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AN EXPERIMENTAL STUDY OF
CONCRETE MIXTURES WITH
RESPECT TO QUALITY, DENSITY,
AND YIELD

Thesis for the Degree of B. S.
D. W. Stonecliffe
1936

THESIS

Concrete

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An Experimental Study of Concrete Mixtures
With Respect to
Quality, Density, and Yield

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

by

D. W. Stonecliffe

Candidate for the Degree of
Bachelor of Science

June, 1936

THESES

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INTRODUCTION

The subject of the design of concrete mixtures is one that has been experimented with for many years, and needless to say, much has been published on this important topic. The outstanding contribution of the mass of published data is unquestionably that of Duff Abrams. His principle or law of the importance of the ratio of water to cement has formed the basis of practically all methods of mix design.

[In spite of all the available data on the subject of mixes, a great many in the industry are still using arbitrary volume proportions such as 1-2-4 etc., with no thought given to the possibilities of economy and quality by using the water-cement ratio principle and so adjusting the characteristics of the aggregate to insure quality and get the most concrete for a given quantity of cement.]

While this thesis admittedly will do more to develop the technique, judgement and experience of the writer on the subject of good concrete mixtures than it will to contribute something original to the concrete industry, at the same time this seems an excellent opportunity to show by experiment some definite relationships.

The object of this thesis then is to demonstrate the relation between grading and size of aggregates, the relative amounts of fine and coarse aggregates, the total quantity of water-cement parts and the quality, density and yield of concrete, all mixes using a constant water-cement ratio and constant slump.

Concrete exposed to the weather must be water-tight. That means it must contain a minimum of air spaces or pores which allow the entrance of water. These pore spaces are due primarily to two causes, - first, harshness or insufficient mortar to fill the voids in the coarse aggregate or if enough cement was used the mix may be described as undersanded; and second, too great a water content. Less than three gallons of water per sack of cement are necessary to thoroughly hydrate the cement; beyond this point, the water merely acts as a lubricant for the batch. Too much water will prove a detriment, because after the cement has been hydrated and the batch lubricated, the excess water will dry out leaving pores in the concrete. This tends toward a porous mix. All these conditions must be guarded against in designing mixes for economical, good quality, dense concrete.

As a basis for yield in this study, it was thought best to obtain data for unit-weight curves for each of six different combinations of sand and coarse aggregate. Fine sand, coarse sand, coarse aggregate less than one inch, coarse aggregate greater than one inch, and a combined coarse aggregate were to be the aggregates used in making these curves. The high points on these curves would then represent those mixes which had the greatest unit-weight of aggregate -- the first step in getting a dense mix.

[In order that as many variables as possible could be eliminated in these mixes, a constant water-cement ratio

and slump would be used. The constant water-cement ratio should also produce a constant strength, thereby eliminating another variable.

The values then remaining to be computed and observed would be weight or density and yield.

PROCEDURE

It was first necessary to obtain material to work with. There was enough fine sand in the bins of the concrete laboratory to take care of all the needs; also there was some mixed coarse aggregate, which had to be screened through a one inch screen to separate all the material greater than one inch from that less than one inch. As there was no coarse sand to work with, and seemingly not enough coarse aggregate, a trip was made out to the Boichot Sand & Gravel Company on Highway U. S. 27, north of Lansing. Here, there was a good grade of coarse sand, and a coarse aggregate that had a lot of material greater than one inch present. One cubic yard of each aggregate was ordered and delivered within a few days.

As soon as all the material was delivered, the coarse sand was immediately put in large drying pans, placed over a slow-burning flame, and dried out until the surface moisture had disappeared. It was advantageous to stop drying at this point, so that none of the inner moisture of the sand particles would be drawn out. If this inner moisture had been drawn out, extra water above the water-cement ratio point would necessarily have been added to be reabsorbed into the particles. The same drying process was repeated with the fine sand, and the two sands put in separate barrels until ready for use.

When the cubic yard of newly acquired coarse aggregate was screened, it was found that much more fine material was

present than had been expected, and it looked as if there might be a shortage of material greater than one inch.

Such did not prove to be the case, however. As the coarse aggregate had been washed previous to delivery, it was not necessary to rewash it, so the two screened aggregates were put in individual bins and left to dry from room temperature.

After all the aggregate, both sand and coarse, had dried out sufficiently, a 1000 gram representative sample of each was picked out, and a sieve analysis of each was run. The Tyler Standard Screen System of square openings was used. Numbers 4, 8, 14, 28, 48, and 100 were used for the sands, while the $1\frac{1}{2}$ ", $\frac{3}{4}$ ", and $3/8$ ", and number 4 were used for the coarse aggregate. The weights retained on each screen were recorded, and percentages were computed with the possibility in view of finding a relationship between these values and yield or density.

All that remained to be done then before beginning the unit weight charts, was the determination of the dry, rodded, unit weight of each aggregate. This was found by taking a representative sample of each aggregate, filling a half cubic foot measure one quarter full, rodding 25 times, filling the measure one half full, rodding another 25 times, filling three-quarters full, rodding another 25 times, then filling the measure level full, rodding a last 25 times, leveling off, and finally weighing on a Howe Scales which weighed to the closest one-half pound. Multiplying the net weight of the

aggregate by two resulted in the unit weight required per cubic foot.

Two methods were used to get data for the unit weight charts. The first was unsuccessful, the later worked out very well.

The first method was as follows: One cubic foot of coarse aggregate was weighed out and placed on a canvas blanket. 10% of a cubic foot of sand by weight, was added to the coarse aggregate. The mixture was rolled on the canvas to insure good mixing, then the one-half cubic foot measure was filled, being rodded as described above. The measure was weighed, and the unit weight of the 10% sand mixture determined, by doubling this net weight. 10% more sand was added to the cubic foot of coarse aggregate making a total of 20% sand present in the mixture. The unit weight of this was found and the process repeated until 50% of a cubic foot of sand was present to one cubic foot of coarse aggregate.

The process was then reversed and one cubic foot of sand was mixed with 10% by weight of coarse aggregate; the aggregate was mixed well and the unit weight found as before. 10% more of coarse aggregate was added, and so on until 50% of coarse aggregate was mixed with the cubic foot of sand.

The curve was supposed to check out at the 50% point, but obviously, as was later realized, one cubic foot of coarse aggregate plus one half cubic foot of sand will not

have the same unit weight as one cubic foot of sand plus one half cubic foot of coarse aggregate; consequently, the curve did not check out. This rebuttal forced the adoption of a different method.

It was plain to see that in order to get a smooth curve; as 10% of sand was added to the cubic foot of coarse aggregate, 10% of coarse aggregate would have to be removed, leaving 90% of coarse aggregate in the mixture. In this manner, a whole cubic foot by weight of sand and coarse aggregate was present in each mixture, because as 10% of sand was added, another 10% of coarse aggregate would be taken away. Finally, the next to the last point on the curve was the unit weight of a mixture of 90% sand and 10% coarse aggregate. In order to have better control over the unit-weight of each mixture, a special cubic-foot measuring box was built.

The box was constructed of white pine in the Building and Grounds Woodshop. The inside dimensions of the base were 9.3 inches on a side, the height of the box being 20 inches, thereby making 1 inch of height equal 5% of a cubic foot. Every inch of height was marked around the



Cubic-Foot Measuring Box

inside of the box, then as a mix of a certain percentage of sand and another percentage of coarse aggregate was placed in the box, it could be noted just what percentage of a cubic foot the given mixture occupied. The weight of the given percentage being known, the unit weight of the mixture was then accurately computed.

The above procedure was followed out with six different combinations of sand and coarse aggregate:

1. Fine sand and (1"-) C.A.
2. Fine sand and (1"+) C.A.
3. Fine sand and Combined C.A.
4. Coarse sand and (1"-) C.A.
5. Coarse sand and (1"+) C.A.
6. Coarse sand and Combined C.A.

The data was recorded in each case and suitable curves were drawn up to show the variation in unit weights.

At this point it might be well to mention that for each curve, the percentage of voids in the coarse aggregate was computed; this value being plotted as a vertical line along the horizontal scale of each curve as a sand percentage. The theory was that back of that void percentage line, the sand content would not be great enough and the mix would be harsh. Such was proven to be the case.

UNIT WEIGHTS OF MATERIALS

Fine Sand.....	106.5	lbs. per Cu. Ft.		
Coarse Sand.....	112.5	"	"	"
(1"-) Coarse Aggregate....	107.5	"	"	"
(1"+) Coarse Aggregate....	103.0	"	"	"
Combined Coarse Aggregate.	111.5	"	"	"

Percent Voids in Coarse Aggregate in Mixtures

$$\% \text{ Voids} = 1 - \text{Absolute Vol.}$$

$$\text{Combined C. A. and Coarse Sand} - \% \text{ Voids} = 1 - \frac{111.5}{2.65 \times 62.5} = .33$$

$$\text{Combined C. A. and Fine Sand} - \% \text{ Voids} = 1 - \frac{111.5}{2.65 \times 62.5} = .33$$

$$(1"-) \text{ C. A. and Coarse Sand} - \% \text{ Voids} = 1 - \frac{107.5}{2.65 \times 62.5} = .35$$

$$(1"-) \text{ C. A. and Fine Sand} - \% \text{ Voids} = 1 - \frac{107.5}{2.65 \times 62.5} = .35$$

$$(1"+) \text{ C. A. and Fine Sand} - \% \text{ Voids} = 1 - \frac{103}{2.65 \times 62.5} = .38$$

$$(1"+) \text{ C. A. and Coarse Sand} - \% \text{ Voids} = 1 - \frac{103}{2.65 \times 62.5} = .38$$

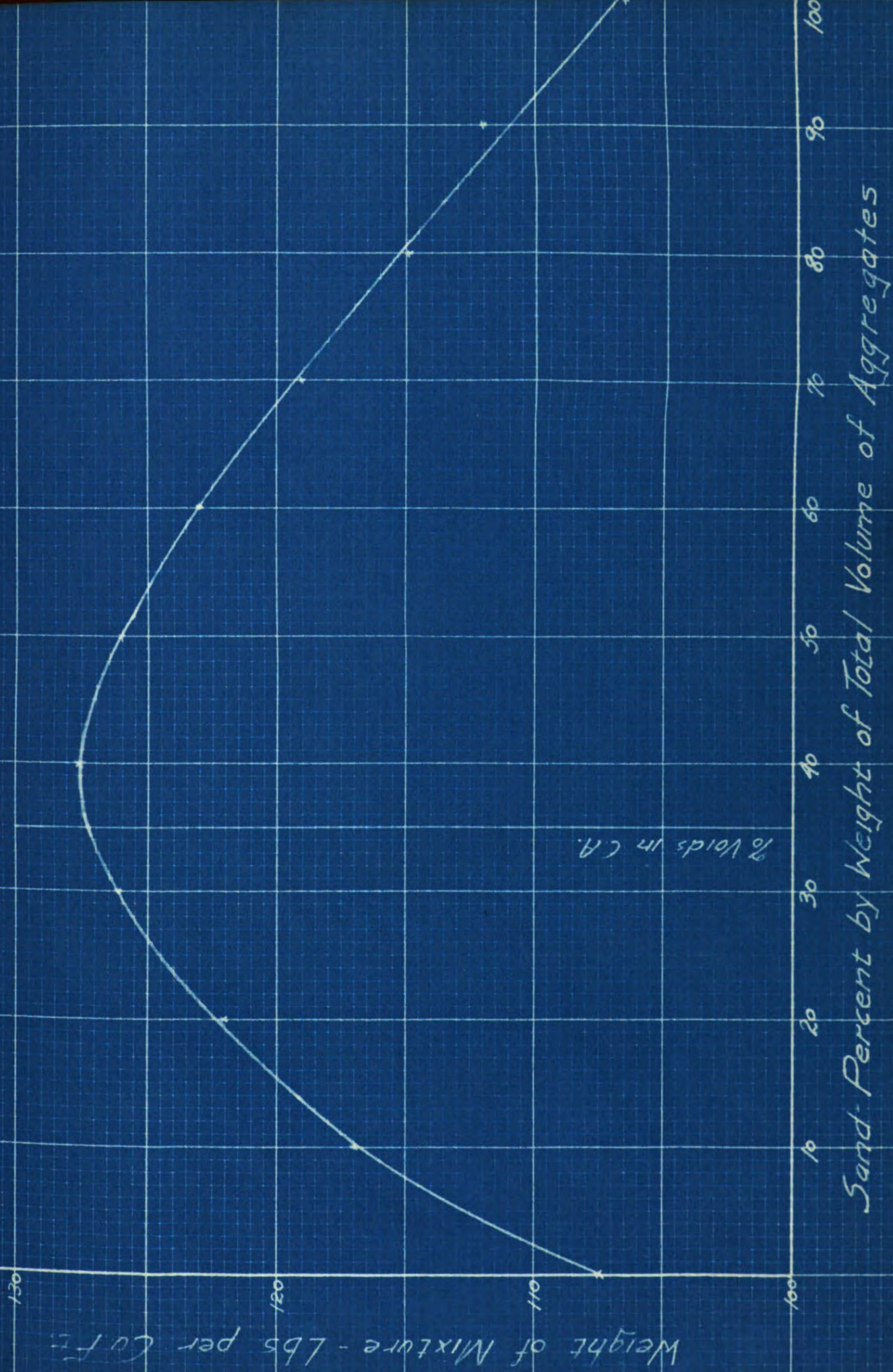
(1"-) COARSE AGGREGATE AND FINE SAND

Mix	Aggregate		Sand		Portion of Cu. Ft. Sam- ple Occupies	Weight of Sample	Weight of Sample per Cu. Ft.
	%	Weight	%	Weight			
1	100	107.50	00	00.00	1.00	107.50	107.5
2	90	96.75	10	10.75	.92	107.50	117.0
3	80	86.00	20	21.25	.87	107.25	122.0
4	70	75.25	30	32.00	.85	107.25	126.2
5	60	64.50	40	42.50	.84	107.00	127.5
6	50	53.75	50	53.25	.85	107.00	126.0
7	40	43.00	60	64.00	.87	107.00	123.0
8	30	32.25	70	74.50	.89	106.75	119.0
9	20	21.50	80	85.25	.93	106.75	114.9
10	10	10.75	90	95.75	.95	106.50	112.0
11	00	0.00	100	106.50	1.00	106.50	106.5

(1"-) COARSE AGGREGATE AND COARSE SAND

Mix	Aggregate		Sand		Portion of Cu. Ft. Sam- ple Occupies	Weight of Sample	Weight of Sample per Cu. Ft.
	%	Weight	%	Weight			
1	100	107.50	00	00.00	1.00	107.50	107.5
2	90	96.75	10	11.25	.95	108.00	113.8
3	80	86.00	20	22.50	.91	108.50	119.2
4	70	75.25	30	33.75	.90	109.00	121.0
5	60	64.50	40	45.00	.88	109.50	124.5
6	50	53.75	50	56.25	.88	110.00	125.0
7	40	43.00	60	67.50	.89	110.50	124.1
8	30	32.25	70	78.75	.91	111.00	122.0
9	20	21.50	80	90.00	.93	111.50	120.0
10	10	10.75	90	101.25	.97	112.00	115.5
11	00	00.00	100	112.50	1.00	112.50	112.5

(1") Coarse Agg. & Fine Sand
Cylinders 25-32 in.

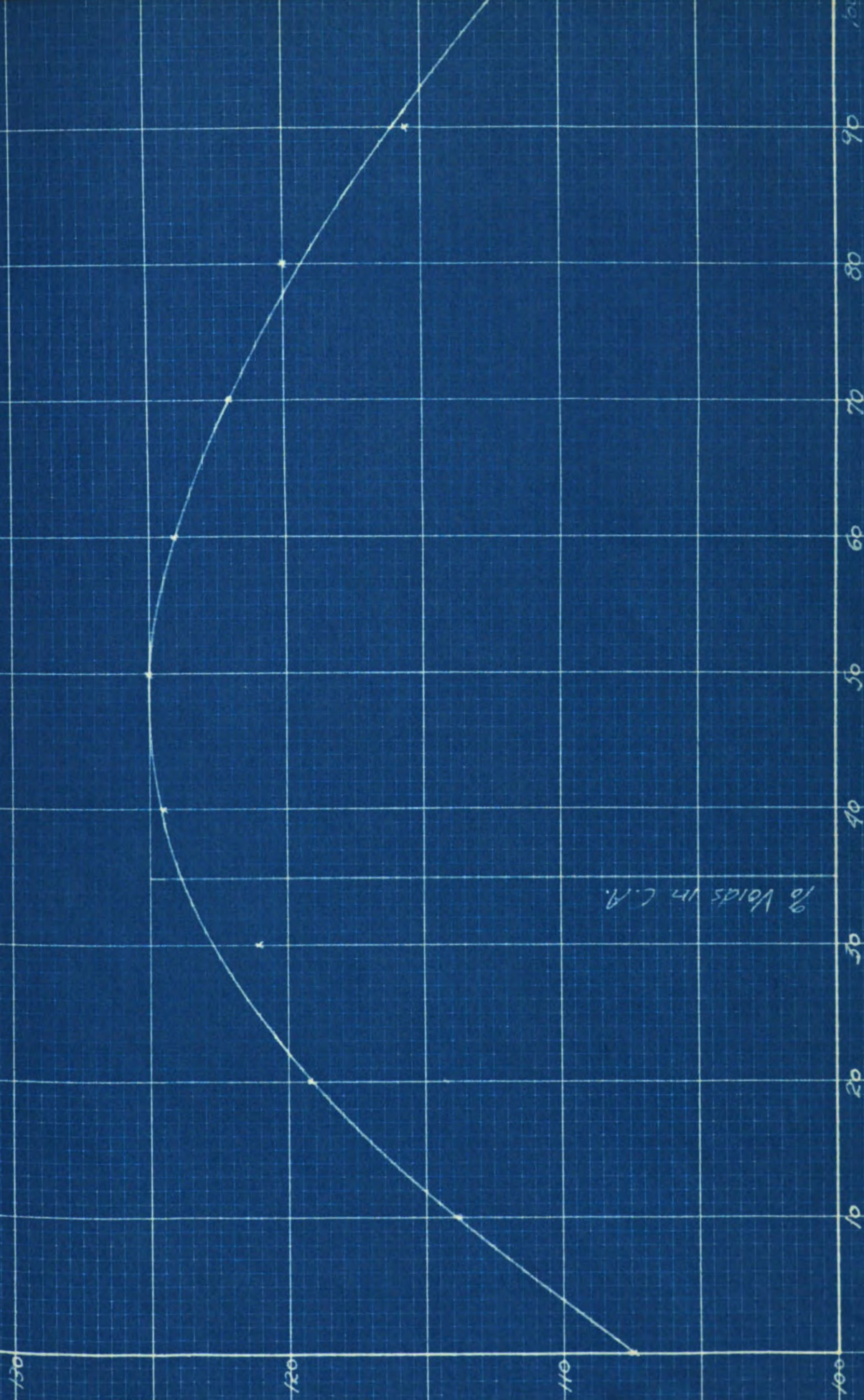


1 1/2" Coarse Agg. & Coarse Sand
Cylinders 11-24 in.

Weight of Mixture - lbs. per cu.ft.

% Voids in C.A.

Sand-Percent by Weight of Total Volume of Aggregates



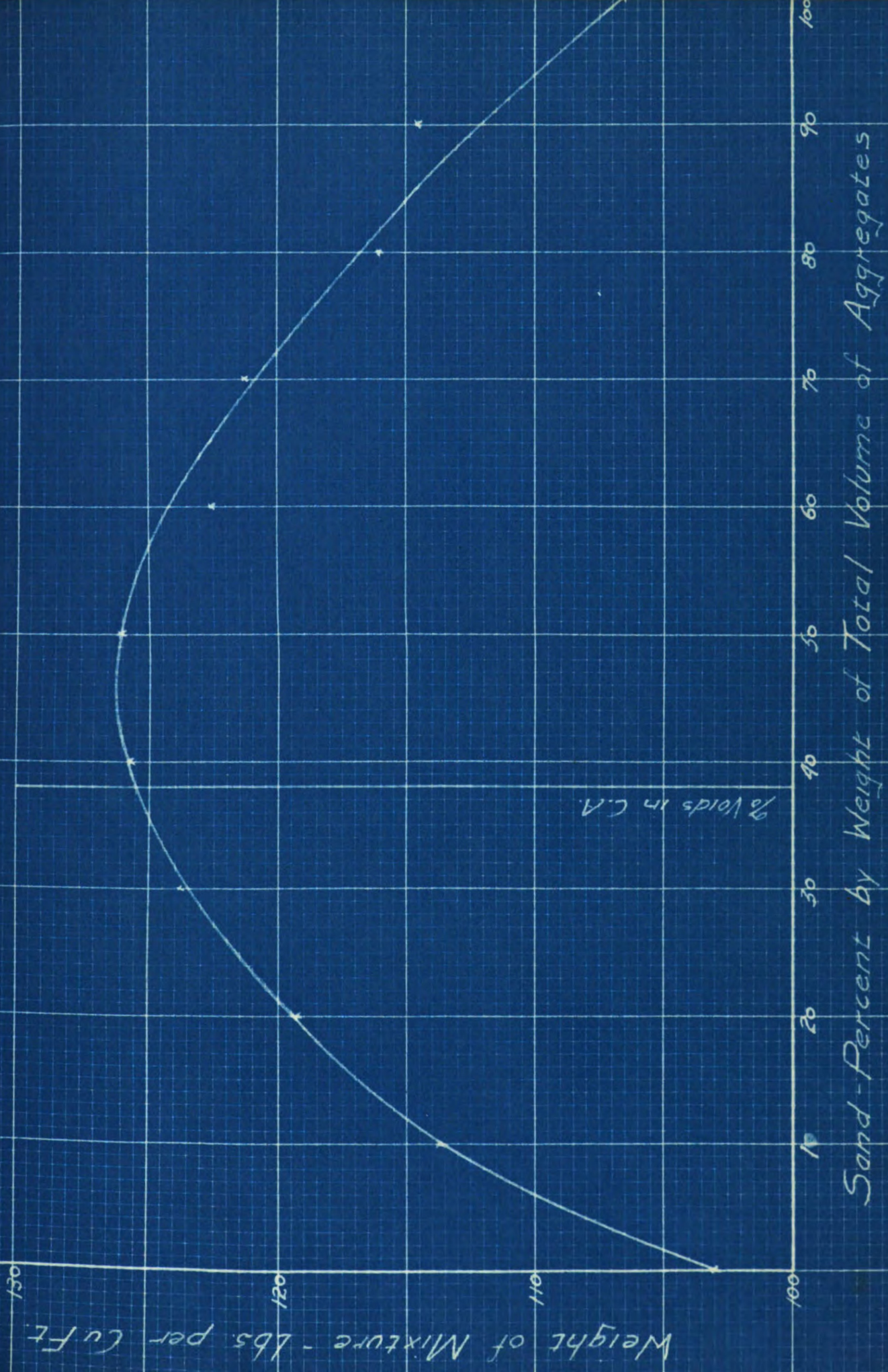
(1"+) COARSE AGGREGATE AND FINE SAND

Mix	Aggregate		Sand		Portion of Cu. Ft. Sam- ple Occupies	Weight of Sample	Weight of Sample per Cu. Ft.
	%	Weight	%	Weight			
1	100	103.00	00	0.00	1.00	103.00	103.0
2	90	92.75	10	10.75	.91	103.50	113.7
3	80	82.50	20	21.25	.87	103.75	119.3
4	70	72.00	30	32.00	.84	104.00	123.8
5	60	61.75	40	42.50	.83	104.25	125.7
6	50	51.50	50	53.25	.83	104.75	126.0
7	40	41.25	60	64.00	.86	105.25	122.5
8	30	31.00	70	74.50	.87	105.50	121.2
9	20	20.50	80	85.25	.91	105.75	116.0
10	10	10.25	90	95.75	.95	106.00	109.5
11	00	0.00	100	106.50	1.00	106.50	106.5

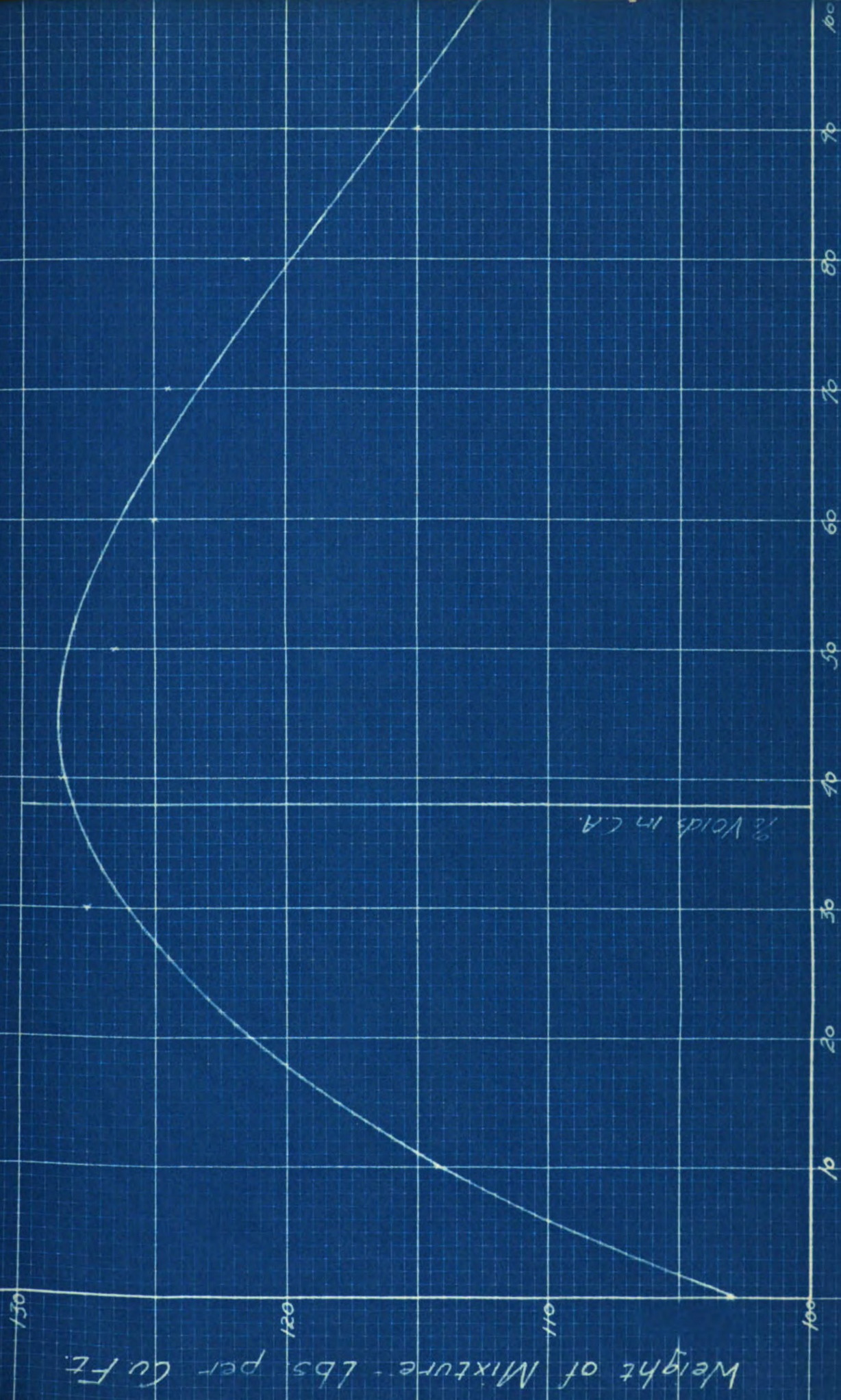
(1"+) COARSE AGGREGATE AND COARSE SAND

Mix	Aggregate		Sand		Portion of Cu. Ft. Sam- ple Occupies	Weight of Sample	Weight of Sample per Cu. Ft.
	%	Weight	%	Weight			
1	100	103.00	00	00.00	1.00	103.00	103.0
2	90	92.75	10	11.25	.91	104.00	114.3
3	80	82.50	20	22.50	.87	105.00	120.9
4	70	72.00	30	33.75	.83	105.75	127.5
5	60	61.75	40	45.00	.83	106.75	128.5
6	50	51.50	50	56.25	.85	107.50	126.5
7	40	41.25	60	67.50	.87	108.75	125.0
8	30	31.00	70	78.75	.88	109.75	124.5
9	20	20.50	80	90.00	.91	110.50	121.5
10	10	10.25	90	101.25	.97	111.50	115.0
11	00	00.00	100	112.50	1.00	112.50	112.5

(1") Coarse Agg. & Fine Sand
Cylinders 33.38 incl.



(1") Coarse Agg. & Coarse Sand
Cylinders 2' x 42 in.



% Voids in C.A.

Sand Percent by Weight of Total Volume of Aggregates

COMBINED COARSE AGGREGATE AND FINE SAND

Mix	Aggregate		Sand		Portion of Cu.Ft. Sam- ple Occupies	Weight of Sample	Weight of Sample per Cu. Ft.
	%	Weight	%	Weight			
1	100	111.50	00	00.00	1.00	111.50	111.5
2	90	100.25	10	10.75	.93	111.00	119.5
3	80	89.25	20	21.25	.87	110.25	126.8
4	70	78.00	30	32.00	.85	110.00	129.5
5	60	67.00	40	42.50	.83	109.50	132.0
6	50	55.75	50	53.25	.84	109.00	130.0
7	40	44.50	60	64.00	.86	108.50	126.2
8	30	33.50	70	74.50	.88	108.00	122.8
9	20	22.25	80	85.25	.91	107.50	118.0
10	10	11.25	90	95.75	.95	107.00	112.5
11	00	00.00	100	106.50	1.00	106.50	106.5

COMBINED COARSE AGGREGATE AND COARSE SAND

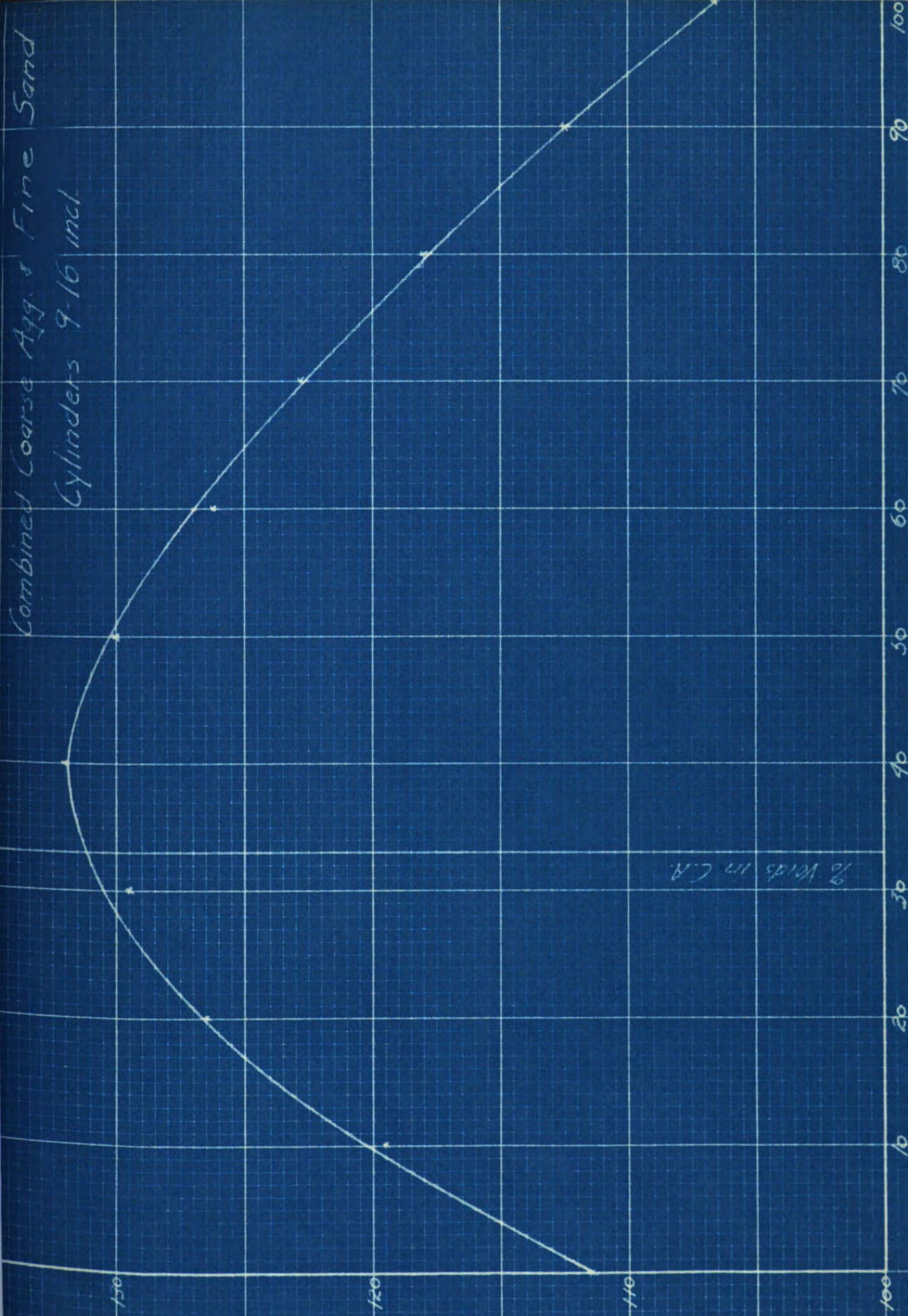
Mix	Aggregate		Sand		Portion of Cu.Ft. Sam- ple Occupies	Weight of Sample	Weight of Sample per Cu. Ft.
	%	Weight	%	Weight			
1	100	111.50	00	00.00	1.00	111.50	111.5
2	90	100.25	10	11.25	.95	111.50	117.5
3	80	89.25	20	22.50	.90	111.75	124.0
4	70	78.00	30	33.75	.88	111.75	127.0
5	60	67.00	40	45.00	.87	112.00	128.8
6	50	55.75	50	56.25	.87	112.00	128.8
7	40	44.50	60	67.50	.88	112.00	127.3
8	30	33.50	70	78.75	.91	112.25	123.5
9	20	22.25	80	90.00	.95	112.25	118.0
10	10	11.25	90	101.25	.98	112.50	115.0
11	00	00.00	100	112.50	1.00	112.50	112.5

Combined Coarse Agg. & Fine Sand
Cylinders 9-16 incl.

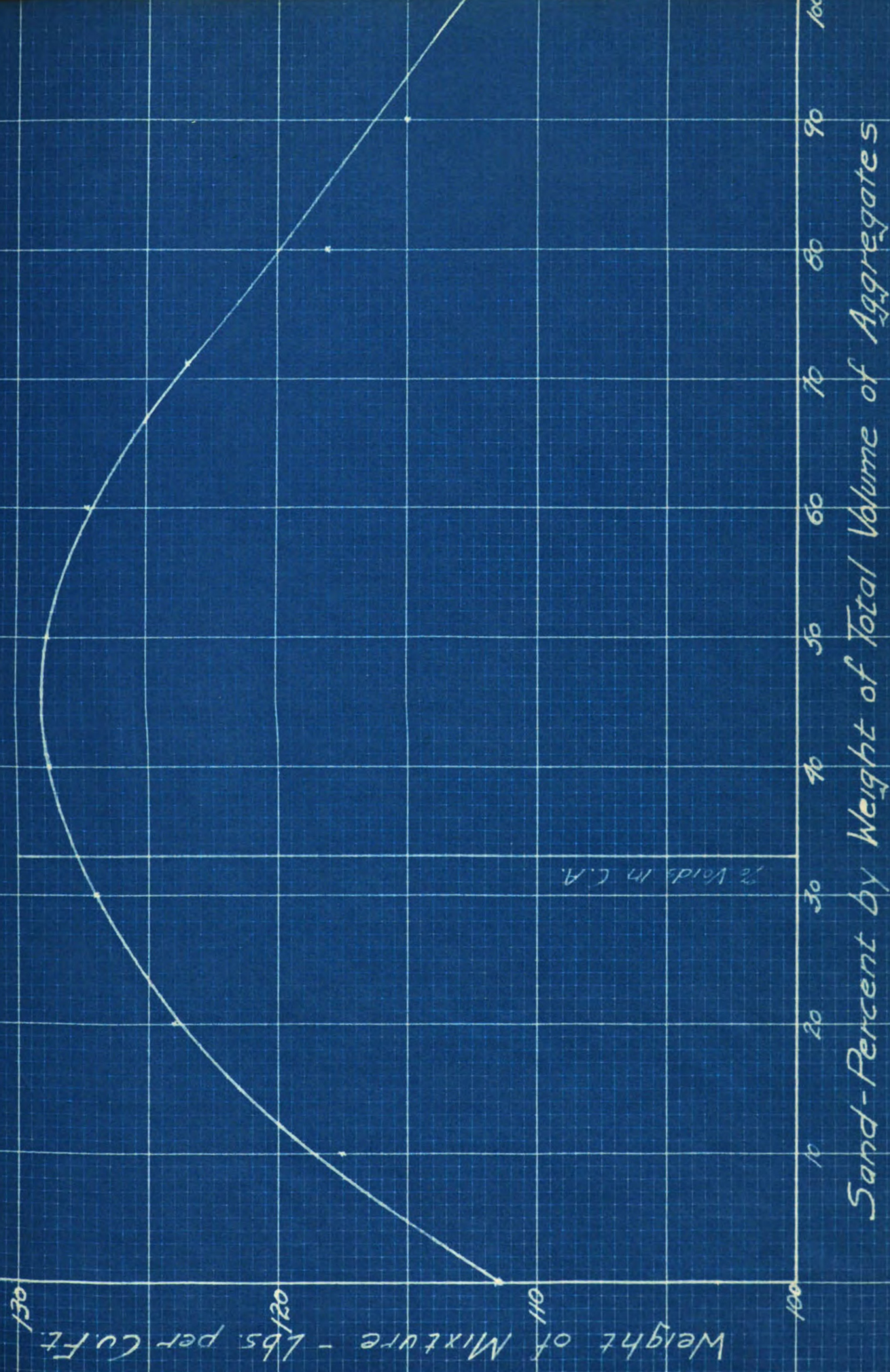
Weight of Mixture - Lbs. per Cu Ft.

% Voids in C.A.

Sand-Percent by Weight of Total Volume of Aggregates



Combined Course Agg. & Course Sand
Cylinders 1-8 incl.



In order to judge all the mixes on the same basis, a constant water-cement ratio of .80 was used in each case. This water-cement ratio is equivalent to the use of six gallons of water per bag of cement and according to the curve in "Concrete Practice" by Hool and Pulver, this ratio should have given concrete capable of withstanding 3000 pounds per square inch in each case.

One half cubic foot of aggregate was estimated to be sufficient to fill two test cylinders 6" x 12" likewise 1/10 bag or 9.5 lbs. of cement was thought to be sufficient. The computed weight of water to be used, relative to the 9.5 lbs. of cement, was 5 lbs. plus 0.5 lb. for absorption making a total of 15 lbs. of mortar for each batch.

The mixing trough was first dampened to do away with any surface absorption, then the carefully weighed out portions of sand and coarse aggregate were thoroughly mixed together in the trough. The mortar was mixed separately in a pail; first 9.5 lbs. of cement were weighed out, then 5.5 lbs. of water were added and the mortar thoroughly mixed. The mortar was added to the aggregate until the well-mixed concrete gave a slump of four inches. After observing the quality of each mix as to harshness, oversandedness, etc., the concrete was placed in cylinders and allowed to set for twenty-four hours. After the desired slump of four inches had been reached, the remaining mortar was weighed to determine what portion had been used in the mix. Then the

of Hool and Pulver:

$$S_{28} = S_7 + 30 \sqrt{S_7}$$

Photographs were taken of the broken cylinders to show the placement of aggregate and mortar in the various mixes.

SIEVE ANALYSES

Fine Sand - Unit Weight = 106.5#

Weight of sample = 1000 grams

Retained on No.		wt.		%
4	-	2.0	grams	0.20
"	"	15.3	"	1.53
"	"	51.3	"	5.13
"	"	115.6	"	11.56
"	"	422.4	"	42.24
"	"	333.4	"	33.34
"	"	60.0	"	6.00
Pan	-			

Coarse Sand - Unit Weight = 112.5#

Weight of sample = 1000 grams

Retained on No.		wt.		%
4	-	10.1	grams	1.01
"	"	88.7	"	8.87
"	"	211.6	"	21.10
"	"	243.5	"	24.15
"	"	313.7	"	31.17
"	"	119.5	"	11.95
"	"	13.9	"	1.39
Pan	-			

SIEVE ANALYSES

(1"-) Coarse Aggregate - Unit Weight = 107.5#

Weight of sample = 1000 grams

			wt.	%
Retained on	1 1/2"	-	0.0	0.00
"	"	3/4"	240.4	24.40
"	"	3/8"	529.2	52.92
"	"	No. 4	203.9	20.39
"	"	Pan	26.5	2.65

(1"+) Coarse Aggregate - Unit Weight = 103.0#

Weight of sample = 3000 grams

			wt.		%
Retained on	1 1/2"	-	955	grams	31.8
"	"	3/4"	2045	"	68.2
"	"	3/8"	00		00.0
"	"	No. 4	00		00.0

WEIGHTS PER SAMPLE

Cylinder	% Sand	Sand	C. A.	Cement	Water	Weight of Batch
1	30	16.75	39.00	7.75	4.5	68.00
2	30	16.75	39.00	7.75	4.5	68.00
3	40	22.50	33.50	5.85	3.4	65.25
4	40	22.50	33.50	5.85	3.4	65.25
5	50	28.25	28.00	6.15	3.6	66.00
6	50	28.25	28.00	6.15	3.6	66.00
7	45	25.25	30.50	6.95	4.05	66.75
8	45	25.25	30.50	6.95	4.05	66.75
9	30	16.00	39.00	4.43	2.57	62.00
10	30	16.00	39.00	4.43	2.57	62.00
11	40	21.25	33.50	7.45	4.3	66.50
12	40	21.25	33.50	7.45	4.3	66.50
13	50	26.25	28.00	11.72	6.78	72.75
14	50	26.25	28.00	11.72	6.78	72.75
15	60	32.00	22.25	12.34	7.16	73.75
16	60	32.00	22.25	12.34	7.16	73.75
17	30	17.00	37.75	7.6	4.4	66.75
18	30	17.00	37.75	7.6	4.4	66.75
19	40	22.50	32.25	8.24	4.76	67.75
20	40	22.50	32.25	8.24	4.76	67.75
21	50	28.25	27.00	9.65	5.6	70.50
22	50	28.25	27.00	9.65	5.6	70.50
23	60	33.75	21.50	11.25	6.5	73.00
24	60	33.75	21.50	11.25	6.5	73.00
25	30	16.00	37.75	7.76	4.49	66.00
26	30	16.00	37.75	7.76	4.49	66.00
27	40	21.25	32.25	9.65	5.6	68.75
28	40	21.25	32.25	9.65	5.6	68.75
29	50	26.75	26.75	12.20	7.05	72.75
30	50	26.75	26.75	12.20	7.05	72.75
31	60	32.00	21.50	12.5	7.25	73.25
32	60	32.00	21.50	12.5	7.25	73.25

(Cont'd)

(Cont'd)

WEIGHTS PER SAMPLE

<u>Cylinder</u>	<u>% Sand</u>	<u>Sand</u>	<u>C. A.</u>	<u>Cement</u>	<u>Water</u>	<u>Weight of Batch</u>
33	30	16.00	36.00	7.3	4.20	63.50
34	30	16.00	36.00	7.3	4.20	63.50
35	40	21.25	31.00	10.45	6.05	68.75
36	40	21.25	31.00	10.45	6.05	68.75
37	50	26.75	25.75	10.6	6.15	69.25
38	50	26.75	25.75	10.6	6.15	69.25
39	30	26.75	36.00	7.75	4.5	75.00
40	30	26.75	36.00	7.75	4.5	75.00
41	50	28.25	25.75	8.25	4.75	67.00
42	50	28.25	25.75	8.25	4.75	67.00

WEIGHTS PER SACK OF CEMENT

<u>Cylinder</u>	<u>% Sand</u>	<u>Sand</u>	<u>C. A.</u>	<u>Cement</u>	<u>Water</u>	<u>Weight of Mix</u>
1	30	194.5	453.0	95.0	52.3	794.8
2	30	194.5	453.0	95.0	52.3	794.8
3	40	365.0	544.0	95.0	55.2	1059.2
4	40	365.0	544.0	95.0	55.2	1059.2
5	50	436.0	432.0	95.0	55.6	1018.6
6	50	436.0	432.0	95.0	55.6	1018.6
7	45	345.0	416.0	95.0	55.4	911.4
8	45	345.0	416.0	95.0	55.4	911.4
9	30	342.5	835.0	95.0	55.0	1327.5
10	30	342.5	835.0	95.0	55.0	1327.5
11	40	271.0	427.0	95.0	54.8	847.8
12	40	271.0	427.0	95.0	54.8	847.8
13	50	212.5	226.5	95.0	54.9	588.9
14	50	212.5	226.5	95.0	54.9	588.9
15	60	246.0	171.0	95.0	55.0	567.0
16	60	246.0	171.0	95.0	55.0	567.0
17	30	212.0	472.0	95.0	55.0	834.0
18	30	212.0	472.0	95.0	55.0	834.0
19	40	259.0	372.0	95.0	54.9	780.9
20	40	259.0	372.0	95.0	54.9	780.9
21	50	278.0	268.0	95.0	55.1	696.1
22	50	278.0	268.0	95.0	55.1	696.1
23	60	284.0	181.5	95.0	54.8	615.3
24	60	284.0	181.5	95.0	54.8	615.3
25	30	196.0	462.0	95.0	55.0	808.0
26	30	196.0	462.0	95.0	55.0	808.0
27	40	209.0	317.0	95.0	55.1	676.1
28	40	209.0	317.0	95.0	55.1	676.1
29	50	205.0	205.0	95.0	55.0	560.0
30	50	205.0	205.0	95.0	55.0	560.0
31	60	243.0	163.5	95.0	55.0	556.5
32	60	243.0	163.5	95.0	55.0	556.5

(Cont'd)

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WEIGHTS PER SACK OF CEMENT

<u>Cylinder</u>	<u>% Sand</u>	<u>Sand</u>	<u>C. A.</u>	<u>Cement</u>	<u>Water</u>	<u>Weight of Mix</u>
33	30	208.0	468.0	95.0	54.6	825.6
34	30	208.0	468.0	95.0	54.6	825.6
35	40	193.0	282.0	95.0	55.0	625.0
36	40	193.0	282.0	95.0	55.0	625.0
37	50	239.0	230.0	95.0	55.0	619.0
38	50	239.0	230.0	95.0	55.0	619.0
39	30	327.0	441.0	95.0	55.1	918.0
40	30	327.0	441.0	95.0	55.1	918.0
41	50	325.0	296.0	95.0	54.7	770.7
42	50	325.0	296.0	95.0	54.7	770.7

YIELD PER SACK OF CEMENT

Cylinder	Sand			C. A.			Cement	Water	Yield
	Unit Wt.	Vol.	Abs. Vol.	Unit Wt.	Vol.	Abs. Vol.			
1	112.5	1.73	1.18	111.5	4.06	2.74	.49	.84	5.25
2	112.5	1.73	1.18	111.5	4.06	2.74	.49	.84	5.25
3	112.5	3.24	2.20	111.5	4.88	3.29	.49	.89	6.87
4	112.5	3.24	2.20	111.5	4.88	3.29	.49	.89	6.87
5	112.5	3.87	2.63	111.5	3.88	2.62	.49	.89	6.63
6	112.5	3.87	2.63	111.5	3.88	2.62	.49	.89	6.63
7	112.5	3.07	2.09	111.5	3.73	2.52	.49	.89	5.99
8	112.5	3.07	2.09	111.5	3.73	2.52	.49	.89	5.99
9	106.5	3.22	2.07	111.5	7.50	5.06	.49	.88	8.50
10	106.5	3.22	2.07	111.5	7.50	5.06	.49	.88	8.50
11	106.5	2.54	1.64	111.5	3.83	2.58	.49	.88	5.59
12	106.5	2.54	1.64	111.5	3.83	2.58	.49	.88	5.59
13	106.5	2.00	1.29	111.5	2.03	1.37	.49	.88	4.03
14	106.5	2.00	1.29	111.5	2.03	1.37	.49	.88	4.03
15	106.5	2.31	1.49	111.5	1.54	1.04	.49	.88	3.90
16	106.5	2.31	1.49	111.5	1.54	1.04	.49	.88	3.90
17	112.5	1.89	1.29	107.5	4.40	2.86	.49	.88	5.52
18	112.5	1.89	1.29	107.5	4.40	2.86	.49	.88	5.52
19	112.5	2.30	1.57	107.5	3.46	2.25	.49	.88	5.19
20	112.5	2.30	1.57	107.5	3.46	2.25	.49	.88	5.19
21	112.5	2.47	1.68	107.5	2.50	1.63	.49	.88	4.68
22	112.5	2.47	1.68	107.5	2.50	1.63	.49	.88	4.68
23	112.5	2.52	1.72	107.5	1.69	1.10	.49	.88	4.19
24	112.5	2.52	1.72	107.5	1.69	1.10	.49	.88	4.19
25	106.5	1.76	1.13	107.5	4.30	2.80	.49	.88	5.30
26	106.5	1.76	1.13	107.5	4.30	2.80	.49	.88	5.30
27	106.5	1.96	1.26	107.5	2.95	1.92	.49	.88	4.55
28	106.5	1.96	1.26	107.5	2.95	1.92	.49	.88	4.55
29	106.5	1.92	1.24	107.5	1.91	1.24	.49	.88	3.85
30	106.5	1.92	1.24	107.5	1.91	1.24	.49	.88	3.85
31	106.5	2.28	1.47	107.5	1.52	.99	.49	.88	3.83
32	106.5	2.28	1.47	107.5	1.52	.99	.49	.88	3.83

(Cont'd)

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YIELD PER SACK OF CEMENT

Cylinder	Sand			C. A.			Cement	Water	Yield
	Unit Wt.	Vol.	Abs. Vol.	Unit Wt.	Vol.	Abs. Vol.			
33	106.5	1.95	1.26	103.0	4.55	2.83	.49	.88	5.46
34	106.5	1.95	1.26	103.0	4.55	2.83	.49	.88	5.46
35	106.5	1.81	1.17	103.0	2.74	1.71	.49	.88	4.25
36	106.5	1.81	1.17	103.0	2.74	1.71	.49	.88	4.25
37	106.5	2.24	1.44	103.0	2.23	1.39	.49	.88	4.20
38	106.5	2.24	1.44	103.0	2.23	1.39	.49	.88	4.20
39	112.5	2.91	1.98	103.0	4.28	2.67	.49	.88	6.02
40	112.5	2.91	1.98	103.0	4.28	2.67	.49	.88	6.02
41	112.5	2.89	1.97	103.0	2.88	1.79	.49	.88	5.13
42	112.5	2.89	1.97	103.0	2.88	1.79	.49	.88	5.13

STRENGTH

Cylinder	Weight	Constant	Load 1000#	Net Load 1000#	S ₇ #/sq.in.	S ₂₈ #/sq.in.
1	29.50	27	90	53	1875	3174
2	29.36	30	72	42	1490	2648
3	29.29	30	78	48	1700	2938
4	29.19	30	82	52	1840	3130
5	28.76	30	63	33	1170	2196
6	28.82	30	53	23	814	1672
7	28.93	30	65	35	1238.	2294
8	29.02	30	63	33	1168.	2194
9	29.02	27	63	36	1275.	2346
10	29.60	27	54	27	956.	1985.
11	28.60	27	72.5	45.5	1610.	2813.
12	28.92	27	75.	48.	1700.	2938.
13	28.13	27	67.	40.	1415.	2543.
14	28.00	27	75.	48	1700.	2938.
15	27.35	27	87.5	60.5	2140.	3529.
16	27.30	27	87.5	60.5	2140.	3529.
17	29.45	27	88	61.	2160.	3555.
18	29.93	41	106.	65	2300.	3740
19	29.23	41	124.	83	2940.	4569
20	29.56	27	82.5	55.5	1965.	3297
21	28.83	41	114.0	73.0	2580.	4104
22	28.66	41	118.0	77.	2720.	4284
23	28.15	41	92.5	51.5	1825.	3109
24	28.10	41	102.5	61.5	2175.	3576
25	29.43	41	99	58	2050	3412
26	29.35	41	113	72	2550	4065
27	29.14	41	113	72	2550	4065
28	28.94	41	111	70	2480	3994
29	28.09	41	116	75	2650	4195
30	28.19	41	109	68	2400	3870
31	27.80	41	94	53	1875	3174
32	27.54	41	99	58	2050	3412

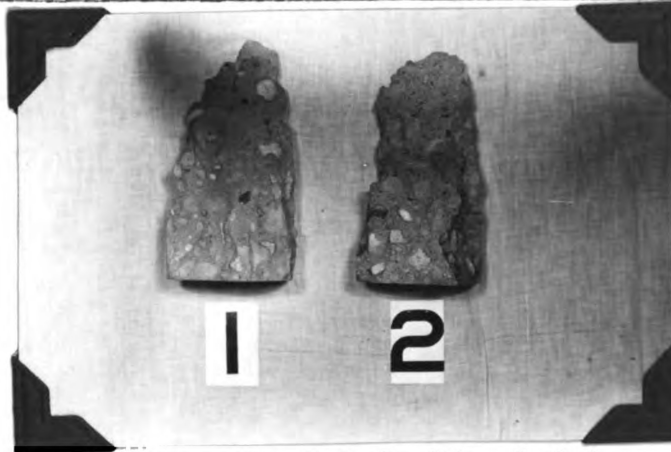
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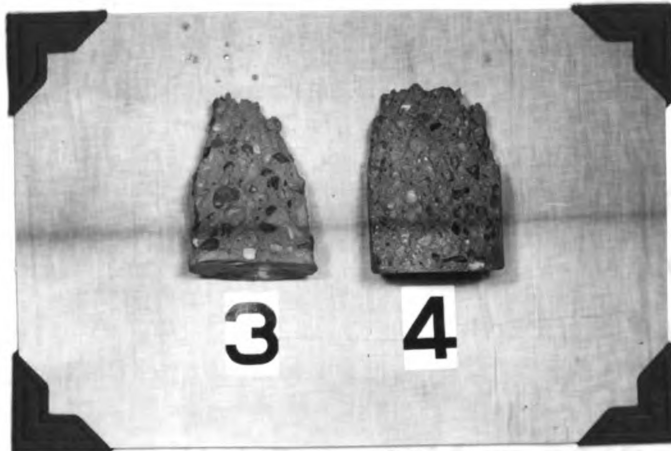
STRENGTH

Cylinder	Weight	Constant	Load 1000#	Net Load 1000#	S ₇ #/sq.in.	S ₂₈ #/sq.in.
33	29.22	41	97	56	1980	3215
34	29.33	41	64	23	814	1669
35	29.24	41	104	63	2230	3646
36	29.02	41	99	58	2050	3409
37	28.93	41	97	56	1980	3215
38	28.58	41	100	59	2090	3458
39	29.42	2	49	47	1665	2889
40	30.09	2	49	47	1665	2889
41	28.83	2	64	62	2195	3599
42	29.38	2	64	62	2195	3599

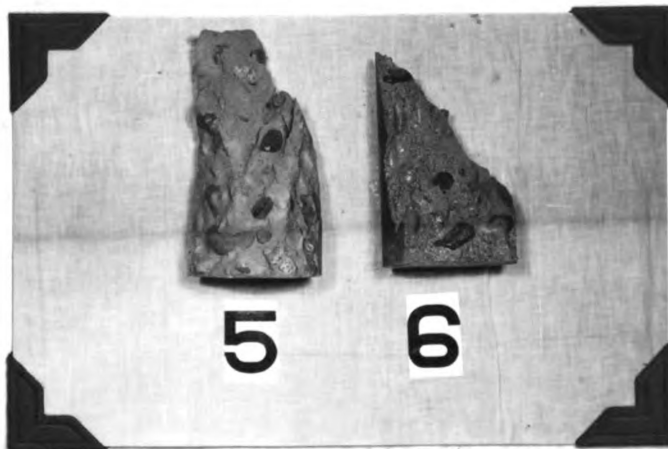
PHOTOGRAPHS SHOWING PLACEMENT OF AGGREGATE AND MORTAR



1. Fine Sand & Combined C.A.
2. Coarse Sand & Combined C.A.



3. Fine Sand & (1"-) C.A.
4. Coarse Sand & (1"-) C.A.



5. Fine Sand & (1"+) C.A.
6. Coarse Sand & (1"+) C.A.

CONCLUSIONS

1. Sieve Analyses

The three groups which produced the most yield all contained coarse sand which had the most material retained on No. 48 screen, then on No. 28, and then on No. 14. The fine sand also had most of its material retained on the No. 48 screen, but then the tendency was toward the finer No. 100 screen. This shows that the coarser sand particles tend to make a denser mix of better yield.

2. Grading of Aggregate

The mix that produced the greatest yield with a corresponding superior weight was the mix of coarse sand and combined coarse aggregate showing that not alone can coarse aggregate greater than one inch produce good yield, and not alone can coarse aggregate less than one inch produce good yield. It takes a uniform grading of the two from less than one inch to the largest practical coarse aggregate to give best results.

3. Quality

In every case a batch made up with a percentage of sand lying below or back of the vertical percentage void line was found to be harsh showing that the voids in the coarse aggregate were not being filled with mortar. On the average, those mixes containing an equal percentage of sand and coarse aggregate were of the best quality, while beyond

a zone between the 50% sand and 60% sand, the mixes tended to be oversanded.

4. Density and Yield

With one exception, all the groups showed a tendency for weight per sack of cement and yield per sack of cement to decrease as the percentage of sand increased. This shows conclusively that oversanding is uneconomical as it decreases both density and yield.

5. Strength

Although the strengths were to have been constant with a given water-cement ratio, there was still quite a variation. As a rule, the good quality mixes, in which the percentages of sand and coarse aggregate were about the same, gave the highest strength. A trend towards either harshness or oversanding would tend to weaken the concrete.

In general a mix using a coarse aggregate uniformly graded to the largest maximum size practical under job conditions and a coarse sand containing only enough fines for good finishing should produce a concrete having greatest density and yield per sack of cement. Harsh mixes will give greater yield although the density tends to be less, and mixes of even proportions -- 50% of each -- give better quality and higher strength. In mixes using coarse aggregate uniformly graded above one inch, it is probable that the ideal mix will lie between the 40% and 50% sand content. Regardless of the grading of coarse aggregate, the ideal

mix will contain 5% to 10% more fine material than the percentage of voids in the compacted coarse aggregate.

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