AN EXPERIMENTAL STUDY OF THE EFFECT OF DRYING OUT CONCRETE IN EARLY AGES UPON LATER STRENGTH AND EFFECT OF SOAKING AT DIFFERENT AGES TO LEARN THE ULTIMATE DAMAGE OF DRYING

Thesis for the Degree of B. S.

G. F. Baker

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A Thesis Submitted to the

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by

G. F. Baker June 1928.

Candidate for the Degree of Bachelor of Science.

THESIS

Introduction:

It is a well known fact that the conditions under which concrete, probably one of the most important building materials known to the engineering profession today, is cured plays a very important part in the results which may be expected from its use as a building material. By experiment the ideal conditions have been found to be one day in damp sand and about twenty eight days under water or at least in a very damp condition. The old theory of mixing a certain amount of concrete with a specified amount of fine and coarse aggregate in proportions that by previous experience had given accecptable results and adding water until by observation the engineer thought that the proper consistency had been reached has been proven to be very poor practice and is becoming more obsolete every day. It is now known that the strength of a concrete depends on the ratio of the amount of water to cement in the mixture and not, as was formerly supposed, simply on the amount of cement in the mixture. Poor curing conditions will however ruin the best concrete mixed and one of the big problems for the engineer is to furnish the proper amount of moisture to the concrete during the curing process.

Object:

The object of the test described in the following pages was to determine if possible the amount of damage that would be done to a concrete if it was completely dried out at some time during the curing process. When concrete is poured it begins to harden or set at once and its strength increases very papidly for a few days after which the action slows down but continues so that very nearly full strength will be reached in about twenty eight days. If however the concrete is dried out some time before full stremgth is reached the action will be retarded and the curve of its compressive strength will fall below the curve that would represent the strength at successive time intervals were the curing conditions ideal. It is supposed or I might say known that after retardation due to drying out the concrete will will slowly gain in strength but it will never attain the strength that could have been expected had it never been allowed to dry out.

Proceedure:

To make this test fifty six test cylinders were made as described later in three different batches with a two day interval between mixings. These cylinders were all dried to a constant weight at a constant temperature of one hundred degrees F. with a trough of sodium chloride in the drier to collect the moisture. They were then divided up into fourteen groups of four cylinders each and at intervals of two days beginning two days after the first bunch were made were set aside to cure immersed in water held at a practically constant temperature. One group being immersed in water two days after being dried out, another two days later and so on thus keeping each group dry two days longer than the preceeding group. At the end of twenty eight days these cylinders were all broken and the compressive force required for the first sign of failure noted. The average of the forces required for the different cylinders of each group was then computed and taken as the force required to break a cylinder from that group. The concrete was designed to withstand a compressive force of three thousand pounds per square inch.

At the same time as the cylinders for the test were made a set of ten cylinders were made for the purpose of constructing an ideal curve for the strength of the concrete. These cylinders were cured twenty four hours in damp sand and then twenty seven days immersed in water at a constant temperature. That is one of the cylinders was cured the full twenty eight days. The other nine were broken successively at intervals of three days and the compressive strength noted. From these compressive forces an ideal curve for the concrete was constructed showing what strength at different time intervals might be expected and what ultimate strength might be looked for.

Forms used for the cylinders were one quart ice cream boxes having an end area of nine and six one hundredths square inches. When the cylinders were broken one end was covered with a cap made of plaster of paris and fashioned perfectly smooth thus a uniform bearing surface was procured. The results obtained were as given in the following tables and graphs.

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BULKING OF AGGREGATE	Sand	C. A.
Wt. of damp sample		
Wt. of dried sample		
Wt. of water, damp sample		
Per cent of moisture		
Wt. per cu. ft., damp loose		
Wt. dry aggr. in 1 cu. ft. damp loose (x)		
Wt. Water in 1 cu. ft. damp loose		
Wt. per cu. ft., dry rodded (y)		
BULKING FACTOR (y/x)		

SIEVE ANALYSIS
For Fineness Modulus

SIEVE	SAND			COARSE AGGREGATE		
	Wt. on Sieve	% on Sieve	Total % Coarser	Wt. on Sieve	% on Sieve	Total % Coarser
1-½"	0		0	243		12.15
¾"	0		0	0		0.0
⅜"	0		0	647.		44.5
# 4	6.8		0.68	965		92.7
# 8	54.2		6.105	107.7		97.4
# 14	129.1		19.015	11.0		98.2
# 28	179.5		39.965	10.0		98.7
# 48	409.75		77.94	7.2		99.0
#100	202.0		98.14	6.0		99.4
Pan	21.0		xxx	4.0		xxx
TOTAL	1000.5		339.085	2000.9		741.6
Fineness Modulus			3.39			7.42
Maximum Size			3/8			3/4
Max. Size of Mixed Aggr. (based on % % Mix.)						

G. F. Baker.

Operator.

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DESIGN OF CONCRETE MIXTURES

Design Data

Job........................ Date June 1928

Source of Materials..................................

	Sand	C. A.
Wt. of damp sample		
Wt. of dried sample	80 # 5oz.	98 #
Wt. of water in damp sample		
Percent of moisture		
Wt. of one cu. ft. damp loose		
Wt. of one cu. ft. dry rodded	112 # 12oz	108 # 8oz
Wt. dry material in 1 cu. ft. damp loose		
Wt. water in 1 cu. ft. damp loose		
Bulking factor		
Fineness modulus	3.39	7.42
Maximum size	3/8	3/4

Desired 28 day strength 3000 # sq. in. Exposure .... Slump 6-7

Real Mix 1:3 Gals. water per sack cement 5.734 Allowable Fin. Mod. Mixed Aggr. 5.25

Percent Sand (r) 56 Percent C. A. (1-r). 44

Wt. 1 cu. ft. separated aggregates (dry rodded) 110.91 #

Wt. 1 cu. ft. mixed aggregates (dry rodded)..........

Shrinkage factor.......... Nominal Mix..........

Field Mix 1:1.76:1.38 Bulked Field Mix..........

Water carried by aggregates in a 1 sack batch..........

Absorbed water in aggregates in a 1 sack batch 1%

Batch Data—Cement..........lbs., Water..........gals., Sand..........lbs., C. A..........lbs.

G. F. Baker

Operator.

Results:

For ideal curve.

Cylinder.	Area. sq. in.	Compressive strength in lbs.	Compressive strength in Lbs. per sq. in.
No. 1	9.06	8400	934.7
No.2	9.06	18920	2094.7
No.3	9.06	28120	3137.5
No.4	9.06	36230	4032.3
No.5	9.06	35280	3920.0
No.6	9.06	43470	4874.4
No.7	9.06	40000	4444.4
No.8	9.06	35000	3999.9
No.9	9.06	38960	4323.8
No. 10	9.06	38670	4260.0

Results:

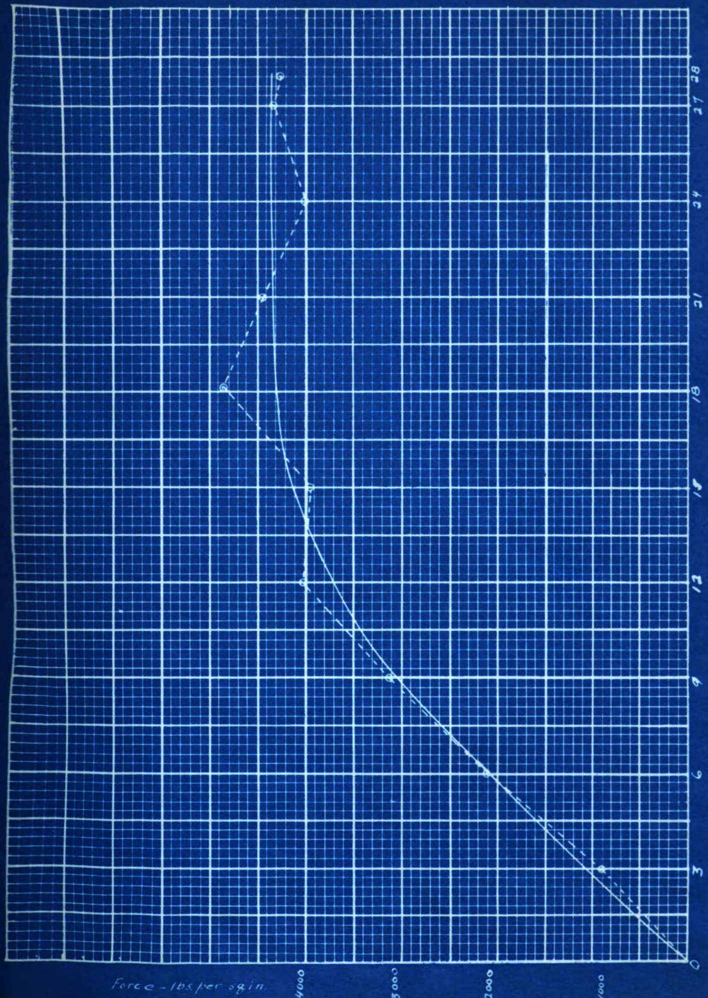
For fifty six test cylinders.

Group	Area sq. in.	Compressive strength lbs.	Average	Compressive strength lbs. per sq. in.
No. 1				
a.	9.06	28560.0		
b.	9.06	30000.0		
c.	9.06	28250.0		
d.	9.06	25430.0	28060	3110.0
No. 2				
a.	9.06	30450.0		
b.	9.06	29050.0		
c.	9.06	27140.0		
d.	9.06	31530.0	29540	3250.0
No. 3				
a.	9.06	27150.0		
b.	9.06	29670.0		
c.	9.06	27360.0		
d.	9.06	27700.0	27970	3080.0
No. 4				
a.	9.06	23670.0		
b.	9.06	26600.0		
c.	9.06	23920.0		
d.	9.06	25270.0	24890	2750.0
No. 5				
a.	9.06	20430.0		
b.	9.06	17830.0		
c.	9.06	23340.0		
d.	9.06	21130.0	21633	2390.0
No. 6				
a.	9.06	24930.0		
b.	9.06	26200.0		
c.	9.06	26220.0		
d.	9.06	27700.0	26262	2890.0
No. 7				
a.	9.06	23880.0		
b.	9.06	24280.0		
c.	9.06	24750.0		
d.	9.06	24580.0	24372	2680.0
No. 8				
a.	9.06	22690.0		
b.	9.06	19730.0		
c.	9.06	17750.0		
d.	9.06	21810.0	21410	2360.0

Results cont'd.:

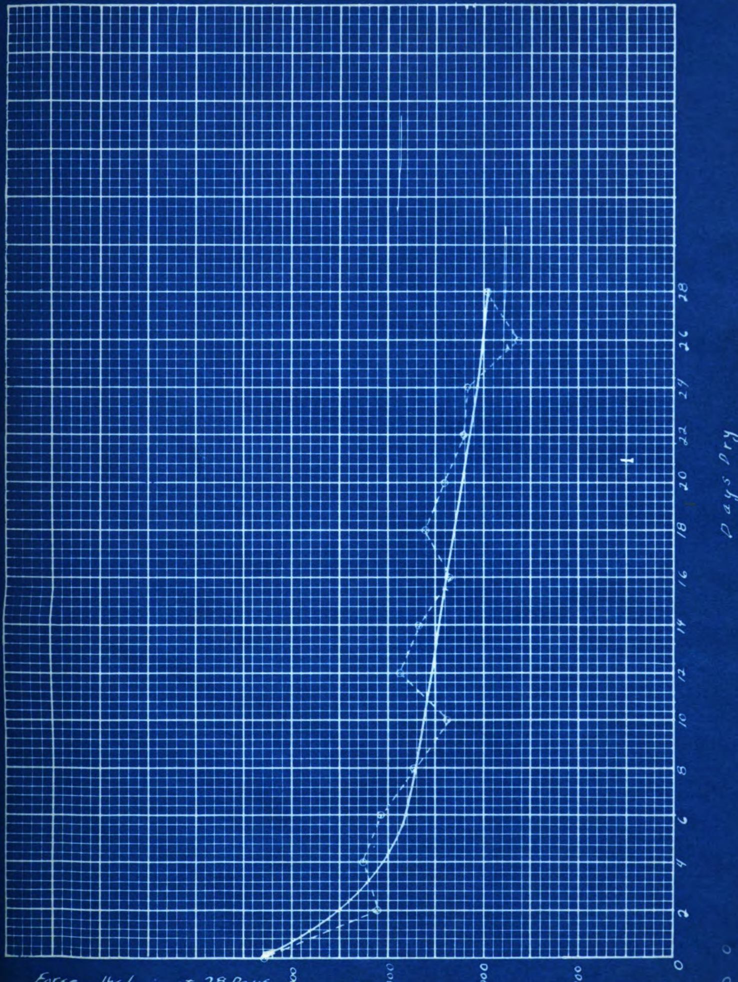
Group	Area sq. in.	Compressive strength lbs.	Average	Compressive strength lbs. per sq. in.
No. 9				
a.	9.06	23960.0		
b.	9.06	20000.0		
c.	9.06	23660.0		
d.	9.06	27330.0	23737	2610.0
No. 10				
a.	9.06	23780.0		
b.	9.06	22815.0		
c.	9.06	21580.0		
d.	9.06	19800.0	21994	2420.0
No. 11				
a.	9.06	23070.0		
b.	9.06	18420.0		
c.	9.06	15840.0		
d.	9.06	18590.0	20027	2210.0
No. 12				
a.	9.06	19310.0		
b.	9.06	15960.0		
c.	9.06	19270.0		
d.	9.06	19900.0	19493	2150.0
No. 13				
a.	9.06	15720.0		
b.	9.06	15310.0		
c.	9.06	19430.0		
d.	9.06	13710.0	14913	1645.0
No. 14				
a.	9.06	19230.0		
b.	9.06	18040.0		
c.	9.06	17540.0		
d.	9.06	17500.0	18077	1990.0

No. 1.



Time ~ Days
0
3
6
9
12
15
18
21
24
27
28
Force - lbs. per sq. in.
1000
2000
3000
4000

No. 2.



Explanation of tabulated results:

1. For ideal curve.

The compressive force required to break each cylinder was noted and tabulated in a separate column. This force was then divided by the end area of each cylinder and the compressive force in pounds per square inch was tabulated in another column.

2. For fifty six test cylinders.

These cylinders were divided into fourteen groups, the grouping being governed by the number of days that the cylinders were kept dry. These groups were composed of four cylinders each designated by a, b, c, &d. The compressive force required to break each cylinder was tabulated and the average of the forces for the four cylinders of each group taken as the compressive strength of the group. This average was then divided by the end area of each cylinder to give the compressive strength in pounds per square inch.

Explanation of graphs.

1. For ideal curve.

The time of curing was plotted against the compressive strength in pounds per square inch. A dotted straight line graph was then drawn through the various points. A smooth curve was then drawn which struck an average for the various breaking points. The formula given by "Duff A. Abrams" Professor in charge of laboratory at Lewis Institute, Chicago for the curve of ideal strength of a concrete is $s = \frac{14000}{7^x}$ in which s is the compressive strength in pounds per square inch, and x is the water cement ratio. In this test x was found to be equal to

Explanation of graphs cont'd.

.78 and the constant b which in Abrams curve was 7.0 was found to be equal to 7.26

For fifty six test cylinders.

In this curve the time that the cylinders were kept dry was plotted against the compressive strength of each group. In determining the compressive strength for each group it was seen that the compressive strength of some of the separate cylinders varied a great deal from what should be expected. These cylinders were there fore disregarded in the computation of the average strength of a group. Thus in group 5 b was thrown out, also c in group 8, c in 11, b in 12, and c in 13. On the graph a straight-line curve was first drawn through the various points, the a smooth curve was drawn which struck an average for the various strengths starting at the strength determined by curve No. 1 for the ideal strength at the end of twenty eight days.

Conclusions:

Although this concrete for the test was designed for a compressive strength of three thousand pounds at the end of twenty eight days, an examination of the results and the graph No. 1 for ideal strength will show that the actual strength at the end of twenty eight days was about four thousand pounds per square inch. This was undoubtedly due to two different factors. First, since the time that the curve showing the proper water cement ratio was determined the more refined methods of production of cement have brought about a cement that is vastly superior to the grade used for the determination of this curve and from this alone an increase over the designed strength of five or six hundred pounds is not uncommon. Second,it is an established fact that the amount of water in the concrete is a governing factor as far as the strength is concerned. In this test dried aggregates were used and one per cent of water added for absopption, however the mixing pans were not moistened befor the mixing was done and a certain amount of moisture would be used up in wetting the pans. This would lessen the amount of water in the concrete and thus increase the strength.

It will be seen that the strength of the concrete after being dried dropped a very appreciable amount by an examination of the results and the enclosed graphs. Since the scope of this work is so limited a specific statement of the decrease in strength cannot be made with any very great degree of certainty. An examination of graph No. 2 showa an initial drop in compressive strength of very nearly 37% though and this result may

be accecpted as approximately the correct figure. At the end of twenty eight days a drop of about 53% was found to exist. This is equally as correct as the preceeding drop. These results show that it is extremely important for the contractor to cure his concrete in the presence of external moisture and not give it a chance to become dried out at any time during the curing process. This is especially true of highway work where during the summer if no precautions are taken such as covering with soil and sprinkling the concrete is exposed to the direct rays of the sun as well as the high summer temperature and may thus be materially damaged as far as its compressive strength is concerned, and compressive strength and wearing qualities go hand in hand as required qualities of highway concrete. This is also true of concrete used in columns and other structural members and is of equal importance to the structural contractor. Although this test is inadequate and fails to reach any absolutely definite conclusion as to the exact amount of damage that will be done by drying, it proves conclusively that it will be very much to any contractor's or engineer's advantage to take special care to see that his concrete is cured under as nearly ideal conditions as possible, that is,in as damp a condition as may be consistent with local conditions and at the same time economical.