THESIS

VARYING WATER RATIOS

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1921

An Experimental Study of Concrete With Varying Water Ratios.

A Thesis Submitted to

The Faculty of

MICHIGAN AGRICULTURAL COLLEGE

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Bachelor of Science.

June 1921.

THESIS

copy 1

Effect of Variation of Water Ratios on Compressive Strength of Concrete.

Although the tendency now is to use wetter mixtures of concretes than prevailed in general practice some years ago, there is still controversy among self styled authorities, engineers and contractors as to the proper consistency for concrete mixtures. In most cases, the amount of water used has represented the arbitrary opinion of the engineers or persons in responsible charge of the construction. For example, in several sets of old specifications may be found clauses such as " The mass shall appear to be about as damp as moist brown sugar." and "The consistendy will be deemed to be right when a handful squeezed in the hand will not stain the skin, but will show the shape of the fingers when the hand is open and will thus stand until the hand is shaken, when the whole mass will fall down." Experience shows, and anyone who has worked at all with concrete will agree that such concrete requires much tamping, therefore strong forms, and consequently will have a high labor cost.

When concrete was first used, dry mixes were advocated; this was universally true; but in 1835, French Engineers wrote a paper, describing experiments performed several years prior to that date, advocating more water. The consistency they discovered was the same as is ideal today. Such a consistency is described by Ernest McCullough, C.E. in the Scientific American as, one in which a stone the size of a mans fist placed on top of the mass will sink less than half its thickness before the congrete obtains the initial set.

The average contractor simply for his own convenience, will frequently use more water in his concrete then necessary because a wet mixture facilitates spouting, and consequently saves time and money in placing.

In reinforced concrete work, there is no question but that wet mixtures facilitate placing the concrete in intimate contact with the reinforcement. There is a possibility that too much water will be used, so that after the process of crystilization has been completed in the cement, an examination of the concrete would show pockets or voids along the reinforcements.

As in all things there must be a happy medium. In concrete it is evident that the advocates of dry mixtures and advocates of wet ones cannot both be correct. Results have been published of experiments made in the Engineering Testing Laboratory of the Sheffield Scientific School, Yale University involving experiments based on 1:2:4 mixtures used with varying percentages of water, Conclusions based on these tests show that concrete mixed with 27% of water, 96323
developed at the end of 30 days a maximum of resistance, both to tension and compression in comparison with mixtures made with other percentages of water. The series of some

50,000 such tests conducted under the direction of Prof. Duff A. Abrams at the Structural Materials Research Laboratory, Lewis Institute, Chicago, for the purpose of determining proper percentages of water and aggregates led to similar results. In other words all these experiments pointed to the fact that there is a definite limit to the amount of water that should be used, and that htis limit is much below that generally used in most constructions.

The fact that these experiments are being continued is evidence enough that it is expected that more can and will be learned, and so in the work for this thesis, we have conducted tests on a series of 128-6"x12" cylinders, this being the same size cylinder as wasused in all the tests by Abrams.

The purpose of our work has been to determine the effect of varying the precentage of water used in mixes varying from 1:2 to 1:9, the same aggregate being used thruout the tests. The water ratios to be used were .3, .7, 1.1 and 1.5, but upon reaching the 1:6 mix, it was discovered that with a .3 water ratio the concrete was so dry that the specimens would not stand up when the forms were removed, but that they crumbled disintegrated so that the ends could not be maintained as smooth surfaces. Therefore at this point we adopted a .5 water ratio as a minimum instead of the .3.

It should be explained at his point that for example, by a .7 water ratio, is meant that in a given mix, the volume of water used is ;7 of the volume of cement.

To further explain this we will take as an example a 1:5 mix and follow through the mixing process. Measurements were all made with a basin, the volume of which was 1300 cubic centimeters. Ten basins of gravel were first measured out: the mix being a 1:5 requird d two basins of cement. Using the .7 water ratio, we determined that the water required would be .7 of two basins or .7 of 2600 C.C. or 1820 C.c. One basin of water was measured, the remaining 520 cc being measured with a graduate. By the same method, the quantities in each mix were determined. In cases where a fractional part of a basin of cement was to be used, this fractional part was determined by carefully weighing on balances.

The gravel used thruout these tests was obtained from one of the south Lansing gravel pits. Screen tests were made of a sample of this gravel which showed the following results:

Retained on 1" screen	551	Grams
" " ½" "	1159	"
" " 1/8" "	1430	"
Passing thru 1/8" screen	2809	"

	Total sample	5949 grams.
Total larger than 1/8" screen		3140 "

Per cent larger than 1/8" screen 3140 divided by 5949 equals 52.8. The gravel when first obtained from the pits contained a considerable proportion or percentage of water, and since our tests were to be conducted to determine the effect of changing the water ratio it became necessary to make moisture tests at different times. Such a test was made by weighing out 200 grams; this was spread evenly upon a very fine screen, set upon a plate over a gas burner and allowed to dry; the sample was the reweighed. Such a test showed the following result.

Weight of original sample	200 grams
" after drying "	197.4
" lost by drying	2.6

Several of such tests were made, allowance being made by subtracting this amount from the computed quantity of water needed. The gravel however, being stored in one corner of the laboratory, near a steam pipe, soon dried out so that it was no longer necessary to make allowance.

The forms used for making the cylinders consisted of 6" iron pipe, 12" long, cut into halves parallel to the axis,. These two halves were held together very rigidly by wedging, a section of larger pipe, about 5" in length, around their middle. The inside of the form was oiled with a heavy lubricating oil to facilitate removal after the concrete had set.

It was thought best to save time by making the 28 day cylinders first. By 28 day cylinders is meant, cylinders whe which are allowed to set 28 days before testing. While the 28 day cylinders were curing, the seven day cylinders were set up, allowed to cure, and tested. By the time this work had been completed, the first of the 28 day cylinders were ready to be tested, and so the work was continued without any more lapse of time than 2 or 3 days, which was utilized in reading and preparing the data already obtained, and in making graphs to show relative strengths.

In order to obtain better average results, and to cover possibilities of breakage of cylinders, it was thought best to set up 2 cylinders for each water ratio, and so we began by preparing a 1:2 mix with a .3 water ratio, mixing up a batch of sufficient size to set up the two cylinders. We did the same thing with the 17, 1.1, and 1.5 water ratios, thus completing a set of 8 cylinders of th 1:2 mix, with the four above mentioned ratios. The process when continued through the 8 mixes gave us a total of 64 cylinders for each of the 7 and28 day series.

In the beginning, we undertook to place small, oiled, glass plates under the forms, but we discovered that tamping broke the plates which we were unable to replace, so that it was decided to use sheets of paper, which served as well as the glass plates to keep the specimens from adhering to the concrete floor. It was also found expedient to bank the bottom of the forms around the outside with damp sand, to prevent the water from being forced of the wetter mixtures.

In setting up the cylinders composed of rich, wet mixes, we found that the volume of the batch was considerably more than that of the forms, so that we continued putting in the solid part of the mix, at the expense of losing a considerable portion of the water and cement, by overflow. With the equipment at hand however, this was unavoidable, and is quite inaccordance with what usually happens on a large job.

In compacting the cylinders in the forms, it was of course, found necessary to tamp, except in cases of wet mixes, and in such cases it was on the contrary found best not to tamp, because this caused the coarser aggregate to settle to the bottom, giving a non-uniform specimen.

All cylinders were allowed to set in the forms for 24 hours except in the case of those made on a week end, which remained in the forms 48 hours. Upon removal from the forms, all cylinders were immersed in water and allowed to cure the full time.

All tests were made one Reihle 100,000 pound duty testing machine provided with removable bearing head. In order to get a perfectly smooth bearing surface, each end of the cylinder was faced with a plaster of Paris, flattened down with steel plates and allowed to set 15 minutes. The plates were, however, first covered with a thick coat of heavy oil to facilitate their removal after the test.

It was observed throughout the test that upon failure, practically every cylinder showed small cracks parallel to its axis. Some, of course, were pretty well broken downe before the machine could be stopped.

. The accompanying graphs show the variation of compressive strength with the variation of the water ratio, and are self explanatory.

Accompanying will also be found tables 1 and 2. Table 1 shows the increase in compressive strength due to increase in time. The values as tabulated are in each case the average of those found for the two similar cylinders. Table 2 gives a list of the units compressive strenghts for each mix and age, of the strongest cylinders, together with the computed amount in pounds of water per cubic foot of loose material.

Conclusions:

These tests point to the fact that there is a definite limit to the amount of water that should be used, and this limit is much below that generally used in most construction;

in other words there is a definite relation between the water ratio and the compressive strength.

They show that the consistency which makes the strongest concrete should be " quaky"; that is, the concrete when put into the forms should show no water standing on the top of the mixture, except after considerable tamping, it should be sticky and when troweled should give a smooth finish.

The amount of water as computed, was found to vary with different mixes, from 5.74 pounds to 20.4 pounds per cubic foot of loose material, and that for mixes up to 1:6 the point 7 water ratio gave the greatest unit strength, while in the 1:7 mix, the 1.1 ratio gave the greatest strength, and in the 1:8 and 1:9 mixes, the 1.5 ratio was best. From these results, it is further concluded that the leaner the mix, the greater the percentage of water necessary.

TABLE NO. 1

Mix	Ratio	7 Day	28 Day	Increase	Percent of Increase
1:2	.3	781	1245	464	59.5
1:2	.7	2665	3465	800	30.0
1:2	1.1	752	1690	938	124.7
1:2	1.5	569	839	270	47.5
1:3	.3	468	1151	683	146.0
1:3	.7	2110	3560	1450	68.8
1:3	1.1	786	1142	356	45.2
1:3	1.5	396	905	509	128.6
1:4	.3	156	1485	1329	853.0
1:4	.7	2845	3570	1125	46.0
1:4	1.1	826	1815	989	119.6
1:4	1.5	430	925	495	115.0
1:5	.3	160	310	150	94.0
1:5	.7	1094	1707	613	56.9
1:5	1.1	460	1522	1062	231.5
1:5	1.5	279	844	565	202.5
1:6	.5	356	447	91	25.6
1:6	.7	484	1450	966	199.6
1:6	1.1	393	1360	1067	271.5
1:6	1.5	350	786	436	124.4
1:7	.5	397	283		-
1:7	.7	898	924	26	2.9
1:7	1.1	870	1920	1050	120.7
1:7	1.5	339	788	449	132.4
1:8	.5	96	184	88	9.15
1:8	.7	268	292	24	9.0
1:8	1.1	690	1044	354	51.2
1:8	1.5	514	1275	761	148.0
1:9	.5	125	195	70	60.0
1:9	.7	437	370		
1:9	1.1	677	744	67	9.9
1:9	1.5	434	805	371	85.4

TABLE NO. 2.

Mix	Time	Water Ratio	Wt. of Water in Grams	Vol. Agg. Used in Cu.Ft.	Wt of Wtr. Lbs	Wt of Wtr per Cu. Ft.	F c
1:2	28	.7	4450	.5	10.1	20.4	3465
1:3	28	.7	2900	.5	6.4	12.8	3560
1:4	28	.7	2275	.5	5.01	10.02	3570
1:5	28	.7	1820	.5	4.02	8.04	1707
1:6	28	1.1	2388	.5	5.27	10.54	1460
1:7	28	1.1	2045	.5	4.51	9.02	1920
1:8	28	1.5	2438	.5	5.38	10.76	1275
1:9	28	1.5	2158	.5	4.76	9.52	805
1:2	7	.7	4550	.5	10.1	20.2	2665
1:3	7	.7	2900	.5	6.4	12.8	2110
1:4	7	.7	2275	.5	5.01	10.02	2445
1:5	7	.7	1820	.5	4.02	8.04	1094
1:6	7	.7	1520	.5	3.35	6.70	484
1:7	7	.7	1300	.5	2.87	5.74	898
1:8	7	1.1	1788	.5	3.94	7.88	690
1:9	7	1.1	1587	.5	3.50	7.0	670

TABLE NO. 8.
Data on 28 day cylinders.

No.	Mix	Water ratio	Pressure	Area	Unit P.	Ave.
1	1:2	.3	29000	28.27	1058	
1	1:2	.3	40520	28.27	1432	1245
2	1:2	.7	98000	"	3465	
2	1:2	.7	Would not break			3465
3	1:2	1.1	46880	"	1660	
3	1:2	1.1	48650	"	1720	1690
4	1:2	1.5	22200	"	785	
4	1:2	1.5	25220	"	893	839
5	1:3	.3	39500	"	1396	
5	1:3	.3	24700	27.27	907	1151
6	1:3	.7	Would not break	28.27		
6	1:3	.7	100,500	"	3560	3560
7	1:3	1.1	34600	"	1224	
7	1:3	1.1	30000	"	1060	1142
8	1:3	1.5	25500	"	899	
8	1:3	1.5	25750	"	912	905
9	1:4	.3	40000	"	1415	
9	1:4	.3	40100	"	1555	1485
10	1:4	.7	101000	"	3570	
10	1:4	.7	100000	Would not break		3570
11	1:4	1.1	52550	"	1860	
11	1:4	1.1	50120	"	1770	1815
12	1:4	1.5	28310	"	1000	
12	1:4	1.5	24100	"	850	925
13	1:5	.3	8670	28.27	307	
13	1:5	.3	8810	28.27	312	310
14	1:5	.7	43930	"	1554	
14	1:5	.7	52600	"	1860	1707
15	1:5	1.1	45900	"	1625	
15	1:5	1.1	40210	"	1420	1522
16	1:5	1.5	24300	"	860	
16	1:5	1.5	23400	"	828	844
17	1:6	.5	12310	"	437	
17	1:6	.5	12900	"	457	447
18	1:6	.7	44600	"	1580	
18	1:6	.7	30000	27.27	1320	1450
19	1:6	1.1	41000	28.27	1450	
19	1:6	1.1	41570	"	1470	1460
20	1:6	1.5	20400	"	722	
20	1:6	1.5	24000	"	850	786
2	1:7	.5	8300	"	294	
21	1:7	.5	7700	"	272	283
22	1:7	.7	21700	"	770	
22	1:7	.7	30500	"	1077	924
23	1:7	1.1	52550	"	1860	
23	1:7	1.1	55900	"	1980	1920
24	1:7	1.5	20000	"	708	
24	1:7	1.5	24500	"	867	788
25	1:8	.5	4500	"	159	~~25~~
25	1:8	.5	5900	"	209	184
26	1:8	.7	8700	"	308	
26	1:8	.7	7800	"	276	292

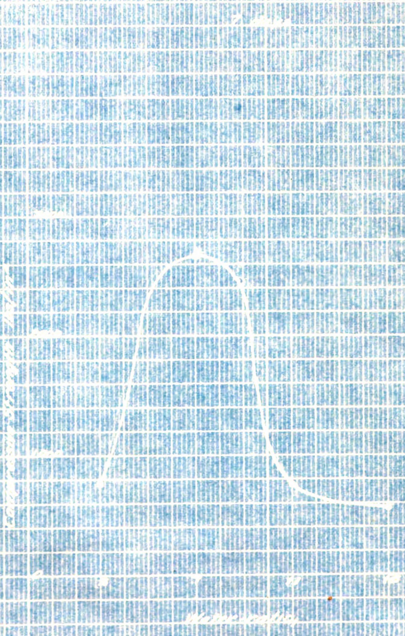
No.	Mix	Water ratio	Pressure	[illegible]	[illegible]	Ave.
27	1:8	1.1	23000	28.27	[illegible]	
27	1:8	1.1	30000	"	1274	1044
28	1:8	1.5	30700	"	1085	
28	1:8	1.5	41400	28.27	1465	1275
29	1:9	.5	5100	28.27	201	
29	1:9	.5	5300	28.27	188	195
30	1:9	.7	11000	"	[illegible]	
30	1:9	.7	9900	"	350	370
31	1:9	1.1	23500	"	832	
31	1:9	1.1	18000	"	655	744
32	1:9	1.5	23100.	"	816	
32	1:9	1.5	20000	28.27	795	805

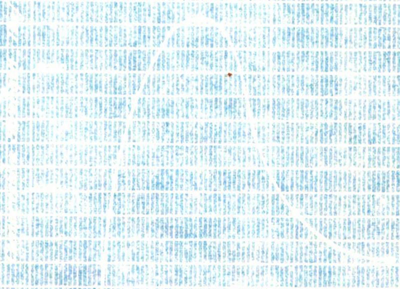
TABLE NO. 3 CONTINUED
Data on 7 Day Cylinder

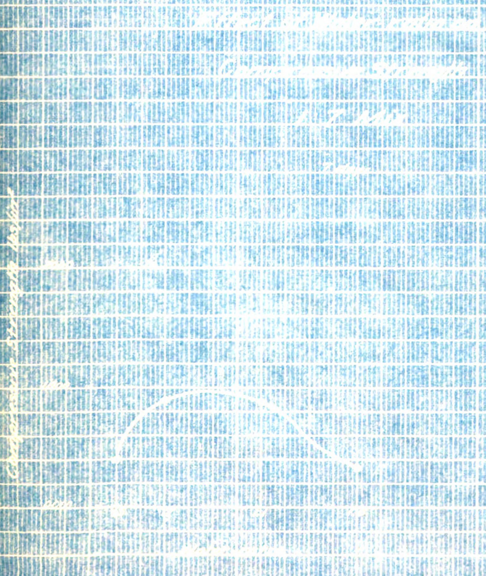
No	Mix	Water Ratio	Pressure	Area	Unit P.	Ave.
33	1:2	.3	21580	28.27	762	
33	1:2	.3	22600	"	799	781
34	1:2	.7	65400	"	2330	
34	1:2	.7	84950	"	3000	2665
35	1:2	1.1	19000	"	671	
35	1:2	1.1	23560	"	832	752
36	1:2	1.5	15460	"	547	
36	1:2	1.5	16680	"	590	569
37	1:3	.3	12680	"	448	
37	1:3	.3	13800	"	488	468
38	1:3	.7	61940	"	2190	
38	1:3	.7	57400	"	2030	2110
39	1:3	1.1	22570	"	797	
39	1:3	1.1	22930	"	775	786
40	1:3	1.5	10850	"	384	
40	1:3	1.5	11560	"	408	396
41	1:4	.3	4500		159	
41	1:4	.3	4300	"	152	156
42	1:4	.7	74860	"	2650	
42	1:4	.7	63350	"	2240	2445
43	1:4	1.1	24100	"	850	
43	1:4	1.1	22670	"	802	826
44	1:4	1.5	11800	"	417	
44	1:4	1.5	10530	"	443	430
45	1:5	.3	4060	"	144	
45	1:5	.3	4940	"	175	160
46	1:5	.7	30550	"	1080	
46	1:5	.7	31270	"	1107	1094
47	1:5	1.1	13200	"	466	
47	1:5	1.1	12800	"	453	460
48	1:5	1.5	7580	"	268	
48	1:5	1.5	8190	"	289	279
49	1:6	.5	10280	"	363	
49	1:6	.5	9870	"	349	356
50	1:6	.7	13470	"	465	
50	1:6	.7	14230	"	503	484
51	1:6	1.1	11350	"	402	
51	1:6	1.1	10850	"	384	393
52	1:6	1.5	10290	"	364	
52	1:6	1.5	9470	"	335	350
53	1:7	.5	10700	"	378	
53	1:7	.5	11420	"	405	397
54	1:7	.7	24860	"	879	
54	1:7	.7	23100	"	817	898
55	1:7	1.1	25000	"	884	
55	1:7	1.1	24200	"	855	870
56	1:7	1.5	10570	"	374	
56	1:7	1.5	8750	"	303	339
57	1:8	.5	2600	"	92	
57	1:8	.5	2800	"	99	96
58	1:8	.7	6900	"	244	
58	1:8	.7	8230	"	291	268
59	1:8	1.1	18400	"	650	
59	1:8	1.1	20640	"	730	690

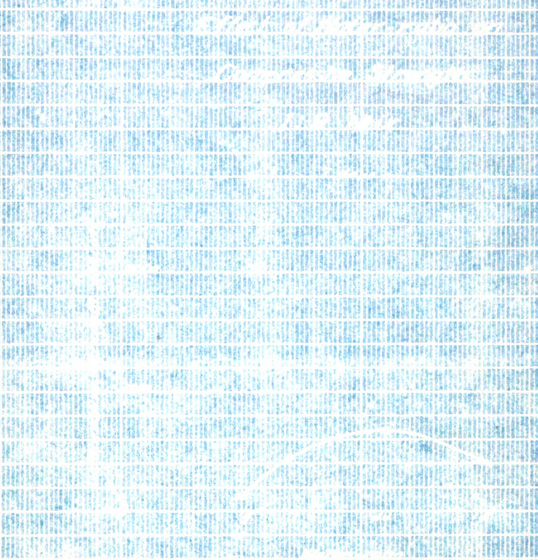
No.	Mix	Water Ratio	Pressure	Area	Unit P.	Ave.
60	1:8	1.5	15370	28.27	543	
60	1:8	1.5	13700	"	484	514
61	1:9	.5	2930	"	104	
61	1:9	.5	4110	"	145	125
62	1:9	.7	11830	"	418	
62	1:9	.7	12900	"	456	437
63	1:9	1.1	19990	"	703	
63	1:9	1.1	18430	"	651	677
64	1:9	1.5	12620	"	446	
64	1:9	1.5	11900	"	421	434

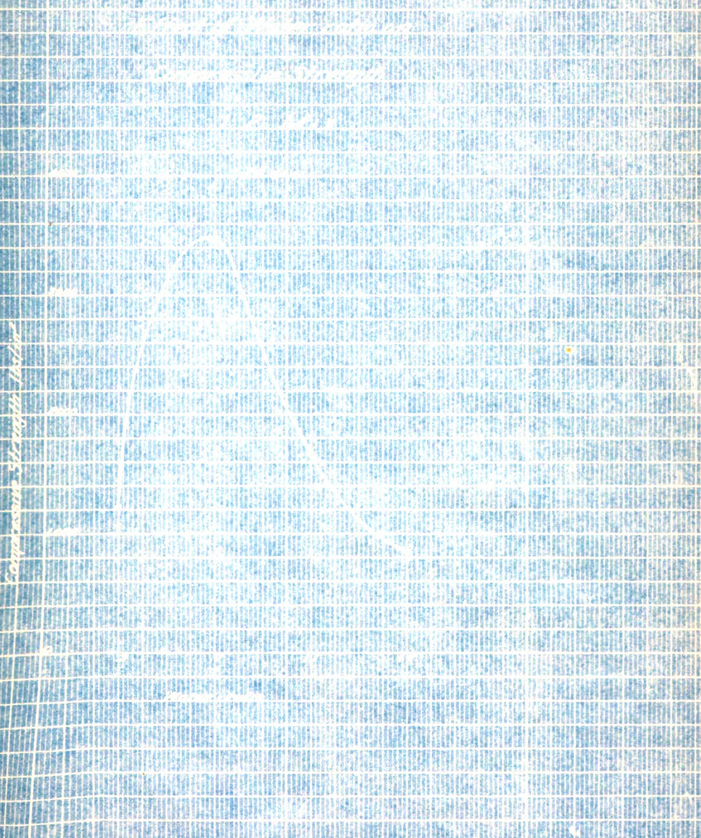
Compressive Strength

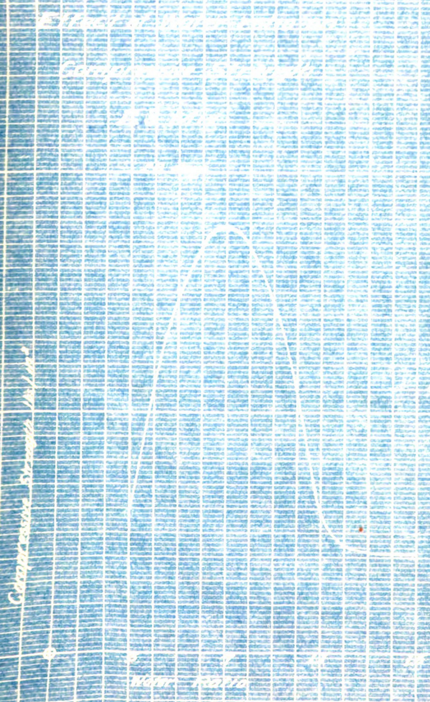


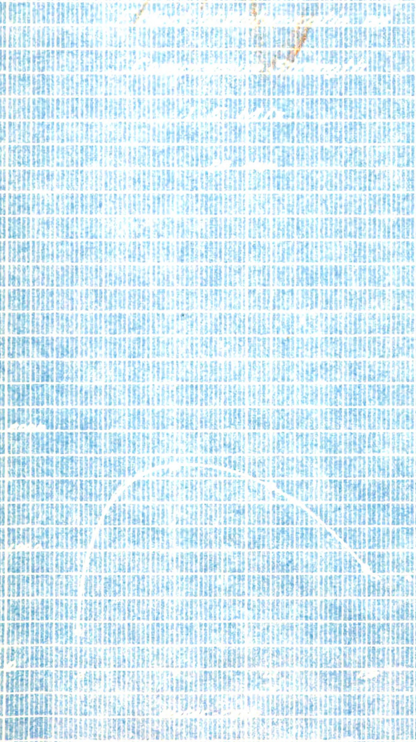







Compressive Strength lbs/in²


Effect of
Compressive Strength
Ratio



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