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The strength of cement under different conditions

Francis Joseph Tayman

Department: Civil, Architectural and Environmental Engineering

A.D.

THESIS

ON

THE STRENGTH OF CEMENT UNDER DIFFERENT CONDITIONS.

1st STRENGTH and TIME. NEAT CEMENT. ⊙

2nd STRENGTH and TIME. 1 to 1 CEMENT MORTAR. ⊙

3rd STRENGTH and DIFFERENT PARTS OF SAND. ⊙

4th STRENGTH and DIFFERENT AMOUNTS OF WATER. +

5th STRENGTH and DIFFERENT PARTS OF SAND. +

6th STRENGTH UNDER VARIOUS CONDITIONS. ⊙

⊙ hardened under water.
\+ " in air.

for degree of B-S in C-E

by
Francis J. Tayman

1899.

12-8-9? [illegible]

THESIS ON THE STRENGTH OF CEMENT UNDER THE DIFFERENT CONDITIONS.

1st. Relation between Strength and Time(neat Cement)in water.

2nd. Relation between Strength and Time (of one Cement,to one sand) in water.

3rd. Relation between Strength and proportion of sand(in water)

4th. Relation between Strength and quantity of water (neat Cement).

5th. Relation between Strength and proportion of sand(out of water)

6th. Strength under various conditions.

Object:-

Derivation of some Empirical Formulae,showing relation between breaking strength,and various functions which enter into Cement testing.

We find a great deal of experimental work done in Cement testing,also some curves plotted,but there are but few equations fitted to these curves,this,then,is the object of the present work.

In this work a great many interesting points have been made manifest,most of them are of no practical value but merely of interest in themselves. The work has been on several of the most important ones,to be given subsequently.

On these and a few others is the foundation of Cement testing, as given by all writers on the subject.

This work is entirely on the tensile strength,as that is the most important,so that all the experimental data show relations existing between breaking strength in pounds per square inch,and the other functions which may enter in the experiments.

Apparatus.

The following is a list of the Apparatus used in this work:

1st. Testing Machine.

2nd. Moulds,

3rd. Sieves,

4th. Trowels,

5th. Others of minor importance, such as thermometers, scales, glass, water, etc.

The testing machine was of Rheile's make and capable of registering a breaking strength from 0 to 1000 poundw.

The moulds were Tinius, Olsen & Co's. "Standard Type."

Sieves. They were of "Standard mesh" used to get various sizes of sand, and remove any foreign products which may happen to be present, and also in testing the fineness of the Cement.

Sand.

The sand used was not Standard sand, nor as good a quality as desired, but it was the best at hand. It was not analyzed but apparently had some material in it, such as chert, which injures its quality as a material for cement mortars.

It was dried and cooled to the temperature of the room before using.

Materials.

Cement, Sand and Water were the materials for this work.

The Cement was the best quality of Portland Cement that could be obtained. Sufficient quantity was taken from the barrel at a time for each experiment, which comprised from one hundred to one hundred and fifty briquettes.

This quantity was placed in a box and thoroughly mixed, the object of mixing being to have all the material in each briquette as nearly an average as possible. For instance, if the cement was used directly out of the barrel we might get cement of different quality for the different briquettes, due to the conditions of packing the cement, and also the difference between outer surface of barrel and center.

preliminary Tests.

I used cement from two different barrels, that is, in experiment I and II cement was used from one barrel, and in experiments III, IV, V, VI cement was used from another barrel.

The following are the Preliminary tests made upon these barrels.

Fineness of first barrel:

Cement depends greatly upon fineness of grinding for some of its good qualities, hence tests for fineness are usually made.

The sieves used for the test were, viz.

No. 50 (2500 meshes to square inch)

No. 80 (6400 meshes to square inch)

The average results of the cement of the first barrel in experiments I and II were as follows:

Of two hundred (200) grams taken there were rejected from

No. 50 sieve = 3.6 grams = a

No 80 sieve = 15.04 " = b

so that total rejection of No. 80 was a + b = 18.64

Rejected from No. 100 sieve = 21.5 grams = c

Hence total rejection from No. 100 was a + b + c = 40.14 grams.

Therefore

200 − 40.14 = 159.86 grams passed through all the sieves.

Soundness:- of first barrel.

This test is made to determine whether or not the cement will bulge or crack.

The test was made by the usual method, that is, one fourth part of water and three-fourths part cement (neat).

The pats made from the cement gave no sign of bulging or cracking.

Setting.

This test was determined by the aid of two wires, one of which had a point finer than the other, the latter having a larger brass (weighted) ball on the end than the former, The lighter ball containing the thicker wire was used to determine the time of beginning of setting, that is, when the pat of cement held the lighter ball "setting had commenced", and when it held the finer wire with the larger ball it was completely set.

The following are results from first barrel:

On March 1st. 1899 at 11.40 o'clock A.M. I made a mixture of cement and one quarter water,

It held wire No. 1 (or began to set) at 1.o'clock P.M.

It held wire No. 2 (or was set) at 6 o'clock P.M.

Fineness:-of second barrel.

Of 200 grams taken there were rejected from

No. 50 sieve = 2.7 grams = a

No. 80 " = 14.00 " = b

so that the total rejection of a + b = 16.7 grams rejected from No.100 sieve = 20.01 grams = c, making a total of a + b + c = 36.71 grams.

Hence

200 − 36.71 = 163.29 passed all sieves.

Soundness of second Barrel.

I could see no signs of bulging or cracking.

Setting for Second Barrel.

I made up pats under the same conditions as first. It was made up March 22nd. at 6 o'clock,A.M.

Held No. 1 wire at 7.55 o'clock A.M.

Held No. 2 wire at 2 o'clock,P.M.

Mortars.

The sand and cement were weighed instead of taking parts of volume,and water was first measured in a graduate before using. The temperature was also noted.

After weighing out the desired amount for conditions of each mortar,the sand and cement were thoroughly mixed before being made into briquettes.

The proportions used will be given in the details of the different experiments.

Experiments.

The experiments will first be briefly stated and explained in a general way.

The object of each experiment was to find,if possible,a relation between breaking strength and some one of the various functions,such as time,quantity of sand, quantity of water,etc., keeping all other conditions constant.

The temperature of the room and water was always recorded before mixing a batch of briquettes.

Experiment No. 1.

Strength and Time (neat cement).

The object of this experiment was to find a relation between tensile strength per square inch, and time after mixing.

Having mixed cement with water I noted the quantity of cement, quantity of water and temperature of room and of water.

The quantity of cement and water were the same for each lot of thirteen.

The amount of water used was 375 grams to 1500 grams of cement, or 25% was water.

For this experiment I made up thirteen batches of eleven briquettes. Each batch required 1500 grams of cement and 375 grams of water.

Each batch was allowed to set 24 hours in air(after being made. They were then placed uder water to harden and there remained until time for breaking.

In breaking I took one from each batch at the end of first day after mixing and breaking it, and the average gave me one point for a curve. I repeated this at end of second day, also fourth day, etc. This was continued until all the points were obtained, which enabled me to plot my curve, the record and discussion of which will be given later.

Experiment No. 2.

Strength and Time of a 1 to 1 cement mortar (in water).

This experiment was to determine the relation between breaking strength per square inch, and time after mixing of a 1 to 1 mortar, all other quantities being constant as in experiment No. 1.

In this experiment I used 1500 grams of mixture, that is, 750 grams of Cement and 750 grams of Sand and 250 grams of water.

The sand was passed through a No. 20 sieve to remove pebbles, stones, etc.

The sand and cement were weighed separately, thoroughly mixed before moulding and then treated as in the previous experiment.

This time I had an average of twelve briquettes instead of thirteen as in the first experiment.

I let them all set for twenty-four hours in air, just as in the previous experiment before putting them in water. Then as before explained I tested one from each lot at the end of certain times, such as first day, second day, etc. and obtained my average from the different points of the curve (which will be discussed later).

Although a 1 to 1 mortar was used, it is rational to suppose that for the same conditions any other mortor as 1 to 2, or 1 to 3, etc. should follow the same law, the only difference being in the constants involved in the equations.

Experiment No. 3.

Cement with different proportions of Sand (in water).

Here the ratio of the constituents in the mortar varied, all other things remained constant.

The mortar varied from a neat cement to all sand, giving thirteen points for the curve.

The method of making and breaking the briquettes was as follows:

In order to get the best average, the lot was made up of one batch at a time, making conditions for the average the same as in experiments I and II.

The temperature of room and of water used were recorded.

The quantity of water used was 250 grams to 1500 grams of the mixture of sand and cement.

In this experiment the briquettes were allowed to set for three days before putting them in water as some of them contained much sand and appeared very wet, and by this means had time to dry and to set thoroughly

Experiment No. 4.

Strength of Neat Cement by Varying Amount of Water for Mixing. (let harden under water).

In this experiment the weight of cement, time, etc. remains constant, but the quantity of water varies.

In this experiment it is necessary that the different batches, or lots be made up without loss of water.

The moulds rested on glass, (as in the other experiments) and were sealed around the edge on the lower side with oil to prevent the cement, (which was almost liquid in some cases) from escaping.

The mixture of cement was as usual 1500 grams but the quantity of water varied from 50 grams to 1000 grams, giving eleven points for the curve.

In this experiment the briquettes were allowed to set two days in air before placing them under water.

Experiment No. 5.

Strength with Different Proportions of Sand (out of water).

In this experiment the preliminary discussion is the same as for experiment No. 3. as all the conditions, etc. are the same except in this case the briquettes are allowed to harden in the air, instead of under water.

In this experiment batch No. 62 (where the mixture is all sand) is the same as batch No. 32 of experiment No. 3,as I took six briquettes from it,as it is also all sand.

Experiment No. 6.

Neat Cement Briquettes,Hardening under Water for Various Purposes.

The objects of this experiment are as follows:

1st. Strngth at six months.
2nd. Strength at one year.
3rd. Strength in five years

All to varify or prove the results obtained from equation of curve in experiment No. 1.

4th. Time required to break the briquettes under some percent of the average maximum load,that is,suppose than ten (10) of these briquettes are broken at one year,and by this means get an average, then,I load a briquette up to 75% of this average maximum load and wait for it to break,continuing this process and at different percentages of the maximum loading I get(by this means) some relations that are yet to be obtained.

The briquettes for this experiment are finished but the limit of time is so great that it will not be possible for me to put any of the results in this thesis,but the conditions,such as making them up, quantities of cement and water,temperature,etc. are just the same as in Experiment No. 1.

Some general remarks upon the different Experiments.

I used two barrels of cement for this work. The first barrel was used up on Experiments No. 1 and No. 2.

The second barrel was used for the rest of the experiments.

The water used was well and cistern water,obtained from those of the Missouri School of Mines at Rolla,Missouri.

In all these experiments the cement was sieved through a No. 30 Sand sieve to get rid of all foreign particles.

In experiment No. 2, and No. 3, the sand was sifted through a No. 20 sieve to remove pebbles etc. Then the sand was thoroughly dried and cooled to the temperature of the room before using, as hot dry sand may evaporate some of the water added in mixing.

In experiment No. 1 Sets G. and I. were mixed on a cold, freezing day, and as a result cracked and had to be thrown out as the results were so bad. Hence only had eleven in a set for an average instead of thirteen as stated before.

In all the data where parentheses (---) appear are places where results were so bad that they were disregarded.

In all cases the moulds were oiled and placed upon glass, so that they could be easily slipped in order to prepare them for further moulding.

The weight of Balls and diameter of wires of the previous described articles for testing the setting of Cements are as follows:
No 1 (for testing beginning of setting this contains small Ball + thick wire) its Ball weighs 113.3 grams, and diameter of wire is 1/12 of an inch
No 2 (Large ball + fine wire for testing complete setting)
Ball = 453.3 grams, and diameter of wire = 1/24 of an inch

Discussion of Curve No. I.

Results of my first experiment are given on page [illegible] from which the data given on page (18) were obtained by taking the average results of one day, two days four days, etc.

From this data the curve on Plate I was plotted, strength per square inch being plotted as ordinates and time as abscisses.

A curve drawn through these points resembles that of an Equilateral Hyperbola whose asymptotes are parallel to the axes.

The curve is shown in Figure I and all reference will be made to it during the derivation of its equation

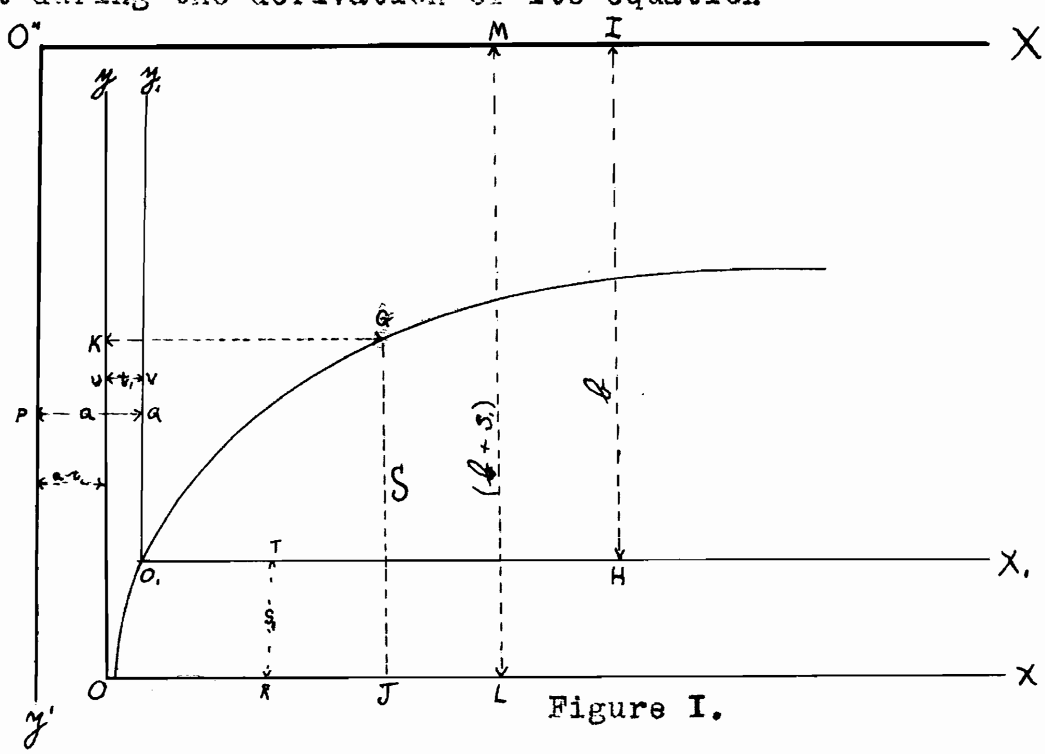


Figure I.

Let us assume the general equation of an Hyperbola which is

$x\ y = c$ c being a constant.

Let O" X' and O"Y' be asymptotes of the curve.

Since the curve does not pass through the origin take some know point O_1 for reference, this is referring the curve to a new axis, and in this case the origin is the first point on the curve, hence we have O_1X_1 and $O_1\,y_1$ as the new axis and the coordinates of the new origin are S_1 and t_1

Hence the equation of the curve with reference to the asymptotes is $X'\ Y' = C$ - - - 1

The problem is to get a constant value of C.

Take any known or average point on the curve as G.

$S = J\,G$ = average strength in pounds per square inch after mixing it is also equal to the distance of the average point from the old X axis.

$b = HI$ = distance of new X_1 axis from asymptotes O" Y'

$b + S_1$ = distance of Old X. axis from asymptote O" Y'

$t = KG$ = time in days after mixing before briquettes were broken, also distance of average point from old Y axis.

$a = PQ$ = distance of new Y_1 axis from the asymptote O"Y'

$S_1 = RT$ = average strength of eleven briquettes of one day after mixing.

$t_1 = UV$ = Time (one day) of breaking of first lot after mixing.

Now again let X_1 and Y_1 pass through O_1 and now we use this as origin.

Now to get values of X' and Y' in terms of $(t - t_1)$ and $(S - S_1)$ hence we have from figure

$X' = (X_1 - a)$

$Y' = (b - y_1)$

$c = ab$ Hence for any point

$(X_1 + a)(b - y_1) = ab = c$ - - - - - - - - - - - - - - (2)

Now x of first point is a

y of first point is b hence solving for C. we get from (2)

$bx_1 - x_1y_1 + ab - ay = ab$

$bx_1 - x_1y_1 - ay_1 = 0$ Now to solve for a and b as $c = ab$.

$(b - Y_1)x_1 = ay_1$ divided by x_1 and y_1

we get $\frac{b - y_1}{y_1} = \frac{a}{x_1}$

$\frac{b}{y_1} - 1 = \frac{a}{x_1}$ didived by $\frac{1}{a}$

$\left(\frac{b}{a} \times \frac{1}{y_1}\right) - \frac{1}{a} = \frac{1}{x_1}$ divided by $\frac{b}{a}$ or multiplied by $\frac{a}{b}$

and we have $\left(\frac{1}{y_1} - \frac{1}{b}\right) = \left(\frac{a}{b} \times \frac{1}{x_1}\right)$ this is equal

$\frac{1}{y_1} = \frac{1}{b} + \left(\frac{a}{b} \times \frac{1}{x}\right)$ but $y_1 = S - S_1$ and $X_1 = t - t_1$

$$\therefore \quad \left(\frac{1}{S - s_1}\right) = \left(\frac{1}{b}\right) + \left(\frac{a}{b}\right)\left(\frac{1}{t - t_1}\right) \quad \text{- - - - - - - - - - - - (3)}$$

In which $\frac{1}{b}$ is the intercept and $\frac{a}{b}$ is the slope of line.

Now multiplying by b we get

$$\left(\frac{b}{S - s_1}\right) = 1 + ab \left(\frac{1}{t - t_1}\right) \therefore ab = \left(\frac{b}{S - s_1} - 1\right)(t - t) = c.$$

If this assumed equation is the right equation to the curve they by plotting $\frac{1}{S - s_1}$ and $\frac{1}{t - t_1}$ we get a straight line as Shown on plate I which proves our statement.

Let us now investigate the meaning of the constants involved in this equation.

From the intercept on the $\frac{1}{S - S_1}$ axis the value of $\frac{1}{b}$ taken from the plot is 0016. from which b = 625.

Likewise $\frac{a}{b} = \tan\alpha = \frac{8}{9.25} = .8648.$

and from the value of b = (625) we find that a = b tan = 540.5.

S_1 and t_1 are other constants that enter but whose values are given in the tables.

Having these constants determined we may simplify equation(3) by putting in their values.

$S_1 = 17.7.$

$t_1 = 1.$

$a = 540.5$

$b = 625.$

Hence equation (3) becomes

$$\left(\frac{1}{S - 17.7}\right) = \left\{\left(\frac{1}{625}\right) + \left(\frac{540.5}{625}\right)\left(\frac{1}{t - 1}\right)\right\}$$ from this

$$S = \frac{1}{\left\{\frac{1}{625} + \frac{540.5}{625}\;\frac{1}{t - 1}\right\}} - 17.7$$

RESULTS OF EXPERIMENT No 1.

Bach A	Tempt of Room: 20°C	
	Tempt of Water 22°	
No	Time in Days	Strength in # Per Sq. inch.
1	1	50
2	2	208
3	4	297
4	7	382
5	14	383
6	21	617
7	30	553
8	40	677
9	60	634
10	90	667
11		

Bach C	Tempt of Room 23°	
	Tempt of Water 18½°	
No	Time in Days	Strength in # Per Sq. inch.
1	1	36
2	2	153
3	4	280
4	7	312
5	14	550
6	21	638
7	30	562
8	40	677
9	60	746
10	90	679
11		

Bach B	Tempt of Room 23°	
	Tempt of Water 17°	
No	Time in Days	Strength in # Per Sq. inch.
1	1	20
2	2	110
3	4	247
4	7	352
5	14	542
6	21	606
7	30	(436)
8	40	682
9	60	738
10	90	(609)?
11		

Bach D	Tempt of Room = 12¾°	
	Tempt of Water = 12½°	
No	Time in Days	Strength in # Per Sq. inch.
1	1	17
2	2	55
3	4	266
4	7	351
5	14	364
6	21	561
7	30	638
8	40	406
9	60	612
10	90	746
11		

Bach E	Tempt of Room = 12¾°	
	Tempt of Water = 12¾°	
No.	Time in Days	Strength in # Per. Sq. inch.
1	1	9
2	2	62
3	4	197
4	7	417
5	14	482
6	21	620
7	30	680
8	40	[illegible]
9	60	586
10	90	783
11		

Bach G	Tempt of Room 16°	
	Tempt of Water = 15°	
No.	Time in Days	Strength in # Per Sq. inch
1	1	[illegible]
2	2	79
3	4	[illegible]6
4	7	[illegible]77
5	14	5[illegible]
6	21	620
7	30	645
8	40	(7[illegible]0)
9	60	753
10	90	808
11		

Bach F	Tempt of Room = 16°	
	Tempt of Water = 15°	
No.	Time in Days	Strength in # Per Sq. inch
1	1	11
2	2	63
3	4	287
4	7	376
5	14	657
6	21	613
7	30	570
8	40	564
9	60	725
10	90	723
11		

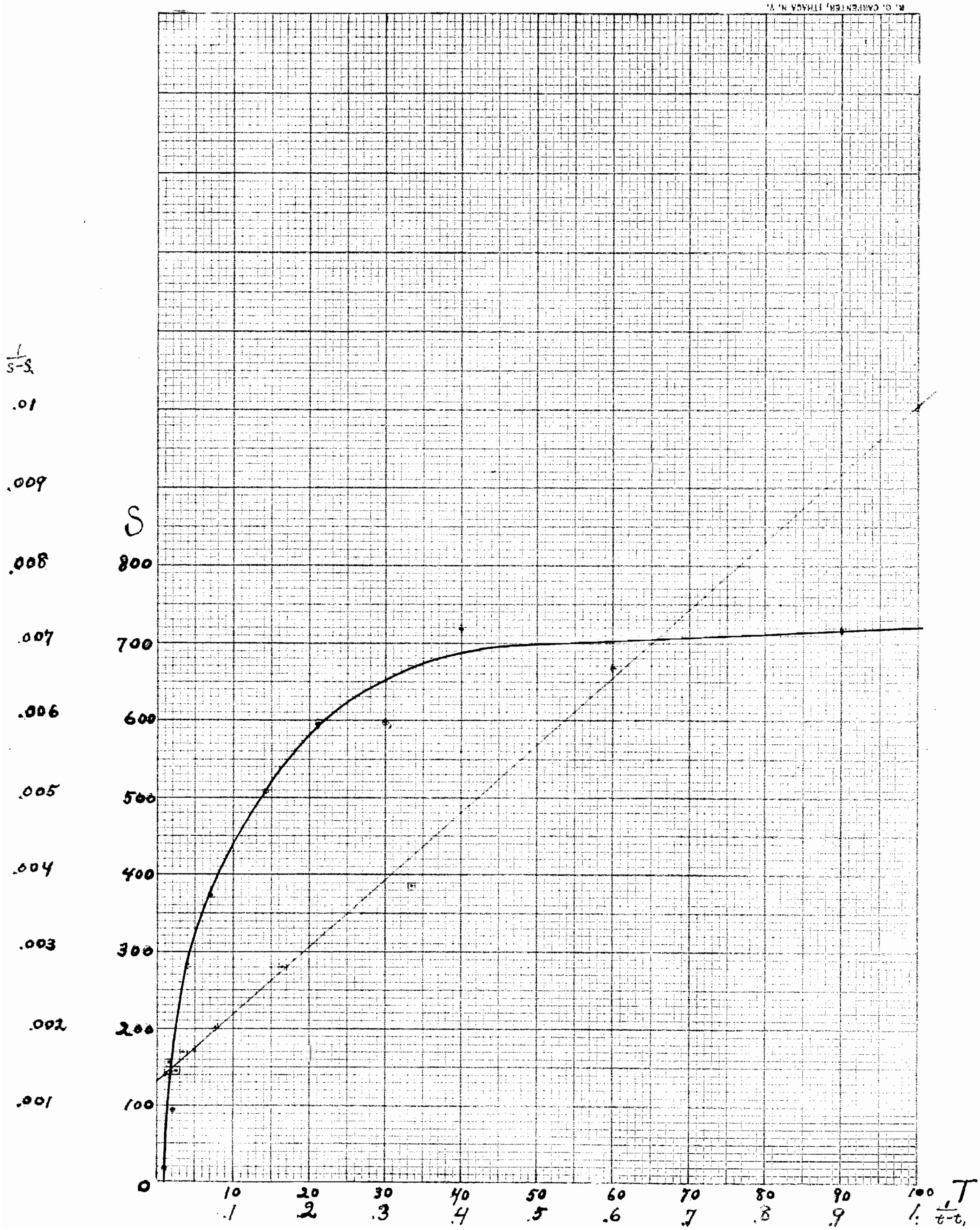
Bach J	Tempt of Room = 14¼°	
	Tempt of Water = 13½°	
No	Time in Days	Strength in # Per. Sq. inch.
1	1	11
2	2	41
3	4	223
4	7	320
5	14	[illegible]38
6	21	477
7	30	572
8	40	613
9	60	602
10	90	
11		

Bach K	Tempt of Room = 13½°	
	Tempt of Water = 12½°	
No.	Time in Days	Strength in # Per Sq inch.
1	1	6
2	2	36
3	4	227
4	7	334
5	14	410
6	21	551
7	30	572
8	40	562
9	60	664
10	90	
11		

Bach M	Tempt. of Room = 17°	
	Tempt of Water = 15½°	
No.	Time in Days.	Strength in # Per Sq inch.
1	1	13
2	2	93
3	4	290
4	7	373
5	14	538
6	21	619
7	30	596
8	40	709
9	60	658
10	90	
11		

Bach L	Tempt of Room = 15¾°	
	Tempt of Water = 13¼°	
No	Time in Days	Strength in # Per Sq inch
1	1	11
2	2	77
3	4	311
4	7	412
5	14	475
6	21	594
7	30	594
8	40	490
9	60	547
10	90	
11		

Bach	Tempt of Room =	
	Tempt of Water =	
No.	Time in Days	Strength in # Per Sq inch.
1	1	
2	2	
3	4	
4	7	
5	14	
6	21	
7	30	
8	40	
9	60	
10	90	



$\frac{1}{S-S_1}$
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
S
800
700
600
500
400
300
200
100
0
10 20 30 40 50 60 70 80 90 100
T
.1 .2 .3 .4 .5 .6 .7 .8 .9 1.
$\frac{1}{t-t_1}$

PLATE I.

DATA.

1	2	3	4	5	6
S Average Strength of 10-or-11 Briquettes	T Time in days after mixing	$S - S_1$ S minus Strength at one day	$t - t_1$ t minus one day	$\frac{1}{S - S_1}$	$\frac{1}{t - t_1}$
17.7	1	0.	0		
93.8	2	76.1	1	.01314	1.
282.4	4	264.7	3	.00378	.33⅓
375.	7	357.3	6	.0028	.166
507.2	11	489.5	13	.00204	.077
594.9	21	577.2	20	.00173	.05
598.2	30	580.3	29	.00170	.0344
718.3	40	700.6	39	.00143	.0256
660.5	60	642.8	59	.00155	.0170
715.4	90	697.7	89	.00143	.01123

Discussion of Curve No. II.

This curve is shown on Plate II page 25 and when plotted it has the appearance of being of same type as curve No.I.

Hence we are justified in assuming a similar equation as in first case, the derivation of which is the same, and need not be repeated.

If we use an equation similar to (3) of curve No.1, but introducing the values obtained for this second curve we will obtain a line and if it is straight our second assumption is correct. The values of these quantities of second curve are given in Plate II. page (26).

The results of this plot is shown on Plate II. A straight line apparently satisfies all the points. Therefore our assumption in Experiment No.I also holds good for this second experiment.

The symbols S, t &tc. involved in the following discussion, are strength, time, etc. as before explained, the equation then is.

$$\frac{1}{s - s_1} = \frac{a}{b}\,\frac{1}{t - t_1} + \frac{1}{b} \quad \text{-------------(1)}$$

The constants for this equation are determined as they were in previous discussion.

$\frac{1}{b}$ the intercept on the $\frac{1}{s - s_1}$ axis is = .0028 from which $b = 357.1$.

Now $\frac{a}{b} = \tan .B$ = slope of line and $= \frac{22}{28} = .857$.

$a = b \tan\beta = 357.1 \times .857 = 306.035$.

Combining these values (b and $\frac{a}{b}$) we get = 306.035.

$b + S_1$ gives the strength that the briquettes would reach at an infinite time. b+S' being the distance of old X axis to X' axis. X' axis being one asymptote of the curve.

This is also shown directly from the equation by making $t = \infty$ thus

$$\frac{1}{s - s_1} = \frac{a}{b}\ \frac{1}{t - t_1} + \frac{1}{b} \quad \text{becomes}$$

$$\frac{1}{s - s_1} = 0 \quad + \frac{1}{b} \quad \text{from which}$$

$$b = s - s_1 \text{ or } s = b + s_1 = b + 9.29 = 357.1 + 9.29 = 366.39$$

To determine the other asymptote(which is Y') may be done in either of two ways. First,by knowing the value of a and t_1 taken from the plot, Second, by making $s = \infty$ in equation of the curve.

The equation then becomes

$$\frac{1}{\infty - s_1} = \frac{a}{b}\left(\frac{1}{t - t_1}\right) + \frac{1}{b}$$

$$\text{or } 0 = \left[(a)\left(\frac{1}{t - t_1}\right) + 1\right] \quad \text{dividing through by } \frac{1}{b}$$

and multiplying out gaves:- $t = t' - a = 1 - 306.035 = - 305.035.$

The curve fully drawn shows that for any time after the curve crosses the X axis that the strength is very negative but apparently has no physical meaning.

The equation in its reduced form obtained by the substitution of the known values of the constants is

$$S = \frac{1}{\left[\left(\frac{1}{b} + \frac{a}{b}\left(\frac{1}{t - t_1}\right)\right) - S_1\right]} = \frac{1}{\left[\left(.0028 + .857\left(\frac{1}{t - 1}\right)\right) - 9.3\right]}$$

Bym making $S = 0$. t becomes equal to 11 hours 20.4 minutes which shows that same thing holds true in this experiment as in experiment No.I. viz. that it takes a certain time after mixing before cement acquires any strength.

This gives a means of determining the time of setting of cement mortars(allowing this time to be what we call time of setting) which cannot be accurately done by arbitrary means,used for neat cements, the most common being the wires and balls as previously explained.

It will be noticed in this experiment that the values of the time when S = 0 is greater than in experiment No.I. This seems rational from the experimental data, viz. that it requires a longer time for a briquette of morter to reach a given strength than one of neat cement.

From this it is rational to conclude that as proportion of mortar increases the time of setting also increases, that is a mortar of all sand would require and infinite time to set in order to give any strength. This interesting point gives material for further investigation, viz. to determine relation that exists between amount of sand and cement used and time of setting, also the relations that exists between strength and different proportions of sand in the mortar. This latter is considered in next curve discussed.

By making S = 0 we get t = 11 hours and 20.4 minutes which shows from calculation, and also from plot that there is a certain time after mixing before cement acquires any strength.

This being the case it seems allowable to call this time t' at which cement began to show strength.

From plot the time t' = 21 hours.

The curve shows that strength approaches an infinite limit in an infinite time.

This finite value is = b + s, = 357.1 + 9.29 = 366.39 pounds per square inch, hence our curve becomes a horizontal line after a comparatively short time.

RESULTS OF EXPERIMENT. No. 2.

Bach N	Tempt of Room 17½°	
	Tempt of Water 21½°	
No.	Time in Days	Strength in # Per. Sq inch.
1	1	7
2	2	57
3	4	122
4	7	219
5	14	242
6	21	249
7	30	248
8	40	311
9	60	374
10	80	
11		

Bach P	Tempt of Room = 17½°	
	Tempt of Water = 18½°	
No.	Time in Days	Strength in # Per Sq inch.
1	1	10
2	2	72
3	4	168
4	7	220
5	14	254
6	21	338
7	30	382
8	40	342
9	60	378
10	80	
11		

Bach O	Tempt of Room = 17½°	
	Tempt of Water = 16½°	
No.	Time in Days	Strength in # Per Sq inch
1	1	10
2	2	78
3	4	152
4	7	123
5	14	270
6	21	273
7	30	318
8	40	340
9	60	368
10	80	
11		

Bach Q	Tempt of Room = 19°	
	Tempt of Water = 17°	
No.	Time in Days	Strength in # Per. Sq inch
1	1	8
2	2	70
3	4	174
4	7	244
5	14	296
6	21	273
7	30	304
8	40	340
9	60	370
10	80	
11		

Bach R	Tempt of Room = 19½° Tempt of Water = 17½°	
No.	Time in Days	Strength in # Per Sq. inch
1	1	11
2	2	59
3	4	185
4	7	224
5	14	302
6	21	339
7	30	328
8	40	348
9	60	378
10	80	
11		

Bach T	Tempt of Room = 20° Tempt of Water = 20½°	
No.	Time in Days	Strength in # Per. Sq. inch
1	1	8
2	2	76
3	4	177
4	7	216
5	14	317
6	21	308
7	30	348
8	40	324
9	60	436
10	80	
11		

Bach S	Tempt of Room = 20° Tempt of Water = 18½°	
No.	Time in Days	Strength in # Per Sq. inch
1	1	9
2	2	63
3	4	170
4	7	222
5	14	322
6	21	248
7	30	308
8	40	308
9	60	430
10	80	
11		

Bach U	Tempt of Room = 18¾° Tempt of Water = 19¾°	
No.	Time in Days	Strength in # Per. Sq. inch
1	1	11
2	2	72
3	4	162
4	7	171
5	14	274
6	21	306
7	30	348
8	40	350
9	60	412
10	80	
11		

Bach V	Tempt of Room = 17½°	
	Tempt of Water = 18¾°	
No.	Time in Days	Strength in # Per Sq. inch
1	1	15
2	2	74
3	4	164
4	7	218
5	14	215
6	21	270
7	30	313
8	40	347
9	60	390
10	80	
11		

Bach X	Tempt of Room = 16½°	
	Tempt of Water = 16½°	
No.	Time in Days	Strength in # Per. Sq. inch
1	1	6
2	2	62
3	4	194
4	7	222
5	14	253
6	21	315
7	30	278
8	40	310
9	60	432
10	80	
11		

Bach W	Tempt of Room = 16¾°	
	Tempt of Water = 17½°	
No.	Time in Days	Strength in # Per. Sq. inch.
1	1	8
2	2	65
3	4	166
4	7	262
5	14	258
6	21	278
7	30	346
8	40	375
9	60	370
10	80	
11		

Bach Y	Tempt of Room = 16°	
	Tempt of Water = 16°	
No.	Time in Days	Strength in # Per Sq. inch
1	1	9
2	2	70
3	4	178
4	7	222
5	14	272
6	21	325
7	30	307
8	40	344
9	60	407
10	80	
11		

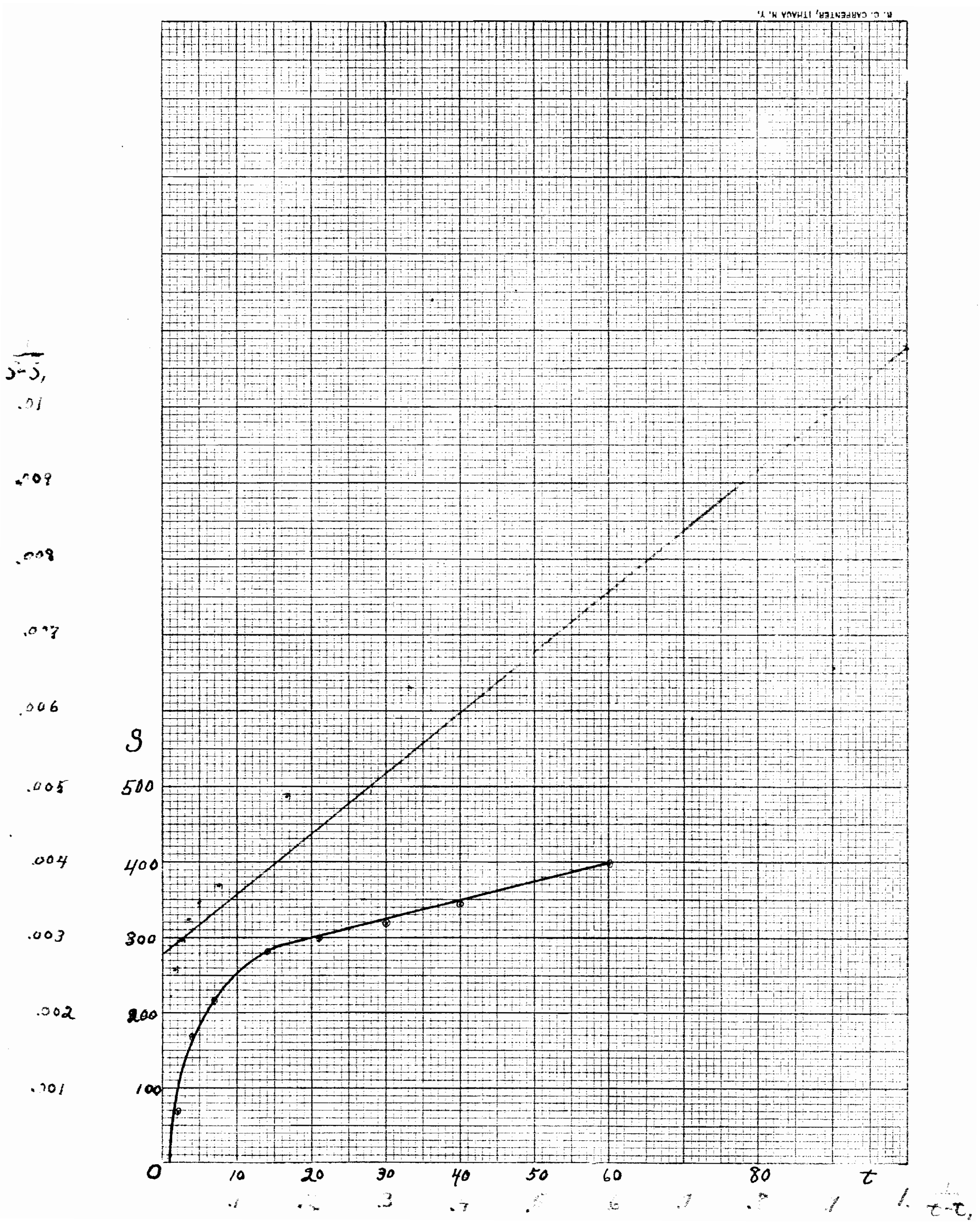

R. C. CARPENTER, ITHACA N. Y.
S
500
400
300
200
100
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
10
20
30
40
50
60
80
t
.1
.2
.3
.4
.6
.8
1.

PLATE II.

DATA.

1	2	3	4	5	6
S Average Strength of 12 Briquetts	t Time in Days After Mixing	S - S. S minus Strength at One Day.	t - t. t minus One Day	$\frac{1}{S-S_1}$	$\frac{1}{t-t_1}$
9.29	1	0	0		
68.4	2	59.1	1	.01776	1.
167.6	4	158.3	3	.00631	.33$\frac{1}{3}$
215.2	7	205.9	6	.00485	.166
281.2	14	271.9	13	.00367	.077
299.8	21	290.5	20	.00344	.05
319.	30	309.7	29	.00322	.0344
343.75	40	334.4	39	.00299	.0256
398.75	60	389.4	59	.00256	.0170
	80		79		.0126

Discussion of Curve Number III.

The results of the third experiment are as given on page (29) from which the data on page 33 were obtained by taking the average of eleven briquettes.

From this data the curve on Plate III was plotted, with strength as ordinates and parts of sand as abscissae.

This curve gives results which seems to justify the assumption of an equation to an equilateral hyperbola referred to its asymptotes (X Y) as axis.

The derivation of the equation is as follows:

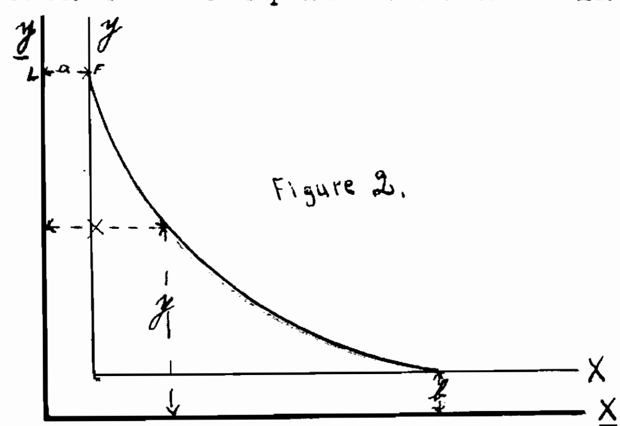


Figure 2.

Let us assume that the equation referred to X Y as axis is

$x\,y = K$ - (1)

Let S average strength of ten briquettes in pounds per square inch.

p = proportion of sand.

a and b = distance between y Y and x X respectively.

s = 0 F (fig. 2) = strength of neat cement (properly slacked)

Let us now take point F for reference.

Let B be any point on the curve whose coordinates are x and y referred to X Y axes.

Now $A\,B = X = p + a$

$B\,C = y = s + b$

Substituting in equation (1) we get.

$(p+a)(S+b)=K$ - (2)

To find the value of K in terms of known constant S' and unknown constants a and b, consider the point F on the curve. The x and y of this point are a and b + S' respectively.

Then K for this point F = xy = a(s'+ b) putting this value in (2) we have.

$$(p+a)(s+b) = a(S'+b)$$

multiplying and reducing we get

$$S = \frac{a(s' - s)}{p} - b \quad \text{- (3)}$$

If our assumption is correct, by plotting s and $\frac{S' - s}{p}$ we get a straight line.

a = slope and b = intercept on s axis.

The points were so scattered in parts of *the plot* that the line could only be drawn approximately.

This line is shown on Plate III page (*33*).

The value of b = - 65 and $\frac{b}{a}$ = $\tan\alpha = \frac{2}{5}$ = .4 $a = \frac{b}{.4} = \frac{-65}{.4} = -162.5$

The values of a and b having been determined equation(3) may be written

$$s = \frac{-162.5 \times 600 \quad 65}{p \quad (-162.5)}$$

By making S = 0 we get p 23.1 proportion of sand that would give a zero breaking strength.

By making S = ∞ we get the value of p which located the X axis = - a.

Thus $S = a\left(\frac{s' - s}{p}\right) - b$

$ps = as' - as - pb.$

$s(p+a) = as' - pb$ from which

$$p + a = \frac{As' - pb}{s} = \frac{A s' - pb}{\infty} = 0$$

$\therefore \; p = -a$

By making $p = \infty$ we locate X :- thus

$$S = a\left(\frac{s' - s}{p}\right) - b = a\left(\frac{s' - s}{\infty}\right) - b$$

$\therefore \quad S = -b$

S' from plot $= 600$

RESULTS OF EXPERIMENT No. 3.

Bach 20. No.	Tempt of Room = 12° Tempt of Water = $12\frac{3}{4}$° Prop. of Cement + Sand	Strength in # Per Sq. inch
1	All Cement	298
2	" "	299
3	" "	274
4	" "	244
5	" "	338
6	" "	441
7	" "	346
8	" "	366
9	" "	382
10	" "	352
11	" "	442

Bach 21. No.	Tempt of Room = $14\frac{1}{2}$° Tempt of Water = $13\frac{1}{2}$° Prop. of Cement + Sand	Strength in # Per Sq. inch
1	4C to 1 S	317
2	" " "	572
3	" " "	515
4	" " "	506
5	" " "	512
6	" " "	551
7	" " "	474
8	" " "	512
9	" " "	530
10	" " "	574
11	" " "	438

Bach 22. No.	Tempt of Room = 14° Tempt of Water 13° Prop. of Cement + Sand	Strength in # Per Sq. inch
1	2C to 1 S	382
2	" " "	476
3	" " "	462
4	" " "	502
5	" " "	490
6	" " "	485
7	" " "	383
8	" " "	476
9	" " "	471
10	" " "	434
11	" " "	428

Bach 23 No.	Tempt of Room = $13\frac{3}{4}$° Tempt of Water = $13\frac{1}{2}$° Prop. of Cement + Sand	Strength in # Per Sq. inch
1	1C to 1 S	304
2	" " "	341
3	" " "	390
4	" " "	402
5	" " "	252
6	" " "	345
7	" " "	350
8	" " "	395
9	" " "	408
10	" " "	364
11	" " "	251

Bach 24	Tempt of Room = 13½°	
	Tempt of Water = 13½°	
No.	Prop. of Cement & Sand	Strength in # Per Sq. inch
1	1C to 2 S	225
2	" " "	211
3	" " "	207
4	" " "	228
5	" " "	237
6	" " "	194
7	" " "	208
8	" " "	241
9	" " "	252
10	" " "	208
11	" " "	223

Bach 25	Tempt of Room = 13½°	
	Tempt of Water 13½°	
No.	Prop. of Cement & Sand	Strength in # Per. Sq. inch.
1	1C to 3 S	132
2	" " "	156
3	" " "	132
4	" " "	137
5	" " "	152
6	" " "	146
7	" " "	155
8	" " "	136
9	" " "	170
10	" " "	162
11	" " "	157

Bach 26	Tempt of Room = 15°	
	Tempt of Water = 14°	
No.	Prop. of Cement & Sand	Strength in # Per. Sq. inch.
1	1C to 4 S	105
2	" " "	125
3	" " "	148
4	" " "	128
5	" " "	129
6	" " "	120
7	" " "	105
8	" " "	101
9	" " "	115
10	" " "	134
11	" " "	98

Bach 27	Tempt of Room = 15°	
	Tempt of Water = 14½°	
No.	Prop. of Cement & Sand	Strength in # Per. Sq. inch.
1	1C to 5 S	81
2	" " "	69
3	" " "	92
4	" " "	75
5	" " "	81
6	" " "	103
7	" " "	96
8	" " "	70
9	" " "	86
10	" " "	95
11	" " "	X

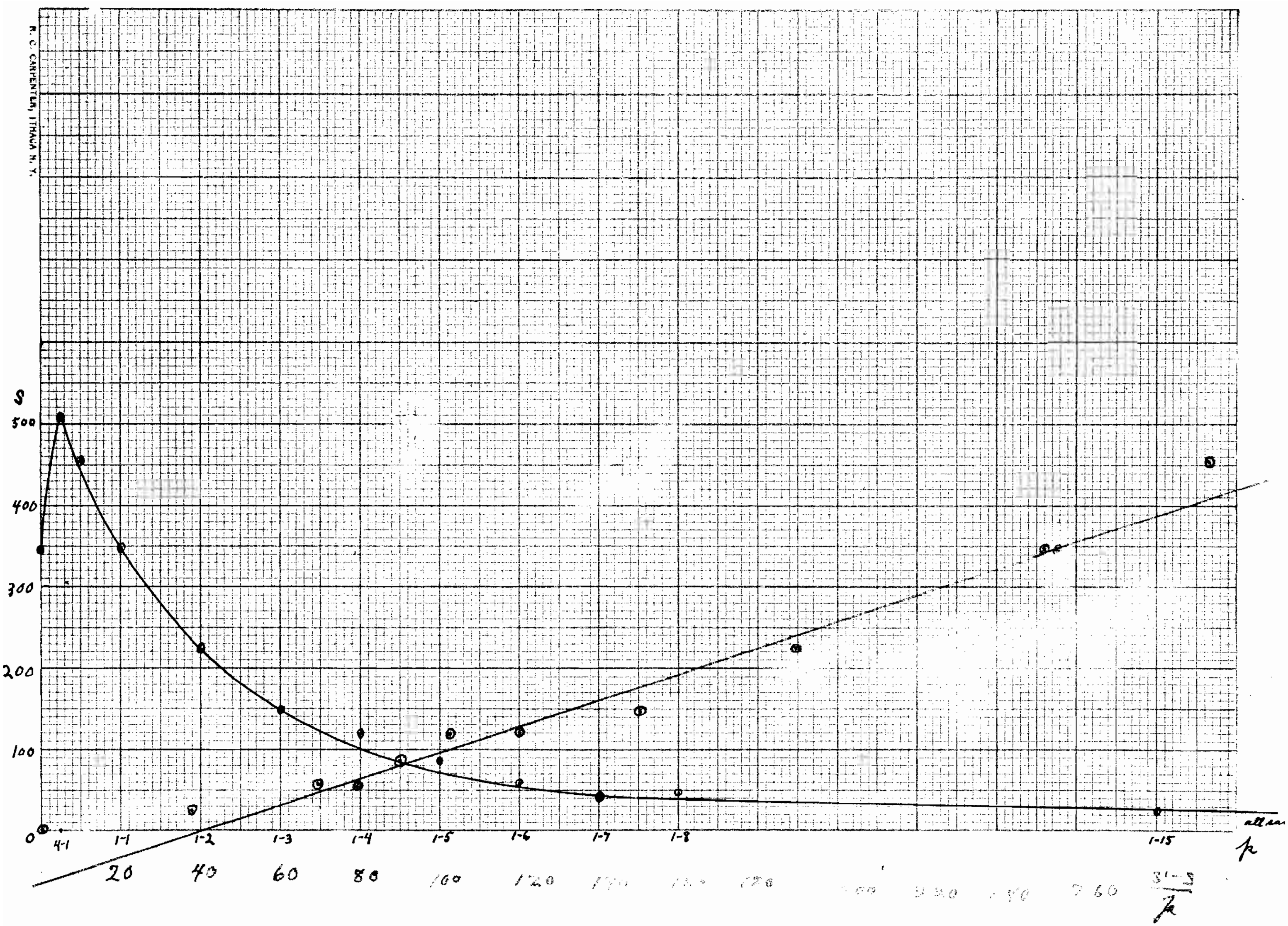
Bach 28	Tempt of Room 14½°	
	Tempt of Water 14½°	
No.	Prop. of Cement + Sand	Strength in # Per Sq. inch
1	1C to 6 S	61
2	" " "	64
3	" " "	58
4	" " "	65
5	" " "	59
6	" " "	59
7	" " "	54
8	" " "	52
9	" " "	51
10	" " "	72
11	" " "	58

Bach 29	Tempt of Room =	
	Tempt of Water =	
No.	Prop. of Cement + Sand	Strength in # Per Sq inch
1	1C to 7 S	
2	" " "	
3	" " "	
4	" " "	
5	" " "	
6	" " "	
7	" " "	
8	" " "	
9	" " "	
10	" " "	
11	" " "	

Bach 30	Tempt of Room =	
	Tempt of Water =	
No.	Prop. of Cement + Sand	Strength in # Per Sq inch
1	1C to 8 S	
2	" " "	
3	" " "	
4	" " "	
5	" " "	
6	" " "	
7	" " "	
8	" " "	
9	" " "	
10	" " "	
11	" " "	

Bach 31	Tempt of Room = 14½°	
	Tempt of Water = 13¾°	
No	Prop. of Cement + Sand	Strength in # Per Sq. inch
1	1C to 15 S	27
2	" " "	20
3	" " "	30
4	" " "	21
5	" " "	26
6	" " "	21
7	" " "	23
8	" " "	21
9	" " "	30
10	" " "	21
11	" " "	23

Bach 32	Tempt of Room = 14°	
	Tempt of Water = 14½°	
No.	Prop. of Cement + Sand	Strength in # Per. Sq inch.
1	All Sand	0
2	" "	0
3	" "	0
4	" "	0
5	" "	0
6	" "	0
7	" "	0
8	" "	0
9	" "	0
10	" "	0
11	" "	0



R. C. CARPENTER, ITHACA N.Y.
S
500
400
300
200
100
0
4-1
1-1
1-2
1-3
1-4
1-5
1-6
1-7
1-8
1-15
p
20
40
60
80

PLATE III.

DATA.

1	2	3	4
S	p	S' – S	$\frac{S' - S}{p}$
Average Strength of 11 Briquettes	Parts of Cement + Sand	Strength of neat briquettes minus S	
343.8	All Cement	256.2	∞
507.0	4C to 1S	93.	372.
453.5	2C to 1S	146.5	2930
347.2	1C to 1S	252.8	252.8
221.3	1C to 2S	378.7	189.3
148.6	1C to 3S	451.4	150.4
119.3	1C to 4S	480.7	120.2
84.8	1C to 5S	515.2	1[illegible].0
59.3	1C to 6S	540.7	[illegible]
41.8	1C to 7S	558.2	79.7
47.6	1C to 8S	552.4	6[illegible].05
23.2	1C to 15S	576.8	33.4
0	All Sand	600.	0

Discussion of Curve No.IV.

The results are given on page (35). from which the data on Plate IV. page (38) is obtained and from this data we plotted the curve shown on Plate IV.,using breaking strength as ordinates and amounts of water as abscissas.

The curve is so irregular that it is impossible to derive an equation for it,so that all I can conclude from the curve is that it rises gradually until it reaches a certain height,about 520 pounds and then remains constant regardless of amount of water used,provided the experiment is conducted as we preformed it,that is, be sure and keep putting cement in the moulds until they are completely filled or packed and allowing all excess of water to flow off.

It is also reasonable to suppose that strength decreases as water(added) decreases,and that it finally reaches zero when there is not enough water added to slack the cement,or cause setting.

RESULTS OF EXPERIMENT No. 4

Bach 39	Tempt of Room = 14°	
	Tempt of Water = 15°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	322
2	"	400
3	"	292
4	"	448
5	"	345
6	"	460
7	"	466
8	"	507
9	"	458
10	"	503
11	"	445

Bach 40	Tempt of Room = 14°	
	Tempt of Water = 13¾°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	435
2	"	248
3	"	322
4	"	410
5	"	321
6	"	414
7	"	468
8	"	438
9	"	377
10	"	338
11	"	389

Bach 41	Tempt of Room = 12°	
	Tempt of Water = 14°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	360
2	"	346
3	"	458
4	"	412
5	"	370
6	"	374
7	"	424
8	"	414
9	"	467
10	"	344
11	"	422

Bach 42	Tempt of Room = 12°	
	Tempt of Water = 14°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	614
2	"	540
3	"	560
4	"	493
5	"	544
6	"	418
7	"	499
8	"	480
9	"	464
10	"	508
11	"	500

Bach 43	Tempt of Room = $16\frac{1}{2}°$	
	Tempt of Water = 15°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	505
2	"	563
3	"	624
4	"	645
5	"	646
6	"	581
7	"	419
8	"	624
9	"	519
10	"	652
11	"	X

Bach 44	Tempt of Room = $18\frac{1}{2}°$	
	Tempt of Water = $16\frac{3}{4}°$	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	503
2	"	506
3	"	446
4	"	548
5	"	511
6	"	502
7	"	575
8	"	474
9	"	610
10	"	566
11	"	555

Bach 45	Tempt of Room = 20°	
	Tempt of Water = 18°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	520
2	"	527
3	"	465
4	"	536
5	"	571
6	"	545
7	"	551
8	"	528
9	"	501
10	"	536
11	"	538

Bach 46	Tempt of Room = $21\frac{1}{4}°$	
	Tempt of Water = $20\frac{1}{2}°$	
No.	Time in Days	Strength in # Per. Sq. inch.
1	60	421
2	"	525
3	"	518
4	"	498
5	"	479
6	"	503
7	"	570
8	"	566
9	"	621
10	"	645
11	"	584

Bach 47	Tempt of Room = 18½°	
	Tempt of Water = 18½°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	494
2	"	440
3	"	490
4	"	502
5	"	508
6	"	492
7	"	500
8	"	465
9	"	498
10	"	376
11	"	510

Bach 48	Tempt of Room 15½°	
	Tempt of Water 16½°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	599
2	"	562
3	"	523
4	"	620
5	"	561
6	"	490 ?
7	"	607
8	"	510
9	"	638
10	"	404
11	"	677

Bach 49	Tempt of Room = 14½°	
	Tempt of Water = 15½°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	501
2	"	470
3	"	503
4	"	574
5	"	530
6	"	624
7	"	507
8	"	555
9	"	542
10	"	508
11	"	X

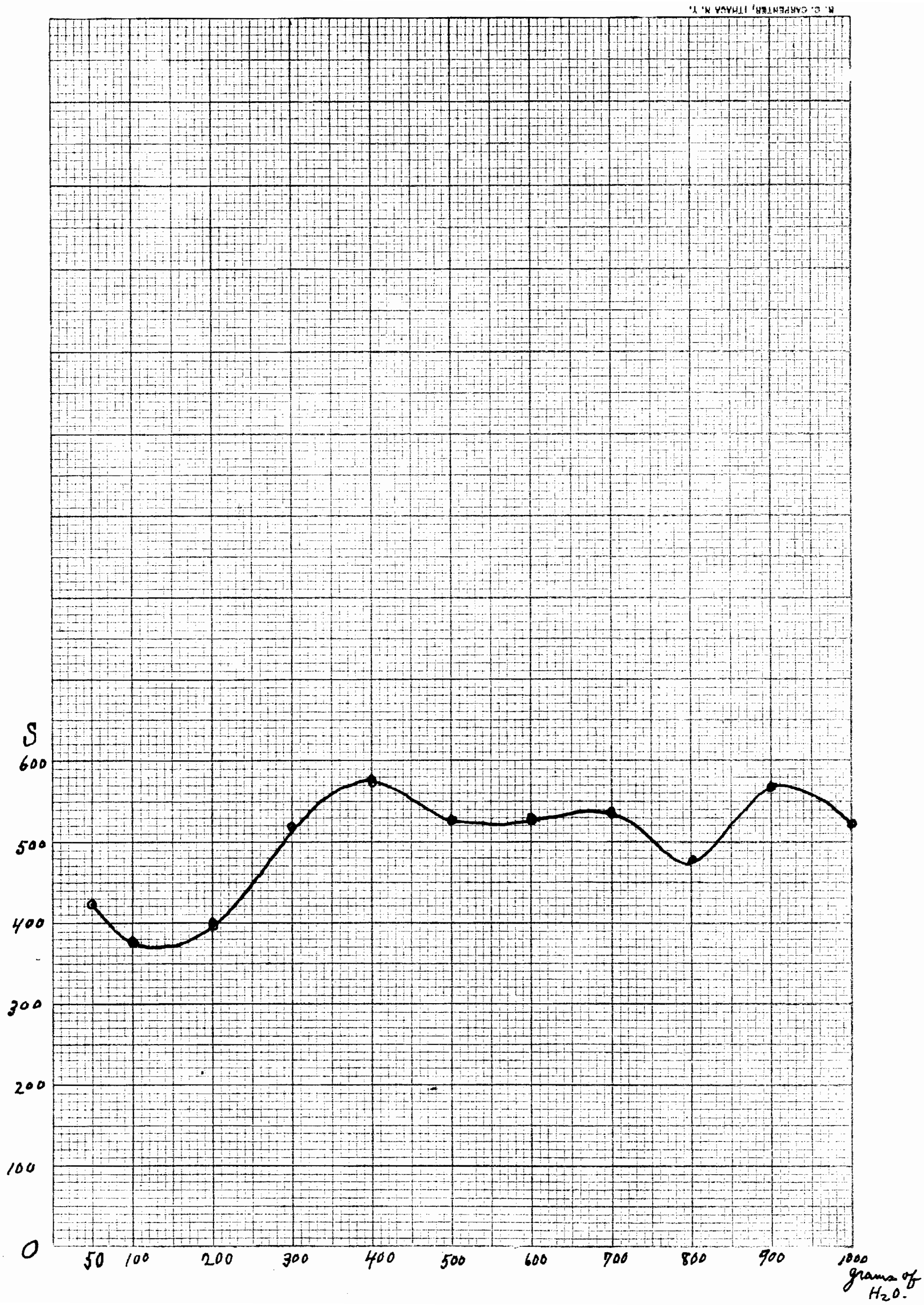

S
600
500
400
300
200
100
0
50
100
200
300
400
500
600
700
800
900
1000
grams of H_2O.

PLATE XV.

DATA.

1	2
Quantity of water in Grams.	Average Strength of 11 Briquettes
50.	422.4
100.	378.2
200.	399.2
300.	510.9
400.	577.8
500.	526.9
600.	528.9
700.	539.1
800.	479.6
900.	568.2
1000.	531.4

Discussion of Curve Number V.

The results are shown on page 41 and data on page 45 from which the curve shown on Plate V was obtained.

Now this curve is similar to that of No.III and all the conditions that fulfill No.III likewise fulfill this curve, therefore the discussion are exactly similar and need not be repeated here. The only difference between this Experiment and Experiment No.III is, that the briquettes in this experiment were allowed to harden in air instead of under water. Theconstants involved are the only things that differ.

S', S a,b, etc. have similar meaning to those of Curve No.III.

$S' = 590$

$b = -25$

$$\frac{b}{a} = \tan\beta = \frac{2}{10} = \frac{1}{5} = .2$$

$$a = \frac{-25}{.2} = -125.$$

$$S = \frac{S'a - b}{a + p} = \frac{590 \times (-125) + 25}{-125 + p}$$

Similar

$p = -a$ and $S = -b$

The following conclusions may be drawn:

As amount of sand increases the strength decreases. Hence curve has two finite limits, one being strength with zero amount of sand, and the other being pure sand with zero strength.

It can also be noted that the more sand used the longer it takes to set (in order to gain strength) From this we conclude that a pure sand briquette must set for an infinite time in order to obtain strength or set, this however has no physical meaning.

RESULTS OF EXPERIMENT No. 5.

Bach 50	Tempt of Room: 13½°	
	Tempt of Water = 13½°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	314
2	"	249
3	"	269
4	"	210
5	"	156
6	"	204
7	"	309
8	"	199
9	"	232
10	"	218
11	"	252

Bach 52	Tempt of Room: 19½°	
	Tempt of Water = 16°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	440
2	"	393
3	"	357
4	"	395
5	"	358
6	"	341
7	"	409
8	"	432
9	"	414
10	"	415
11	"	387

Bach 51	Tempt of Room - 19°	
	Tempt of Water = 16°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	414
2	"	474
3	"	575
4	"	502
5	"	446
6	"	489
7	"	461
8	"	510
9	"	459
10	"	464
11	"	478

Bach 53	Tempt of Room = 18°	
	Tempt of Water = 12°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	244
2	"	267
3	"	221
4	"	299
5	"	298
6	"	270
7	"	264
8	"	261
9	"	358
10	"	273
11	"	274

Bach 54	Tempt of Room = 18°	
	Tempt of Water = $12\frac{3}{4}$°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	196
2	"	135
3	"	219
4	"	199
5	"	162
6	"	205
7	"	144
8	"	160
9	"	158
10	"	155
11	"	161

Bach 55	Tempt of Room = 20°	
	Tempt of Water $16\frac{1}{2}$°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	115
2	"	83
3	"	116
4	"	155
5	"	114
6	"	160
7	"	170
8	"	151
9	"	156
10	"	161
11	"	128

Bach 56	Tempt of Room = 21°	
	Tempt of Water = $19\frac{1}{2}$°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	109
2	"	73
3	"	80
4	"	118
5	"	110
6	"	75
7	"	91
8	"	132
9	"	88
10	"	98
11	"	102

Bach 57	Tempt of Room = 22°	
	Tempt of Water 19°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	65
2	"	71
3	"	56
4	"	102
5	"	106
6	"	90
7	"	82
8	"	60
9	"	61
10	"	103
11	"	99

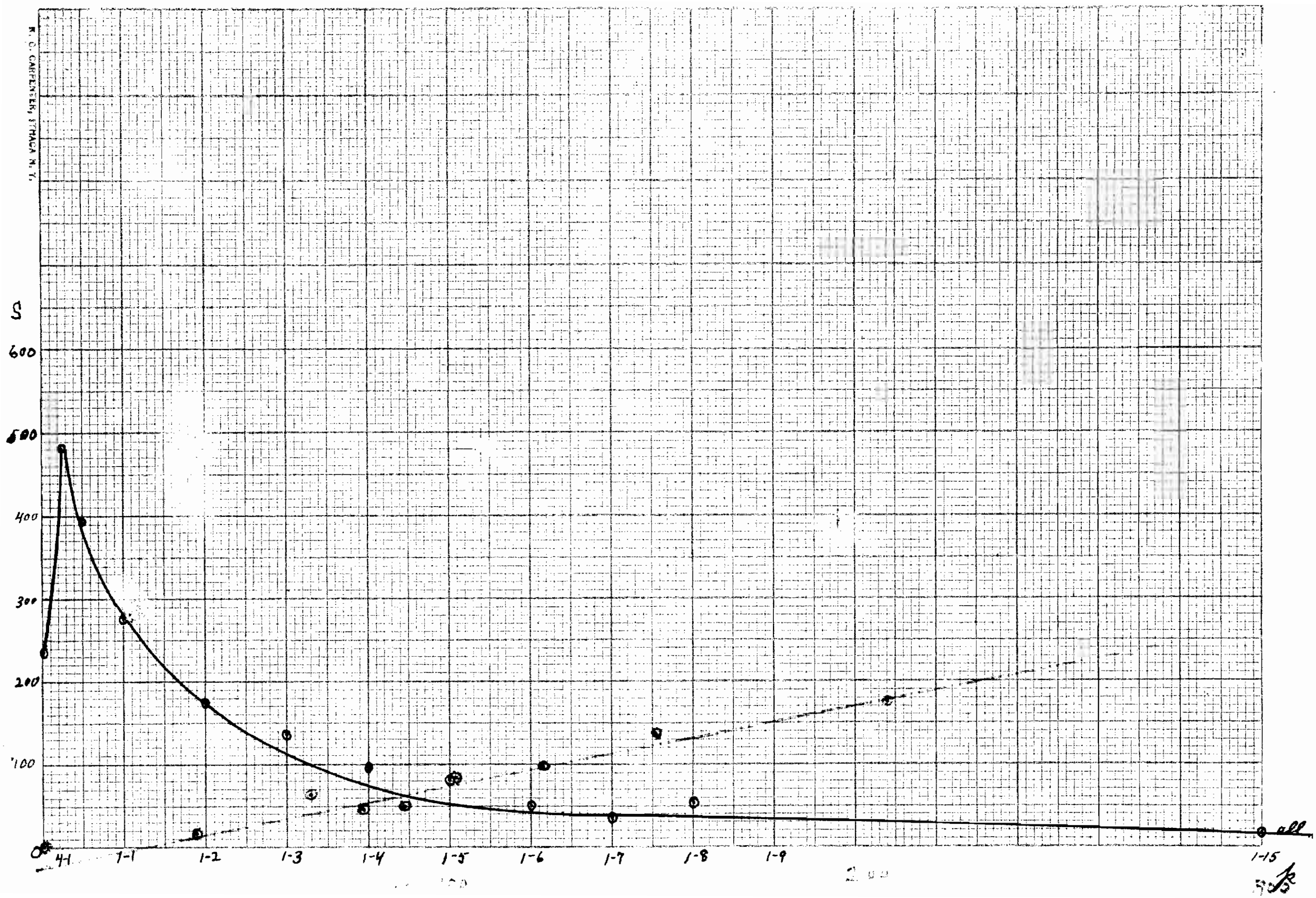
Bach 58	Tempt of Room = 15½°	
	Tempt of Water = 11½°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	46
2	"	47
3	"	60
4	"	33
5	"	48
6	"	53
7	"	32.
8	"	59
9	"	50
10	"	60
11	"	69

Bach 59	Tempt of Room = 8½°	
	Tempt of Water = 11½°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	31
2	"	24
3	"	37
4	"	40
5	"	34
6	"	37
7	"	40
8	"	34
9	"	37
10	"	26
11	"	38

Bach 60	Tempt of Room = 20°	
	Tempt of Water = 19°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	61
2	"	55
3	"	57
4	"	52
5	"	62
6	"	62
7	"	56
8	"	59
9	"	57
10	"	55
11	"	X

Bach 61	Tempt of Room = 20°	
	Tempt of Water = 19°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	19
2	"	17
3	"	13
4	"	4
5	"	15
6	"	23
7	"	16
8	"	10
9	"	24
10	"	14
11	"	X

Bach 62	Tempt of Room = 14° Tempt of Water = 14½°	
No.	Time in Days	Strength in # Per. Sq. inch
1	60	0
2	"	0
3	"	0
4	"	0
5	"	0
6	"	0
7	"	0
8	"	0
9	"	0
10	"	0
11	"	0



S
600
500
400
300
200
100
0
.41
1-1
1-2
1-3
1-4
1-5
1-6
1-7
1-8
1-9
1-15
all

PLATE. V.

DATA.

1	2	3	4
S	p	S′ − S	$\frac{S' - S}{p}$
Average of 11 Briquettes	Parts of Cement + Sand	Strength of neat Briquettes minus S	
236.5	All Cement	353.5	—
481.1	4C to 1 S	108.9	435.6
393.7	2C to 1 S	196.3	3926
275.3	1C to 1 S	314.7	314.7
173	1C to 2 S	417	208.5
137.2	1C to 3 S	452.8	150.9
97.9	1C to 4 S	492.1	123.0
81.4	1C to 5 S	508.6	101.7
50.6	1C to 6 S	539.4	89.9
34.4	1C to 7 S	555.6	79.3
56.7	1C to 8 S	533.3	66.6
15.5	1C to 15 S	574.5	33.3
0	all Sand	590	0

Conclusion.

From these experiments it is observed that many experiments coůld be preformed,as there are other relations that might be discussed, accompanied by many points of interest,hence we conclude that this subject is unlimited in regard to experimental work.