

AN INVESTIGATION OF THE EFFECTS OF
ABNORMAL CURING CONDITIONS ON
DOLOMITIC LIMESTONE PORTLAND CEMENT CONCRETE

By

Albert C. Ringelstein

A Thesis Submitted to the Graduate Committee

For the Degree of

MASTER OF SCIENCE

in

Civil Engineering

Approved:

Head of Department

Dean of Engineering

Chairman, Graduate Committee

Virginia Polytechnic Institute
Blacksburg, Virginia
June, 1938

ACKNOWLEDGMENTS

The author wishes to express his appreciation to
Director of Concrete Research at
Virginia Polytechnic Institute, for his cooperation and assistance
in the carrying on of this investigation.

Acknowledgment is also made to:

Head of the Geology Department, Virginia
Polytechnic Institute, for the information given on the materials used
in this investigation.

Dean of Engineering, Virginia
Polytechnic Institute, and Head of the
Department of Civil Engineering, Virginia Polytechnic Institute, for
making possible this research by supplying the necessary materials and
equipment.

Head of the Ceramics Department,
Virginia Polytechnic Institute, and Manager of the
Virginia Polytechnic Institute Creamery, for the use of their equipment.
Associate Professor of Sanitary Engineering,
Virginia Polytechnic Institute, and Assistant Pro-
fessor of Architectural Engineering, Virginia Polytechnic Institute,
for taking the pictures shown in this thesis.

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I. INTRODUCTION

For the layman it is only logical to assume that satisfactory concrete can be produced using any hard durable rock as an aggregate; but such is not the case. Any cement or concrete expert will inform you that cement should never be permitted to chemically combine with any of the other ingredients of concrete, aside from the water, as it is very detrimental to the strength of the concrete. For this reason it is not advisable to use shale or slate as an aggregate for concrete. This proved to be very disastrous in two cases where dams were built employing these materials. The deterioration was so great that in the course of twenty years both dams were considered unsafe and one had to be partially rebuilt at a cost of \$300,000.

Magnesium is considered poison in cement, but Dolomitic limestone rock is rich in this poison. Dolomitic limestone rock is composed of two minerals, namely, calcite (calcium carbonate, CaCO_3) and Dolomite (calcium magnesium carbonate, $\text{CaCO}_3 \cdot \text{MgCO}_3$), found in varying proportions, and certain argillaceous impurities. Dolomitic limestone rock has been successfully used for many years as the coarse aggregate for concrete. The development of Portland cement was chiefly responsible for this use. Natural cement is manufactured at relatively low temperatures and any magnesium present remains active, but, in the manufacture of Portland cement very high temperatures are employed and as a result the magnesium is made inert. The magnesium in Dolomitic limestone rock is also relatively stable and the two, Portland cement and Dolomitic limestone rock, may be combined to form good concrete.

Out of the great success realized in the use of Dolomitic limestone rock has recently developed the use of Dolomitic limestone sand, the screenings from the crushed rock graded in size to correspond to ordinary quartz and silica sands, as the fine aggregate for Portland cement concrete. One of the greatest projects ever to use Dolomitic limestone sand was the Norris Dam in Tennessee. The Student Activities Building of the Virginia Polytechnic Institute, Stroubles Creek Conduit, and many highways in West Virginia have also used this sand. Up to the present time all have given satisfactory performance.

Exhaustive research has been done on the silica sands as an aggregate for Portland cement concrete, but very little has been done in the investigation of Dolomitic sand. Dr. R. J. Holden, Head of the Geology Department, Virginia Polytechnic Institute, has shown great interest in this product and is now making long time studies on test samples taken from the Norris Dam. Mr. W. T. Hartman, Jr., Associate Professor of Civil Engineering and Director of Concrete Research at Virginia Polytechnic Institute, is also carrying on some long time studies of his own, independent of Dr. Holden. Mr. Hartman has been very influential in the development of the use of Dolomitic limestone sand in the State of Virginia.

A product attracting such wide interest demands that its properties be thoroughly investigated.

II. REVIEW OF LITERATURE

Seeking a substitute for Petersburg sand as the fine aggregate for Portland cement concrete, Mr. H. C. Broyles, a Graduate Fellow at Virginia Polytechnic Institute, 1936, investigated the possibilities of Dolomitic limestone sand. In his thesis, "Investigation of the Use of Dolomitic Limestone Sand as a Fine Aggregate for Portland Cement Concrete," he presents the results of his research. From his results he definitely concluded that "dolomitic limestone sand, when properly graded, is entirely satisfactory as a fine aggregate in the making of Portland cement concrete." From the same results he also concluded that "concrete in which dolomitic limestone sand was used as the fine aggregate gave twenty-five per cent greater compressive strength than concrete in which Petersburg sand was used."

In order to verify the conclusion of Mr. Broyles, a section of this investigation is devoted to a comparison between the relative worth of Petersburg sand and Dolomitic sand as the fine aggregate for Portland cement concrete.

In his thesis, "An Investigation of the Effect on the Ultimate Strength of Concrete Loaded During the Curing Period," V. P. I., 1937, Mr. J. L. Brown states the following: "Beginning with the construction of the Storage Building in 1934, the V. P. I. Experimental Station has availed itself of the opportunity of conducting studies on the concrete used in the newer developments here at V. P. I. Since that time studies have been made of the concrete used in the construction of a conduit for Stroubles Creek, and more recently, a study of the concrete poured during

the construction of the new Student Activities Building." In the "Field Studies" section of Mr. Brown's thesis are given the results of the aforementioned studies. These results seem to support what Mr. Broyles had concluded in his investigation.

The investigation about to follow still concerns itself with the use of Dolomitic limestone sand as the fine aggregate for Portland cement concrete, but its manner of treatment is quite different from that employed by Mr. Broyles.

III. INVESTIGATION

A. Object of Investigation

The aim and purpose of the investigation is to determine in what ways the strength of Portland Cement Concrete, using Dolomitic Limestone Sand as the fine aggregate, is affected by abnormal high and low temperatures during the various stages of curing. What is herein disclosed may be very valuable in its application to precasting and placing of concrete, but it is not the concern of the author at this time to investigate these possibilities. As a check on the previous research a comparison is made between the relative strengths of concrete employing Dolomitic and Petersburg sand as a fine aggregate.

B. Procedure

1. Plan of Attack

Problem I

In the investigation of the freezing and thawing effect on the strength of concrete three variables were considered: (1) the length of time the concrete was frozen immediately following removal of forms; (2) the length of time the concrete was allowed to set before being frozen; and (3) the length of time the concrete was frozen after the variable setting periods. The problem was attacked in the following manner.

a. Concrete cylinders were frozen for one, three, five seven and ten days immediately following removal of forms (variable No. 1), and were cured in moist closet for the remainder of twenty-eight days.

b. After being cured for one, three, five, seven, and ten days in moist closet (variable No. 2), concrete cylinders were frozen for the remainder of twenty-eight days.

c. After being cured for one, three, five, seven, ten, and fourteen days in moist closet, concrete cylinders were frozen for one, three, five, seven and nine days (variable No. 3), and then cured for the remainder of twenty-eight days in moist closet.

The freezing temperature employed was 0° Fahrenheit, the prevailing temperature of the refrigerator located in the Dairy Husbandry Building of the Virginia Polytechnic Institute. Due to the frequency with which the refrigerator doors had been opened and closed, the temperature did not remain constant but fluctuated about 0° F.

All cylinders were given compression tests at the age of twenty-eight days.

Problem II

In the investigation of the high temperature effect on the strength of concrete, 65° C. was the temperature arbitrarily selected. Fresh concrete, if maintained at this temperature, will dry out very quickly and the chemical processes going on within will come to a halt, water being an essential part. In order to forestall this as much as possible, a pan of water was placed in the curing oven together with the concrete cylinders. It is not the purpose of the author to steam cure the concrete, and the water was added merely to slow up evaporation. The leakage of the oven was very great, as a result no pressure was built up and the relative humidity never quite reached one hundred per cent.

After a few days in the oven the water in the concrete would finally evaporate. To restore this water the concrete cylinders were immersed in the water for varying periods. Having done this, the concrete cylinders were further cured at 65° C., and after a short period, again immersed in water. Compression tests were made during the various states of curing. To determine the effect this high temperature curing had on the ultimate strength of the concrete, specimens were given successive treatment in the oven and water and allowed to attain an age of twenty-eight days in moist closet, after which they were tested. This problem was attacked in the following manner.

a. Concrete cylinders were cured from one to five days at 65° C. and given compression tests upon removal from oven.

b. After being cured for one, two and three days at 65° C., concrete cylinders were immersed in water for one, two and three days. Compression tests were given upon removal from water.

c. After being cured as in b, concrete cylinders were placed back in oven for one and two days. Compression tests were given upon removal from oven.

d. After being cured as in c, concrete cylinders were again immersed in water for one and two days. Compression tests were given upon removal from water.

e. Concrete cylinders were cured for one, two and three days at 65° C., immersed in water for one and two days and cured in moist closet for the remainder of twenty-eight days. Compression tests were given at the end of twenty-eight days of curing.

Problem III

As a check on the work done on Dolomitic sand by Mr. Broyles, a comparison was made between the twenty-eight day compressive strength of Portland cement concrete using Petersburg sand as the fine aggregate and Portland cement concrete using Dolomitic sand as the fine aggregate.

Twelve concrete cylinders were prepared with Petersburg sand, using the same mix as for the Dolomitic. Eight of these cylinders were cured in moist closet for twenty-eight days and the remaining four were cured in water for a like period. Compression tests were given to all specimens at the end of twenty-eight days of curing. These results were checked with the check cylinder strengths.

2. Materials and Apparatus

It is well at this point to give a brief explanation of the materials and apparatus used in this investigation.

As was stated previously, Dolomitic limestone sand was used as the fine aggregate. Crushed limestone rock was used as the coarse aggregate and Portland cement as the binding material. The water used throughout was the same as used for drinking purposes at the Institute.

In order to be consistent with previous research, a 1-2-3 mix (by volume) with seven and one-half gallons of water per cubic foot of cement was used. Concrete cylinders, 2" x 4", were employed throughout the investigation, and were prepared according to the A. S. T. M. specifications.

The following is a list of the materials used, together with their exact proportions:

1. Weight of cement per cubic foot - - - 94 lbs. 0 oz.
 2. Weight of dry rodded Dolomitic sand
per cubic foot - - - - - 106 lbs. 8 oz.
 3. Weight of dry rodded Petersburg sand
per cubic foot - - - - - 101 lbs. 0 oz.
 4. Weight of dry rodded crushed limestone
rock per cubic foot - - - - - 95 lbs. 6 oz.
- Volume of twelve 2" x 4" cylinders = 151 cu. in.

Materials used for one batch of twelve cylinders:

1. For all batches using Dolomitic sand

Water - - 1.46 pints

Cement - - 42 cubic inches - - - 2 lbs. $4\frac{1}{2}$ oz.

Dolomitic sand - 84 cubic inches - 5 lbs. 3 oz.

Crushed limestone - 126 cubic inches - 6 lbs. $15\frac{1}{2}$ oz.

2. For batch using Petersburg sand

Water - - 1.46 pints

Cement - 42 cubic inches - - - 2 lbs. $4\frac{1}{2}$ oz.

Petersburg sand - 84 cubic inches - 4 lbs. $14\frac{1}{2}$ oz.

Crushed limestone - 126 cubic inches - 6 lbs. $15\frac{1}{2}$ oz.

The 100,000-pound Tinius Olsen machine was used for applying the breaking loads. For all concrete cylinders, twenty-eight days old, a 50,000-pound rider was used on the machine, unless otherwise noted, and for all concrete cylinders of ages less than twenty-eight days a 10,000-pound rider was used. The speed of the moving head for all runs was .0308 inches per minute. The Freas electric oven, which was used in the high temperature curing of the concrete, had a range of 20° C. to 80° C. The Fairbanks scale, which was used to weigh out the material, read to the nearest quarter of an ounce. The auxiliary apparatus used in the preliminary tests was all standard equipment conforming to A. S. T. M. specifications.

Fig. 1. 100,000
lb. Tinius Olsen
Testing Machine.

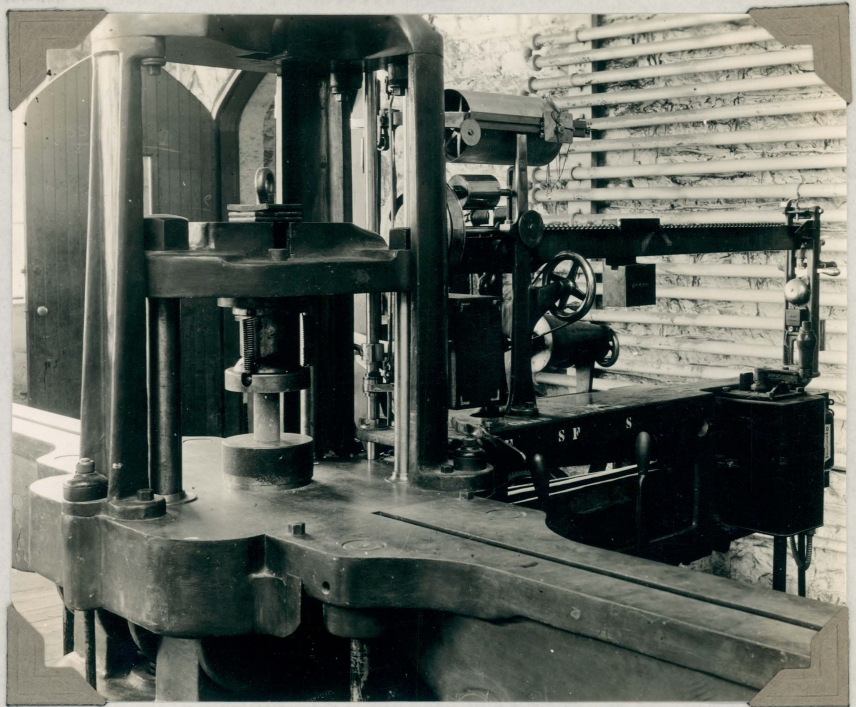


Fig. 1.



Fig. 2. The Freas
Electric Oven.

Fig. 2.

3. Preliminary Tests

Relative values were used throughout this investigation, but, for the purpose of comparison with A. S. T. M. (American Society for Testing Materials) standards, certain preliminary tests were performed on the cement, fine and coarse aggregates. No attempt will be made to explain these tests in detail, as they may be very easily referred to in the A. S. T. M. Specifications.

Cement:

- a. Normal consistency 25.6 per cent
- b. Initial set $3\frac{1}{4}$ hours
- c. Final set 6 hours

Sand:

- a. Sieve analysis

For each sand a 500-gram sample was given eight minutes in the Ro-Tap Testing Sieve Shaker, without the tapper.

Dolomitic No. 1

<u>Sieve No.</u>	<u>Grams Retained</u>	<u>Per Cent Retained</u>	<u>Grams Passing</u>	<u>Per Cent Passing</u>
10	87.4	17.48	412.6	82.52
20	240.1	48.02	172.5	34.50
40	103.2	20.64	69.3	13.86
50	23.0	4.60	46.3	9.26
60	14.1	2.82	32.2	6.44
80	7.7	1.54	24.5	4.90
100	4.5	.90	20.0	4.00
pan	20.0	4.00	0.0	0.00
	<u>500.0</u>	<u>100.00</u>		

Dolomitic No. 2

<u>Sieve No.</u>	<u>Grams Retained</u>	<u>Per Cent Retained</u>	<u>Grams Passing</u>	<u>Per Cent Passing</u>
10	81.7	163.4	418.3	83.66
20	220.9	44.18	197.4	39.48
30	82.3	16.46	115.1	23.02
60	74.5	14.90	40.6	8.12
80	8.4	1.68	32.2	6.44
100	5.7	1.14	26.5	5.30
Pan	26.5	5.30	00.0	0.00
	<u>500.0</u>	<u>100.00</u>		

Petersburg

<u>Sieve No.</u>	<u>Grams Retained</u>	<u>Per Cent Retained</u>	<u>Grams Passing</u>	<u>Per Cent Passing</u>
10	68.7	13.74	431.3	86.26
20	177.5	35.50	253.8	50.76
30	114.3	22.86	139.5	27.90
50	71.9	14.38	67.6	13.52
60	23.2	4.64	44.4	8.88
80	12.1	2.42	32.3	6.46
100	9.1	1.82	23.2	4.64
Pan	23.2	4.64	0.0	0.00
	<u>500.0</u>	<u>100.00</u>		

b. Colormetric Test:

Tests show both Dolomitic and Petersburg sand suitable for grade A concrete.

c. Decantation Test:

Both Dolomitic and Petersburg sand are satisfactory.

Crushed Limestone Rock

a. Sieve Analysis

<u>Sieve</u>	<u>Grams Retained</u>	<u>Per Cent Retained</u>	<u>Grams Passing</u>	<u>Per Cent Passing</u>
1/2 inch	0.0	0.00	2000.0	100.00
3/8 inch	789.7	39.49	1210.3	60.52
1/4 inch	871.3	43.56	339.0	16.95
No. 4	132.2	6.61	206.8	10.34
No. 8	193.8	9.69	13.0	.65
Pan	13.0	.65	0.0	0.00
	<u>2000.0</u>	<u>100.00</u>		

4. Preparation of Specimens

After the proper amount of constituents was determined, the next step was to prepare the specimens. The method as used in the investigation is described below.

The exact amount of coarse aggregate was weighed out on the Fairbanks scale (shown in Fig. 3) and spread out in an even layer on the bottom of the pan. The exact amount of fine aggregate was then weighed out and spread in an even layer over the coarse aggregate. The exact amount of cement was weighed out and spread in an even layer over the two previous layers. The edges of the layers were drawn in toward the center with a trowel, forming a pile in the middle of the pan. Working from the edges toward the center, the pile was turned over four consecutive times, leaving the pile again in the center of the pan. The central pile was then spread out flat and a spiral ditch (shown in Fig. 3) formed with the tip of the trowel.

The required water was then poured into the spiral ditch. As the water soaked in, the dry edges were turned into the center of the material, forming a new pile in the middle of the pan. This pile was then turned over four times, as done previously.

The concrete, having been thoroughly mixed, was then placed in cylindrical molds (shown in Fig. 3) in the following manner. Concrete was scooped out of the pan with a trowel and placed in greased molds in four layers one inch in depth. Each layer was rodded twenty-eight times with one-half inch round steel rod. The last layer having been

rodded, the tops of the cylinders were smoothed off with the trowel to give an even finish. Cylinders were allowed to set in molds for twenty-four after which they were removed, marked, and cured in the manner as called for by the schedule.

In order to insure an even distribution of load when tested, all roughened surfaces were capped with plaster, setting in approximately one-half hour.

Fig. 3. Apparatus
and tools used in
investigation.

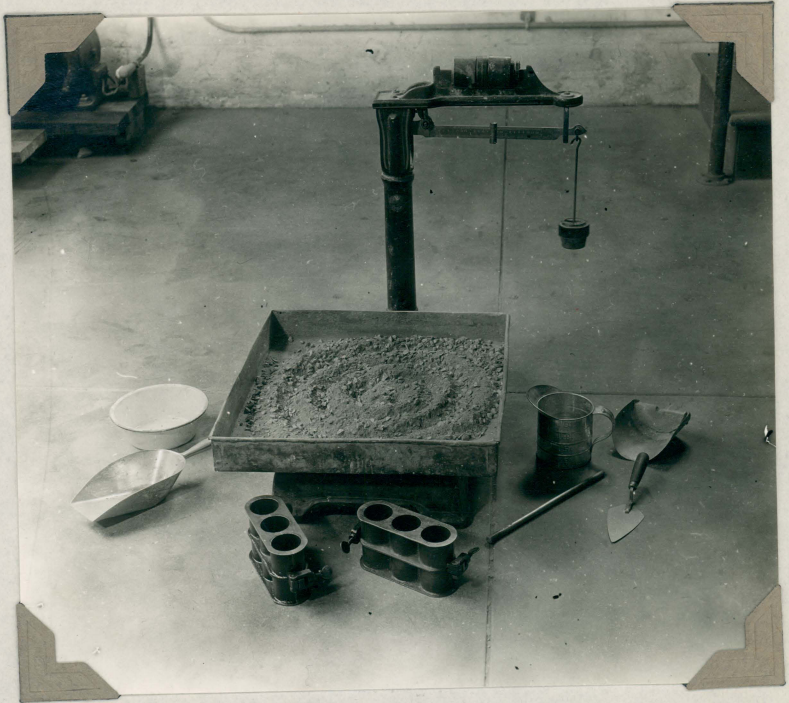


Fig. 3.



Fig. 4. Concrete
cylinders before
and after failure.

Fig. 4.

C. Results

1. Problem I

TABLES NOS. FMC-1 AND FMC-2

Sand: Dolomitic No. 1

Cylinders 1 to 10 frozen for one, three, five, seven and ten days and then placed in moist closet for the remainder of twenty-eight days. Age of concrete, twenty-eight days.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet.

Remarks: Temperatures read upon entering refrigerator. Average temperature considered as 0° F. Surfaces moist along planes of failure.

Table FMC-1.

Cyl. No.	Days Frozen	Temp. in (Fahr.)	Temp. out (Fahr.)	Days in M. C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	1	-3	10	26	9,000	2,865	90.9
2	1	-3	10	26	7,700	2,450	77.8
3	3	-3	5	24	8,750	2,735	83.4
4	3	-3	5	24	8,150	2,594	82.3
5	5	-3	1	22	8,450	2,690	85.4
6	5	-3	1	22	8,700	2,770	87.9
7	7	-3	4	20	8,500	2,706	85.9
8	7	-3	4	20	7,800	2,433	78.8
9	10	-3	-5	17	9,150	2,913	92.5
10	10	-3	-5	17	8,250	2,626	83.4
Check							
11	--	--	--	27	10,250	3,263	----
12	--	--	--	27	9,550	3,040	----

Table FMC-2.

Cyl. No.	Days Frozen	Temp. in (Fahr.)	Temp. out (Fahr.)	Days in M. C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	1	5	-3	26	9,000	2,865	80.3
2	1	5	-3	26	10,000	3,133	89.3
3	3	5	-2	24	8,950	2,849	79.9
4	3	5	-2	24	11,150	3,549	99.5
5	5	5	0	22	8,550	2,722	76.9
6	5	5	0	22	9,300	2,960	83.0
7	7	5	1	20	8,900	2,833	79.5
8	7	5	1	20	10,600	3,374	94.6
9	10	5	-1	17	8,850	2,817	79.0
10	10	5	-1	17	8,700	2,769	77.6
Check							
11	--	--	--	27	10,450	3,327	----
12	--	--	--	27	11,950	3,604	----

TABLES NOS. MCF-1 AND MCF-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured for one, three, five, seven and ten days in moist closet and then frozen for the remainder of twenty-eight days. Age of concrete, twenty-eight days.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet.

Remarks: Temperatures read upon entering refrigerator. Average temperature considered as 0° F. Surfaces moist along planes of failure.

Table MCF-1.

: Cyl. No. :	Days in M. C. :	Days Frozen :	Temp. in (Fahr.) :	Temp. out (Fahr.) :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	1 :	26 :	5 :	3 :	3,150 :	1,003 :	36.0 :
: 2 :	1 :	26 :	5 :	3 :	3,000 :	955 :	34.3 :
: 3 :	3 :	24 :	1 :	3 :	4,970 :	1,592 :	56.8 :
: 4 :	3 :	24 :	1 :	3 :	4,900 :	1,560 :	56.0 :
: 5 :	5 :	22 :	1 :	3 :	5,490 :	1,748 :	62.7 :
: 6 :	5 :	22 :	1 :	3 :	7,030 :	2,237 :	80.4 :
: 7 :	7 :	20 :	9 :	3 :	7,000 :	2,228 :	80.0 :
: 8 :	7 :	20 :	9 :	3 :	7,000 :	2,228 :	80.0 :
: 9 :	10 :	17 :	5 :	3 :	8,200 :	2,610 :	93.7 :
: 10 :	10 :	17 :	5 :	3 :	7,900 :	2,515 :	90.3 :
: Check :	:	:	:	:	:	:	:
: 11 :	27 :	-- :	-- :	-- :	8,450 :	2,690 :	---- :
: 12 :	28 :	-- :	-- :	-- :	9,000 :	2,865 :	---- :

Table MCF-2.

: Cyl. No. :	Days in M. C. :	Days Frozen :	Temp. in (Fahr.) :	Temp. out (Fahr.) :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	1 :	26 :	-2 :	9 :	4,550 :	1,448 :	38.5 :
: 2 :	1 :	26 :	-2 :	9 :	4,460 :	1,420 :	37.7 :
: 3 :	3 :	24 :	0 :	9 :	7,110 :	2,263 :	60.1 :
: 4 :	3 :	24 :	0 :	9 :	7,460 :	2,375 :	63.0 :
: 5 :	5 :	22 :	1 :	9 :	7,780 :	2,477 :	65.8 :
: 6 :	5 :	22 :	1 :	9 :	7,510 :	2,390 :	63.5 :
: 7 :	7 :	20 :	1 :	9 :	9,100 :	2,897 :	76.9 :
: 8 :	7 :	20 :	1 :	9 :	8,600 :	2,738 :	72.7 :
: 9 :	10 :	17 :	4 :	9 :	10,850 :	3,454 :	91.6 :
: 10 :	10 :	17 :	4 :	9 :	9,750 :	3,104 :	82.4 :
: Check :	:	:	:	:	:	:	:
: 11 :	27 :	-- :	-- :	-- :	12,600 :	4,011 :	---- :
: 12 :	27 :	-- :	-- :	-- :	11,050 :	3,518 :	---- :

TABLES NOS. 1F-1 AND 1F-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured in moist closet one day, then in refrigerator for one, three, five, seven and nine days and back in moist closet for the remainder of twenty-eight days. Age of concrete, twenty-eight days.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Temperatures read upon entering refrigerator. Average temperature considered as 0° F. Surfaces moist along planes of failure.

Table 1F-1.

Cyl. No.	Days Frozen	Temp. in (Fahr.)	Temp. out (Fahr.)	Days in M. C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	1	-3	10	25	8,550	2,722	90.0
2	1	-3	10	25	9,150	2,913	96.4
3	3	-3	5	23	8,700	2,770	91.6
4	3	-3	5	23	8,650	2,754	91.0
5	5	-3	1	21	8,550	2,722	90.0
6	5	-3	1	21	9,800	3,120	103.1
7	7	-3	4	19	9,350	2,976	98.5
8	7	-3	4	19	10,150	3,231	106.9
9	9	-3	9	17	9,250	2,945	97.4
10	9	-3	9	17	7,900	2,515	83.2
Check							
11	-	--	--	27	8,550	2,722	----
12	-	--	--	27	10,450	3,327	----

Table 1F-3

Cyl. No.	Days Frozen	Temp. in (Fahr.)	Temp. out (Fahr.)	Days in M. C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	1	5	-3	25	8,300	2,642	81.3
2	1	5	-3	25	9,150	2,912	90.1
3	3	5	-2	23	8,450	2,690	83.2
4	3	5	-2	23	8,650	2,753	85.2
5	5	5	0	21	9,800	3,119	96.5
6	5	5	0	21	10,050	3,199	99.0
7	7	5	1	19	9,300	2,960	91.6
8	7	5	1	19	9,250	2,944	91.1
9	9	5	1	17	10,550	3,358	104.0
10	9	5	1	17	9,350	2,976	92.1
Check							
11	-	--	--	27	9,700	3,088	----
12	-	--	--	27	10,600	3,374	----

TABLES NOS. 3F-1 AND 3F-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured in moist closet three days, then in refrigerator for one, three, five, seven and nine days, and back in moist closet for the remainder of twenty-eight days. Age of concrete, twenty-eight days.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Temperature read upon entering refrigerator.
Average temperature considered as 0° F. Surfaces moist along planes of failure.

Table 3F-1.

: Cyl. No. :	Days Frozen :	Temp. in (Fahr.) :	Temp. out (Fahr.) :	Days in M. C. :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	1 :	3 :	10 :	23 :	8,500 :	2,642 :	122.1 :
: 2 :	1 :	3 :	10 :	23 :	7,400 :	2,355 :	109.0 :
: 3 :	3 :	3 :	5 :	21 :	8,550 :	2,721 :	125.9 :
: 4 :	3 :	3 :	5 :	21 :	8,400 :	2,674 :	123.5 :
: 5 :	5 :	3 :	1 :	19 :	8,700 :	2,769 :	128.0 :
: 6 :	5 :	3 :	1 :	19 :	9,700 :	3,088 :	142.8 :
: 7 :	7 :	3 :	4 :	17 :	8,100 :	2,550 :	119.1 :
: 8 :	7 :	3 :	4 :	17 :	8,750 :	2,785 :	128.8 :
: 9 :	9 :	3 :	9 :	15 :	7,650 :	2,435 :	112.5 :
: 10 :	9 :	3 :	9 :	15 :	7,850 :	2,499 :	115.5 :
: Check :	:	:	:	:	:	:	:
: 11 :	- :	-- :	-- :	27 :	6,650 :	2,117 :	----- :
: 12 :	- :	-- :	-- :	27 :	6,950 :	2,212 :	----- :

Table 3F-2.

: Cyl. No. :	Days Frozen :	Temp. in (Fahr.) :	Temp. out (Fahr.) :	Days in M. C. :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	1 :	5 :	-3 :	23 :	10,950 :	3,486 :	107.5 :
: 2 :	1 :	5 :	-3 :	23 :	11,550 :	3,661 :	113.5 :
: 3 :	3 :	5 :	-2 :	21 :	10,300 :	3,279 :	101.2 :
: 4 :	3 :	5 :	-2 :	21 :	10,150 :	3,231 :	99.9 :
: 5 :	5 :	5 :	0 :	19 :	9,350 :	2,976 :	91.9 :
: 6 :	5 :	5 :	0 :	19 :	10,450 :	3,326 :	102.8 :
: 7 :	7 :	5 :	1 :	17 :	10,400 :	3,311 :	102.2 :
: 8 :	7 :	5 :	1 :	17 :	9,150 :	2,913 :	90.0 :
: 9 :	9 :	5 :	1 :	15 :	9,250 :	2,944 :	91.0 :
: 10 :	9 :	5 :	1 :	15 :	11,700 :	3,724 :	115.0 :
: Check :	:	:	:	:	:	:	:
: 11 :	- :	-- :	-- :	27 :	10,950 :	3,486 :	----- :
: 12 :	- :	-- :	-- :	27 :	9,400 :	2,992 :	----- :

TABLES NOS. 5F-1 AND 5F-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured in moist closet five days, then in refrigerator for one, three, five, seven and nine days and back in moist closet for the remainder of twenty-eight days. Age of concrete, twenty-eight days.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and checked.

Remarks: Temperatures read upon entering refrigerator. Average temperature considered as 0° F. Surfaces moist along planes of failure.

Table 5F-1.

Cyl. No.	Days Frozen	Temp. in (Fahr.)	Temp. out (Fahr.)	Days in M. C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	1	-3	10	21	8,250	2,626	101.5
2	1	-3	10	21	8,600	2,737	105.9
3	3	-3	5	19	8,950	2,849	110.1
4	3	-3	5	19	8,350	2,658	102.8
5	5	-3	1	17	8,350	2,658	102.8
6	5	-3	1	17	7,000	2,228	86.1
7	7	-3	4	15	7,100	2,260	87.4
8	7	-3	4	15	8,150	2,594	100.3
9	9	-3	9	13	8,950	2,849	110.1
10	9	-3	9	13	9,000	2,865	110.8
Check							
11	-	--	--	27	8,250	2,626	-----
12	-	--	--	27	8,000	2,546	-----

Table 5F-2.

Cyl. No.	Days Frozen	Temp. in (Fahr.)	Temp. out (Fahr.)	Days in M. C.	Load Pounds	Stress Lbs. per sq. in.	Per cent of 28 day strength
1	1	5	-3	21	9,700	3,086	80.7
2	1	5	-3	21	9,050	2,879	73.3
3	3	5	-2	19	10,750	3,420	89.5
4	3	5	-2	19	9,650	3,070	80.4
5	5	5	0	17	10,750	3,420	89.5
6	5	5	0	17	10,450	3,324	87.0
7	7	5	1	15	12,650	4,024	105.5
8	7	5	1	15	12,000	3,818	100.0
9	9	5	1	13	10,950	3,484	91.3
10	9	5	1	13	9,150	2,911	76.2
Check							
11	-	--	--	27	12,400	3,945	-----
12	-	--	--	27	11,600	3,690	-----

TABLES NOS. 7F-1 AND 7F-2.

Sands: Dolomitic No. 1

Cylinders 1 to 10 cured in moist closet seven days, then in refrigerator for one, three, five, seven and nine days, and back in moist closet for remainder of twenty-eight days. Age of concrete, twenty-eight days.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Temperatures read upon entering refrigerator. Average temperature considered as 0° F. Surfaces moist along planes of failure.

*Cylinder No. 6, Table 7F-2, may be slightly lower than actual, due to an error in balancing of machine.

Table 7F-1.

Cyl. No.	Days Frozen	Temp. in (Fahr.)	Temp. out (Fahr.)	Days in M. C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	1	-3	10	19	8,250	2,626	91.4
2	1	-3	10	19	8,300	2,642	92.0
3	3	-3	5	17	9,600	3,056	106.3
4	3	-3	5	17	9,350	2,976	103.5
5	5	-3	1	15	8,550	2,721	94.7
6	5	-3	1	15	8,750	2,785	97.0
7	7	-3	4	13	8,450	2,690	93.6
8	7	-3	4	13	8,350	2,658	92.5
9	9	-3	9	11	9,400	2,992	104.0
10	9	-3	9	11	9,000	2,865	99.7
Check							
11	-	--	--	27	9,250	2,944	-----
12	-	--	--	27	8,800	2,801	-----

Table 7F-2.

Cyl. No.	Days Frozen	Temp. in (Fahr.)	Temp. out (Fahr.)	Days in M. C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	1	5	-3	19	10,750	3,422	92.1
2	1	5	-3	19	10,350	3,295	88.6
3	3	5	-2	17	11,700	3,724	100.2
4	3	5	-2	17	10,900	3,470	93.4
5	5	5	0	15	12,050	3,836	103.2
*6	5	5	0	15	*8,800	*2,801	*75.4
7	7	5	1	13	10,900	3,470	93.4
8	7	5	1	13	10,200	3,246	87.4
9	9	5	1	11	9,600	3,056	82.2
10	9	5	1	11	11,350	3,613	97.3
Check							
11	-	--	--	27	11,250	3,581	-----
12	-	--	--	27	12,100	3,852	-----

TABLES NOS. 10F-1 AND 10F-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured in moist closet ten days, then in refrigerator for one, three, five, seven and nine days, and back in moist closet for the remainder of twenty-eight days. Age of concrete, twenty-eight days.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Temperatures read upon entering refrigerator. Average temperature considered 0° F. Surfaces moist along planes of failure.

Table 10F-1.

Cyl. No.	Days Frozen	Temp. in (Fahr.)	Temp. out (Fahr.)	Days in M. C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	1	-3	10	16	8,800	2,801	112.0
2	1	-3	10	16	9,250	2,944	117.9
3	3	-3	5	14	9,600	3,056	122.2
4	3	-3	5	14	8,000	2,546	101.9
5	5	-3	1	12	8,800	2,801	112.0
6	5	-3	1	12	10,400	3,310	132.5
7	7	-3	4	10	9,800	3,120	124.9
8	7	-3	4	10	9,300	2,960	118.3
9	9	-3	9	8	7,900	2,515	100.5
10	9	-3	9	8	8,200	2,610	104.4
Check							
11	-	--	--	27	7,900	2,515	-----
12	-	--	--	27	7,800	2,483	-----

Table 10F-2.

Cyl. No.	Days Frozen	Temp. in (Fahr.)	Temp. out (Fahr.)	Days in M. C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	1	5	-3	16	9,650	3,072	106.1
2	1	5	-3	16	9,580	3,050	105.4
3	3	5	-2	14	11,700	3,724	128.9
4	3	5	-2	14	9,750	3,104	107.2
5	5	5	0	12	9,170	2,919	101.0
6	5	5	0	12	10,500	3,342	115.5
7	7	5	1	10	10,900	3,470	120.0
8	7	5	1	10	9,520	3,031	104.8
9	9	5	1	8	10,500	3,342	115.5
10	9	5	1	8	8,680	2,763	95.5
Check	9						
11	-	--	--	27	8,880	2,801	-----
12	-	--	--	27	9,300	2,960	-----

TABLES NOS. 14F-1 AND 14F-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured in moist closet fourteen days, then in refrigerator for one, three, five, seven and nine days, and back in moist closet for the remainder of twenty-eight days. Age of concrete, twenty-eight days.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Temperatures read upon entering refrigerator. Average temperature considered as 0° F. Surfaces moist along planes of failure.

Table 14F-1.

: Cyl. No. :	Days Frozen :	Temp. in (Fahr.) :	Temp. out (Fahr.) :	Days in M. C. :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	1 :	-3 :	10 :	12 :	11,100 :	3,533 :	110.3 :
: 2 :	1 :	-3 :	10 :	12 :	10,100 :	3,215 :	100.4 :
: 3 :	3 :	-3 :	5 :	10 :	10,000 :	3,183 :	99.4 :
: 4 :	3 :	-3 :	5 :	10 :	9,100 :	2,896 :	90.5 :
: 5 :	5 :	-3 :	1 :	8 :	9,400 :	2,992 :	93.4 :
: 6 :	5 :	-3 :	1 :	8 :	10,100 :	3,215 :	100.4 :
: 7 :	7 :	-3 :	4 :	6 :	9,000 :	2,865 :	89.5 :
: 8 :	7 :	-3 :	4 :	6 :	10,200 :	3,246 :	101.4 :
: 9 :	9 :	-3 :	9 :	4 :	9,600 :	3,056 :	95.4 :
: 10 :	9 :	-3 :	9 :	4 :	10,300 :	3,279 :	102.3 :
: Check :	:	:	:	:	:	:	:
: 11 :	- :	-- :	-- :	27 :	9,600 :	3,056 :	----- :
: 12 :	- :	-- :	-- :	27 :	10,500 :	3,342 :	----- :

Table 14F-2.

: Cyl. No. :	Days Frozen :	Temp. in (Fahr.) :	Temp. out (Fahr.) :	Days in M. C. :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	1 :	5 :	-3 :	12 :	9,800 :	3,120 :	102.3 :
: 2 :	1 :	5 :	-3 :	12 :	10,150 :	3,231 :	106.0 :
: 3 :	3 :	5 :	-2 :	10 :	9,450 :	3,008 :	98.7 :
: 4 :	3 :	5 :	-2 :	10 :	10,450 :	3,327 :	109.2 :
: 5 :	5 :	5 :	0 :	8 :	9,200 :	2,929 :	96.0 :
: 6 :	5 :	5 :	0 :	8 :	9,400 :	2,992 :	98.2 :
: 7 :	7 :	5 :	1 :	6 :	9,450 :	3,008 :	98.7 :
: 8 :	7 :	5 :	1 :	6 :	9,350 :	2,976 :	97.6 :
: 9 :	9 :	5 :	1 :	4 :	8,350 :	2,658 :	87.2 :
: 10 :	9 :	5 :	1 :	4 :	8,700 :	2,769 :	90.9 :
: Check :	:	:	:	:	:	:	:
: 11 :	- :	---	-- :	27 :	8,900 :	2,833 :	----- :
: 12 :	- :	---	-- :	27 :	10,250 :	3,263 :	----- :

Group	Unit Stress in lbs. per square inch	Per cent of 23 day strength									
Number	Number of Days Frozen	1	3	5	7	9	1	3	5	7	9
1F	2797	2742	3040	3028	2949	2949	89.6	87.8	97.2	97.0	94.2
3F	3040	2976	3040	2897	2901	2901	113.0	112.6	116.4	110.0	108.5
5F	2833	3000	2909	3175	3028	3028	90.9	95.7	91.4	98.3	97.1
7F	2996	3307	3114	3015	3132	3132	91.0	100.9	92.6	91.7	95.8
10F	2967	3108	3093	3145	2807	2807	110.4	115.1	117.0	117.0	104.0
14F	3275	3103	3032	3024	2941	2941	104.8	99.5	97.0	96.8	94.0
F.M.C.	2841	2944	2785	2849	2782	2782	84.6	87.5	83.3	84.7	83.1
M.C.F.	1806	1945	2213	2523	2921	2921	36.6	59.0	68.1	77.4	89.5

SUMMARY TABLE NO. 1

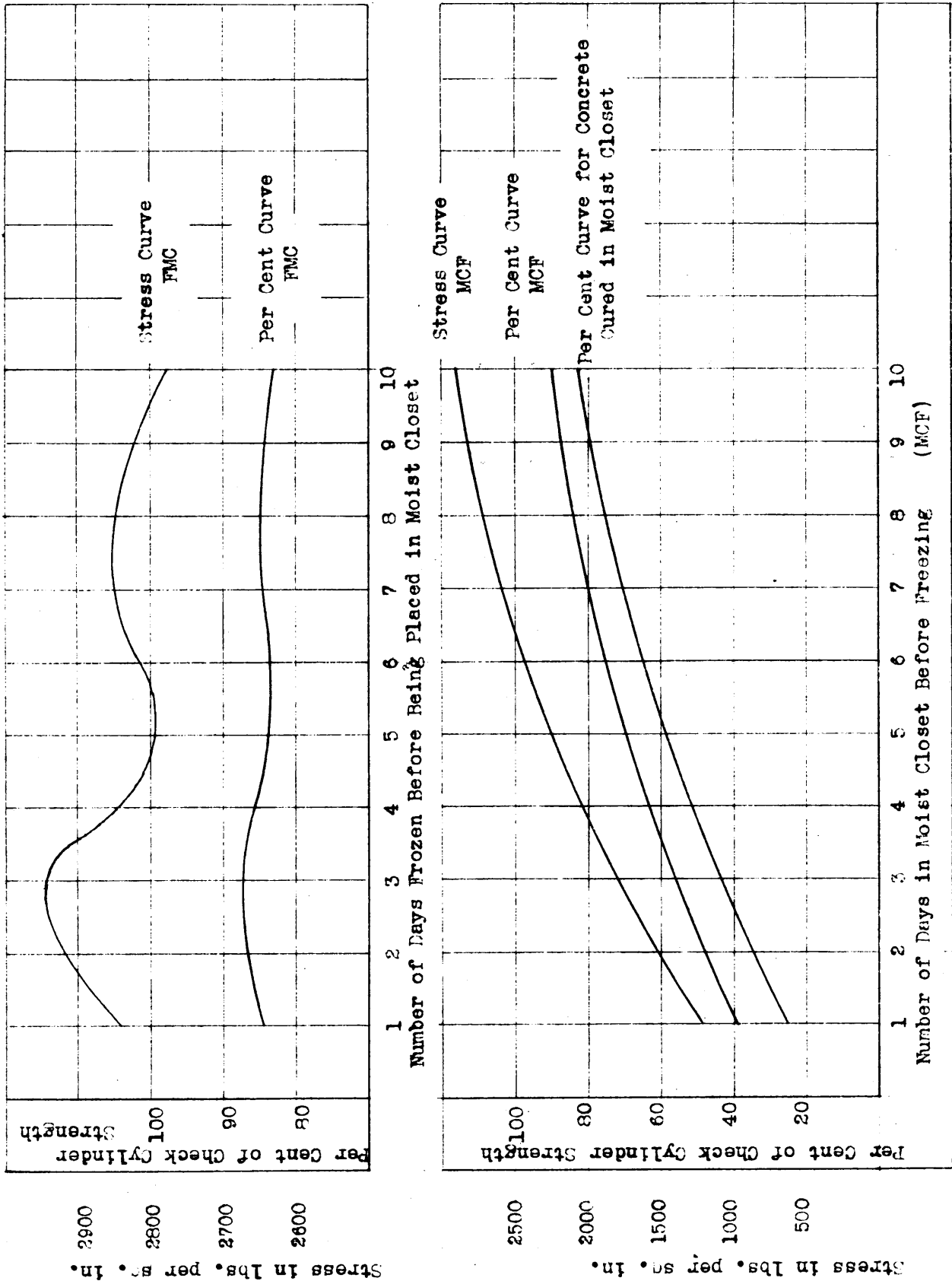
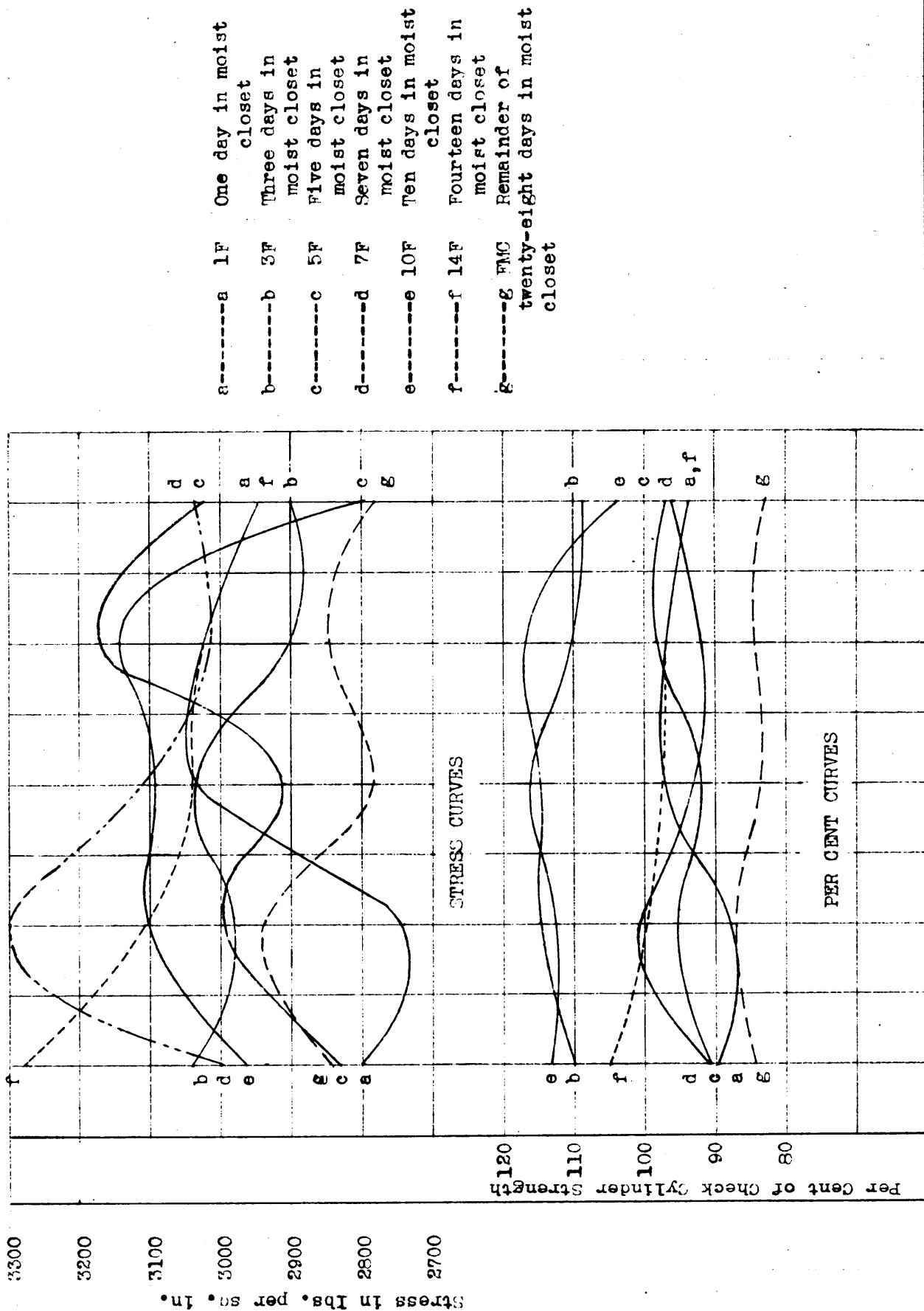


Fig. 5.



Number of Days Frozen After Removal From Moist Closet

FIG. 6.

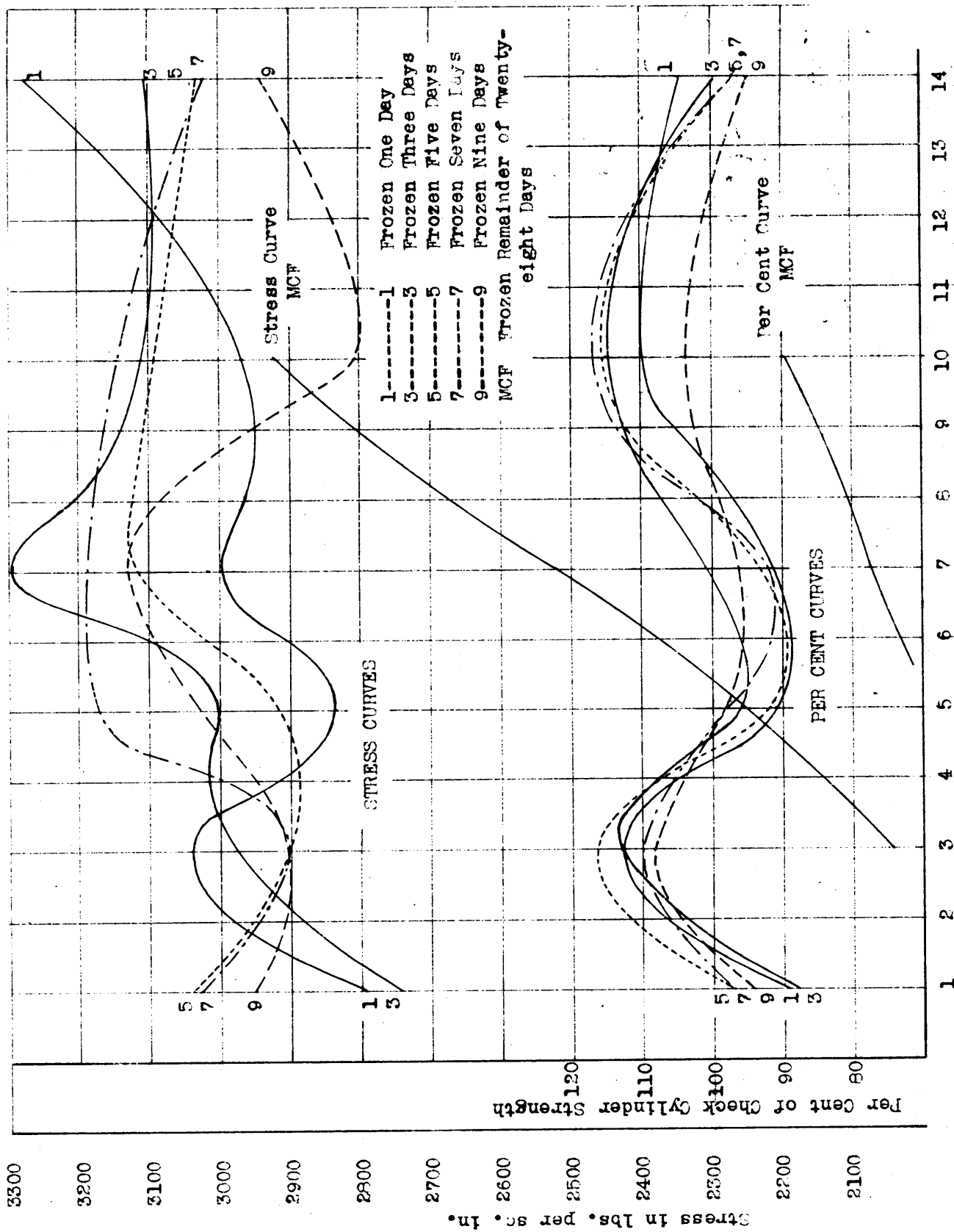


FIG. 7.

Discussion of Problem I

Group FMC

The following results were observed for those cylinders frozen for one, three, five, seven, and ten days after pouring, and cured for the remainder of twenty-eight days in a moist closet.

It was noted (Fig. 5) that concrete, frozen for three days, exhibited the greatest unit compressive stress. It had a strength equal to 87.5 per cent of the check cylinder strength and a unit stress of 2,944 pounds per square inch. The concrete, frozen for ten days, exhibited the least strength of the group. Although it was frozen for that length of time, it recovered sufficiently to attain a strength of 83.1 per cent of check cylinder strength and had a unit stress of 2782 pounds per square inch. The concrete, frozen for five days, attained 83.8 per cent of check cylinder strength and was not much stronger than the concrete frozen for ten days. The concrete, frozen for only one day, exhibited 84.6 per cent of check cylinder strength and that, frozen for seven days, 84.7 per cent normal strength.

From the above results it appears that the freezing of concrete, immediately after pouring, has a considerable effect on the strength of the concrete, but whether it be one or ten days makes little difference. The curves do show an apparent decrease in strength, going from one to ten days, but the difference is so slight that it is considered negligible in this case. If concrete is given sufficient time to recover, after it has been frozen, it will approach the strength of concrete cured under normal conditions.

Group MCF

The following results were observed for those concrete cylinders, which, after one, three, five, seven and ten days of curing in a moist closet, were frozen for the remainder of twenty-eight days.

It was noted (Fig. 5) that the concrete allowed to set for only one day in the moist closet before being frozen attained a compressive strength of 1206 pounds per square inch or 39 per cent of the check cylinder strength. The concrete, given ten days in the moist closet, came within 89.5 per cent of the check cylinder strength and averaged 2921 pounds per square inch. The others averaged 59.0 per cent for three days in moist closet, 68.1 per cent for five days in moist closet, and 77.4 per cent for seven days in moist closet.

From the above results it is very clear that freezing of concrete for any great length of time within eleven days after pouring has a noticeable effect upon the strength of the concrete. Although the temperature was kept as low as zero degrees Fahrenheit, the curves show that the concrete continued to gain strength while in the frozen state. For comparative purposes, concrete cylinders were cured in moist closet for periods varying from two to eleven days and then tested. The results of these tests are shown in Fig. 5. From the curves plotted (Fig. 5), it may be observed that the strength of the frozen concrete at twenty-eight days is greater than that of the concrete cured in the moist closet, having an age at time of testing corresponding to the age of the concrete at time of freezing. If both these strengths were equal it would indicate that curing ceases as soon as the concrete is frozen. But such

is not the case, and the frozen concrete shows a gain in strength from 14.5 per cent of check cylinder strength at one day frozen to 8.0 per cent of check cylinder strength at ten days frozen. The curves also show that the concrete allowed to cure only one day in moist closet before being frozen gained the equivalent of two and one-half days of curing in moist closet, and that the concrete allowed to cure seven days in moist closet before being frozen gained the equivalent of two days of curing in moist closet. All of which goes to substantiate the fact that concrete is not inert when in the frozen state.

Groups 1F, 3F, 5F, 7F, 10F and 14F

The following results were observed for those concrete cylinders, which, after one, three, five, seven, ten and fourteen days of curing in moist closet were frozen for one, three, five, seven, and nine days and then cured for the remainder of twenty-eight days in the moist closet.

Concrete frozen for one to nine days after curing three and ten days in moist closet seemed to have the greatest strength, as indicated by its per cent of check cylinder strength (Fig. 6). The strength was above 100 per cent in all cases, and after seven days of freezing for the concrete nine days in moist closet, it reached a peak of 117 per cent. The concrete cured in the moist closet for one, five, seven, and fourteen days before freezing had, with the exception of two cases, strengths below those of the check cylinders; the exceptions being the concrete seven and fourteen days in the moist closet and frozen three and one days respectively.

In a comparison of actual twenty-eight day compressive strengths, in pounds per square inch, it was observed (Fig. 6) that concrete frozen one day gave greatest strength when allowed to cure fourteen days in moist closet before freezing and had the least strength when allowed to cure only one day in moist closet before freezing. Again our attention is drawn to the fact that concrete frozen for a short period of time, very soon after pouring, loses more of its strength than does concrete frozen for the same period, but not as soon after being poured. When three days frozen, concrete cured seven days in moist closet has jumped from third place; when frozen one day, to first place, and the concrete fourteen days in moist closet has dropped to third. Concrete cured one day in moist closet is still on the bottom, having dropped a little lower than before. At five days frozen, the strength curves come together and range between 2900 pounds per square inch and 3100 pounds per square inch. At seven days frozen, the curves again diverge and concrete cured five days in moist closet gives maximum strength and the concrete cured three days in moist closet, minimum strength. At ten days frozen, concrete seven days in moist closet gives maximum strength and concrete ten days in moist closet gives minimum strength.

Considering the per cent of check cylinder strength, it is noted (Fig. 6) that the curves for the three and ten days in moist closet are well above the others and the per cent well exceeds one hundred. This condition may better be seen in the curves shown in Figure 7 where it manifests itself into the peaks shown thereon. This does not necessarily mean that these groups give the maximum strengths. It is very possible

that the check cylinders, due to the inconsistency of concrete, indicated strengths below their true values. Turning attention back to Figure 7, it will be noted that the valleys in the percentage curves occur at the points, five and seven days in the moist closet, but, going up to the curves of actual strength in pounds per square inch, the seven-day point represents a peak for all the curves. The apparent inconsistency is due to the fact that the actual strength of the concrete was very high for seven days in moist closet, but the strength of the check cylinders was still higher.

Curves for the strength of concrete cured are three, five, seven and ten days in moist closet and, frozen for the remainder of twenty-eight days, are also shown in Figure 6 and Figure 7. Curves (Fig. 7) indicate that the strength of the concrete frozen up until the day of testing varied directly with the number of days in moist closet before freezing and inversely with the number of days frozen. The concrete that was given time to recover, approached, and in some cases exceeded normal check cylinder strength. The curves also indicate that the strength of this concrete has a tendency to vary directly with the number of days frozen. Such is the case even after fourteen days of curing in moist closet prior to being frozen.

Conclusions - Problem I

For Portland Cement Concrete using Dolomitic Limestone Sand as the fine aggregate the following may be concluded:

1. The length of time concrete is frozen has a definite effect on the ultimate strength of the concrete.
2. The freezing and thawing of fresh concrete does not have a very serious effect on the ultimate strength of the concrete.
3. The freezing of concrete immediately after pouring has a greater detrimental effect on the twenty-eight day ultimate strength of the concrete than has the freezing of the concrete for the same period, but not quite as soon after pouring.
4. Frozen concrete continues to gain strength even at a temperature as low as zero degrees Fahrenheit.
5. The twenty-eight day strength of concrete is noticeably affected by freezing even after fourteen days of normal curing.
6. Frozen concrete, if given a chance to recover, will attain a strength equivalent to the ultimate strength of concrete cured under normal conditions, in a time equivalent to or less than the time in the frozen state.

2. Problem II

TABLES NOS. 65^o-1, 65^o-2, 65^o-3 AND 65^o-4.

Sand: Dolomitic No. 1 (Tables 65^o-1, 65^o-2 and 65^o-4.)

Dolomitic No. 2 (Table 65^o-3.)

Cylinders (1 to 10) cured at 65^o C. for one to five days and tested.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces powdery along plane of failure.

*Cylinders Nos. 7 and 8 (Table 65^o-2) were left exposed in laboratory for twelve hours after having been capped.

**Due to a shortage in concrete, cylinder No. 10 (Table 65^o-1) was only 2 $\frac{1}{8}$ inches high instead of the required height of 4 inches and must, therefore be voided.

***Cylinders Nos. 7, 9 and 10 fell from oven and were slightly chipped, but showed no apparent weakness.

Table 65^o-1.

Cyl. No.	Age (days)	Days at 65 ^o C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	2	1	4,240	1,350	49.5
2	2	1	4,130	1,315	48.1
3	3	2	4,710	1,499	55.0
4	3	2	3,380	1,063	39.4
5	4	3	3,860	1,229	45.0
6	4	3	4,460	1,415	52.0
7	5	4	3,920	1,248	45.7
8	5	4	4,650	1,480	54.2
9	6	5	4,150	1,321	48.4
**10	6	5	3,580	1,140	41.7
Check					
11	28	-	8,800	2,801	----
12	28	-	8,360	2,661	----

Table 65^o-2.

Cyl. No.	Age (days)	Days at 65 ^o C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	2	1	3,390	1,079	37.0
2	2	1	3,000	955	32.8
3	3	2	3,400	1,082	37.2
4	3	2	2,880	917	31.3
5	4	3	2,840	904	31.0
6	4	3	4,130	1,315	45.2
*7	5	4	2,450	780	26.8
*8	5	4	3,370	1,073	36.8
9	6	5	3,310	1,054	36.1
10	6	5	2,450	780	26.8
Check					
11	28	-	8,960	2,852	----
12	28	-	9,350	2,976	----

Table 65°-3.

: Cyl. No. :	: Age (days) :	: Days at 65° C. :	: Load Pounds :	: Stress lbs. per sq. in. :	: Per cent of 28 day strength :
: 1 :	: 2 :	: 1 :	: 4,250 :	: 1,353 :	: 35.6 :
: 2 :	: 2 :	: 1 :	: 4,620 :	: 1,471 :	: 36.5 :
: 3 :	: 3 :	: 2 :	: 3,920 :	: 1,184 :	: 29.4 :
: 4 :	: 3 :	: 2 :	: 5,020 :	: 1,598 :	: 39.7 :
: 5 :	: 4 :	: 3 :	: 3,920 :	: 1,248 :	: 31.0 :
: 6 :	: 4 :	: 3 :	: 4,160 :	: 1,324 :	: 32.9 :
: 7 :	: 5 :	: 4 :	: 4,840 :	: 1,541 :	: 38.2 :
: 8 :	: 5 :	: 4 :	: 5,050 :	: 1,608 :	: 39.9 :
: 9 :	: 6 :	: 5 :	: 5,970 :	: 1,900 :	: 47.2 :
: 10 :	: 6 :	: 5 :	: 5,860 :	: 1,865 :	: 46.4 :
: Check :	:	:	:	:	:
: 11 :	: 28 :	: -- :	: 13,500 :	: 4,298 :	: ---- :
: 12 :	: 28 :	: -- :	: 11,800 :	: 3,756 :	: ---- :

Table 65°-4.

: Cyl. No. :	: Age (days) :	: Days at 65° C. :	: Load Pounds :	: Stress lbs. per sq. in. :	: Per cent of 28 day strength :
: 1 :	: 2 :	: 1 :	: 4,180 :	: 1,330 :	: 45.1 :
: 2 :	: 2 :	: 1 :	: 4,480 :	: 1,420 :	: 48.0 :
: 3 :	: 3 :	: 2 :	: 4,250 :	: 1,353 :	: 45.8 :
: 4 :	: 3 :	: 2 :	: 4,000 :	: 1,273 :	: 43.1 :
: 5 :	: 4 :	: 3 :	: 3,880 :	: 1,235 :	: 41.8 :
: 6 :	: 4 :	: 3 :	: 4,170 :	: 1,327 :	: 45.0 :
: ***7 :	: 5 :	: 4 :	: 3,510 :	: 1,117 :	: 37.8 :
: 8 :	: 5 :	: 4 :	: 4,080 :	: 1,280 :	: 43.4 :
: ***9 :	: 6 :	: 5 :	: 4,070 :	: 1,295 :	: 43.9 :
: ***10 :	: 6 :	: 5 :	: 3,190 :	: 1,015 :	: 34.4 :
: Check :	:	:	:	:	:
: 11 :	: 28 :	: - :	: 9,000 :	: 2,865 :	: ---- :
: 12 :	: 28 :	: - :	: 9,550 :	: 3,040 :	: ---- :

TABLES NOS. 65°1W-1 AND 65°1W-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured at 65° C. for one day and then placed in water for one, two, three, four and twenty-six days. Tested upon removal from water.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces wet along planes of failure.

Table 65°1W-1.

: Cyl. No. :	: Age (days) :	: Days in Water :	: Load Pounds :	: Stress lbs. per sq. in. :	: Per cent of 28 day strength :
: 1 :	: 3 :	: 1 :	: 4,800 :	: 1,528 :	: 41.4 :
: 2 :	: 3 :	: 1 :	: 4,250 :	: 1,353 :	: 36.6 :
: 3 :	: 4 :	: 2 :	: 5,320 :	: 1,693 :	: 45.8 :
: 4 :	: 4 :	: 2 :	: 5,620 :	: 1,789 :	: 48.5 :
: 5 :	: 5 :	: 3 :	: 6,600 :	: 2,101 :	: 56.9 :
: 6 :	: 5 :	: 3 :	: 5,660 :	: 1,770 :	: 48.0 :
: 7 :	: 6 :	: 4 :	: 6,690 :	: 2,129 :	: 57.6 :
: 8 :	: 6 :	: 4 :	: 5,170 :	: 1,646 :	: 44.5 :
: 9 :	: 28 :	: 26 :	: 8,800 :	: 2,801 :	: 75.9 :
: 10 :	: 28 :	: 26 :	: 9,400 :	: 2,992 :	: 81.0 :
: Check :	:	:	:	:	:
: 11 :	: 28 :	: -- :	: 11,800 :	: 3,756 :	: ---- :
: 12 :	: 28 :	: -- :	: 11,400 :	: 3,629 :	: ---- :

Table 65°1W-2.

: Cyl. No. :	: Age (days) :	: Days in Water :	: Load Pounds :	: Stress lbs. per sq. in. :	: Per cent of 28 day strength :
: 1 :	: 3 :	: 1 :	: 5,080 :	: 1,598 :	: 48.7 :
: 2 :	: 3 :	: 1 :	: 4,490 :	: 1,429 :	: 43.5 :
: 3 :	: 4 :	: 2 :	: 5,340 :	: 1,700 :	: 51.3 :
: 4 :	: 4 :	: 2 :	: 5,190 :	: 1,652 :	: 50.4 :
: 5 :	: 5 :	: 3 :	: 6,300 :	: 2,005 :	: 61.1 :
: 6 :	: 5 :	: 3 :	: 5,980 :	: 1,904 :	: 58.0 :
: 7 :	: 6 :	: 4 :	: 5,950 :	: 1,894 :	: 57.7 :
: 8 :	: 6 :	: 4 :	: 6,260 :	: 1,993 :	: 60.7 :
: 9 :	: 28 :	: 26 :	: 9,300 :	: 2,960 :	: 90.2 :
: 10 :	: 28 :	: 26 :	: 10,180 :	: 3,231 :	: 98.5 :
: Check :	:	:	:	:	:
: 11 :	: 28 :	: -- :	: 9,900 :	: 3,152 :	: ---- :
: 12 :	: 28 :	: -- :	: 10,700 :	: 3,406 :	: ---- :

TABLES NOS. 65°2W-1 AND 65°2W-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured at 65° C. for two days and then placed in water for one, two, three, four and twenty-five days. Tested upon removal from water.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces wet along planes of failure.

Table 65°2W-1.

Cyl. No.	Age (days)	Days in Water	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	4	1	5,150	1,639	50.6
2	4	1	4,620	1,471	45.4
3	5	2	6,140	1,954	60.4
4	5	2	5,060	1,611	49.7
5	6	3	6,190	1,970	60.8
6	6	3	5,180	1,649	50.9
7	7	4	5,660	1,802	55.6
8	7	4	5,860	1,865	57.6
9	28	25	7,800	2,483	76.7
10	28	25	8,800	2,801	86.5
Check					
11	28	28	10,650	3,390	----
12	28	28	9,700	3,088	----

Table 65°2W-2.

Cyl. No.	Age (days)	Days in Water	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	4	1	4,730	1,506	43.4
2	4	1	4,060	1,292	37.2
3	5	2	5,260	1,674	48.3
4	5	2	4,990	1,568	45.8
5	6	3	5,520	1,757	50.6
6	6	3	5,490	1,748	50.4
7	7	4	6,230	1,983	57.1
8	7	4	6,680	2,127	61.3
9	28	25	9,050	2,881	83.0
10	28	25	8,700	2,770	79.8
Check					
11	28	--	10,400	3,311	----
12	28	--	11,400	2,629	----

TABLES NOS. 65°3W-1, 65°3W-2, AND 65°3W-3.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured at 65° C. for three days and then placed in water for one, two, three, four and twenty-four days. Tested upon removal from water.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces wet along planes of failure.

Table 65°3W-1.

: Cyl. No. :	: Age (days) :	: Days in Water :	: Load Pounds :	: Stress lbs. per sq. in. :	: Per cent of 28 day strength :
: 1 :	: 5 :	: 1 :	: 4,280 :	: 1,362 :	: 49.8 :
: 2 :	: 5 :	: 1 :	: 4,770 :	: 1,518 :	: 55.5 :
: 3 :	: 6 :	: 2 :	: 5,510 :	: 1,754 :	: 64.2 :
: 4 :	: 6 :	: 2 :	: 4,850 :	: 1,544 :	: 56.4 :
: 5 :	: 7 :	: 3 :	: 5,920 :	: 1,884 :	: 68.9 :
: 6 :	: 7 :	: 3 :	: 5,400 :	: 1,719 :	: 62.8 :
: 7 :	: 8 :	: 4 :	: 6,470 :	: 2,060 :	: 75.2 :
: 8 :	: 8 :	: 4 :	: 6,380 :	: 2,031 :	: 74.2 :
: 9 :	: 28 :	: 24 :	: 10,500 :	: 3,342 :	: 122.0 :
: 10 :	: 28 :	: 24 :	: 9,350 :	: 2,976 :	: 108.7 :
: Check :	:	:	:	:	:
: 11 :	: 28 :	: -- :	: 8,800 :	: 2,801 :	: ----- :
: 12 :	: 28 :	: -- :	: 8,400 :	: 2,674 :	: ----- :

Table 65°3W-2.

: Cyl. No. :	: Age (days) :	: Days in Water :	: Load Pounds :	: Stress lbs. per sq. in. :	: Per cent of 28 day strength :
: 1 :	: 5 :	: 1 :	: 4,250 :	: 1,353 :	: 42.2 :
: 2 :	: 5 :	: 1 :	: 3,890 :	: 1,238 :	: 38.6 :
: 3 :	: 6 :	: 2 :	: 4,630 :	: 1,474 :	: 46.0 :
: 4 :	: 6 :	: 2 :	: 4,560 :	: 1,452 :	: 45.3 :
: 5 :	: 7 :	: 3 :	: 5,070 :	: 1,614 :	: 50.3 :
: 6 :	: 7 :	: 3 :	: 6,250 :	: 1,990 :	: 62.0 :
: 7 :	: 8 :	: 4 :	: 5,300 :	: 1,687 :	: 52.6 :
: 8 :	: 8 :	: 4 :	: 5,860 :	: 1,865 :	: 58.2 :
: 9 :	: 28 :	: 24 :	: 9,350 :	: 2,976 :	: 92.8 :
: 10 :	: 28 :	: 24 :	: 8,150 :	: 2,594 :	: 80.9 :
: Check :	:	:	:	:	:
: 11 :	: 28 :	: -- :	: 10,850 :	: 3,454 :	: ----- :
: 12 :	: 28 :	: -- :	: 9,300 :	: 2,960 :	: ----- :

Table 65°3W-3.

: Cyl. :	Age :	Days :	Load :	Stress :	Per cent of :
: No. :	(days) :	in :	Pounds :	lbs. per :	28 day :
:	:	Water :	:	sq. in. :	strength :
: 1 :	5 :	1 :	3,910 :	1,245 :	41.9 :
: 2 :	5 :	1 :	4,050 :	1,289 :	43.4 :
: 3 :	6 :	2 :	5,000 :	1,592 :	53.6 :
: 4 :	6 :	2 :	5,000 :	1,592 :	53.6 :
: 5 :	7 :	3 :	5,290 :	1,684 :	56.7 :
: 6 :	7 :	3 :	5,640 :	1,795 :	60.5 :
: 7 :	8 :	4 :	5,540 :	1,764 :	59.4 :
: 8 :	8 :	4 :	5,440 :	1,732 :	58.3 :
: 9 :	28 :	24 :	8,500 :	2,706 :	91.0 :
: 10 :	28 :	24 :	8,700 :	2,769 :	93.2 :
: Check :	:	:	:	:	:
: 11 :	28 :	-- :	9,850 :	3,135 :	---- :
: 12 :	28 :	-- :	8,800 :	2,801 :	---- :

TABLES NOS. 65°1WO-1 AND 65°1WO-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured at 65° C. for one day, then placed in water for one, two, and three days and back in oven for one and two days. Tested upon removal from oven second time.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces dry along planes of failure.

Table 65°1W0-1.

: Cyl. No. :	Age (days) :	Days in Water :	Days at 65° C. :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	4 :	1 :	1 :	6,000 :	1,910 :	70.6 :
: 2 :	4 :	1 :	1 :	6,030 :	1,919 :	70.9 :
: 3 :	5 :	2 :	1 :	7,220 :	2,298 :	85.0 :
: 4 :	5 :	2 :	1 :	6,760 :	2,152 :	79.5 :
: 5 :	6 :	3 :	1 :	6,400 :	2,037 :	75.3 :
: 6 :	6 :	3 :	1 :	7,120 :	2,266 :	83.7 :
: 7 :	6 :	2 :	2 :	5,910 :	1,881 :	69.5 :
: 8 :	6 :	2 :	2 :	6,970 :	2,219 :	82.0 :
: 9 :	7 :	3 :	2 :	6,490 :	2,066 :	76.4 :
: 10 :	7 :	3 :	2 :	7,840 :	2,496 :	92.2 :
: Check :	:	:	:	:	:	:
: 11 :	28 :	- :	- :	8,500 :	2,706 :	---- :
: 12 :	28 :	- :	- :	8,500 :	2,706 :	---- :

Table 65°1W0-2.

: Cyl. No. :	Age (days) :	Days in Water :	Days at 65° C. :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	4 :	1 :	1 :	6,480 :	2,063 :	74.1 :
: 2 :	4 :	1 :	1 :	5,770 :	1,837 :	65.0 :
: 3 :	5 :	2 :	1 :	6,960 :	2,215 :	78.5 :
: 4 :	5 :	2 :	1 :	6,300 :	2,005 :	71.0 :
: 5 :	6 :	3 :	1 :	6,720 :	2,139 :	75.8 :
: 6 :	6 :	3 :	1 :	7,930 :	2,524 :	89.4 :
: 7 :	6 :	2 :	2 :	8,370 :	2,664 :	94.4 :
: 8 :	6 :	2 :	2 :	8,380 :	2,668 :	94.5 :
: 9 :	7 :	3 :	2 :	7,740 :	2,464 :	87.3 :
: 10 :	7 :	3 :	2 :	8,320 :	2,649 :	93.8 :
: Check :	:	:	:	:	:	:
: 11 :	28 :	- :	- :	8,000 :	2,547 :	---- :
: 12 :	28 :	- :	- :	9,750 :	3,104 :	---- :

TABLES NOS. 65°2WO-1 AND 65°2WO-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured at 65° C. for two days, then placed in water for one, two and three days, and back in oven for one and two days. Tested upon removal from oven second time.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces dry along planes of failure.

Table 65° 2W0-1.

Cyl. No.	Age (days)	Days in Water	Days at 65° C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	5	1	1	5,140	1,636	58.9
2	5	1	1	5,620	1,789	64.4
3	6	2	1	6,100	1,942	69.9
4	6	2	1	6,480	2,063	74.3
5	7	3	1	7,220	2,298	82.7
6	7	3	1	7,040	2,241	80.6
7	7	2	2	6,090	1,939	69.9
8	7	2	2	6,270	1,996	71.9
9	8	3	2	6,600	2,101	75.6
10	8	3	2	7,600	2,419	87.1
Check						
11	28	-	-	8,750	2,785	----
12	28	-	-	8,700	2,769	----

Table 65° 2W0-2.

Cyl. No.	Age (days)	Days in Water	Days at 65° C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	5	1	1	6,440	2,050	66.9
2	5	1	1	6,190	1,970	64.3
3	6	2	1	6,930	2,206	72.0
4	6	2	1	7,870	2,505	81.8
5	7	3	1	7,570	2,410	78.7
6	7	3	1	7,000	2,228	72.7
7	7	2	2	7,480	2,381	77.7
8	7	2	2	7,420	2,362	77.1
9	8	3	2	8,240	2,623	85.5
10	8	3	2	7,080	2,254	73.5
Check						
11	28	-	-	10,800	3,438	----
12	28	-	-	8,450	2,690	----

TABLES NOS. 65°3W0-1 AND 65°3W0-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured at 65° C. for three days, then placed in water for one, two and three days and back in oven for one and two days. Tested upon removal from oven second time.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces dry along planes of failure.

Table 65°3W0-1.

Cyl. No.	Age (days)	Days in Water	Days at 65° C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	6	1	1	5,620	1,789	70.3
2	6	1	1	6,440	2,050	80.5
3	7	2	1	7,700	2,451	96.3
4	7	2	1	7,510	2,391	94.0
5	8	3	1	7,530	2,397	94.1
6	8	3	1	6,510	2,009	79.0
7	8	2	2	6,600	2,101	82.5
8	8	2	2	7,220	2,298	90.3
9	9	3	2	7,590	2,352	92.4
10	9	3	2	7,470	2,378	93.4
Check						
11	28	-	-	7,650	2,435	-----
12	28	-	-	8,350	2,658	-----

Table 65°3W0-2.

Cyl. No.	Age (days)	Days in Water	Days at 65° C.	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	6	1	1	6,190	1,970	60.5
2	6	1	1	7,410	2,359	72.4
3	7	2	1	6,440	2,050	62.8
4	7	2	1	7,130	2,270	69.6
5	8	3	1	8,050	2,562	78.5
6	8	3	1	7,510	2,327	71.4
7	8	2	2	8,100	2,578	79.1
8	8	2	2	7,500	2,388	73.2
9	9	3	2	8,360	2,661	81.7
10	9	3	2	8,870	2,824	86.6
Check						
11	28	-	-	10,200	3,247	-----
12	28	-	-	10,250	3,263	-----

TABLES NOS. 65°1WOW-1 AND 65°1WOW-2.

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured at 65° C. for one day, placed in water for one, two and three days, then in over for one and two days and back in water for one and two days. Tested upon removal from water the second time.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces wet along planes of failure.

*Values for cylinder No. 4 (Table 65°1WOW-2) to be voided due to an error in reading load.

Table 65°1WOW-1.

: Cyl. No. :	Age (days) :	Days in Water :	Days at 65° C. :	Days in Water :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	5 :	1 :	1 :	1 :	5,640 :	1,795 :	68.1 :
: 2 :	5 :	1 :	1 :	1 :	6,460 :	2,056 :	78.0 :
: 3 :	6 :	2 :	1 :	1 :	5,720 :	1,821 :	69.2 :
: 4 :	6 :	2 :	1 :	1 :	6,010 :	1,913 :	72.6 :
: 5 :	7 :	3 :	1 :	1 :	7,340 :	2,336 :	88.6 :
: 6 :	7 :	3 :	1 :	1 :	6,370 :	2,028 :	77.0 :
: 7 :	8 :	2 :	2 :	2 :	5,400 :	1,719 :	65.3 :
: 8 :	8 :	2 :	2 :	2 :	5,820 :	1,853 :	70.4 :
: 9 :	9 :	3 :	2 :	2 :	7,020 :	2,235 :	84.8 :
: 10 :	9 :	3 :	2 :	2 :	6,910 :	2,200 :	83.5 :
: Check :	:	:	:	:	:	:	:
: 11 :	28 :	- :	- :	- :	7,950 :	2,531 :	---- :
: 12 :	28 :	- :	- :	- :	8,600 :	2,730 :	---- :

Table 65°1WOW-2.

: Cyl. No. :	Age (days) :	Days in Water :	Days at 65° C. :	Days in Water :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	5 :	1 :	1 :	1 :	5,640 :	1,795 :	63.7 :
: 2 :	5 :	1 :	1 :	1 :	6,130 :	1,951 :	69.4 :
: 3 :	6 :	2 :	1 :	1 :	6,750 :	2,149 :	76.3 :
: *4 :	6 :	2 :	1 :	1 :	5,400 :	1,719 :	61.0 :
: 5 :	7 :	3 :	1 :	1 :	6,940 :	2,209 :	78.4 :
: 6 :	7 :	3 :	1 :	1 :	7,330 :	2,333 :	82.9 :
: 7 :	8 :	2 :	2 :	2 :	8,010 :	2,550 :	90.0 :
: 8 :	8 :	2 :	2 :	2 :	7,290 :	2,320 :	82.4 :
: 9 :	9 :	3 :	2 :	2 :	6,230 :	1,983 :	70.5 :
: 10 :	9 :	3 :	2 :	2 :	8,080 :	2,572 :	91.4 :
: Check :	:	:	:	:	:	:	:
: 11 :	28 :	- :	- :	- :	8,600 :	2,738 :	---- :
: 12 :	28 :	- :	- :	- :	8,700 :	2,769 :	---- :

TABLES NOS. 65°2WOW-1 AND 65°2WOW-2

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured at 65° C. for two days, placed in water for one, two and three days, then in oven (65° C.) for one and two days and back in water for one, two and three days (Table 65°2WOW-1) and one and two days (Table 65°2WOW-2. Tested upon removal from water the second time.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces wet along planes of failure.

*Machine came down too fast on cylinder No. 11 (Table 65°2WOW-1) and as a result no reading of load could be taken.

Table 65° 2WOW-1.

Cyl. No.	Age (days)	Days in Water	Days at 65° C.	Days in Water	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	6	1	1	1	6,110	1,945	71.9
2	6	1	1	1	5,260	1,674	61.9
3	7	2	1	1	6,090	1,939	71.6
4	7	2	1	1	7,110	2,263	83.7
5	8	3	1	1	6,610	2,104	77.9
6	8	3	1	1	6,210	1,977	73.1
7	9	2	2	2	7,360	2,343	86.6
8	9	2	2	2	6,390	2,034	75.2
9	11	3	2	3	7,110	2,263	83.7
10	11	3	2	3	6,980	2,222	82.2
Check							
*11	28	-	-	-	-----	-----	-----
12	28	-	-	-	8,500	2,706	-----

Table 65° 2WOW-2.

Cyl. No.	Age (days)	Days in Water	Days at 65° C.	Days in Water	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	6	1	1	1	6,860	2,184	59.9
2	6	1	1	1	6,250	1,990	54.5
3	7	2	1	1	6,610	2,104	57.7
4	7	2	1	1	6,580	2,095	57.4
5	8	3	1	1	6,600	2,101	57.6
6	8	3	1	1	8,590	2,735	75.0
7	9	2	2	2	6,390	2,034	55.8
8	9	2	2	2	7,890	2,512	68.8
9	10	3	2	2	7,400	2,356	64.6
10	10	3	2	2	7,800	2,483	68.1
Check							
11	28	-	-	-	10,700	3,406	-----
12	28	-	-	-	12,200	3,884	-----

TABLES NOS. 65°3WOW-1 AND 65°3WOW-2

Sand: Dolomitic No. 2 (Table 65°3WOW-1)

Dolomitic No. 1 (Table 65°3WOW-2)

Cylinders 1 to 10 cured at 65° C. for three days, placed in water for one, two and three days, then in oven (65° C.) for one and two days, and back in water for one, two and three days. Tested upon removal from water the second time.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces wet along planes of failure.

Table 65°3WOW-1.

Cyl. No.	Age (days)	Days in Water	Days at 65° C.	Days in Water	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	7	1	1	1	5,190	1,652	56.0
2	7	1	1	1	5,230	1,665	56.4
3	8	2	1	1	5,380	1,713	58.0
4	8	2	1	1	5,870	1,869	63.5
5	9	3	1	1	6,020	1,916	65.0
6	9	3	1	1	6,370	2,028	68.7
7	10	2	2	2	5,970	1,900	64.4
8	10	2	2	2	5,870	1,869	63.5
9	11	3	2	2	5,940	1,891	64.0
10	11	3	2	2	6,390	2,034	68.9
Check							
11	28	-	-	-	9,000	2,865	----
12	28	-	-	-	9,550	3,040	----

Table 65°3WOW-2.

Cyl. No.	Age (days)	Days in Water	Days at 65° C.	Days in Water	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	7	1	1	1	5,480	1,744	56.8
2	7	1	1	1	5,560	1,770	57.7
3	8	2	1	1	6,980	2,222	72.4
4	8	2	1	1	6,720	2,139	69.7
5	9	3	1	1	7,150	2,276	74.1
6	9	3	1	1	7,720	2,457	80.1
7	10	2	2	2	6,950	2,212	72.0
8	10	2	2	2	7,130	2,270	74.0
9	12	3	2	3	7,000	2,228	72.6
10	12	3	2	3	6,550	2,085	67.9
Check							
11	28	-	-	-	9,750	3,104	----
12	28	-	-	-	9,550	3,040	----

TABLES NOS. 65° WMC-1 AND 65° WMC-2

Sand: Dolomitic No. 2

Cylinders 1 to 10 cured at 65° C. for one, two and three days, then in water for one and two days, and in moist closet for the remainder of twenty-eight days. Age of concrete, twenty-eight days.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces damp along planes of failure.

TABLE 65°WMC-1.

: Cyl. No. :	Days at 65° C. :	Days in Water :	Days in M. C. :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	1 :	1 :	25 :	9,800 :	3,120 :	94.2 :
: 2 :	1 :	1 :	25 :	9,700 :	3,088 :	93.2 :
: 3 :	2 :	1 :	24 :	8,850 :	2,817 :	85.1 :
: 4 :	2 :	1 :	24 :	12,100 :	3,852 :	116.3 :
: 5 :	3 :	1 :	23 :	9,500 :	3,024 :	91.4 :
: 6 :	3 :	1 :	23 :	11,600 :	3,693 :	111.5 :
: 7 :	2 :	2 :	23 :	11,150 :	3,549 :	107.2 :
: 8 :	2 :	2 :	23 :	9,450 :	3,008 :	90.8 :
: 9 :	3 :	2 :	22 :	10,250 :	3,263 :	98.6 :
: 10 :	3 :	2 :	22 :	9,350 :	2,976 :	89.8 :
: Check :	:	:	:	:	:	:
: 11 :	- :	- :	27 :	9,250 :	2,944 :	---- :
: 12 :	- :	- :	27 :	10,550 :	3,358 :	---- :

TABLE 65°WMC-2.

: Cyl. No. :	Days at 65° C. :	Days in Water :	Days in M. C. :	Load Pounds :	Stress lbs. per sq. in. :	Per cent of 28 day strength :
: 1 :	1 :	1 :	25 :	8,650 :	2,754 :	107.1 :
: 2 :	1 :	1 :	25 :	9,200 :	2,929 :	114.0 :
: 3 :	2 :	1 :	24 :	8,850 :	2,817 :	109.6 :
: 4 :	2 :	1 :	24 :	8,850 :	2,817 :	109.6 :
: 5 :	3 :	1 :	23 :	8,850 :	2,817 :	109.6 :
: 6 :	3 :	1 :	23 :	9,450 :	3,008 :	117.0 :
: 7 :	2 :	2 :	23 :	9,450 :	3,008 :	117.0 :
: 8 :	2 :	2 :	23 :	9,050 :	2,881 :	112.1 :
: 9 :	3 :	2 :	22 :	9,550 :	3,040 :	118.2 :
: 10 :	3 :	2 :	22 :	8,750 :	2,785 :	108.4 :
: Check :	:	:	:	:	:	:
: 11 :	- :	- :	27 :	8,000 :	2,547 :	---- :
: 12 :	- :	- :	27 :	8,150 :	2,594 :	---- :

TABLES NOS. MC-1 AND MC-2

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured in moist closet for one, two, three, four and five days and tested upon removal from the same.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces damp along planes of failure.

Cylinders Nos. 11 and 12 first loaded up to 10,000 pounds. Load withdrawn and machine reset to read 50,000 pounds maximum.

Cylinders again loaded until failure occurred.

TABLE MC-1.

: Cyl. No. :	: Age (days) :	: Days in M. C. :	: Load (pounds) :	: Stress lbs. per sq. in. :	: Per cent of 28 day strength :
: 1 :	: 2 :	: 1 :	: 2,410 :	: 767 :	: 19.8 :
: 2 :	: 2 :	: 1 :	: 2,660 :	: 847 :	: 22.0 :
: 3 :	: 3 :	: 2 :	: 3,810 :	: 1,213 :	: 31.5 :
: 4 :	: 3 :	: 2 :	: 3,820 :	: 1,216 :	: 31.6 :
: 5 :	: 4 :	: 3 :	: 4,460 :	: 1,420 :	: 36.8 :
: 6 :	: 4 :	: 3 :	: 4,740 :	: 1,509 :	: 39.2 :
: 7 :	: 5 :	: 4 :	: ----- :	: ----- :	: ----- :
: 8 :	: 5 :	: 4 :	: 4,830 :	: 1,537 :	: 40.0 :
: 9 :	: 6 :	: 5 :	: 5,790 :	: 1,843 :	: 47.9 :
: 10 :	: 6 :	: 5 :	: 6,460 :	: 2,056 :	: 53.5 :
: Check :	:	:	:	:	:
: 11 :	: 28 :	: 27 :	: 11,550 :	: 3,676 :	: ----- :
: 12 :	: 28 :	: 27 :	: 12,650 :	: 3,841 :	: ----- :

TABLE MC-2.

: Cyl. No. :	: Age (days) :	: Days in M. C. :	: Load (pounds) :	: Stress lbs. per sq. in. :	: Per cent of 28 day strength :
: 1 :	: 2 :	: 1 :	: 2,970 :	: 945 :	: 29.7 :
: 2 :	: 2 :	: 1 :	: 2,960 :	: 942 :	: 29.6 :
: 3 :	: 3 :	: 2 :	: 3,910 :	: 1,245 :	: 39.1 :
: 4 :	: 3 :	: 2 :	: 3,930 :	: 1,251 :	: 39.3 :
: 5 :	: 4 :	: 3 :	: 4,660 :	: 1,483 :	: 46.6 :
: 6 :	: 4 :	: 3 :	: 4,790 :	: 1,525 :	: 47.9 :
: 7 :	: 5 :	: 4 :	: 4,870 :	: 1,530 :	: 48.7 :
: 8 :	: 5 :	: 4 :	: 5,588 :	: 1,776 :	: 55.8 :
: 9 :	: 6 :	: 5 :	: 5,350 :	: 1,703 :	: 53.5 :
: 10 :	: 6 :	: 5 :	: 5,710 :	: 1,817 :	: 57.1 :
: Check :	:	:	:	:	:
: 11 :	: 28 :	: 27 :	: 10,000 :	: 3,183 :	: ----- :
: 12 :	: 28 :	: 27 :	: 10,000 :	: 3,183 :	: ----- :

TABLES NOS. MC-3 AND MC-4

Sand: Dolomitic No. 1

Cylinders 1 to 10 cured in moist closet for six, seven, eight, nine and ten days and tested upon removal from the same.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces damp along planes of failure.

Table MC-3.

: Cyl. No. :	: Age (days) :	: Days in M. C. :	: Load (pounds) :	: Stress lbs. per sq. in. :	: Per cent of 28 day strength :
: 1 :	: 7 :	: 6 :	: 4,570 :	: 1,456 :	: 66.0 :
: 2 :	: 7 :	: 6 :	: 4,380 :	: 1,394 :	: 63.3 :
: 3 :	: 8 :	: 7 :	: 5,080 :	: 1,617 :	: 73.4 :
: 4 :	: 8 :	: 7 :	: 4,770 :	: 1,518 :	: 68.9 :
: 5 :	: 9 :	: 8 :	: 4,860 :	: 1,546 :	: 70.2 :
: 6 :	: 9 :	: 8 :	: 5,510 :	: 1,754 :	: 79.6 :
: 7 :	: 10 :	: 9 :	: 6,310 :	: 2,009 :	: 91.1 :
: 8 :	: 10 :	: 9 :	: 6,220 :	: 1,980 :	: 89.7 :
: 9 :	: 11 :	: 10 :	: 5,580 :	: 1,776 :	: 80.6 :
: 10 :	: 11 :	: 10 :	: 6,200 :	: 1,974 :	: 89.5 :
: Check :	:	:	:	:	:
: 11 :	: 28 :	: 27 :	: 7,250 :	: 2,308 :	: ---- :
: 12 :	: 28 :	: 27 :	: 6,600 :	: 2,101 :	: ---- :

Table MC-4.

: Cyl. No. :	: Age (days) :	: Days in M. C. :	: Load (pounds) :	: Stress lbs. per sq. in. :	: Per cent of 28 day strength :
: 1 :	: 7 :	: 6 :	: 6,340 :	: 2,018 :	: 69.6 :
: 2 :	: 7 :	: 6 :	: 5,640 :	: 1,795 :	: 62.0 :
: 3 :	: 8 :	: 7 :	: 5,820 :	: 1,853 :	: 64.0 :
: 4 :	: 8 :	: 7 :	: 6,100 :	: 1,942 :	: 67.0 :
: 5 :	: 9 :	: 8 :	: 6,820 :	: 2,171 :	: 75.0 :
: 6 :	: 9 :	: 8 :	: 6,490 :	: 2,066 :	: 71.3 :
: 7 :	: 10 :	: 9 :	: 6,820 :	: 2,171 :	: 75.0 :
: 8 :	: 10 :	: 9 :	: 7,050 :	: 2,244 :	: 77.5 :
: 9 :	: 11 :	: 10 :	: 6,660 :	: 2,120 :	: 73.2 :
: 10 :	: 11 :	: 10 :	: 8,250 :	: 2,626 :	: 90.7 :
: Check :	:	:	:	:	:
: 11 :	: 28 :	: 27 :	: 9,430 :	: 3,002 :	: ---- :
: 12 :	: 28 :	: 27 :	: 8,770 :	: 2,792 :	: ---- :

TABLES NOS. W-1 AND W-2

Sand: Dolomitic No. 1 (Table W-1)

Dolomitic No. 2 (Table W-2)

Cylinders 1 to 10 cured in water for one, two, three, four and five days and tested.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces wet along planes of failure.

Table W-1.

Cyl. No.	Age (days)	Days in Water	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	2	1	3,070	977	37.2
2	2	1	2,800	891	33.9
3	3	2	4,290	1,366	52.0
4	3	2	4,630	1,474	56.1
5	4	3	5,160	1,643	62.6
6	4	3	5,040	1,604	61.0
7	5	4	5,420	1,725	65.7
8	5	4	5,050	1,608	61.2
9	6	5	7,210	2,295	87.5
10	6	5	5,990	1,907	72.7
Check					
11	28	-	8,550	2,722	----
12	28	-	7,950	2,531	----

Table W-2.

Cyl. No.	Age (days)	Days in Water	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	2	1	2,130	678	22.8
2	2	1	2,490	793	26.6
3	3	2	4,030	1,283	43.2
4	3	2	4,230	1,347	45.3
5	4	3	6,140	1,955	65.6
6	4	3	5,890	1,875	63.0
7	5	4	6,930	2,206	74.2
8	5	4	7,430	2,365	79.5
9	6	5	7,300	2,324	78.1
10	6	5	7,450	2,372	79.7
Check					
11	28	-	8,750	2,785	----
12	28	-	9,950	3,167	----

TABLES NOS. W-3 AND W-4

Sand: Dolomitic No. 1 (Table W-3)

Dolomitic No. 2 (Table W-4)

Cylinders 1 to 10 cured in water for six, seven, eight, nine and ten days (Table W-3) for six, seven, nine, ten and eleven days (Table W-4) and tested.

Two check cylinders (11 and 12) were cured for twenty-seven days in moist closet and tested.

Remarks: Surfaces wet along planes of failure.

Table W-3.

Cyl. No.	Age (days)	Days in Water	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	7	6	7,550	2,403	68.9
2	7	6	7,920	2,521	72.3
3	8	7	8,110	2,582	74.0
4	8	7	7,570	2,410	69.0
4	9	8	8,500	2,706	77.5
6	9	8	9,720	3,094	88.7
7	10	9	9,225	2,937	84.0
8	10	9	9,100	2,897	83.0
9	11	10	9,700	3,088	88.5
10	11	10	8,950	2,849	81.6
Check					
11	28	--	11,800	3,756	----
12	28	--	10,150	3,231	----

Table W-4.

Cyl. No.	Age (days)	Days in Water	Load Pounds	Stress lbs. per sq. in.	Per cent of 28 day strength
1	7	6	8,200	2,610	97.6
2	7	6	9,080	2,890	108.1
3	8	7	7,680	2,445	91.5
4	8	7	8,710	2,773	103.8
5	10	9	9,260	2,948	110.2
6	10	9	8,470	2,696	100.9
7	11	10	8,980	2,859	107.0
8	11	10	8,780	2,795	104.6
9	12	11	9,090	2,894	108.2
10	12	11	8,990	2,862	107.0
Check					
11	28	--	8,150	2,594	----
12	28	--	8,650	2,754	----

		Age - days										
		2	3	4	5	6	7	8	9	10	11	
: Group #	: (1) Unit Stress, #/sq.in.	: 1284	: 1250	: 1266	: 1319	:	:	:	:	:	:	
: : (2) % of 28 day strength:	:	: 41.3	: 40.1	: 40.5	: 40.4	: 40.5	:	:	:	:	:	
: 65° C	: (1)	: 1485	: 1709	: 1955	: 1916	:	:	:	:	:	:	
: : (2)	: (2)	: 48.6	: 49.0	: 56.0	: 55.1	:	:	:	:	:	:	
: 65° C-1W	: (1)	: 1477	: 1707	: 1761	: 1944	:	:	:	:	:	:	
: : (2)	: (2)	: 44.3	: 51.1	: 53.2	: 57.9	:	:	:	:	:	:	
: 65° C-2W	: (1)	:	:	: 1554	: 1668	: 1761	: 1856	:	:	:	:	
: : (2)	: (2)	:	:	: 45.2	: 53.2	: 58.5	: 63.0	:	:	:	:	
: 65° C-3W	: (1)	:	: 1932	: 2169	: 2242	: 2419	:	:	:	:	:	
: : (2)	: (2)	: 70.2	: 78.5	: 81.1	: 87.4	:	:	:	:	:	:	
: 65° C-1	: (1)	:	:	:	: 2358	:	:	:	:	:	:	
: : (2)	: (2)	:	:	:	: 85.1	:	:	:	:	:	:	
: 65° C-2	: (1)	:	: 1543	: 2179	: 2294	: 2349	:	:	:	:	:	
: : (2)	: (2)	:	: 63.6	: 74.5	: 78.7	: 80.4	:	:	:	:	:	
: 65° C-3	: (1)	:	:	:	:	: 2169	:	:	:	:	:	
: : (2)	: (2)	:	:	:	:	: 74.2	:	:	:	:	:	
: 65° C-1	: (1)	:	:	:	: 2040	: 2290	: 2324	: 2554	:	:	:	
: : (2)	: (2)	:	:	:	: 70.9	: 80.7	: 80.8	: 88.5	:	:	:	
: 65° C-3	: (1)	:	:	:	:	:	: 2341	:	:	:	:	
: : (2)	: (2)	:	:	:	:	:	: 81.3	:	:	:	:	
: 65° C-1	: (1)	:	: 1900	: 1961	: 2227	: 2110	: 2246	:	:	:	:	
: : (2)	: (2)	: 69.8	: 72.7	: 81.7	: 77.0	: 82.6	:	:	:	:	:	
: 65° C-2	: (1)	:	:	: 1948	: 2100	: 2229	: 2231	: 2419	:	:	:	
: : (2)	: (2)	: 68.1	: 67.6	: 70.9	: 71.6	: 66.4	:	:	:	:	:	
: 65° C-3	: (1)	:	:	:	:	: 1708	: 1986	: 2169	: 2065	: 1962	:	
: : (2)	: (2)	:	:	:	:	: 56.7	: 65.9	: 72.0	: 68.4	: 66.5	:	
: Moist	: (1)	: 875	: 1231	: 1494	: 1622	: 1665	: 1666	: 1733	: 1694	: 2101	: 2124	
: : (2)	: (2)	: 25.3	: 36.4	: 40.1	: 49.2	: 53.0	: 66.2	: 68.3	: 74.0	: 83.3	: 83.5	
: Closet	: (1)	: 915	: 1367	: 1769	: 1976	: 2224	: 2527	: 2552	: 2900	: 2869	: 2898	
: : (2)	: (2)	: 30.1	: 49.2	: 63.1	: 70.2	: 79.5	: 86.7	: 84.6	: 83.1	: 94.5	: 95.4	

SUMMARY TABLE NO. 2

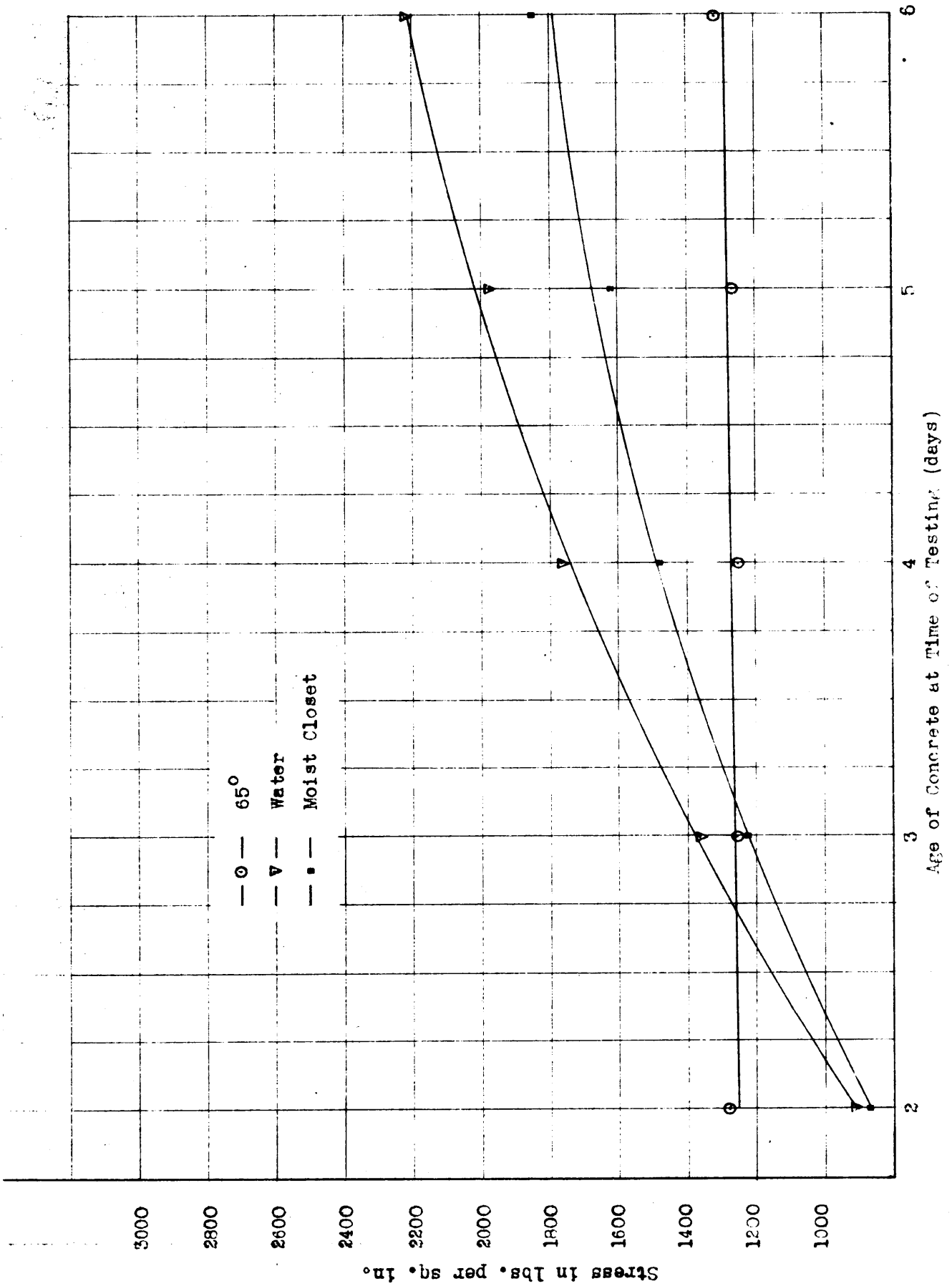
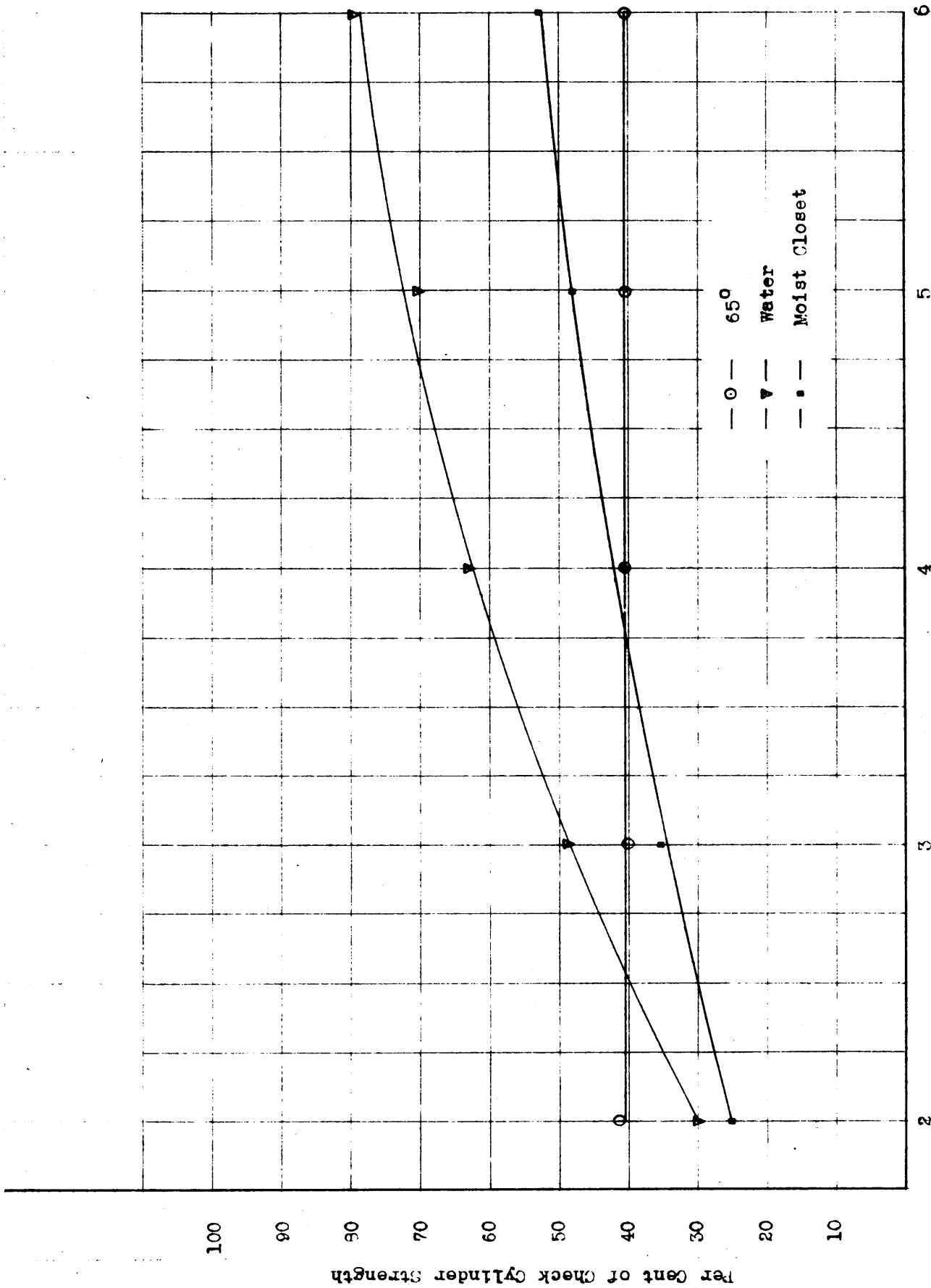


Fig. 8.



Age of Concrete at Time of Testing (days)

FIG. 9.

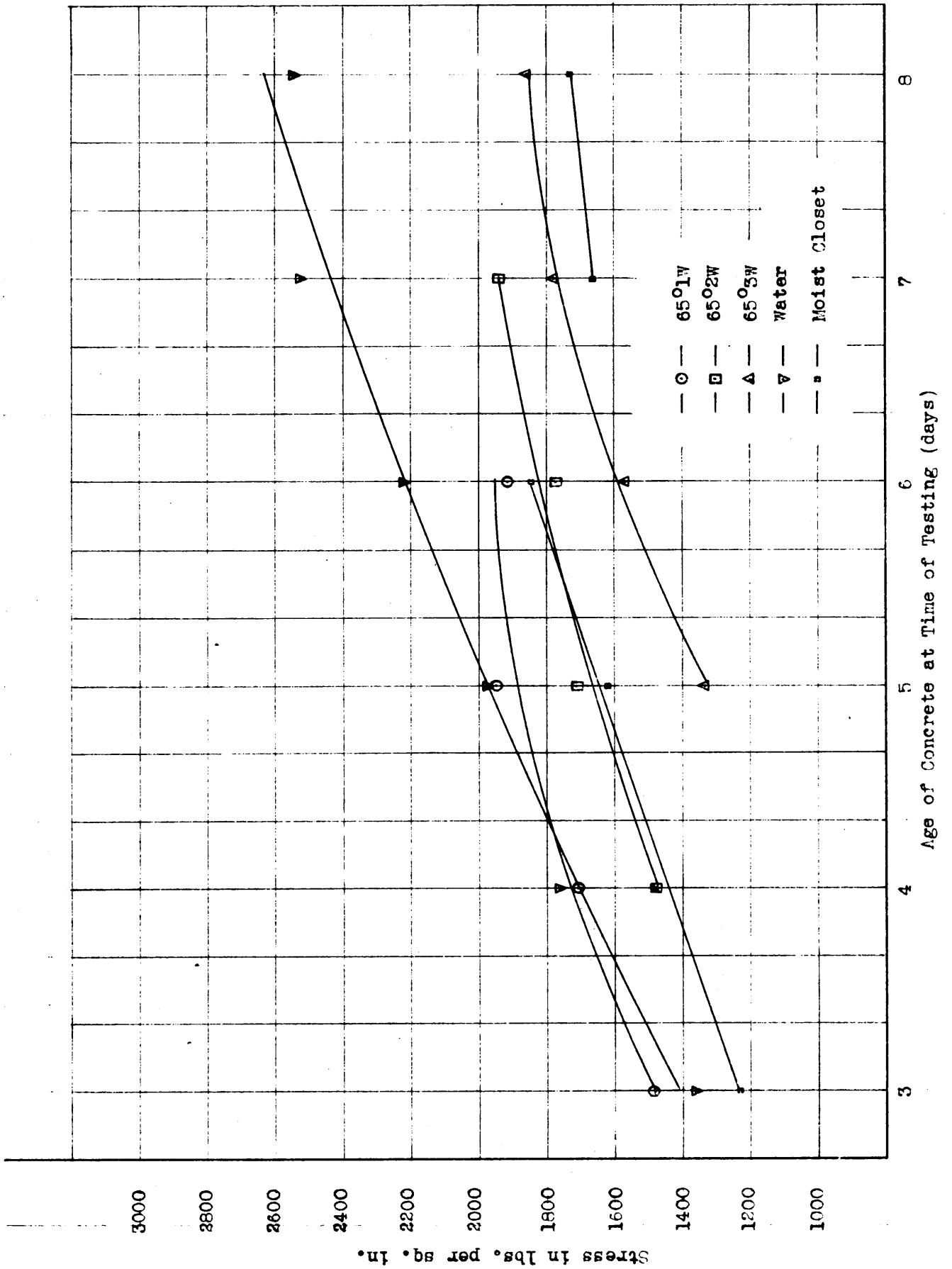
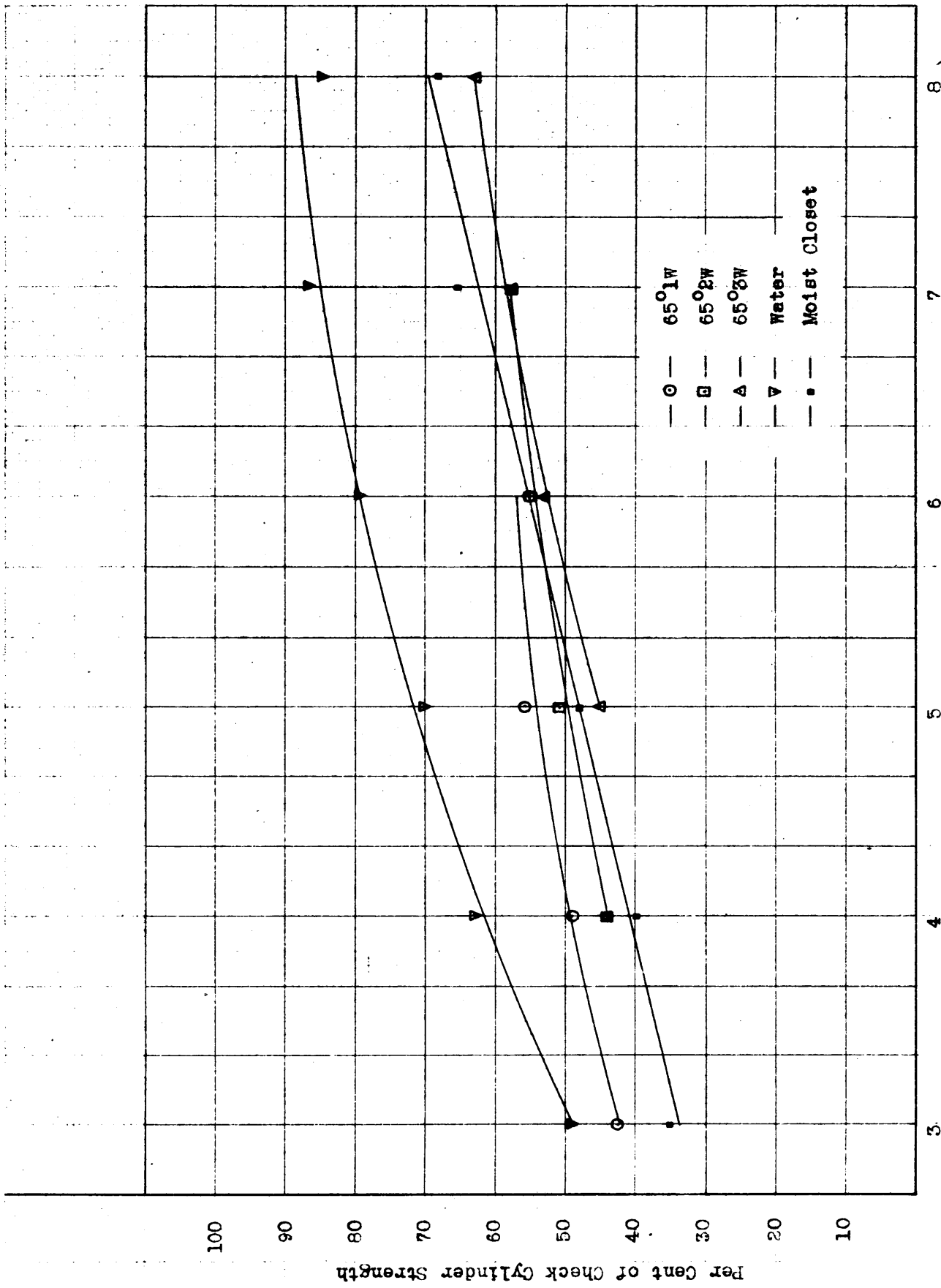


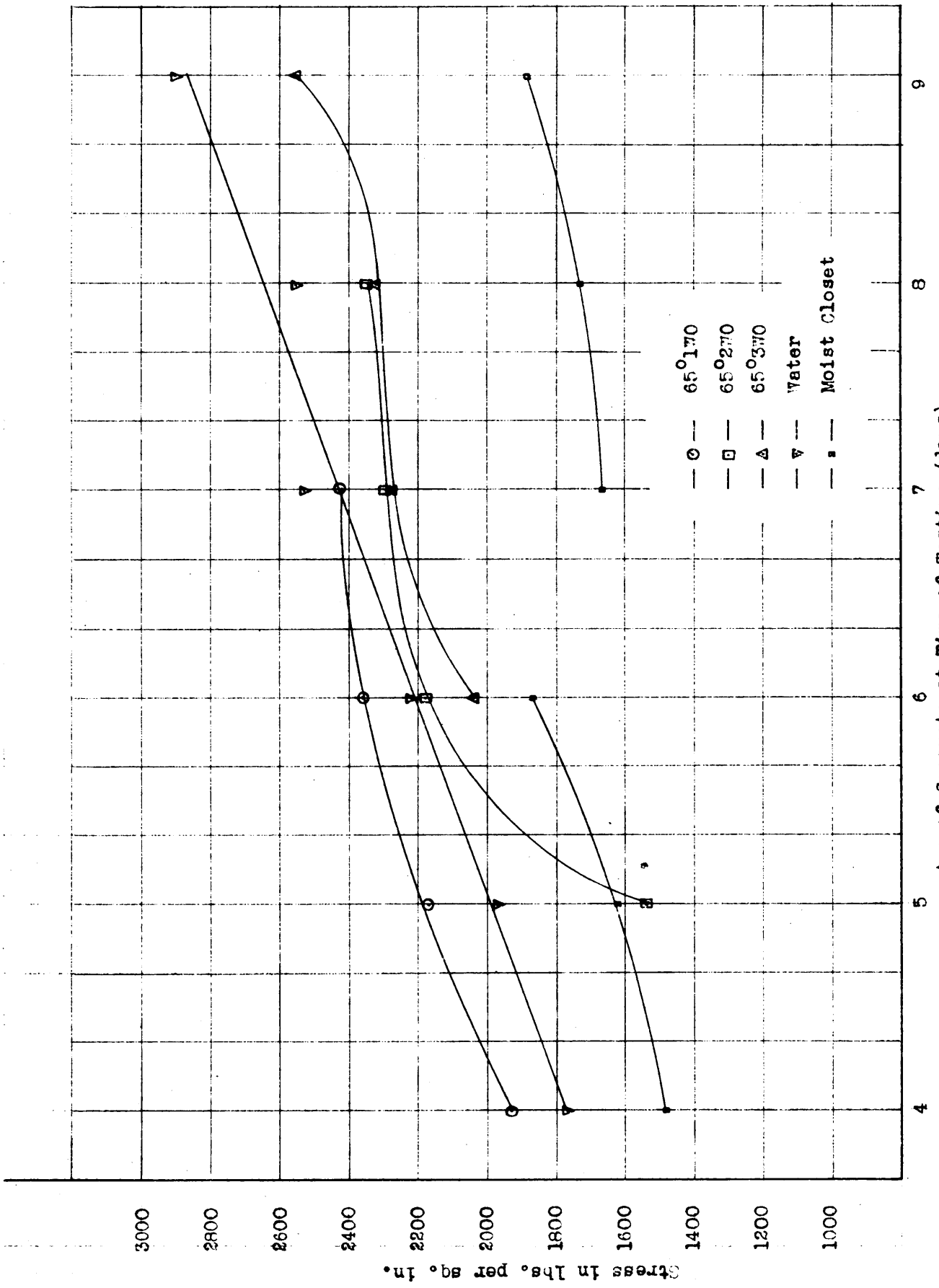
Fig. 10.



Age of Concrete at Time of Testing (days)

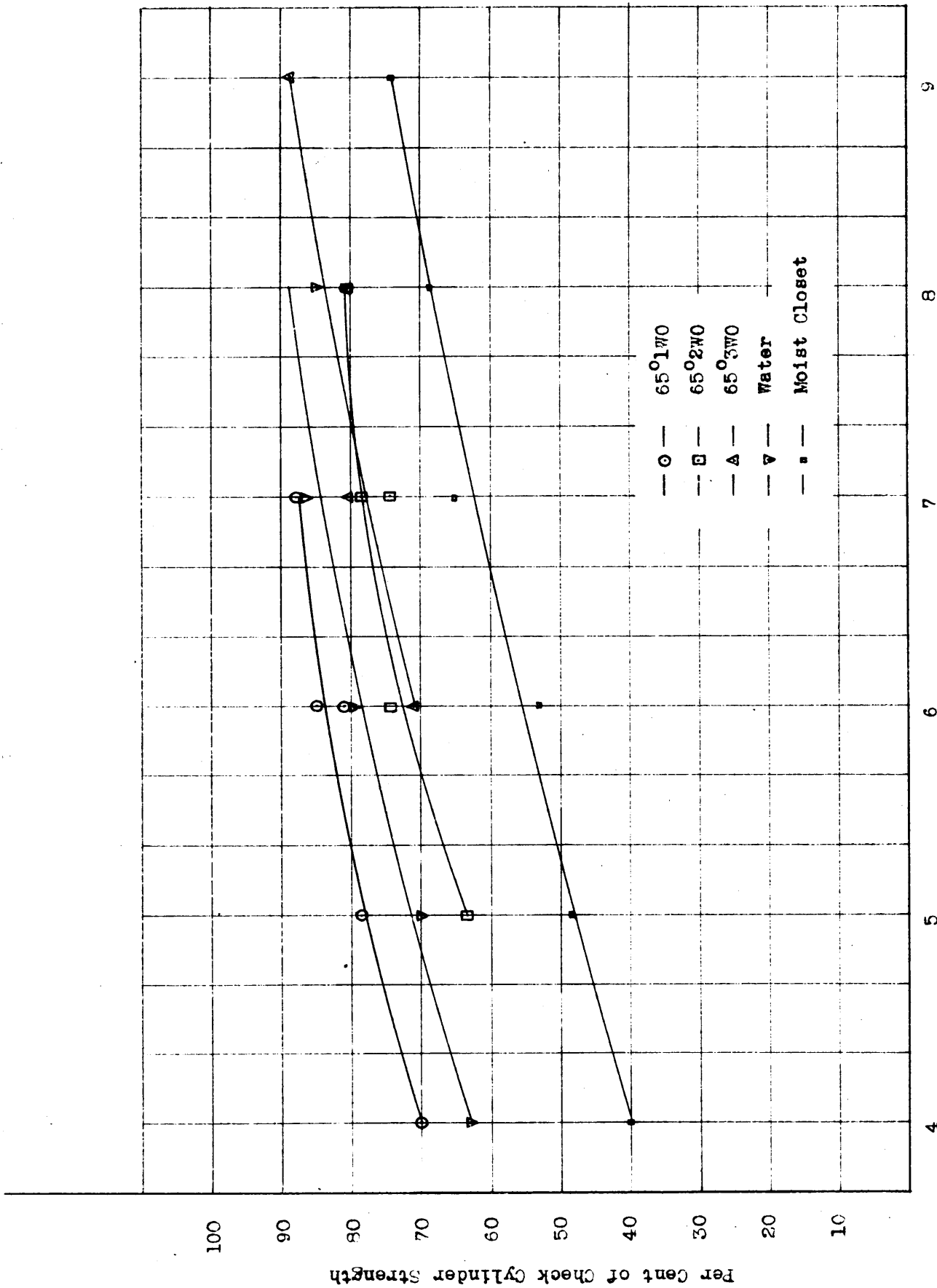
FIG. 11.

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Age of Concrete at Time of Testing (days)

Fig. 12.



Age of Concrete at Time of Testing (days)

Fig. 13.

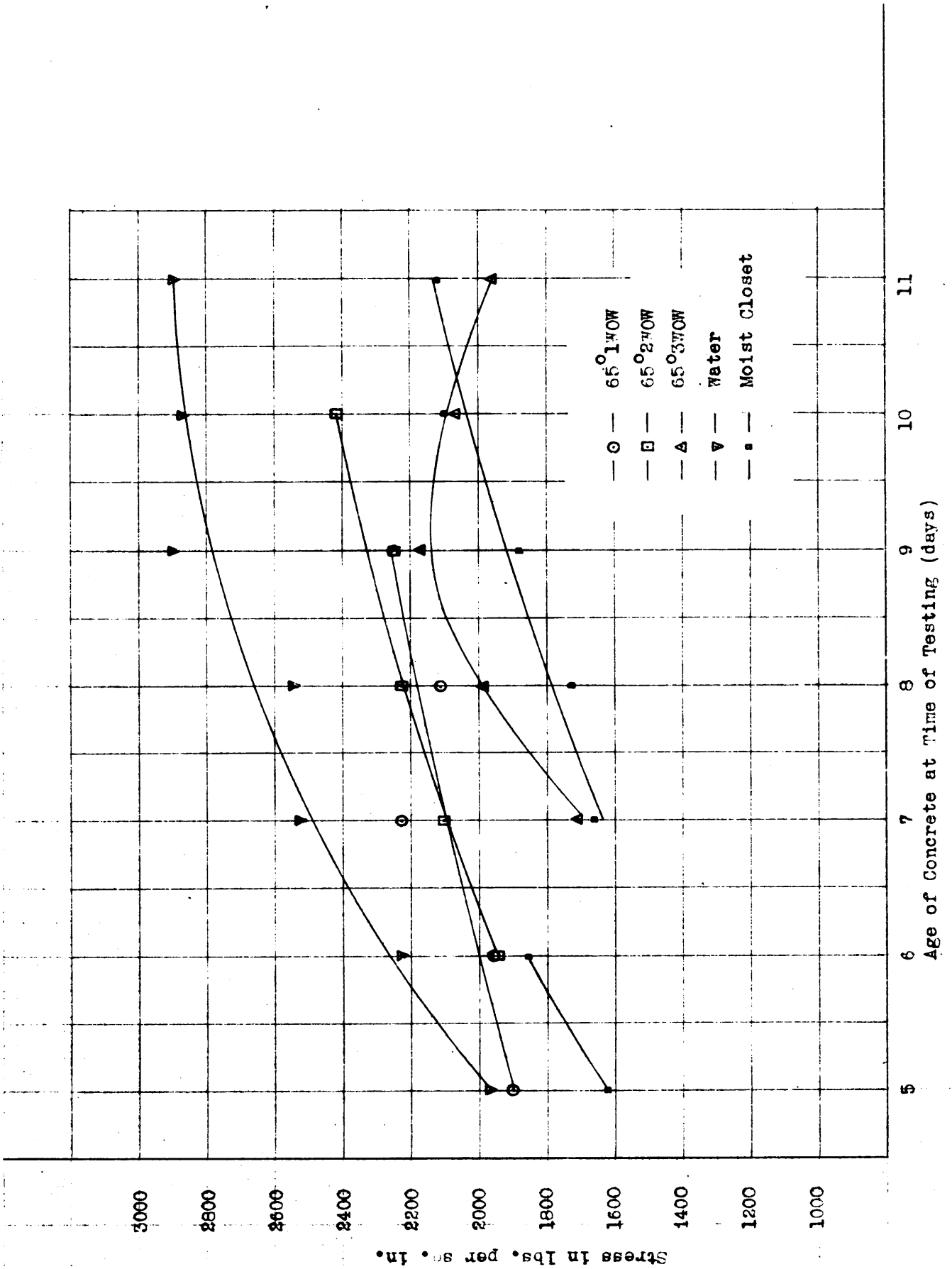
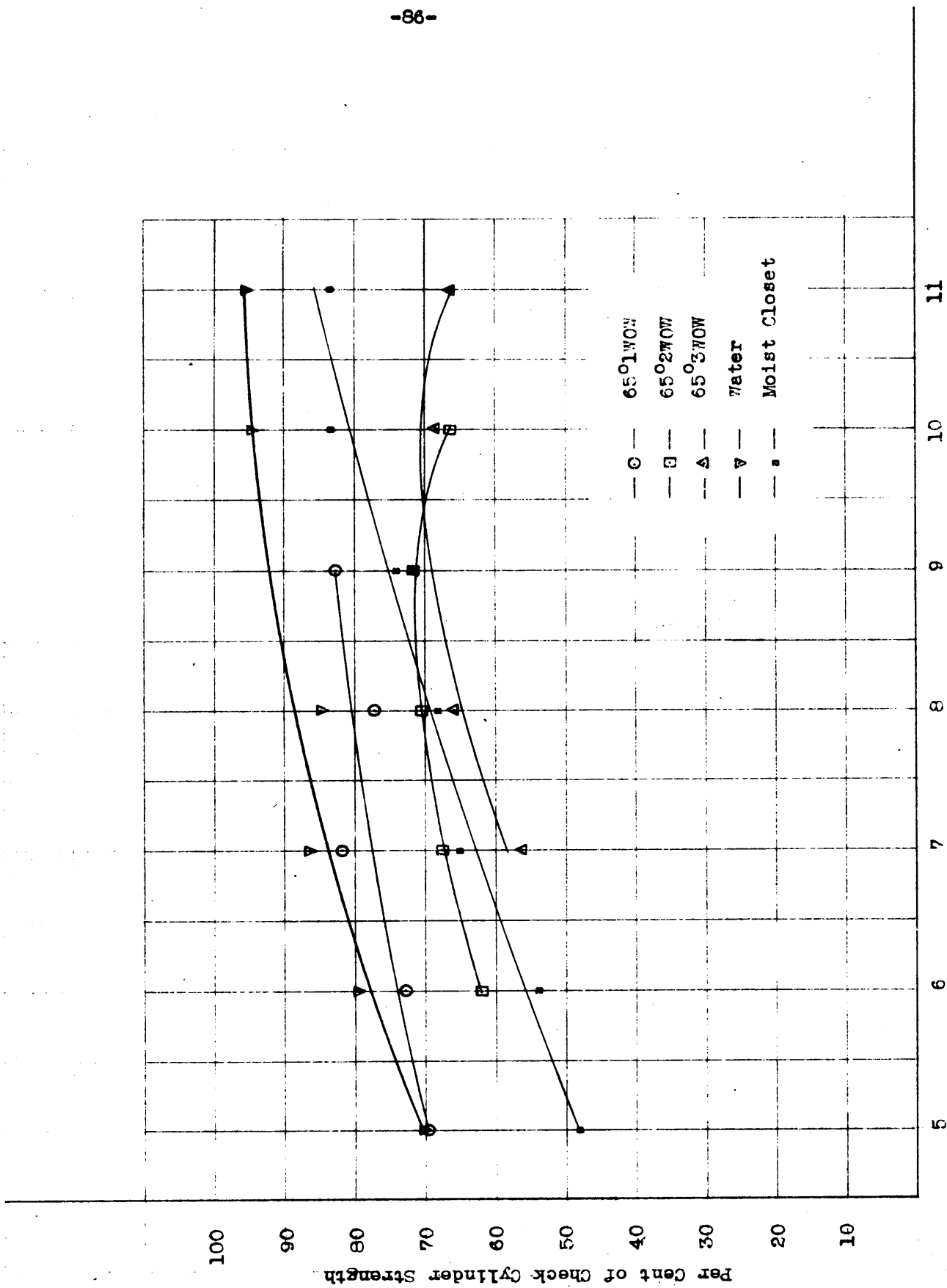


Fig. 14.

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Age of Concrete at Time of Testing (days)

Fig. 15.

Concrete cured one, two, and three days in oven (65°C), in water one and two days, and in moist closet for the remainder of twenty-eight days.

Age at time of testing, twenty-eight days.

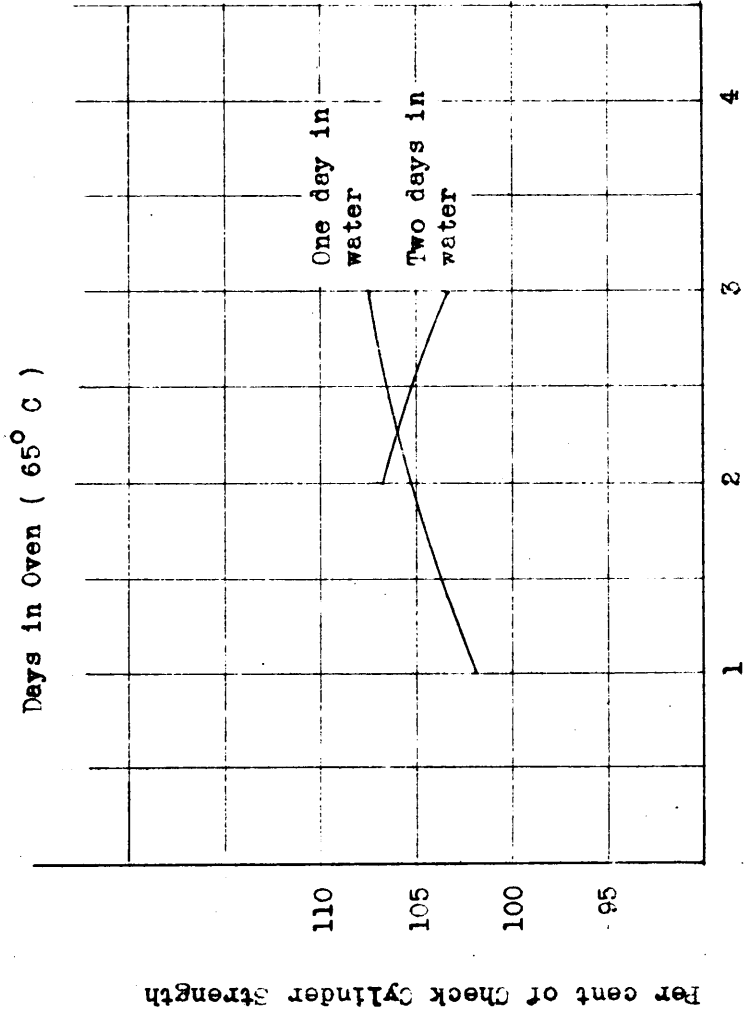
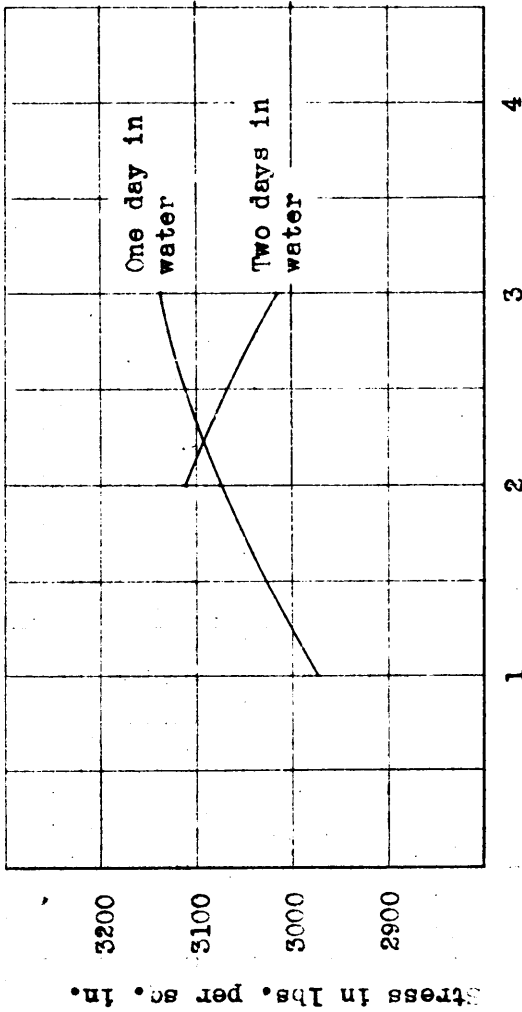


Fig. 16.

Discussion of Problem II

Group 65° C.

The following results were observed for concrete cylinders which were cured for one to five days at 65° C. and tested upon removal from the oven.

It was noted (Fig. 8) that concrete cured for one day at 65° C. gave a strength of 1284 pounds per square inch at an age of two days, corresponding to 41.3 per cent (Fig. 9) of the check cylinder strength. Leaving the concrete in the oven for two, three, four, and five days did not increase its strength in spite of the subsequent increase in age. The fact that the high temperature drove off practically all of the water in the new concrete is the only logical explanation for this phenomenon. It was noted (Fig. 8 and Fig. 9) that the concrete cured at 65° C. had a greater strength at two days than both the concrete cured in the moist closet and the concrete cured in water.

<u>Age in days</u>	<u>Method of Curing</u>	<u>Lbs. per sq. in.</u>	<u>Per cent of Check Cylinder Strength</u>
2	65° C.	1284	41.3
2	Water	915	30.1
2	Moist Closet	875	25.3

At the age of three days the strength of the concrete cured in water rises above that for the concrete cured at 65° C., but that for the concrete cured in the moist closet still falls below.

From the above results it may be seen that curing of concrete at 65° C. causes the concrete to set very quickly, but also drives off

the water making all further curing impossible. This leads directly into the next part of this problem where the water is again replaced.

Group 65°W

The following results were observed for the concrete, which, after one, two, and three days curing at 65° C. was immersed in water for one, two, and three days.

The group exhibiting the greatest strength (Figs. 10 and 11) was the one cured for one day at 65° C. and in the water for one, two and three days; next in order came the concrete cured for two days at 65° C. and last came the concrete cured for three days at 65° C. The per cent curve (Fig. 11) for the concrete cured for one day at 65° C. is below that for the concrete cured in water, but is always above that for the concrete cured in the moist closet. At four and five days of age, the per cent curve for the concrete cured two days at 65° C. is above that for the concrete cured in the moist closet, going below at six and seven days of age. The per cent curve for the concrete cured two days at 65° C. is entirely below that for the concrete cured in the moist closet. The unit stress curves (Fig. 10) show all curves for concrete cured at 65° C. below that for concrete cured in water, with the exception of the concrete three and four days old and cured for one day at 65° C. The 65°1W curve is always above the moist closet curve; the 65°2W curve is above the moist closet curve at four and five days of age, but below it at six days of age; and the 65°3W curve is below the moist closet curve at five and six days of age.

The water lost through evaporation has now been replaced and the next step is to continue the curing at 65° C.

Group 65°W0

The following data were observed for those concrete cylinders, which, after one, two, and three days of curing at 65° C. were immersed in water for one, two, and three days and then placed back in the oven for one and two days.

The strength curve (Fig. 12) for the concrete cured for one day at 65° C. is above both the curve for the concrete cured in water and the curve for the concrete cured in the moist closet. The stress curve for the concrete cured for two days at 65° C. is below that for the concrete cured one day at 65° C. and also below that for the concrete cured in water. However, it is still well above the stress curve for the concrete cured in the moist closet, and in only one instance, at the age of five days, does it fall below. The stress curve for the concrete cured for three days at 65° C. is below that for one and two days and below that for the concrete cured in water, but still well above that for the concrete cured in the moist closet.

The per cent curves (Fig. 13) are very much similar to the stress curves, differing in only two instances where, at the age of five days, the two day curve is above that for the concrete cured in the moist closet and where, at the age of seven days, the three day curve crosses over and is above the two day curve.

The evaporation of water had again weakened the concrete and the next step was to again replace this lost water.

Group 65°W0W

The following results were observed for concrete cylinders,

which, after one, two and three days curing at 65°C. were immersed in water for one, two and three days, then cured at 65° C. for one and two days, and again immersed in water for one and two days.

In Figure 14 it is noted that all the curves fall below that for the concrete cured in water, and all, with the exception of the 65°WOW curve at an age of eleven days, are above the curve for the concrete cured in the moist closet. The concrete cured three days at 65° C. still has the least strength of the high temperature cured concrete. The concrete cured for one day at 65° C. is the strongest up to seven days of age where its curve crosses below that of the concrete cured two days at 65° C. which then has the greater strength.

The percentage curves (Fig. 15) still show the curve for the water cured concrete well above all the other curves. The concrete cured one day at 65° C. is the strongest of the high temperature cured concrete; the concrete cured two days at 65° C. is the next in strength and the concrete cured three days at 65° C. is the weakest. The one day curve is completely above the curve for the concrete cured in the moist closet, and the two day curve is partially above, passing below at an age of eight days. The three day curve is entirely below the moist closet curve and at an age of ten days passes above that for the concrete cured two days at 65° C.

The above results show that one day at 65° C. is the best method for the high temperature curing of the concrete and increases the strength of the concrete in all cases above that of concrete treated in moist closet, and in some cases increases the strength above that for the concrete cured in water.

Group 65° WMC

In order to see what effect this high temperature curing would have on the twenty-eight day ultimate strength of concrete, the following tests were made.

Concrete cylinders were cured for one, two, and three days at 65° C., immersed in water for one and two days and cured for the remainder of twenty-eight days in the moist closet. From the results of the compression tests performed on these concrete cylinders the following was observed.

All the concrete cylinders, with the exception of those cured one day at 65° C. and one day in water, had a greater twenty-eight day strength than the concrete cured in the moist closet for the same period of time. The minimum strength of the concrete cured in oven and water was 2973 pounds per square inch or 102.1 per cent of the check cylinder strength (Fig. 16). The maximum strength was 3135 pounds per square inch or 107.4 per cent of the check cylinder strength. It is interesting to note that in all cases the per cent of check cylinder strength was over 100 per cent. The average twenty-eight day strength for the ninety-seven check cylinders used in this investigation was 3016 pounds per square inch.

The strength of the concrete, cured in the water for one day after its removal from the oven, increased directly with the number of days cured at 65° C. However, in the case of the concrete cured two days in the water, just the opposite happened and the strength varied inversely with the number of days cured at 65° C. The greatest strength obtained was for that concrete, cured for three days at 65° C., then in water for one day and in the moist closet for the remainder of twenty-eight days.

This proves to be very interesting, since all other concrete of ages less than twenty-eight days, exhibited least strengths when cured for three days at 65° C.

Conclusions - Problem II

For Portland Cement Concrete using Dolomitic Limestone Sand as the fine aggregate the following may be concluded:

1. By curing freshly poured concrete at 65° C. a two day strength can be obtained equivalent to the four day strength of concrete cured in the moist closet under normal conditions.

2. By placing concrete in water for one to four days after having been cured for one, two, and three days at 65° C. the strength of the concrete is increased above that of concrete cured in moist closet under normal conditions for the same period; gain in strength varies inversely with the number of days cured at 65° C.

3. If concrete, after having been cured for one, two, and three days at 65° C. and then for one and two days in water, is cured at 65° C., its strength will again increase over that for concrete cured in moist closet under normal conditions for the same period. Concrete cured one day at 65° C., then in water for one, two, and three days and back at 65° C. for one and two days has a strength even greater than the concrete cured in water for the same period.

4. Concrete, cured at 65° C. for one day, in water for one, two, and three days, again at 65° C. for one and two days and back in water for one and two days, has a strength greater than that of concrete cured in moist closet under normal conditions for the same period.

5. Curing of concrete at 65° C. for one to three days does not decrease its twenty-eight day strength, providing the water lost through evaporation is replaced.

6. From the data obtained in this investigation, high temperature curing of concrete tends to increase the strength of the concrete above that of concrete cured under normal conditions.

3. Problem III

Table P.

: Cyl. No. :	Days in M. C. :	Days in Water :	Load Pounds :	Stress lbs. per sq. in. :
: 1 :	27 :	-- :	10,900 :	3,470 :
: 2 :	27 :	-- :	10,350 :	3,295 :
: 3 :	27 :	-- :	10,800 :	3,434 :
: 4 :	27 :	-- :	10,600 :	3,374 :
: 5 :	27 :	-- :	10,600 :	3,374 :
: 6 :	27 :	-- :	10,850 :	3,454 :
: 7 :	27 :	-- :	11,650 :	3,708 :
: 8 :	27 :	-- :	10,800 :	3,438 :
: 9 :	-- :	27 :	13,550 :	4,313 :
: 10 :	-- :	27 :	14,650 :	4,663 :
: 11 :	-- :	27 :	14,000 :	4,456 :
: 12 :	-- :	27 :	13,900 :	4,425 :

Sand: Petersburg

Cylinders 1 to 8 cured twenty-seven days in moist closet and tested. Cylinders 9 to 12 cured in water for twenty-seven days and tested. Age of concrete, twenty-eight days.

Remarks:

3,444 pounds per square inch is average stress for concrete cured in moist closet.

4,465 pounds per square inch is average stress for concrete cured in water.

3,017 pounds per square inch is average stress for the ninety-seven check cylinders, using dolomitic sand as the fine aggregate.

Discussion of Problem III

When Petersburg sand was used as the fine aggregate in the concrete in place of Dolomitic sand, the following results were obtained from the compression tests.

Those concrete cylinders which were cured in the moist closet for twenty-eight days developed an average unit stress of 3444 pounds per square inch. The concrete cylinders cured in the water for twenty-eight days had an even greater strength and developed an average unit stress of 4465 pounds per square inch. The average unit stress for all of the ninety-seven check cylinders using Dolomitic Sand was 3017 pounds per square inch. From these results it seems that the Petersburg sand gives the greatest strength. It must be remembered, though, that the 3017 is an average for 97 concrete cylinders, while the 3444 is the average for only eight.

In looking over the tables of results, values for Dolomitic sand concrete may be found that are as great and in some cases greater than the 3444 for the Petersburg sand concrete. This investigation does show that Dolomitic sand is satisfactory for use in Portland cement concrete. The difference in strength between concrete using Dolomitic sand and that using Petersburg is so slight that it may be considered negligible.

IV. SUMMARY

Based on the results of this investigation certain conclusions were arrived at relative to Portland cement concrete using Dolomitic limestone sand as the fine aggregate. The most important of these are as follows:

1. Fresh concrete continues to gain strength while in the frozen state.
2. Freezing and then thawing of fresh concrete does not have an appreciable effect on the twenty-eight day ultimate strength, and the concrete, if given time to recover, will compare favorably with concrete cured under normal conditions.
3. Freezing of concrete immediately after pouring has a greater effect on the twenty-eight day ultimate strength of the concrete than has freezing for the same period at a more advanced age within the twenty-eight days.
4. Concrete cured at 65° C. tends to increase its twenty-eight day ultimate strength, providing the water lost through evaporation is replaced.
5. High early strength concrete can be obtained by curing ordinary Portland cement concrete at high temperatures.

Based on the results of compression tests performed in this investigation, Dolomitic limestone sand has been found to be satisfactory as the fine aggregate for Portland cement concrete; verifying what Messrs. Broyles and Brown had said in 1936 and 1937 respectively.

What has been done in the way of concrete research at Virginia Polytechnic Institute is satisfactory for relatively new concrete using

Dolomitic limestone sand as the fine aggregate; but it is wondered how this concrete will stand up over a long period of time. Professor Hartman and Dr. Holden have inaugurated some long time studies at the Institution, but there is still much room for further investigation. Dolomitic limestone rock has proven itself worthy when used as the coarse aggregate for Portland cement concrete. It is up to time and future research to prove the worth of its sand used as the fine aggregate.

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