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COLD CONCRETE

Carl D. Stormer

April 1970

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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PREFACE

This study was performed by Mr. Carl D. Stormer to fulfill part of the requirements for the degree of Master of Engineering, at the Thayer School of Engineering, Dartmouth College. Mr. Stormer is now a Civil Engineer with the Alaska District, Corps of Engineers. This report is published under DA Task 1T062112A13001.

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Mr. Frederick Sanger of CRREL technically reviewed this report and served on the Thayer School faculty committee for this thesis.

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COLD CONCRETE

by

Carl D. Stormer

REVIEW OF THE LITERATURE

Concrete best develops its strength when cured at 100% relative humidity and at temperatures between 50 and 70°F, conditions almost never found in field practice. Thus, some way of controlling the environment of freshly placed concrete is nearly always necessary. Low-temperature conditions create a problem in winter in the temperate zones and are almost always a problem in the cold regions of the world. The process of pouring and curing concrete at these low temperatures is detrimental to the strength of the concrete and expensive when a great amount of protection is required. What is desired is a way of placing concrete that would allow it to gain sufficient strength in a reasonable time while reducing the extensive protection and special mixing and placing techniques required when ordinary concreting is done at low temperatures.

One way of accomplishing this is by using "cold concrete," which contains sufficient salt, usually calcium chloride and/or sodium chloride, to lower the freezing point of the water so that it will not freeze until the concrete has enough strength to withstand the early stresses created by the freezing temperature. Other ionizing salts have been experimented with, but they are more costly than those mentioned so are not used in practice.

Calcium chloride was first used in cement as early as the 1880's and 1890's in Europe. Since then much experimenting has been done with $CaCl_2$ and other salts in cements and concrete. But the American Concrete Institute (ACI) Standard Recommended Practice for Winter Concreting still states that "no more than 2% (by weight of cement) calcium chloride" should be used. Literature now available shows that 2, 3, or more times as much calcium chloride can be used without damaging effects (if temperature is low enough) and still allow good strength development at lower temperatures.

The most common method of evaluating concrete is by its compressive strength. Throughout this report, this standard will be used as a means of evaluation. Temperature is also one of the major considerations when concreting is done in cold regions. Figure 1 illustrates relationships of time, temperature, and compressive strength.

It can easily be seen from this figure that the lower the temperature, the slower the hydration of the cement; this results in the slower development of compressive strength. This figure also shows what happens when 2% $CaCl_2$ is added: the calcium chloride accelerates the rate of hydration and results in increased compressive strengths of up to 356% at early ages. The early strength is advantageous in that form work and protection can be removed earlier than if the accelerator is not used.

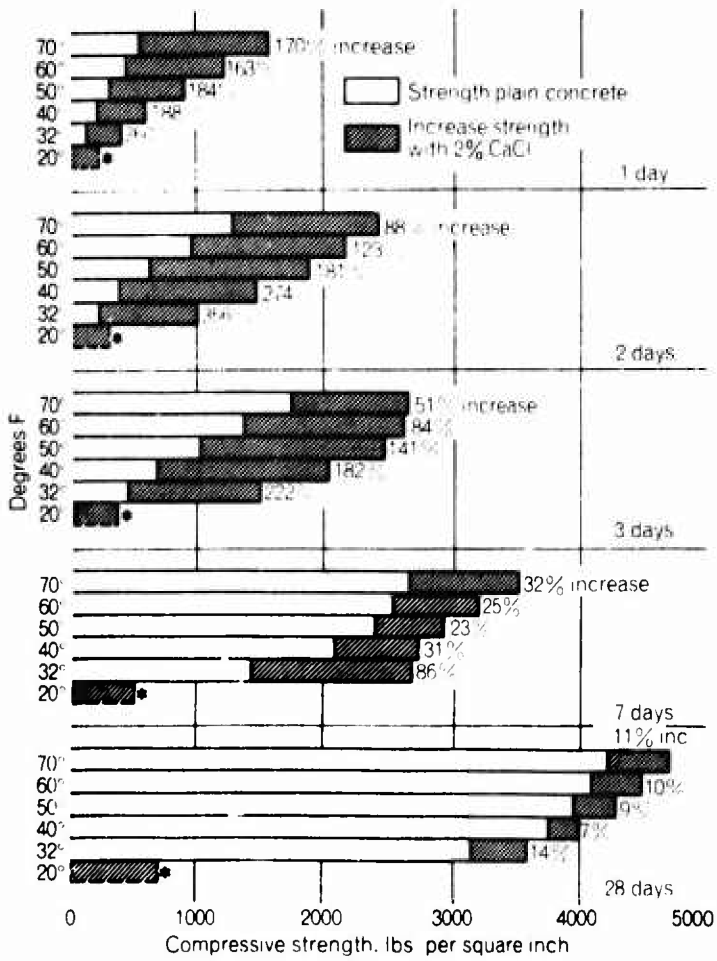

Figure 1. Comparative effects of calcium chloride on strengths of concrete at temperatures of 70°F and lower and at varying ages. (Copyright, Allied Chemical Corp.; reprinted by permission.)

McNeese (1952) made a series of experiments with and without salts on the effects on concrete when it was frozen in the early stage of its initial set. A cylinder with no salt additives was kept at 32°F or lower up to 72 hours. Compressive strength tests were made at 3, 7, and 28 days on most of the specimens. From this McNeese concluded:

1. A relationship exists between the time and temperature at which the concrete is frozen after it has been placed.

2. Losses in compressive strengths of up to 50% occur.

3. If damage is to occur, freezing must take place in the first 6 hours. (Twenty-four hours is a common specification for the frost protection of concrete.)

4. The length of time the concrete is frozen has little effect on loss of strength.

5. If the concrete is frozen while plastic and thawed at 75°F, it still loses about 45% of its strength.

These results establish the need for protecting, and being careful with, concrete at early ages in freezing environments. When a salt like calcium chloride is added to the concrete, the concrete has its own built-in protection. The salt also permits higher workability with lower water/cement ratios, resulting in higher strengths with little change in placement characteristics.

Klieger (1958) made some experiments with concrete at 40°F with 0% and 2% calcium chloride by weight of cement, cured at 40°F and 25°F. His results showed that the concrete with the calcium chloride had a higher early strength than that without the chloride and that there was little difference between the two at the end of 28 days. When calcium chloride was used, the concrete cured at 25°F had a compressive strength comparable with that of concrete cured at higher temperatures. Thus, it can be said that the addition of calcium chloride seems to be beneficial to the development of concrete strength at early ages and low temperatures.

Yates (1941) made a similar experiment using concrete with 0, 1, 2, 3, and 4% $CaCl_2$ by weight of cement, cured at 20°F, 25°F, 32°F, and 40°F. He showed that the addition of calcium chloride increased the strength of the concrete at all temperatures and all ages. He also noted that there was a greater increase in strength at the lower temperatures and early ages.

Price (1952) reported that the addition of calcium chloride to concrete at 40°F increased the compressive strength at any age and that only 2% to 3% of the salt by weight of cement was required because more than 3% did not increase the strength significantly.

In a short article about the effect of calcium chloride on cements in cold weather, Howard (1952) stated that in all cases the strengths were higher where calcium chloride was used. Five different brands of cement were used to measure flow, stiffening, and bleeding rates. In almost every case, each brand of cement gave different results, indicating variability in the brands of cement. This is also brought out in the Russian literature, and it is suggested that when there is a difference in the mineralogical content of the cement the properties of cold concrete will differ.

Shideler (1952) described the general properties of cold concrete, based on information from many sources. In almost all cases the chloride content did not exceed 2 to 4% and did increase the strength.

When the strength characteristics are being studied, the type of cement (I, III, etc.), placing and curing temperature, and cement content should be considered. The experimental part of this report will consider only the placing and curing temperature.

When calcium chloride is added to cement, the heat of hydration is released more quickly than without the chloride (see Fig. 2). This higher early heat of hydration helps in two ways to protect concrete when it is poured at low temperatures: 1) it permits the concrete to develop a higher early strength, making it more resistant to frost damage; and 2) it helps to keep the concrete from freezing because the concrete is at a higher temperature during the first and most critical day.

The National Bureau of Standards (NBS) conducted tests on concrete with 0% and 1% calcium chloride by weight of cement. The specimens, made of type II cement, were mixed and cured for 1 day at 50°F, then stored at 16°F, 33°F, 50°F, 70°F, and 100°F. The 33°F and 16°F temperatures in Figure 3 are of particular interest. At 16°F water freezes, thus eliminating any further hydration. (1% $CaCl_2$ is not sufficient to prevent the water from freezing at 16°F.) When the temperature is at 33°F none of the water freezes and strength develops at a reasonable rate. Note the increase in strength created by adding 1% calcium chloride. Except in a few isolated instances the addition of calcium chloride in small percentages increased the compressive strength in all NBS tests. This seems to indicate that small additions would be beneficial to strength even where freezing and low curing temperatures are found.

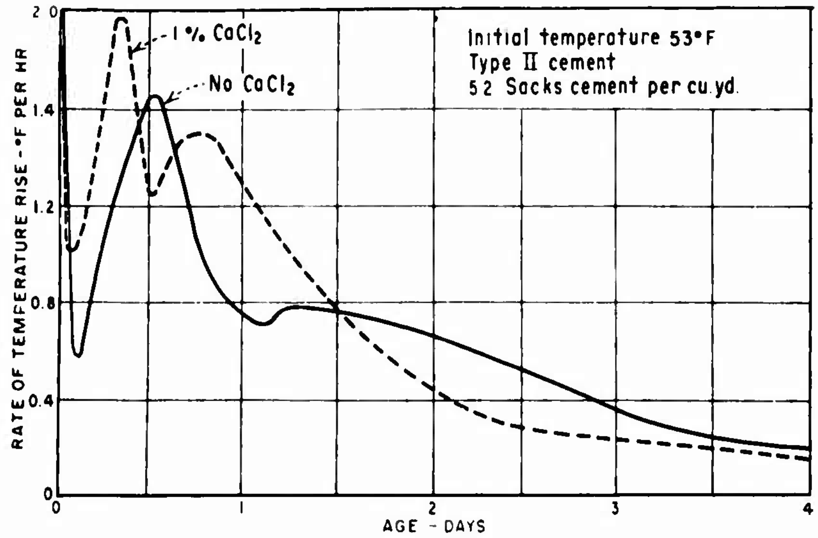

Figure 2. Early heat development with $CaCl_2$. (Shideler, 1952. Copyright, American Concrete Institute; reprinted by permission.)

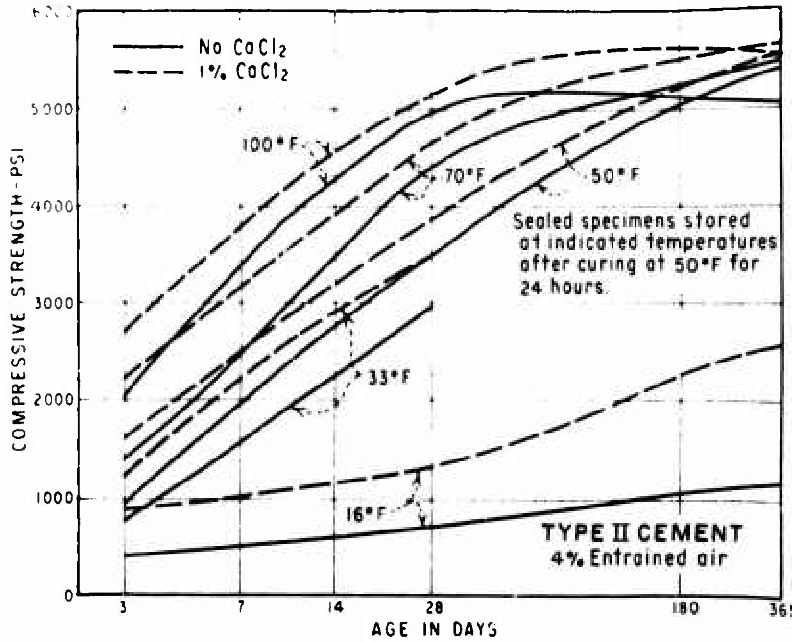

Figure 3. Increase in strength by use of $CaCl_2$. (Shideler, 1952. Copyright, American Concrete Institute; reprinted by permission.)

Durability of the cold concrete is another factor of the greatest importance. Here durability was evaluated by determining the loss of weight following dry freeze-thaw cycling. Figure 4 shows data from tests conducted by NBS. At first it appears to give a favorable picture when erosion and cavitation are considered. Although no actual description of the tests was included in Shideler's paper, examination of this figure shows that the concrete was cured at 70°F, under ideal laboratory conditions, with low quantities of chloride. What happens when higher quantities of salts are used and curing temperatures are lower will be considered later in this report (p. 6).

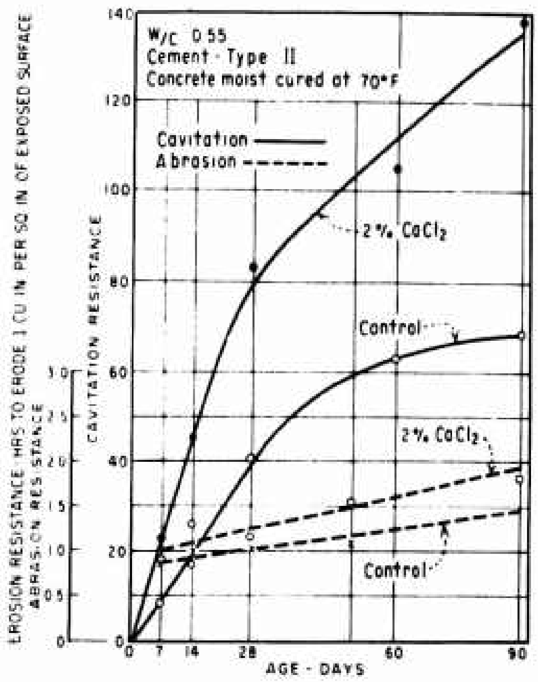

Figure 4. Erosion resistance of 2% $CaCl_2$ concrete. (From Shideler, 1952. Copyright, American Concrete Institute; reprinted by permission.)

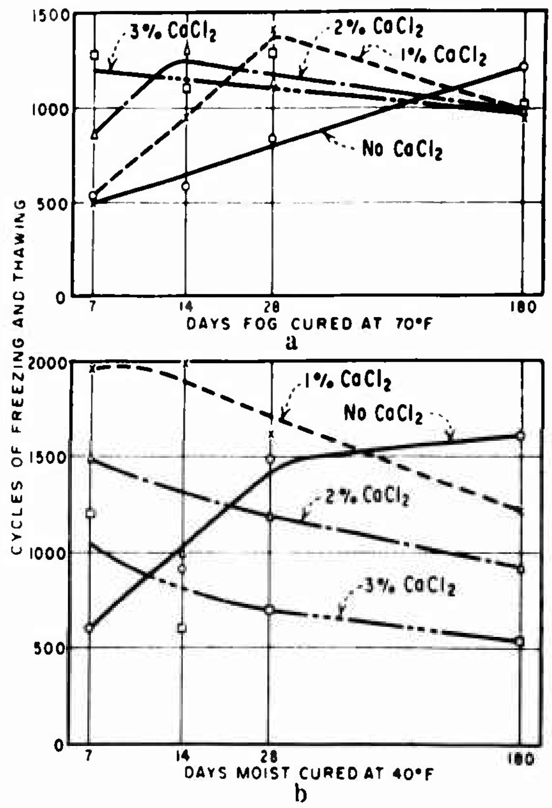

Figure 5. $CaCl_2$ improves durability of air-entraining concrete at early ages but is detrimental at early stages. (From Shideler, 1952. Copyright, American Concrete Institute; reprinted by permission.)

The Bureau of Reclamation, Department of the Interior, studied the effects of calcium chloride during freeze-thaw durability tests: Figure 5 shows the results. First, concrete cured at 70°F showed marked early freeze-thaw durability for the first 14 to 28 days, after which the durability decreased with salt additives. Second, when curing was at a lower temperature, the high early durability deteriorated sooner, and the more salt added the lower the durability. Third, comparison of Figures 4 and 5a for a calcium chloride content of 2% shows that the freeze-thaw tested concrete began to deteriorate while erosion and cavitation resistance were still increasing at the end of 90 days. For this reason, the freeze-thaw test does not imply much concerning the cavitation or erosion resistance. However, since this test indicates a degree of durability it was included in the testing program.

Up to this point, we have not considered salt contents over 4%, curing temperatures to 0°F, and a combination of salts–for example, 5% calcium chloride and 5% sodium chloride. All of these factors are studied and used in the USSR. Although many papers on this subject are available, few have been translated into English. One translated paper, by Mironov and Krylov (1956), is of particular interest.

Mironov and Krylov discuss chloride contents of up to 20% by weight of water (approximately 10% by weight of cement), the recommended maximum, in various combinations. They believe that the hydration of the cement can be controlled, according to the environment, by different mixtures of chlorides. In the USSR, the two most used salts are calcium chloride and sodium chloride because of their high solubility and low cost. The $CaCl_2$ accelerates hydration, and the NaCl controls the rate of hydration. The high chloride content lowers the freezing point of the water and the combinations of salts control the hydration process. In addition, $CaCl_2$ loses its plasticizer qualities at low temperatures. With the addition of the NaCl, however, the workability of the concrete is restored and a good amount of frost protection is gained. This combination of salts is recommended for use down to -20°C (-4°F). However, even with this amount of salt and antifreeze quality, a certain amount of covering for the concrete is required at the lower temperatures. No newly placed concrete surface should be exposed to freezing air.

The strength of concrete placed in freezing temperatures is influenced primarily by:

1. type and mineralogical content of cement
2. water/cement ratio
3. kinds, amounts, and ratios of salts
4. temperature of the environment.

The portland cement concretes listed in Table I, with the exception of the control specimens, were cured at temperatures between -8°C and -18°C (17.6°F and 0°F), with water/cement ratios of 0.4 and 0.6 and salt contents of 15% $CaCl_2$ and 7% NaCl, and 10% $CaCl_2$ and 5% NaCl. The control specimens (made with plain water) were cured at 57° to 64°F.

Table I. Concrete curing at freezing temperatures.*

Salt content**	Water/cement ratio	Compressive strength (psi) 3 days	7 days	15 days	30 days
Control	0.4	850 (?)†	2280	3000	4400
Control	0.6	850 (?)†	1780	2020	2490
10% $CaCl_2$ 5% NaCl	0.4	850 (?)†	1560	2280	2920
10% $CaCl_2$ 5% NaCl	0.6	374	850	1350	1990
15% $CaCl_2$ 7% NaCl	0.4	850 (?)†	1801	2280	3770
15% $CaCl_2$ 7% NaCl	0.6	850 (?)†	1680	1990	2280

*Compiled from data of Mironov and Krylov (1956).
†In the Russian original.
**Percent by weight of water.

The Russians made frost-resistance tests that appear similar to the U.S. standard freeze-thaw test. Many variables were compared of specimens prepared under the same conditions as those for the strength test samples. After 10 to 25 freeze-thaw cycles, losses in strength were from 40% to 60% and losses in weight from 4% to 8%. In some cases the samples were soaked in water for extended periods; this resulted in lower weight and strength losses. However, in most cases results seemed to vary widely and were very poor. The conclusion was that the frost resistance was dependent on the quantity of salt, mineralogical content of the cement, and water/cement ratio. Generally, the lower the salt content and the lower the water/cement ratio, the higher the frost resistance.

The use of high salt contents in concrete is effective in curing concrete below 32°F. While this eliminates the problems of freezing, extensive heating, and need for protection of the concrete, it also creates the problem of lower frost resistance. The Russian references indicate that cold concrete has been used effectively on footings, pavements and hydraulic structures and that it has several other advantages. Briefly, these advantages, according to Mironov and Krylov (1956), are:

1. Concretes with high $CaCl_2$ and NaCl contents are economical and effective for winter concreting.

2. Chlorides assure the hydration of the cement at low temperatures, including exposure to frost.

3. Bond strength of high-salt-content concretes equals or exceeds that of plain concrete.

4. Frost protection during the cure of high-salt-content concretes exceeds that of plain concrete.

5. Permeability of high-salt-content concrete is less than that of plain concrete.

6. In good concreting practice, reinforcement is not excessively affected by the salts.

7. High-chloride concretes may be mixed cold, transported cold, and placed in cold forms.

EXPERIMENTS WITH COLD CONCRETE

Salt solutions

The basic idea of cold concrete is to lower the freezing point of the mixing water enough to prohibit its freezing at the temperature at which the mortar or concrete is to be poured.

The amounts of salts added for these tests were taken from tables in the Handbook of Chemistry and Physics (The Chemical Rubber Co., 1965-66) (see Tables II and III) or obtained by experimentation. The solutions of one salt, either calcium chloride or sodium chloride, were made by following these tables directly (using the columns headed C_s, anhydrous solute concentration, and freezing point depression C). The remaining two solutions contained an equal molar concentration of each salt, for example, 0.6 mole of calcium chloride and 0.6 mole of sodium chloride. These concentrations were determined by making six 0.1-liter specimens, and storing them at the mixing-and-curing temperature overnight. The next morning the specimen that had the lowest salt concentration and that did not show any sign of freezing was used. An attempt was made to justify this by figuring the freezing point depressions of the salt solutions with the Debye-Huckel theory for very dilute solutions. This did not prove to be very successful at the high concentrations.

Once a value for the concentration was found, it was expanded into a sufficient quantity to make the necessary mortar specimens in one of two ways:

1. From the tables:

$$\frac{\text{grams}}{\text{liter}} \times \text{gallons} \times \frac{\text{liters}}{\text{gallon}} = \text{grams added}$$

2. From experiments:

$$\text{molarity} \times \text{gram molecular weight} \times \text{gallons} \times \frac{\text{liters}}{\text{gallon}} = \text{grams added.}$$

The solutions (see Table IV) were prepared at least one day before they were used and stored at the mixing and curing temperature.

Table II. Concentrative properties of aqueous solutions.

(Copyright, The Chemical Rubber Co.: reprinted by permission.)

CALCIUM CHLORIDE, $CaCl_2 \cdot 2H_2O$

MOLECULAR WEIGHT = 110.99 FORMULA WEIGHT, HYDRATE = 147.03

RELATIVE SPECIFIC REFRACTIVITY = .865

A % by wt.	H % by wt.	D_{20}^{20}	C_s g/l	M g-mol/l	C_w g/l	$(C_o - C_w)$ g/l	$(n - n_o)$ × 10^4	n	Δ °C	S g-mol/l
.00	.00	1.0000	0	.000	998.2	0	0	1.3330	.00	.000
.50	.66	1.0041	5.0	.045	997.3	.9	12	1.3342	.22	.063
1.00	1.32	1.0083	10.1	.091	996.4	1.8	24	1.3354	.44	.127
1.50	1.99	1.0124	15.2	.137	995.5	2.7	36	1.3366	.66	.192
2.00	2.65	1.0166	20.3	.183	994.5	3.7	48	1.3378	.88	.257
2.50	3.31	1.0208	25.5	.230	993.5	4.7	60	1.3390	1.10	.320
3.00	3.97	1.0250	30.7	.277	992.5	5.8	72	1.3402	1.33	.387
3.50	4.64	1.0292	36.0	.324	991.4	6.8	84	1.3414	1.57	.458
4.00	5.30	1.0334	41.3	.372	990.3	7.9	96	1.3426	1.82	.531
4.50	5.96	1.0376	46.6	.420	989.2	9.0	108	1.3438	2.08	.608
5.00	6.62	1.0419	52.0	.469	988.1	10.2	120	1.3450	2.36	.688
5.50	7.29	1.0462	57.4	.518	986.9	11.3	133	1.3463	2.64	.770
6.00	7.95	1.0505	62.9	.567	985.7	12.5	145	1.3475	2.94	.856
6.50	8.61	1.0548	68.4	.617	984.5	13.8	157	1.3487	3.26	.944
7.00	9.27	1.0591	74.0	.667	983.2	15.0	170	1.3499	3.58	1.035
7.50	9.94	1.0634	79.6	.717	981.9	16.3	182	1.3512	3.93	1.130
8.00	10.60	1.0678	85.3	.768	980.6	17.6	194	1.3524	4.28	1.234
8.50	11.26	1.0722	91.0	.820	979.3	18.9	207	1.3537	4.65	1.335
9.00	11.92	1.0766	96.7	.871	977.9	20.[illegible]	219	1.3549	5.04	1.439
9.50	12.58	1.0810	102.5	.924	976.6	21.7	232	1.3562	5.44	1.546
10.00	13.25	1.0854	108.4	.976	975.2	23.1	245	1.3575	5.85	1.655
11.00	14.57	1.0944	120.2	1.083	972.3	25.9	270	1.3600	6.73	1.880
12.00	15.90	1.1034	132.2	1.191	969.3	28.9	296	1.3626	7.69	2.115
13.00	17.22	1.1126	144.4	1.301	966.2	32.0	322	1.3652	8.71	2.359
14.00	18.55	1.1218	156.8	1.412	963.0	35.2	348	1.3678	9.81	2.611

Table III. Concentrative properties of aqueous solutions.

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SODIUM CHLORIDE, NaCl

MOLECULAR WEIGHT = 58.45

RELATIVE SPECIFIC REFRACTIVITY = .797

A % by wt.	D_{20}^{20}	C_s g/l	M g-mol/l	C_w g/l	$(C_o - C_w)$ g/l	$(n - n_o)$ × 10^4	n	Δ °C	S g-mol/l
.00	1.0000	.0	.000	998.2	.0	0	1.3330	.00	.000
.50	1.0035	5.0	.086	996.8	1.5	9	1.3339	.30	.086
1.00	1.0071	10.1	.172	995.3	3.0	18	1.3347	.59	.172
1.50	1.0107	15.1	.259	993.8	4.5	26	1.3356	.89	.259
2.00	1.0143	20.2	.346	992.2	6.0	35	1.3365	1.19	.346
2.50	1.0178	25.4	.435	990.6	7.6	44	1.3374	1.49	.435
3.00	1.0214	30.6	.523	989.0	9.2	53	1.3382	1.79	.523
3.50	1.0250	35.8	.613	987.4	10.8	61	1.3391	2.10	.613
4.00	1.0286	41.1	.703	985.7	12.5	70	1.3400	2.41	.703
4.50	1.0322	46.4	.793	984.1	14.2	79	1.3409	2.72	.793
5.00	1.0359	51.7	.885	982.3	15.9	88	1.3417	3.05	.885
5.50	1.0395	57.1	.976	980.6	17.6	96	1.3426	3.36	.976
6.00	1.0431	62.5	1.069	978.8	19.4	105	1.3435	3.69	1.069
6.50	1.0468	67.9	1.162	977.0	21.2	114	1.3444	4.02	1.162
7.00	1.0504	73.4	1.256	975.2	23.1	123	1.3453	4.36	1.256
7.50	1.0541	78.9	1.350	973.3	24.9	131	1.3461	4.70	1.350
8.00	1.0578	84.5	1.445	971.4	26.8	140	1.3470	5.05	1.445
8.50	1.0615	90.1	1.541	969.5	28.7	149	1.3479	5.41	1.541
9.00	1.0652	95.7	1.637	967.6	30.6	158	1.3488	5.78	1.637
9.50	1.0689	101.4	1.734	965.6	32.6	167	1.3496	6.16	1.734
10.00	1.0726	107.1	1.832	963.6	34.6	175	1.3505	6.54	1.832
11.00	1.0801	118.6	2.029	959.6	38.7	193	1.3523	7.33	2.029
12.00	1.0876	130.3	2.229	955.4	42.8	211	1.3541	8.16	2.229
13.00	1.0952	142.1	2.432	951.1	47.1	228	1.3558	9.03	2.432
14.00	1.1028	154.1	2.637	946.7	51.5	246	1.3576	9.93	2.637
15.00	1.1105	166.3	2.845	942.3	56.0	264	1.3594	10.88	2.845
16.00	1.1182	178.6	3.056	937.7	60.6	282	1.3612	11.88	3.056
17.00	1.1260	191.1	3.269	933.0	65.3	300	1.3630	12.93	3.269
18.00	1.1339	203.7	3.486	928.2	70.1	318	1.3648	14.04	3.486
19.00	1.1418	216.6	3.705	923.3	75.0	336	1.3666	15.21	3.705
20.00	1.1498	229.6	3.927	918.2	80.0	354	1.3684	16.45	3.927
22.00	1.1660	256.1	4.381	907.9	90.3	391	1.3721	19.18	4.381
24.00	1.1825	283.3	4.847	897.1	101.1	428	1.3758		4.847
26.00	1.1993	311.3	5.325	885.9	112.3	466	1.3796		5.325

Table IV. Quantities and percentages of salts used.

	Temp 23°F (−5°C)		Temp 14°F (−10°C)	
Salt	*Percent*	*Quantity (g/gal)*	*Percent*	*Quantity (g/gal)*
$CaCl_2$	12.2	460	21.5	815
NaCl	9.9	378	16.0	605
50/50* NaCl and $CaCl_2$	12.5	173 300	19.1	262 463

*The solution contains equal molar concentration of each salt.

Mixing, molding, and curing

The materials used for this experiment are listed in Table V. All materials and solutions were stored for at least one day at the planned mixing temperature. Two temperatures were used because they were sufficiently below the freezing point of water, and available coldrooms at CRREL were at or approximately at these temperatures: 23°F and 14°F.

Table V. Test materials.

Material	*Type*	*Manufacturer*	*Source*	*Remarks*
Portland cement	I	Alpha Cement Co. Catskill Plant	Trumbull-Nelson Construction Company, Inc. Hanover, N.H.	No air-entraining agent added
Salts	$CaCl_2$	Dow Chemical Company, Inc.	Wayne Feed Supply Company, Inc. W. Lebanon, N.H.	Commercial grade 77% pure salt
	NaCl	Morton Salt Co.	CO-OP Food Store Hanover, N.H.	Pure precipitated salt
Sand	Mason's	Lebanon Crushed Stone, Inc.	Lebanon Crushed Stone, Inc. Lebanon, N.H.	-- --
Water	--	--	Hanover Water Co., Hanover, N.H.	--

A heavy trowel was used to mix the materials. A Vicat needle apparatus was used to obtain values of the consistency of the mix. A trowel was used to fill the mold and compact the mortar. A small pan and glass flask were used to weigh out the cement, sand and water.

Figure 6 shows the molds. Ten of the molds were made of exterior-waterproof plywood with routed joints. Each mold produced six cubes, 4 in. on a side. Just prior to mixing and placing, each mold was painted with a standard commercial form oil to prevent the mortar from sticking to the sides.

During the preparation of some preliminary trial batches, mix proportions were designed so that one batch would fill one mold. The criteria for the mix were those of the standard 3-sand to 1-cement mortar mix, with a water/cement ratio of 0.6 by weight.

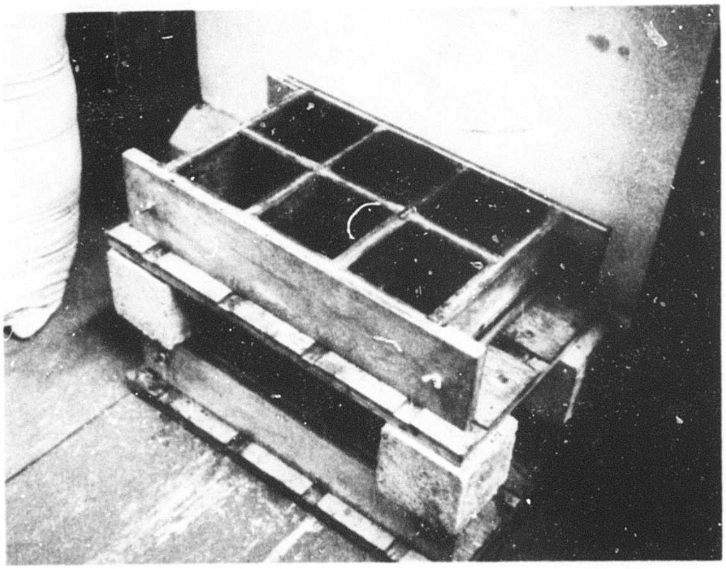

Figure 6. Molds.

Mix criteria	*Design mix (lb)*
Standard 3:1 mix	22.00 sand
Water/cement ratio = 0.6 by weight	7.34 cement
	4.40 salt solution

Dry materials were weighed on a balance and mixed in the pan until they were a uniform gray. The salt solution was then weighed and poured over a dry sand-cement mixture. The material was mixed by hand until all the sand and cement had been wetted and appeared to have a uniform consistency. This wet mortar was pushed into a ball in the front of the pan and its consistency was tested with a standard Vicat needle apparatus.

The sample for the Vicat needle test was taken from the center of the ball of mortar. The mortar was leveled with the top of the brass ring and the end of the needle was brought into contact with the top of the mortar. The reading was noted and the needle was released until all apparent movement had stopped. A new reading was taken and the value for the test was the difference between these two readings. The sample of mortar was then mixed back into the mortar used to fill the molds. The value of the Vicat needle reading was used only for comparison to try to maintain a similar consistency throughout all batches of a particular run.

The mold was then filled and each section in the mold was marked with an identifying number as shown in Figure 7. Each section was filled as full as possible and then compacted by chopping with the square-end trowel 25 to 30 times. Each section was filled in two layers and then screened.

After each mold had been completely filled and marked, it was covered with a piece of plastic to prevent the top surface from drying out in the low humidity of the coldroom. The molds were then stacked with at least 4 in. of air space between them and open on three sides to prevent excessive buildup of heat, except that which was retained by each mold individually. This stacking is shown in Figure 8.

The cubes remained in the molds for at least a day, and usually two days, prior to being stripped and stacked in open cribs with air spaces of about 1 in. to permit cold air to circulate (Fig. 9). Space limitations made stacking and cribbing of the molds and cubes necessary.

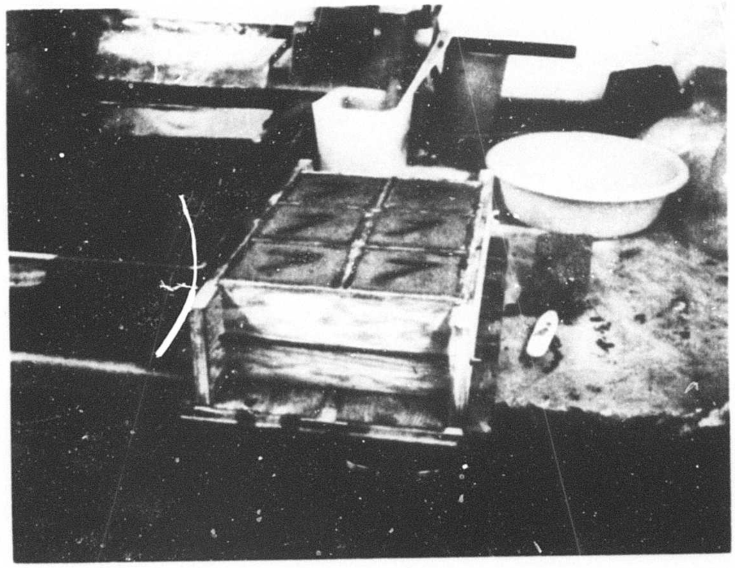

Figure 7. Specimens compacted and marked.

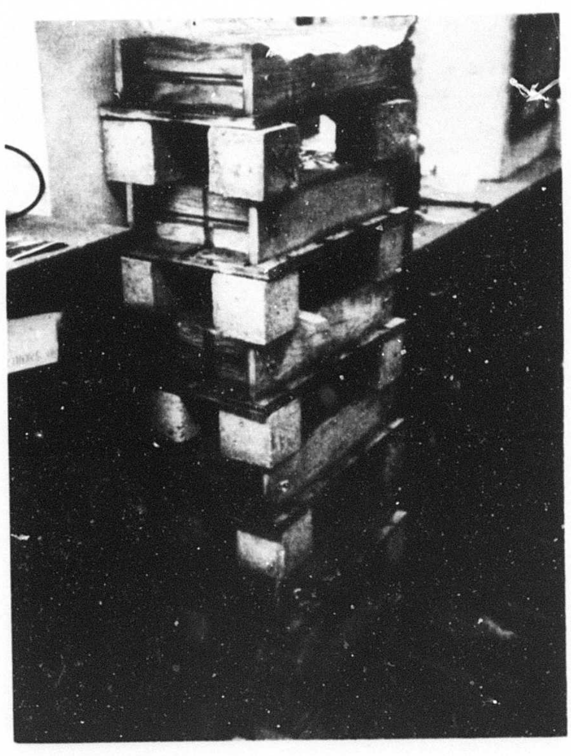

Figure 8. Curing.

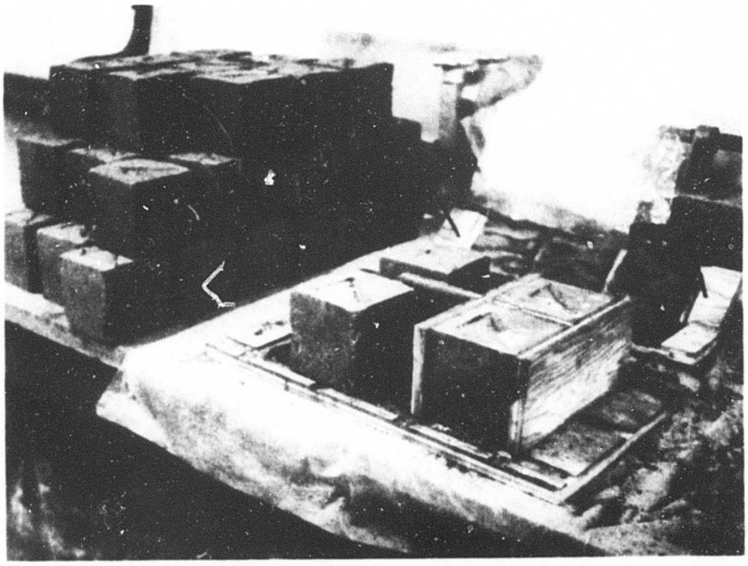

Figure 9. Stripping.

The cubes remained in the cribs until they were to be tested. They were tested at 3, 7, 14, 28, and 56 days.

Compression tests

After the required curing time had elapsed, the cubes that were to be tested were removed in a random manner from the curing crib. Each cube was then calipered at the midpoint of each of three sides, giving the length and width of the compression face and the depth to be used in calculating the stress and density. As this was done each cube was put on a lab-cart. After all the cubes had been measured, they were covered with two canvas bags and taken out of the coldroom to be weighed. The specimens were never in a warm room over 5 min and were always protected except when being weighed.

After being weighed, the specimens were moved to the Tinius-Olsen testing machine located in a coldroom which is normally kept below 32°F. Here they were tested using a floating compression head and a strain rate of 0.05 in./min. It was unnecessary to cap the specimens because the sides of each mortar cube were sufficiently flat and were parallel to the opposite face. Several stress-strain diagrams were made and the secant modulus of elasticity was calculated from them.

A minimum of 8 and a maximum of 12 cubes were tested at each age. A single average value was obtained by discarding the highest and the lowest test, and averaging the rest if there were 11 or 12 tested. Otherwise, all specimens were averaged and the results were plotted on two-cycle semilog graph paper.

Freeze-thaw tests

The mortar cubes for the freeze-thaw test were molded in a similar manner to those of the compression tests and allowed to cure for at least 14 days before being tested. At the end of the storage period, two cubes were selected from each test group, weighed, and placed in the test apparatus. This consisted of a cabinet capable of maintaining temperatures between –20°F and +67°F and a cam-operated thermostat that could vary the temperature corresponding to a predetermined cam. With this equipment, one cycle was obtained every 8 hours with a temperature variation of 0°F to +40°F, the temperature remaining above or below the maximum or minimum temperature for at least 2 hours (see Fig. 15). This allowed the internal temperature of each cube to vary well above and below 32°F. Five thermocouples were used to check the performance of the cabinet; one of these measured cube temperatures. No cube containing a thermocouple was used to collect data.

At the end of a thaw cycle, the cubes were removed from the cabinet, and their entire surfaces were brushed with two firm strokes with a standard wire brush. They were then weighed, turned upside down and returned to the cabinet.

RESULTS OF THE EXPERIMENTS

Compression test results

At the beginning of the experiments, it was difficult to make the salt solution for the 50-50 $NaCl/CaCl_2$ molar concentration remain unfrozen. This problem was solved by experimentally determining the molar quantity of the salt to be added. A molar quantity was used because this gave an approximately equal number of molecules for each salt. The salt solution was added to the cement-sand mixture by weight of solution. Since each solution had a different amount of salt, it had a water/cement ratio less than the designed 0.6 water/cement ratio (by weight). The addition of salt increased the weight of the water per gallon by 1.8 lb, or 1 gal of water weighed 10.145 lb. The mix design called for 4.40 lb per batch of salt solution. If the weights of the salts are subtracted, the true water/cement ratios are obtained (see Table VI).

Table VI. Compression test details.

Temp °F	*Salt*	*Salt (%)*	*Wt of salt* per batch (lb)*	*Wt of water† per batch (lb)*	*True water/cement ratios***
23	$CaCl_2$	12.2	0.53	3.87	0.527
23	NaCl	9.9	.43	3.97	.527
23	50-50†† NaCl and $CaCl_2$	12.5	.55	3.85	.525
14	$CaCl_2$	21.5	.94	3.46	.472
14	NaCl	16.0	.70	3.70	.504
14	50-50†† NaCl and $CaCl_2$	19.1	.84	3.50	.477

*Weight of salt = 4.40 lb × $\frac{\%}{100}$.

†Weight of water = 4.40 lb − weight of salt.

**True water/cement ratio = weight of water per 7.34 lb of cement.

††Equal molar concentration of salts.

There is a considerable difference in water/cement ratios; however, the consistency of the mix was about the same in almost all cases. The Vicat needle apparatus used to measure the consistency of the cement mortar before it was molded into the cubes did not appear to work well because of the widely varying readings on a mortar of seemingly similar consistency. Since each mold was filled and mixed by hand, the author can only say that the mix for each different salt content was nearly the same. Vicat readings were similar for each salt content, varying up to 7 or 8 mm within the same salt content or 42% of the total possible movement of the needle.

Since the cement mortar tended to be rather stiff, the compaction by chopping with the trowel often did not produce clean, firm corners of the cubes. In most cases this did not appear to affect the strength. Any cubes that looked like "popcorn balls" were rejected.

Curing in stacks with a minimum of 4 in. between each tier prevented the heat generated by one mold from affecting another mold. One entire run of cubes (21.5% $CaCl_2$ at 14°F) was rejected because it was not consistent witn previous runs. The cubes had been cured at a stacking distance of ¾ in.; this created a much higher temperature environment than desired. The results of compressive strength tests on these cubes showed strengths 4 to 5 times in excess of expected values. As will be shown later, this mix gave exceptionally high strengths at 7 days even when stacking distance was 4 in.

When the cubes were removed from the mold, they were dark gray. The cubes with NaCl, however, tended to be a much darker gray-green than those with either of the other salts. The cubes changed to gray as the surface dried in the low humidity of the coldrooms. The higher salt contents produced a white powder on the surface; this is believed to be the "salting out" effect described by Mironov and Krylov (1956). Cubes made with 20 or 21% salts salted out considerably.

At one point in the testing program, thermocouples were placed on the inside (center) and on the surface of the cubes. Figure 10 shows the results of this side experiment to study temperature changes. The curve was drawn through points plotted every 15 min.

The cubes were tested in compression in CRREL's 300,000-lb testing machine. If the cubes to be tested were to be transferred to another room or moved through spaces where the temperatures were different from the curing temperature, they were wrapped in several layers of sample bags or, in some cases, enclosed in a 2-in.-thick Styrofoam box for protection. Temperatures in the testing machine room were kept below freezing at all times during tests.

Table VII shows all the results of the compression tests. Figures 11-13 are graphs of these results. The strengths are average strengths of a minimum of 8 and not more than 10 sample cubes, 4 in. on a side. If 12 sample cubes were tested for a single point, the highest and the lowest values were discarded.

Each cube was tested at the same temperature at which it was cured. The control (0% salt) samples were tested at 70°F. Since the salt solution was designed to insure that no water would freeze during curing, no ice was in the cubes at the time they were tested. Also, when the cubes were thawed during the freeze-thaw test or when the freezer control malfunctioned, no water drained from, or appeared on, the surface of any of the cubes.

Figure 14 shows three examples of the four-sided pyramidal fractures that were typical of every test specimen.

Freeze-thaw test results

The freeze-thaw testing apparatus was capable of a modified test only; the specimen was frozen and thawed in air with no introduction of water at any part of the cycle.

Table VII. Compression test results.

Salt	Compressive strength (psi)				
	3 days	*7 days*	*14 days*	*28 days*	*56 days*
$CaCl_2$ 12.2% 23°F	580	1438	1426* 2644	2668	2006* 2666
NaCl 9.9% 23°F	530	1316	1922	260[illegible]	3200
NaCl $CaCl_2$ 50-50† 12.5% 23°F	422	1675	2507	3244	3416
$CaCl_2$ 21.5% 14°F	--	2701	3164	3680	4185
NaCl 16.0% 14°F	126	822	1544	1918	2399
NaCl $CaCl_2$ 50-50† 19.[illegible]% 14°F	501	1262	2200	2490	3157
Control 0% 70°F	1117	1631	2460	3198	--

*Extra points plotted (using 18 samples to determine the point) because of the flat linear strength-age curve at 14, 28, and 56 days. Both points were used in the final plot.
†Equal molar concentration of NaCl and $CaCl_2$.

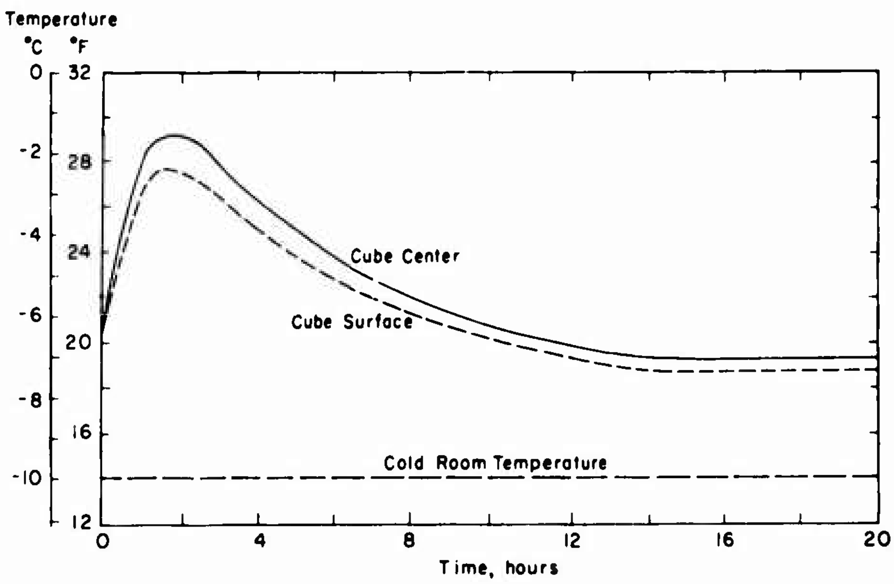

Figure 10. Temperature during curing vs time.

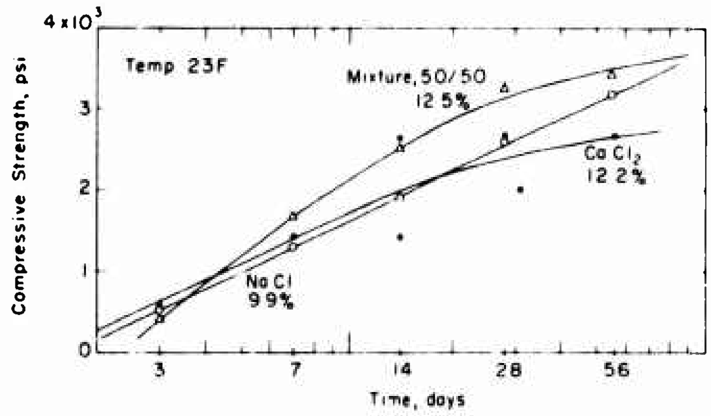

Figure 11. Compressive strength vs age.

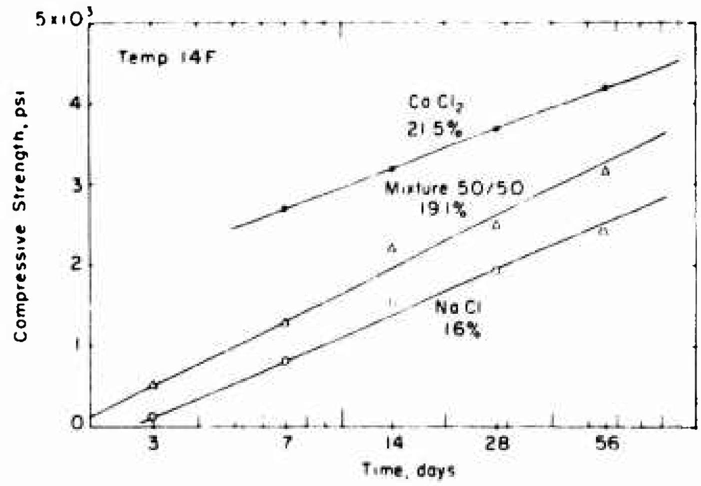

Figure 12. Compressive strength vs age.

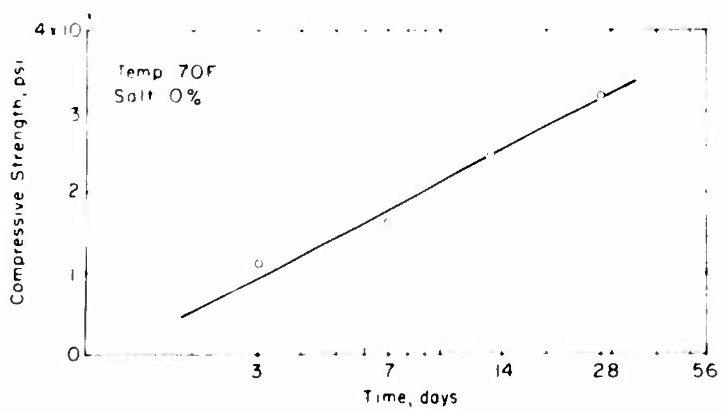

Figure 13. Compressive strength vs age.

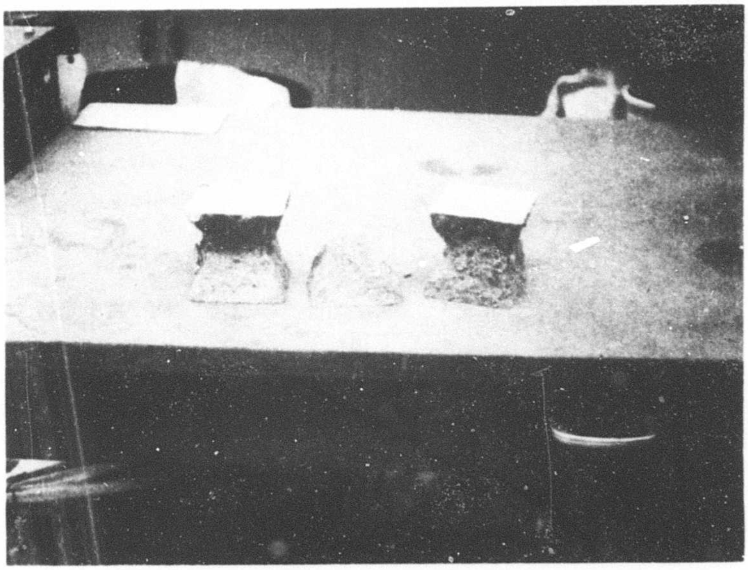

Figure 14. Typical fractures of specimens.

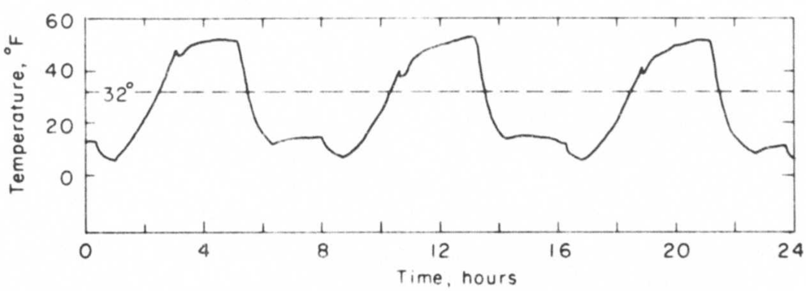

Figure 15. Typical temperature cycles in 24 hr.

The cycle was controlled by an automatic cam device that produced three freeze-thaw cycles in 24 hours. Figure 15 shows a typical 24-hour period during the test. The length of time that the cubes spent above 32°F was limited to about 3 hours, or 38% of the total time. Four cubes that were not tested for freeze-thaw durability had thermocouples in their centers and were checked periodically to insure that the centers of the cubes had reached a temperature greater than 32°F. The temperature differential between the centers and the cabinet was between 7 and 10°F.

The criterion used for this freeze-thaw test was percentage of weight loss. Initial weights of the cubes were recorded. After a number of cycles, the cubes were wire brushed and new weights were recorded. Table VIII gives the total percentage of weight loss. Figures 16-18 give plots of the average percentages of weight loss. The percentages are the averages of the groups listed in Table VIII.

Figure 19 shows $CaCl_2$, NaCl, 50-50 molar concentration of NaCl and $CaCl_2$ and control (left to right) freeze-thaw cubes cured at 23°F, at the time they were removed from the test apparatus. Figure 20 shows cubes with the same composition cured at 14°F. These figures show that the cubes have not deteriorated. It is believed that the loss of weight in this case was largely due to the simple drying out of each cube.

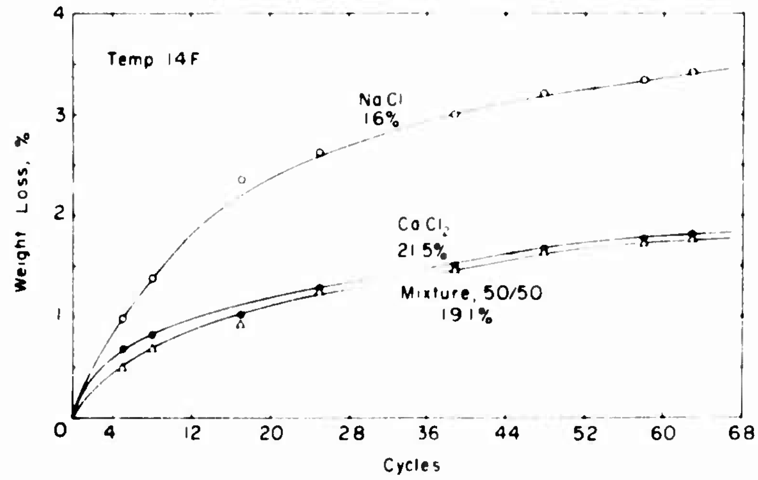

Figure 16. Average weight loss percentages for given numbers of freeze-thaw cycles.

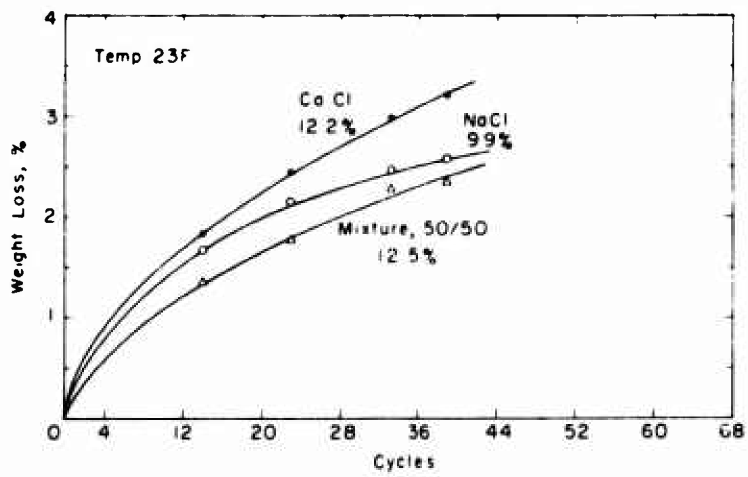

Figure 17. Average weight loss percentages for given numbers of freeze-thaw cycles.

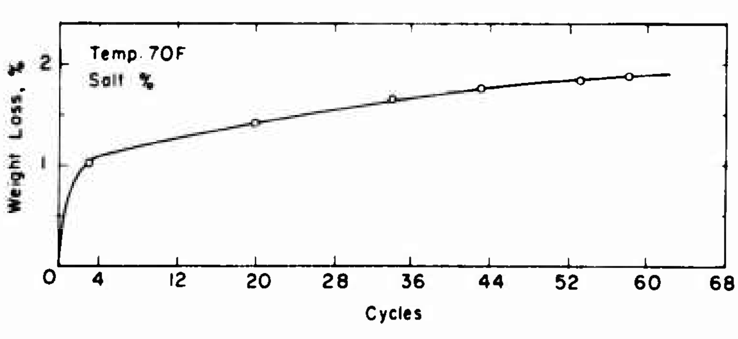

Figure 18. Average weight loss percentages for given numbers of freeze-thaw cycles.

Table VIII. Total percentage of weight loss in freeze-thaw tests.

Sample	Cycles							
	5	*8*	*17*	*25*	*39*	*48*	*58*	*63*
1	0.636	0.847	1.06	1.31	1.53	1.74	1.78	1.78
2	0.74	0.782	1.03	1.28	1.52	1.65	1.77	1.81
3	0.913	1.37	2.30	2.44	2.82	3.07	3.20	3.28
4	1.01	1.60	2.44	2.87	3.16	3.33	3.46	3.55
5	0.62	0.785	1.03	1.40	1.61	1.78	1.90	1.95
6	0.412	0.576	0.821	1.15	1.36	1.48	1.56	1.60

Sample	Cycles						
	3	*12*	*20*	*34*	*45*	*53*	*58*
7	1.45	?	1.09	1.35	1.48	1.57	1.57
8	0.655	1.48	1.74	1.96	2.05	2.14	2.22

Sample	Cycles			
	14	*23*	*33*	*38*
9	2.02	2.59	3.12	3.33
10	1.63	2.29	2.86	3.11
11	1.65	2.11	2.48	2.61
12	1.70	2.16	2.45	2.58
13	1.34	1.75	2.40	2.40
14	1.36	1.78	2.16	2.29

1. Samples 1 and 2, 21.5% $CaCl_2$, at 14°F.
2. Samples 3 and 4, 16.0% NaCl, at 14°F.
3. Samples 5 and 6, 19.1% 50-50 molar concentration of NaCl and $CaCl_2$, at 14°F.
4. Samples 7 and 8, 0% salt (control), at 70°F.
5. Samples 9 and 10, 12.2% $CaCl_2$, at 23°F.
6. Samples 11 and 12, 9.9% NaCl, at 23°F.
7. Samples 13 and 14, 12.5% 50-50 molar concentration of NaCl and $CaCl_2$, at 23°F.

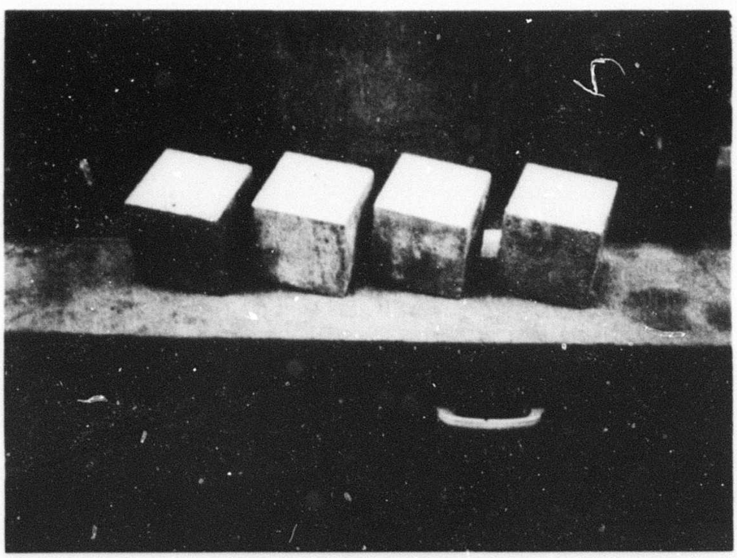

Figure 19. Freeze-thaw specimens at the end of a test at 23°F.

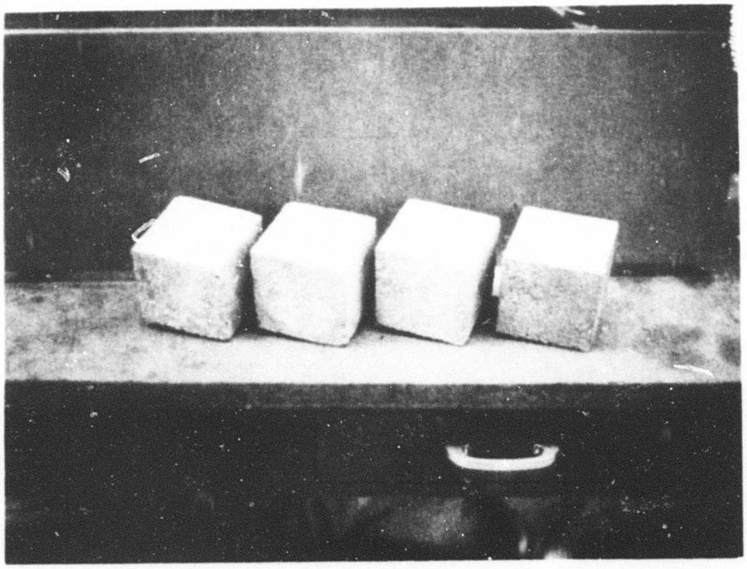

Figure 20. 14°F freeze-thaw cubes at end of test.

Chemical analysis of cement and salts

Table IX presents a typical chemical analysis of the Alpha Brand Type I dark portland cement provided by the Alpha Cement Co. Catskill plant, with calculated percentages of mineral compounds. Table X gives a typical chemical analysis of the Dow Flake calcium chloride obtained from the Dow Chemical Company. The NaCl was obtained from the Morton Salt Company and was 100% pure precipitated sodium chloride.

Table IX. Typical analysis of Alpha Brand Type I dark portland cement.

Chemical analysis (Alpha Cement Co.)

SiO_2	22.3%
Al_2O_3	4.5
Fe_2O_3	3.6
CaO	64.6
MgO	1.4
SO_3	2.2
Ignition loss	1.0

Mineral analysis

C_3S	50 %
C_2S	27
C_4AF	11
C_3A	6
MgO	1½
$CaSo_4$	4

Tabe X. Typical analysis of the Dow Flake calcium chloride (from Dow Chemical Company).

$CaCl_2$	78.5%
Total alkali chlorides (as NaCl) (max)	1.75
Total magnesium (max)	0.07
$Ca(OH)_2$ (max)	0.10
$CaCO_3$ (max)	0.06
Sulfate (max)	0.20
Iron (max)	0.001
Heavy metal (max)	0.002
Water	remaining

ANALYSIS OF RESULTS AND COMPARISON WITH PUBLISHED DATA

Compressive strengths - Russian literature

This section is concerned with a comparison of the Russian literature on the "salt method" of winter concreting with the results of these experiments on compressive strength.

The basic idea of adding high concentrations of salts to a concrete mix is twofold: 1) to accelerate the strength development, and 2) to lower the freezing point of the water phase of the mix. Both actions prevent freezing damage to newly placed concrete.

Four criteria determine the strength of concrete that has been placed by the salt method.

1. Type and mineralogical content of the cement
2. Water cement ratio
3. Kinds, amounts and ratios of salts
4. Temperature of the environment.

An examination of the data presented earlier (p. 13) and those in the Russian literature indicates very close agreement in average values of the water/cement ratios.

Lowering the freezing point of the liquid phase of the mix enough to ensure that it would not freeze determined the amounts of the salts in the experiments. To do this the freezing point of the salt solution had to be lower than the curing temperature. The method of determining amounts of salts was also presented earlier (p. 7).

Table XI shows that the salt concentrations of these experiments are higher than those presented in the Russian literature. There can be three reasons for this. 1) In the experiment, it was decided to have all the materials, i.e. water, cement, and sand, at the curing temperature when mixed. 2) Mironov and Krylov (1956) stated that the best mix temperature for placing concrete is between -5°C and +5°C (23°F and 41°F); hence, the salt solution would not freeze with the lower amounts of salts. 3) The combination of the salt and cement in the water might create a freezing point lower than that of the salt alone. Also, the more massive the section, the less salt needed for protection, because of higher temperatures with the lower area/volume ratio.

Since it is believed that NaCl does not enter into the chemical reaction with the cement minerals, as the concrete hardens the concentration increases and a lower freezing point of the water phase is reached. Also, the lower amounts of salts are more than adequate for accelerating the strength development.

Table XI. Comparison of total percentages of salt by weight of water with curing temperature.

These experiments			*USSR data*		
Salt	*Curing temp*		*Salt*	*Curing temp*	
(%)	*(°F)*	*(°C)*	*(%)*	*(°F)*	*(°C)*
12.2	23	– 5	6.5	32 to 23	– 5
9.9	23		12.0	23 to 14	–10
12.5	23		16.0	14 to 5	–15
21.5	14	–10	20.0	5 to 4	–20
16.0	14				
19.1	14				

Even though there are differences in the salt content, they are not considered to be significant. For example, at 23°F both the experiments and the Russian literature give about 12% salt, and at 14°F about 2-4% higher. The higher amounts were necessary to attain the desired freezing point.

The temperature of the refrigerator referred to in the Russian literature varied from -8°C to -18°C (about 20°F to 0°F). How much, if at all, the temperature was changed during the Russian experiments was not mentioned in the presentation of the data. If any fluctuation occurred, and was within these limits, a significant difference in strength would not occur.

The mineralogical content of the Russian cements produced at several different plants is not known; therefore, no comparison can be made. However, normal, slag and pozzolan cements produced at different plants gave different strength characteristics.

Tables XII and XIII are two representative excerpts of Russian compressive strength data, derived from Figures 2 and 4 of Mironov and Krylov (1956). Table XIV gives the compressive strength for the experiments conducted in this investigation. Table XV is a comparison of Tables XII, XIII and XIV using the total percentage of salts, water/cement ratio, and 30-day compressive strength. The curing temperatures of Tables XIII and XIV were between -8°C and -18°C, and the curing temperature of Table XIV was -10°C. Table XV shows that the Russian strengths are all within about 500 psi of each other. The data of these experiments fit well enough with the Russian data and are acceptable.

Table XII. Representative Russian data (Mironov and Krylov, 1956).

Salt content	*Water/cement ratio*	*Compressive strength (psi)* 3 days	7 days	15 days	30 days
Control	0.4	850 (?)*	2280	3000	4400
Control	0.6	850 (?)*	1780	2020	2490
10% $CaCl_2$ 5% NaCl	0.4	850 (?)*	1560	2280	2920
10% $CaCl_2$ 5% NaCl	0.6	384	850	1350	1990
15% $CaCl_2$ 7% NaCl	0.4	850 (?)*	1801	2280	3770
15% $CaCl_2$ 7% NaCl	0.6	850 (?)*	1680	1990	2280

*sic.

Table XIII. Representative Russian data (Mironov and Krylov, 1956).

Salt content	Water/cement ratio	Compressive strength (psi) 3 days	7 days	15 days	30 days	90 days
Control	0.4	57*	113*	227*	440*	1320*
Control	0.6	43*	71*	113*	198*	640*
10% $CaCl_2$ 5% NaCl	0.4	1560	1700	2060	2410	--
10% $CaCl_2$ 5% NaCl	0.6	1060	1250	1490	2480	2650
15% $CaCl_2$ 7% NaCl	0.6	1060	1500	1770	2130	2340
3% $CaCl_2$ 7% NaCl	0.4	710	1700	4250	4650	4750
3% $CaCl_2$ 7% NaCl	0.6	567	1130	2470	3030	4080

*sic

Table XIV. Results of these experiments.

Salt	Water/cement ratio	Compressive strength (psi) 3 days	7 days	14 days	28 days	56 days
$CaCl_2$ 12.2% 23°F	0.527	580	1438	1426* 2644	2668	2006* 2666
NaCl 9.9% 23°F	0.541	530	1316	1922	2604	3200
NaCl $CaCl_2$ 50-50† 12.5% 23°F	0.525	442	1675	2507	3244	3416
$CaCl_2$ 21.5% 14°F	0.472	--	2701	3164	3680	4185
NaCl 16.0% 14°F	0.504	126	822	1544	1918	2399
NaCl $CaCl_2$ 50-50† 19.1% 14°F	0.477	501	1262	2200	2490	3157
Control 0% 70°F	0.6	1117	1631	2460	3198	--

*Extra points were plotted (using 18 specimens to determine the points) because of the flat linear nature of the strength-age curve at ages 14, 28, and 56 days. Both points were used in the final plot.
†Equal molar concentration of NaCl and $CaCl_2$.

Table XV. Comparison of Russian data and results of these experiments.

Salt content (%)	*Water/cement ratio*	Compressive strength at about 30 days (psi)		
		Table XII	*Table XIII*	*Table XIV*
15	0.4	2920	2410	
15	.6	1990	2480	
16	.504			1918*
22	.4	3770		
22	.6	2280	2130	
21.5	.472			3680*
19.1	.477			2490*

*At 28 days

Durability - Russian literature

The results of this study indicate that when the cement cured at below freezing temperatures is subjected to alternate freezing and thawing in only air its durability is good. However, since some standard tests introduce moisture between cycles, all that can be said is that the cement is durable when kept dry. The introduction of moisture into the cycle is important since most concrete comes in contact with moisture, particularly when frozen in cold climates. Mironov and Krylov (1956) say that since experiments on freeze-thaw durability have produced widely varying results more study and experimentation are needed. Since the durability experiments of this study did not involve moisture, the author also considers that the subject should be investigated further.

The freeze-thaw durability of cement depends on the ratios and amounts of salts, the mineralogical content of the cement, and the water/cement ratio. Generally, experiments have proved that the higher the salt content and the higher the water/cement ratio, the lower the durability. When the freeze-thaw experiment was done in dry air, no conclusion could be made because all specimens tested behaved in the same way.

General - U.S. literature

Publications regarding the placing and curing of concrete, written in English, and for the most part originating in the United States, can be divided into two categories: those concerning the placing and curing of concrete without special cold weather techniques (above 40°F) and those concerning the placing and curing of concrete below 40°F. For the first category, a maximum of 1% or 2% $CaCl_2$ is recommended; all available data agree with this recommendation. An addition of only 1% $CaCl_2$ to a mix at a normal temperature accelerates growth of strength, durability, etc. Experiments by Shideler (1952) showed that at normal temperatures 7% or more $CaCl_2$ by weight of cement is detrimental to strength and durability. The 2% maximum limit of $CaCl_2$ is correct for present concreting techniques above 40°F because more than this amount has been shown to be harmful; for example, at these temperatures it may cause quick setting.

Where the environment has a temperature below 40°F cold concrete practice might be applicable. *For cold concrete to be effective, the temperature at which it is mixed and placed is of critical importance. If the techniques are used outside specific temperature limits (mixes with specific salt contents are not used between specific temperatures), concrete of a poor quality will result.* Curing temperatures throughout the mass of newly placed concrete must be maintained low enough to prevent quick setting. This is done by regulating the mix temperature and salt content according to the ambient temperature.

As mentioned earlier, $CaCl_2$ in cold concrete is used as an accelerator and as a freezing point depressant. Its use for the latter purpose is not well accepted because experience indicates that the high salt concentrations needed are detrimental at normal temperatures (Mironov and Krylov, 1956). The few experiments at temperatures below 32°F gave poor results because the salts were not intended to depress the freezing point; thus not enough salt was used and combinations of salts were not tried. Accordingly, no meaningful comparisons between cold concrete and standard U.S. practices can be made.

CONCLUSIONS

The results of this study have increased the knowledge of cold concrete as a winter concreting method. For many years USSR engineers have been using large amounts of ionizing salts (mainly NaCl and $CaCl_2$) in their mixtures to facilitate placing concrete at low temperatures. To date U.S. codes and standards have not allowed more than 2% $CaCl_2$ by weight of cement. After a study of some of the Russian and U.S. literature, an experiment was conducted to permit as many comparisons as possible. Freezing points of the salt solutions served as the initial basis for the design of the experiment; but the availability of equipment and materials, size of specimens, and controls were some of the more important factors considered in planning the experiment.

Throughout the work, the data gathered from the compressive strength tests appeared very encouraging. The strength values of the specimens with salt plotted as straight lines with a slightly less steep slope than the strength of the control (salt-free) specimens. This relationship is considered normal and shows that the hydration reactions of both types of cement most probably are similar, except that the lower temperature causes a lower reaction rate.

The freeze-thaw test was modified in that no water was added during any part of the cycling. The result was a very durable concrete with the percentage loss in weight believed to be primarily due to drying of the samples.

Several similarities have been found between the cold concrete experiments done by this author, and those cited by Mironov and Krylov (1956). Both sets of data have approximately the same water/cement ratios and strengths. The greatest differences lie in the amounts and ratios of the salts. These, however, are believed to be close enough to allow the following generalizations to be made.

The technique of using large amounts of $CaCl_2$ and NaCl as accelerators and freezing point depressants, as a cold weather concreting method, is definitely promising. The data presented in this paper, although not specifically duplicating the results of the Russians, do show that their values are probably correct; previously they had been questioned, if not doubted. Desired strength has been proved possible to achieve, although admittedly it is not the only characteristic necessary in a high-quality concrete.

Durability, corrosion of reinforcement, impermeability, sulfate resistance, flexural strength, tensile strength, good bonding between concrete and steel, time effects, and other considerations must be more thoroughly investigated before complete confidence can be placed in cold concrete. Continued study is recommended to ensure that all the characteristics of cold concrete are known for design.

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13. ABSTRACT

For many years winter concreting has been an expensive as well as a difficult operation and it is becoming even more so with current accelerated building schedules. The primary techniques commonly practiced for placing concrete in the winter include heating the mix materials and providing a suitable protective environment such as extensive, heated canvas or plastic shelters, or adding an insulating material to the form work. An additive of 2% calcium chloride is permitted by most building codes to accelerate the growth of strength and allow faster removal of protection and forms. Most building codes permit the addition of 1 or 2% (by weight of cement) of calcium chloride. Another method developed in the USSR, is the use of cold concrete. This involves the greater use of calcium chloride and sodium chloride as accelerators, and freezing point depressants. Most of the cold concrete research has been reported in the Russian literature and little has been translated. The purpose of this study was to verify some of the translated data to determine whether this method is practicable and worthy of further investigation. A comparison of USSR compression test results and those of this study showed similarities in the water/cement ratios, strengths, and curing temperatures. Salt contents were $1\frac{1}{2}$ to 2 times those reported in the Russian literature. When cold concrete is more thoroughly investigated it may become a competitive winter concreting technique for some purposes.

14. Key Words

Antifreezes Cold weather construction Winter concreting

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