A COMPARISON OF COMPRESSIVE AND FLEXURAL STRENGTH OF CONCRETE AND DESIGN AND CONSTRUCTION OF BEAM TESTING MACHINE

THESIS FOR THE DEGREE OF B. S.

G. H. Jennings W. B. Hanlon

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A Comparison of Compressive and Flexural Strength of Concrete and Design and Construction of Beam Testing Machine

A Thesis Submitted to

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AGRICULTURE AND APPLIED SCIENCE

By

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Candidates for the Degree of

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THESIS

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Introduction

In all reinforced concrete design the compressive strength of the concrete alone is considered. The steel reinforcing is designed to carry all of the tensile strength. Tests have proven that concrete structures will carry a greater load than their calculated load due to the flexural strength of the concrete. However it is still considered the better practice to disregard the flexural strength in designing. In concrete road construction the flexural strength is the controlling factor in the design. As a definite ratio exists between the compressive and flexural strength it would be possible to consider the flexural strength in some designs. This would give greater economy as the sections would be lighter thus using less material.

In the experimental work for this report, tests were made upon different mixes of concrete to determine the compressive and flexural strength and the ratio existing between them.

Test Specimens

The concrete for the test specimens was made according to the water-cement ratio theory to give different strengths. The sand used was clean and graded 0" to ¼" with a fineness modulus of about 2.8. Washed gravel having a size of ¼" to 1" and a fineness modulus of about 7 used for the coarse aggregate. The mixing was done in a 2½ cu. ft. Smith mixer. Curve "A" was used in the designs of the mixes. Each batch was tested for slump and a constant consistency of 3" to 4" slump was maintained.

The moulds were made from 6" and 8" channel sections to give a 6"x8"x36" beam. This was long enough to give two breaks on each beam. They were broken with the 8" side vertical. One break was made with the top as poured and the other with it down. This method of breaking would tend to eliminate any irregularity that there might be due to segregation or variation in the concrete in the beam. The cylinders were the standard cylinders 6" in diameter and 12" high.

All of the beams and cylinders were cured in wet sand for 28 days. Before breaking the test pieces were allowed to dry for a few hours and then brushed clean. The cylinders were capped on both ends with plaster of paris to insure an even bearing over the whole surface. A Watson Stillman Hydraulic compression machine of 200,000 lbs. capacity was used. The beams were fastened in place between the steel plates of the beam testing machine which was made as a part of this thesis.

Compressive and Flexural Strength

of Test Specimens

	Set # 1.		Set # 2.		Set # 3.	
	Comp. Str.	Mod. of Rupture	Comp. Str.	Mod. of Rupture	Comp. Str.	Mod. of Rupture
	4070	481	3180	474	4250	527
	2660	470	3720	538	4260	633
	3250	510	3450	538	3820	608
	1860 ✓	570	4070	563	2940	519
	3360	479	4000	519	3980	674
	2060	489	2600	633	4080	563
	2720	512	3600	519	4400	583
	4500	583	3980	519	3290 ✓	521
	2300	414	3010	548	4330	597
	1660 ✓	487	3180	543	3780	570
	4040	495	3900	565	4400	591
	4140	536	3720	610	4400	508
Av.	3310	547	3534	547	4174	577

	Set # 4.		Set # 5.		Set # 6.	
	Comp. Str.	Mod. of Rupture	Comp. Str.	Mod. of Rupture	Comp. Str.	Mod. of Rupture
	4800	643	4960	699	5310	735
	5400	557	6480	643	6200	758
	5450	643	6020	695	5310	707
	5400	625	5520	578	5330	688
	4600	625	5660	625	6220	767
	5140	570	6020	671	6370	535
	5900	614	3210	783	5840	763
	5210	587	6370	674	5400	707
	5360	591	4250 ✓	558	5220	688
	5150	585	6730	644	5240	631
	5860	608	5320	619	5310	707
	4810	555	4600 ✓	619	4790 ✓	707
Av.	5256	600	5830	667	5577	699

Check Mark thus ✓, indicates specimen was not used in average of results.

Deviation in Percent of Individual Values for

Flexural Strength From the Mean of Each Set

	Set #1.	Set #2.	Set #3.	Set #4.	Set #5.	Set #6.
	4.18	13.48	8.68	7.16	4.80	5.14
	6.37	1.65	9.72	7.16	3.60	9.74
	1.79	1.65	5.73	7.16	14.20	1.14
	13.50	2.56	9.90	4.17	13.35	1.57
	4.58	5.12	16.83	4.17	6.30	9.70
	2.59	15.74	2.43	5.00	0.60	23.50
	1.98	5.12	1.04	2.23	17.40	9.15
	16.00	5.12	9.72	2.16	0.75	1.14
	17.50	0.18	3.47	1.50	13.65	1.57
	2.98	0.73	1.30	2.50	3.45	9.70
	1.39	3.30	2.43	1.33	7.20	1.14
	6.77	29.80	11.97	7.50	7.20	1.14
Av.	6.64	7.04	6.83	4.34	7.71	6.22

Deviation in Percent of Individual Values of

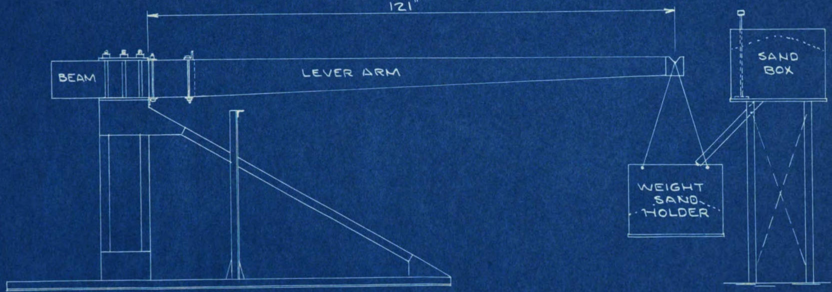
Compressive Strength From the Mean of Each Set

	Set # 1.	Set #2.	Set #3.	Set #4.	Set #5.	Set #6.
	22.90	12.85	1.82	8.70	4.80	5.14
	19.60	5.26	2.06	2.74	3.60	9.74
	1.81	3.51	8.50	3.70	14.20	1.14
	44.20	15.20	29.60	2.74	13.35	1.57
	1.51	13.20	4.65	12.50	6.30	9.70
	37.80	26.40	2.30	2.21	0.60	23.50
	11.80	1.86	6.38	12.20	17.40	9.15
	36.00	12.62	21.20	0.86	0.75	1.14
	30.50	12.00	3.74	1.98	13.65	1.57
	49.50	10.00	9.26	1.98	3.45	9.70
	22.00	10.35	5.42	12.65	7.20	1.14
	41.40	5.26	5.42	8.50	7.20	1.14
Av.	26.58	10.71	8.36	5.98	10.82	7.39

The Machine

The machine used for the flexural tests was built according to the enclosed drawing. It is composed of a steel frame for holding the test beam in place and a wooden lever arm attached to the test beam in such a manner as to introduce a bending moment in the beam. The container supported at the end of the lever arm was gradually filled with sand to increase the moment. The flow of sand into this container was stopped as soon as the beam broke. This method of loading gives a gradual increase in the load and eliminates impact which may occur when larger weights are placed upon the beam.

Knowing the lever arm, the moment due to the sand load was easily computed. The moment due to the lever arm and beam overhang was constant so the total moment was obtained by adding the moment due to the sand load to this constant moment.

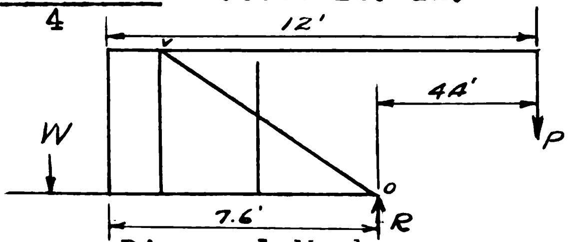


DIAGRAMATIC DRAWING OF
BEAM TESTING MACHINE
W.B. HANLON, G.H. JENNINGS
EAST LANSING, MICHIGAN.
MAY 1930

Computations

Assume maximum flexural strength as 1500 lb. per sq. in.

$$M = \frac{sI}{c} = \frac{256 \times 1500}{4} = 96000 \text{ lb. in.}$$



Diagonal Member

$$P = \frac{96000}{108} = 888 \text{ lbs.}$$

$M_o = 4.4 \times 888 - 8.65W$ $W = 450$ lbs.

$$R = 888 + 450 = 1338 \times \frac{7.7}{4} = 2570 \text{ lbs.}$$

$$\frac{2570}{2 \times .94} = 1370 \text{ lbs. per sq. in.}$$

$$\frac{l}{r} = \frac{7.7 \times 12}{.37} = 237$$

Allowable stress = 16000 - 50 x 237 = 4150 lbs. per sq. in

3/8 in. rivet in shear = 1100 lbs. 2 rivets (O.K)

3/8 in. rivet in bearing = 24000 x 3/8 x 1/8 = 1125 lbs. (O.K)

Upright Members

$$\frac{96000}{2} = 48000 \text{ lbs. in. taken by each side}$$

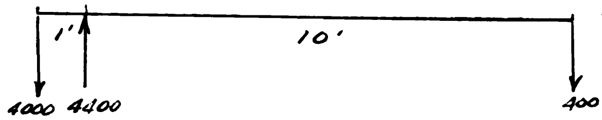
$$\frac{48000}{10.875} = 4420 \text{ lbs. stress}$$

3/8 in. rivets in shear = 1320   3 required

Bearing with 3 rivets $= \dfrac{4420}{.0703 \; 0.94} = 16400$ lbs. (O.K)

Lever Arm

Assume d = 8 in. I = 42.667b



M = 4000 x 12 = 48000 lb. in.

$$\frac{M}{s} = \frac{I}{c} = \frac{42.667b}{4} = \frac{48000}{1200} = 40$$

b = 3.75" use 2 - 2" x 8" Oak

Clamp Bolts

M = 1.5C + 6B + 10.5A

= 1.5C + 6(4C) + 10.5(7C)

= (1.5 + 24 + 73.5)C = 99C

99C = 96000

C = 970

7C = 6790

$\frac{6790}{16000}$ = .425 sq. in. Use $\frac{3}{4}$" bolts.

Applying the formula $s = \frac{Mc}{I}$, in which

s = flexural strength in lbs. per sq. in.

M = total moment in lb. in.

c = distance to extreme fibre from neutral axis.

I = moment of inertia about the neutral axis.

$c = 4$ in. $d = 8$ in. $b = 6$ in. $I = 256$ in. $\frac{c}{I} = \frac{1}{64}$ in.

we have $s = M/64$

But $M = M_1 + M_2 + M_3 = W_1 l_1 + W_2 l_2 + W_3 l_3$, in which

W_1 = wt. of beam overhang 50 lbs. (varies slightly)

W_2 = wt. of lever arm = 95.5 lbs.

W_3 = wt. of sand load.

l_1 = distance to center of gravity of beam overhang = 6 in.

l_2 = distance to center of gravity of lever arm = $52\frac{1}{2}$ in.

l_3 = distance to center of gravity of sand load = 121 in.

Therefore $s = \frac{W_1 l_1 + W_2 l_2}{64} + \frac{W_3 l_3}{64}$

$$= \frac{(50 \times 6) + (95.5 \times 52.5)}{64} + \frac{W \times 121}{64}$$

$$= 83 + 1.89\, W$$

The steel frame was fabricated by the Jarvis Engineering Co.

The total cost of the machine was slightly under 45 dollars.

Conclusions

There is a definite relation between the flexural and compressive strength of the same concrete. It varies, however, with different strengths. The relations we obtained were for concretes of the higher strengths than ordinarily. They varied from 11% to 15%. As brought out in tests by the Portland Cement Co., and the Structural Materials Laboratory the ratio increases up to as much as 35% as the compressive strength decreases to about 1500 lb. per sq. in.

The modulus of rupture of the beams in each set increases over the preceeding one which is as it should be according to our design of the mixes. This does not prove to be the case with the compressive strength of the cylinders. Then, too, the average deviation of the modulus of rupture of the beams proved to be less than the average deviation of the compressive strength of the cylinders from the average compressive strength of the cylinders. This shows that the results obtained are more consistant in the case of the modulus of rupture of the beams than in the compressive strength of cylinders.

Because of the simplicity of the beam testing machine and its lightness it is possible to have one in the field and obtain better results with less time and trouble than taking cylinders to the laboratory.

It means more to field men to see the tests done on the job and note what each particular concrete can stand than by reading a report from a laboratory.

Bibliography

Report of Director of Research; Portland Cement Association.
Nov. 1928 137-200

Public Roads Vol. 8, No. 12, Feb. 1928

The National Sand and Gravel Bulletin Mar. 1928 13-31

University of Michigan, Official Publication Vol. 31,
No. 14, Aug. 24, 1929 73-87

Bulletin 11; Structural Materials Research Laboratory.

Proceedings of the American Concrete Institute Vol. 22,
1926 388-389

Proceedings of the American Concrete Institute Vol. 24,
1928 212-237

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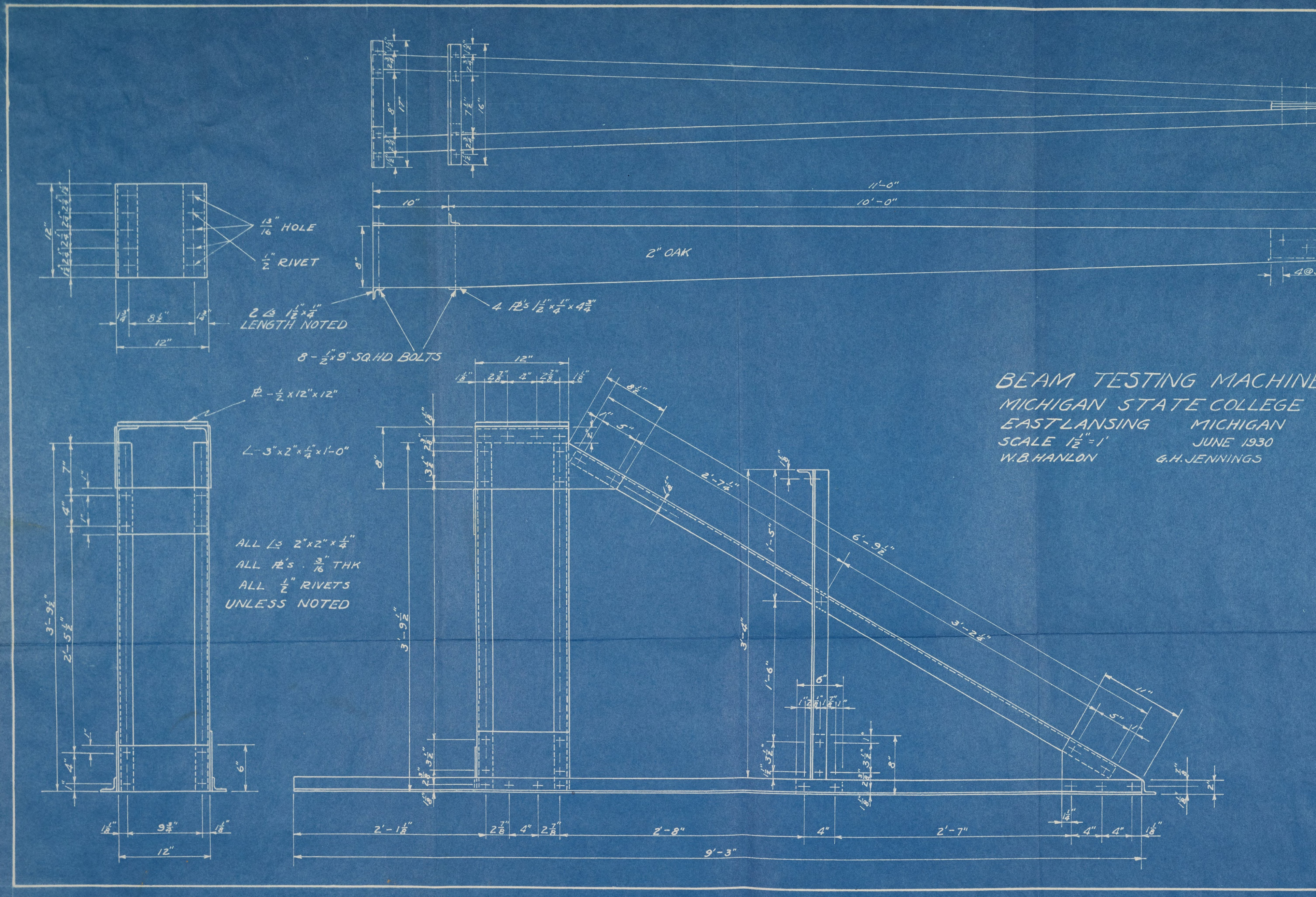
BEAM TESTING MACHINE
MICHIGAN STATE COLLEGE
EAST LANSING MICHIGAN
SCALE 1½" = 1' JUNE 1930
W.B. HANLON G.H. JENNINGS
13/16" HOLE
½" RIVET
2" OAK
11'-0"
10'-0"
10"
4@3"=12"
2 Ls 1½"×¼" LENGTH NOTED
4 PL'S 1½"×¼"×4¾"
8-½"×9" SQ.HD. BOLTS
PL.-½×12"×12"
L-3"×2"×¼"×1'-0"
ALL Ls 2"×2"×¼"
ALL PL'S 3/16" THK
ALL ½" RIVETS
UNLESS NOTED
9'-3"
2'-1⅛"
2'-8"
2'-7"
3'-9½"
2'-5½"
3'-4"
6'-9½"
3'-2⅞"
2'-7½"
1'-5"
1'-6"
12"
11"

Fineness Modulus of Sand on Hand.

Size of Screen	Per Cent Coarser Trial #1	Per Cent Coarser Trial #2
1½	0	0
¾	0	0
⅜	0	0
4	.187	1.42
8	1.116	8.02
14	23.01	23.27
30	47.11	52.62
48	77.01	81.82
100	95.51	97.34
Fineness Modulus	2.557	2.645

Av. Fineness Modulus of two trials = 2.60

Fineness Modulus of Gravel on Hand

Size of Screen	Per Cent Coarser Trial #1	Per Cent Coarser Trial #2
1½	0	0
¾	1.77	24.7
⅜	78.9	81.0
4	99.8	99.9
8	100.0	100.0
14	100.0	100.0
30	100.0	100.0
48	100.0	100.0
100	100.0	100.0
Fineness Modulus	6.964	7.056

Average Fineness Modulus of two trials = 7.01

FINENESS MODULUS OF SAND DELIVERED BY LANSING SAND AND GRAVEL CO.

Size of Screen	Per Cent Coarser Trial #1	Per Cent Coarser Trial #2
1½	0	0
¾	0	0
⅜	0	0
4	2.00	1.12
8	12.00	12.22
16	31.62	31.22
30	71.12	73.72
48	93.62	95.02
100	98.56	99.02
Fineness Modulus	3.09	3.12

Average Fineness Modulus of two trials = 3.10

FINENESS MODULUS OF GRAVEL DELIVERED BY LANSING SAND AND GRAVEL CO.

Size of Screen	Per Cent Coarser
1½	0
¾	6.72
⅜	87.45
4	99.43
8	100.00
16	100.00
30	100.00
48	100.00
100	100.00
Fineness Modulus	6.936

APRIL 10, 1930

DESIGN OF 1500# CONCRETE (CURVE "A")

FINENESS MODULUS OF MIXED AGGREGATE = 5.13

VOLUME OF DRY MIXED AGGREGATE TO CEMENT = 7.4-1

$$r = \frac{7.01 - 5.13}{7.01 - 2.60} = 45\% \text{ sand}$$

WT. OF ONE CU. FT. DRY RODDED SAND = 113#

" " " " " " GRAVEL = 106.3#

.45 x 113. = 50.8#

.55 x 106.3 = 58.2#

TOTAL = 109#

SINCE A CUBIC FOOT OF THE MIXED AGGREGATES IN THESE PROPORTIONS WEIGHS 128# IT WILL REQUIRE $\frac{109}{128}$ = .85 VOLUMES OF MIXED AGGREGATE TO CORRESPOND TO ONE VOLUME OF AGGREGATES MEASURED SEPARATELY THEREFORE THE VOLUME OF DRY AGG.S MEASURED SEPARATELY = $\frac{7.4}{.85}$ = 8.68 MIX = 1 : 8.68

.45 x 8.68 x 113 = 442# SAND

.55 x 8.68 x 106.3 = 508# GRAVEL.

THE MIX BY WT. THEN IS 94 : 442 : 508

THE W/C RATIO IS 1.16

1.16 x 62.4 = 72.4# WATER.

THE TOTAL MIX BY WT. THEN IS

72.4 : 94 : 442 : 508

BECAUSE OF THE DRY CONDITION OF THE SAND AND GRAVEL ON HAND, NO DEDUCTIONS IN MIXING WATER WAS NECESSARY TO KEEP THE PRESCRIBED W/C RATIO

APRIL 11, 1930

DESIGN OF 2000# CONCRETE (CURVE "A")

FINENESS MODULUS OF MIXED AGGREGATE = 5.2
VOLUME OF DRY MIXED AGGREGATE TO CEMENT = 6.2:1

$r = \frac{7.0 - 5.2}{7.0 - 2.6} = 41\%$ SAND

WT. OF ONE CU. FT. OF DRY RODDED SAND = 113#
" " " " " " " " GRAVEL = 106.3#

.41 x 113 = 46.2
.59 x 106.3 = 62.9
TOTAL = 109.1 SINCE A CU. FT. OF MIXED AGGREGATES IN THESE PROPORTIONS WEIGHS 128# IT WILL REQUIRE $\frac{109}{128} = .85$ VOLUMES OF MIXED AGGREGATES MEASURED SEPARATELY. THEREFORE THE VOLUME OF DRY AGG^S MEASURED SEPARATELY = $\frac{6.2}{.85}$ = 7.28 CU. FT.
41 x 7.28 x 113 = 336# SAND
59 x 7.28 x 106.3 = 458# GRAVEL

THE MIX BY WT. THEN IS 94 : 336 : 458

THE W/C RATIO IS 1.00 = 62.4# water per sack.

THE TOTAL MIX BY WT. THEN IS
62.4 : 94 : 336 : 458

BECAUSE OF THE DRY CONDITION OF THE SAND AND GRAVEL ON HAND, NO DEDUCTIONS IN MIXING WATER WAS NECESSARY TO KEEP THE PRESCRIBED W/C RATIO

APRIL 12, 1930

DESIGN OF 2500# CONCRETE (CURVE "A")

FINENESS MODULUS OF MIXED AGGREGATE = 5.3

VOLUME OF DRY MIXED AGGREGATE TO CEMENT 5.1 : 1

$r = \frac{7-5.3}{7-2.6} = 38.7\%$ SAND

WT. OF ONE CU. FT. OF DRY RODDED SAND = 113#
" " " " " " " " GRAVEL = 106.3#

38.7 x 113 = 43.8#
61.3 x 106.3 = 65.3#
TOTAL 109.1

SINCE A CU. FT. OF THE MIXED AGGREGATES IN THESE PROPORTIONS WEIGHS 126# IT WILL REQUIRE $\frac{109}{126}$ = .866 VOLUMES OF MIXED AGGREGATES TO CORRESPOND TO ONE VOLUME OF AGGREGATES MEASURED SEPARATELY THEREFORE THE VOLUME OF DRY AGGREGATES MEASURED SEPARATELY = $\frac{5.3}{.866}$ = 5.89 CU. FT.

38.7 x 5.89 x 113 = 258# SAND
61.3 x 106.3 x 5.89 = 384# GRAVEL

THE MIX BY WT. THEN IS 94 : 258 : 384
THE W/C RATIO IS .90 OR 56.16# per sack.
2¼# WATER WATER WAS ADDED TO GIVE 1% ABSORPTION

THE TOTAL MIX BY WT THEN IS
(56.16 + 2.25) : 94 : 258 : 384 or
58.4 : 94 : 258 : 384

APRIL 14, 1930

DESIGN OF 3000# CONCRETE (CURVE "A")

FINENESS MODULUS OF MIXED AGGREGATE = 5.38

VOLUME OF DRY RODDED AGGREGATE TO CEMENT = 4.2

$$r = \frac{7 - 5.38}{7 - 2.6} = 36.9\% \text{ sand.}$$

36.9 x 113 = 41.6#
63.1 x 106.3 = 67.2#
TOTAL = 108.8#

SINCE A CUBIC FOOT OF THE MIXED AGGREGATES IN THESE PROPORTIONS WEIGHS 126# IT WILL REQUIRE $\frac{108.8}{126}$ = .862 VOLUMES OF MIXED AGGREGATE TO CORRESPOND TO ONE VOLUME OF AGGREGATE MEASURED SEPARATELY. THEREFORE THE VOLUME OF DRY AGGREGATES MEASURED SEPARATELY = $\frac{4.2}{.862}$ = 4.87 CU.FT.

.369 x 4.87 x 113 = 203# SAND
.631 x 4.87 x 106.3 = 326# GRAVEL

THE MIX BY WT. THEN IS 94 : 203 : 326

THE W/C RATIO IS .80 OR 49.8# WATER PER SACK
ADD 2.2# FOR .005 LACK IN SAND AND .003 LACK IN GRAVEL.
TOTAL WATER = 52#

THE TOTAL MIX BY WT. THEN IS
52 : 94 : 203 : 326

APRIL 16, 1930

DESIGN OF 3500# CONCRETE (GRAVEL)

FINENESS MODULUS OF MIXED AGGREGATE = 5.45

VOLUME OF DRY RODDED AGGREGATE TO CEMENT = 3.5:1

$$r = \frac{6.9 - 5.45}{6.9 - 3.10} = 38.1\% \text{ SAND}$$

WT. OF ONE CU. FT. OF DRY RODDED SAND = 110.3#

" " " " " " " " GRAVEL = 107.8#

.381 x 110.3 = 42.1#

.619 x 107.8 = 66.6#

TOTAL = 108.7

SINCE A CUBIC FOOT OF THE MIXED AGGREGATES IN THESE PROPORTIONS WEIGHS 128# IT WILL REQUIRE $\frac{108.7}{128}$ = .848 VOLUMES OF MIXED AGGREGATE TO CORRESPOND TO ONE VOLUME OF AGGREGATES MEASURED SEPARATELY. THEREFORE THE VOLUME OF DRY AGGREGATES MEASURED SEPARATELY = 3.5/.848 = 4.13 CU. FT.

.381 x 4.13 x 110.3 = 1.74# SAND

.619 x 4.13 x 107.8 = 275# GRAVEL

THE W/C RATIO IS .72 OR 45# WATER PER SACK CEMENT

ADD (174# x .01 = 1.74# FOR SAND) AND (275 x .01 = 2.75# FOR GRAVEL)

% WATER IN SAND = 2.76 — GRAVEL 1.43

SUBTRACT (174 x .0276 = 4.8#) AND (275 x .0143 = 3.9#) TOTAL = 8.7#

LBS. OF WATER TO USE PER SACK = 45 + (1.74 + 2.75) − 8.7 = 40.8

THE MIX BY WT. THEN IS

40.8 ; 94 ; 174 ; 275.

APRIL 17, 1930.

DESIGN OF 4000# CONCRETE (CURVE "A")

FINENESS MODULUS OF MIXED AGGREGATE = 5.52

VOLUME OF DRY RODDED AGGREGATE TO CEMENT = 2.8 : 1

$$r = \frac{6.9 - 5.52}{6.9 - 3.1} = 36.3\% \text{ SAND}$$

.363 x 110.3 = 40.1
.637 x 107.8 = 68.5
TOTAL 108.6

SINCE A CUBIC FOOT OF THE MIXED AGGREGATE IN THESE PROPORTIONS WEIGHS 129# IT WILL REQUIRE $\frac{108.6}{129}$ = .842 VOLUMES OF MIXED AGGREGATE TO CORRESPOND TO ONE VOLUME OF AGGREGATE MEASURED SEPARATELY. THEREFORE THE VOLUME OF DRY AGGREGATES MEASURED SEPARATELY = $\frac{2.8}{.842}$ = 3.33 CU.FT.

.363 x 3.33 x 110.3 = 133.5# SAND
.637 x 3.33 x 107.8 = 228# GRAVEL

THE W/C RATIO IS .645 OR 40.2# WATER PER SACK.
ADD 1% FOR ABSORPTION = 1.33 + 2.28 = 3.61#
DEDUCT 4.35% FROM SAND AND 2.46% FROM GRAVEL
OR 5.8# AND 5.6# = 11.4#
TOTAL WATER TO USE = 40.2 + 3.61 − 11.4 = 32.4#

THE MIX BY WT. THEN IS
32.4 : 94 : 133.5 : 228.