALT7	3.5	145.7	3.75	83	"			1
9	01/15/91	CVALT8	4.0	144.5	0.50	80	"	350		1
10	01/15/91	CVALT9	4.1	146.1	1.50	80	"	1150		1
11	03/23/91	CVALT10	4.2	144.4	2.00	94	"	1660		1
12	03/23/91	CVALT11	4.7	144.1	2.25	94	"	1590		1
13	03/23/91	CVALT12	5.0	142.9	3.00	98	"	1630		1
14	03/26/91	CVALT13	2.7	149.0	0.50	96	"	2870		1
15	03/26/91	CVALT14	4.5	148.2	1.50	94	"	5010		1
16	03/26/91	CVALT15	3.6	147.6	0.00	96	"	5450		1
17	04/02/91	CVALT16	6.0	142.0	4.00	80	"	1430		3
18	04/02/91	CVALT17	4.1	144.5	2.00	81	"	390	2550	1
19	04/04/91	CVALT18	4.5	146.1	2.00	86	"	2120		1
20	04/04/91	CVALT19	4.0	146.1	1.50	86	"	1530		1
21	04/09/91	CVALT20	6.2	144.1	3.00	78	"	2450		1
22	04/16/91	CVALT21	3.8	146.1	3.00	77	"	3120		1
23	04/30/91	C/VE(CC)/3	3.4	146.1	3.00	90.	"	2680		1
24	06/18/91	C/VE(CC)/1	6.6	142.4	2.25	85	"	2165		1
25	06/28/91	CVALT22	2.9	148.2	2.00	85	"	3180		1
26	07/09/91	CVALT23	7.7		2.25	81	"	350	2030	1
27	07/15/91	CVALT24	8.0	136.4	3.50	82	"	180	2030	1

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Table B.1 Properties of VES (CG) concrete -- Continued

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at Design		Note
								4 hr	6 hr	
28	08/29/91	CVALT25	7.4	142.4	1.75	82	"		1200	1
29	09/25/91	CVALT26	4.8	149.4	10.50	73	"	2070	2430	3
30	09/25/91	CVALT27	3.9		9.00		"		2530	3
31	09/30/91	CVALT28	6.0	144.1	10.00	70	"	1870	2210	3
32	09/30/91	CVALT29	5.8	146.5	9.50	80	"	1670	2590	3
33	11/20/91	CVALT30	4.6	149.8	1.00	81	"	2570		1
34	12/17/91	CVALT31	4.9	147.8	2.50	75	"	300	2550	1
35	12/18/91	CVALT32	3.2	149.8	1.50	81	Styrofoam		2380	1
36	12/19/91	CVALT33	7.7	141.6	3.50	77	"	190	2710	1
37	12/20/91	CVALT34	4.8	143.7	4.50	80	"		3060	2
38	12/21/91	CVALT35	4.5	144.9	3.25	80	"	1780	3480	1
39	12/21/91	CVALT36	7.0	141.6	4.75	75	"	120	2850	3
40	12/23/91	CVALT37	4.4	143.7	3.50	91	"	2250	3760	1
41	12/23/91	CVALT38	2.5	147.3	2.75	89	"	3800	5950	1
42	01/04/92	CVALT39	3.0	149.8	1.00	102	"	2980	5150	1
43	01/04/92	CVALT40	4.8	142.0	2.75	96	"	1610	3240	1
44	01/06/92	CVALT41	4.2	146.5	0.75	92	"	2360	4630	1
45	01/07/92	C/VE(C)/3	7.0	138.0	3.75	96	"	2210	3380	3
46	01/10/92	C/VE(C)/.34	4.8	146.9	1.50	99	"	2680	5150	1
47	01/22/92	CVALT42	2.0	151.4	1.00	81	"	2030	3700	1
48	02/05/92	CVALT43			0.00	67	"			1
49	02/26/92	CVALT44	4.5	149.4	3.00	82	"		870	1
50	02/28/92	CVALT45	2.7	149.4	3.00	80	"			1
51	03/04/92	CVALT46	3.3	145.3	3.50	80	"		3480	1
52	03/04/92	CVALT47	5.0	144.1	5.50	75	"		2670	2
53	03/05/92	CVALT48	5.0	144.1	4.50	77	"		2650	2
54	03/05/92	CVALT49	10.5	133.5	8.50	72	"		1130	3

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Table B.1 Properties of VES (CG) concrete -- Continued

	Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at Design		Note
									4 hr	6 hr	
	55	03/05/92	CVALT50	5.0	141.6	6.50	73	"		1760	2
	56	03/05/92	CVALT51	6.1	145.7	10.50	70	"	1110		3
	57	03/09/92	CVALT52	4.2	146.1	2.50	80	"		2650	1
	58	03/09/92	CVALT53	9.3	135.5	6.00	72	"		1000	3
*	59	03/09/92	CVALT54	6.2	148.6	8.00	75	"	2530		
	60	03/11/92	C/VE(PYR)/3F	3.5	154.3	0.00	66	"	3110		1
	61	03/11/92	CVALT55	8.3	138.4	5.50	70	"		1330	3
	62	03/11/92	CVALT56	15.0	127.8	7.50	65	"			5
	63	03/13/92	CVALT57	3.3	151.4	4.50	63	"	2220		3
	64	03/13/92	C/VE(C)/3R5	11.0	134.3	6.25	72	"			5
*	65	03/20/92	CVALT58	6.0	150.2	6.50	72	"	2510		
*	66	03/20/92	CVALT59	6.5	142.0	5.00	71	"		2090	
*	67	03/23/92	C/VE(C)/3R6	10.1	133.9	6.50	82	"		2460	
*	68	03/25/92	C/VE(PYR)/3	3.6	152.2	3.75	76	"	2680		
*	69	04/08/92	C/VE(C)/1	11.0	133.9	7.00	87	"		2710	
	70	04/20/92	C/VE(PYR)/1	5.2	150.6	1.25	84	"	2980		1
*	71	05/08/92	C/VE(C*)/3	9.3	134.7	7.00	86	Moist		2490	
	72	05/13/92	C/VE(C)/2	9.3	135.9	6.50	79	Styrofoam	1670		3
	73	05/19/92	C/VE(CS)/3N	1.2	153.1	7.00	85	"		2810	2
	74	05/27/92	C/VE(PYR)/2	4.1	153.5	2.50	81	"	2885		1
*	75	05/27/92	CVALT59	5.6	147.3	4.75	71	"		2510	
	76	05/27/92	CVALT60	4.3	148.6	3.50	72	"			2
	77	05/28/92	CVALT61	5.0	148.2		75	"			2
	78	05/29/92	CVALT62	4.8	147.3	3.75	71	"			2
	79	06/10/92	CVALT63	5.0	147.3	3.25	77	"		3140	1
	80	06/10/92	CVALT64	4.0	149.0	4.00	77	"		3450	2
	81	06/11/92	CVALT65	5.3	145.7	5.00	78	"		2940	2

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Table B.1 Properties of VES (CG) concrete -- Continued

Ref No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at Design		Note
								4 hr	6 hr	
82	06/11/92	CVALT66	5.3	144.9	5.50	76	"		2900	2
83	06/16/92	CVALT67	5.4	146.1	6.50	76	"		3160	2
84	06/16/92	CVALT68	5.4	146.1	6.00	76	"		2880	2
85	06/23/92	C/VE(C)/J	10.0	142.4	6.50	78	"		2460	5
86	07/16/92	CVALT69	6.5	156.3	2.00	82	Air		1530	1
87	07/17/92	CVALT70	3.9	153.1	1.00	82	Air		1420	1
88	07/21/92	CVALT71	13.0	131.8	5.00	80	Styrofoam			5
89	07/21/92	CVALT72		137.6	5.50	80	"			5
90	07/22/92	CVALT73	4.7	149.0	5.50	76	"			2
91	07/22/92	CVALT74	5.9	142.4	6.50	79	"			5
92	07/23/92	CVALT77	8.5	142.0	5.25	79	"			5
93	07/23/92	CVALT78		143.7	5.50	80	"			5
94	07/29/92	CVALT79	6.5	148.6	1.75	76	Air			1
95	07/29/92	CVALT80	5.5	148.2	6.00	77	"			5
96	07/29/92	CVALT81	5.3	149.0	5.00	77	"			2
97	07/29/92	CVALT82	4.0	149.4	5.00	78	"			2
98	07/30/92	CVALT83	3.8	150.6	1.50	80	Moist cure		3620	1
99	08/11/92	CVALT84	7.4	140.0	5.50	80	"	875		3

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze-thaw resistance
5. Other inadequate performance

Table B.2 Properties of VES (MM) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at Design		Note
								4 hr	6 hr	
150	09/19/90	MVALT1	4.8	143.7	3.50		Box		2440	2
151	04/25/91	MVALT2	11.0	130.2	7.50	73	"	630	1250	3
152	05/03/91	MVALT3	5.9	139.2	4.25	75	"	2150		3
153	05/07/91	MVALT4	5.0	140.0	2.50	78	"	2730		1
154	06/07/91	M/VE(CC)/3	4.2	144.1	0.75		"		4080	1
155	06/07/91	MVE(CC)1F3	4.5	145.3	0.00	84	"	1640		1
156	06/19/91	MVE(CC)1F2	3.3	144.9	0.50	85	"			1
157	06/21/91	MVE(CC)1F1	3.8	144.5	0.25	86	"			1
158	06/02/91	M/VE(CC)/1	4.0	145.7	0.25	78	"	3070		1
159	11/15/91	M/VE(C)/2	10.0	130.6	7.75	82	"			5
160	11/20/91	MVALT5	7.2	138.0	8.50	80	"	680	1050	3
161	11/27/91	MVALT6	5.9	143.7	1.25	68	"	1510		1
162	11/27/91	MVALT7	5.8	141.6	2.50	71	"	1200		1
163	11/29/91	MVALT8	6.9	141.2	8.50	83	"	490		3
164	11/29/91	MVALT9	6.6	140.4	9.00	80	"	510		3
165	01/29/92	M/VE(PYR)/1	7.0	140.0	2.50	87	"	1150		1
166	01/31/92	MVE(PYR)2F	5.4	141.6	3.50	89	"	1110		1
167	02/05/92	MVE(PYR)1R	5.8	142.4	8.75	80	"	920		3
168	03/25/92	MVALT10	6.5	140.0	6.50	72	Styrofoam		1750	3
169	03/25/92	MVALT11	6.4	140.0	7.00	75	"		2000	3
170	04/13/92	M/VE(C)/1	10.0	131.4	8.50	87	"			3
171	04/22/92	MVALT12	4.9	143.3	10.25	83	"	1180		3
172	04/24/92	MVALT13	4.0	146.1	9.00	82	"	1810		3
173	04/24/92	MVALT14	5.8	141.6	8.50	82	"	1920		3
174	04/28/92	MVALT15	6.5	144.5	8.50	73	"	1740		3
175	04/28/92	MVALT16	6.5	141.6	8.00	73	"	1610		3
176	05/06/92	M/VE(C)/3	9.0	129.4	8.25	83	"		1900	3

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Table B.2 Properties of VES (MM) concrete -- Continued

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at Design		Note
								4 hr	6 hr	
177	05/07/92	MVALT17	4.2	145.3	8.50	75	"	1740		3
178	05/07/92	MVALT18	7.0	141.2	4.00	72	"	2270		
179	05/28/92	M/VE(C)/2	10.0	128.6	8.50	85	"			3
180	05/29/92	M/VE(PYR)/1	7.8	140.4	7.50	80	"	1970		3
181	06/18/92	M/VE(PYR)/2	5.0	146.1	0.75	80	"	2680		1
182	06/23/92	M/VE(PYR)/3	6.2	145.7	4.25	81	"	1950		3
183	08/24/92	MVALT IB	3.2	148.2	2.75	81	Air			1
184	08/26/92	MVALT IA	2.8	150.6	3.75	87	Air			5

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze-thaw resistance
5. Other inadequate performance

Table B.3 Properties of VES (RG) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at Design		Note
								4 hr	6 hr	
200	10/04/90	RVALT1	3.0	142.0	3.50	80	Box	2080		2
201	10/10/90	RVALT2	4.3	144.5	5.75		"	1090		2
202	10/16/90	RVALT3	4.8	138.4	5.75	81	"	1560		2
203	04/25/91	RVALT4	3.6	144.1	2.25	71	"	2150		1
204	05/03/91	RVALT5	3.6	140.0	5.00	76	"	1550		2
205	05/07/91	RVALT6	3.0	146.1	1.00	76	"	2790		1
206	06/24/91	R/VE(CC)/1	2.5	146.5	0.50	82	"	3410		1
207	01/22/92	R/VE(C)/.34	4.5	143.3	3.00	89	"	1190	3680	1
208	03/27/92	RVALT7	4.9	139.6	5.00	72	Styrofoam		3140	2
209	03/27/92	RVALT8	4.6	140.0	4.00	73	"		3340	2
210	03/27/92	RVALT9	3.6	148.6	2.50	70	"	2630		1
211	04/01/92	RVALT10	4.4	143.7	3.00	73	"		3460	1
212	04/01/92	RVALT11		144.3	2.50	71	"		3090	1
213	04/03/92	RVALT12	11.0	128.6	6.00	70	"		1470	3
214	04/03/92	RVALT13	9.5	131.4	5.75	68	"		1430	3
215	04/03/92	RVALT14	7.3	134.3	.4.25	67	"		1670	3
216	04/08/92	RVALT15	10.0	131.8	6.50	74	"		1710	3
217	04/08/92	RVALT16	12.0	131.2	7.00	73	"		1440	3
* 218	04/10/92	RVALT17	7.5	137.6	6.00	79	"		2360	
219	04/15/92	R/VE(C)/32	14.0	125.8	7.75	84	"		1730	3

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Table B.3 Properties of VES (RG) concrete -- Continued

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at Design		Note
								4 hr	6 hr	
220	04/15/92	R/VE(C)/1	12.0	129.0	7.50	86	"			5
221	04/22/92	RVALT18	4.5	147.8	8.00	85	"	2150		2
222	04/24/92	RVALT19	3.7	149.4	3.50	75	"	3060		2
223	05/07/92	R/VE(PYR)/1	3.6	147.3	3.00	83	"	3140		1
224	06/01/92	R/VE(C)/2	12.0	129.0	7.00	79	"			5
* 225	06/02/92	R/VE(PYR)/2	3.9	148.6	4.50	81	"	2850		
226	06/16/92	R/VE(PYR)/3	4.5	144.1			"	1610		3

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze-thaw resistance
5. Other inadequate performance

Table B.4 Properties of VES (DL) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at Design		Note
								4 hr	6 hr	
250	05/28/91		3.8	147.0	3.60	88	Box			2
251	05/29/91		4.8	145.2	6.40	85	Cured			2
252	06/03/91		5.5	143.2	4.00	82	"			2
253	06/04/91		5.2	145.5	3.60	82	"			2
254	06/05/91		5.4	145.7	3.90	81	"			2
255	06/06/91		6.0	145.7	2.80	82	"			1
256	06/12/91		5.1	144.4	3.10	83	"			1
257	06/13/91		5.4	145.0	3.60	88	"			2
258	06/17/91		4.2	147.7	3.50	90	"			2
259	06/19/91		4.0	148.0	2.70	89	"			1
260	07/03/91		4.4	146.7	3.50	89	"			2
261	07/18/91		3.8	147.5	3.10	95	"			1
262	10/10/91		5.9	138.8	2.50	78	"		1310	1
263	11/01/91		4.3	146.3	2.10	71	"			1
264	11/13/91		5.9	144.1	3.90	76	"		724	3
265	11/14/91		5.7	146.4	2.00	70	"			1
266	11/15/91		4.9	145.2	2.20	85	"			1
267	11/15/91		5.9	146.7	2.40	83	"		1970	1
268	11/18/91		6.2	143.9	3.70	83	"		1425	3
269	11/20/91		5.1	146.9	1.90	78	"			1
270	11/21/91		7.6	144.1	3.70	80	"		875	3
271	11/27/91		7.8	140.4	4.00	81	"		680	3
272	11/28/91		4.8	145.4	1.80	81	"			1
273	12/04/91		6.0	144.8	2.90	80	"		1065	1
274	12/04/91		6.0	147.1	3.10	80	"		1180	1
275	12/05/91		4.6	151.2	1.60	80	"			1
276	12/09/91		4.1	153.2	2.20	85	"			1

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Table B.4 Properties of VES (DL) concrete -- Continued

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at Design		Note
								4 hr	6 hr	
277	12/11/91		5.2	147.5	2.50	80	"			1
278	12/17/91		6.0	144.0	3.40	85	"		1930	1
279	12/18/91		6.8	144.4	3.30	84	"		1910	1
* 280	05/13/92	VET01	5.0	144.7	4.75	84	"		2760	
281	05/14/92	VET02	6.6	142.9	6.50	84	"			5
* 282	05/15/92	VET03	5.5	143.2	4.25	82	"		2340	
* 283	05/20/92	VET04	6.0	143.7	4.25	83	"		2740	
* 284	06/01/92	VET05	6.1	141.8	4.75	81	"		2550	
285	06/12/92	VEPT01	5.1	150.5	2.50	81	"	2380		1
286	06/17/92	VEPT02	4.5	152.3	2.00	82	"	3090		1
287	06/26/92	VEPT03	6.1	149.0	3.00	81	"	2620		1
* 288	07/01/92	VEPT04	6.9	149.0	6.75	83	"	2490		
* 289	07/20/92	VEPT05	5.0	145.0	4.50	85	"	2660		
290	07/31/92	VEPT06	7.6	148.0	6.75	72	"	2325		3
* 291	08/12/92	VEPT07	7.2	151.0	7.75	72	"	2540		

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze–thaw resistance
5. Other inadequate performance

Table B.5 Properties of HES (CG) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at 1 day	Note
300	10/25/90	C/HE(C)/1	4.8	142.8	7.00		Bag	5360	2
301	11/14/90	CHALT1	2.3	148.0	3.50	77	"	4750	2
302	11/21/90	CHALT2	4.2	142.4	4.00		"	6450	2
303	04/09/91	CHALT3	5.9	143.7	3.25	94	"	5190	1
304	04/16/91	CHALT4	3.5	147.8	1.75	91	"	6660	1
305	06/04/91	C/HE(C)/1	3.0	149.4			"		2
306	06/04/91	C/HE(C)/3F1	3.4	149.0			"		2
307	06/11/91	C/HE(C)/3F	3.9	148.2	1.75	75	"	6390	1
308	06/13/91	C/HE(C)/1	4.3	146.1	1.50	77	"	6000	1
309	06/26/91	C/HE(C*)/3	5.4	144.1	2.00	81	Moist	5150	1
310	07/08/91	CHALT5	4.2	148.2	0.50	80	Bag		1
311	07/08/91	CHALT6	3.2	148.2	0.75	84	"		1
312	07/09/91	CHALT7	4.9	149.0	0.50	79	"	6860	1
313	07/16/91	CHALT8	12.0	129.4	3.75	81	"	3200	3
314	07/16/91	CHALT9	5.0	142.7	1.25	80	"	6890	1
315	08/26/91	CHALT10	3.8	148.6	0.75		"		1
316	08/27/91	CHALT11	5.3	145.3	1.00	80	"	5410	1
317	09/04/91	CHALT12	3.5	148.2	0.25	81	"		1
318	11/12/91	C/HE(C)/2	9.0	138.0	7.00	72	"	5140	
319	11/14/91	C/HE(C)/3	8.9	140.0		73	"		1
320	02/17/92	CHALT13	5.4	147.3	8.50	78	"		2
321	06/25/92	C/HE(C)/J	4.0	149.0	7.00	82	Air	4340	2

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze–thaw resistance
5. Other inadequate performance

Table B.6 Properties of HES (MM) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at 1 day	Note
350	11/09/90	M/HE(C)/1F	2.7	138.4	8.75	76	Bag	4270	2
351	11/29/90	M/HE(C)/1R	4.4	139.6	3.75		"	5950	2
352	12/07/90	M/HE(L)/1	8.0	133.6	10.75		"	2190	3
353	12/20/90	M/HE(L)/1R1	4.9	139.6	7.25	81	"	4460	2
354	06/26/91	M/HE(C)/1	4.2	145.0	0.00	79	"	6050	1
355	06/28/91	MHALT1	3.2	145.3	0.00	82	"	5410	1
356	06/09/91	M/HE(L)/1R2	3.2		1.50	77	"		1
*357	11/04/91	M/HE(C)/2	5.6	138.4	6.75	73	"	5610	
358	11/08/91	M/HE(L)/2	2.1	139.6		65	"	4225	2
359	12/16/91	M/HE(C)/3	6.7	136.3	8.50	78	"	3840	3
360	12/17/91	M/HE(L)/3	2.3	138.8	10.00	72	"	2960	2

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze–thaw resistance
5. Other inadequate performance

Table B.7 Properties of HES (RG) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at 1 day	Note
400	11/14/90	R/HE(C)/1F	2.6	143.6	0.75	85	Bag	6560	1
401	11/29/90	R/HE(C)/1R	4.2	142.4	4.00		"	6810	2
402	12/07/90	R/HE(C*)/1F	13.0	122.4	6.25	80	Moist	3550	3
403	12/20/90	R/HE(C*)/1R	4.6	141.6	4.75	81	"	6960	2
404	07/01/91	R/HE(C)/1	4.0	144.1	1.75	78	Bag		1
405	07/05/91	R/HE(C*)/1	3.9	146.5	1.75	86	Moist	5260	1
406	11/01/91	R/HE(C*)/2	6.6	138.4	7.00	84	"	5690	
407	11/05/91	R/HE(C)/2	2.1	146.1	3.50	70	Bag		2
408	12/19/91	R/HE(C)/3	2.0	149.8	2.00	76	"	4420	1

Notes:
1. Inadequate workability
2. Inadequate air content
3: Inadequate design strength
4. Inadequate freeze–thaw resistance
5. Other inadequate performance

Table B.8 Properties of HES (DL) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at 1 day	Note
450	01/31/91		5.9	145.2	4.70	62	Air	4805	3
451	02/12/91		3.8	149.2	2.60	71	"		1
452	02/19/91		4.7	146.1	6.20	72	"	6150	2
453	02/26/91		3.3	150.4	4.70	66	"	8020	2
454	03/04/91		2.9	148.3	2.40	72	"		1
455	03/05/91		4.0	150.0	5.10	74	"		2
* 456	03/11/91		7.0	144.0	6.20	74	"	5270	
* 457	03/12/91		5.5	146.5	5.50	70	"	5380	
458	04/16/91		6.0	147.5	6.10	73	"	4600	3
459	04/16/91		8.5	143.0	7.50	75	"		5
460	04/18/91		4.7	147.0	4.30	76	"	5550	2
* 461	04/18/91		6.0	146.0	6.50	79	"	5450	
462	08/28/91	HET01	14.5	129.5	6.50	85	"		5
463	08/29/91	HET02	14.0	129.8	8.00	88	"		5
464	08/30/91	HET03	3.0	147.0	3.20	88	"		1
465	09/03/91	HET04	4.3	145.5	4.30	80	"		2
466	09/04/91	HET05	7.0	137.7	4.40	82	"	4780	3
467	09/05/91	HET06	4.7	139.4	1.50	81	"		1
468	09/09/91	HET07	7.0	141.4	4.00	84	"	4840	3
469	09/10/91	HET08	5.5	144.2	3.60	85	"	4845	3
470	09/17/91	HET09	6.0	138.5	3.00	79	"	5030	1
471	09/23/91	HET10	7.0	142.4	4.50	72	"	4700	3
472	09/30/91	HET12	4.7	144.4	3.10	75	"		1
* 473	10/01/91	HET13	6.0	143.5	4.00	78	"	5260	
474	01/09/92	HET14	6.4	145.3	3.20	81	"	4980	1
475	01/24/92	HET15	4.7	146.8	2.40	76	"	5280	1
476	01/27/92	HET16	5.3	140.5	2.40	76	"	5125	1
477	01/28/92	HET17	4.9	146.0	3.50	78	"	5600	2

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Table B.8 Properties of HES (DL) concrete -- Continued

	Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at 1 day	Note
	478	01/29/92	HET18	5.1	146.4	3.20	77	"	5300	1
	479	02/05/92	HET19	8.5	138.7	4.10	77	"		5
	480	02/11/92	HET20	5.6	139.5	3.70	79	"		5
	481	05/12/92	HET21	7.6	134.3	4.00	78	Bag	4300	3
*	482	05/15/92	HET22	5.9	144.3	3.50	79	"	5010	
	483	06/01/92	HET23	5.5	143.9	3.50	76	"	4900	3
	484	06/03/92	HET24	5.3	145.3	4.25	80	"	5210	2
	485	06/05/92	HET25	5.1	145.3	4.00	83	"	5100	2
	486	06/10/92	HESG3B1	3.7	149.6	2.50	85	"	5920	1
	487	07/06/92	HESG3B2	5.0	146.0	3.75	87	"	5280	2
*	488	07/22/92	HESG3B3	6.5	143.0	4.75	78	"	4950	
	489	09/03/92	HESG3B4	5.1	145.3	3.75	80	"	5510	2

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze-thaw resistance
5. Other inadequate performance

Table B.9 Properties of VHS (CG) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at 28 days	Note
500	09/13/90	CSALT1	3.7	146.8	3.75	83	Moist	11520	2
501	10/16/90	CSALT2	8.5	138.0	9.50	79	"	8650	3
502	12/28/90	CSALT3	2.8	146.8	10.00		"		2
503	12/28/90	CSALT4	9.8	136.7	9.00		"		5
504	01/19/91	CSALT5	7.2	134.8	3.00	78	"	5530	1
505	01/19/91	CSALT6	5.0	138.0	3.75	79	"	6060	2
506	01/19/91	CSALT7	4.6	140.8	2.25	79	"	7050	1
507	01/24/91	C/VH(S*)/1	4.5	143.2	5.00	76	"	9360	2
508	01/29/91	CSALT8	5.2	142.4	1.25	75	"	8050	1
509	01/29/91	CSALT9	4.9	139.6	1.00	76	"	8120	1
510	01/29/91	CSALT10	3.9	142.4	0.50	77	"	7870	1
511	05/09/91	CSALT11	4.2	147.8	0.50	78	"	9790	1
512	05/09/91	CSALT12	3.9	148.2	0.75	79	"	10270	1
513	05/09/91	CSALT13	3.8	148.2	0.50	77	"	10310	1
514	05/14/91	CSALT14F1	15.0	130.6			"		5
515	05/16/91	CSALT14F2	14.5	129.4			"		5
516	05/21/91	CSALT14	4.7	146.5	1.50	73	"	11780	1
517	07/02/91	C/VH(S)/3F	4.5	148.2		77	"		2
518	07/03/91	C/VH(S)/3	5.0	143.5	2.75	80	"		1
* 519	07/10/91	C/VH(F)/1	5.5	141.9	3.50	80	"	12200	
520	08/26/91	C/VH(S)/1	4.1		3.00	80	"	12200	1

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Table B.9 Properties of VHS (CG) concrete -- Continued

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at 28 days	Note
* 521	10/10/91	C/VH(F)/2	6.0	146.1	7.00	73	"	11425	
522	10/14/91	C/VH(S)/2	9.0	139.6	4.00	78	"	8325	3
523	10/17/91	C/VH(F)/3	6.8	144.1	2.50	72	"		1
524	02/19/92	C/VH(F)/3CF2	4.2	150.2	8.00	72	"	8060	2
525	02/21/92	C/VH(S)/3CF1	3.9	150.2	1.25	72	"		1
526	04/16/92	C/VH(S)/3C	3.5	152.2	2.00	75	"	12910	1

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze–thaw resistance
5. Other inadequate performance

Table B.10 Properties of VHS (MM) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at 28 days	Note
550	01/29/91	M/VH(S*)/1	7.8	132.4	7.25	77	Moist	5850	3
551	05/23/91	MSALT1	7.8	135.9	7.00	78	"	7080	3
552	05/28/91	MSALT2	5.0	143.1	4.50	81	"	7320	3
553	08/27/91	M/VH(S)/1	4.9	142.9	5.00	77	"	7900	2
554	09/05/91	M/VH(F)/1F			0.00		"		1
555	10/04/91	M/VH(F)/1	3.6	146.9	8.50		"		2
556	10/21/91	M/VH(S)/3	5.6	143.3	4.25	77	"	8460	3
557	10/24/91	M/VH(F)/2F1	16.1	119.6	8.00		"		5
558	10/25/91	M/VH(F)/2F2	13.0	122.0	8.50		"		5
559	10/26/91	M/VH(F)/2F3	14.5	122.0			"		5
560	10/29/91	M/VH(S)/2	10.0	135.9	9.50		"		5
561	11/02/91	M/VH(F)/2F4	4.5	140.0	10.00	76	"		2
562	11/17/91	M/VH(F)/2	5.1	138.0	11.00	73	"	5600	2
563	12/18/91	M/VH(F)/3F1	10.6	126.1	9.50	72	"	5250	3
564	02/26/92	M/VH(F)/3F2	12.0	129.0	9.00	72	"		5
565	03/06/92	M/VH(F)/3	8.0	134.3	10.00	72	"		5

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze–thaw resistance
5. Other inadequate performance

Table B.11 Properties of VHS (RG) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at 28 days	Note
600	01/24/91	R/VH(S*)/1	5.5	144.8	0.00	75	Moist	8840	1
601	05/16/91	RSALT1	5.3	140.8	8.50		"	7620	2
602	05/21/91	RSALT2	5.7	141.6	6.00	72	"	8750	3
603	05/28/91	RSALT3	3.6	148.2	1.25	82	"	10170	1
604	07/15/91	R/VH(F)/1	4.5		7.00	81	"		2
605	07/17/91	R/VH(S)/1	3.2	150.6	0.25	78	"		1
606	10/24/91	R/VH(F)/2	4.2	144.5	0.50	76	"		1
607	10/25/91	R/VH(S)/2	7.3	141.2	3.00	80	"		1
608	11/06/91	R/VH(S)/3	8.0			69	"	8000	3
609	12/20/91	R/VH(F)/3	2.0	150.2	7.00	69	"	8970	2
610	04/20/92	R/VH(F)/3C	3.0	147.3	0.50	73	"	9250	1
611	05/21/92	R/VH(S)/3R	2.7	151.8	0.50	73	"		1

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze-thaw resistance
5. Other inadequate performance

Table B.12 Properties of VHS (DL) concrete

Ref. No.	Mixing Date	Batch ID	Air (%)	Unit Wt pcy	Slump (in.)	Conc. Temp. (°F)	Curing	Compressive Strength (psi) at 28 days	Note
650	02/14/92	VHFAT01	6.0	145.5	4.40	76	Air		5
651	02/17/92	VHFAT02	9.6	141.0	6.30	72	"	8300	3
652	02/19/92	VHFAT03	9.6	141.0	3.80	73	"	6875	3
653	02/24/92	VHFAT04	6.8	147.0	3.00	72	"	8900	1
654	03/23/92	VHFAT05	7.0	146.7	2.50	62	"	8600	1
* 655	04/27/92	VHFAT06	5.9	145.0	3.25	68	Lime	10240	
656	06/08/92	VHFAT07	4.5	148.8	2.75	78	Water	10440	1
* 657	06/10/92	VHFAG3B1	6.3	149.6	4.00	81	"	9980	
658	07/08/92	VHFAG3B2	5.0	145.0	3.00	83	"	9520	1
659	07/22/92	VHFAG3B3	6.2	147.8	6.25	76	"	9640	3
660	02/21/92	VHSFT01	4.2	147.7	1.50	73	Air	8540	1
661	02/26/92	VHSFT02	7.9	144.3	1.50	61	"	8380	1
662	03/03/92	VHSFT03	3.6	147.0	0.50	74	"		1
663	03/09/92	VHSFT04	9.8	148.0	4.25	73	"	8660	3
664	03/11/92	VHSFT05	7.1	146.0	4.25	60	"	9380	3
665	04/13/92	VHSFT06	11.0	142.6	6.80	71	"		5
666	04/20/92	VHSFT07	6.5	145.8	3.00	73	Lime	8960	1
* 667	05/27/92	VHSFT08	5.5	148.0	2.25	70	Water	10120	
668	06/10/92	VHSFG3B1	4.5	151.6	1.50	80	"	10020	1
669	07/22/92	VHSFG3B2	5.1	149.7	2.50	76	"	10210	1
670	07/27/92	VHSFG3B3	7.0	148.0	5.50	72	"	9600	3

Notes:
1. Inadequate workability
2. Inadequate air content
3. Inadequate design strength
4. Inadequate freeze-thaw resistance
5. Other inadequate performance