CINDERS AS AN AGGREGATE
FOR CONCRETE

Thesis for the Degree of B. S.
MICHIGAN STATE COLLEGE
D. J. Westerby
1943

THESIS

CINDERS AS AN AGGREGATE

FOR CONCRETE

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

by

D. J. Westerby

Candidate for the Degree of

Bachelor of Science

1943

THESIS

ACKNOWLEDGEMENT

The author wishes to acknowledge his indebtedness to Mr. Lee J. Rothgary, assistant professor in the Civil Engineering Department at Michigan State College, for his many valuable suggestions and to the Civil Engineering Department for the use of their concrete laboratory.

CONTENTS

Cinders as an Aggregate for Concrete

1. GENERAL INFORMATION

Cinders are produced from both anthracite and bituminous coals. Their physical characteristics differ to a small degree. Anthracite cinders have been demanded over bituminous cinders by certain specifications but evidence does not justify this attitude. Some engineers on the other hand prefer bituminous cinders because the particles are stronger and the major part of the combustible matter is coke.

Cinders for aggregate should be obtained from gas works, industrial plants, locomotives or similiar sources where a large amount of coal is burned. If the cinders are obtained from the above sources where efficient firing is maintained, a fairly uniform ash will result.

The combustion process is practically always incomplete. The ash left usually contains unburned coal or coke. Well fired bituminous coal used in the following tests contain from 18% to 15% combustible material.

11. CINDER AGGREGATE TESTS

Many of the standard tests for stone aggreg te can not be applied to cinders as cinders vary greatly when compared to stone. Cinders vary in weight, hardness, porosity, absorption, foreign material, and strength.

A. Specifications

The following specifications have been suggested; Cinders, when used for concrete, shall be the product of high temperature combustion of coal or coke. Residue from domestic furnaces shall not be used. The cinders shall be well burned, free from foreign matter, and so graded from coarse to fine as to produce cinder concrete or sand-cinder concrete, meeting the strength requirements of the building code. The cinders shall contain not more than 0.45 per-cent sulphur trioxide as sulphate.

Experience indicates that if the first part of the specifications as to source is met,the cinders will also meet the requirements for unconsumed carbon and sulphur compounds.

Cinder aggregate should be graded from coarse to fine. Cinders from high temperature combustion do not contain any amount of fine, fluffy ash—they contain some fine gritty material. These fines are rarely present in any undesirable excess--they are needed for workability. A typical cinder aggregate usually contains less than 10% finer than the #100 mesh. The maximum size used in building units is generally 3/4 inches or less.

B. Sieve Analysis

A sieve analysis is used to determine the particle size distribution of fine and coarse aggregate, using sieves with square holes. The apparatus used consisted of a nest of Tyler sieves, (1-1/2, 3/4, 3/8, #4, #8, #14,#28, #48, #100), automatic shaker and scales (accurate to the nearest gram).

Three representative test samples (cinders from power plant at Michigan State College) were obtained by quartering and shaking in the automatic shaker for 5 minutes. The results were tabulated in table 1. Curves were drawn (figs. 1, 2, and 3), plotting sieve sizes and per-cent retained. The fineness was calculated for the different samples of cinders to determine if there was enough of each size.

C. Absorption

Compared with sand and gravel, cinders are porous and highly absorptive. Although the absorption is important, it is not a criterion as to whether a cellular material will produce a dry wall. Suction is an important factor. A driving rainstorm does not ordinarily penetrate an 8 inch wall by its own force; the water is usually drawn by capillary force, which for cinder concrete is very low.

To determine the absorption of cinders, several tests were made on surface dry cinders (ungraded). The results varied greatly and were not recorded. The samples were then graded in five parts by a set of sieves (#4, #14, #28, #48, #100, pan). The absorption was found for each of the graded sizes (table 2). By knowing the grams retained on each of these sieves in our sieve analysis, we were able to calculate the water in the total sample, hence the absorption, which checked within .2 of one per-cent.

The following apparatus was used in this test--

1. Balance (accurate to the nearest gram)
2. Oven (100-120 c)
3. Beaker
4. Trowel
5. Dry pans

The test samples were representative samples which were screened to the sizes mentioned above. Each part of the sample was soaked for 24 hours and was first placed in a pan in the sun to surface dry. Next, the samples were placed in cans of known weight and weighed. Then they were placed in the drying oven for 24 hours and reweighed to determine the moisture loss, which is tabulated in table 3. From this loss we calculated the absorption (table 4).

D. Weight

One of the advantages of cinder concrete is its weight. For the cinder used in these tests (obtained from the Michigan State College power plant) the unit weight was found to be 61.4 per cubic foot.

The apparatus used in this test was as follows--

1. Balance (accurate to the nearest gram)
2. Tamping rod (5/8 inches diameter)
3. Measure (1/2 cubic foot)

The cinders were room dried and thoroughly mixed. The measure was filled 1/3 full and the top leveled off with the fingers. The mass was then rodded 25 times, distributing the strokes evevly over the surface. The measure was then filled to 2/3 full and again rodded 25 times. The container was now filled overflowing and for the third time rodded. The surplus was struck off leaving a level surface. The container was then weighed and the net weight determined. From this net weight the weight per cubic foot was calculated.(table 5)

E. Specific Gravity

In this test the following pieces of equipment were used--

1. Balance (sensitive to .1 gram)

2. Graduated flask

The flask was filled to the 200 c.c. mark. A 500 gram, surface dry sample was slowly poured into the flask, and the combined volume read and recorded. The increase in volume is the difference in the two readings and is also equal to the approximate volume of the cinders. The weight divided by the volume will give the approximate specific gravity (table 6).

111. CINDER CONCRETE TESTS

A. Driving and pulling of nails.

In this experiment six-penny nails were driven into 21 day and 28 day cinder concrete. It was found to be readily nailable, and moisture increased the ease of driving.

B. Sound Absorption

Cinders which are porous are efficient in absorbing sound.

The Portland Cement Association has made tests for the coefficient of absorption by using the Sabine reverberation method in which the time that elapses when various standard sounds die out in a specially constructed room, both with and without the sound absorbing samples, are measured. Calculations based on these periods give coefficients of absorption that can be used to determine the area or amount of sound absorbent surface that will be needed to control the sound in any room.

Calculations showing the absorption coefficients made on walls built of standard 4 x 8 x 16 inch, 3-core concrete masonry partition unit is found in table 7. It can be observed that concrete masonry units made of porous aggregate such as haydite and conders are efficient from a sound-absorbing stand point.

C. <u>Strength</u>

Cinder concrete is used in making hollow cinder concrete building units. The specifications call for a 700 p.s.i. gross area at 28 days.

It was observed in the following test that a water-cement ratio of 1.0 or higher had to be used to get 875 pounds net area which is equivalent to the 700 p.s.i. gross area. However these tests were only 21 day tests and higher water-cement ratio could be used. A water-cement ratio of 1.0 means that 7.5 gallon of water is used per sack of cement.

Tables 8 and 9 show the data as to the mix and compressive strength. Figure 4 shows a curve plotting water-cement ratio against compressive strength.

D. <u>Comparative Costs</u>

Suppose that it is desirable to determine the relative costs of cinder blocks (8 x 8 x 16 inch units), clay tile (8 x 12 x 12 inch units), and clay brick for the construction of a building requiring 2000 square feet of 8 inch wall. Tables 10 and 11 show the calculations for this wall. It will be noticed that cinder units are a good deal less expensive.

IV. SUMMARY

Cinders, when used as an aggregate for concrete, do not give a strength comparable to that of stone and sand concrete, but it does have other properties which favor it as a building material.

One of the principle factors for the use of cinder concrete is its light weight. Its weight is less than one half of that of stone concrete. This property makes it an excellent material for partitions in buildings where weight is important.

Cinder concrete has good sound absorption and gives a high degree of satisfaction on many jobs like hotels, hospitals, or apartments, where sound insulation is important.

Cinders are readily nailable which is an added good feature.

Cinder units make a inexpensive wall when compared to clay tile or brick walls. Its fire resistance also equals that of these other walls.

A bad feature of cinder concrete is that it is highly absorbant and should not be used where it is constantly in contact with moisture unless a water proofing is used.

On the whole we can say that cinders as an aggregate for concrete has its place in building materials.

ENGINEERING EXPERIMENTAL STATION

SIEVE ANALYSIS CONVERSION CHART

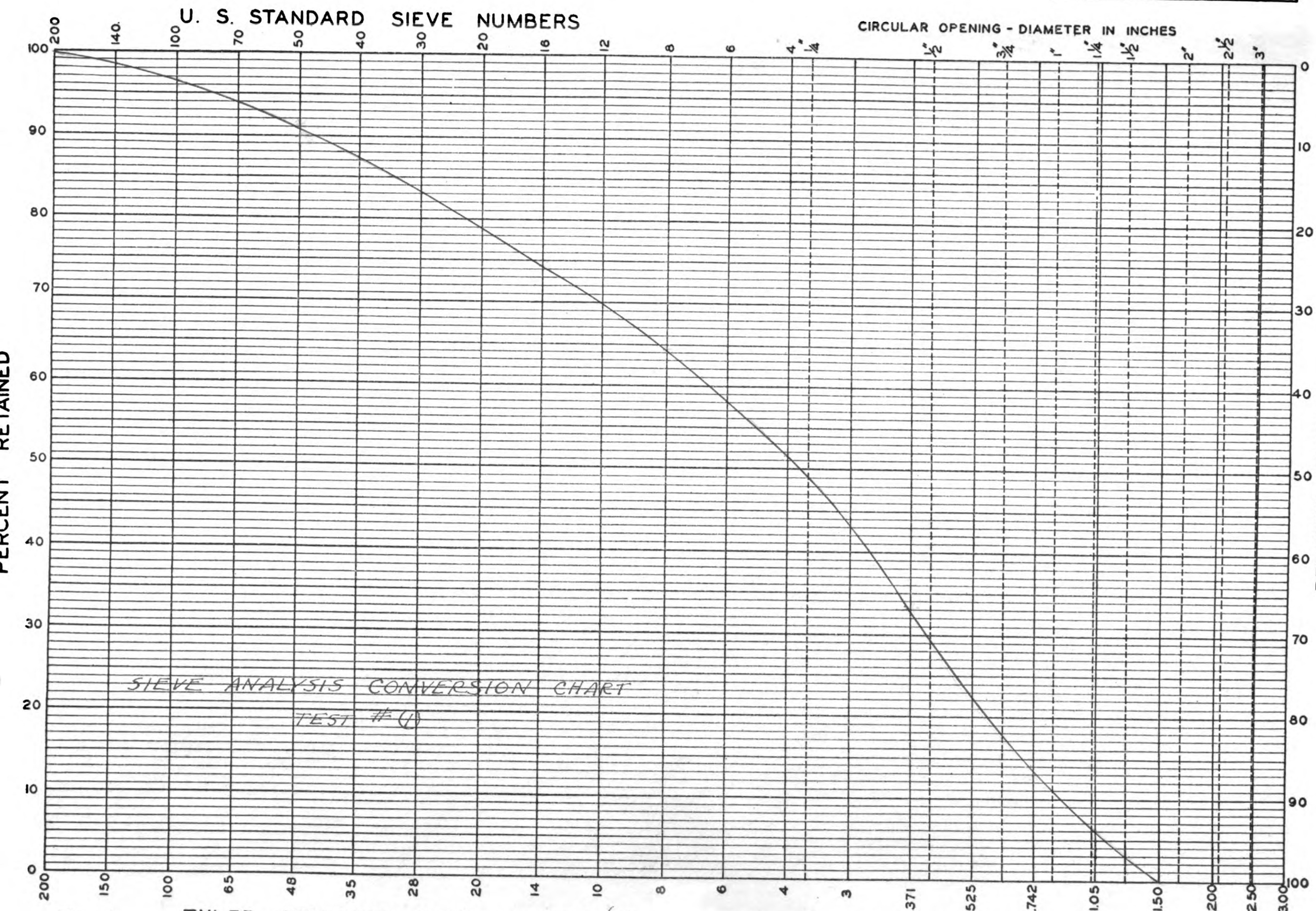

Fig. 1. TYLER STANDARD SIEVE NUMBERS {Fin[illegible]s Modulus 6.07

ENGINEERING EXPERIMENTAL STATION

SIEVE ANALYSIS CONVERSION CHART

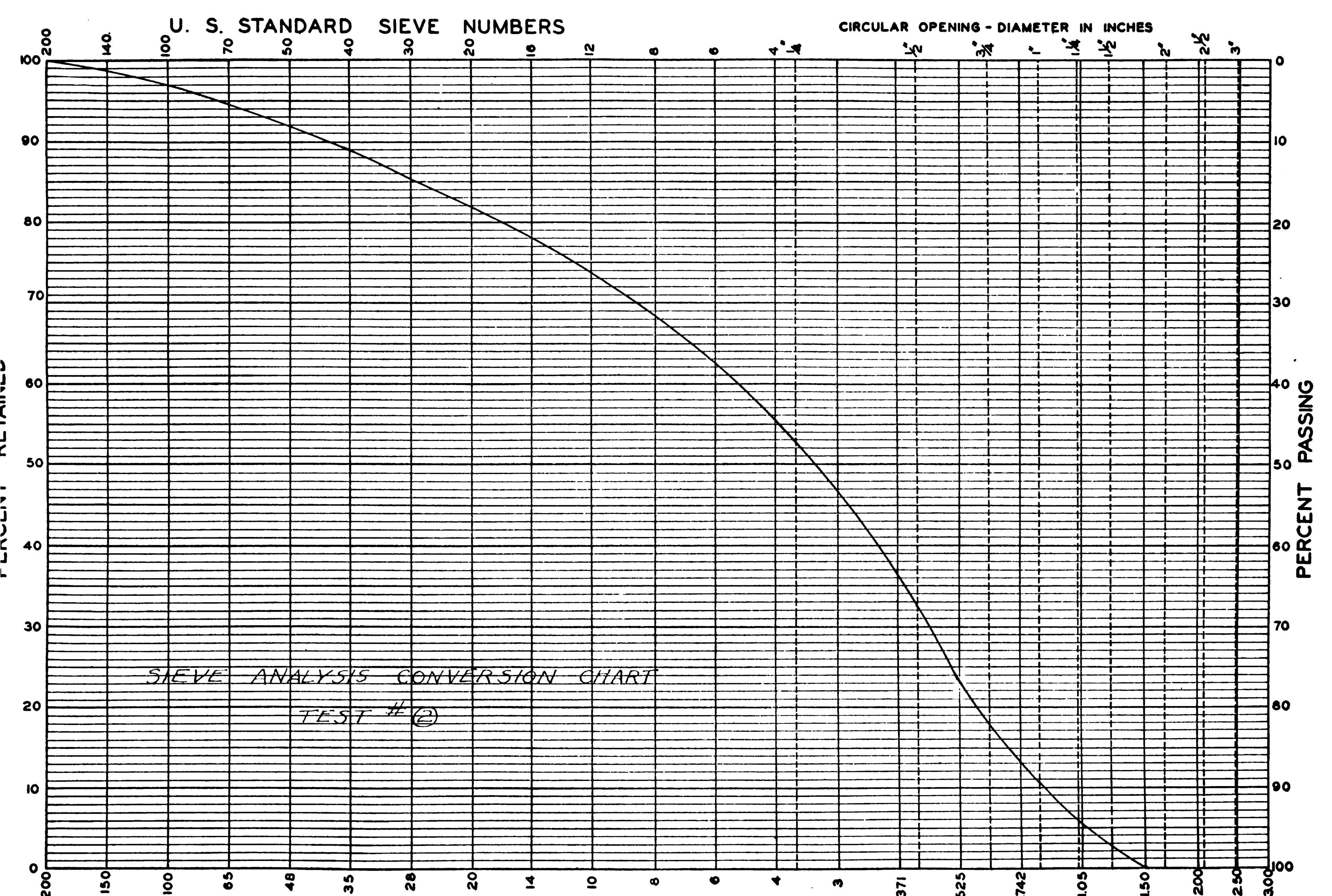

FIG. 2

NESS MODULUS 6.22

ENGINEERING EXPERIMENTAL STATION
SIEVE ANALYSIS CONVERSION CHART

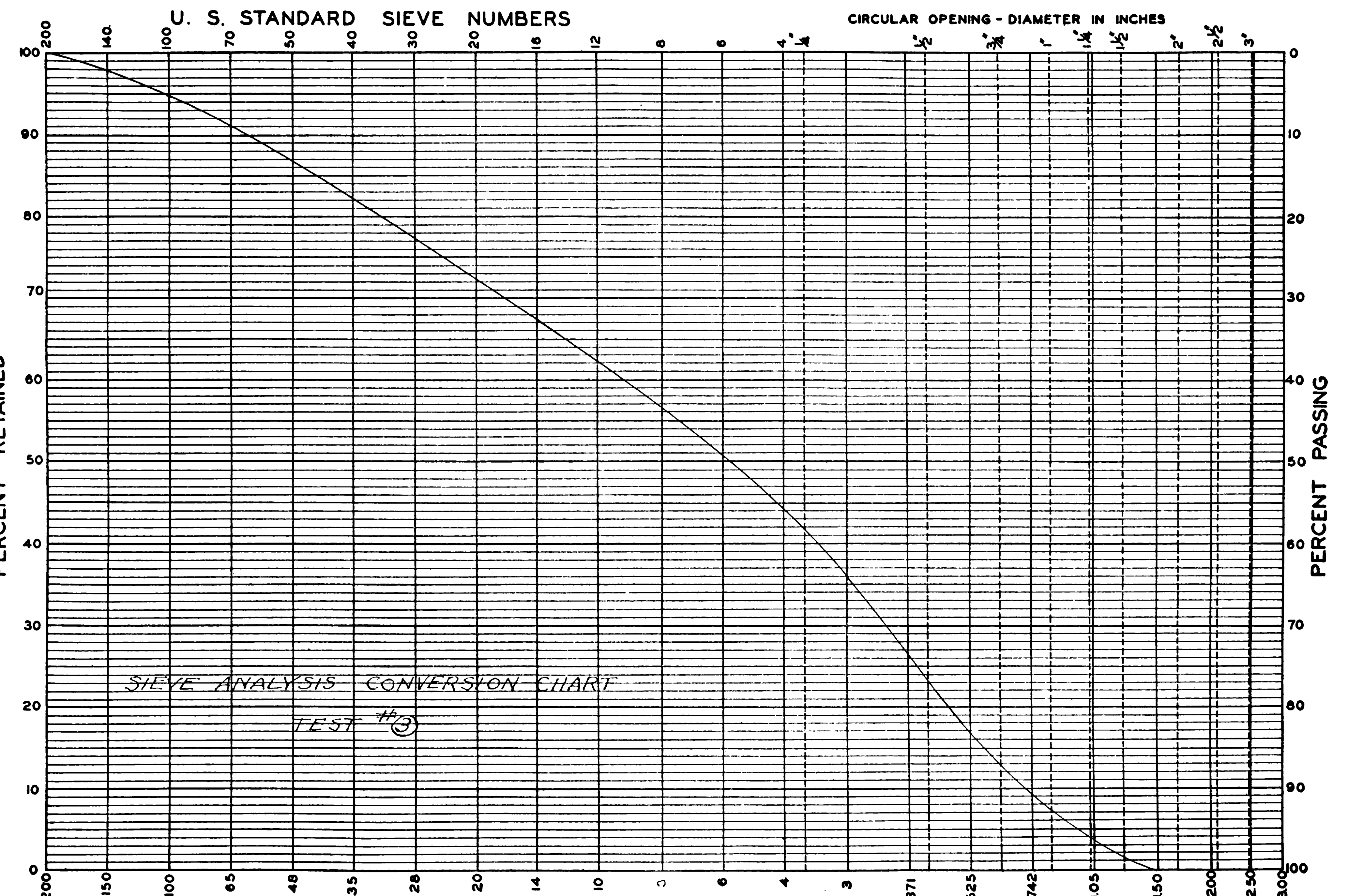

FIG. 3

NESS 5-59
ULUS

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TABLE 1.

TEST 1.

Sieve Size	Wt Retained in gms	% Retained on Sieves	Acculative % on each Sieve
1½	0	0	0
¾	183	2.9	12.9
⅜	288	20.3	33.2
#4	264	186	51.8
#8	180	12.7	64.5
#14	130	9.2	74 2
#28	132	9.3	83.0
#48	112	7.9	90.9
#100	83	5.8	96.8
Pan	46	3.3	100.0
Total	1418	100.0	607.3

TEST 2.

Sieve Size	Wt Retained in gms	% Retained on Sieves	Acculative % on each Sieve
1½	0	0	0
¾	178	11.30	11.30
⅜	385	24.46	35.76
#4	310	19.70	55.46
#8	195	12.38	67.84
#14	160	10.12	78.00
#28	102	6.49	84.49
#48	111	7.05	91.54
#100	88	5.59	97.30
Pan	45	2.89	100.00
			622.16

TEST 3

Sieve Size	Wt. Retained in gms	% Retained on Sieves	Acculative % on each Sieve
1½	0	0	0
¾	130	8.87	8.87
⅜	270	18.43	27.30
#4	238	16.25	43.35
#8	188	12.83	56.38
#14	155	10.58	66.96
#28	127	8.67	75.63
#48	132	9.01	84.64
#100	172	11.74	96.38
Pan	53	3.62	559.51

TABLE 2
Absorption Tests

Sample No.	Sieve Size	Can Weight	Surface Dry Sample & Can	Surface dry Sample	Bone Dry Sample & Can	Bone Dry Sample	Loss in Weight	Loss in % of Dry Wt	Ave Loss in Wt.
1	#4	128.50	515.70	387.20	477.00	348.50	38.70	11.1	
2	#4	148.85	517.40	368.55	476.46	327.61	40.94	12.5	11.15%
3	#4	147.25	486.7	339.45	452.50	305.25	34.20	11.2	
1b	#14	41.40	164.4	132.00	149.50	108.10	14.90	13.8	
2b	#14	46.60	160.3	119.70	105.57	104.97	14.73	14.0	13.9%
3b	#14	32.25	151.0	118.75	137.97	105.72	13.03	12.8	
1a	#48	41.69	126.5	84.81	121.40	79.71	5.10	6.40	
2a	#48	41.90	124.40	82.50	118.40	76.50	6.00	7.84	
3a	#48	41.73	136.6	95.30	130.75	89.45	5.85	6.55	6.48%
1d	#100	41.60	82.4	40.67	78.90	37.17	3.50	9.41	
2d	#100	40.75	70.8	29.2	68.48	26.88	2.32	8.62	
3d	#100	40.80	70.5	29.75	68.10	27.35	2.40	8.77	8.70%
1C	Pan	40.10	80.75	40.45	71.85	31.55	8.90	28.20	
2C	Pan	41.90	78.9	38.80	70.10	30.00	8.80	29.3	
3C	Pan	41.30	78.0	36.10	69.90	23.00	8.10	28.9	29.1%

TABLE 3

Total Wt.=1418 gms

TEST 1.

Using Sample #1	#4 Sieve	#14 Sieve	#48 Sieve	#100 Sieve	Pan	
Accumulative Gms	735	310	244	83	46	See Table 1
Absorption In % of Dry Wt.	11.15	13.9	6.48	8.70	29.1	See Table 2
Wt of Water in Cinders Retained on each Sieve	82.0	42.1	15.8	7.22	13.4	
Total Wt. of Water in Cinder sample	—	—	—	—	160.52	
Total Absorption in % of Dry Wt.					11.3%	

Total Wt=1574

TEST 2.

Using Sample #2	#4 Sieve	#14 Sieve	#48 Sieve	#100 Sieve	Pan	
Accumulative Gms	873	355	113	88	45	See Table I
Absorption In % of Dry Wt.	11.15	13.9	6.48	8.70	29.1	See Table 2
Wt of Water in Cinders Retained on each Sieve	97.2	49.4	7.34	7.66	13.1	
Total Wt. of Water in Cinder Sample	—	—	—	—	174.7	
Total Absorption in % of Dry Wt.					11.1%	

Total Wt. 1465

TEST 3.

Using Sample #3	#4 Sieve	#14 Sieve	#48 Sieve	#100 Sieve	Pan	
Accumulative Gms	638	343	259	172	53	
Absorption In % of Dry Wt.	11.15	13.9	6.48	8.70	29.1	
Wt of Water in Cinders Retained on each Sieve	71.0	47.7	16.8	15.0	15.4	
Total Wt of Water in Cinder Sample	—	—	—	—	165.9	
Total Absorption in % of Dry Wt.					11.3%	

Grand Ave. = 11.23%

UNIT WEIGHT
TABLE 4

TEST 1

Materials	Cinders
Date	April 5, 1943
Size of Container	.5 Cu. Ft.
Net Wt. of Cinders	13,844 gms.
Wt. in Lbs. Per Cu. Ft.	61.0 Lbs

TEST 2

Material	Cinders
Date	April 5, 1943
Size of Container	.5 Cu. Ft.
Net Wt. of Cinders	13,861 gms.
Wt. in Lbs. Per Cu. Ft.	61.+ Lbs

TEST 3

Material	Cinders
Date	April 5, 1943
Size of Container	.5 Cu. Ft.
Net Weight of Cinders	13,892 gms
Wt. in Lbs. Per Cu. Ft.	61.1 lbs.

Table 5:- Specific Gravity Tests

Test 1.	
Material	Cinders
Wt. of Sample (gms)	500
Initial Reading (C.C.)	200
Combined Volume (C.C.)	495
Vol. of Aggregate (C.C.)	295
Specific Gravity	1.695

Test 2.	
Material	Cinders
Wt of Sample (gms)	500
Initial Reading (C.C.)	200
Combined Vol. (C.C.)	495
Vol. of Aggregate (C.C.)	295
Specific Gravity	1.695

Test 3	
Material	Cinders
Wt of Sample (gms.)	500
Initial Reading (C.C.)	200
Combined Vol. (C.C.)	496
Vol. of Aggregate (C.C.)	296
Specific Gravity	1.705

Table 6 :- Absorption Coefficients						
Material	Frequency of Sound					
	250	500	1000	2000	4000	Ave. Coef.
	Cinder Aggregate Concrete					
C-1-S (Unpainted)	0.47	0.51	0.61	0.61	0.55	0.55
C-1-S (Painted)	0.44	0.44	0.52	0.55	0.52	0.49
C-2-S (Unpainted)	0.58	0.44	0.36	0.58	0.58	0.51
C-2-S (Painted)	0.58	0.39	0.33	0.45	0.47	0.44
	Sand & Gravel Aggregate Concrete					
S1S (Unpainted)	0.28	0.35	0.50	0.44	0.36	0.37
S1S (Painted)	0.25	0.29	0.28	0.24	0.27	0.27
S2S (Unpainted)	0.26	0.35	0.35	0.21	0.16	0.26
S2S (Painted)	0.20	0.23	0.18	0.13	0.16	0.18
	Limestone Aggregate Concrete					
L1S	0.21	0.26	0.21	0.19	0.20	0.21
L2S	0.23	0.22	0.23	0.23	0.15	0.21
	Haydite Aggregate Concrete					
H1S	0.58	0.56	0.33	0.51	0.50	0.50
H2S	0.42	0.70	0.33	0.54	0.51	0.50

TABLE 7

Sample Number	Date Mixed	Date Tested	Time in Moist Room	Total Load	# Per Sq. In.	gal per Sack	Water-Cement Ratio
1T	April 14	May 5	21	23,425	827	9.77	1.30
1A	" 19	" 10	21	33,300	940	8.4	1.12
1B	" 19	" 10	21	31,700	895	8.4	1.12
1C	" 19	" 10	21	33,700	952	8.4	1.12
1D	" 19	" 10	21	34,000	960	8.4	1.12
1E	" 19	" 10	21	—	—	—	1.12
2T	" 20	" 11	21	10,170	359	8.4	1.12
2A	" 21	" 11	21	20,800	736	10.5	1.40
2B	" 21	" 11	21	20,390	722	10.5	1.40
2C	" 21	" 11	21	18,250	646	10.5	1.40
2D	" 21	" 11	21	19,530	691	10.5	1.40
2E	" 21	" 11	21	—	—	—	—
3A	" 22	" 12	21	48,000	1553	3.6	.48
3B	" 22	" 12	21	44,000	1566	3.6	.48
3C	" 22	" 12	21	43,500	1539	3.6	.48
3T	" 22	" 12	21	37,000	1310	4.6	.61
4A	" 23	" 13	21	45,000	1590	4.6	.61
4B	" 23	" 13	21	44,000	1556	4.6	.61
4C	" 23	" 13	21	50,500	1786	4.6	.61
4D	" 23	" 13	21	44,500	1574	4.6	.61
4E	" 23	" 13	21	—	—	4.6	.61

TABLE 8

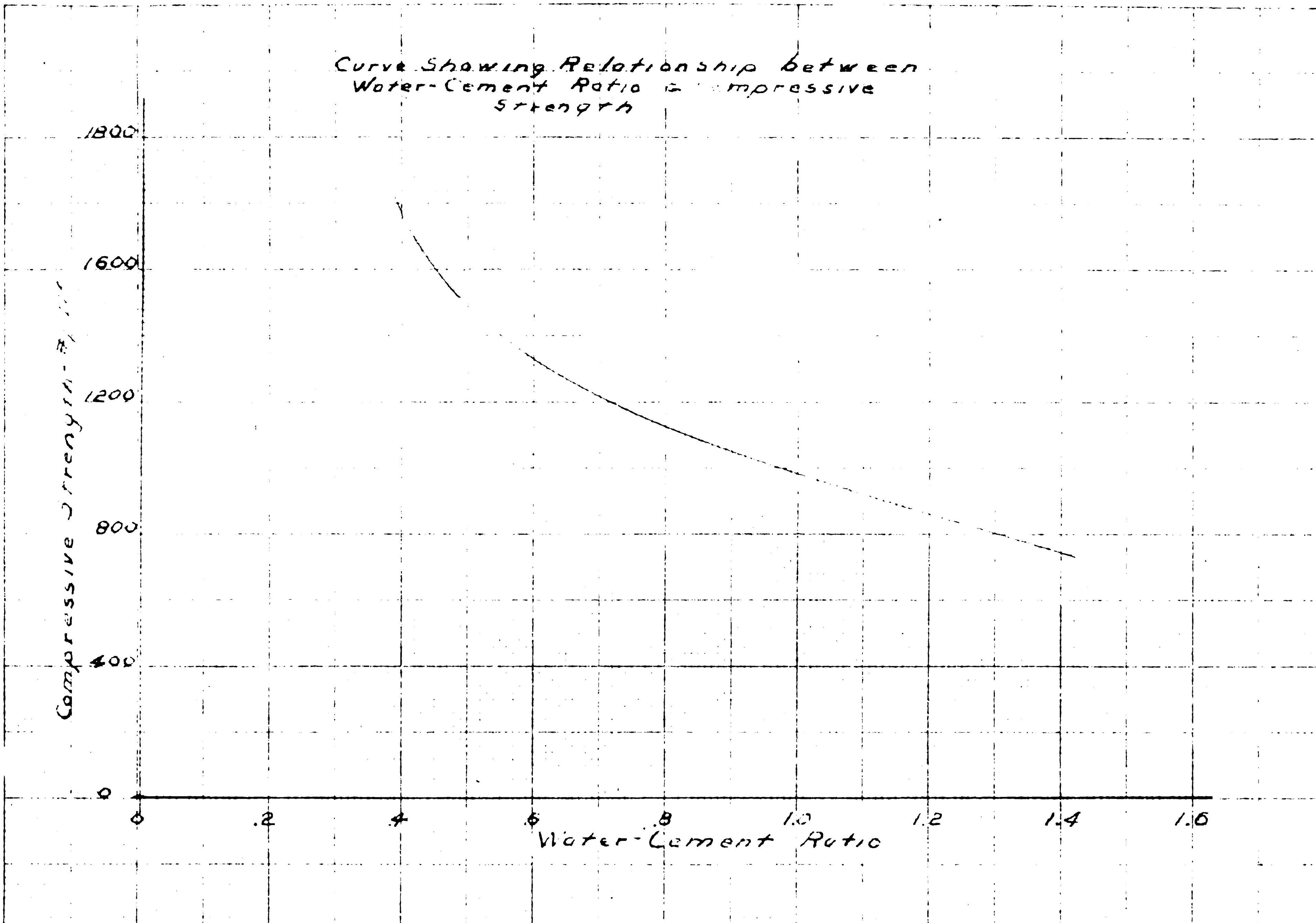
Sample No.	Wt. of Aggregate	Wt of Cement	Wt of Water Used	Cement Cinder Ratio	Specific Gravity	% Moisture Content	Absorption	Water-Cement Ratio
1T	23*	5.75	17.3	1:4	1.69	0%	11.23	1.30
1A	150.0	25.00	26.6	1:6	1.69	8.7%	11.23	1.12
1B					1.69	8.7%	11.23	1.12
1C					1.69	8.7%	11.23	1.12
1D					1.69	8.7%	11.23	1.12
1E					1.69	8.7%	11.23	1.12
2T	150	25.00	26.6	1:6	1.69	8.7%	11.23	1.12
2A	75*	24.1	24.4	1:3.11	1.69	8.7%	11.23	1.40
2B					1.69	8.7%	11.23	1.40
2C					1.69	8.7%	11.23	1.40
2D					1.69	8.7%	11.23	1.40
2E					1.69	8.7%	11.23	1.40
3A	60	20.0	7.9	1:3	1.69	8.7%	11.23	.48
3B					1.69	8.7%	11.23	.48
3C					1.69	8.7%	11.23	.48
3D					1.69	8.7%	11.23	.61
4A	70	13.18	6.8	1:53	1.69	8.7%	11.23	61
4B				1:53	169	8.7%	11.23	.61
4C					1.69	8.7%	11.23	.61
4D					1.69	8.7%	11.23	.61
4E					169	8.7%	11.23	.61

Table 9:-Material & Labor Estimate

Type Of Construction	Size of Units	No. of Units	Mortar in Cu. Ft.	Labor Hrs Of Mason	Labors Hrs. Of Labor
Cinder-Masonry	8"X8"X16"	2200	65.0	65	60
Clay Tile	8"X8"X12"	1860	98.0	106	94
Brick	Standard	24,660	400.0	180	220

Table 10:-Relative Costs

	Cinder Masonry 8"X8"X16"			Clay Tile			Brick		
	Quantity	Unit Cost	Total Cost	Quantity	Unit Cost	Total Cost	Quantity	Unit Cost	Total Cost
Cinder Units	2200	$.14	$308.00	1860	$.17	$316.20	24,660	$.014	345.24
Mortar (Cu. ft.)	65	.31	20.15	98	.31	30.38	400	.31	124.00
Mason Hours	65	$2.00	130.00	106	2.00	212.00	180	2.00	360.00
Labor Hours	60	1.00	60.00	94	1.00	94.00	220	1.00	220.00
Totals			518.15			652.58			1,049.24



Curve Showing Relationship between Water-Cement Ratio & Compressive Strength
1800
1600
1200
800
400
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
Water-Cement Ratio
Compressive Strength

Fig. 4