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A RESEARCH STUDY OF CONCRETE
SET UNDER PRESSURE

THESIS FOR THE DEGREE OF B. S.

S. D. Long

1932

THESIS

Concrete - Testing

Civil engineering - Strength of materials

**A Research Study of Concrete
Set Under Pressure**

**A Thesis Submitted to
The Faculty of
MICHIGAN STATE COLLEGE
of
AGRICULTURE AND APPLIED SCIENCE
by**

Accepted
Submitted
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**Candidate for the Degree of
Bachelor of Science**

June 1932

THESIS

In the building industry of to-day there is one material which presents a vast field for researchive study. It is concrete. Although Portland cement was patented in 1824, it is still baffling the world's best engineers when it comes to designing a mix that will in every way surpass the advantages of steel.

Research work in this field has been carried on by all cement manufacturers in a vain attempt to produce a product that would meet the utmost of demands. A great deal of work was done on the fineness modulus, which cement companies tell us is no longer the accepted method giving way to a mix determined entirely by weight. Much time and energy was spent before the water-cement-ratio theory was advanced. But in spite of all the previous study given this subject, the ultimate strength of concrete is much the same to-day as it was a quarter of a century ago. Attention has been paid almost entirely to the designing of the mix rather than to increasing its ultimate strength. In these designs a 4,000 lb. concrete was considered of extremely high strength. The purpose of these experiments was to determine if it was possible to raise the ultimate compressive strength of concrete, to determine the reason for any increase in strength, and lastly to what extent it is applicable to the building industry of to-day and future days. If one of these statements is determined to our benefit something of real value will have been accomplished.

The methods used in this work, through the best knowledgs available, are entirely new in this country. There has been some talk that a French concrete was designed for an ultimate strength above 10,000 lbs. per. sq. in. The method of setting under pressure is believed to have been used. However, for the American engineer it is something entirely new and worthy of a great deal more study in the future.

The idea behind the experiment is in itself very simple. There are two known ways of increasing the compressive strength of concrete; namely, by designing a very dense mix or by decreasing the water-cement-ratio. By allowing concrete to take the initial set under pressure it might be able to accompolish both of the above items.

To make this possible a steel cylinder was designed which would allow a concrete cylinder to be cast inside ithaving a finished size of 5" by $2\frac{1}{2}$ " dia. It was necessary to use a $2\frac{1}{2}$ " diameter in view of the fact that the compression machine had available a maximum pressure of 200,000 lbs., or would give a unit pressure of 41,000 lbs. on the concrete cylinder. The complete design was carried out as follows:

A butt joint cylinder of #14 gauge sheet iron was rolled to a size of 7" by $2\frac{1}{2}$ " inside diameter. A steel cylinder, 7" long, 5" O.D., $2\frac{1}{4}$ " core, was cast in grey machine iron having an ultimate tensile strength of 40000 lbs. per. sq. in. The core hole was then reamed out to

take the sheet iron cylinder in a good tight fit. A piece of cold rolled steel shafting, $2\frac{1}{2}$ " in diameter and 3" long was used as a piston to apply the pressure from the press to the concrete.

The assembly was used in the following way. The inside of the steel cylinder was greased with a heavy graphite grease and the sheet iron cylinder forced in until one end was flush with the steel cylinder. The inside of sheet iron cylinder was greased with the same grease and the concrete placed in resulting mould. The height of the concrete in the mould was about 6" leaving 1" of the cylinder above the concrete. This left a convenient rest for the piston. The assembly was placed in the compression machine and any desired pressure applied.

The walls of the steel cylinder were designed as though under absolute hydraulic pressure and were made 1" thick. This proved erroneous by more than 50%.

Out side of the fact that the concrete cylinder and the sheet iron sleeve had to be forced out of the steel cylinder by pressure, the assembly served admirably, withstanding pressures of 200,000 lbs. on the piston.

The plan of the experiment was to make four cylinders at a time, allowing three of them to set as standard 4" by 8" cylinders and one as a pressure set cylinder. This would allow a comparative test of each set of cylinders. The pressure was raised from 0 to

200,000 lbs. on the piston. The equivalent unit pressure is 0 to 41,000 lbs. per sq. in. Since a 28 day compressive test was desired, only a limited number of cylinders could be made and tested during the allotted time. These, with a number of 7 day compressive tests, should give comparative results.

The mixing of the concrete was carried on in a uniform manner. The temperature was constant, the mixing of the aggregate was methodical each time. After remaining in the cylinders for twenty-four hours, the concrete was placed in water and allowed to cure for 28 days. At the end of the curing period all four cylinders were tested at the same time. Those having set under pressure were capped with plaster of paris and allowed to harden before testing. All data pertaining to the tests was kept on abstract cards.

As time was of great importance it was necessary to confine the tests to one standard mix. From a collaboration of data, namely, fineness modulus of the aggregate, type of aggregate, size of standard and pressure cylinders it was decided that a 1:1.5:2.6 mix would be the best suited for the tests. This mix was used in all the tests.

The coarse aggregate used was crushed stone. During the first part of the tests the coarse aggregate was a combination of crushed and uncrushed stone screened to a size of $\frac{1}{4}$ " to $\frac{3}{4}$ ". This gave a very dense mix. The last

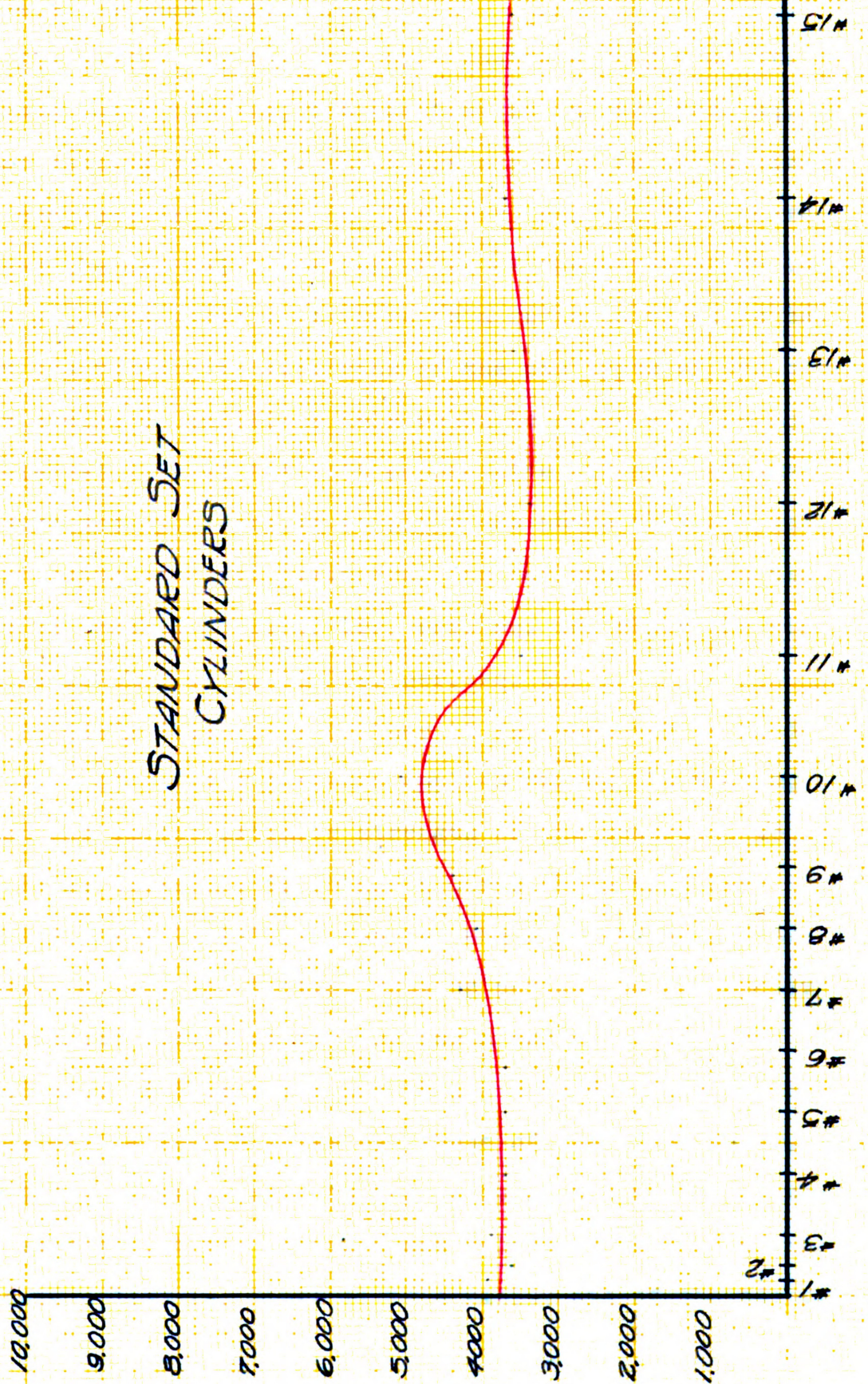
part of the experiment was run using an aggregate of pure crushed stone already screened to a size of $\frac{1}{4}$ " to $\frac{3}{4}$ ". This mix was not quite as dense as the previous one.

A Study of the Results

A study of the results of this experiment are very interesting, being somewhat opposite of those expected. In this type of work a comparison study is best suited to bring about the desired ends. To do this three curves have been plotted showing the functions of two variables. A fourth plate shows the three curves plotted on a common axis.

The first plate shows the variation in compressive strength of the standard cylinders. The abscissa is in cylinder sets and the ordinate is in lbs. per. sq. in. It must be remembered that cylinder sets correspond to applied pressure, since for each cylinder set made there is a corresponding applied pressure. It will be noticed that the first part of this curve is stable at an average of 4,500 lbs. per sq. in. It is then seen to drop suddenly to an average of 3,500 lbs. per. sq. in. This is in all probability due to the change in the coarse aggregate that was mentioned before. The first aggregate gave a very dense mix, being of crushed and uncrushed stone, size $\frac{1}{4}$ " to $\frac{3}{4}$ ". The second aggregate of pure crushed stone didn't give as dense a mix as the first one. Taking the curve as a unit it shows that a good average

STANDARD SET CYLINDERS



concrete was used throughout.

Plate #2 shows the unit compressive strength of the pressure set cylinders. The abscissa is in lbs. per. sq. in. of setting pressure, while the ordinate is the ultimate unit compressive strength in lbs. per. sq. in. This curve follows the general characteristics of the curve shown in plate #1. This shows that there is a definite relation between the respective strengths of the two types of cylinders. Under ordinary conditions this would be expected. The point of interest is that the unit compressive strength of the pressure set cylinders is at all times above that of the corresponding standard cylinders. The maximum point on this curve is reached at 9,500 lbs. per. sq. in. while the minimum is reached at 4,000 lbs. per. sq. in.

To study this curve further it is necessary to find just what effect the pressure applied during the setting period has on the ultimate strength of the concrete. To do this it is necessary to obtain a curve which will have only the characteristics due to the application of the pressure during the initial setting period. To accomplish this a third curve, called the index curve, is plotted. The coordinates of this curve are obtained by dividing the ordinates of the second curve by those of the first curve. This index curve represents the ratio of the unit compressive strength of the pressure set cylinders to that of the standard cylinders. Since it is a ratio, all of the strength

PRESSURE SET
CYLINDERS

PLATE No 2

10,000

9,000

8,000

7,000

6,000

5,000

4,000

3,000

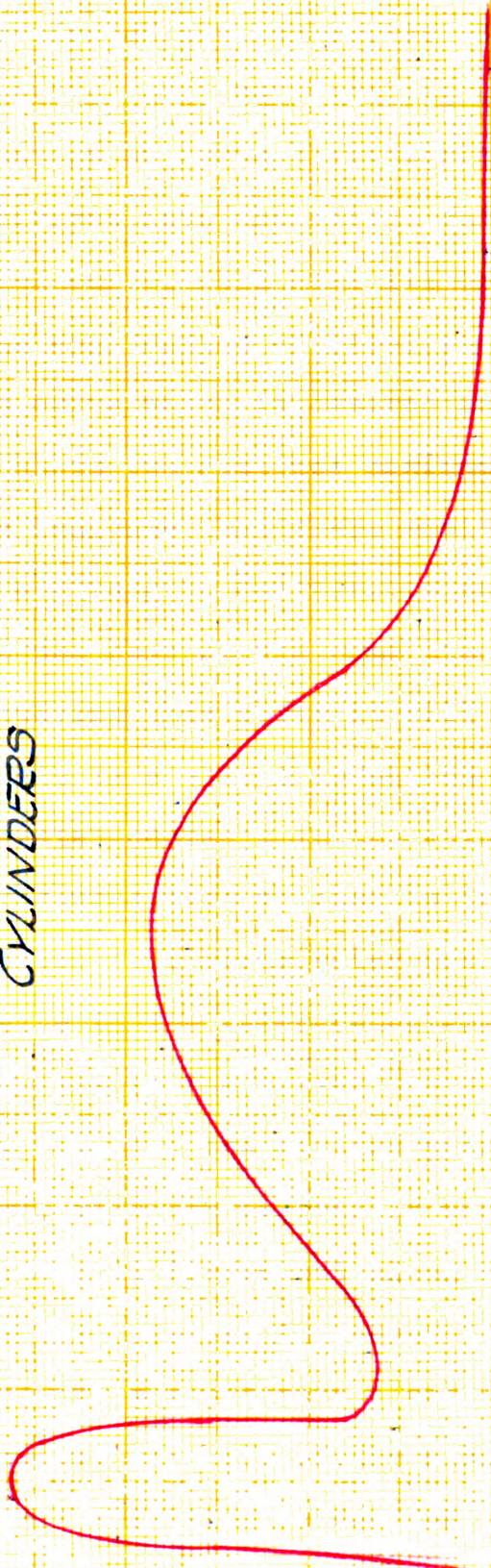
2,000

1,000

ULTIMATE COMPRESSION
POUNDS PER SQ. IN.

48,000
40,000
37,500
35,000
32,500
30,000
27,500
25,000
22,500
20,000
17,500
15,000
12,500
10,000
7,500
5,000
2,500

SETTING PRESSURE LBS. PER SQ. IN. DRAWN 6-1-32 JOK.



characteristics of the two curves which are variations in the concrete, will be identical and will cancel out of the equation of curve characteristics when the first curve is divided into the second curve. The third curve, or the index curve, will have its characteristics determined by the application of pressure to the setting concrete. It is this curve which is desired and is best suited for study. It shows two distinct maximum points, which in themselves indicate that there must be two reasons for an increase in strength. Further, it shows that these two increases do not come at the same time. This is unfortunate.

In studying this curve it will be seen to rise very rapidly. This is a strong indication that the increase is due to a partial decrease in the water-cement-ratio. When the low pressures were applied to the setting concrete, it was noticed that clear water was forced out of the mould. This decrease in the water-cement-ratio would account for the sudden rise in the curve.

After reaching the maximum point the curve drops slowly down. This can be readily understood. As the pressure increases it forces out along with the water a little cement. As the pressure increases it forces out more and more cement. This would have a decided effect in lowering the compressive strength of the mix.

Up until this time no decided settling of the piston was noticed. This was an indication that the mix was not being compressed to any considerable extent. That is, the mix was not made much denser by the application of the

2.50

2.25

2.00

1.75

1.50

1.25

1.00

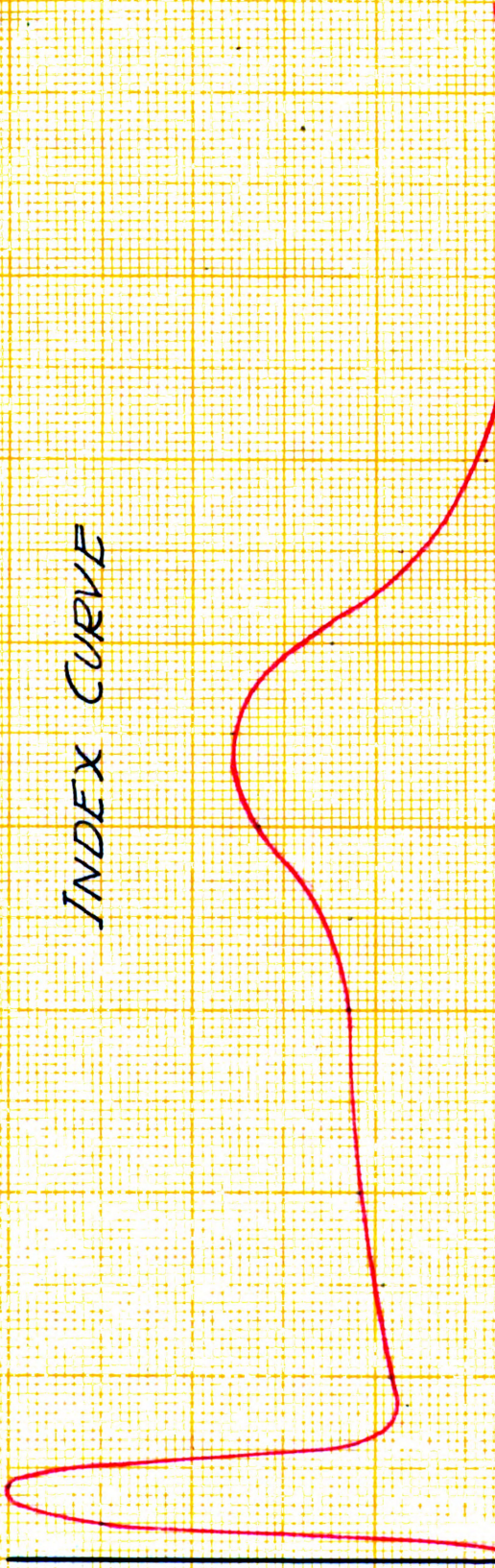
.75

.50

.25

RATIO OF UNIT STRENGTHS

INDEX CURVE



Note:- The ordinates of this curve were obtained by dividing those of curve #2 by those of curve #1.

PLATE NO 3

2,500

5,000

7,500

10,000

12,500

15,000

17,500

20,000

22,500

25,000

27,500

30,000

32,500

35,000

37,500

40,000

42,500

SETTING PRESSURE LBS. PER SQ. IN. DRAWN 6-1-32-30A

pressure up to this point. As the pressure was increased above 12,000 lbs. per. sq. in. a settle was noticed. As the pressure went on up to 42,000 lbs per. sq. in. the settling was in some cases as high as 1". This showed a much denser mix was being effected. This second maximum point is due, then, to the effecting of a denser mix.

As the pressure was raised above 20,000 lbs. per. sq. in. the settling was rather uniform. This is to be expected, for some place along the curve a point must be reached where any further increase in pressure would not produce a further increase in strength, but would serve to fracture the aggregate. When it is seen that some of aggregate was under a unit pressure of 42,000 lbs. and further that this pressure was not purely hydraulic, it will be easy to realize that some of the larger pieces of the aggregate were under considerable pressure. If a few of the larger pieces carried the brunt of the pressure and did fracture, they would certainly serve to bring the index curve down very suddenly as it is seen to do.

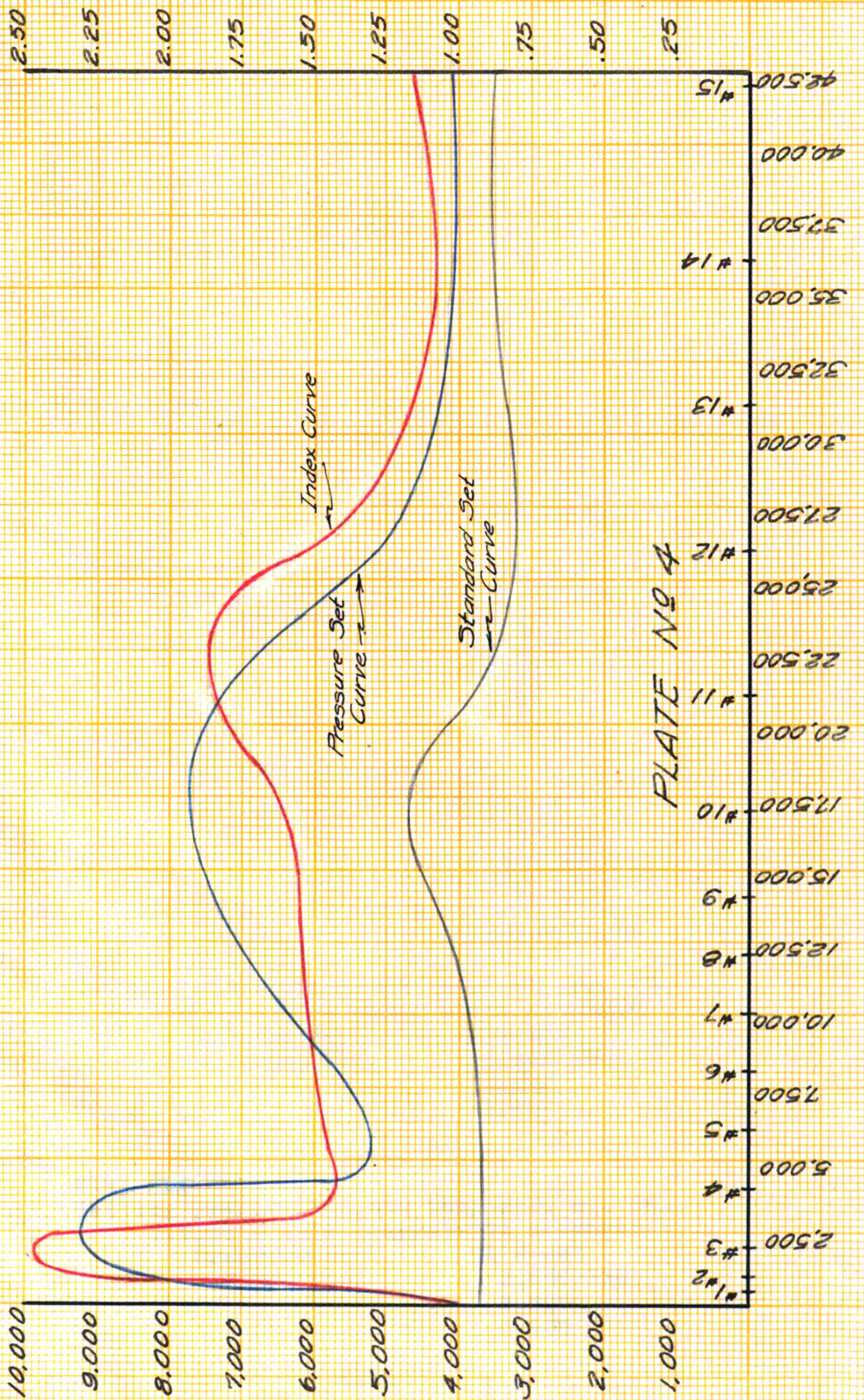
In the complete study of this curve it is quite probable that the following are true: The strength of concrete can be increased by the application of pressure during the setting period; that this increase is due to two things, namely, decrease of the water-cement-ratio and effecting a denser mix; and lastly that these two increases do not come at the same setting pressures.

So far it has been shown that high ultimate strength concrete can be obtained, a reason has been forwarded to explain this increase, and now the use of such a concrete in the future will be taken up.

It is hard to conceive of a concrete structure in which the concrete is set in forms under pressure. The cost of such a set-up would be prohibitive in modern construction. With the exception of concrete cast in the form of blocks it is unlikely that pressure set concrete will ever find its way into the building industry. However, concrete in this form could be used in the construction of arch bridges and the like. But in the ordinary structure the advantages of pressure set concrete must be used in another manner. Some way must be developed to decrease the water-cement- ratio after the water has been placed into the mix to make it workable. Whether this is to be done by mechanical or chemical means remains to be worked out. In this study the method of pressure was used because it presented the easiest method of reducing the water. In a further study of this subject it should be carried on at low pressures and with a machine that is capable of effecting and recording these low pressures. Pressure applied from a lever would be ideal for these low pressures. Also with low pressures the size of the cylinder could be increased which would be a decided advantage. A close tabulation on the amount of water pressed out would be valuable. This was done on several of the cylinders and the new water-

cement-ratio computed. When referred to the strength curves it gave a strength fairly close to that observed. Another interesting thing was noted on some of the 7 day tests. It was discovered that at seven days some of the tests gave the same compressive strength as they did at twenty-eight days. Since only a few seven day tests were made it is difficult to make any conclusions from the results. However, in the future use of pressure set concrete this matter should be investigated.

In conclusion it will be seen that in the all too short time allotted for such a study several rather interesting things have been discovered. It has shown the way for a further study along the general lines of high ultimate strength concrete. It has shown too, that the water-cement-ratio theory has sound reasoning behind it and can be further studied. To be short, it has shown that there is a method yet unknown that will make concrete as desirable as steel in the construction industry of the world.



Data

Mix #1.

1::1.5::2.6

.8 water from strength curve, "Concrete Practice".

Aetna Cement

Coarse aggregate of crushed and uncrushed stone
size after screening $\frac{1}{4}$ "- $\frac{3}{4}$ ".

Fine aggregate as found in the bin.

Mix #2.

1::1.5::2.6

.8 water as above.

Aetna cement

Coarse aggregate of crushed stone already screened
to a size of $\frac{1}{4}$ "- $\frac{3}{4}$ ".

Fine aggregate as found in bin.

Set #1a.

Date: 3-30-32

Mix: #1.

Setting pressure: 500 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set

St'd-set

5000 lbs

3,800 lbs.

4,200

4,000

Set #1b.

Date: 3-31-32

Mix: #1.

Setting pressure: 500 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set

St'd-set

4,800 lbs

3,600 lbs.

3,800 lbs.

4,300 lbs.

Set #2a.

Date: 3-31-32

Mix: #1.

Setting pressure: 1,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set

St'd-set

8,200 lbs.

3,400 lbs.

3,200

3,800

Set #2b.

Date: 4-4-32

Mix: #1.

Setting pressure: 1,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set

St'd-set

8,000 lbs.

3,500 lbs.

3,200

3,500

Set #3a.

Date: 4-5-32

Mix: #1.

Setting pressure: 2,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
9,500 lbs.	4,000 lbs.
	3,800
	4,000

Set #3b.

Date: 4-7-32

Mix: #1.

Setting pressure: 2,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
9,200 lbs.	3,800 lbs.
	3,900 lbs.
	4,000 lbs.

Set #4a.

Date: 4-8-32

Mix: #1.

Setting pressure: 4,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
5,100 lbs.	4,000 lbs.
	3,700
	4,100

Set #4b.

Date: 4-10-32

Mix: #1.

Setting pressure: 4,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
5,000 lbs.	3,600 lbs.
	3,900
	3,800

Set #5a.

Date: 4-11-32

Mix: #1.

Setting pressure: 6,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
5,500 lbs.	3,700 lbs.
	3,900 lbs.
	4,000 lbs.

Set #5b.

Date: 4-12-32

Mix: #1.

Setting pressure: 6,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
5,200 lbs.	3,600 lbs.
	3,800 lbs.
	3,700 lbs.

Set #6a

Date: 4-13-32

Mix: #1.

Setting pressure: 8,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
6,100 lbs.	3,000 lbs.
	3,800 lbs.
	4,800 lbs.

Set #6b.

Date: 4-14-32

Mix: #1.

Setting pressure: 8,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
6,200 lbs.	3,900 lbs.
	3,600 lbs.
	3,800 lbs.

Set #7a.

Date: 4-15-32

Mix: #1.

Setting pressure: 10,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
6,300 lbs.	4,400 lbs.
	3,600 lbs.
	4,000 lbs.

Set #7b.

Date: 4-16-32

Mix: #1.

Setting pressure: 10,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
6,200 lbs.	4,500 lbs.
	5,500 lbs.
	3,600 lbs.

Set #8a.

Date: 4-19-32

Mix: #1.

Setting pressure: 12,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
6,500 lbs.	4,000 lbs.
	5,000 lbs.
	3,800 lbs.

Set #8b.

Date: 4-20-32

Mix: #1.

Setting pressure: 12,000 lbs. per. sq. in.

Ultimate unit compressive strength.

Pressure-set	St'd-set
6,300 lbs.	3,900 lbs.
	3,800 lbs.
	3,800 lbs.

Set #9a.

Date: 4-21-32

Mix: #1.

Setting pressure: 14,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
7,500 lbs.	4,400 lbs.
	4,000 lbs.
	4,600 lbs.

Set #9b.

Date : 4-22-32

Mix: #1.

Setting pressure: 14,000 lbs. per. sq. in.

Ultimate unit compressive strength.

Pressure-set	St'd-set
7,750 lbs.	4,100 lbs.
	4,300 lbs.
	4,250 lbs.

Set #10a.

Date: 4-23-32

Mix: #1.

Setting pressure: 17,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
7,400 lbs.	4,900 lbs.
	5,300 lbs.
	5,300 lbs.

Set #10b.

Date: 4-24-32

Mix: #1

Setting pressure: 17,000 lbs. per. sq. in.

Ultimate unit compressive strength.

Pressure-set	St'd-set
7,300 lbs.	5,500 lbs.
	4,600 lbs.
	4,800 lbs.

Set #11a.

Date: 4-25-32

Mix: #2.

Setting pressure: 21,000 lbs. per. sq. in.

Ultimate unit compressive strength.

Pressure-set	St'd-set
7,500 lbs.	4,200 lbs.
	3,800 lbs.
	3,600 lbs.

Set #11b.

Date: 4-26-32

Mix: #2

Setting pressure: 21,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
7400 lbs.	4,100 lbs.
	3,400 lbs.
	3,800 lbs.

Set #12a.

Date: 4-27-32

Mix: #2

Setting pressure: 26,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
4,900 lbs.	3,200 lbs.
	3,600 lbs.
	2,900 lbs.

Set #12b.

Date: 28-4-32

Mix: #2.

Setting pressure: 26,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
4,700 lbs.	3,600 lbs.
	3,300 lbs.
	3,200 lbs.

Set #13a.

Date: 4-29-32

Mix: #2

Setting pressure: 31,000 lbs. per. sq. in.

Ultimate unit compressive strength.

Pressure-set	St'd-set
4,300 lbs.	3,200 lbs.
	3,600 lbs.
	4,000 lbs.

Set #13b.

Date: 4-30-32

Mix: #2

Setting pressure: 31,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
4,100 lbs.	3,400 lbs.
	3,800 lbs.
	3,700 lbs.

Set #14a.

Date: 5-1-32

Mix: #2.

Setting pressure: 36,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
4,100 lbs.	3,800 lbs.
	4,000 lbs.
	3,600 lbs.

Set #14b.

Date: 5-2-32

Mix: #2.

Setting pressure: 36,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
4,000 lbs.	3,900 lbs.
	3,500 lbs.
	3,300 lbs.

Set #15a.

Date: 5-3-32

Mix: #2.

Setting pressure: 42,000 lbs. per. sq. in.

Ultimate unit compressive strength

Pressure-set	St'd-set
4,000 lbs,	3,300 lbs.
	3,600 lbs.
	3,400 lbs.

Set # 15b.

Date: 5-4-32

Mix: #2.

Setting pressure: 42,000 lbs.per. sq. in.

Ultimate unit compressive strength

Pressure-set

St'd-set

4,000 lbs.

3,400 lbs.

3,500 lbs.

3,600 lbs.

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