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STRENGTH OF CONCRETE BY DIFFERENT  
PROPORTIONS OF AGGREGATE

Thesis for the Degree of B. S.

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1914

# Civil engineering - Structural materials

This thesis was contributed by

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Thesis  
for  
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by

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and

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East Lansing, Mich.

1914.

**Strength of Concrete**  
**by**  
**Different Proportions of Aggregate.**

**103437**

In selecting this subject for our thesis we had in mind the possible results which could be obtained by performing various experiments along some definite outlines as suggested and described in practically all textbooks dealing with concrete. Every textbook on the market, dealing with this subject, emphasises the importance of a thorough study of the aggregates and their proper proportions. However, when we looked for comparative results, or what had been done in this line, we could not find any written matter along this particular subject. The theory has been well discusst but practical results as jet have not been published.

For references we used various textbooks, the most noteworthy ones being: "Treatise on Masonry Construction" by Baker, "Concrete Plain and Reinforced" by Tailor and Thompson, Report of Committee on Specifications and Methods of Tests for Concrete Materials", "American Civil Engineer's Pocketbook", and Trautwine's Civil Engineer's Pocketbook".

The object of our thesis is to determine the strength of concrete of a given mixture by different proportions of aggregate. Concrete under discussion is plain and not reinforced, for reinforced concrete an over cemented mixture is some times necessary, particularly in column construction.

The experiments in our thesis are based upon the theory that the strength of concrete depends entirely on the adhesion of the cement to the sand and stone. Since concrete is always designed for compression only, the tensile strength was not taken into consideration and no tests were made for the tensile strength.

The two theories which govern the proper proportioning of concrete are:

(1) For the same cement and the same sand the strength increases with the amount of cement in a unit of volume of the mortar.

(2) For the same proportion of cement, in a given volume of mortar the strongest mortar is that which has the greatest density, i. e. contains the largest proportion of solid matter. In other words the ideal or theoretically perfect concrete is that in which the best aggregates are proportioned and graded in size so as to reduce the per centage of voids to a minimum, and giving the greatest density.

The truth of the first law is obvious, because a clear cement mixture is stronger than a cement mixture with some matrix. The second law, however, is not so easily analyzed. The first condition entering in deals mainly with the percentages of voids. If only one or two different grades of aggregates are used the process of determining the percentages of voids of each material is very

simple, but it is more difficult where a large number of different sizes of aggregates are used. Yet, it is not so difficult in practical work but that it can be used, when one is familiar with making accurate measurements and figuring percentages. Perhaps the best and easiest method of determining the percentages of voids is by direct measurements. There are a large number of methods used in different countries and all of them have their faults. Some of them are tedious and not well adapted for ordinary practical work.

Another condition that enters in the second theory is the density of the stone. If the aggregate varies in physical conditions, such as specific gravity, the method of determining the percentages of voids, or maximum density, becomes more complicated, particularly where the density is obtained by specific gravity.

Again a third condition to be considered is the size of the specimen. In small specimens a slight deviation might lead to erroneous conclusions.

The most valuable use of the method of proportioning by mechanical analysis is in cases where the character of the work warrants employing several grades, that is several sizes of stone and sand. Such mixtures are being increasingly employed as engineers and contractors more fully appreciate the necessity of so economically proportioning the materials as to produce a mixture of the greatest possible density, that is with the fewest possible voids, thereby reducing the quantity of cement and at the same time improving the quality of the concrete, in other words, making both a better and cheaper concrete.



A second object in view was the variation in the strength of the concrete by the use of different sands. Good sand cannot be easily defined, or an inflexible specification written, as sands of various proportions and properties belonging to it may make equally good concrete. The usual specifications for sand are: "The sand shall be sharp, clean and coarse". For the use in our tests the sand was screened thru two different screens. The largest screen was one of 1/20 inch mesh and all the sand passing this screen and remaining on a 1/30 inch screen was used thruout one test. The sand passing the 1/30 inch screen was used for a comparative test.

In order that we might observe the difference in the strength of the cement and if possible compare results of similar tests we decided to use two different kinds of cement. For this purpose we selected a Michigan Rock Cement, manufactured by the Wolverine Cement Co. for one series of tests and the Universal Portland Cement, manufactured by the Universal Portland Cement Co. This latter cement was chosen because it is of known reputation and is a slag cement, made by mixing and grinding blast furnace slag and hydrated lime.

### Method of procedure:

In order that we should obtain results that correspond to some standard specifications we adopted the rules laid down by the American Concrete Institute. These rules will be briefly stated below:

- (1) The best shape of a test piece is a cylinder.
- (2) Cubes, cylinders, or prisms not shorter in length than their least diameter, can be used for comparative tests.
- (3) The smallest dimension of the test piece should be at least four times the size of the largest particle of stone.
- (4) Tests of similar concrete made with different percentages of water confirm that an increase in the quantity of water in mixing reduces the strength of the concrete to a marked degree, particularly in the early stages.

The aggregate used was obtained from local gravel-banks. Gravel as found in this vicinity is from a terminal moraine, and consists of sandstone, trap, limestone, granite, and some quartz. The latter being chiefly present in the sand. This aggregate was then screened thru different sized screens, the largest screen having a one inch mesh. The other sizes of screens were as follows: 3/4 inch, 1/2 inch, 1/4 inch, 1/6 inch, 1/8 inch, 1/20 inch, and 1/30 inch mesh.

The sand and gravel was perfectly dry and no moisture present. This was determined by weighing out 200 grams of the sand and heating this amount over a gas burner for an hour. No difference in the weight was noticed.

The next step was to determine the percent of impurities in the sand. This was done by measuring out 200 grams of the sand in a graduated tube and then adding water to it.

By successive washings the silt, clay, and other impurities were removed. These were then poured in another graduated tube and allowed to stand for an hour. When they had settled to the bottom the number of c.c. were read. The number of c.c. thus obtained divided by 200 gave us the per cent of impurities. A considerable amount of impurities were found in the number 30 sand. This, however was as expected, because it contained a lot of fine material. Sand No. 30 showed 8.5 per cent of impurities while sand No. 20 showed but 1 percent of impurities.

When everything was ready for the actual mixing of the concrete different methods for obtaining the percentages of voids were considered. After some studying of all the methods outlined in various books and treatises we decided to use the method usually known as the determination of voids by measurements. This method is not as accurate as some others, but where the materials are carefully mixed and graded, and consist of a large number of different sizes of aggregate, the error is quite small. The chief inaccuracy of this method of basing the proportions of the fine materials of a concrete mixture upon water contents of the voids in the larger, is due to the difference in the compactness of the material under varied methods of handling. Another factor entering in is the fact that the actual volume of voids in a coarse material may not, and usually does not correspond to the quantity of sand required to fill the voids. The reason for this is : the grains of sand thrust apart the particles of stone, and because with most aggregates a portion of the particles of sand or fine screenings are too coarse to enter the voids of the coarsest materials. Keeping in mind that an excess of sand always increases the

voids in the concrete, we decided to use a proportion of 1:2: 7. This was decided upon after several mixtures of different combinations were tried without the cement and a suitable percentage of voids obtained. Later, cement in the above stated proportion was added and the percentage of voids correctly determined.

The method as followed in our experiments will be briefly described. We took an average sample of the mixture of 200 c.c. and put it in a graduated tube. In another graduated tube 200 c.c. of water were poured and into this the 200c.c. of the mixture added. Care was taken to allow all the air to escape. After the mixture stood long enough, so as to settle, the number of c.c. of settled matter were read and also the final volume. The difference between the first two quantities put together i.e. 400 c.c. and the final, divided by 200 gave us the percentage of voids. This method is short and simple and we used it because we were limited in time.

The next step was the mixing. The proportions of the various sizes of the aggregate were taken at random, measured out, and emptied in a large tin pan. The same was done with the sand and cement but put in a separate pan. Here the two materials were mixed by hand until the mixture showed a uniform color throughout. The coarse material was then mixed and added to the fine and both mixed dry by shoveling the whole over not less than three times. Water was then added till a normal consistency was obtained as suggested by the American Concrete Institute.

The concrete was then placed in the forms in layers of about two inches deep and carefully tamped with a wooden tamper. Another layer of the same thickness was then placed on top of



this and again tamped. This was then continued till the form was full. It was then leveled off with a trowel and covered with damp cloths and allowed to remain there for 24 hours. The forms were then removed and the blocks stored in a large tank filled with water. The water in the tank had a temperature from 67 to 70 degrees Fahrenheit. We made eight samples, each of eight different mixtures of aggregates. In the first set of samples sand No. 30 was used. In the second set we used sand No. 20. In the third set and also in the fourth sand No. 30 and No. 20 was used respectively, but a different cement was substituted.

Due to the short period of time in which we had to perform the testing we decided to break the cubes at regular intervals. These intervals were as follows: 4-7-10-14-17-21-24 and 28 days.

The testing was done in a Amsler Hydraulic Testing Machine. This machine is well suited for this kind of work. The pressure can be applied very slowly and uniformly. The machine has a capacity of 150,000# and is operated by hand. The specimens were allowed to remain in the water till they were ready for the testing. When the time was up and the specimen ready for testing it was taken out of the water and placed in the machine. Here it was imbedded in several layers of cushioned paper on the top and bottom. When it was carefully centered the pressure was applied and the sample tested to complete failure. The maximum pressure obtained was then recorded. It was also noted that when the total pressure went up to about 18,000 # all the sandstone failed.

### Difficulties encountered.

One difficulty that confronted us was the matter of normal consistency. Because of the difference in the effect of different sands upon the consistency, it was impossible to specify a definite percentage of water. For this reason we followed the suggestions of the American Concrete Institute. They recommend that in filling a conical form with concrete, immediately inverting this, and by repeated trials a consistency can be found such that the amount of water will cause the cone just to begin to slump when the form is removed. A dry mixture is of course unsatisfactory while it is almost impossible to describe a wet mix that will give uniform results. The advantage of this method lies in the fact that the original amount of moisture in the sand and aggregate does not effect the final normal consistency.

Another difficulty that we had to encounter was the matter of forms. We expected to use cylindrical forms but it was found to be inconvenient to make them for our short tests. In order not to conflict with the other requirements of tests by the American Concrete Institute we had to use cubes at least five inches in diameter. There were no forms of that size in the laboratory so we constructed wooden forms of that size, each holding eight cubes. These forms were built out of one inch dressed lumber and held together by clamps and wedges. These forms were thoroughly oiled with a heavy oil before being used.

But perhaps the biggest odds we had to fight was the short period of time. Due to this fact our results are probably low and do not represent an average condition. Undoubtedly tests extending over a longer period of time would be more reliable.

### Conclusions.

The results as obtained show that the proper proportioning of the aggregate, of any concrete, influence greatly the strength of the concrete. Incidentally this is the same thing as saying that by proper proportioning of aggregates the voids are reduced to a minimum, and hence the first law, as stated in the beginning, should be satisfied. Again the second law was verified in as far as will be seen from the curves. An analysis of the curves will show that the ideal mixture is the only one that will satisfy all the conditions which have been considered.

Further observations will show that the sand has a considerable influence on the strength of the concrete. In nearly all of the cases, where the concrete was made of the fine sand, a greater strength was obtained than where the coarse sand was used. The latter complied theoretically to all requirements, but did not show as good final results as the other concrete, although the fine sand contained 8.5 per cent impurities. This particular subject has received considerable attention of late by many engineers and it is hoped that results and data will be available for comparative tests.

It is altogether a reasonable proposition to state that these proportions, made of selected ingredients, produce a concrete which is actually stronger than if they are selected at random.

A method of proper proportioning of aggregates, as opposed to the usual practice of specifying arbitrary proportions regardless of the character of the available ingredients, or of the work to be done, has the advantage of offering an incentive

to good workmanship. While the ingredients may in some cases prove more expensive, the resulting concrete actually costs less per cubic yard. With expensive aggregates the engineer will take less chances of waste, and therefore exert more care in mixing and placing. Arbitrary specifications, which simply state good sand and stone shall be used together with Portland Cement, meeting certain tests, mixed in proportions 1-2-4, or 1-2-6, as the case may be, may mean a very rich mixture, or again result in a very lean concrete.

The large number of conditions, such as normal consistency, workmanship, care in placing, care after the concrete is placed, temperature at the time of mixing and at the time of setting, etc. all effecting the final strength of the concrete, cannot be neglected. But if they are kept constant it is a reasonable proposition that the final strength of the concrete can be figured within a small margin, provided the character of the ingredients are known and the proportion of such aggregates definitely stated which will give a maximum density.

The thought of maximum density should be kept constantly in mind and the idea of arbitrary proportions eliminated, for the character of the aggregates will entirely govern the proportions which will give the strongest concrete.

## First Mixture.

Percentage of voids = 19.0

2 parts of 1 inch gravel  
 1 " "  $\frac{3}{4}$  " "  
 1 " "  $\frac{1}{2}$  " "  
 1 " "  $\frac{1}{4}$  " "  
 1 " "  $\frac{1}{6}$  " "  
 1 " "  $\frac{1}{8}$  " "  
 2 " " No. 20 sand  
 1 " " Wolverine Cement.

## Crushing Strength at different ages.

4 days 22600# or 905#/sq. inch.  
 7 " 29500 " 1180 " "  
 10 " 31600 " 1262 " "  
 14 " 28800 " 1156 " "  
 17 " 28700 " 1148 " "  
 21 " 28500 " 1138 " "  
 24 " 30000 " 1200 " "  
 28 " 36400 " 1454 " "

**Second Mixture.**

Percentage of voids = 18.5

2 parts of 1 inch gravel

2 " "  $\frac{3}{4}$  " "1 " "  $\frac{1}{2}$  " "1 " "  $\frac{1}{4}$  " "1 " "  $\frac{1}{6}$  " "1 " "  $\frac{1}{8}$  " "

2 " " No. 30 sand

1 " " Wolverine Cement

**Crushing Strength at different ages.**

4 days 20200# or 808#/sq. inch.

7 " 28300 " 1131 " "

10 " 32500 " 1300 " "

14 " 38600 " 1542 " "

17 " 40700 " 1624 " "

21 " 38100 " 1523 " "

24 " 37000 " 1478 " "

28 " 39200 " 1570 " "

## Third Mixture.

Percentage of voids = 12.5

1 part of 1 inch gravel

1 " "  $\frac{3}{4}$  " "2 " "  $\frac{1}{2}$  " "1 " "  $\frac{1}{4}$  " "1 " "  $\frac{1}{6}$  " "1 " "  $\frac{1}{8}$  " "

2 " " No.30 sand

1 " " Wolverine Cement.

## Crushing Strength at different ages.

4 Days 11800#/sq. inch. or 473#/sq. inch.

7 " 18200 " 728 " "

10 " 19600 " 785 " "

14 " 22800 " 912 " "

17 " 18700 " 754 " "

21 " 25600 " 1024 " "

24 " 22400 " 896 " "

28 " 25400 " 1015 " #

**Fourth Mixture.**

Percentage of voids = 26.0

2 parts of  $\frac{1}{2}$  inch gravel

2 " "  $\frac{1}{4}$  " "

2 " "  $\frac{1}{6}$  " "

1 " "  $\frac{1}{8}$  " "

2 " " sand No. 30.

1 " " Wolverine Cement.

**Crushing Strength at different ages.**

4 days 6600 # or 264 #/sq. inch.

7 " 9000 " 360 " "

10 " 10400 " 416 " "

14 " 12500 " 500 " "

17 " 11800 " 472 " "

21 " 14000 " 560 " "

24 " 14400 " 576 " "

28 " 14900 " 596 " "

**Fifth Mixture.**

Percentage of voids = 17.5

4 parts of 1 inch gravel.

1 " "  $\frac{3}{4}$  " "

1 " "  $\frac{1}{2}$  " "

1 " "  $\frac{1}{8}$  " "

2 " " sand No. 30

1 " " Wolverine Cement.

**Crushing Strength at different ages.**

4 days 15900# or 636 #/sq. inch.

7 " 23800 " 952 " "

10 " 30400 " 1217 " "

14 " 23500 " 940 " "

17 " 28000 " 1120 " "

21 " 36000 " 1438 " "

24 " 42600 " 1702 " "

28 " 39700 " 1538 " "

## Sixth Mixture.

Percentage of voids = 21.0

4 parts of  $\frac{1}{2}$  inch gravel  
 1 " "  $\frac{1}{4}$  " "  
 1 " "  $\frac{1}{6}$  " "  
 1 " "  $\frac{1}{8}$  " "  
 2 " " sand No.30  
 1 " " Wolverine Cement.

## Crushing Strength at different ages.

4 days 14900 $\frac{lb}{sq. inch}$  or 596 $\frac{lb}{sq. inch}$ .  
 7 " 20600 " 832 " "  
 10 " 22600 " 905 " "  
 14 " 27600 " 1102 " "  
 17 " 22900 " 916 " "  
 21 " 28100 " 1124 " "  
 24 " 26200 " 1046 " "  
 28 " 29200 " 1168 " "

## Seventh Mixture.

Percentage of voids = 23.5

4 Parts of  $\frac{3}{4}$  inch gravel.1 " "  $\frac{1}{4}$  " "1 " "  $\frac{1}{6}$  " "1 " "  $\frac{1}{8}$  " "

2 " " sand No. 30

1 " " Wolverine Cement.

## Crushing Strength at different ages.

4 Days 15100# or 604 #/sq. inch

7 " 20300 " 812 " "

10 " 24400 " 976 " "

14 " 24100 " 965 " "

17 " 26600 " 1062 " "

21 " 24600 " 984 " "

24 " 27000 " 1080 " "

28 " 32000 " 1280 " "



## Eighth Mixture.

Percentage of voids = 16.5

4 parts of 1 inch gravel.

1 " "  $\frac{1}{2}$  " " $\frac{1}{2}$  " "  $\frac{1}{4}$  " " $\frac{1}{8}$  " "  $\frac{1}{6}$  " "1 " "  $\frac{1}{8}$  " "

2 " " No. 30 sand

1 " " Wolverine Cement.

## Crushing Strength at different ages.

4 days 27000# or 1080 #/sq. inch

7 " 28000 " 1120 " "

10 " 31200 " 1280 " "

14 " 38600 " 1545 " "

17 " 38200 " 1525 " "

21 " 38700 " 1548 " "

24 " 35800 " 1432 " "

28 " 42700 " 1710 " "

**Ninth Mixture.**

Mixture No. 9 is the same as mixture No.1 except in place of sand No. 30 we used sand No. 20.

Crushing Strength at different ages.

4 days 21000 $\frac{1}{2}$  or 840 $\frac{1}{2}$ /sq. inch.

|    |   |       |   |      |   |   |
|----|---|-------|---|------|---|---|
| 7  | " | 21700 | " | 867  | " | " |
| 10 | " | 22100 | " | 883  | " | " |
| 14 | " | 22900 | " | 916  | " | " |
| 17 | " | 30800 | " | 1230 | " | " |
| 21 | " | 32200 | " | 1267 | " | " |
| 24 | " | 36400 | " | 1415 | " | " |
| 28 | " | 34000 | " | 1360 | " | " |

**Tenth Mixture.**

Mixture No. 10 is the same as mixture No.2 except in place of sand No. 30 we used sand No. 20.

Crushing Strength at different ages.

4 days 11400 $\frac{1}{2}$  or 448 $\frac{1}{2}$ /sq. inch

|    |   |       |   |      |   |   |
|----|---|-------|---|------|---|---|
| 7  | " | 17400 | " | 669  | " | " |
| 10 | " | 18800 | " | 752  | " | " |
| 14 | " | 17800 | " | 712  | " | " |
| 17 | " | 20600 | " | 824  | " | " |
| 21 | " | 21600 | " | 865  | " | " |
| 24 | " | 18000 | " | 720  | " | " |
| 28 | " | 25600 | " | 1022 | " | " |

### **Eleventh Mixture.**

Mixture No. 11 is the same as mixture No. 3 except in place of sand No. 30 we used sand No. 20.

Crushing Strength at different ages.

4 days 11100# or 440#/sq. inch.

|      |       |   |      |   |   |
|------|-------|---|------|---|---|
| 7 "  | 14200 | " | 568  | " | " |
| 10 " | 19100 | " | 724  | " | " |
| 14 " | 22200 | " | 888  | " | " |
| 17 " | 20500 | " | 820  | " | " |
| 21 " | 22000 | " | 880  | " | " |
| 24 " | 25400 | " | 1015 | " | " |
| 28 " | 31600 | " | 1265 | " | " |

### **Twelfth Mixture.**

Mixture No. 12 is the same as mixture No. 4 except in place of sand No. 30 we used sand No. 20.

Crushing Strength at different ages.

4 days 6900# or 276#/sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 8000  | " | 320 | " | " |
| 10 " | 12000 | " | 480 | " | " |
| 14 " | 14500 | " | 580 | " | " |
| 17 " | 16500 | " | 620 | " | " |
| 21 " | 18600 | " | 744 | " | " |
| 24 " | 20300 | " | 812 | " | " |
| 28 " | 20700 | " | 828 | " | " |

### Thirteenth Mixture.

Mixture No. 13 is the same as mixture No. 5 except in place of sand No. 30 we used sand No. 20.

Crushing Strength at different ages.

4 days 12600 # or 504 $\frac{1}{2}$ /sq. inch.

7 " 15400 " 616 " "

10 " 17500 " 700 " "

14 " 20800 " 831 " "

17 " 20200 " 808 " "

21 " 19400 " 775 " "

24 " 25400 " 1016 " "

28 " 27300 " 1090 " "

### Fourteenth Mixture.

Mixture No. 14 is the same as mixture NO.6 except in place of sand No. 30 we used sand No. 20.

Crushing Strength at different ages.

4 days 8700 $\frac{1}{2}$  or 348 $\frac{1}{2}$ /sq. inch.

7 " 13300 " 532 " "

10 " 15000 " 600 " "

14 " 14100 " 564 " "

17 " 17300 " 692 " "

21 " 19600 " 784 " "

24 " 24700 " 988 " "

28 " 25400 " 1016 " "

### Fifteenth Mixture.

Mixture No. 15 is the same as mixture No. 7 except in place of sand No. 30 we used sand No. 20.

Crushing Strength at different ages.

4 days 10500 $\frac{1}{2}$  or 420 $\frac{1}{2}$ /sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 11600 | " | 464 | " | " |
| 10 " | 17200 | " | 688 | " | " |
| 14 " | 15500 | " | 620 | " | " |
| 17 " | 21000 | " | 840 | " | " |
| 21 " | 21100 | " | 844 | " | " |
| 24 " | 22800 | " | 912 | " | " |
| 26 " | 22600 | " | 908 | " | " |

### Sixteenth Mixture.

Mixture No. 16 is the same as mixture No. 8 except in place of sand No. 30 we used sand No. 20.

Crushing Strength at different ages.

4 days 10600 $\frac{1}{2}$  or 424  $\frac{1}{2}$ /sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 17400 | " | 696 | " | " |
| 10 " | 17400 | " | 696 | " | " |
| 14 " | 18600 | " | 742 | " | " |
| 17 " | 21300 | " | 852 | " | " |
| 21 " | 17300 | " | 691 | " | " |
| 24 " | 21800 | " | 872 | " | " |
| 28 " | 21000 | " | 840 | " | " |

## Seventeenth Mixture.

Mixture No. 17 is the same as mixture No. 1 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 7400 # or 296 #/sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 9500  | " | 380 | " | " |
| 10 " | 9000  | " | 360 | " | " |
| 14 " | 11800 | " | 472 | " | " |
| 17 " | 14000 | " | 560 | " | " |
| 21 " | 13700 | " | 548 | " | " |
| 24 " | 14900 | " | 596 | " | " |
| 28 " | 16000 | " | 640 | " | " |

## Eighteenth Mixture.

Mixture No. 18 is the same as mixture No. 2 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 8000# or 320#/sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 10200 | " | 408 | " | " |
| 10 " | 12800 | " | 512 | " | " |
| 14 " | 14000 | " | 560 | " | " |
| 17 " | 15000 | " | 600 | " | " |
| 21 " | 16800 | " | 672 | " | " |
| 24 " | 17500 | " | 700 | " | " |
| 28 " | 19000 | " | 760 | " | " |

### Nineteenth Mixture.

Mixture No. 19 is the same as mixture No.3 except in place of Wolverine Cement we used Universal Cement.

#### Crushing Strength at different ages.

|    |      |       |    |     |             |
|----|------|-------|----|-----|-------------|
| 4  | days | 7500# | or | 300 | #/sq. inch. |
| 7  | "    | 9600  | "  | 334 | " "         |
| 10 | "    | 11900 | "  | 476 | " "         |
| 14 | "    | 13500 | "  | 540 | " "         |
| 17 | "    | 13200 | "  | 528 | " "         |
| 21 | "    | 15400 | "  | 616 | " "         |
| 24 | "    | 16800 | "  | 672 | " "         |
| 28 | "    | 18000 | "  | 720 | " "         |

### Twentieth Mixture.

Mixture No. 20 is the same as mixture No.4 except in place of Wolverine Cement we used Universal Cement.

#### Crushing Strength at different ages.

|    |      |       |    |     |             |
|----|------|-------|----|-----|-------------|
| 4  | days | 5000# | or | 200 | #/sq. inch. |
| 7  | "    | 6500  | "  | 270 | " "         |
| 10 | "    | 7700  | "  | 308 | " "         |
| 14 | "    | 10800 | "  | 432 | " "         |
| 17 | "    | 11400 | "  | 456 | " "         |
| 21 | "    | 10000 | "  | 400 | " "         |
| 24 | "    | 12000 | "  | 488 | " "         |
| 28 | "    | 13000 | "  | 520 | " "         |

## Twenty-first Mixture.

Mixture No. 21 is the same as mixture No.5 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days...11000 $\frac{1}{2}$  or 440  $\frac{1}{2}$ /sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 14600 | " | 584 | " | " |
| 10 " | 15200 | " | 627 | " | " |
| 14 " | 15800 | " | 672 | " | " |
| 17 " | 18200 | " | 727 | " | " |
| 21 " | 18200 | " | 727 | " | " |
| 24 " | 19000 | " | 760 | " | " |
| 28 " | 20300 | " | 812 | " | " |

## Twenty-second Mixture.

Mixture No.22 is the same as mixture No.6 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 4000 $\frac{1}{2}$  or 160  $\frac{1}{2}$ /sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 5800  | " | 232 | " | " |
| 10 " | 6800  | " | 272 | " | " |
| 14 " | 9000  | " | 360 | " | " |
| 17 " | 11000 | " | 440 | " | " |
| 21 " | 13000 | " | 520 | " | " |
| 24 " | 14000 | " | 560 | " | " |
| 28 " | 15900 | " | 632 | " | " |

### Twenty-third Mixture.

Mixture No. 23 is the same as mixture No. 7 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 5500 $\frac{1}{2}$  or 220  $\frac{1}{2}$ /sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 7700  | " | 308 | " | " |
| 10 " | 7700  | " | 308 | " | " |
| 14 " | 11000 | " | 440 | " | " |
| 17 " | 11800 | " | 472 | " | " |
| 21 " | 12000 | " | 480 | " | " |
| 24 " | 13100 | " | 524 | " | " |
| 28 " | 14000 | " | 560 | " | " |

### Twenty-fourth Mixture.

Mixture No. 24 is the same as mixture No. 8 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 8200 $\frac{1}{2}$  or 328  $\frac{1}{2}$ /sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 15000 | " | 600 | " | " |
| 10 " | 16900 | " | 625 | " | " |
| 14 " | 12600 | " | 504 | " | " |
| 17 " | 17400 | " | 696 | " | " |
| 21 " | 18800 | " | 752 | " | " |
| 24 " | 19300 | " | 772 | " | " |
| 28 " | 20600 | " | 825 | " | " |

### Twenty-fifth Mixture.

Mixture No. 25 is the same as mixture No. 9 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 4250 $\frac{1}{2}$  or 170  $\frac{1}{2}$ /sq. inch.

7 " sample lost.

10 " 6500 $\frac{1}{2}$  or 260  $\frac{1}{2}$ /sq. inch.

14 " 9000 " 360 " "

17 " 10750 " 430 " "

21 " 11750 " 470 " "

24 " 16000 " 640 " "

28 " 17000 " 680 " "

### Twenty-sixth Mixture.

Mixture No. 26 is the same as mixture No. 10 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 5000 $\frac{1}{2}$  or 200  $\frac{1}{2}$ /sq. inch.

7 " 6850 " 274 " "

10 " 6520 " 261 " "

14 " 7750 " 310 " "

17 " 7700 " 308 " "

21 " 8750 " 350 " "

24 " 10200 " 410 " "

28 " 12500 " 500 " "

**Twenty-seventh Mixture.**

Mixture No. 27 is the same as mixture No. 11 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 4750 $\frac{1}{2}$  or 190  $\frac{1}{2}$ /sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 6250  | " | 250 | " | " |
| 10 " | 9000  | " | 360 | " | " |
| 14 " | 8500  | " | 340 | " | " |
| 17 " | 10500 | " | 420 | " | " |
| 21 " | 12700 | " | 510 | " | " |
| 24 " | 15200 | " | 610 | " | " |
| 28 " | 19200 | " | 770 | " | " |

**Twenty-eighth Mixture.**

Mixture No. 28 is the same as mixture No. 12 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days...5750 $\frac{1}{2}$  or 230  $\frac{1}{2}$ /sq. inch.

|      |       |   |     |   |   |
|------|-------|---|-----|---|---|
| 7 "  | 7500  | " | 300 | " | " |
| 10 " | 9500  | " | 380 | " | " |
| 14 " | 11500 | " | 460 | " | " |
| 17 " | 12500 | " | 500 | " | " |
| 21 " | 15000 | " | 600 | " | " |
| 24 " | 16000 | " | 640 | " | " |
| 28 " | 17300 | " | 690 | " | " |

### Twenty-ninth Mixyure.

Mixture No. 29 is the same as mixture No. 13 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 9000 $\frac{1}{2}$  or 360  $\frac{1}{2}$ /sq. inch.

7 " 10500 " 420 " "

10 " 12800 " 510 " "

14 " 13200 " 520 " "

17 " 14500 " 580 " "

21 " Sample missing

24 " 17000 $\frac{1}{2}$  or 680 " "

28 " 16700 " 670 " "

### Thirtieth Mixture.

Mixture No. 30 is the same as mixture No.14 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 4500 $\frac{1}{2}$  or 180  $\frac{1}{2}$ /sq. inch.

7 " 6000 " 240 " "

10 " 9000 " 360 " "

14 " 8000 " 320 " "

17 " 8000 " 320 " "

21 " 7700 " 310 " "

24 " 9500 " 380 " "

28 " 10500 " 420 " "

**Thirty-first Mixture.**

Mixture No. 31 is the same as mixture No. 15 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 2800 $\frac{1}{2}$  or 110  $\frac{1}{2}$ /sq. inch.

7 " 4300 " 170 " "

10 " 5000 " 200 " "

14 " 7200 " 290 " "

17 " 7500 " 300 " "

21 " 10300 " 410 " "

24 " 11000 " 440 " "

28 " 12500 " 500 " "

**Thirty- second Mixture.**

Mixture No. 32 is the same as mixture No. 16 except in place of Wolverine Cement we used Universal Cement.

Crushing Strength at different ages.

4 days 6000 $\frac{1}{2}$  or 240  $\frac{1}{2}$ /sq. inch.

7 " 7300 " 290 " "

10 " 10000 " 400 " "

14 " 10300 " 410 " "

17 " 12500 " 500 " "

21 " 13500 " 540 " "

24 " 15300 " 610 " "

28 " 14000 " 560 " "





26 Stress in 100 sq. in.

24

22

100 sq. in. of gravel passing the screen

90 18

80 16

70 14

60 12

50 10

40 8

30 6

20 4

10 2

0

Age of Specimens in days

Dia. of Aggregate in inches

0.1

0.2

0.4

0.6

0.8

1.0

1.2

1.4

1.6

1.8

2

Curve 1: Theoretical curve of mixture

" 2: Curve of mixture 2

" 3: Stress curve of mixture 2

" 4: " " " " " 10

" 5: " " " " " 2.9

" 6: " " " " " 10.4

Steel No. 2



26 Stress in 100 lb

24

22

100 gals of gravel passing the screen

90

80

70

60

50

40

30

20

10

0

0

0

0

0

0

0

0

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

1.1

1.2

1.3

1.4

1.5

1.6

1.7

1.8

1.9

2.0

2.1

2.2

2.3

2.4

2.5

2.6

2.7

2.8

2.9

3.0

Curve 1 = Theoretical curve of mixture

2 = Curve of mixture

3 = Stress curve of mixture 4

4 = " " " " " "

5 = " " " " " "

6 = " " " " " "

7 = " " " " " "

8 = " " " " " "

9 = " " " " " "

10 = " " " " " "

11 = " " " " " "

12 = " " " " " "

13 = " " " " " "

14 = " " " " " "

15 = " " " " " "

16 = " " " " " "

17 = " " " " " "

18 = " " " " " "

19 = " " " " " "

Age of Specimens in days

Div. of Aggregate in inches

Sheet No. 4

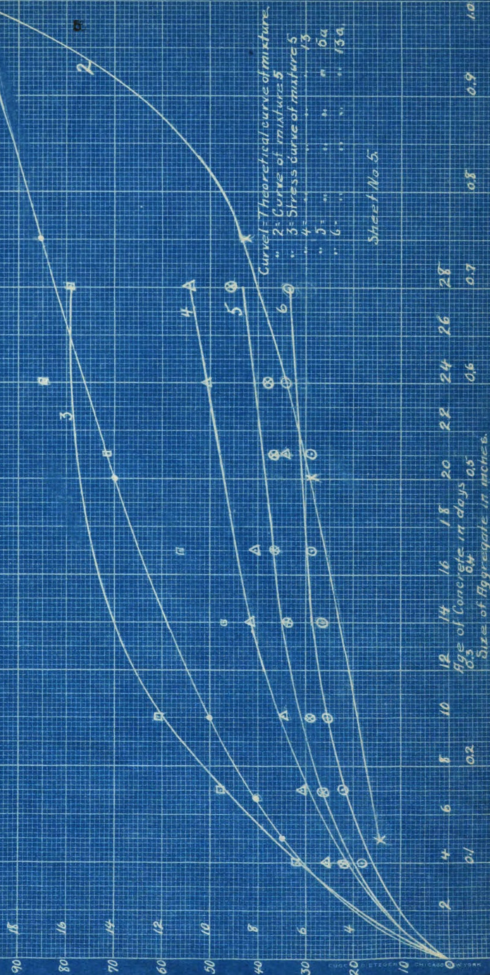


26. Stress in  $100 \pi / \text{m}^2$

24

22

100% of gravel passing screen









26. Stress in 60 #/sq

24

22

100 % of gravel passing screen

90

80

70

60

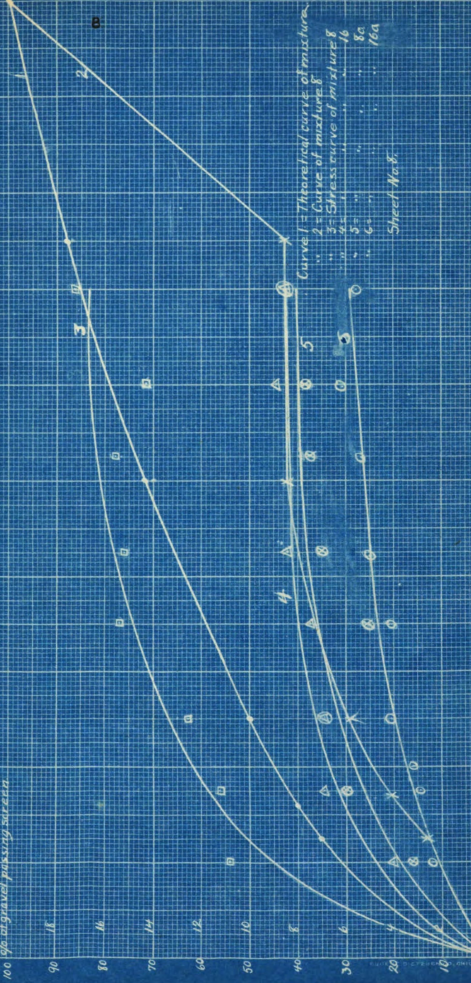
50

40

30

20

10



Sheet No. 5

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