SECOND SESSION

FRIDAY, DECEMBER 3, 1925, AT 2:00 P M.

A J BROSSEAU, Presiding
Mack Trucks Inc , New York City

Chairman Brosseau The first paper on this afternoon's program will be the report of the Committee on Character and Use of Road Materials

REPORT OF COMMITTEE ON CHARACTER AND USE OF ROAD MATERIALS

Chairman, H S MATTIMORE
Pennsylvania State Highway Department, Harrisburg, Pennsylvania

This committee has aimed to select problems for investigation which are of major importance at the present time in the highway field Of the problems selected for investigation during the past year, several of them, such as the selection of material for surface treatment in gravel and earth roads, and study of concrete durability as affected by different aggregates, are still under way, and at this time progress can be reported without any definite conclusions

Separate reports are being submitted by different members of the committee These reports represent individual work in compiling the data, but each report has been concurred in by the entire committee

Report on Use of Accelerators in Portland Cement Concrete, reported by R W Crum

Quick Hardening Cements, reported by F C Lang

Investigations of Asphaltic Paving Mixtures Relative to Deformation of Surfaces Under Traffic, reported by B. A Anderton

Highway Traffic Line (Zone) Paint, reported by H. S. Mattimore

REPORT ON USE OF ACCELERATORS IN PORTLAND CEMENT CONCRETE

R W CRUM
Iowa State Highway Commission, Ames, Iowa

Many users of concrete have felt the need at times of some means of accelerating the setting and hardening of normal Portland cement, and therefore a great deal of experimenting has been done with the use of various admixtures It is the purpose of this paper to review and report contributions to the study of this problem The use of calcium chloride and calcium chloride compounds mixed with the concrete only will be considered in this report

From the standpoint of the highway engineer, there are four important questions to be answered concerning the use of admixtures as accelerators

1 What will be the effect upon the strength of the concrete? (a) early, (b) final
2 Will the use of the accelerator protect against low temperature and permit the concrete to be laid at lower temperatures than would otherwise be possible?
3 Will the hardening be accelerated so that the structure or pavement may be opened to use at an earlier age than when normal Portland cement concrete is used?
4 Will there be any deleterious effect upon the steel reinforcement?

The answers to these questions as given in the publications of various investigators are presented herewith No attempt is made herein to present the various investigations in detail

1

EFFECT UPON STRENGTH

From "*Calcium Chloride as an Admixture in Concrete*," by Duff A. Abrams Proceedings American Society for Testing Materials, 1924, reprinted as Bulletin 13, Structural Materials Research Laboratory, Lewis Institute This report covers three extensive series of tests as follows Series 156 comprised compression tests of about 4,000 6 by 12 inch concrete cylinders and 1,250 2 by 4 inch mortar cylinders, specimens made June to August, 1921

The following admixtures were used

Calcium chloride A } Samples from different manufacturers.
Calcium chloride B }
"Cal" furnished by Cal Chemical Co , Hagerstown, Md
"Vitriflux" furnished by The Granitex Co , New York City
Magnesium chloride, purchased in Chicago

Concrete and mortar tests were made at ages ranging from 2 days to 3 years The tests on calcium chloride B were extended to include wide variations in mixtures and consistencies and four different cements Tables I to V, also VII, X and XI of Abrams' paper give the principal results of the tests in this series

Professor Abrams' principal conclusion concerning effect upon strength is as follows

"In the use of calcium chloride no advantage was gained for the percentages of the commercial product gretaer than 2 or 3 per cent of the weight of the cement" (chlorine content 1 to 1½ per cent) "This amount when used in mixes of about 1 5 and in consistencies suitable for building construction showed an increase in compressive strength

of from 100 to 200 pounds per square inch, which increase was practically constant at ages of 2 days to 3 years For richer mixes and drier consistencies the strength increase was greater and for leaner mixes and wetter concretes it was less "

In comparing the various admixtures used, the data in Professor Abrams' paper indicate that the compounds based upon calcium chloride gave similar results, the effect being roughly proportional to the chlorine content, but that the magnesium chloride in most cases lowered the strength

The paper further calls attention to the facts that the effect of the admixture upon strength is influenced by the quantity of cement, quantity of mixing water, curing conditions, amount of calcium chloride in the compound, brand of cement and age of concrete It is especially interesting to note in these data, "that for all but the lean and wetter mixes the increase in strength produced by the addition of 2 per cent calcium chloride when expressed in pounds per square inch was approximately constant for all ages of test "

Figures 1 and 2 depict the typical relationships shown

From discussion of above paper by Professor M B Lagaard, University of Minnesota —Professor Lagaard states that tests conducted at the University of Minnesota on 1 to 3 mortar briquettes show that "The strength increases with the use of small percentages of calcium chloride and that beyond a certain amount the strengths begin to fall off " "It was also found that this was not true for air curing " "The air-cured calcium chloride specimens showed very high strengths at 3 and 7 days while at 28 days the difference was very much less "

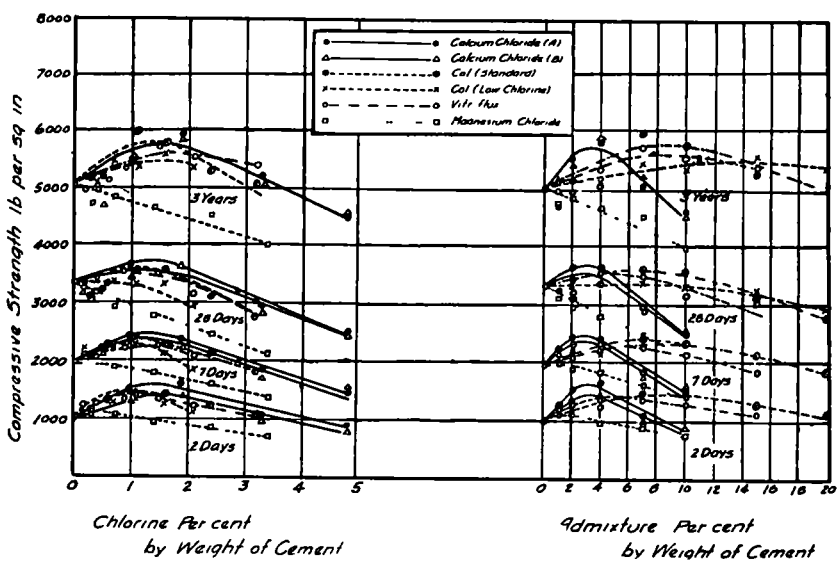

Figure 1—Effect of type of admixture on strength of concrete. From experiments by D. A. Abrams

From report of Committee C9, American Society for Testing Materials, 1923.—Report of Cooperative Series of Tests on Accelerators Conducted under the Auspices of Committee C9

This report summarizes the result of a series of tests in which 9 laboratories cooperated in making strength tests to determine the effect

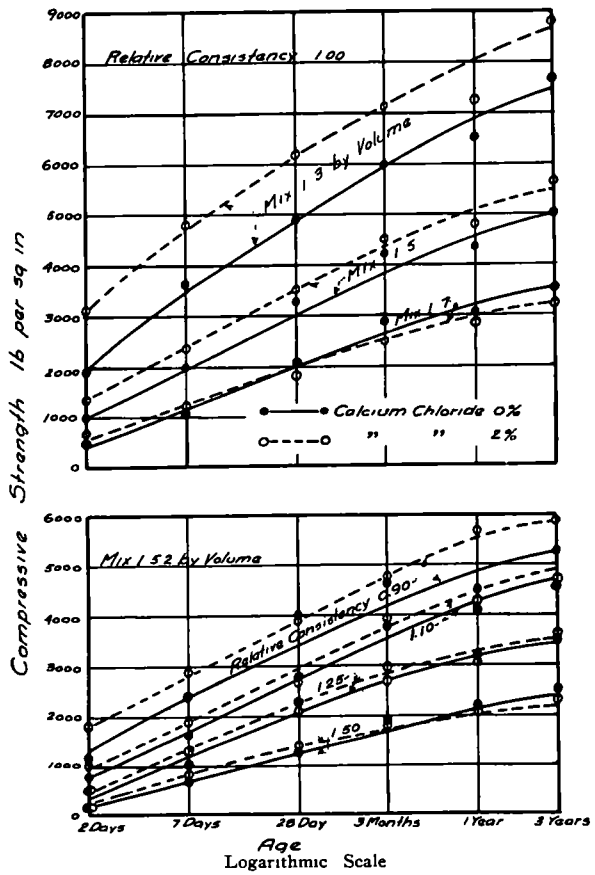

Figure 2—Effect of age, mix, and consistency on strength of concrete From experiments by D A. Abrams

of 4 accelerators Two mixtures were used, 1 2 4 concrete and 1 2½ mortar. The accelerators are designated in the accompanying diagrams by the letters A, B, C, and D A and B refer to a commercial calcium chloride and are respectively, solutions of 2 per cent and 4 per cent of the chloride as marketed, in the mixing water C and D are proprietary materials comparing very roughly with B and A, respectively, in content of anhydrous calcium chloride.

The committee is of the opinion that "The individual results show a very wide range and numerous inconsistencies

"However, the averages of all the results seem to establish the general conclusion that the beneficial effects of the accelerators are

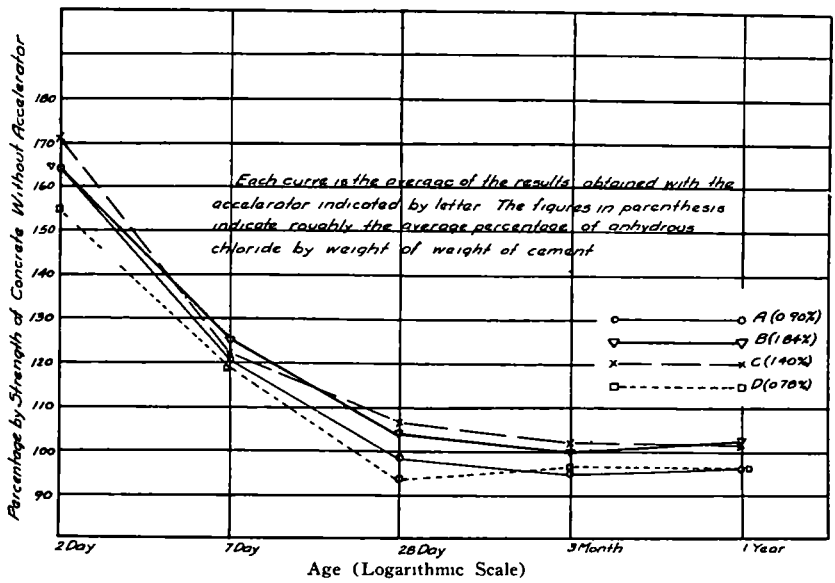

Figure 3—Relative compressive strength of 1 2 4 concrete containing accelerators From report of Committee C9, A S T M

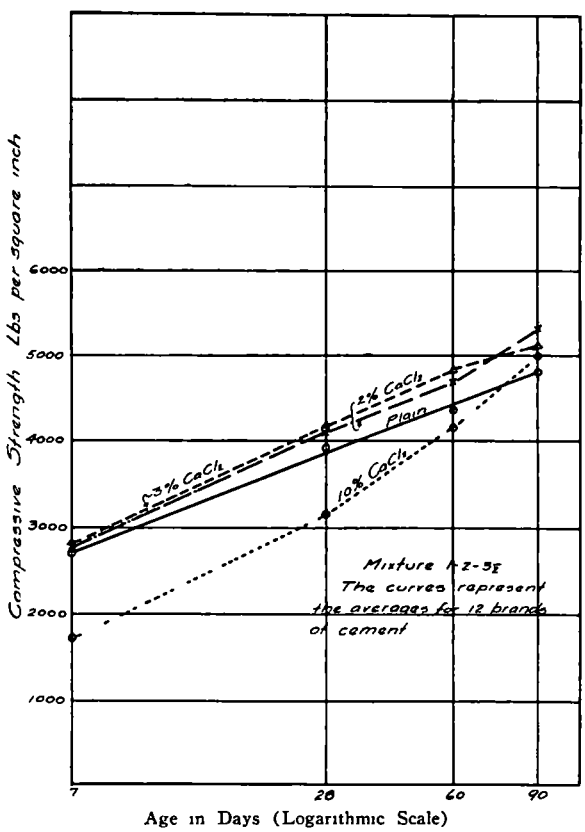

Figure 4—Influence of age and percentage of calcium chloride. From experiments by Clemmer and Burggraf

confined to the early ages under the prescribed laboratory conditions of curing and storage" "Under these conditions the effect of the calcium chloride is to accelerate the hydration of the cement markedly during the first few days, but the resulting gain in strength largely disappears at the 28-day period and thereafter" Figure 3 summarizes the results of these tests

From "An Investigation in the Use of Calcium Chloride as a Curing Agent and Accelerator of Concrete," by H F Clemmer and Fred Burggraf Proceedings American Society for Testing Materials, 1923

The data presented in this paper indicate that calcium chloride within certain optimum limits gives increase in strength

Figure 4 compiled from data in Table II of Clemmer and Burggraf's paper shows the influence of age and percentage of calcium chloride upon compressive strength as indicated by these data

From discussion of above paper, by H S Mattimore Data submitted by Mr Mattimore in the two tables following indicate about 16 per cent average increase in strength with the use of 4 per cent calcium chloride for ages of from 3 to 28 days, the increase, however, becoming very slight at 12 months age

TABLE I

Cement	Condition	3 Days	7 Days	14 Days	21 Days	28 Days
Standard blend	Plain	100	100	100	100	100
Standard blend	With 4% $CaCl_2$	120	125	104	112	113
Commercial cement	Plain	135	103	87	97	95
Commercial cement	With 4% $CaCl_2$	155	117	107	112	118

TABLE II

Age	Compressive strength (6-inch cubes)			
	Plain concrete		Concrete with 4 per cent $CaCl_2$	
	Lb per sq in	Per cent	Lb per sq in	Per cent
3 Days	3,500	100	4,050	116
7 Days	4,200	100	4,900	117
28 Days	5,200	100	6,200	119
3 Months	6,200	100	6,850	111
6 Months	6,450	100	6,900	107
12 Months	8,760	100	8,810	101

Mr Mattimore says —"The practical application of the use of calcium chloride as an accelerator in a concrete mix is illustrated in a concrete roadway placed at several bridge approaches over which traffic was admitted seven days after the roadway was placed The following series of tests give the compressive strength of concrete cores taken from this roadway when six months old"

TABLE III

Number of specimens	Compressive strength lbs per sq in		
	Maximum	Minimum	Average
Two plain concrete	4,851	3,476	4,163
Four 4-per cent solution $CaCl_2$	3,559	3,053	3,230
Four 2-per cent solution $CaCl_2$	4,175	3,218	3,747

Discussion by Raymond Harsch, U S Bureau of Public Roads A comparison of strength between plain concrete, and concrete containing a commercial hardener (essentially a Ca0 Cl_2) in the proportion of 1 gallon of hardener per sack of cement is afforded The concrete mixture used was 1 2 4 by volume

BEAM TESTS

Data on Beams			Modulus of rupture, lbs per sq in
Plain concrete	12″x6″x7′	Average of 4	351
With hardener	12″x6″x7′	Average of 4	322
Plain concrete	6″x8″x48′	Average of 2	443
With hardener	6″x8″x48′	Average of 2	349

COMPRESSIVE TESTS

Data on specimens			Compressive strength lbs per sq in
Plain concrete	2 ″x4″	Cores Average of 6	4,091
With hardener	2 ″x4″	Cores Average of 6	3,705
Plain concrete	4½″x6″	Cores Average of 4	3,352
With hardener	4½″x6″	Cores average of 4	3,348
Plain concrete	6 ″x12″	Control cylinders average of 3	2,197
With hardener	6 ″x12″	Control cylinders average of 3	2,327

From the "Economic Value of Admixtures," by Pearson and Hitchcock, Proceedings American Concrete Institute, 1924.

Figure 5 arranged from data in Table I of the above paper affords a comparison between concretes of four different proportions with and without admixtures of the calcium chloride type The exact amounts of the admixtures used are not stated. The curve for the accelerators is plotted from data which gives the average of the strengths obtained with each of the three materials in the several mixtures.

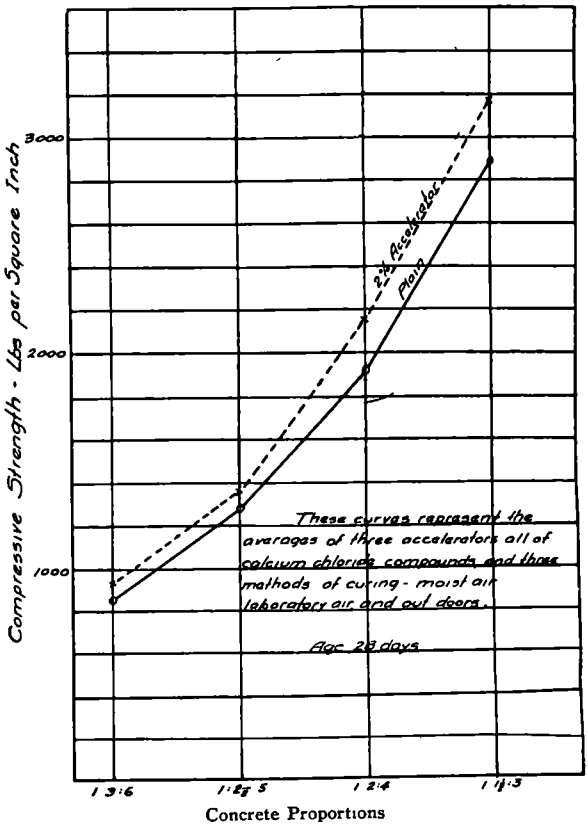

Figure 5—Effect of admixtures. From experiments by Pearson and Hitchcock

From Technologic Paper No 174, U S Bureau of Standards "Effects of Cal as an Accelerator of the Hardening of Portland Cement Concrete"

This paper states that "Cal is essentially an oxychloride of calcium" "The products of its decomposition by water are calcium chloride and calcium hydroxide, equivalent in effect to a simultaneous addition of calcium chloride and finely divided hydrated lime" With respect to

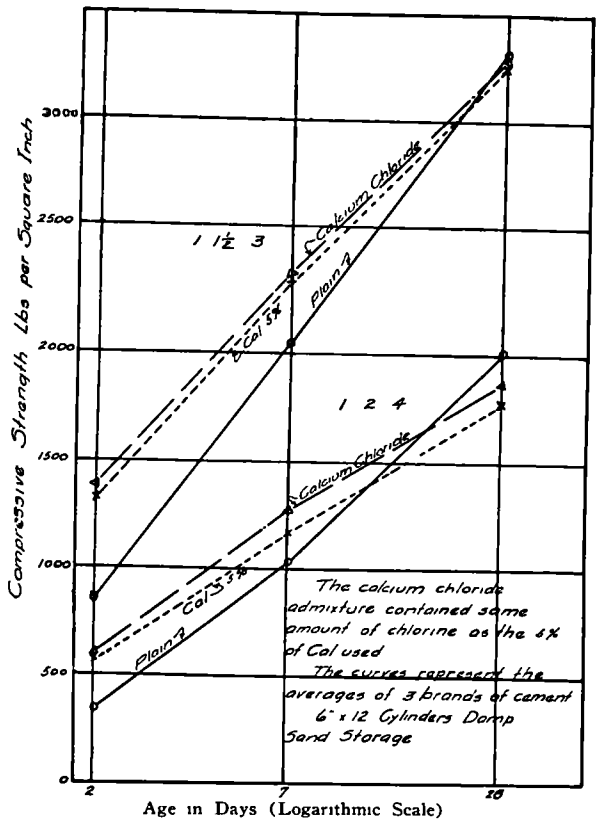

Figure 6—Effect of age and mix From Technologic Paper 174, U S Bureau of Standards

the strength tests the author states that, "The most important facts deduced from these data are as follows

1 In all cases the strength of the treated concrete was greater than that of the corresponding untreated concrete at the two and seven day periods
2 The strength of the treated concrete was practically the same as that of the untreated at the 28-day period
3. The effect of Cal at the 2-day period was very nearly the same for all cements, proportions, and conditions of the tests.
4 The results produced by Cal and calcium chloride are practically the same"

Figure 6 drawn from the data in Table No 7 of the paper illustrates the typical relationships demonstrated by this series of tests.

2

WILL THE USE OF THE ACCELERATOR PROTECT THE CONCRETE AGAINST LOW TEMPERATURE?

The data in Professor Abrams' paper (A S T M , 1924) indicate that within the percentages of calcium chloride which do not have a deleterious effect upon the strength only a slight hastening in the setting of the cement can be expected, and that the "temperature of the concrete made and cured outdoors was not appreciably affected by the addition of calcium chloride " As shown in Table IV the use of 3 per cent calcium chloride gave concrete of higher strength than concrete without admixture when made and cured outdoors at a low temperature, but that the concrete even then was much weaker than corresponding concrete made under more normal conditions These data also show that to lower the freezing point of the water requires the addition of so much of the salt that the effect upon the strength of the concrete would be very bad Professor Abrams concludes "That dependence should not be placed on the lowered freezing point of the mixing water In cold weather work it is much more desirable to heat the materials and furnish proper protection and artificial heat to the structure, than to depend upon chemcial admixtures "

TABLE IV

EARLY STRENGTH OF CONCRETE CURED AT LOW TEMPERATURES FROM PAPER BY D A ABRAMS

Conditions of test	Compressive strength, lb per sq in			
	2 Days	7 Days	28 Days	3 Months
Specimens made in laboratory, cured in moist room				
0 per cent calcium chloride	410	1,230	2,640	4,620
3 per cent calcium chloride	600	1,260	2,320	3,670
Specimens made in laboratory, cured outdoors				
0 per cent calcium chloride	100	430	1,670	2,930
3 per cent calcium chloride	200	750	1,820	2,670
Specimens made outdoors, cured in moist room				
0 per cent calcium chloride	180	960	2,680	4,410
3 per cent calcium chloride	380	1,010	2,160	3,440
Specimens made outdoors, cured outdoors				
0 per cent calcium chloride	45	300	1,660	2,820
3 per cent calcium chloride	185	710	1,980	2,900

Note 1 and 4 day values omitted

Figure 7 (Figure 9 of the paper), from the paper by Clemmer and Burggraf shows that the initial set of neat cement can be hastened by the addition of calcium chloride, but the following Table V of transverse strengths of concrete made and cured at low temperatures shows little advantage from the probable earlier activity of the cement

TABLE V

TRANSVERSE STRENGTHS OF TEST SPECIMENS CONTAINING VARIOUS QUANTITIES OF CALCIUM CHLORIDE FROM PAPER BY CLEMMER AND BURGGRAF

Treatment	Transverse strength lb per sq in		Flow	Temperatures deg Fahr	
	14 Day	28 Day		Air	Concrete
No treatment	85	230	185	26 to 28	40
2 per cent $CaCl_2$ (Incorporated)	171	222	190	26 to 28	40
4 per cent $CaCl_2$ (Incorporated)	228	249	180	26 to 28	40
6 per cent $CaCl_2$ (Incorporated)	167	234	175	26 to 28	40
No treatment	87	123	180	19 to 22	55
2 per cent $CaCl_2$ (Incorporated)	156	138	170	19 to 22	55
4 per cent $CaCl_2$ (Incorporated)	168	201	185	19 to 22	55
6 per cent $CaCl_2$ (Incorporated)	186	255	170	19 to 22	55
10 per cent $CaCl_2$ (Incorporated)	176	256	165	19 to 22	55

The authors of this paper therefore conclude "The investigations conducted with concrete specimens poured in low temperatures merely illustrated the fact that even the presence of a large percentage of calcium chloride will not allow the placing of concrete in freezing temperatures without some provision being made to protect the concrete from the cold weather"

Figure 8 plotted from data for tests of concrete in Mr Mattimore's discussion of the paper by Clemmer and Burggraf indicates that concrete cured under rather low temperatures may be improved by the addition of calcium chloride although this will not in itself produce concrete equal to that cured under favorable conditions. Tests of mortar in the same investigation show similar results

3

EFFECT ON RATE OF HARDENING

If early strength can be induced in otherwise normal concrete, so that the structure or pavement can be put in service with less loss of time, a very large economic advantage will result

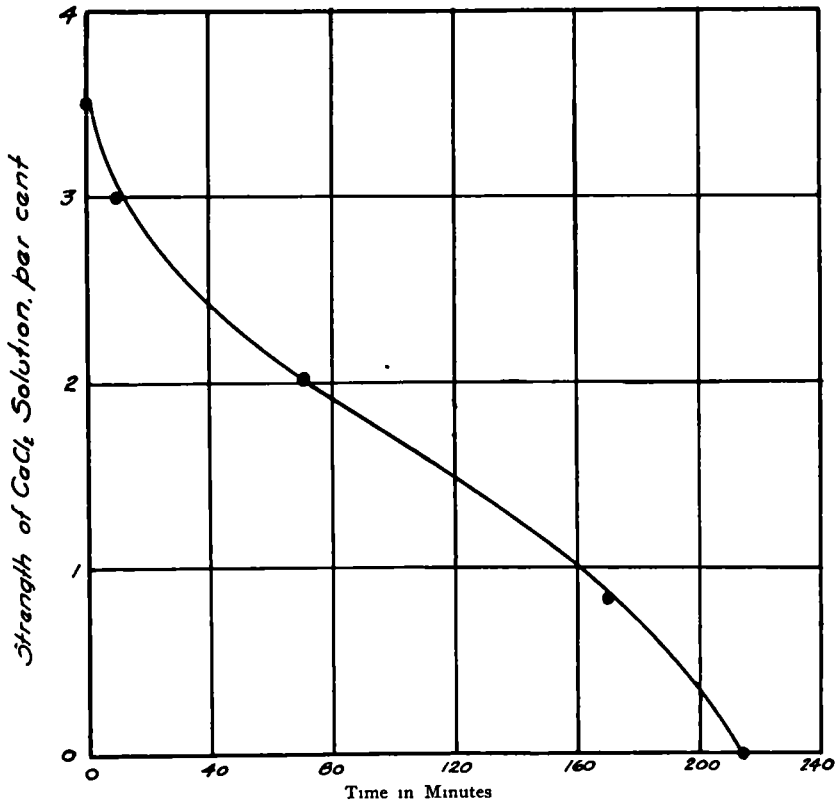

Figure 7—Effect on initial set of concrete From experiments by Clemmer and Burggraf

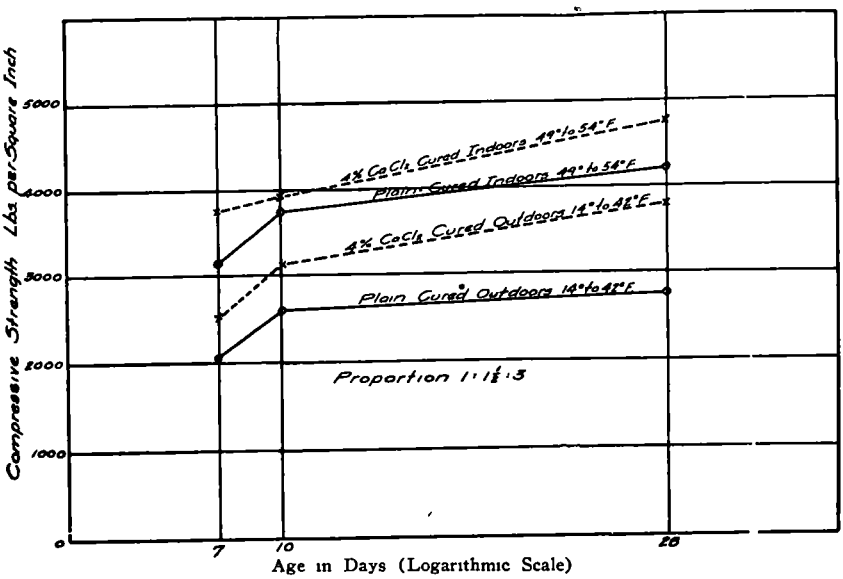

Figure 8—Effect of low curing temperature. From discussion by Mattimore

Figure 2 from Abrams' paper (A S T M 1924), indicates that 2 per cent of calcium chloride will increase the early strength of 1 5 2 (1 2 4) concrete so that 14 to 21 days curing depending upon mixture and consistency may be equivalent to 28 days without the admixture Professor Abrams says "It is evident that the effect of calcium chloride is to produce an increase in strength at the early ages which is maintained throughout the later periods of test"

Figure 4 from the paper by Clemmer and Burggraf (A S T M 1923), previously referred to indicates that 2 or 3 per cent calcium chloride in a 1–2–3½ mix will give concrete strengths at about 21 days equivalent to the 28 days plain concrete strengths

Mr Mattimore's discussion of the above paper by Clemmer and Burggraf indicates that concrete may be made in 7 to 14 days, equivalent in strength to plain concrete at 28 days by the addition of 4 per cent calcium chloride This is shown in Table II

Although the data in Technologic Paper 174, U S Bureau of Standards show comparatively large increases in strength due to Cal and calcium chloride at the two and seven day periods, they do not show that strength equal to the 28-day strength will be reached enough earlier to make it possible to open the structure or pavement to service much earlier See Figure 6

4

EFFECT ON STEEL REINFORCEMENT

In his discussion of Professor Abrams' paper (A S T M 1924), H S Mattimore stated, "We have used calcium chloride incorporated in the mix in concrete road slabs in which steel mesh was used as reinforcement Cores were drilled from these slabs about four years after placing and an examination of the steel did not show any detrimental effect.

In discussing the paper by Clemmer and Burggraf (A S T M 1923), J. C Pearson of the U S Bureau of Standards described and exhibited some specimens of rods which had been imbedded in concrete containing calcium chloride, for six years His statement was as follows "I think that the majority of people would pass upon them as being entirely satisfactory In one or two of the mortar mixtures there is a surface corrosion that is not by any means deep, though it is general over the surface In the case of the specimens buried in concrete, corrosion is absent over the greater portion of the surfaces of the rods, what rust occurred being localized apparently where voids occurred on the surface of the steel Comparisons of the one year and five year specimens indicate that corrosion is not progressive"

In his paper "Shall Anything be Added to Portland Cement," Proceedings American Concrete Institute, 1925, Maximilian Toch makes

the following statement "Where calcium chloride is used as an antifreeze or some other of the basic chlorides, they are very likely to rust steel in spite of the excess of lime that may be in the concrete It is therefore essential to paint them with an alkali or chloride proof paint, and in that case a simple wash with concrete is not sufficient"

SUMMARY

The various investigations reviewed in this report appear to be in substantial accord to the following extent

Calcium chloride and other soluble compounds of calcium chloride base act as accelerators of the hardening of concrete, and when used within limits of approximately 0 to 4 per cent increase the strength to a limited degree The effect of the accelerator being roughly in proportion to the amount of anhydrous calcium chloride in the compound used Since the increase in strength is practically the same for all ages, the relative increase is greatest at early ages Considerable variation in results secured with different brands of cement is also noted

It would therefore appear that there are at least two useful functions for such admixtures

1 To increase the early hardening so that the structure or pavement may be put into earlier service than is possible with normal Portland cement Further special investigations are needed to formulate rules of practice for varying local conditions and different cements
2 To counteract, to some extent, low strength due to curing concrete at low temperatures, provided that the temperature is not below freezing, and the concrete is protected during the setting period Calcium chloride can not be depended upon to protect against freezing during the mixing and setting period

The possible increase in final strength of concrete produced by the use of an accelerator is slight compared with the possible increase due to other recognized methods

The effect of calcium chloride upon steel reinforcement is not definitely determined by the data reviewed

QUICK HARDENING CEMENTS

F C Lang

Minnesota State Highway Department, St Paul, Minnesota

INTRODUCTION

The term "quick-hardening cements" is used in this paper to cover all cements giving high early strengths Much investigation has been