WEAVER CONSTRUCTION MANAGEMENT, INC.
3679 S. Huron St., Suite 404
Englewood, CO 80110
Phone: (303) 789-4111 FAX: (303) 789-4310

SUBMITTAL TRANSMITAL

July 26, 2011
WGC Submittal No: 03300-009.H

PROJECT:
Harold Thompson Regional WRF
Birdsall Rd.
Fountain, CO 80817
Job No. 2908

ENGINEER:
GMS, Inc.
611 No. Weber St., #300
Colorado Springs, CO 80903
719-475-2935 Roger Sams

OWNER:
Lower Fountain Metropolitan
Sewage Disposal District
901 S. Santa Fe Ave.
Fountain, CO 80817
719-382-5303 James Heckman

CONTRACTOR:
Baker Concrete Construction
1904 Jasper Street
Aurora, CO 80011
937-536-9000 Nick Dewald

SUBJECT: Resubmittal of product data for mix design for Headworks Building.

Note: "Attached is submittal 009H concerning more back up information for the use of mix design A70F at a 5" slump for the Headworks Building. I have included the contact information for the BASF representative and we feel that if the EOR and the BASF rep can have a conversation, concerning the use of high range water reducer, it might eliminate the EOR's reservations to use a 5"slump. Any help with facilitating a conversation between the EOR and BASF rep would be much appreciated."

SPEC SECTION: 03300 – Cast-In-Place Concrete

PREVIOUS SUBMISSION DATES: 6/14/11

DEVIATIONS FROM SPEC: ____ YES _X_ NO

CONTRACTOR'S STAMP: This submittal has been reviewed by Weaver General Construction and approved with respect to the means, methods, techniques, & safety precautions & programs incidental thereto. Weaver General Construction also warrants that this submittal complies with contracted documents and comprises on deviations thereto:

Contractor's Stamp:	Engineer's Stamp:
Date: 7/26/11 Reviewed by: H.C. Myers (X) Reviewed Without Comments ( ) Reviewed With Comments	

ENGINEER'S
COMMENTS:____
____

BAKER™
CONCRETE CONSTRUCTION
expect more

Letter of Transmittal/Submittal

FROM:

Baker Concrete Construction
1904 Jasper Street
Aurora, CO 80011
303.367.8111
Nick Dewald 937.536.9000

DATE *07/25/11*	JOB NUMBER *9921*
ATTENTION	*John Jacob/Leslie Brown*
RE:	*Harold Thompson Regional WRF*
TR#	*03300-024*
SM#	*03300-009H*

TO:
John Jacob/Leslie Brown
Weaver General Construction Co.
3679 South Huron St., Suite 404
Englewood, CO 80110
john@weavergc.com / leslie@weavergc.com

We are sending you: *ATTACHED* via *EMAIL* the following: *SPECIFICATION*

COPIES	DATE	PAGES	Description
1	*7/25/2011*	*27*	*Mix Design - Polyheed 997 Back up for 5" Slump*

THESE ARE TRANSMITTED as noted below:

FOR APPROVAL

REMARKS *Attached is more back up for the use of Polyheed 997 (High Range Water Reducer) in mix A70F for the Headworks Building. BASF's representative is available to speak with the EOR concerning the use of Polyheed 997 if they have any further questions, see contact info below.*
William Deal
Cell (303) 324-6343
Email William.deal@basf.com

COPY TO *File*

SIGNED: Nick Dewald
Baker Concrete Construction, Inc.

If enclosures are not as noted, kindly notify us at once

BASF
The Chemical Company

July 20, 2011

Zachoriah J. Ballard, EI
Quality Control Manager
Rocky Mountain Premix, Inc.
2895 Capital Drive
Colorado Springs, CO 80915

RE: PolyHeed 997 Mid-Range Water Reducing Admixture

Dear Mr. Ballard:

Per request of BASF Sales Representative Bill Deal, this is to confirm that PolyHeed 997 Admixture is a Mid-Range Water Reducing Admixture capable of producing concrete with varying slumps over a wide range of mix designs.

PolyHeed 997 was introduced into the market in 1984 and has since been widely used in North America and throughout many other regions of the world. It provides superior workability, pumpability and finishability qualities in concrete. PolyHeed 997 Admixture is recommended for use throughout the dosage range of 3-15 fl. oz./cwt. of cementitious material. One of the benefits this provides to concrete producers is the ability to supply concrete with various slumps by simply adjusting the admixture dosage. Since concrete strength is primarily a function of water/cement ratio, increasing dosage level of PolyHeed 997 Admixture will not adversely affect strength, as long as the specified w/c ratio is not exceeded and the integrity of the mix is maintained. In this way, a given mix design can be supplied with the desired level of workability by varying the PolyHeed 997 Admixture dosage, with little effect on plastic or hardened concrete properties.

PolyHeed 997 Admixture conforms to ASTM C494 Type A, Water–Reducing and Type F, High-Range Water-Reducing Admixture specifications. The ASTM C494 Test Reports are available for review upon request.

Please feel free to contact me with any further questions you may have concerning this matter.

Mark E. Piechuta
Sr. Technical Marketing Specialist
BASF Corporation
(216) 839-7072

cc: Bill Deal- BASF

BASF Corporation
23700 Chagrin Boulevard
Cleveland, Ohio 44122 USA
216 839-7500 ph
www.masterbuilders.com

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Admixture Solutions

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ENGINEERS & CONSTRUCTION
TECHNOLOGY CONSULTANTS

www.CTLGroup.com

November 19, 2008

Mr. Mark Piechuta
BASF Construction Chemicals, LLC
23700 Chagrin Blvd.
Beechwood, Ohio 44122

Via E-mail: mark.piechuta@basf.com

Results of ASTM C 494 Admixture Evaluation of Polyheed 997
CTLGroup Project No. 390618

Dear Mr. Piechuta:

Attached are test results for the referenced product. Your firm submitted and identified a sample of Polyheed 997 that was received at CTLGroup in September 2007.

Testing was performed in accordance with ASTM C 494/C 494M–05a, "Standard Specification for Chemical Admixtures for Concrete." Results indicate the sample of Polyheed 997 used at 5.1 oz/cwt meets the requirements of a Type A water-reducing admixture as stated in ASTM C 494M-05a.

Should you have any questions, please contact me.

Sincerely,

CTLGroup, Inc.
An AASHTO Accredited Laboratory – Aggregates, Cement & Concrete

Willy Morrison

W. Morrison
Principal Materials Scientist
Materials Consulting
wmorrison@CTLGroup.com
Direct Phone: 847-972-3162

Attachments

TABLE I - ADMIXTURES

ASTM Specification C 494 / AASHTO M 194

	Reference Admixture	Test Admixture
		BASF Construction Chemicals, LLC
Brand Name	Neutralized Vinsol Resin	Polyheed 997
Lot Number	18L0075	1640497W7
Quantity Supplied	*1 gallon container*	*5 gallon container*
Total Solids, %	13.61	47.15
Specific Gravity	1.038	1.272
pH	12.16	9.17

TABLE II - CEMENT

PROPERTIES OF CEMENT

ASTM C 150 and AASHTO M85
Lot No. 18L0091

CHEMICAL ANALYSIS

CONSTITUENT	WEIGHT, %
Silicon dioxide	20.1
Aluminum oxide	5.6
Ferric oxide	2.1
Calcium oxide	64
Magnesium oxide	1.7
Sulfur trioxide	3.4
Sodium oxide	0.21
Potassium oxide	0.36
Tricalcium aluminate (C_3A)	11
ALKALIES AS Na_2O	0.45
INSOLUBLE RESIDUE	0.22

PHYSICAL ANALYSIS

PROPERTY	RESULT
COMPRESSIVE STRENGTH	
3 day, psi	4600
7 day, psi	5710
SETTING TIME (Vicat)	
Initial, minutes	120
Final, minutes	185
AIR CONTENT, %	8
LOSS ON IGNITION	2.2
AUTOCLAVE EXPANSION, %	0.01
FINENESS (BLAINE)	389

This cement is a Type I portland cement.

TABLE III - AGGREGATES

ASTM C 33

PROPERTIES OF AGGREGATES

	LOT 18L0093		LOT 18L0095 & 18L0096	
	FINE AGGREGATE		**COARSE AGGREGATE**	
GRADATION				
ASTM C 136	SIEVE	CUMULATIVE BY WEIGHT, %	SIEVE	CUMULATIVE BY WEIGHT, %
	# 4	100	1 "	100
	8	91	3 / 4	98
	16	72	1 / 2	42
	30	49	3 / 8	41
	50	15	# 4	0
	100	2	8	0
	200	1		
	Pan	0		
	F.M.	2.71		
ORGANIC				
ASTM C 40	COLOR	#1		
SPEC. GRAVITY				
ASTM C 128, SSD			3/4"	2.67
ASTM C 127, SSD		2.66	3/8"	2.67
ABSORPTION				
ASTM C 128		1.56	3/4"	1.06
and C 127			3/8"	1.39
UNIT WEIGHT				
ASTM C 29	DRY RODDED	110.6	DRY RODDED 3/4"	102.9
			3/8"	103.5

The coarse aggregate source is a siliceous rounded river gravel from Eau Claire, Wisconsin.
The gravel sizes have been separated and recombined.
The concrete sand is used as received.

TABLE IV Laboratory Data	Concrete Mixtures and Testing Results Polyheed 997							Polyheed 997 added at a rate of 5.1 oz/cwt	
	REFERENCE				Polyheed 997				ASTM C 494 TYPE A AASHTO M194 TYPE A
Batch	Control #1	Control #2	Control #3	AVER.	Test #1	Test #2	Test #3	AVER.	
Date	9/25/2007	9/26/2007	9/27/2007	(Test Value)	9/26/2007	9/26/2007	9/26/2007	(Test Value)	
Actual Cement Content, pcy	518	519	518	**518**	519	518	516	**518**	**517± 5**
Sand, pcy	1239	1241	1238	**1239**	1263	1261	1258	**1261**	
Gravel, pcy	1923	1927	1922	**1924**	1924	1922	1917	**1921**	
Actual Water Content, pcy	246	244	242	**244**	225	224	224	**224**	
Relative Yield, cy	1.000	1.000	1.000	**1.000**	1.000	1.000	1.000	**1.000**	
Water Content (Percent of Control)								**92%**	**≤95%**
AEA name		Vinsol Resin				Vinsol Resin			
" , oz/cwt	1.00	1.00	1.00	**1.00**	0.88	0.79	0.77	**0.81**	
Admixture name						Polyheed 997			
Polyheed 997, oz/cwt					5.0	5.1	5.1	**5.1**	
WATER CEMENT RATIO	0.475	0.470	0.467	**0.471**	0.434	0.432	0.434	**0.433**	
Slump, inches	3.50	3.75	3.50	**3.50**	3.50	3.75	3.50	**3.50**	**3.5 ± .5**
Entrained Air, %	5.5	5.5	5.5	**5.5**	5.9	5.9	5.9	**5.9**	**5.0 ± 1.0 (±0.5)**
Density, pcf	145.4	145.6	145.2	**145.4**	145.6	145.4	145.0	**145.3**	
SETTING TIME									
Initial, hr:mn	4:35	4:40	4:38	**4:37**	5:06	5:18	5:19	**5:14**	
Final, hr:mn	5:59	6:11	6:06	**6:05**	6:32	6:51	6:35	**6:39**	
TIME of SETTING (deviation from reference)									
Initial, hr:mn								**0:37**	**not more than 1:00 earlier nor 1:30 later**
Final, hr:mn								**0:34**	**not more than 1:00 earlier nor 1:30 later**
COMPRESSIVE STRENGTH, psi									
1 Day, psi	1620	1560	1590	**1590**	2180	2130	2270	**2190**	
3 Days, psi	3060	3100	3350	**3170**	4020	4090	4070	**4060**	
7 Days, psi	4290	4370	4320	**4330**	4820	4460	5080	**4790**	
28 Days, psi	5730	5520	5600	**5620**	6290	6200	6230	**6240**	
90 Days, psi	6320	6300	6140	**6250**	7030	6800	7070	**6970**	
6 Months, psi	6390	6290	6360	**6350**	7170	6730	7280	**7060**	
1 Year, psi	6740	6750	6590	**6690**	7490	7540	7440	**7490**	
1 Day, psi								**138%**	——
3 Days, psi								**128%**	≥110%
7 Days, psi								**111%**	≥110%
28 Days, psi								**111%**	≥110% (≥120%)[A]
90 Days, psi								**112%**	(≥117%)[A]
6 Months, psi								**111%**	≥100%(≥113%)[A]
1 Year, psi								**112%**	≥100%
FLEXURAL STRENGTH, psi									
3 Days, psi	530	560	560	**550**	630	610	630	**620**	
7 Days, psi	730	690	670	**700**	850	650	770	**760**	
28 Days, psi	790	800	680	**760**	830	710	800	**780**	
3 Days, % reference								**113%**	≥100%
7 Days, % reference								**109%**	≥100%
28 Days, % reference								**103%**	≥100%
LENGTH CHANGE, %	-0.0290	-0.0290	-0.0270	**-0.0283**	-0.0390	-0.0360	-0.0390	**-0.0380**	
Increase over reference								**-0.0097**	**<=0.010[B]**
RESISTANCE TO FREEZING AND THAWING									
Relative Dynamic Modulus, %									
0 cycles	100/100	100/100	100/100	100	100/10	100/100	100/100	100	
34 cycles	98/95	100/99	98/98	98	99/97	98/97	95/97	97	
73 cycles	100/96	100/98	98/98	98	99/96	98/98	99/99	98	
112 cycles	98/95	99/99	98/98	98	98/95	97/97	99/97	97	
141 cycles	98/95	99/99	98/99	98	98/95	98/96	99/97	97	
176 cycles	97/96	99/99	96/98	98	98/96	97/97	100/98	97	
20 cycles	99/97	100/99	100/100	99	100/96	98/96	100/98	98	
270 cycles	97/97	100/99	97/98	98	98/96	96/97	99/98	97	
286 cycles	98/96	99/99	96/96	97	97/96	95/96	100/96	97	
300 cycles	100/97	100/98	100/98	99	98/96	95/96	99/95	97	
RELATIVE DURABILITY FACTOR								**98**	**min 80**

A. Alternative requirement. If any of the measured relative strengths are greater than the requirement in parentheses, the admixture shall be considered provisionally qualified until the 1-year strength test results are obtained.

B. Increased shrinkage over control.

TABLE V
TESTS OF CHEMICAL ADMIXTURES FOR CONCRETE
Polyheed 997
ASTM Specification C 494 / AASHTO M 194
TYPE A, Water-Reducing

MIXTURE DESIGNATION	CONTROL	Polyheed 997	CHANGE vs. CONTROL	SPECIFICATION REQUIREMENT
MIXTURE PROPORTIONS				
ACTUAL CEMENT, pcy	**518**	**518**		**517± 5**
SAND, pcy	**1239**	**1261**		
GRAVEL, pcy	**1924**	**1921**		
ACTUAL WATER, pcy	**244**	**224**	**92%**	**≤95%**
RELATIVE YIELD, cy	**1.000**	**1.000**		
AEA (Vinsol Resin), oz/cwt	**1.00**	**0.81**		
Polyheed 997, oz/cwt		**5.1**		
RATIO OF FINE TO TOTAL AGG., %	**39**	**40**		
WATER/CEMENT RATIO, lb./lb.	**0.471**	**0.433**		
SLUMP, inches	**3.50**	**3.50**	**0.00**	**3.5 ± .5**
ENTRAINED AIR, %	**5.5**	**5.9**	**0.4**	**5.0 ± 1.0 (±0.5)**
UNIT WEIGHT, pcf	**145.4**	**145.3**		
SET TIME, hr:min				
INITIAL	**4:37**	**5:14**	**0:37**	**not more than 1:00 earlier nor 1:30 later**
FINAL	**6:05**	**6:39**	**0:34**	**not more than 1:00 earlier nor 1:30 later**
COMPRESSIVE STRENGTH, psi				
1 DAY	**1590**	**2190**	**138%**	**——**
3 DAYS	**3170**	**4060**	**128%**	**≥110%**
7 DAYS	**4330**	**4790**	**111%**	**≥110%**
28 DAYS	**5620**	**6240**	**111%**	**≥110% (≥120%)[A]**
90 DAYS	**6250**	**6970**	**112%**	**(≥117%)[A]**
6 MONTHS	**6350**	**7060**	**111%**	**≥100%(≥113%)[A]**
1 YEAR	**6690**	**7490**	**112%**	**≥100%**
FLEXURAL STRENGTH, psi				
3 DAYS	**550**	**620**	**113%**	**≥100%**
7 DAYS	**700**	**760**	**109%**	**≥100%**
28 DAYS	**760**	**780**	**103%**	**≥100%**
LENGTH CHANGE	**-0.028**	**-0.038**		
Increase over reference			**-0.0097**	**<=0.010[B]**
RELATIVE DURABILITY FACTOR		**98**		**min 80**

A. Alternative requirement. If any of the measured relative strengths are greater than the requirement in parentheses, the admixture shall be considered provisionally qualified until the 1-year strength test results are obtained.

B. Increased shrinkage over control.

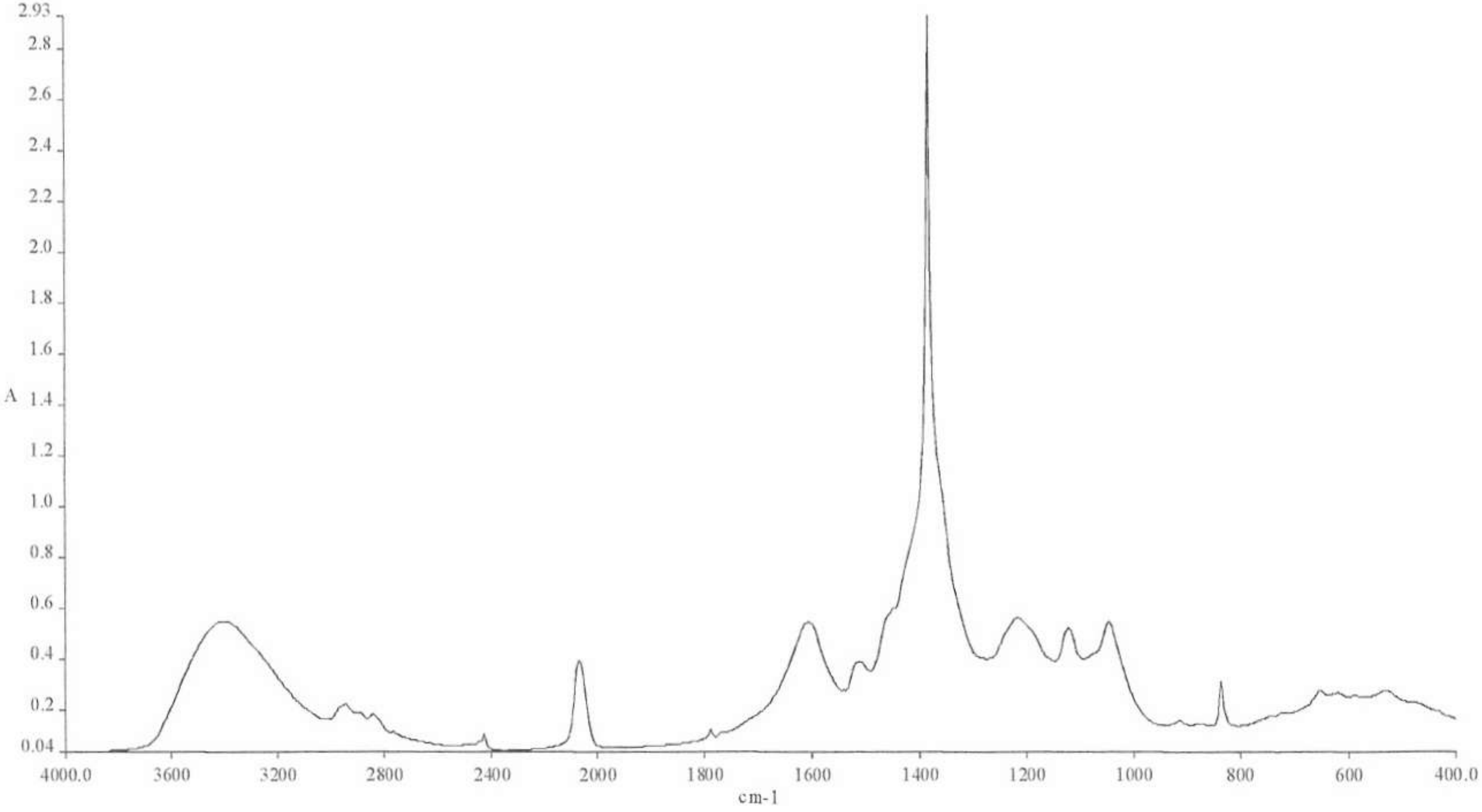

Figure 1 - Infrared spectrum of BASF Polyheed 997 (CTL ID 1958801); KBr disk per ASTM C 494

TEC Services
Testing • Engineering • Consulting

June 9, 2011

Mr. Mark Piechuta
BASF Construction Chemicals, LLC
23700 Chagrin Blvd.
Cleveland, OH, 44122

Phone: (216) 839-7072
Email: mark.piechuta@basf.com

Subject: **Final Report for BASF POLYHEED 997, Compliance Verification Type 'F' Admixture AASHTO M 194-06** ***Standard Specification for Chemical Admixtures for Concrete***
TEC Services Project No: TEC 06-0570
TEC Services Laboratory No: 10-233

Dear Mr. Piechuta:

Testing, Engineering and Consulting Services, Inc. (TEC Services), an AASHTO R18 and ISO 17025 accredited laboratory, is pleased to present this report of our compliance verification testing of POLYHEED 997, an ASTM C 494-08a Type F *(High Range Water Reducing)* admixture. Our services were performed in accordance with our service agreement date June 16, 2006.

Sample preparation and testing was performed in accordance with applicable sections of AASHTO M 194-06, ASTM C 494 and documents referenced therein. Material and procedures outlined in AASHTO M 194-06 were used. Based on our results, POLYHEED 997 complies with the requirements in AASHTO M 194 and Table 1 of ASTM C 494. These results pertain only to the sample tested.

The compliance verification was performed by TEC Services in Lawrenceville, Georgia. Concrete batching was performed on three different days in June, 2010. One control mixture and one test mixture containing POLYHEED 997, both meeting the requirements of AASHTO M 194 and ASTM C 494 for fresh concrete properties, were produced each day. Two 1-gallon samples of POLYHEED 997 were supplied to TEC Service by BASF Construction Chemicals, LLC. The air-entraining agent used in this testing was a commercially available vinsol resin, meeting the requirements of AASHTO M 154-06.

Mixture proportions and results of our testing are given in Tables 1 to 3. Information and test data on fine and coarse aggregates are listed in Tables 4 to 6. Table 7 contains information supplied by the producers of POLYHEED 997 and the air-entraining admixture. Product information and test data on the Type I cement is included in Table 8. Test results for each of the six batches prepared for this report are included in Tables 9 thru 12.

Table 1: POLYHEED 997 performance and AASHTO M 194 requirements for a Type F admixture

	POLYHEED 997	**Specification Requirements**
Water content (percent of control)	88	88 (max)
Time of setting, deviation of control		
Initial (hr:min)	1:06	-1:00 to +1:30
Final (hr:min)	0:54	-1:00 to +1:30
Compressive strength (percent of control)		
1 day	148	140 (min)
3 days	145	125 (min)
7 days	133	115 (min)
28 days	124	110, 120* (min)
56 days	119	110 (min)
90 days	124	117* (min)
6 months	124	100, 113* (min)
1 year	119	100 (min)
Flexural strength (percent of control)		
3 days	110	110 (min)
7 days	111	100 (min)
28 days	104	100 (min)
56 days	100	100 (min)
Length change (increase over control)	0.010	0.010 (max)
Relative durability factor	104	80 (min)

*Provisional Requirement

Table 2: Mixture proportions, fresh concrete properties, and ASTM C 494 requirements for a Type F admixture

Average of Three Separate Tests	**Control Mixture**	**POLYHEED 997**	**Specification Requirements**
Cement factor (lb/yd^3)	517	518	517 ± 5
Water (lb/yd^3)	281	247	
Water-cement ratio	0.543	0.478	
Coarse aggregate	1849	1852	
Fine aggregate	1171	1263	
Fine aggregate-total aggregate ratio	0.39	0.41	
PolyHeed 997 (oz/cwt)	0.00	6.50	
Vinsol Resin (oz/cwt)	0.28	0.12	
Slump (in.)	3.75	3.50	3 ½ ± ½
Air content (%)	5.6	5.6	5-7 (± 0.5 of control)
Density (lb/ft^3)	141.4	143.7	
Time of setting			
Initial (hr:min)	4:54	6:01	
dev. of control (hr:min)		1:06	-1:00 to +1:30
Final (hr:min)	6:34	7:28	
dev. of control (hr:min)		0:54	-1:00 to +1:30

Table 3: Properties of hardened concrete

	Control Mixture	**POLYHEED 997**
Compressive strength (psi)		
1 day	1650	2440
3 days	2710	3920
7 days	3570	4740
28 days	4540	5640
56 days	4730	5610
90 days	4870	6020
6 months	5080	6290
1 year	5320	6320
Flexural strength (psi)		
3 days	505	555
7 days	540	600
28 days	570	595
56 days	605	670
Length change (%)	-0.024	-0.034
Durability factor (%)	84	87

Table 4: Properties of fine and coarse aggregates

	Fine aggregate	**Coarse aggregate**
Manufacturer	**Martin Marietta, Shorter**	**Vulcan, Lithonia**
Aggregate type	Natural sand	Crushed Granite
Specific gravity$_{SSD}$	2.64	2.63
Absorption (%)	0.43	0.60

Table 5: Gradation of fine aggregate and ASTM C 494 requirements

	Percent passing	
Sieve	**Fine aggregate**	**Specifications Requirements**
No. 4 (4.75 mm)	100	100
No. 16 (2.36 mm)	74	65 to 75
No. 50 (300 µm)	16	12 to 20
No. 100 (150 µm)	3	2 to 5

Table 6: Gradation of coarse aggregate and ASTM C 494 requirements

	Percent passing	
Sieve	**Coarse aggregate**	**Specifications Requirements**
1.5 in. (37.5 mm)	100	100
1.0 in. (25.4 mm)	99	95 to 100
0.5 in. (12.5 mm)	43	25 to 60
No. 4 (4.75 mm)	4	0 to 10
No. 8 (2.36 mm)	2	0 to 5

Table 7: Admixture information as provided by supplier

	Type F, High Range Water Reducing Admixture
Brand Name	**POLYHEED 997**
Manufacturer	BASF Construction Chemicals, LLC
Lot Number	081809-Polyheed 997
Lot Size	1,000 gallons
Specific Gravity	1.278
Solids content (%)	47.5

Table 8: Cement information and test data

ASTM C 150 Type I cement			
Brand name		Cemex Portland Type I	
Manufacturer		Cemex Cement Company	
Chemical analyses by mass (%)			
Silicon dioxide (SiO_2)	20.3	Titanium dioxide (TiO_2)	0.36
Aluminum oxide (Al_2O_3)	5.1	Phosphorus pentoxide (P_2O_5)	0.07
Iron oxide (Fe_2O_3)	3.9	Manganic oxide (Mn_2O_3)	0.06
Calcium oxide (CaO)	63.8	Strontium oxide (SrO)	0.07
Magnesium oxide (MgO)	1.0	Barium oxide (BaO)	0.01
Sodium oxide (Na_2O)	0.05	Loss on ignition (950ºC)	1.2
Potassium oxide (K_2O)	0.35	Insoluble residue	0.23
Sulfur trioxide (SO_3)	3.0	Alkalies as Na_2O	0.31
Calculated potential compounds as per ASTM C 150-05 (%)			
Tricalcium silicate (C_3S)	56	Tricalcium aluminate (C_3A)	7
Dicalcium silicate (C_2S)	15	Tetracalcium aluminoferrite (C_4AF)	12
Physical Testing and Results			
Fineness Specific Surface (Blaine)	390 m^2/Kg	Air Content (%)	6.7
Setting Times (Vicat) Initial	99 minutes	Autoclave Expansion (%)	-0.03
Final	183 minutes		
Compressive 3 Day Strength (psi)	3737	Compressive 7 Day Strength (psi)	4880
% Expansion @ 4.07% SO_3 (C1038)	-0.010		

Table 9:Yield adjusted mixture proportions, fresh concrete properties, and time of set for three control batches

	Control 1	**Control 2**	**Control 3**	**Average**
Cement factor (lb/yd^3)	517	517	515	517
Water (lb/yd^3)	281	281	280	281
Water-cement ratio	0.543	0.543	0.544	0.543
Coarse aggregate (lb/yd^3)	1852	1850	1844	1849
Fine aggregate (lb/yd^3)	1173	1172	1167	1171
Fine aggregate-total aggregate ratio	0.39	0.39	0.39	0.39
PolyHeed 997 (oz/cwt)	0.00	0.00	0.00	0.00
Vinsol Resin (oz/cwt)	0.28	0.28	0.28	0.28
Slump (in.)	3.50	3.50	4.00	3.75
Air content (%)	5.5	5.7	5.5	5.6
Density (lb/ft^3)	141.6	141.5	141.0	141.4
Time of setting				
Initial (hr:min)	4:51	4:49	5:04	4:54
Final (hr:min)	6:30	6:28	6:46	6:34

Table 10: Properties of hardened concrete from three control test batches

	Control 1	**Control 2**	**Control 3**	**Average**
Compressive strength (psi)				
1 day	1640	1900	1400	1650
3 days	2710	2780	2640	2710
7 days	3500	3730	3470	3570
28 days	4530	4890	4190	4540
56 days	4640	5150	4390	4730
90 days	5130	5250	4220	4870
6 months	5220	5260	4750	5080
1 year	5550	5660	4760	5320
Flexural strength (psi)				
3 days	490	515	515	505
7 days	525	545	545	540
28 days	555	585	565	570
56 days	610	600	605	605
Length change (%)	-0.023	-0.028	-0.021	-0.024
Durability Factor (%)	84	83	84	84

Approximate Total Cycles Completed	Fundamental Transverse Frequency, kHz			Relative Dynamic Modulus, percent			**Average**
	Control 1	Control 2	Control 3	Control 1	Control 2	Control 3	
0 cycles	2.051	2.031	2.051	NA	NA	NA	NA
46 cycles	1.914	1.895	1.934	87	87	89	88
105 cycles	1.914	1.895	1.914	87	87	87	87
149 cycles	1.895	1.875	1.914	85	85	87	86
193 cycles	1.895	1.875	1.914	85	85	87	86
235 cycles	1.895	1.875	1.895	85	85	85	85
277 cycles	1.875	1.855	1.895	84	83	85	84
330 cycles	1.875	1.855	1.875	84	83	84	84

Table 11:Yield adjusted mixture proportions, fresh concrete properties, and time of set for three test batches containing POLYHEED 997

	Test 1	**Test 2**	**Test 3**	**Average**
Cement factor (lb/yd^3)	518	517	518	518
Water (lb/yd^3)	248	247	247	247
Water-cement ratio	0.478	0.478	0.478	0.478
Coarse aggregate (lb/yd^3)	1854	1851	1852	1852
Fine aggregate (lb/yd^3)	1263	1262	1263	1263
Fine aggregate-total aggregate ratio	0.41	0.41	0.41	0.41
PolyHeed 997 (oz/cwt)	6.5	6.5	6.5	6.5
Vinsol Resin (oz/cwt)	0.12	0.12	0.12	0.12
Slump (in.)	3.50	3.25	3.50	3.50
Air content (%)	5.7	5.5	5.6	5.6
Density (lb/ft^3)	143.8	143.6	143.7	143.7
Time of setting				
Initial (hr:min)	6:02	6:01	6:01	6:01
Final (hr:min)	7:28	7:26	7:32	7:28

Table 12: Properties of hardened concrete from three batches containing POLYHEED 997

	Test 1	**Test 2**	**Test 3**	**Average**
Compressive strength (psi)				
1 day	1890	2490	2550	2440
3 days	3980	4060	3720	3920
7 days	4800	4710	4700	4740
28 days	5600	5590	5740	5640
56 days	5680	5630	5520	5610
90 days	6070	5890	6090	6020
6 months	6160	6330	6380	6290
1 year	6550	6270	6150	6320
Flexural strength (psi)				
3 days	540	580	540	555
7 days	550	570	675	600
28 days	565	650	565	595
56 days	695	655	665	670
Length change (%)	-0.038	-0.034	-0.030	-0.034
Durability Factor (%)	87	85	89	87

Approximate Total Cycles Completed	Fundamental Transverse Frequency, kHz			Relative Dynamic Modulus, percent			**Average**
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	
0 cycles	2.07	2.031	2.051	NA	NA	NA	NA
46 cycles	1.973	1.953	2.012	91	92	96	93
105 cycles	1.973	1.934	1.973	91	91	93	91
149 cycles	1.953	1.914	1.973	89	89	93	90
193 cycles	1.953	1.895	1.973	89	87	93	90
235 cycles	1.953	1.875	1.973	89	85	93	89
277 cycles	1.953	1.875	1.953	89	85	91	88
330 cycles	1.934	1.875	1.934	87	85	89	87

We appreciate the opportunity to provide our services to you on this project. Should you have any questions or comments regarding this report, please feel free to contact us at your convenience.

Sincerely,

Testing, Engineering, & Consulting Services, Inc.

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Guide for the Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete

Reported by ACI Committee 212

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High-range water-reducing admixtures can increase the strength of concrete and provide greatly increased workability without adding more water. Consequently, the use of high-range water-reducing admixtures is increasing substantially in the concrete industry. This guide contains information on the effects of these admixtures on the properties of fresh and hardened concrete, the uses of concrete, and the quality control of the concrete. This guide is designed for concrete suppliers, contractors, designers, specifiers, and all others engaged in concrete construction.

Keywords: admixture; batch; consolidation; high-range water-reducing admixture; mixture; mixture proportion; plasticizer; portland cement; quality control; water-reducing admixture; workability.

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ACI 212.4R-04 supersedes ACI 212.4R-93 and became effective September 9, 2004.

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CHAPTER 1—GENERAL INFORMATION

1.1—Introduction

Since the late 1970s, use of a new class of chemical admixture has increased substantially in various segments of the concrete industry. These admixtures are used to significantly increase slump without adding more water or to substantially reduce water content without a loss in slump. Often referred to as a superplasticizer, this material is properly categorized as a high-range water-reducing admixture (HRWRA) meeting the requirements of ASTM C 494 Type F or G or ASTM C 1017 Type I or II. To be categorized as a HRWRA under the requirements of ASTM C 494, the admixture must be capable of reducing the water requirement by at least 12%. As originally marketed in Germany and Japan in the late 1960s, HRWRA consisted primarily of sulfonated condensation products of naphthalene or melamine. In the early 1980s, work began on the development of polyacrylate-based HRWRAs (Bradley and Howarth 1986). These materials and other polycarboxylates have now begun to find practical applications in the field (Okazawa, Umezawa, and Tanaka 1993; Tanaka and Okazawa 1993; Nmai, Schlagbaum, and Violetta 1998; Jeknavorian et al. 1997; Jeknavorian 1998).

Much information on the properties and uses of HRWRAs was published during the period of their introduction and use in the U.S. market. The literature included six ACI special publications based on proceedings of international symposia (SP-62; SP-68; SP-119; SP-148; SP-173; SP-195), a Transportation Research Record (Transportation Research Board 1979), and publications by the Portland Cement Association (Whiting 1979), CANMET (Malhotra 1977, 1979), and the Cement and Concrete Association (1976). Textbooks on concrete admixtures (Ramachandran and Malhotra 1995; Rixom and Mailvaganam 1999) also contain considerable information on HRWRAs.

In the early years, problems in using the admixture in concrete, such as a higher-than-normal rate of slump loss, leading to the need for job-site addition of the material, limited the use of HRWRAs. Under laboratory conditions, Mather (1978) reported a lowered resistance to freezing and thawing. Eventually under laboratory and field conditions, concrete containing HRWRAs proved to be at least as durable as conventional concrete (refer to Section 4.6); however, rapid slump loss was a problem in some concrete mixtures. This concern led to the development of new products aimed at maintaining workability for longer periods of time.

Extended-life HRWRAs were developed in the 1980s, which imparted up to 2 h longer working life to concrete, depending on mixture ingredients and environmental conditions. This allowed adding HRWRAs at the batch plant rather than at the job site, reducing wear on truck mixers, and lessening the need for ancillary equipment such as truck-mounted admixture tanks and dispensers. The result was an increase in the use of HRWRAs in almost all areas of the concrete industry.

1.2—Specifications

Two ASTM specifications include coverage of HRWRAs. ASTM C 494 is normally cited when HRWRAs are used to produce conventional-slump concrete at reduced water content. ASTM C 494 describes two types: Type F, used when high-range water reduction is desired within normal setting times; and Type G, used when high-range water reduction is required with a retarded setting time.

When flowing concrete is desired, HRWRAs are generally specified to conform to the second document, ASTM C 1017. Flowing concrete is defined by ASTM C 1017 as "concrete that is characterized by a slump greater than 7-1/2 in. (190 mm) while maintaining a cohesive nature." ASTM C 1017 describes two types: Type I is used when flowing concrete is desired with normal setting times, and Type II is used when flowing concrete is required with a retarded setting time. Many HRWRAs conform to both ASTM C 494 and ASTM C 1017, and ACI 318 and ACI 301 require HRWRAs to conform to these ASTM standards, as applicable.

CHAPTER 2—EFFECTS OF HIGH-RANGE WATER-REDUCING ADMIXTURES

2.1—General effects

HRWRAs can be used in concrete to increase slump, increase strength by decreasing water content and the resultant water-cementitious material ratio (*w/cm*), or to decrease water and cement content, thus reducing temperature rise and volume change (refer to Section 4.5). All these results are attainable in a wide variety of concrete mixtures. HRWRAs are one of the essential materials in the production and use of high-performance concrete. (ACI 116R defines high-performance concrete as concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices). HRWRAs improve the fresh and hardened physical properties of concrete, increase the efficiency of construction, and help to achieve specific design objectives (refer to Section 2.6). HRWRAs in dry form are also used in some high-performance grouts, mortars, and packaged concrete for similar reasons.

2.2—Mechanisms

The mode of action for naphthalene- or melamine-based HRWRA depends on surface chemistry. The mechanism involves adsorption of the anionic part of the admixture at the solid-water interface. The nonpolar backbone of the polymer is the end that adsorbs onto the cement surface, causing the highly charged hydrophilic end group to be thrust toward the solution. The net effect is an increased negative charge on the cement grain. Consequently, these fine cement grains repel one another (electrostatic repulsion), thus requiring less water for a given degree of concrete workability. Without HRWRAs, these fine grains tend to flocculate due to the attraction of opposite charges adjacent to different particle surfaces. Polycarboxylate HRWRAs provide significantly improved cement dispersion over naphthalene- or melamine-based HRWRAs due to their dual mechanism of electrostatic and steric repulsion. In addition to electrostatic repulsion, side chains of varying lengths, which are formulated to be a part of the backbone of the molecule, physically help keep the cement particles apart allowing water to surround more surface area of the cement particles (steric hindrance) (Ohta, Sugiyama, and Tanaka 1997; Flatt et al. 2000; Burge 2000).

2.3—Fresh concrete properties

Chapter 3 covers the effects of HRWRAs on fresh concrete in detail. In general, however, concrete slump is increased when HRWRAs are added to concrete mixtures and no other changes are made in the mixture proportions (Fig. 2.1 and 2.2). The degree of slump increase can be varied, depending on the performance requirements of the concrete required for various applications. For example, flowing concrete can be proportioned with a slump capable of attaining a level surface with little consolidation effort from the placer (Fig. 2.3). Flowing concrete should be adequately consolidated, with or without vibration, in accordance with ACI 309R.

High-slump or flowing concrete can offer an advantage in the ready-mixed, precast, and prestressed concrete industries. The concrete's ability to flow easily is especially beneficial in applications involving areas of congested reinforcing steel, special form linings, or treatments where the embedments obstruct concrete placement (Fig. 2.4). The flowing characteristic is also advantageous for filling deep forms because the flowability facilitates consolidation around the reinforcing or prestressing steel. Flowing concrete, when placed rapidly, can increase the pressure on formwork. Therefore, the formwork may require additional strengthening (ACI 347). Flowing concrete is used in flatwork and foundations where it can improve the rate of placement. In general, flowing concrete can reduce costs of placing, consolidation, and finishing concrete used in flatwork and foundations (Zummo and Henry 1982).

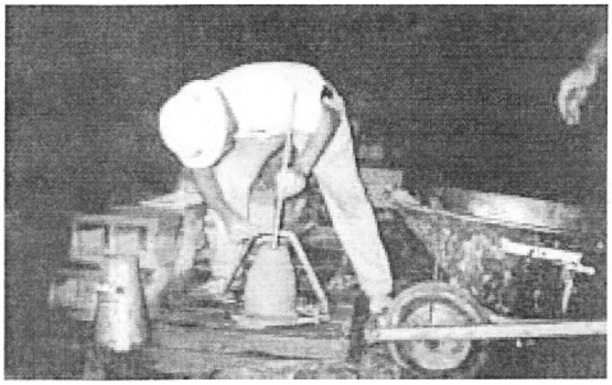

Fig. 2.1—Initial concrete slump before the addition of HRWRA.

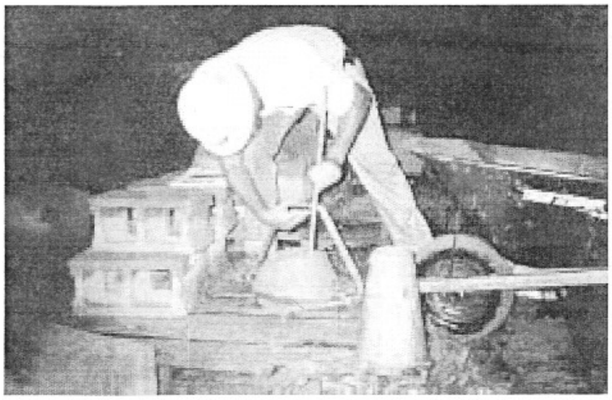

Fig. 2.2—Slump after the addition of HRWRA.

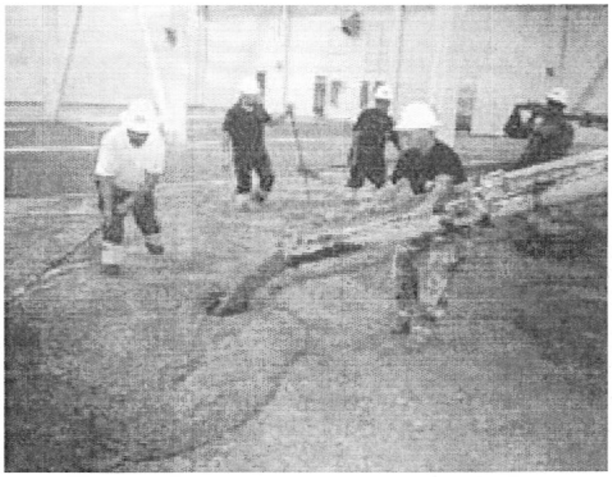

Fig. 2.3—Flowing concrete produced with HRWRA.

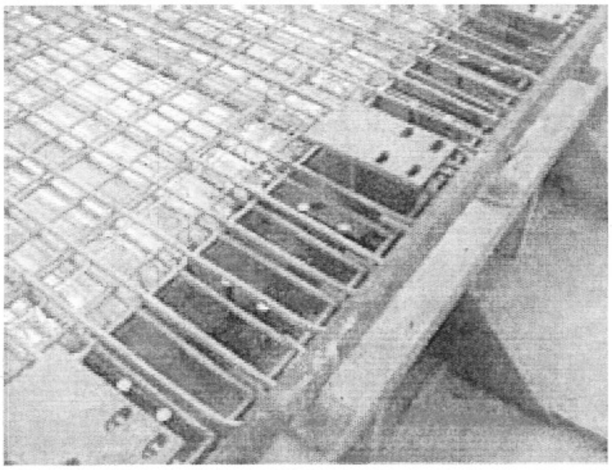

Fig. 2.4—Reinforcing steel and embedments.

2.4—Hardened concrete properties

Chapter 4 covers the effects of HRWRAs on hardened concrete in detail. In general, however, HRWRAs can be used to reduce the water content of concrete, thus decreasing the *w/cm*, which decreases paste porosity and increases strength. High-strength concrete is used in many applications, among them high-rise commercial buildings, high-strength prestressed beams and slabs, impact-resistant structures, and offshore structures. A low *w/cm* is also beneficial in specialty concretes, including the following:

- Low-permeability concrete mixtures used for bridge deck overlays;
- Silica-fume concrete used to obtain very low-permeability and very high-strength concrete in structures, such as parking garages, where they protect reinforcing steel from corrosive deicing agents; and
- Various grouts and prepackaged concretes used for repair and rehabilitation.

Due to the dispersing effect of HRWRAs, more cement surface area is available for hydration, therefore increasing cement efficiency (Bury and Christensen 2002). Increased cement efficiency results in higher strength at all ages at the same cement and water content.

The rate of strength development in flowing concrete containing a HRWRA is equal to or greater than that of low-slump concrete, assuming the same *w/cm* in each mixture. Flowing concrete mixtures are proportioned to fulfill both conventional strength and high-strength (6000 psi [41 MPa] and greater) requirements (Nmai and Violetta 1996). Applications requiring workable high-strength concrete with low water content include structural elements that are either thin or congested with steel, conduit, pipe sleeves, other embedded items, and boxouts (ACI 309R).

In addition to reaching high ultimate strength, concrete with a HRWRA and reduced *w/cm* exhibits strength greater than normal-strength concrete at all ages. This characteristic is desirable in precasting operations where early form stripping is needed.

HRWRAs can reduce both water and cement contents, permitting the use of less cement without reducing strength. Cost savings from the reduced cement content depends on the relative prices of cement and HRWRA. In most cases, the direct economic benefits from cement reductions are minor, although the indirect benefits to the contractor or owner, through paste reduction, may be significant. For example, an application may need lower heat rise or drying shrinkage (refer to Sections 4.4 and 4.5) without changing the slump or *w/cm* and, therefore, strength. Such concrete is desirable for use in massive sections because of its reduced tendency to crack when it cools and dries.

2.5—Increase in the efficiency of construction

When HRWRAs are used to increase slump, reduce *w/cm*, or both, four general benefits to the concrete construction process may occur:

- *Increased productivity*—faster placing, finishing, and stripping of forms;
- *Reduced equipment costs*—increased use of forms, reduced pump pressures, faster turnaround time of concrete trucks, and reduced vibration;
- *Reduced materials costs*—reduction in cement content or use of regular cement instead of high-early cement, and use of more commonly available and less-expensive cementitious material; and
- *Improved quality*—increased certainty that concrete will meet the design specifications for strength, durability, dimensional tolerance by reducing volume change, and appearance.

2.6—Enhanced design and engineering of concrete structures

Engineers and architects use high-performance concrete, often made possible by the application of HRWRAs, to achieve specific design objectives: longer spans, smaller columns, more usable space, flatter slabs, thinner sections, reduced maintenance, longer service life, improved appearance, and architectural flexibility.

CHAPTER 3—EFFECTS ON FRESHLY MIXED CONCRETE

3.1—General

The addition of HRWRA to concrete has many potentially beneficial effects on freshly mixed concrete, such as higher slump without additional water, lower *w/cm* at equivalent slumps, and improved workability and pumpability. Job-site problems that may occur include rapid slump loss, increased time of setting, segregation, or bleeding. Early identification of these problems is accomplished by field trial batches. These problems can then be avoided by field trial batches that will reflect job-site conditions more accurately than laboratory testing, allowing potential problems to be corrected before concrete is used on the project.

3.2—Water reduction

HRWRAs are often used to reduce the water content of concrete while maintaining the same slump. HRWRAs should be capable of reducing the water requirement by at least 12%, but some can reduce the water by more than 30% at a given slump. At lower dosages, HRWRA may impart the same water reduction as can be achieved with Type A water-reducing admixtures (ASTM C 494).

3.3—Slump

When an HRWRA is added to concrete at a constant water content, the slump increases—the higher the dosage of HRWRA, the higher the slump. At very high dosage rates, usually above the manufacturer's recommended dosage range, the affect of additional HRWRA plateaus, providing no additional slump increase. The dosage of HRWRA required to produce flowing consistency varies depending on the cement characteristics, initial slump, *w/cm*, temperature, time of addition, and concrete mixture proportions.

The rate of slump loss of concrete (Meyer and Perenchio 1980) can be affected by the chemistry of the HRWRA; the dosage used; the simultaneous use of an ASTM C 494 Type A, B, or D admixture; the amount, type, and brand of cement; the water content; and the concrete temperature. These factors are not the only ones affecting slump loss, but they are the factors that can typically be controlled by the user. Ambient temperature can also have a dramatic effect on the rate of slump loss of concrete. The common belief that all HRWRA-treated concrete rapidly loses workability is not true (Collepardi and Corradi 1979; Ramachandran et al. 1998).

More recent HRWRA products extend the time before slump loss, allowing batch plant addition and maintaining setting-time characteristics similar to normal concrete while producing a highly plastic mixture at a low *w/cm* (Guennewig 1988; Collepardi and Corradi 1979).

Both specifications for HRWRA (ASTM C 494 and C 1017) discuss slump loss but neither requires tests for slump loss. An admixture that meets the requirements of ASTM C 494 does not necessarily have the slump life that would permit batch-plant addition. As a result of advances in HRWRA technology and the numerous products available, it has become advantageous to describe these products not only by the requirements of ASTM standards but also by whether the HRWRA can be added at the job site or at the batch plant.

When early generations of HRWRAs are added at the job site, the concrete will exhibit, after a time period, moderate to rapid slump loss and normal or retarded initial-setting characteristics. Generally, the higher the dosage rate of HRWRA, the lower the rate of slump loss (Ravina and Mor 1986). Each product, however, has an operating range beyond which other properties of the concrete can be affected. If the dosage rate is increased beyond this range as a means of further lowering the rate of slump loss, the results can include changes in initial-setting characteristics, segregation, or bleeding. HRWRAs should only be used in accordance with the manufacturer's recommended dosage range.

Some HRWRAs added at the batch plant will extend slump retention in the concrete (Collepardi and Corradi 1979), along with either retarded or normal initial-setting characteristics. The difference in performance does not indicate that one product is better than another, but that certain products may be more appropriate in some construction situations than in others.

The chemical composition of cement can also affect the performance characteristics of concrete containing an HRWRA. This is not to say that an HRWRA will not work with a certain type of cement, but that slump loss and other characteristics can be different. For example, Type I and Type III cements typically contain more tricalcium aluminate (C_3A) than Type II and Type V cements. Because of this, concrete made with Type I and Type III cements may exhibit more-rapid slump loss. Dosage rates to achieve a given slump may also vary between different types of cement.

Concrete temperature is another important factor that should be considered when using a HRWRA. As with all concrete, the higher the concrete temperature, the more rapid the slump loss. This effect can be minimized in different ways. One way is to choose an HRWRA that conforms to ASTM C 494, Type G, or to add a retarder Type B or D to the concrete in addition to the HRWRA. The retarding effect can be beneficial in reducing rapid slump loss. Also, an HRWRA specifically formulated to minimize slump loss can be added at the batch plant. Following hot-weather concreting procedures outlined in ACI 305R will also reduce slump loss caused by high concrete temperature.

3.4—Time of setting

ASTM C 494 and C 1017 specify the performance criteria required for chemical admixtures. One criterion is the time of initial setting. ASTM C 494 requires that concrete containing Type F HRWRA, and ASTM C 1017 requires that concrete containing Type I HRWRA reach the time of initial setting no more than 1 h before or 1-1/2 h after that of a reference concrete of similar slump, air content, and temperature. Concrete with retarding Type G or Type II HRWRAs must reach its time of initial setting at least 1 h after, but not more than 3-1/2 h after, the initial setting time of the reference concrete. Both specifications require that these criteria need be met only at one dosage rate, not throughout the entire manufacturer's recommended dosage range.

Most manufacturers of HRWRAs recommend a particular dosage range for their product. Adhering to the recommended range does not necessarily mean the product will meet the requirements of ASTM C 494, Type F or Type G, or ASTM C 1017, Type I and II, throughout this range. This is especially true for the initial time of setting. In most cases, the higher the dosage rate of HRWRA, the greater the retardation of setting time. Manufacturers should provide an acceptable range of dosages because these products are used in a variety of situations and climatic conditions.

3.5—Air entrainment

Numerous tests have been conducted to study the influence of HRWRAs on air-entrained concrete, which is used to resist deicer scaling and damage from freezing-and-thawing cycles (refer to Section 4.6). The air content that an air-entraining admixture is able to produce depends on the type and composition of HRWRA being used, the slump before and after the addition of the HRWRA, and the concrete mixture proportions.

Most tests have shown that the air-void system of air-entrained concrete is altered by the addition of an HRWRA. Typically, the air-void spacing is greater than the recommended value set by ACI 201.2R. This spacing is caused by an increase in the average bubble size and a decrease in the specific surface compared with air-entrained concrete without an HRWRA (refer to Section 4.6).

3.6—Segregation

Segregation in concrete is the separation of mixture components resulting from differences in their particle size or density. Segregation in properly proportioned concrete does not normally occur when a HRWRA is used as a water reducer. When the admixtures are used to create flowing concrete, however, segregation can occur if precautions are not taken. Both improper proportioning and inadequate mixing can result in localized excess fluidity and segregation.

While proportioning deficiencies might not be apparent in relatively low-slump concrete, the higher slump of flowing concrete accentuates these deficiencies and can cause segregation during handling. One way to ensure proper proportioning is to increase the quantity of the smaller sizes of coarse and fine aggregate, and consider the combined aggregate grading. ACI 302.1R recommends that between 8 and 18% for large maximum-size aggregates (such as 1-1/2 in. [38.1 mm]) or 8 and 22% for smaller maximum-size aggregates (such as 1 or 3/4 in. [25 or 19 mm]) be retained on each sieve below the maximum-size and above the No. 100 (150 μm) sieve. Under ideal conditions, the coarse aggregate is suspended in a cohesive mortar that minimizes segregation. Adding more admixture or water can dramatically reduce this cohesiveness, resulting in increased bleeding and segregation.

3.7—Bleeding

Bleeding is the process by which solids settle in fresh concrete, allowing some mixing water to rise to the surface. In concrete where an HRWRA is used as a water reducer, the bleeding generally is decreased because of the lower water content. Ramachandran and Malhotra (1995) verified this for concrete containing Types I, II, and V cements.

The use of an HRWRA to increase the slump should not cause increased bleeding in a properly proportioned concrete. If unacceptable bleeding should occur, it may be reduced by limiting the types of admixtures used in concrete made with a HRWRA. Admixtures formulated with hydroxylated carboxylic acids, for example, tend to increase, to varying degrees, the bleeding tendencies of concrete containing HRWRAs (ACI 212.3R). Bleeding can be further reduced by incorporating the same measures as those used to reduce segregation. Field trial batches should be made to determine the most suitable materials and proportions that will provide a mixture having acceptable bleeding characteristics for the project conditions.

3.8—Pumpability

Pumping is a common method of placing concrete at the construction site. A small amount (1 to 2 in.) of slump loss through the pump line is common for any concrete. Excessive slump loss can stem from a variety of factors, including proportioning, aggregate porosity, loss of air entrainment, degradation of aggregates, climatic conditions, and inadequate pumping equipment. When pumpability becomes a problem, adding water to the concrete should not be considered an acceptable solution. Besides lowering the quality of concrete, the addition of water dilutes the mortar. Pumping pressures can then push mortar ahead of the coarse aggregate, causing a pumpline blockage.

Several options for solving pumpability problems have been used successfully:

- Modify the mixture proportions, giving particular attention to the cement content, the fine aggregate content, and use of pozzolans;
- Use larger and more powerful pumps; and
- Pump from one pump to another (staging) before arriving at the final point of placement.

Adding a HRWRA can provide an economical alternative to the above options by significantly lowering the pumping pressure requirement and increasing pump efficiency. The addition of a HRWRA may reduce pump pressures up to 35% for normalweight concrete, and by 10 to 20% for lightweight concrete (Kasami, Ikeda, and Yamane 1979).

CHAPTER 4—EFFECTS ON HARDENED CONCRETE

4.1—Compressive strength

The primary effects of HRWRAs on concrete compressive strength are derived from their effect on the *w/cm*. When a nonretarding HRWRA is used to lower water requirements at the same slump and cementitious materials content, the resulting decrease in *w/cm* will significantly increase concrete strength at all ages. If mixtures with the same *w/cm* are compared, those containing HRWRA exhibit a slight increase in strength because of the cement-dispersing effect.

Users of HRWRAs should choose the *w/cm* based on the estimated concrete strength using methods described in ACI 211.1. This estimate will be conservative because of the cement-dispersing effect of HRWRAs. Data should be developed on *w/cm* versus strength for actual materials used on each job. The same data can also be used to determine the influence of the admixture on the rate of concrete strength development at early ages. The changes in early strength resulting from the use of HRWRAs can be improved if an accelerating formulation is used in combination. Where a HRWRA is used to increase strength by a reduction in *w/cm*, the early strength will increase because the potential strength is increased.

Because of their effectiveness in reducing the *w/cm*, HRWRAs are helpful in producing concrete with compressive strengths greater than 6000 psi (41 MPa) at 28 days and are essential in achieving strengths that exceed 10,000 psi (69 MPa).

4.2—Tensile strength and modulus of elasticity

HRWRAs in concrete will affect the tensile strength and modulus of elasticity in the same way they affect the compressive strength. HRWRAs do not alter the relationship between compressive strength and tensile strength or modulus of elasticity. Methods for estimating the tensile strength and modulus of elasticity based on compressive strength are the same as those used for concrete without an HRWRA.

4.3—Bond to reinforcement

The bond strength of concrete to reinforcing steel depends on concrete strength, degree of consolidation, bleeding and settlement, and time of setting. When the *w/cm* is reduced with the use of an HRWRA, all of the properties of lower *w/cm*, including increased bond strength, are met. Flowing concrete containing an HRWRA can have the same bond strength as lower slump concrete with an equal *w/cm*, provided the concrete is vibrated, sets normally after consolidation, and exhibits similar compressive strength to conventional concrete. If any of these conditions are not satisfied, however, a reduction in bond strength can occur (Brettmann, Darwin, and Donahey 1986). Flowing or lower-slump concrete that is not properly vibrated can significantly decrease bond strength, as compared with lower-slump or flowing concrete that is properly vibrated. Flowing concrete can significantly increase bond strength as compared with lower-slump concrete that is not properly vibrated. Proper consolidation around reinforcement is more easily achieved with flowing concrete.

4.4—Temperature rise

The temperature rise in concrete due to heat of hydration is not significantly affected by the addition of an HRWRA, unless the amount or composition of the paste is changed. A small change in the time at which the peak concrete temperature is attained can occur due to the increased cement efficiency due to the dispersing effect of HRWRA. A decrease in temperature rise can result when HRWRAs are used to lower the cement content.

4.5—Drying shrinkage and creep

Laboratory studies indicate that HRWRAs may increase concrete drying shrinkage at a given *w/cm* and cement content (given paste content) (Whiting 1979; Gebler 1982). The drying shrinkage of concrete should be less than that of a concrete mixture made without any HRWRA, if there is a simultaneous reduction in cement content and *w/cm* when the HRWRA is added (Tokuda et al. 1981; Martin 1995). There are limits to the simultaneous reduction in cement content and *w/cm*, and therefore water content, consistent with maintaining workability.

If drying shrinkage or creep is a critical factor for the structure being built, the shrinkage (ASTM C 157) and creep (ASTM C 512) should be measured before the mixture proportions are finalized to ensure that the desired value is not exceeded.

4.6—Freezing-and-thawing resistance

Concrete containing HRWRAs exhibits a greater degree of resistance to freezing and thawing and deicer salt scaling if the *w/cm* and air-void system are the same, compared with well-consolidated concrete without HRWRA (Lukas 1981). Resistance of the concrete is further improved if the *w/cm* is decreased (reducing permeability).

A spacing factor of 0.008 in. (0.20 mm) or less generally is needed in hardened concrete to be resistant to freezing-and-thawing cycles. Some HRWRA cause bubble spacing factors *L* higher than generally considered necessary to produce concrete that will resist damage from freezing and thawing. Concrete made with HRWRAs with spacing factors of 0.10 in. (2.5 mm) or higher, however, were found to be highly resistant to freezing and thawing (ACI 212.3R; Perenchio, Whiting, and Kantro 1979; Kobayashi et al. 1981; Okada et al. 1981; Roberts and Scheiner 1981).

4.7—Durability

When HRWRAs are used to lower the *w/cm,* the concrete permeability is decreased and strength increased, increasing the durability of the concrete. Concrete treated with an HRWRA has a resistance to chloride penetration similar or slightly higher than that of nontreated concrete with a similar *w/cm*. When used to reduce the *w/cm*, HRWRAs increase the resistance of concrete to the ingress of chlorides, reducing the potential for corrosion (Lukas 1981; Gebler 1982; Swamy 1989). Results indicate that there is no substantial difference in sulfate resistance between concrete treated with an HRWRA and a nontreated reference concrete at a similar *w/cm*. When an HRWRA is used to reduce the *w/cm* of concrete, the sulfate resistance is much higher (Collepardi and Corradi 1980).

CHAPTER 5—TYPICAL APPLICATIONS OF HIGH-RANGE WATER-REDUCING ADMIXTURES

5.1—General

Concrete containing HRWRAs can be used effectively to satisfy a variety of project needs. Concrete producers can use HRWRAs to increase slump without adding water, improve the efficiency of the cement, and help ensure the required concrete strength levels. Concrete contractors can use flowing concrete to ease placing and consolidating and to speed placement. In addition, the contractor may be able to reduce crew size and speed up the construction cycle, thus increasing profits.

5.2—High-strength concrete

High-strength concrete is defined as having a specified compressive strength of 6000 psi (41 MPa) or greater (ACI 116R). The *w/cm* can range from 0.25 for 56-day strengths in excess of 12,000 psi (83 MPa) to 0.40 for some 6000 psi (41 MPa) mixtures at 28 days. Important factors for producing high-strength concrete include: good strength-producing properties of the cement; low *w/cm*; and strong, clean aggregates that are properly sized and graded (ACI 363R). The grading and size of aggregates are dictated by the type of placing method used and the size and congestion of the structural member being constructed.

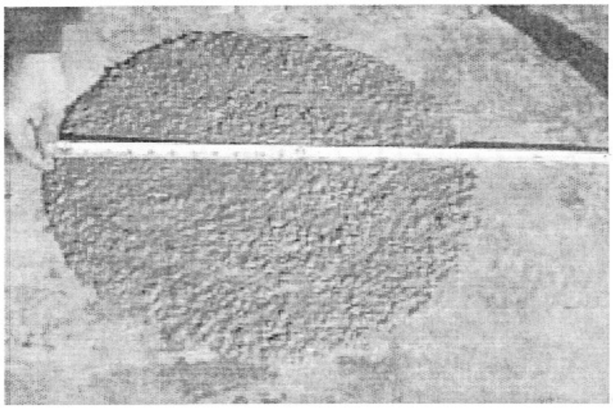

Fig. 5.1—Testing the spread flow of self-consolidating concrete.

When the *w/cm* is below 0.35, HRWRAs are often added at the plant to ensure control of the water and then again in the field for placing purposes. For example, if a mixture has a *w/cm* of 0.33 and a maximum water content of 250 lb/yd^3 (150 kg/m^3), a moderate dose of HRWRA can be added at the plant to produce a 4 to 6 in. (100 to 150 mm) slump. When the concrete is transported to the job site, a second dose of HRWRA can be added to achieve the slump required for pumping or other type of placement. This two-step method of adding an HRWRA results in less retardation in setting time and is particularly useful when the concrete is placed in slabs that will be finished by troweling. Other types of applications may not require the same two-step addition method. When concrete is being placed in columns, the dosage of HRWRA added at the batch plant can be sufficient to ensure the specified slump at the job site and eliminate the need for a second dosage at the job site. For instance, the concrete may have a 9 in. (230 mm) slump at the batch plant and may not require additional admixture, unless construction delays and slump loss occur.

5.3—Precast/prestressed concrete

The benefits of using HRWRAs for low *w/cm*, early strength gain, ease of placement, and rapid form cycling are clearly recognized by the precast/prestressed concrete industry. Precast units often have architectural details that require the use of high-slump concrete, but the concrete should also gain strength quickly to permit early form stripping and turnaround times. Increasing the slump of conventional concrete by adding water will slow early strength gain and delay form stripping. Flowing concrete made with a HRWRA provides high slump plus the strength-gain rate needed for early form removal. The use of an HRWRA to produce self-consolidating concrete (Fig. 5.1) with the same or a lower *w/cm* than conventional concrete can further improve placing and production efficiency, reduce the need to repair surface defects, and reduce or eliminate heat-curing requirements for precast concrete by accelerating strength gain (Corradi et al. 2002).

5.4—Architectural concrete

Architectural concrete is permanently exposed to view and therefore requires special care in the selection of the concrete materials, forming, placing, and finishing to obtain the desired architectural appearance (ACI 116R). Architectural concrete is designed to present a pleasing and consistent appearance with minimal defects. The concrete should reflect the formed surface as much as possible. The concrete mixture should be uniform and workable, without abnormal stickiness to formed surfaces that tends to cause bugholes and other defects either on the exposed surface or slightly below it. An HRWRA can be added to architectural concrete mixtures to increase their workability. The optimum proportions and vibration methods with given materials should be determined by constructing sample panels. Vibration needs vary with the materials used in making the concrete. When an HRWRA is used in architectural concrete, it should be used throughout to achieve color uniformity.

The formwork for flowing architectural concrete containing HRWRAs can be subjected to greater pressures than from conventional concrete mixtures. These pressures can be countered by using forms that are stronger than normal and by sealing form joints and tie holes with materials that will hold fast under high form pressures. Failure to take precautions against the high pressures can result in form blowouts, form-leakage lines, and sand streaks.

5.5—Parking and bridge structures

Parking and bridge structures, due to their exposure and service requirements, often require low *w/cm*; low permeability; and air-entrained concrete that is properly placed, consolidated, finished, and cured. With HRWRAs, easily pumpable or placeable concrete can be proportioned with a *w/cm* of 0.40 or lower. Minimizing voids by properly consolidating the concrete while maintaining an adequate air content throughout the concrete, especially the top surface, is extremely important. The mixture should not exhibit excessive bleeding or segregation.

With any concrete, whether it contains HRWRA or not, overfinishing the surface should be avoided because the procedure can reduce the air content at the surface. Evaporation retardants are commonly sprayed on the surface of the freshly placed concrete one or more times during finishing to prevent plastic shrinkage cracking. If plastic shrinkage cracks develop, they can allow deicers to more easily penetrate the concrete. Properly proportioned concrete with an HRWRA can better resist the ingress of chloride ions than conventional concrete of equal *w/cm* (Lukas 1981) because of the reduced permeability associated with the increased cement efficiency. It is important that concrete placed in parking structures must be properly cured because concrete permeability can be adversely affected by improper curing practices (ACI 308).

5.6—Rapid-cycle high-rise projects

Rapid-cycle high-rise projects are structures with repetitive floor placements where the speed of construction is essential to the success of the project. The choice of a concrete-frame building over a steel-frame building is often made with the expectation that the speed of concrete construction will be a major economic benefit. For adequate safety during construction, most rapid-cycle high-rise projects require a concrete strength of 3000 psi (21 MPa) at 1, 2, or 3 days, when supporting formwork is removed.

Flowing concrete is often used on rapid-cycle projects. Because flowing concrete, made with a HRWRA, produces increased early strengths and can be pumped or otherwise placed rapidly, the finishing operation can usually take place during regular working hours. The flowing concrete should have a *w/cm* that is low enough to ensure early strength development. Concrete containing a HRWRA uses cement more efficiently and satisfies the requirements of rapid-cycle projects extremely well. The lower *w/cm* achieved with HRWRAs produces the highest percentage increase in strength at early ages. In cold weather, a noncorrosive, nonchloride accelerator or Type III cement can be used in combination with the HRWRA to offset the effect of low temperatures on initial setting and early strength gain.

5.7—Industrial slabs

Industrial slabs are subjected to varying degrees of vehicular traffic that place special demands on the concrete. An HRWRA is very helpful in producing concrete that can be proportioned and easily adjusted to accommodate placing and finishing operations while maintaining the quality of the hardened concrete. When finishing is of concern, the mixture proportions should be based on proper aggregate gradation and a minimum amount of fines. An on-site trial placement should be conducted to verify that the concrete finishes in an acceptable manner. An HRWRA may help achieve desirable slab characteristics, including flatness and levelness tolerances, equal to or less than those specified, achievement of the specified compressive and flexural strengths, good to excellent abrasion resistance of the top surface, and a minimum of cracking and curling.

To reduce slab shrinkage, the changes should minimize water content while allowing optimum slump for the method of placement to be used. For strips 25 ft (7.6 m) wide or less that are placed directly from the truck mixer and finished with a vibratory screed, an initial slump of 2 to 3 in. (50 to 75 mm) may only need to be increased to 6 in. (150 mm) by adding an HRWRA. For wider strips, more difficult access, or when the placement method involves pumping, the HRWRA dosage can be increased to produce a higher slump without altering other mixture proportions. The HRWRA dispersing effect is physical in nature and results in predictable water reduction or slump increase and setting time. The appropriate mixture with respect to workability, finishability, and times of setting should be discussed and resolved at a preconstruction meeting after a successful trial slab placement. Successful trial floors should have uniform setting characteristics and be placed within a +1-1/2 in. (38 mm) slump variation for the entire project, based on the concrete contractor's requirements. After the proposed mixture proportions have been approved, the schedule, placing, consolidating, and finishing procedures can also be finalized.

Cracking and curling are related to water content, *w/cm*, and the homogeneity of the concrete mixture. Because a slab normally experiences water loss due to evaporation only from the top surface, it develops differential shrinkage between the top and bottom surfaces, which leads to curling. Adding an HRWRA permits the use of lower water-content concrete that bleeds and curls less (White and Phelan 2002).

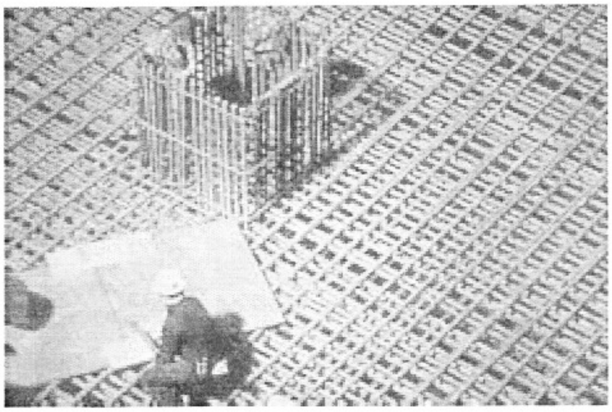

Fig. 5.2—Heavily reinforced mass concrete.

5.8—Massive concrete

Concrete sections that are 2 ft (0.6 m) thick or greater present problems in placement, consolidation, setting times, heat generation, shrinkage, and cracking. Cementitious material and water content should be minimized to reduce heat generation and volume change. At the same time, sufficient workability is needed to permit proper concrete placement and consolidation in large sections where reinforcement can be closely spaced (Fig. 5.2). Flowing concrete containing an HRWRA is well suited for this use. Even though water reductions in lean mass concrete may not be as high as those for richer concrete, the use of an HRWRA is beneficial. Flowing concrete produced with appropriate setting times can be placed faster and with fewer problems related to cracking, inadequate consolidation, or cold joints. For example, an 8000 yd^3 (6000 m^3) mat, 5.5 to 7 ft (1.7 to 2.1 m) thick, was successfully placed in 13-1/2 h using 100 trucks on the International Crossroads project in Mahwah, N.J. Some 10 yd^3 (8 m^3) trucks were discharged in less than a minute (Constructioneer 1986). This speed of discharge and ease of placement improves the probability of successful massive concrete placements.

CHAPTER 6—QUALITY CONTROL

6.1—Introduction

Quality-control procedures for concrete containing an HRWRA are an extension of procedures established for conventional concrete. For both types of concrete, established procedures should ensure that the following areas are adequately addressed:

- Personnel training, including ACI certifications applicable to the task and laboratory competence including accreditation;
- Selection of materials, including materials compatibility;
- Mixture proportions, including trial batches to demonstrate field performance;
- Storage of materials;

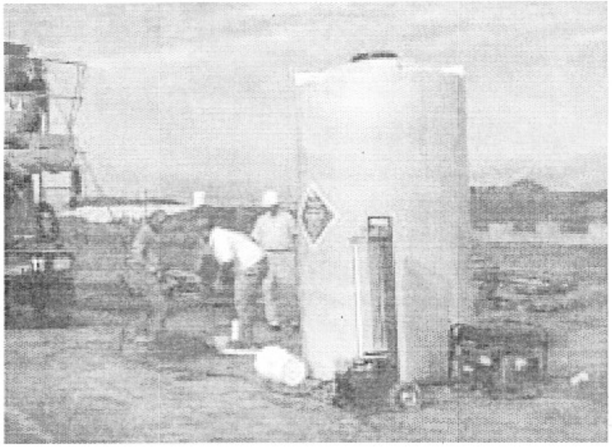

Fig. 6.1—Job-site bulk admixture-dispensing system.

- Plant equipment, including concrete mixer efficiency and effectiveness;
- Batching, measuring, and mixing of materials;
- Delivery equipment;
- Delivery coordination;
- Placement and consolidation;
- Finishing;
- Protection and curing; and
- Establishment of a quality-control and quality-assurance system (ACI 311.4R and ASTM E 329).

Depending on the application and desired results, several quality-control areas require additional attention to ensure acceptable concrete performance is attained:

- *w/cm* (Section 6.2);
- Slump control (Section 6.2);
- Air content control (To avoid excessive loss of entrained air during mixing or placement, the proper sequence should be established for adding the air-entraining admixture relative to other mixture constituents.);
- Measuring and dispensing of HRWRA (Section 6.2.1 and 6.2.2);
- Mixing (Section 6.2.2);
- Redosing with HRWRA (Section 6.3); and Temperature considerations (Section 6.5).

6.2—Water-cementitious material ratio and slump control

Traditionally, the slump test has been used as a means to measure the quality of conventional concrete mixtures. Because the use of an HRWRA can drastically increase slump without increasing the *w/cm*, caution should be used to not improperly reject HRWRA-treated concrete based on slump test results. Through the use of an HRWRA, concrete with very low *w/cm* (< 0.32) and no measurable slump before the addition of the HRWRA can be made flowing and self-consolidating. As with all concrete, maintaining the *w/cm* for each batch produced is critical.

Accurate measurement and compensation of aggregate moisture are crucial factors in maintaining a consistent *w/cm*. Although an error of 1% in moisture compensation for both fine and coarse aggregates would have a minor impact on the amounts of aggregate batched, the batch water could be off by 3 to 4 gal./yd^3 (9 to 12 L/m^3). Aggregate moisture meters can be valuable tools to provide accurate aggregate moisture compensation, providing they are properly installed and calibrated.

Any water left in a truck mixer or from washing down hoppers and blades should be accounted for, and the amount of water batched should be reduced accordingly.

Central-mixed operations should use wattmeters, ammeters, or other means of indicating slumps before adding an HRWRA. The HRWRA can then be measured and added to the central mixer using conventional dispensing equipment.

6.2.1 *Plant-added HRWRA*—One potential advantage to a plant-added HRWRA is that control of initial slumps is centralized usually under the supervision of one person. Transit-mixed operations should have procedures for measuring and controlling the *w/cm* and slump before the addition of an HRWRA. These procedures might include measuring slump, estimating the slump visually, or by the use of slump meters. A slump meter is a mechanical device often used at central-mix concrete plants to provide an indication of slump during mixing, measured by the electrical power needed to turn the mixing drum.

When an HRWRA is used in conjunction with another admixture, each admixture must be dispensed separately into the concrete mixture in a manner that they do not come in contact with each other during the dispensing process.

6.2.2 *Job-site-added HRWRA*—Where an HRWRA is added from a bulk-dispensing system or field-dispensing unit at the job site (Fig. 6.1), the basic procedures previously discussed in Section 6.2.1 should be followed.

When truck-mounted tanks (Fig. 6.2) are used to dispense an HRWRA, several additional procedures need to be addressed. Because these procedures are not routine, drivers should be trained in their use. At the ready-mix plant, an HRWRA is normally measured by the batcher and introduced into the truck tank by the driver. This process requires coordination. Procedures should ensure that the driver is made aware that he or she is to receive the HRWRA in addition to his or her load, is familiar with valves on the truck dispensing equipment, and makes sure that the HRWRA is correctly discharged into the truck-mounted admixture tank.

Once at the job site, the slump should be measured before adding the HRWRA to ensure that the concrete is within the target range—typically 2 to 3 in. (50 to 75 mm). Procedures to deal with slumps that are out of the target range should be discussed and agreed on at the preplacement meeting. The HRWRA is then introduced and mixed into the load. Best results are obtained when the HRWRA is discharged directly onto the concrete. This can require reversing the drum to move partial loads to the rear of the drum before discharging the admixture. Care should be taken during discharge to prevent the stream of admixture from striking the mixer blades and being deflected down the chute. This could result in a loss or a concentration of the HRWRA in a small pump hopper or crane bucket if the truck is already in position on the job. The load should be mixed at mixing speed (18 to 22 rpm) for a

Fig. 6.2—Truck-mounted admixture-dispensing system.

sufficient time to ensure a consistent slump throughout the load, typically 70 to 100 revolutions.

When the HRWRA in a truck tank is not used completely, the tank should be emptied or the HRWRA accounted for to prevent double dosing subsequent loads.

6.3—Redosing to recover lost slump

Additional doses of HRWRA can be used when delays occur and the required slump has not been maintained. Up to two additional doses have been used with success (Carrasquillo and Carrasquillo 1986). Typically, the compressive strength is maintained, but air content is decreased. To redose, a supply of material and calibrated measuring containers or portable dispensing units should be provided.

6.4—Placement of flowing concrete

Flowing concrete containing an HRWRA can be placed quickly and easily. Proper consolidation can be accomplished with much less effort than with conventional concrete, but the need for vibration is not eliminated. Observations should be made to ensure that the mixture is cohesive and nonsegregating. If segregation occurs, mixture proportions should be adjusted. Improving the combined aggregate gradation or increasing the fine-to-coarse-aggregate ratio can usually solve this problem. Increasing the entrained air content within specification limits, or including or increasing the amount of an appropriate mineral admixture, can also be beneficial.

6.5—Temperature considerations

In cold weather, higher dosage rates of HRWRAs may be required to gain the same results obtained in warmer weather, and concrete containing HRWRAs may have delayed times of setting compared with similar concrete without the admixture. High-early-strength cement or accelerating admixtures can be used to normalize the time of initial setting and early strength gain. Attention to proper storage of the HRWRA to protect against freezing helps ensure proper admixture and concrete performance. As with all concrete, proper cold-weather concreting practices are necessary when using HRWRAs (ACI 306.1).

Hot-weather conditions and elevated concrete temperatures can lead to rapid slump loss of concrete treated with a HRWRA. As with all concrete, proper hot-weather concreting practices are strongly recommended when using HRWRAs (ACI 305R).

CHAPTER 7—REFERENCES

7.1—Referenced standards and reports

The standards and reports listed below were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it is desired to refer to the latest version.

American Concrete Institute

116R	Cement and Concrete Terminology
201.2R	Guide to Durable Concrete
211.1	Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
212.3R	Chemical Admixtures for Concrete
301	Specifications for Structural Concrete
302.1R	Guide for Concrete Floor and Slab Construction
305R	Hot Weather Concreting
306.1	Standard Specification for Cold Weather Concreting
308	Standard Practice for Curing Concrete
309R	Guide for Consolidation of Concrete
311.4R	Guide for Concrete Inspection
318	Building Code Requirements for Structural Concrete
347	Guide to Formwork for Concrete
363R	State-of-the-Art Report on High-Strength Concrete
SP-62	Superplasticizers in Concrete
SP-68	Developments in the Use of Superplasticizers
SP-119	Superplasticizers and Other Chemical Admixtures in Concrete
SP-148	Fourth CANMET/ACI International Conference on Superplasticizers and Chemical Admixtures in Concrete
SP-173	Fifth CANMET/ACI International Conference on Superplasticizers and Other Chemical Admixtures in Concrete
SP-195	Sixth CANMET/ACI International Conference on Superplasticizers and Other Chemical Admixtures in Concrete

ASTM International

C 157	Test Method for Length Change of Hardened Hydraulic Cement Mortar and Concrete
C 494	Specification for Chemical Admixtures for Concrete
C 512	Standard Test Method for Creep of Concrete in Compression
C 1017	Specification for Chemical Admixtures for Use in Producing Flowing Concrete
E 329	Standard Specification for Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction

The preceding publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

ASTM International
100 Barr Harbor Dr.
West Conshohocken, PA 19428

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