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Monitoring for Cold Weather Concreting

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James Baty is the Managing Director for the Concrete Foundations Association and Technical Director for the Tilt-Up Concrete Association. He has a career-long emphasis on thermal dynamics and behavior of concrete as well as concrete construction and design education. As a director for the CFA, he overseen the research efforts of multiple projects related to concrete performance.

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Cold Weather Affects on Residential Concrete Foundation Walls

Presented by:
James R. Baty II, Managing Director

Research Results

Phase I, II and III conducted
November, 2002 to July 2003

- Testing Lab Cylinders
- Simulated Field Walls
- Petrographic Investigation

The Research Team

- Research Leader
  - Brad Barnes P.E., North Central Engineering, Ltd., Canton, OH
- Suppliers
  - Master Builders, Inc., Cleveland, OH
  - Osborne-Medina Concrete, Medina, OH
  - Con-Cure Corporation, St. Louis, MO
  - Cemstone Concrete, Minneapolis, MN
- Contractors
  - Lavy Concrete Construction, Piqua, OH
  - Modern Poured Walls, LaGrange, OH
  - Tri-County Excavating Inc., Richfield, OH
  - Dependent Foundations, Brighton, MI
  - Van Wyks, Inc., Waldo, WI
  - JC Concrete Inc., Berrien Springs, MI
  - Martinson Construction, Waterloo, IA

A Response to the Market…

2001 – Ohio
Over a dozen projects shut down by inspectors due to "cold weather".

2002 – North Carolina
Contractors are not permitted to place concrete below 50° F.

2001 – Michigan
Contractors routinely and successfully place at sub-freezing temperatures without restrictions.

Policy #099 – Anchorage, Alaska
Concrete strength to reach 1,500psi at 24 hours…submit documentation verifying results
Tenting must be provided until concrete reaches 1,500psi when temps fall below 35° F.

Precipice

- Need to understand how "cold weather" impacts the residential concrete foundation wall industry.
- Existing codes – Protective measures must be taken; Empirical evidence – they may not be necessary or even helpful.
- Variations in "local" mixture performance mandates a need for method of validation of in place strengths.
- What constitutes cold weather is even debatable. In other words…

The Research Program

- Phase I: Laboratory Chiller Cylinders
  - 36 mix designs
  - 44 maturity curves
  - over 650 cylinders cast and tested
  - Wide range of mixes from very "lean" to very "rich"
  - Two different temperatures, 30°F and 50°F
- Phase II: Field Mock-Up Walls
  - 6 selected mix designs
  - 24-hour blanketed vs. un-blanketed
- Phase III: Laboratory Petrographic Studies

Mix Design Variation

Qty of Cement (Sacks per CY)	Cement Type	Admixtures	Curing Temperature
5	I	None	30°F
5.5		1% Calcium	
6	III	2% Calcium	50°F
6.5		1% Calcium with MRWR	
		Non-Chloride Accelerator (NCA)	

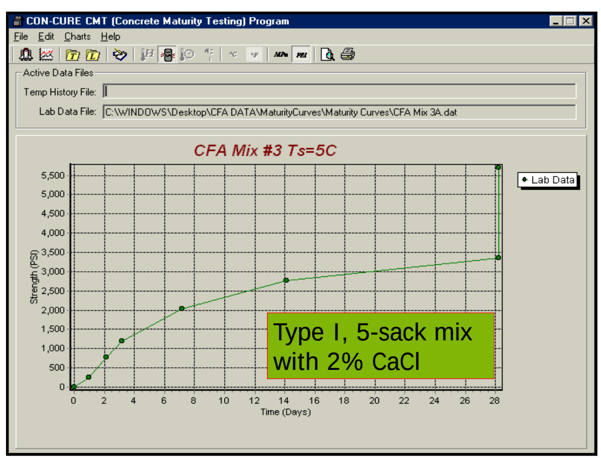
Mix ID	Init Set	Final Set	1D Age,hrs	1D AVGCS psi	2D Age,hrs	2D AVG CS psi	3D Age,hrs	3D CS psi	7D Age,hrs	7D CS psi	14D Age,hrs	14D CS psi	28D Age,hrs
1	10:55	16:07	24.07	100	52.40	560	76.90	1200	172.90	2240	340.40	2860	678.40
2	9:05	13:49	24.05	190	51.47	770	76.13	1300	171.97	2240	339.47	2950	677.55
3	6:52	10:28	24.05	260	51.13	780	75.80	1200	171.63	2040	339.13	2760	677.13
4	5:13	8:55	24.00	390	50.27	1170	74.93	1840	170.68	2900	338.18	3600	676.27
5	8:34	12:55	24.08	410	52.83	1350	77.83	2060	173.33	2990	341.17	3650	677.83
6	11:17	17:47	24.12	130	52.53	690	76.53	1330	172.45	2430	339.95	3160	677.98
7	7:40	12:20	24.07	220	50.15	960	74.65	1550	170.32	2570	337.82	3380	675.90
8	5:19	8:57	24.08	340	49.17	950	73.67	1420	169.25	2490	336.75	3130	674.88
9	5:36	9:28	24.10	370	48.77	1370	73.27	2200	168.77	3210	336.27	3970	674.43
10	8:18	12:17	24.08	450	52.50	1590	77.50	2520	173.00	3540	340.75	3960	677.42
11	9:22	13:09	24.05	320	52.13	1230	77.13	1800	172.55	2750	340.30	3620	676.97
12	7:05	10:47	24.02	510	51.43	1400	76.43	2150	171.77	3080	339.52	4010	676.18
13	4:59	8:06	24.03	680	51.12	1410	76.12	1940	171.37	2670	339.12	3750	675.78
14	4:19	6:57	24.00	820	50.83	2260	75.83	2890	171.00	3910	338.75	4720	675.42
15	7:25	11:15	24.08	460	50.67	1910	75.67	2990	170.75	3940	338.50	4740	675.17
16	8:59	13:00	24.07	290	51.90	1170	77.57	1830	172.57	2740	340.32	3570	676.98
17	6:46	10:09	23.97	510	50.38	1660	75.38	2460	170.30	3260	338.05	4150	674.72
18	5:17	8:26	23.98	720	50.07	1430	75.07	2320	169.90	2990	337.73	3620	674.32
23	12:44	19:46	24.42	190	49.67	680	72.67	1300	174.25	2350	341.17	3630	677.42
24	7:36	11:56	24.05	430	48.72	1190	71.63	1750	173.38	2680	340.13	3420	676.30
25	4:53	7:55	24.25	630	49.00	1400	71.33	1840	173.00	2710	339.75	3470	675.92
26	3:51	6:40	23.75	340	48.42	780	70.67	1290	172.42	3020	339.08	3920	675.25
27	7:17	11:07	23.90	310	47.98	1080	70.23	1840	171.98	3280	338.57	4180	674.73
28	12:02	19:48	24.22	200	49.13	1000	72.05	1790	173.80	3030	340.55	4210	677.13
29	6:17	10:02	23.80	400	47.53	1560	69.87	2370	171.53	3800	338.12	4560	674.37
30	3:48	5:42	24.18	790	47.18	1640	69.52	2330	171.27	3360	337.77	4130	674.02
31	3:17	5:11	24.13	400	46.80	1060	69.13	1810	170.80	3900	337.30	4610	697.88
32	6:57	11:03	24.10	420	46.35	1530	68.68	2360	170.35	3770	336.85	4740	697.43
33	10:37	16:46	24.07	130	51.57	770	76.07	1660	172.90	3620	337.32	4450	676.07
34	7:01	10:22	24.03	680	51.03	1630	75.53	2410	172.28	3960	336.70	4840	675.37
35	3:44	5:51	23.93	1030	50.27	2080	74.77	2700	171.43	4050	335.85	4610	674.43
36	3:29	5:28	23.97	740	49.97	1400	74.47	2380	171.05	3880	335.47	4770	673.97
37	7:13	11:18	24.03	930	49.62	2430	74.12	3350	170.62	4820	335.03	5600	673.45
38	9:54	16:26	23.95	450	49.28	1770	73.78	2560	170.20	4060	334.62	4750	672.95
39	5:41	8:56	24.03	750	49.03	2280	73.53	3170	169.87	4480	334.28	5180	672.53
40	3:34	5:52	24.02	1230	48.68	2240	73.18	3170	169.43	4430	333.85	5160	672.02
19	7:23	10:34	24.13	390	52.63	1220	77.13	2110	173.63	2470	338.63	2880	678.38
20	6:28	9:34	23.92	660	52.33	1860	76.83	2810	173.25	3270	338.25	3860	678.00
21	6:55	10:02	24.00	730	52.08	2120	76.58	2990	172.92	3460	337.92	3620	677.67
22	6:10	8:45	24.07	870	51.82	2410	76.32	3560	172.57	3840	337.65	4520	677.32
41	6:14	9:02	24.00	960	51.50	1960	76.00	3070	172.17	3430	337.25	3830	676.92
42	5:59	8:38	24.00	1130	51.17	2640	75.67	3670	171.75	4160	336.92	4420	676.50
43	5:55	8:15	24.03	1290	50.87	3030	75.37	3980	171.37	4480	336.53	4860	676.12
44	6:02	8:19	24.07	1300	50.57	2990	75.07	4350	170.98	4830	336.23	5390	675.73

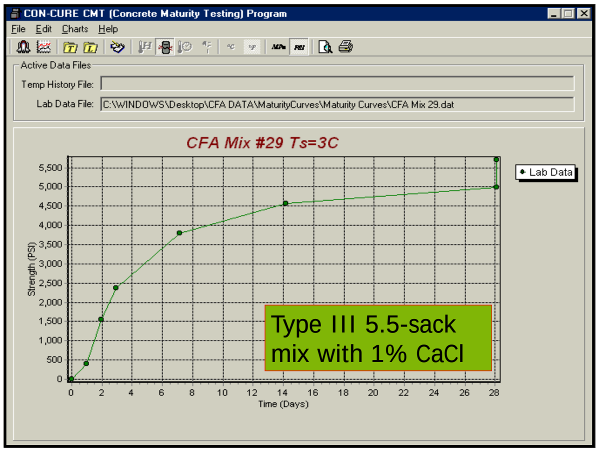
Research Methodology

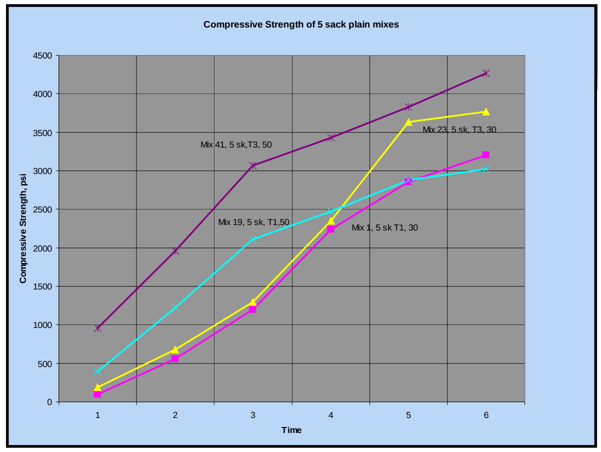
- Designed to a "worst-case" scenario for lab cylinders (Phase I) and received "worst-case" scenario for field walls (Phase II).
- Testing represented a significant deviation from standard conditions (no 70° moist cure).
- All 44 lab maturity curves were checked and entered into the maturity testing software.
- All 12 field maturity curves were also checked by maturity.

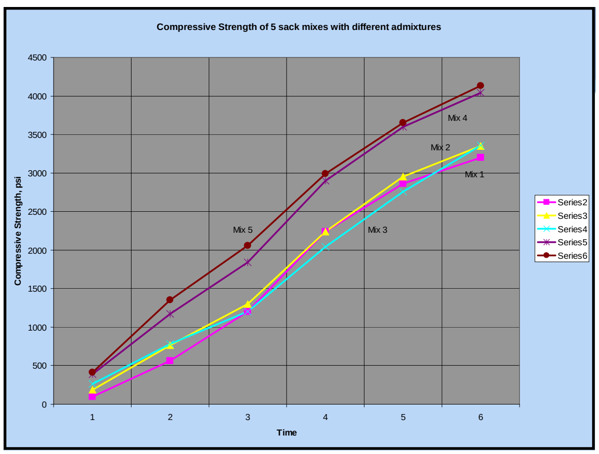
Field Test Weather Detail – 01/2003

JAN-03 FOR CLEVELAND, OH (804')											LAT=41.4N LON= 81.8W
	TEMPERATURE DATA										
	ACTUAL			NORMAL				PRECIPITATION			
	HI	LO	AVG	HI	LO	AVG	DEPT	AMNT	SNOW	SNCVR	HDD
1	34	31	33	34	21	28	5	0.14	trace	0	32
2	31	27	29	33	20	27	3	0.15	1.5	0	36
3	30	25	28	33	20	27	1	0.05	0.6	1	37
4	28	25	27	33	20	27	0	0.05	0.6	2	38
5	31	23	27	33	20	27	1	0.01	0.1	2	38
6	30	20	25	33	20	27	-2	0.41	5	3	40
7	35	10	23	33	19	26	-4	0	0	5	42
8	45	32	39	33	19	26	13	0	0	3	26
9	44	33	39	33	19	26	13	trace	trace	0	26
10	33	20	27	33	19	26	1	0.13	2	0	38
11	20	17	19	33	19	26	-8	0.01	0.2	1	46
12	27	16	22	33	19	26	-5	trace	trace	1	43
13	27	19	23	32	19	26	-3	0.01	0.1	0	42
14	22	18	20	32	19	26	-6	0.02	0.3	0	45
15	20	10	15	32	19	26	-11	0.08	1.6	1	50
16	20	12	16	32	18	25	-9	0.04	0.9	2	49
17	22	6	14	32	18	25	-11	0.06	1.8	2	51
18	22	4	13	32	18	25	-12	trace	0.4	2	52
19	24	14	19	32	18	25	-6	0.05	1	2	46
20	26	15	21	32	18	25	-5	0.06	1.1	3	44
21	19	6	13	32	18	25	-13	trace	trace	2	52
22	14	5	10	32	18	25	-16	0.02	0.6	2	55
23	18	4	11	32	18	25	-14	0.06	2.1	2	54
24	20	14	17	32	18	25	-8	0.02	0.5	3	48
25	25	15	20	32	18	25	-5	trace	trace	3	45
26	27	10	19	33	18	26	-7	0.3	6.6	3	46
27	15	-4	6	33	18	26	-20	trace	trace	7	59
28	29	14	22	33	18	26	-4	0.12	1.3	6	43
29	29	19	24	33	19	26	-2	0.19	2	9	41
30	30	5	18	33	19	26	-9	trace	trace	8	47
31	39	12	26	33	19	26	-1	0	0	8	39
				TOTALS FOR CLE							
HIGHEST TEMPERATURE			45		TOTAL PRECIP			1.98			
LOWEST TEMPERATURE			-4		TOTAL SNOWFALL			30.3			
AVERAGE TEMPERATURE			21.2		NORMAL PRECIP			2.48			
DEPARTURE FROM NORM			-4.5		% OF NORMAL PRECIP			80			



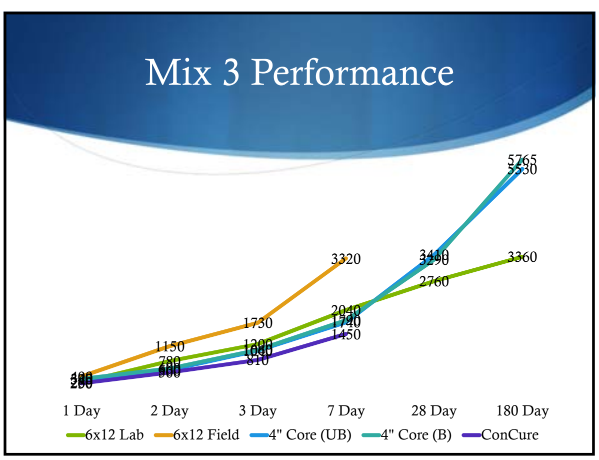


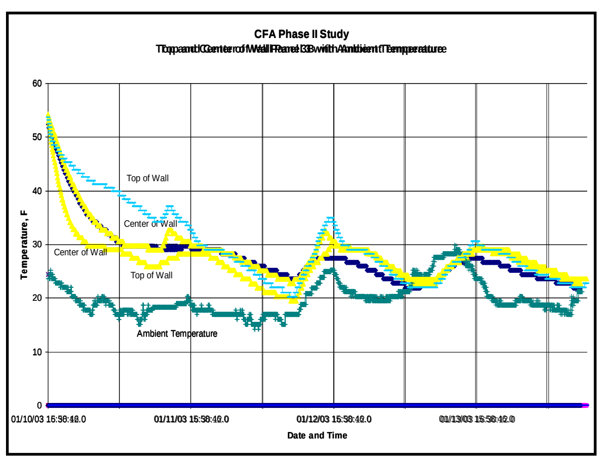




Mix Desc.	Data Set	1 Day (~30 hrs.)	2 Day (~48 hrs.)	3 Day (~73 hrs.)	7 Day (~170 hrs.)	28 Day (~702 hrs.)	180 Day
5-sack Type I 2% CaCl	Uncov.	330	560	1040	1740	3410	5530
	Cov. §	340	600	1060	1790*	3290*	5765
	Matur.	230	500	810	1450	-	-
5.5-sack Type I 2% CaCl	Uncov.	410	600	1020	1650	3460	5695
	Cov. §	400	590	1000	1815*	3520*	6250
	Matur.	280	580	940	1690	-	-
6-sack Type I 2% CaCl	Uncov.	510	700	1160	1840	3800	6955
	Cov. §	520	740	1280	2005*	3605*	-
	Matur.	560	950	1350	2100	-	-
5-sack Type III 1% CaCl	Uncov.	500	840	1350	1750	3150	5750
	Cov. §	510	870	1470	2035*	3270*	5450
	Matur.	450	1050	1560	2070	-	-
5.5-sack Type III 1% CaCl	Uncov.	990	1320	1840	2220	4140	5550
	Cov. §	990	1370	2110	2710*	4180*	5750
	Matur.	550	1530	2280	2990	-	-
6-sack Type III 1% CaCl	Uncov.	1400	1870	2500	3030	5250	6500
	Cov. §	1550	1970	2620	3360*	4965*	6850
	Matur.	1180	2060	2760	3820	-	-

* Average strength of 2 cores taken from the top one foot and center of the same wall panel.
§ Covered with a curing blanket for first 18 hours after it was placed.





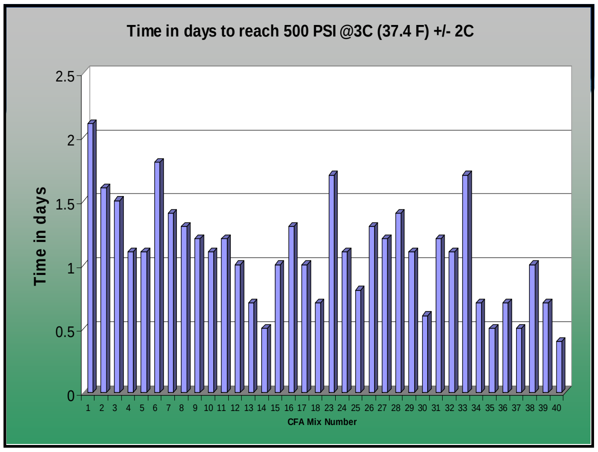
Phase III - Petrography

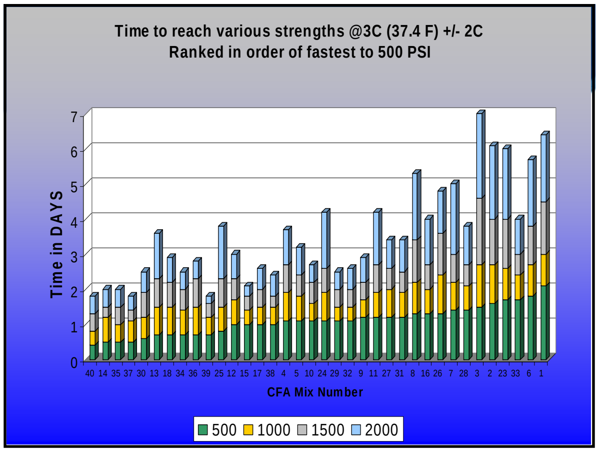
CFA Cold Weather Testing
Phase II Study

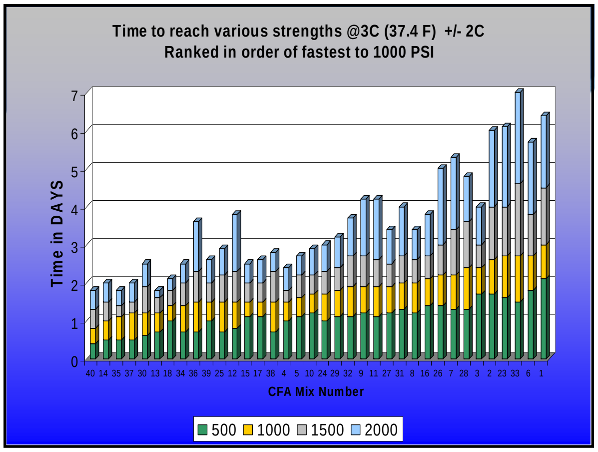
Petrographic Examination Summary

Panel/Mix ID	Microfracturing [1,2] Severe	Microfracturing [1,2] Moderate	Microfracturing [1,2] Mild	Effect on Cement Paste [1,3] Severe	Effect on Cement Paste [1,3] Moderate	Effect on Cement Paste [1,3] Mild
3	½"	1-1/2"	Entire Thickness	1/16"	1-1/4"	N/A
3B	N/A	N/A	N/A	N/A	N/A	1/16"
8	½"	1-1/2"	2-1/2"	1/32"	1-1/4"	N/A
8B	N/A	N/A	N/A	N/A	N/A	Superficial
13	½"	1-1/8"	1-3/4"	1/32"	¾"	N/A
24	¾"	1-3/4"	2-3/4"	1/32"	¾"	N/A
24B	N/A	N/A	N/A	N/A	N/A	1/8" [4]
29	5/8"	1"	1-1/2"	1/32"	3/8"	N/A
29B	N/A	N/A	N/A	N/A	N/A	Superficial
34	1/8"	5/16"	1-1/4"	1/32"	3/16"	N/A
34B	N/A	N/A	1/32"	N/A	N/A	1/64"

Notes:
1. Depth in inches from either end of the wall.
2. Severe, moderate and mild refers to the petrographer's subjective assessment of the concentrations of microfractures.
3. Severe, moderate and mild refers to how much of the cementitious paste exhibited characteristics of unusual whiteness, softness and friability, etc., and the presence of imprints of ice crystals.
4. Occasionally observed up to ¼".







Conclusions for Residential Walls

- Concrete temperature not ambient temperature.
- Hydration does not stop at 40°F…strength gain continues well below freezing.
- Maturity prediction can be used to accurately track in-place strengths.
- 500 psi early strength before freezing is reasonable and can be readily achieved.
- Current restrictive codes should be relaxed through new techniques and professional practice.
- Codes should accommodate better quality control and maturity testing.

Conclusions for Residential Contractors

- No single mix answer.
- Selection of a few mix designs supported by maturity testing to confirm local performance.
- Pour earlier in the day – solar gain on concrete mass
- Type III cements over Type I for performance
- Economical strength gain from use of calcium chloride.
- Slower strength gain in cold weather – use caution when removing support.


cfa
concrete
foundations
association
For More Information:
James R. Baty II, Managing Director
866-232-9255 | jbaty@cfawalls.org | www.cfawalls.org