CONCRETE AND CONCRETE AGGREGATES

THESIS

by

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INTRODUCTION

The primary purpose in choosing concrete and concrete aggregates for this thesis was to give the writer a more complete knowledge of these materials, especially for this immediate vicinity.

At the start of this experiment the fixed objective was to determine the relative strengths of some of the important stones that are located in Los Angeles and vicinity. This particular problem was brought to the writer's attention after it was found that Eaton Canyon materials that were used in a recent addition to the Rose Bowl gave concrete that was far inferior to the concrete that was being prepared under the supervision of Mr. Byron Hill at the Institute, these latter materials being secured from San Gabriel. After some investigation the difference in strength of these two concretes were found to be partially due to the aggregates.

After the experiment was started various tests and experiments somewhat naturally followed in succession. Some stones, for example, might be far superior in strength and hardness to stones from another source, yet the grading of these stones might be such as to give a relative weak concrete under some fixed mix. Or, as was also found, certain stones may be preferred under different conditions of use or preparation of the concrete.

This report is on the whole somewhat interrelated and it would hardly be fair to quote too strongly any particular small section of the experiment.

The lack of consistency in certain phases of this experiment has left the writer with a dubious feeling as to the precise validity of certain parts. It is hoped that certain parts of this report shall encourage further work for a check on the results presented here and a continuation of a field of endeavor that has hardly been touched.

MATERIALS

Sand and stones were obtained from each of the following 4 sources; Eaton Canyon, San Fernando, San Gabriel, and Catalina - Long Beach. From this last source sand was obtained at Long Beach and stones at Catalina. These 4 sources of materials were chosen because they were considered the most representative for Los Angeles, Pasadena, and vicinity. Concrete sand and both 3/4 inch and 1½ inch crushed rocks were desired. In some cases where 3/4 inch and 1½ inch rock could not be obtained, it was necessary to substitute 1 inch rock for the 3/4 inch and 2 inch rock for the 1½ inch rock. In some cases it was also necessary to substitute gravel for crushed rock.

The Eaton Canyon sand and 1 inch crushed rock were obtained from a Pasadena City construction job, and the 1½ inch gravel was obtained from a bin at the Eaton Canyon plant.

San Fernando sand, 1 inch gravel, and 2 inch crushed rock were obtained from the bins at the San Fernando plant of Graham Bros.

San Gabriel sand, 1 inch gravel, and 1½ inch gravel were obtained from the bins of Graham Bros.' San Gabriel plant.

The Long Beach sand and Catalina 1 and 2 inch crushed rocks were sent to the Institute through the courtesy of R. W. Livingston who was at the time connected with Graham Bros., Inc.

GENERAL GEOLOGICAL SURVEY

When all of the materials were on hand, a general geological observation was made with the assistance of David Scharf, a graduate geoldgist at the Institute.

The Eaton Canyon rock had a comparatively large amount of mica which was very cleavable. A good many of the rocks were gneissic, i.e., the minerals were arranged in bands or layers.

The Catalina rock was fine grained and compact with practically no bands or layers. The crushing surfaces were large and very smooth and flat. After several months of weathering the rocks seemed to become somewhat darker on the surfaces.

The San Fernando rock was somewhat less gneissic and micaceous than Eaton Canyon rock but there was, however, a noticible amount present. There were some decomposed peebbles present that could be broken with the hand.

The San Gabriel rock was finer grained and much less gneissic or micaceous than the rocks of Eaton Canyon or San Fernando. It contained a few pebbles of decomposed rock.

The classification in strength, from a geological study of the rocks, is Catalina first, San Gabriel and San Fernando about the same, and Eaton Canyon by far the weakest.

PHYSICAL AND GEOLOGICAL SURVEY

To carry the geological study of the rocks a little further, some rocks from each source were broken and the interior of the rocks were observed. The method of breaking the rocks gave an approximate relative measure of the strength of the four rocks. The pciture on page 8 illustrates the method of breaking. The same testing machine that was used for testing specimens was used but the maximum capacity was reduced to 15,000 pounds and the minimum scale division was then one pound. The rate at which the cross-head moved was about .05 inches per minute, the same as is required for the standard compressive tests of concrete cylinders and which was used throughout. The individual rock that was to be tested was placed on a three quarter inch board that was laying on the weighing table and the load was applied through a steel bolt head that measured one and one quarter inches across and one half inch thick. The load was applied until the rock cracked, broke, or crushed. The board was used in order to give a large bearing area on the bottom. The rocks that were to be tested had to be carefully selected to be sure that the load was applied by the bolt head on only one flat surface of contact and also that the bottom of the rock had a good resting area directly beneath the point where the load was applied. Approximately eight pounds of each of the four larger rocks were taken and from these the specimens were chosen. There were three rocks tested from each source as explained above and then three more were tested but instead of the three quarter inch board a 3/4 inch square wood strip was used.

RESULTS OF BREAKING STRENGTH WITH 3/4 INCH

BOARD BASE

Catalina	Breaking load in pounds	Thickness in inches	Remarks
	2,140	0.5	Dense crystalline structure.
	1,829	1.1	Very fine structure. Partly decomposed.
	1,487	1.3	Partly decomposed rock. Uniform throughout.
San Fernando	1,706	0.8	Dense. Large crystals. Large amount quartz.
	1,625	1.0	No banding. Slightly decomposed.

San Fernando (Con.)	Breaking Load in pounds	Thickness in inches	Remarks
	1,793	1.2	Cracked at 9,000 #. Mica
San Gabriel	1,418	0.7	Dense. Fine structure. Mica.
	946	1.0	Mica.
	(1,390	1.1	Supporting block failed, not the specimen.)
Eaton Canyon	719	0.6	Fine structure. Mica.
	906	1.0	Granite. Decomposition.
	902	0.8,	Partly decomposed throughout.

REPRESENTATIVE BREAKING VALUES

Catalina	1,830 Lbs.
San Fernando	1,710 "
San Gabriel	1,400 "
Eaton Canyon	900 "

RESULTS OF BREAKING STRENGTH WITH 3/4 INCH

STRIP AS BASE

Catalina	Breaking load in pounds	Thickness in Inches	Geological Report
	2,377	0.7	Compact impalable rhyolitic. Apparently not decomposed.
	4,993	1.1	Compact impalable rhyolitic rock. Slightly decomposed along break.

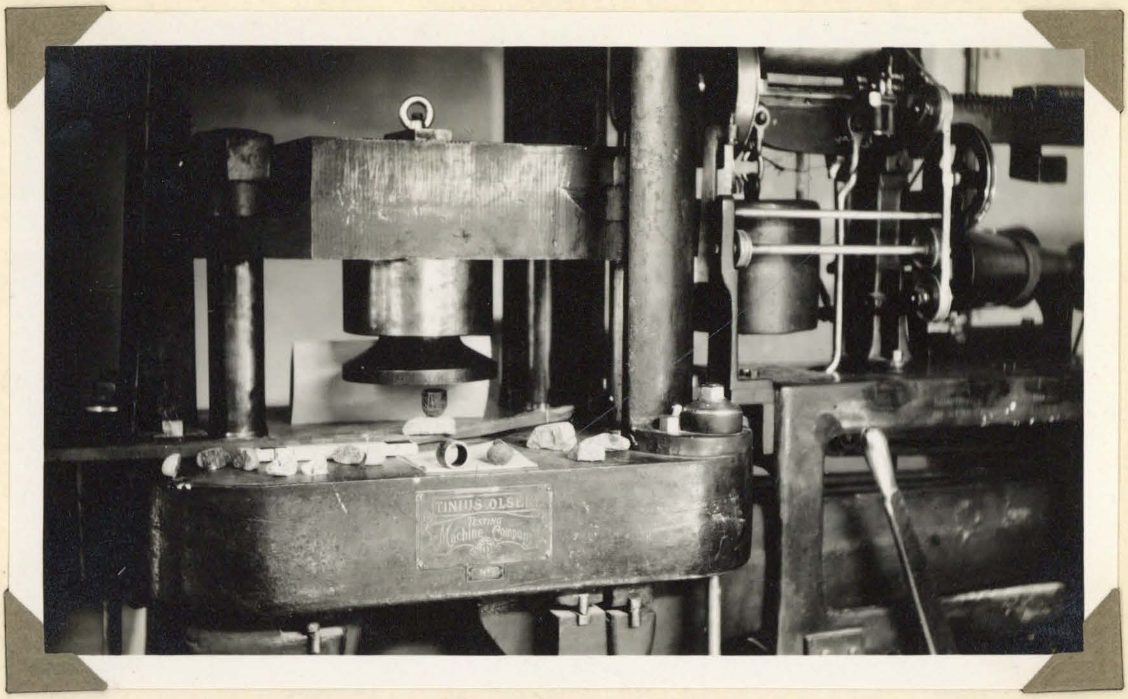
Catalina (Con.)	Breaking Load in pounds	Thickness in Inches	Geological Report
	4,062	1.3	Same kind of rock. Break along a plane of slight decomposition.
Eaton Canyon	961	0.6	Fine grained mica schist, quartz, and feldspar. Break almost parallel to schistosity.
	650	0.7	Medium grained, roughly branded, quartz, feldspar, and mica. Decomposed condition accounts for weakness. Break normal to plane.
	985	1.6	Quartz and felspar much more than mica. Relatively fresh. No banding.
San Fernando	6,198	1.0	Very coarse grained quartz, feldspar, and mica. No banding. Very fresh.
	1,800	0.8	Coarse grained quartz, feldspar, Mica, and a little hornblende. No banding. Slightly decomposed.
	1,921	0.7	Coarse grained quartz and felspar. No Banding.
San Gabriel	2,430	0.9	Gueissic medium grained. Quartz, felspar, and mica arranged in bands which are planes of weakness, but breal occured almost normal to these bands. The load was applied parallel to the bands.

San Gabriel (Con.)	Breaking Load In pounds	Thickness in Inches	Geological Report
	2,242	0.9	Medium grained granite, slightly altered, toward a gneiss. Much more quartz and felspar than mica. Mica arranged in bands but to a much less degree than above rock. Part of break across and part along plane of mica.
	2,995	0.9	Quartz, felspar, and mica approximately equal in amount; uniformly distributed with flakes of mica generally parallel to each other. No banding. Comparative freshness of rock and absence of banding or sebistosity accounts for high strength.

REPRESENTATIVE BREAKING VALUES

Catalina	4,060
San Gabriel	2,430
San Fernando	1,920
Eaton Canyon	960

Since there were few suitable specimens from the 8 lbs. of rock samples in each group, those first chosen and used with the flat board test gave better and more representative results as the range indicates.



TESTING PHYSICAL STRENGTH

OF STONES

UNIT WEIGHTS OF MATERIALS

Sand (Dried)

	Wt. of 0.10 cu.ft.	Wt. of 1 cu.ft.
Eaton Canyon	10.53	105.3
San Fernando	11.36	113.6
San Gabriel	11.03	110.03
Long Beach	10:12	101.2

Check on above.

	Wt. of 1/2 cu.ft.	Wt. of 1 cu.ft.
Eaton Canyon	51.2	102.4
San Fernando	56.4	112.8
San Gabriel	54.0	107.9
Long Beach	48.8	97.6

Sands arrayed by weight

San Fernando

San Gabriel

Eaton Canyon

Long Beach

3/4 INCH STONE

	Wt. of 1/2 cu.ft.	Net Wt. 1 cu.ft.
Eaton Canyon	47.69	95.3
San Fernando	51.45	102.9
San Gabriel	52.77	105.5
Catalina	46.79	93.6

Arrayed by weight

San Gabriel

San Fernando

Eaton Canyon

Catalina

1-1/2 INCH STONE

	Wt. 1/2 cu.ft.	Wt. 1 cu. ft.
Eaton Canyon	49.03	98.1
San Fernando	48.0	96.0
San Gabriel	53.67	107.3
Catalina	46.82	93.6

Arrayed by Weight

San Gabriel

Eaton Canyon

San Fernando

Catalina

SPECIFIC GRAVITY OF ROCKS

The apparent specifc gravity of the stones from each of the four sources were determined by the standard A. S. T. M. method. Each of the four small groups selected by a representative method were first weighed dry, indicated in the following table by A. After 24 hours soaking in water they were again weighed after being blotted dry - B. The soaked rocks were then submerged in water and the net weight is indicated below by C.

	Catalina	Eaton Canyon	San Fernando	San Gabriel
A	1.47	1.04	1.27	1.32
B	1.485	1.05	1.28	1.34
C	.935	.651	.8106	.634
B-C	.550	.399	.469	.506
Specific Gravity $\left(\frac{A}{B-C}\right)$	2.67	2.605	2.71	2.61

ARRAYED SPECIFIC GRAVITIES

San Fernando

Catalina

San Gabriel

Eaton Canyon

PER CENT VOIDS IN 3/4 INCH ROCK

San Fernando $\frac{2.71 \times 62.4 - 102.9}{2.71 \times 62.4} = 39.1$

Catalina $\frac{2.67 \times 62.4 - 93.6}{2.67 \times 62.4} = 43.85$

San Gabriel $\frac{2.61 \times 62.4 - 105.5}{2.61 \times 62.4} = 35.2$

Eaton Canyon $\frac{2.605 \times 62.4 - 95.3}{2.605 \times 62.4} = 41.4$

//.

ARRAYED ACCORDING TO GRADING BY VOIDS

San Gabriel

San Fernando

Eaton Canyon

Catalina

DISINTEGRATION TEST

Six lagge rocks were shosen from each of the 4 sources at random. These stones were tested for disintegration by soaking them in a saturated solution of sodium sulphate for about 12 hours and then drying them at about 100 degrees centigrade for the same length of time. All rocks were kept in the same solution and oven and treated exactly the same.

The fault with this test is the personal element in judging the extent of disintegration. Some of the stones cracked in half, others disintegrated to various extents, while some were not even effected. After about 10 complete cycles, the following order gives the resistance to disintegration.

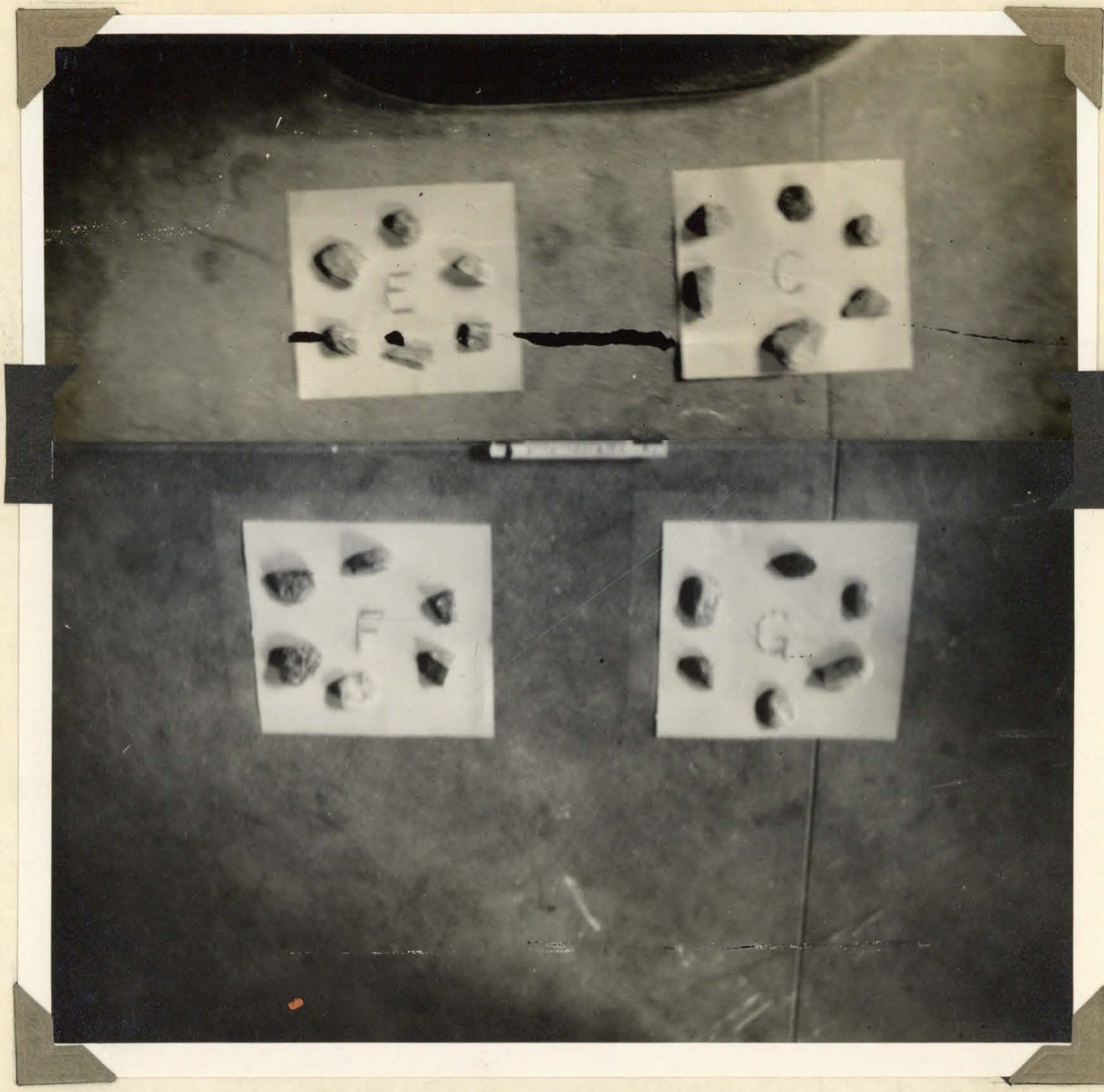
ARRAYED ACCORDING TO RESISTANCE TO WEATHERING.

San Gabriel

Catalina

San Fernando

Eaton Canyon



STONES TESTED

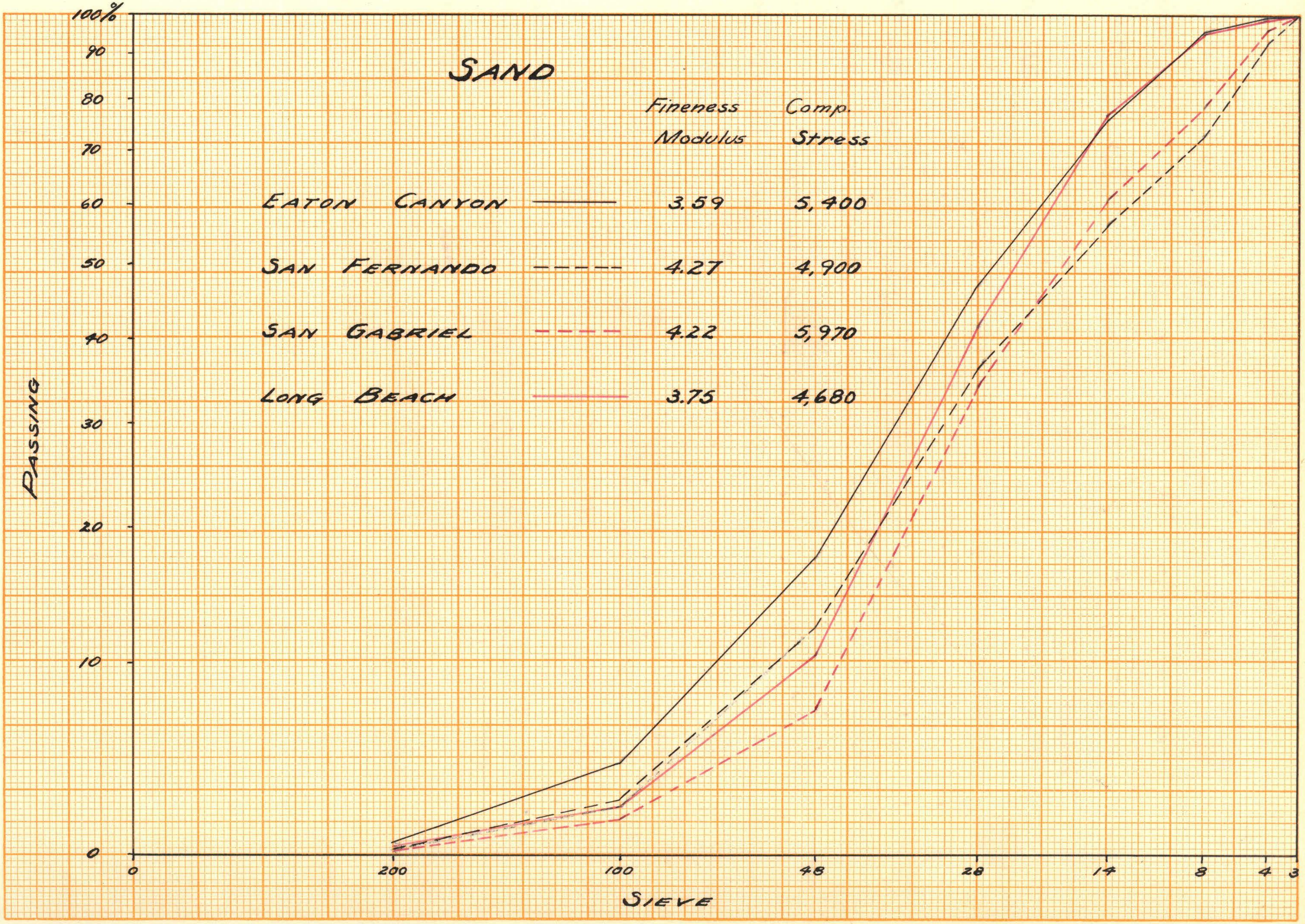
FOR DISINTEGRATION

SIEVE ANALYSIS OF MATERIALS

Representative samples were secured by quartering about 1/2 cubic foot of each material. The sand was oven dried at about 100° C. The free moisture in the sand was measured but has been omitted because of its lack of importance.

Sand Sieve Analysis

	Sieve	200	100	48	28	14	8	4
Eaton Canyon -	Wt. Passing	.02	.14	.58	1.56	2.50	3.14	3.28
	% Passing	.61	4.25	17.6	47.4	76.	95.5	99.7
Long Beach -	Wt. Passing	.01	.06	.31	1.21	2.23	2.73	2.86
	% Passing	.35	2.08	10.7	41.8	77.1	94.5	98.9
San Gabriel -	Wt. Passing	.01	.08	.35	1.66	2.94	3.77	4.61
	% Passing	.21	1.66	7.26	34.5	61.0	72.2	95.6
San Fernando-	Wt. Passing	.01	.08	.40	1.16	1.81	2.31	2.94
	% Passing	.31	2.53	12.52	36.4	56.7	72.5	92.2

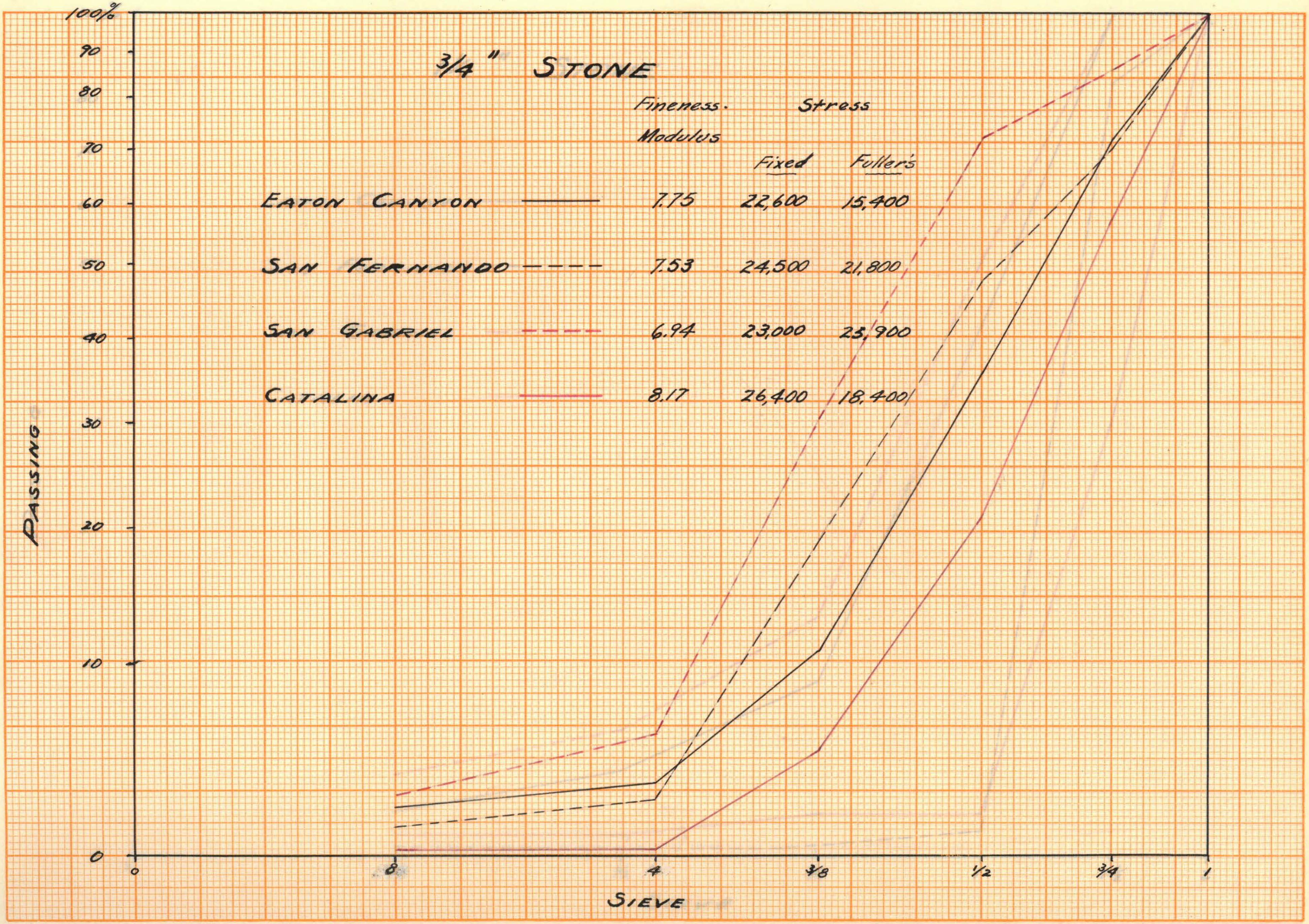

SAND
Fineness Modulus
Comp. Stress
EATON CANYON 3.59 5,400
SAN FERNANDO 4.27 4,900
SAN GABRIEL 4.22 5,970
LONG BEACH 3.75 4,680
PASSING
100%
90
80
70
60
50
40
30
20
10
0
SIEVE
0
200
100
48
28
14
8
4
3

3/4 Inch Stone Sieve Analysis

	Sieve	8	4	.371	.525	.742	1.05
Eaton Canyon-	Wt. Passing	.11	.16	.53	1.72	3.46	4.8
(Crushed)	% Passing	2.29	3.33	11.0	35.8	72.1	100
Catalina	Wt. Passing	.01	.01	.26	1.09	2.95	4.99
(Crushed)	% Passing	.20	.20	5.11	21.4	58.0	98.1
San Gabriel	Wt. Passing	.14	.30	1.55	3.66	4.75	5.05
(Gravel)	% Passing	2.77	5.94	30.7	72.5	94.0	100
San Fernando	Wt. Passing	.06	.13	.96	2.39	3.81	5.0
(Gravel)	% Passing	1.2	2.6	19.2	47.8	76.2	100

1-1/2 Inch Stone Sieve Analysis

	Sieve	.371	.525	.742	1.05	1.5	2.0
Eaton Canyon-	Wt. Passing	.12	.24	.54	2.50	5.96	
(Gravel)	% Passing	2.01	4.02	9.05	41.9	100	
Catalina	Wt. Passing	.01	.01	.02	.02	3.13	10.34
(Crushed)	% Passing	.97	.97	1.93	1.93	30.22	100
San Gabriel	Wt. Passing	.32	.53	1.12	4.33	8.45	
(Gravel)	% Passing	3.78	6.27	13.26	51.2	100	
San Fernando	Wt. Passing	.02	.02	.02	.68	4.93	5.84
(Crushed)	% Passing	.34	.34	.34	1.17	84.5	100


3/4" STONE
Fineness Modulus
Stress
Fixed
Fuller's
EATON CANYON 7.75 22,600 15,400
SAN FERNANDO 7.53 24,500 21,800
SAN GABRIEL 6.94 23,000 25,900
CATALINA 8.17 26,400 18,400
100%
90
80
70
60
50
40
30
20
10
0
PASSING
0
8
4
3/8
1/2
3/4
1
SIEVE

FINENESS MODULUS OF SAND

Sieve	200	100	48	28	14	8	4	Σ
	Per Cent Sand Passing by Weight							
Opening	.0029	.0058	.0116	.9232	.046	.093	.185	
Eaton Canyon	.61	4.25	17.6	47.4	76.	95.5	99.7	341.06
San Fernando	.31+	2.53	12.52	36.4	56.7	72.5	92.2	273.16
San Gabriel	.21	1.66	7.26	34.5	61.0	78.2	95.6	278.43
Long Beach	.35	2.08	10.7	41.8	77.1	94.5	98.9	325.43

FINENESS MODULUS =

$$\frac{7 \times 100 - \Sigma}{100}$$

Eaton Canyon	3.59
San Fernando	4.27
San Gabriel	4.22
Long Beach	3.75

* ARRAYED FINENESS MODULUS

San Fernando	3.27
San Gabriel	3.22
Long Beach	2.75
Eaton Canyon	2.59

* In this final grouping the values are unity ; or one, less than above. Since the 200 mesh is commonly omitted these latter units take this into consideration.

CEMENT

The cement that was used was secured from the various construction jobs that were in progress at the Institute during the time of the experiments. All of the cement, which was of the Riverside Portland brand, came from the same sources but in different shipments. To check the consistency in method of testing and strength of the cement, 4 sacks were tested. The neat cement mixtures were all thoroughly mixed by hand in a glazed pan that was approximately 12 inches in diameter and 4 inches deep. For reference, the sacks were numbered. After the specimens were 1 day old they were then placed in the water curing tank in the testing materials laboratory. The temperature of the water in the curing tank was 13° C. Oiled metal forms were used for all the specimens. All compression tests were made on the Tinius Olson Testing Machine with 150,000 lbs. maximum capacity and a minimum scale division of 10 lbs.

CEMENT MIXTURES

Sack #1	Gross Wt. Cement	=	12.41 Lbs.
	Pan	=	1.34
	Net	=	11.07 "
	Net Vo. Water	=	1273 cc.
	W/C Ratio	=	.382 by Volume.
		=	2.86 gal. per cu. ft. Cement.

CEMENT MIXTURES (CON.)

Sack #2	Gross wt. Cement	-	10.37 Lbs.
	Pan	-	1.32
	Net	-	9.05 "
	Net. Vo. water	-	1040 cc.
	W/C	-	.382 by volume
		-	2.86 gal./ c. ft. cement.
Sack #3	Gross Wt. Cement	-	9.33 Lbs.
	Pan	-	1.33
	Net	-	8.00 "
	Net Vo. water	-	920 cc.
	Water Cement Ratio	-	.382 by volume.
	" " "		2.86 gal.
Sack #4	Gross Wt. Cement	-	9.33 Lbs.
	Pan	-	1.33
	Net	-	8.00 "
	Net Vo. water	-	9.20 cc.
	Water Cement Ratio	-	3.82 by volume.
	" " "	-	2.86 gal.

Combination of above four sacks.

Gross Wt. Cement	-	12.41 Lbs.
Pan	-	1.34
Net	-	11.07 "
Net vol. water	-	1273 cc.
Water cement ratio	-	.382 by volume.
" " "	-	2.86 gal.

28 DAY CEMENT TESTS

		Breaking Strength	Average Unit Brvkg. Strength	Remarks
		26,820		Sudden breaking of small pieces. Cement dust in center
1½" x 3" Cylinders	Sack#1		4,050	
		22,960		Chipped with first application of loading.
		20,230		Sudden failure.
Area = 1.77	Sack#2		10,450	
		16,690		Chipped and broke across near the bottom.
		6,270		Bottom was untrue. Felt used.
	Sack#3		5,930	
		14,690		----
		9,860		----
	Sack#4		8,810	
		21,460		Chipped early and continuously; load still increased.
mbination of above		20,980		----
		21,250		----
		14,950		----

		Breaking Strength	Average Unit Brkg. Strength	Remarks
		46,500		----
3" x 6" cylinders	Sack#1		8,330	
		71,330		Little early chipping. Sudden Failure.
		58,150		Sudden Failure
Area = 7.07	Sack#2		8,250	
		58,630		Felt Used.
		41.750		Much early chipping.
	Sack#3		6,500	
		50,000		Started chipping at about 14,000 Lbs.

28 DAY CEMENT TESTS (CON.)

	Breaking Strength	Average Unit Brkg. Strength	Remarks
	49,900		Chipping at 26,000 Lbs.
Sack #4		7,370	
	54,230		Chipping at 36,000 Lbs.
Combination	38, 370		First Chipping at 32,000 Lb Ran Cross-head too fast.
	49,930	5,960	Chipping at 37,000 Lbs.
	38,230		Chipped at 33,000 Lbs. and 38,000 Lbs.

		Breaking Load	Unit Strength
2" Cubes	Sack #1	20,250	7,560.
Area = 4	Sack #2	32,080	8,010
	Sack #3	24,650	6,140
	Sack #4	19,500	4,880
Combination		14,600	3,650

Briquetts

Sack #1	800
Sack #2	634
Sack #3	555
Sack #4	855
Combination	478

SAND CEMENT SPECIMENS

Exactly 1000 c.c. (2.2 Lbs.) of water and 4.7 lbs. (0.05 cu. ft.) of cement were added to 0.10 cu. ft. of each of the 4 sands. All sands were room dried. When the specimens were 27 days old they were removed from Institute Laboratory curing tank. The specimens were tested from 18 to 23 hours after being removed from the curing tank. The temperature of the curing water was approximately 13° C. during the curing period. Since all metal forms were used, the folliwung areas represent the differnet specimens: the 1½" x 3" molds area = 2.01; the 2" cubes area = 4.0; the 3" x 6" cylinders area = 7.09; and unity for the briquettes.

EATON CANYON

	1½" x 3" Cylinders			2" Cubes		
Breaking Force	8,340	7,050	10,340	27,730	26,700	26,080
Unit Max. Stress	4,150	3,510	5,150	6,930	6,680	6,520
Average(Arith)		4,270			6,710	
Median		4,150			6,680	

	3" x6" Cylinders			Briquettes
Breaking Force	39,290	33,960	37,620	435
Unit Max. Stress	5,550	4,790	5,310	
Arith Average		5,220		
Median		5,310		

SAN FERNANDO

	1½" x 3" Cylinders			2" Cubes		
Breaking Force	7,140	4,820	9,810	23,800	27,480	19,260
Unit Max. Stress	3,560	2,400	4,880	5,950	6,870	4,810
Arith.Average		3,610			5,880	
Median		3,560			5,950	

	3" x 6" Cylinders			Briquettes
Breaking Force	38,290	-	38,770	445
Unit Max. Stress	5,400	-	5,460	
Arith.Average		5,430		
Median		-		

SAN GABRIEL

	1½" x 3" Cylinders			2" Cubes		
Breaking Force	9,420	10,520	9,370	-	25,660	25,460
Unit Max. Stress	4,680	5,230	4,660	-	6,420	6,370
Arith. Average		4,860			6,390	
Median		4,680			-	

	3" x 6" Cylinders			Briquettes
Breaking Force	39,660	38,160	42,330	390
Unit Max. Stress	5,600	5,380	5,970	
Arith. Average		5,650		
Median		5,600		

LONG BEACH

	1½" x #2 Cylinders			2" Cubes		
Breaking Force	9,520	9,000	6,530	18,200	21,100	23,030
Unit Max. Stress	4,730	4,480	3,250	4,550	5,280	5,760
Arith. Average		4,150			5,200	
Median		4,480			5,280	

	3" x 6" Cylinders			Briquettes
Breaking Force	34,520	34,780	31,530	-
Unit Max. Stress	4,870	4,900	4,450	-
Arith. Average		4,740		
Median		4,870		

RESULTS OF COMPRESSIVE TESTS FOR

CEMENT-SAND SPECIMENS

(Cylinders and cubes weighed alike)

	Arith. Averages	Arith. Average of Medians.
Eaton Canyon	5,400	5,380
San Fernando	4,900	4,980
San Gabriel	5,970	5,560
Long Beach	4,680	4,880

ARRAYED SAND TEST RESULTS

San Gabriel

Eaton Canyon

San Fernando

Long Beach

CONCRETE SPECIMENS

Two series of cylinders were prepared and tested. One of the series was where the aggregate ratios were fixed, and the other was where the aggregate ratios for each set of materials were determined by use of Fuller's Curve for maximum density.

MIXES WITH FIXED RATIOS

For the mixes with the fixed ratios an attempt was made to make the break go through the rock, the purpose being to get the relative strength of the rocks. For this reason a rocky mix was chosen. The water, cement, silt, and sand were constant for all of the mixes. San Gabriel silt and sand were used. The silt was the only aggregate with water in it. Since this was such a small quanity and constant for all mixes, it was neglected.

All concrete for the fixed ratio specimens were mixed by hand in the Institute Testing Laboratory. The mixing was done in a large metal mixing box, which was cleaned and dampened for each individual mix. The materials were first thoroughly mixed dry and then the water was carefully added and again the mixture was thoroughly mixed.

The specimens were numbered for each set. Number one was where the specimen form was of cardboard with a tin bottom. The cardboard had only a very light parafin coat. Number two, three, and four were cardboard forms that were well parafined throughout. Number two had a machined metal plate placed in its bottom to save later capping on one end. Specimen number five was of metal It was, immediately after preparation, placed in the Ro-Tap Machine that is used for shaking sieves for twenty two complete shakes or about ten seconds. About one half inch of concrete was shaken out of the form. The water lost or brought to the top was negligable.

CONSTANTS FOR SPECIMENS WITH 3/4 INCH STONE.

	Water	Cement	Silt	Sand
Wt. in Lbs.	16.5	29.6	15.6	35.0
Volume in cu.ft.	.264	.315	.157	.324
Ratio by Vol.	.838	1.0	0.50	1.03

WT. PER CUBIC FOOT OF CONSTANTS

Water	Cement	S.G. Silt	S.G. Sand
62.5	94.0	99.2	107.9

3/4 INCH STONES

	Catalina	Eaton Canyon	San Fernando	San Gabriel
Wt. in Lbs.	88.5	90.0	97.2	99.7
Vol. in cu. Ft.	.945	.945	.945	.945
Ratio by Vol.	3.0	3.0	3.0	3.0

Mix (by volume) 1.00 : 0.50 : 1.03 : 3.0

W/C = 6.29 U.S. gallons per cu.ft. cement

= 0.84 by volume.

	Catalina	Eaton Canyon	San Fernando	San Gabriel
Type of Stone	Crushed	Crushed	Gravel	Gravel
Wt. per cu.ft.	93.6	95.3	102.9	105.5
Flow	173	210	235	230
Slump	$3\frac{1}{2}$	$5\frac{1}{4}$	$7\frac{1}{2}$	$8\frac{1}{2}$

MIXES WITH BOTH SIZES OF STONES

	Water	Cement	Silt	Sand
Wt. in Lbs.	9.9	17.76	9.36	21.0
Vol. in cu. Ft.	.1585	.189	.0943	.1944
Ratio by Vol.	.838	1.0	.50	1.03

WT. PER CUBIC FOOT OF CONSTANTS

Water	Cememt	S.G. Silt	S.G. Sand
62.5	94.0	99.2	107.9

3/4 INCH STONES

	Catalina	Eaton Canyon	San Fernando	San Gabriel
Wt. in Lbs.	17.7	18.0	19.5	20.0
Vol. in cu. Ft.	.189	.189	.189	.189
Ratio by Vol.	1.0	1.0	1.0	1.0

1-1/2 INCH STONES

	Catalina	Eaton Canyon	San Fernando	San Gabriel
Vol. in Lbs.	35.4	37.1	36.3	40.6
Vol. in cu. ft.	.378	.378	.378	.378
Ratio by Vol.	2.0	2.0	2.0	2.0

Mix (by volume) 1.0 : 0.50 : 1.03 : 1.0 : 2.0

W/C = 6.29 U.S. gal. per cu. ft. cement.

	Catalina	Eaton Canyon	San Fernando	San Gabriel
Type of Large Stone	Crushed	Gravel	Crushed	Gravel
Wt. of Large Rock	93.6	98.1	96.0	107.3
Flow	-	230	230	230) Gravel 260) Water
Slump	7½	7¼	6½	5½
Remarks	Very wet.	wet.	wet.	Wettest. Separation of aggregates.

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28 DAY COMPRESSION TEST

San Gabriel

3/4" Stone

1. 61.200 Break thru very few rock.
2. 60,300 Very few breaks. Decomposition.
3. 56,400 Practically no rock breaks.
4. 55,800 " " " "
5. 63,200 Few Breaks.

3/4" and 1-1/2" Stone

1. Less than 20,000 Lbs. Poor Matrix. Cement washed out.

28 DAY COMPRESSION TEST (CON.)

3/4" and 1-1/2" Stone

2. Less than 20,000 Lbs.
3. Less than 20,000. Rocks loose. No. rock breaks. Poor matrix.

Note: Poor bond thru-out.

Eaton Canyon

3/4" Stone

1. 62,500 Many rock breaks. Much mica exposed.
2. 51,000 Poor bearing surface.
3. 54,700 Break thru several rocks.
4. 66,100 Break thru still fewer rocks.
5. 58,900 Many rock breaks. Much mica exposed.

3/4" and 1-1/2" Stone

1. 50,600 Break thru several rocks: around big ones.
2. 46,500 " " " " " " "
3. 52,600 " " " " " " "

Note: Many rocks broken.

San Fernando

3/4" Stone

1. 57,700 Break thru few rocks. Mica and decomposition.
2. 62,700 Same.
3. 65,000 "
4. 64,500 "
5. 65,700 "

28 DAY COMPRESSION TEST (CON.)

San Fernando

3/4" and 1-1/2" Stone

1. 47,900 Break thru few. Mica and decomposition.

2. 59,000 Break thru few. Mica only.

3. 39,500 Break thru several. Note: Mostly mica. Some coarse grained rocks.

X.

Note: Poor bond. Very few rock breaks.

Catalina

3/4" Stone

1. 65,500 Break thru several rocks. Rocks showed decomposition.

2. 73,200 Few breaks. Mostly decomposed rocks.

3. 70,000 Break thru many rocks. While rock looks strong and fine grained and light in color, the breaks were dark and coarse grained. Few of the breaks looked strong like the exterior.

4. 69,600 Break thru several rocks. Rock showed decomposition.

5. 61,000 Break thru few rocks. About 1/2 decomposed. Note: A specimen cracked at damp top at 50,000. Broken upper half.

3/4" and 1-1/2" Stone

1. 43,400 Broke thru several big rocks and several small ones. Some of the big rocks appeared decomposed on the interior only. Note: Cracked at 42,000.

28 DAY COMPRESSION TEST (CON.)

Catalina

3/4" and 1-1/2" Stone

2. 39,200 Broke thru and around several large rocks. Broke thru few small ones.

3. 36,300 Broke thru several big rocks. Some of the broken rocks looked strong while most of the breaks showed decomposition.

RESULTS OF 28 DAY COMPRESSION TESTS

FOR MIXES WITH WATER, CEMENT, AND SANDS FIXED.

3/4" Stone Specimens.

	Eaton Canyon	San Fernando	San Gabriel	Catalina
1	62,500	57,700	61,200	65,500
2	51,000	62,700	56,400	73,200
3	54,700	65,000	60,100	70,000
4	66100	64,500	63,200	69,600
5	58,900	65,700	55,800	61,000
Arith. Aver.	58,600	63,100	59,300	67,900
Median	58,900	64,500	60,100	69,600
Aver. Stress	22,600	24,500	23,0000	26,400

3/4" and 1-1/2" Stone Specimens.

	Eaton Canyon	San Fernando	San Gabriel	Catalina
1	50,600	47,900	No cement.	39,200
2	46,500	59,000	Specimens	31,700
3	52,600	39,500	failed be-	36,300
4	-	-	low 20,000	44,000
5	-	-		43,400
Arith. Aver.	49,900	48,800		38,900
Median	50,600	47,900		39,200
Aver. Stress	19,400	20,500		15,000

ORDER IN MAGNITUDE OF STRENGTH

FOR SPECIMENS WITH 3/4" STONES.

Catalina	(Crushed stone. Flat surfaces)
San Fernando	(Gravel)
San Gabriel	(Gravel)
Eaton Canyon	(Crushed stone)

ORDER IN MAGNITUDE OF STRENGTH

FOR SPECIMENS WITH 3/4" AND 1-1/2" STONES.

Eaton Canyon	(Gravel)
San Fernando	(Crushed stone)
Catalina	(Crushed stone. Flat surfaces)
San Gabriel	(Gravel)

ORDER IN MAGNITUDE OF TESTED SPECIMENS

WITH GREATEST NUMBER OF BROKEN STONES.

Eaton Canyon

Catalina

San Fernando - San Gabriel

ORDER IN MAGNITUDE OF TESTED SPECIMENS

WITH BEST STONE BOND.

Eaton Canyon

Catalina (3/4")

San Fernando

San Gabriel

MIXES DETERMINED BY FULLER'S CURVES

For the mixes determined by Fullers' Curves an attempt was made to get the most practical mix for the field with each of the four sets of materials. The water and cement were kept constant for all mixes.

All of the concrete in this test was mixed by means of a small gasoline mixer, the same as is very commonly used on small construction work. The drum was three feet in diameter and had three sets of paddles for mixing. It revolved at a rate of about eighteen revolutions per minute, its peripheral speed being about 170 feet per minute. All mixes were mixed for two minutes. The concrete was dumped from the mixer into a wheelbarrow. The concrete was placed in the specimen forms according to A.S.T.M. One man placed concrete by thirds in each of the forms while a second man followed up with the tamping.

The day after preparation the specimens were stripped. The specimens were prepared and cured on the Institute campus beneath one of the large oak trees. The three days following the preparation of the specimens they were lightly sprinkled each afternoon.

The following mixes were finally decided upon as the most practical. These mixes were chosen after much labor and with the assistance of Byron Hill who was at the time connected with the Institute Civil Engineering Department.

SPECIMENS PREPARED

ACCORDING TO FULLER'S CURVES & METHODS

SHOWING X-- MIXER USED

PLACE OF CURING

FINISHED SPECIMENS

FULLER'S CURVES

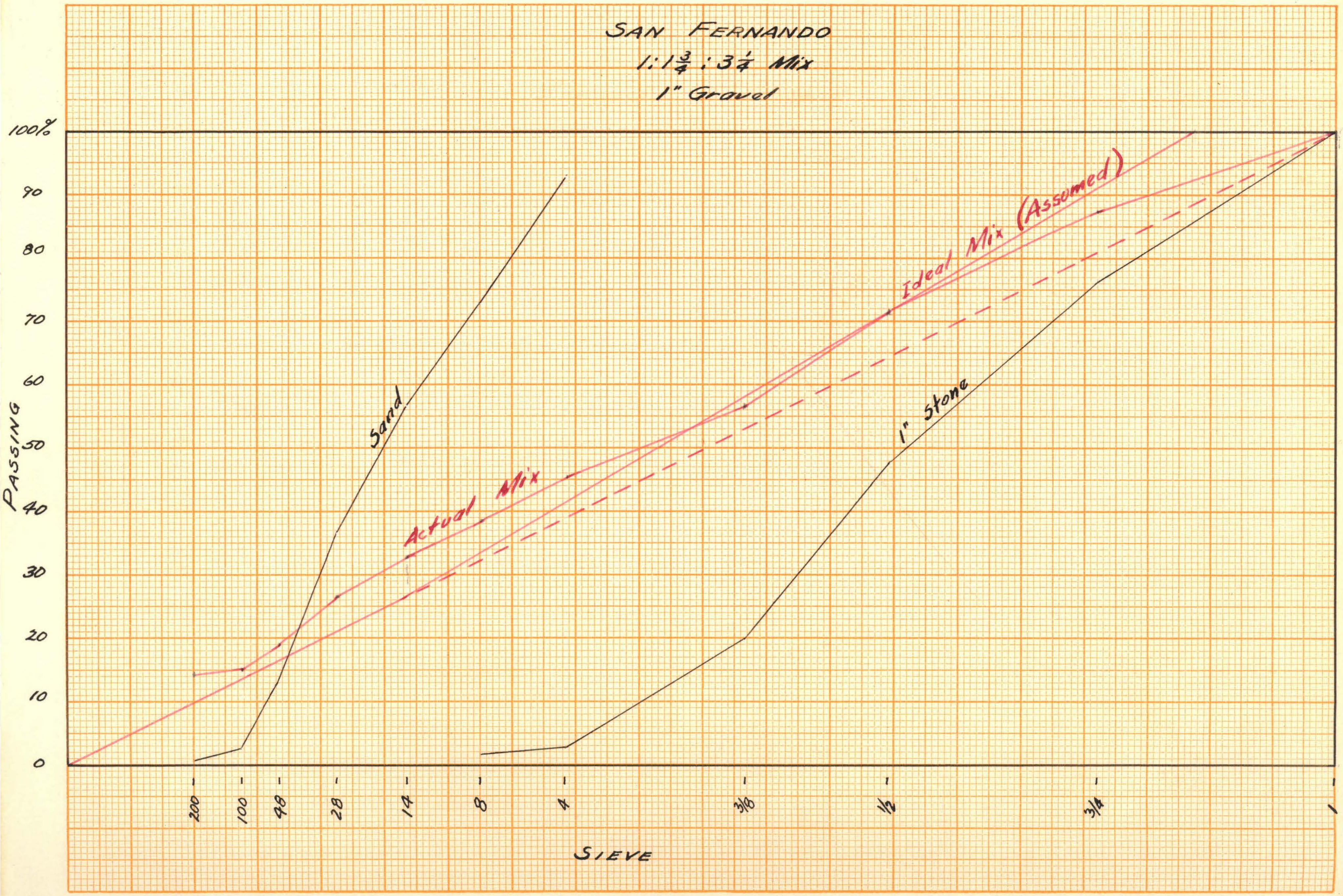
San Fernando Materials

	Volume	Weight	% Weight
Cement	1	94	15.0
Sand	1¾	198	31.6
3/4" Stone	3¼	334	53.4
Total		626	100.0

Sieve	200	100	48	28	14	8	4	3/8	1/2	3/4	1
	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	0.1	0.8	4.0	11.5	17.9	22.9	29.2	31.6	31.6	31.6	31.6
	0	0	0	0	0	0.6	1.4	10.3	25.5	40.7	53.4
	15.1	15.8	19.0	26.5	32.9	38.5	45.6	56.9	72.1	87.3	100.

	Volume	Weight	% Weight
Cement	1	94	15.3
Sand	1¾	198	32.3
3/4" Stone	1 3/8	141	23.0
1½" Stone	1 7/8	180	29.4
		613	100.0

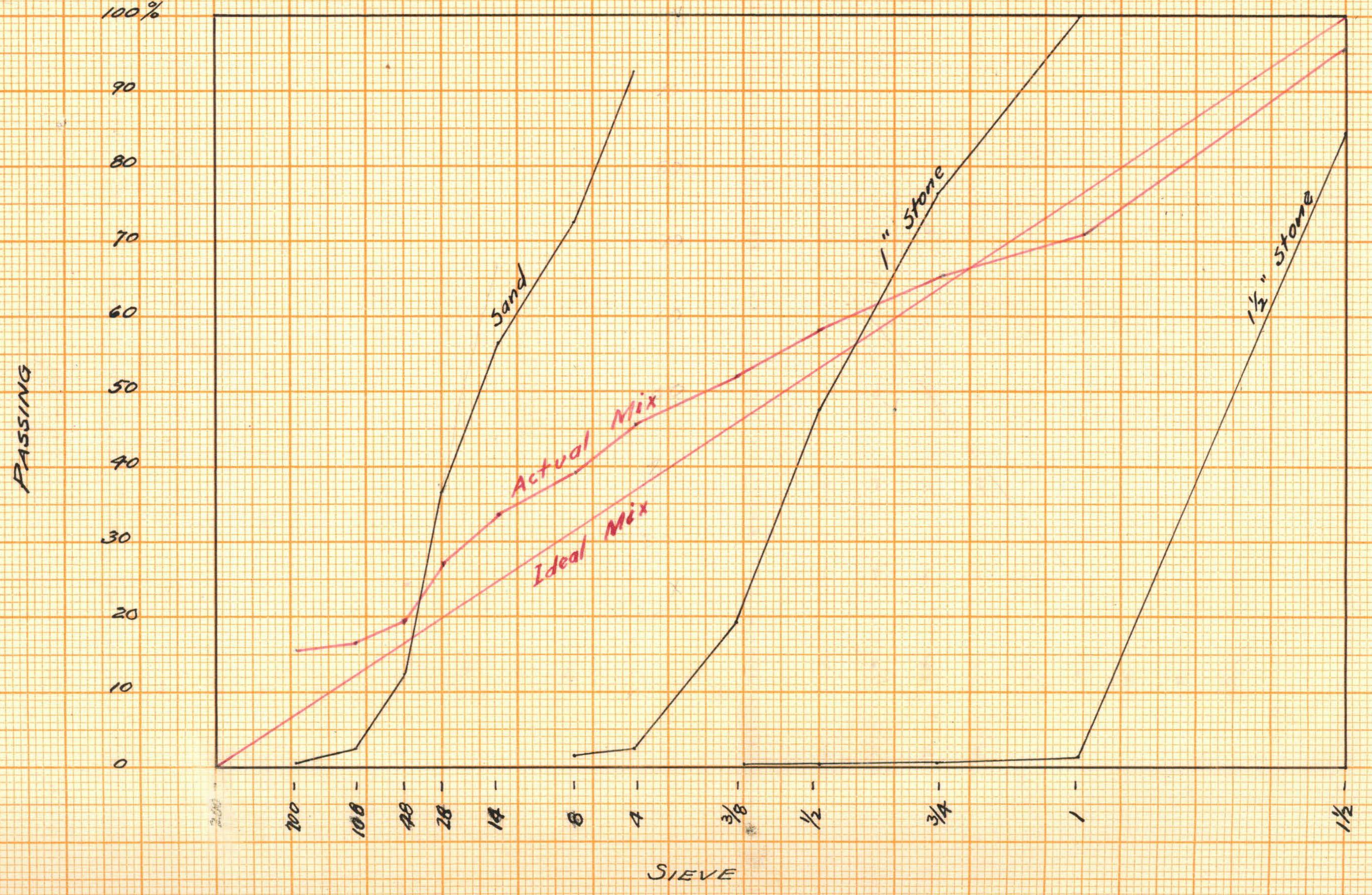
Sieve	200	100	48	28	14	8	4	3/8	1/2	3/4	1	1½	2
	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
	0.1	0.8	4.1	11.8	18.3	23.4	29.9	32.3	32.3	32.3	32.3	32.3	32.3
	0	0	0	0	0	0.3	0.6	4.5	11.0	17.5	23.0	23.0	23.0
	0	0	0	0	0	0	0	0.1	0.1	0.1	0.3	25.0	29.5
	15.4	16.1	19.4	27.1	33.6	39.0	45.8	52.2	58.7	65.2	70.9	95.6	100.1


SAN FERNANDO
1:1 3/4 : 3 1/4 Mix
1" Gravel
100%
90
80
70
60
50
40
30
20
10
0
PASSING
Sand
Actual Mix
Ideal Mix (Assumed)
1" Stone
200
100
48
28
14
8
4
3/8
1/2
3/4
1
SIEVE

SAN FERNANDO

$1:1\frac{3}{4}:1\frac{3}{8}:1\frac{7}{8}$ Mix

1" Gravel - $1\frac{1}{2}$" Crushed



FULLER'S CURVES

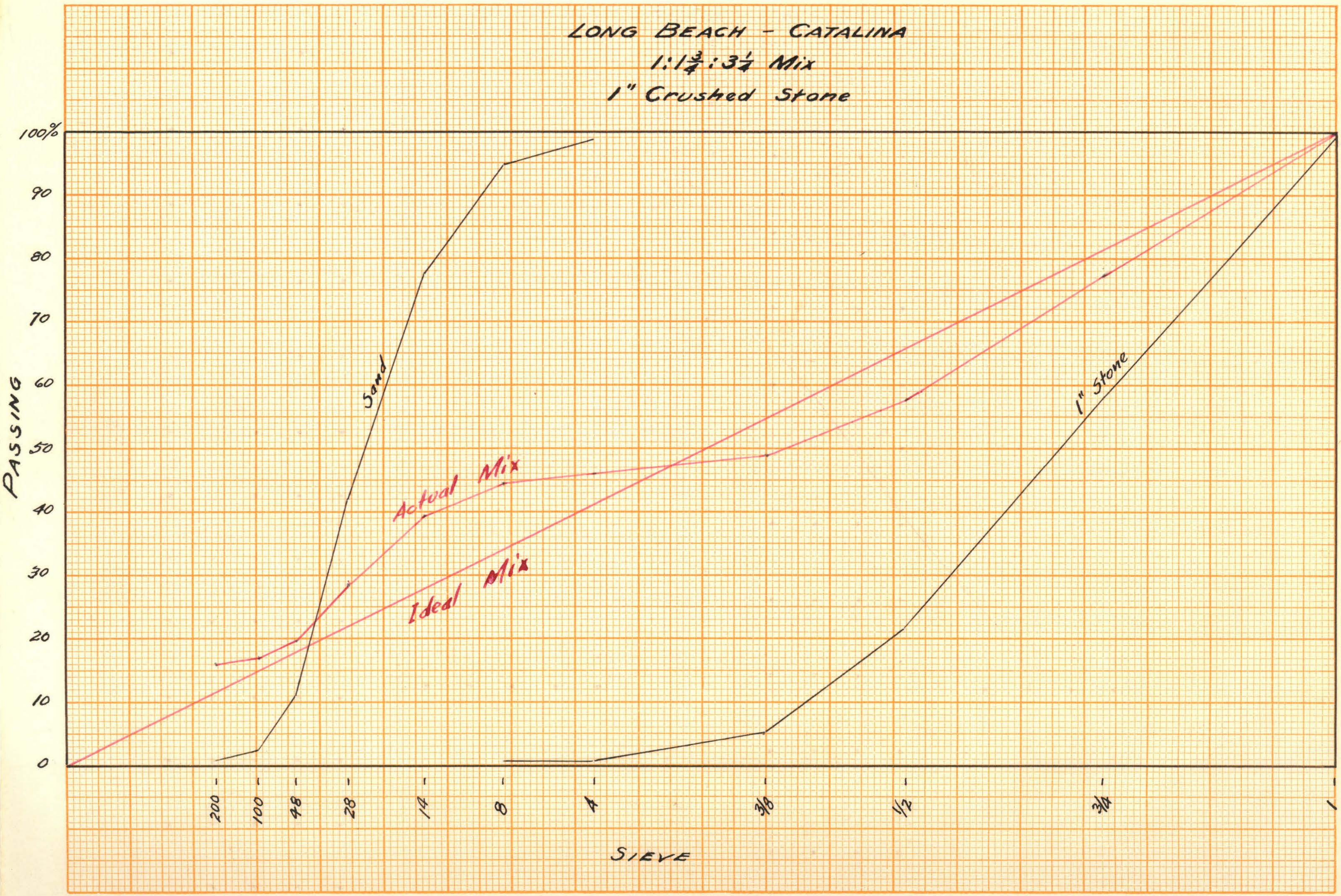
Long Beach and Catalina Materials

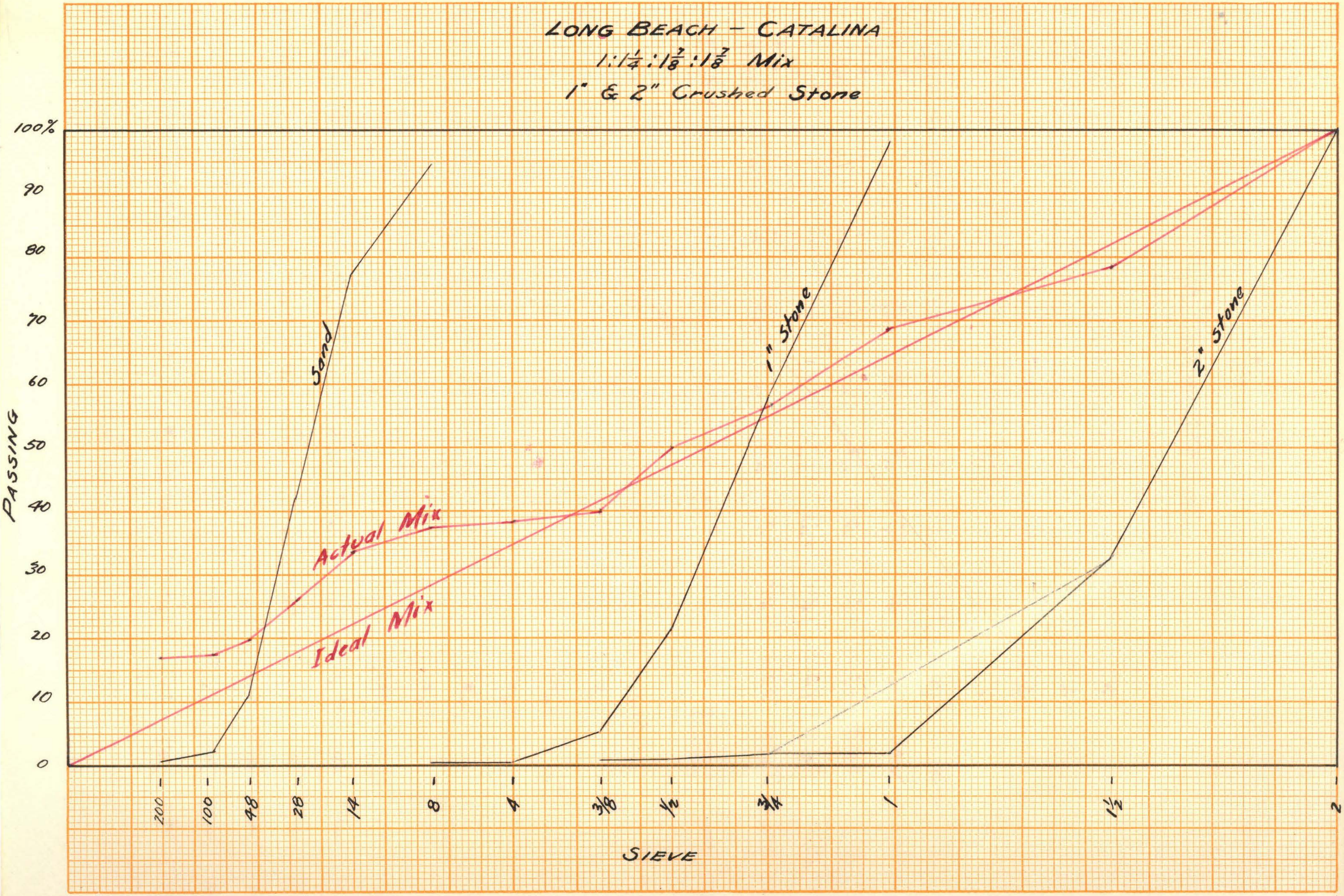
	Volume	Weight	% Weight
Cement	1	94	16.5
Sand	$1\frac{3}{4}$	171	30.1
$\frac{3}{4}$" Stone	$3\frac{1}{4}$	304	53.4
Total		569	100.0

Sieve	200	100	48	28	14	n8	4	3/8	1/2	3/4	1
Cement	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
Sand	0.1	0.6	3.2	12.6	23.2	28.4	29.8	30.1	30.1	30.1	30.1
3/4"	0	0	0	0	0	0.1	0.1	2.7	11.4	31.0	52.4
	16.6	17.1	19.7	29.1	39.7	45	46.4	49.3	58.0	77.6	99.0

	Volume	Weight	% Weight
Cement	1	94	16.5
Sand	1 1/4	122	21.5
3/4" Stone	1 7/8	176	31.0
1 1/2" Stone	1 7/8	176	31.0
		568	100.0

Sieve	200	100	48	28	14	8	4	3/8	1/2	3/4	1	$1\frac{1}{2}$	2
Cem.	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
Sand	0.1	0.5	2.3	9.0	16.6	20.3	21.2	21.5	21.5	21.5	21.5	21.5	21.5
3/4"	0	0	0	0	0	0.1	0.1	1.6	6.6	17.9	30.4	31.0	31.0
1 1/2"	0	0	0	0	0	0	0	0.3	0.3	0.6	0.6	9.4	31.0
	16.6	17.0	18.8	25.5	33.1	36.9	37.8	39.9	44.9	56.5	69.0	78.4	100.0


LONG BEACH - CATALINA
1:1¾:3¼ Mix
1" Crushed Stone
100%
90
80
70
60
50
40
30
20
10
0
PASSING
Sand
Actual Mix
Ideal Mix
1" Stone
200
100
48
28
14
8
4
3/8
1/2
3/4
1
SIEVE


LONG BEACH - CATALINA
1:1¼:1⅞:1⅞ Mix
1" & 2" Crushed Stone
100%
90
80
70
60
50
40
30
20
10
0
PASSING
Sand
1" Stone
2" Stone
Actual Mix
Ideal Mix
200
100
48
28
14
8
4
3/8
1/2
3/4
1
1½
2
SIEVE

FULLER'S CURVES

Eaton Canyon Materials

	Volume	Weight	% Weight
Cement	1	94	16.2
Sand	1½	154	26.5
¾" Stone	3½	334	57.3
Total		582	100.0

Sieve	200	100	48	28	14	8	4	3/8	1/2	3/4	1
Cement	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2
Sand	0.2	1.1	4.7	12.6	20.2	25.3	26.4	26.5	26.5	26.5	26.5
3/4"	0	0	0	0	0	1.3	1.9	6.3	20.5	41.3	57.3
	16.4	17.3	20.9	28.8	36.4	42.8	44.5	49.0	63.2	84.0	100.0

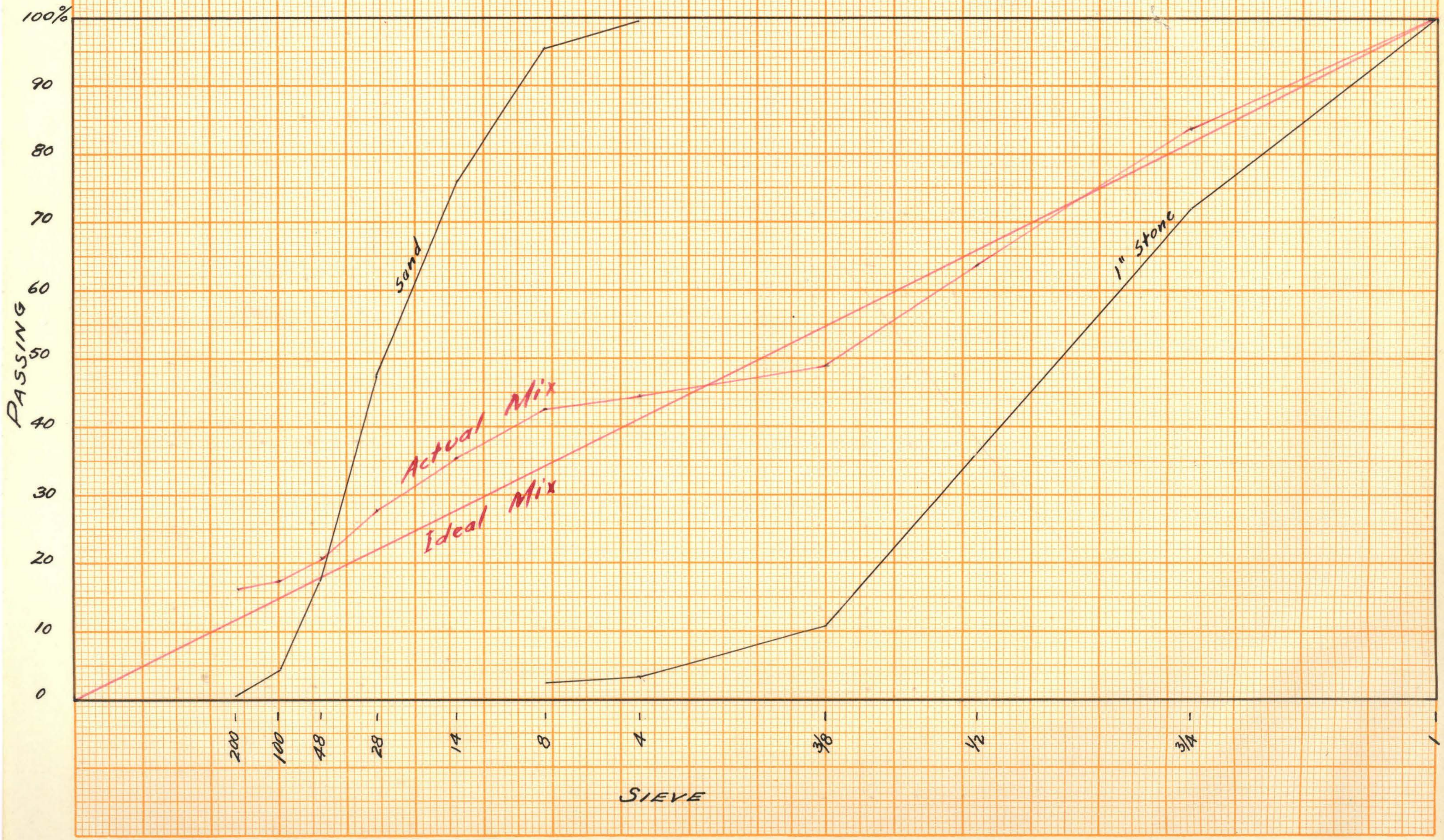
	Volume	Weight	% Weight
Cement	1	94	16.0
Sand	1 1/4	128	21.8
3/4"	1 5/8	155	26.5
1 1/2"	2 1/8	209	35.7
		586	100.0

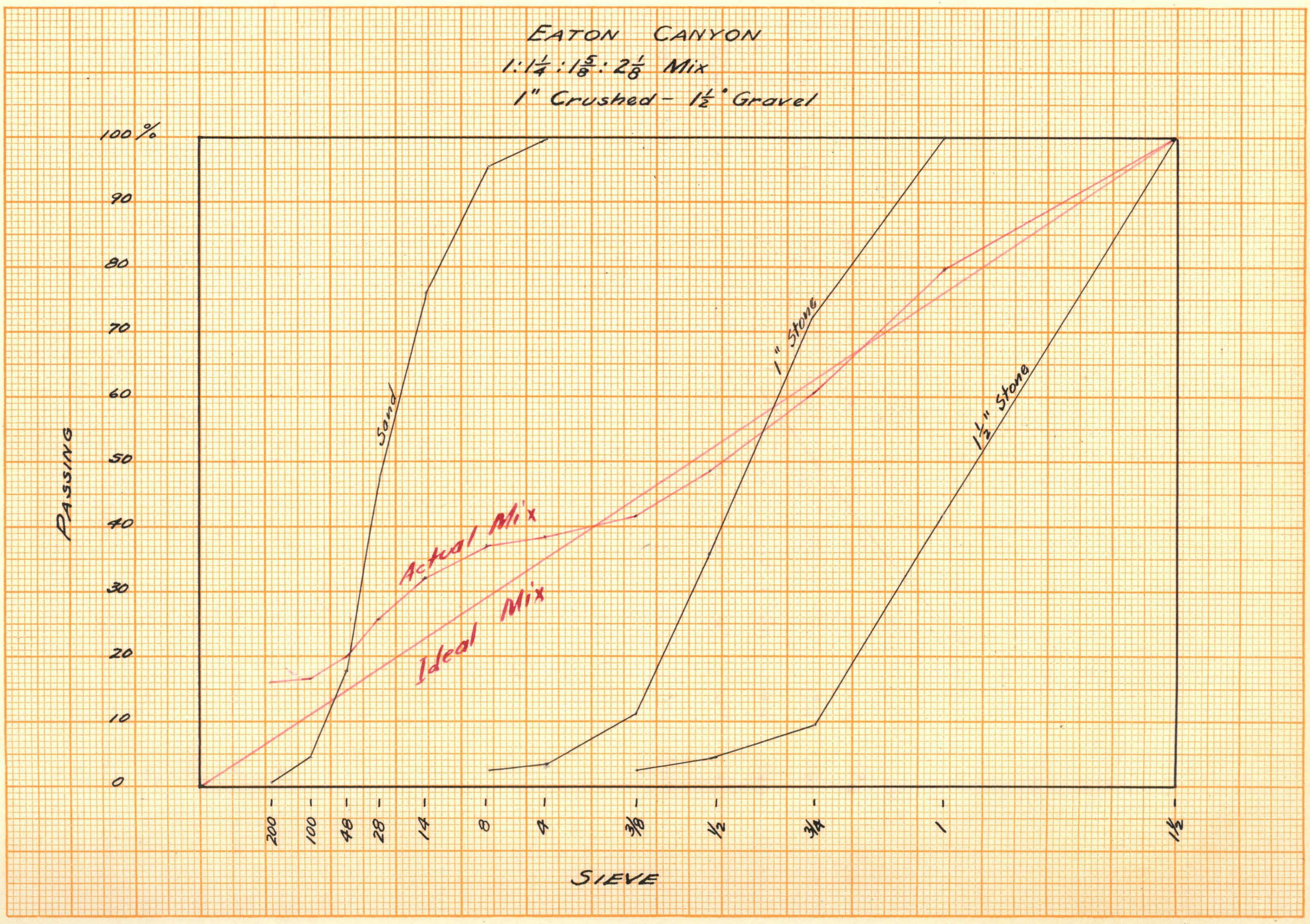
Sieve	200	100	48	28	14	8	4	3/8	1/2	3/4	1	1½
Cem.	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
sand	0.2	0.9	3.8	10.2	16.6	20.8	21.7	21.8	21.8	21.8	21.8	21.8
3/4"	0	0	0	0	0	0.6	0.9	2.9	9.4	19.2	26.5	26.5
1 1/2"	0	0	0	0	0	0	0	0.7	1.5	3.2	15.0	35.7
	16.2	16.9	19.8	26.2	32.6	37.4	38.6	41.4	48.7	60.2	79.3	100.0

EATON CANYON

$1:1\frac{1}{2}:3\frac{1}{2}$ Mix

1" Crushed Stone




EATON CANYON
1:1¼:1⅝:2⅛ Mix
1" Crushed - 1½" Gravel
100 %
90
80
70
60
50
40
30
20
10
0
PASSING
Sand
1" Stone
1½" Stone
Actual Mix
Ideal Mix
200
100
48
28
14
8
4
3/8
1/2
3/4
1
1½
SIEVE

FULLER'S CURVES

San Gabriel Materials

	Volume	Weight	% Weight
Cement	1	94	15.1
Sand	$2\frac{1}{4}$	238	38.3
3/4" Stone	$2\frac{3}{4}$	290	48.6
Total		622	100.0

Sieve	200	100	48	28	14	8	4	3/8	1/2	3/4	1
Cement	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Sand	0.1 0	0.7	2.8	13.3	23.4	30.0	36.8	38.3	38.3	38.3	38.3
3/4"	0	0	0	0	0	1.3	2.7	14.4	33.9	43.8	48.6
	15.2	15.8	17.9	28.4	38.5	46.4	54.6	67.8	87.3	97.2	100.0

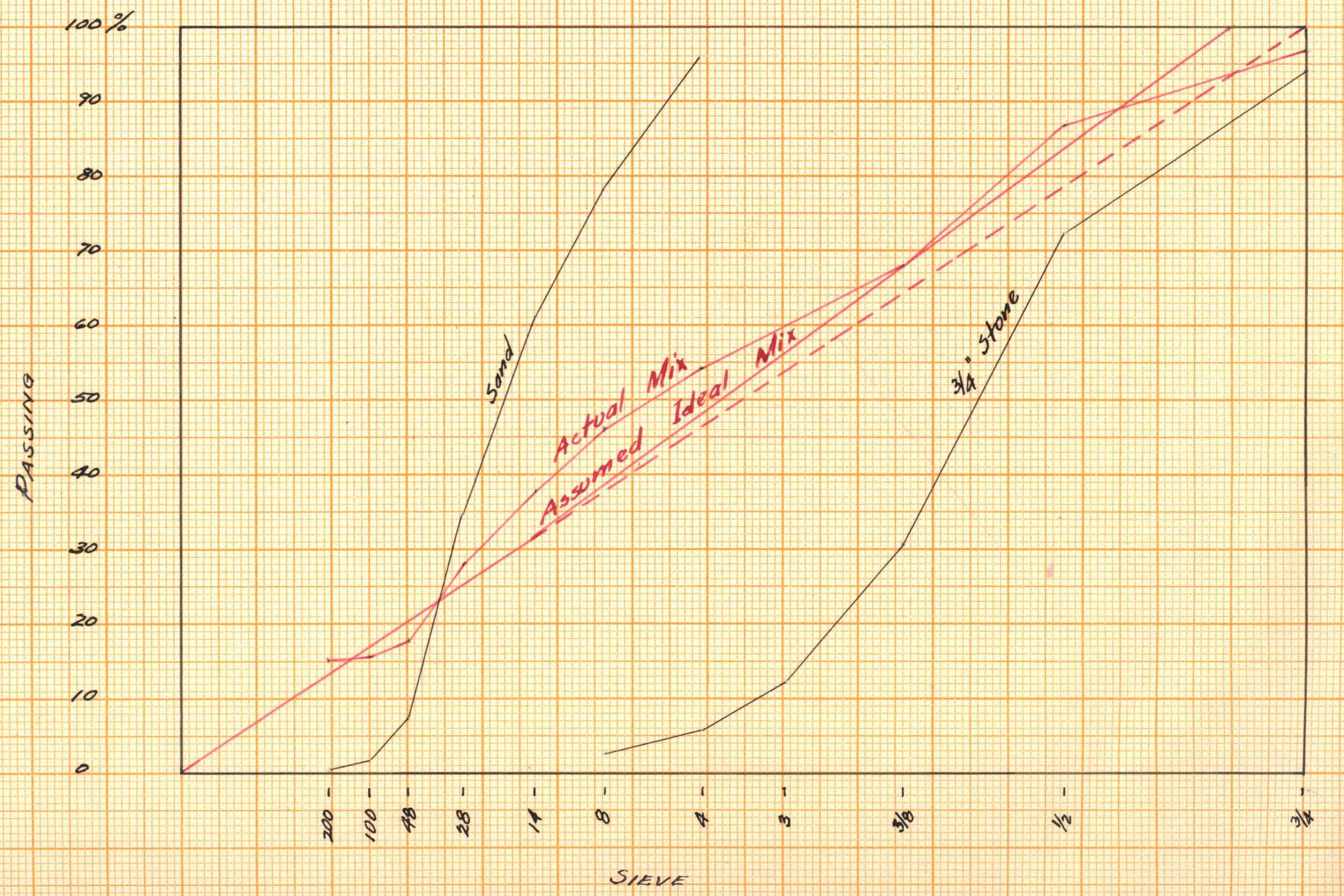
	Volume	Weight	% Weight
Cement	1	94	15.0
Sand	1 1/2	162	25.8
3/4" Stone	1 5/8	171	27.2
1 1/2" Stone	1 7/8	201	32.0
		628	100.0

Sieve	200	100	48	28	14	8	4	3/8	1/2	3/4	1	$1\frac{1}{2}$
Cem.	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Sand	0.1	0.4	1.9	8.9	15.7	20.2	24.7	25.8	25.8	25.8	25.8	25.8
3/4"	0	0	0	0	0	0.7	1.6	8.4	19.7	25.6	27.2	27.2
1 1/2"	0	0	0	0	0	0	0	1.2	2.0	4.2	16.4	32.0
	15.1	15.4	16.9	23.9	30.7	35.9	41.3	50.4	62.5	70.6	84.4	100.0

SAN GABRIEL

1:2¼ : 3¾ Mix

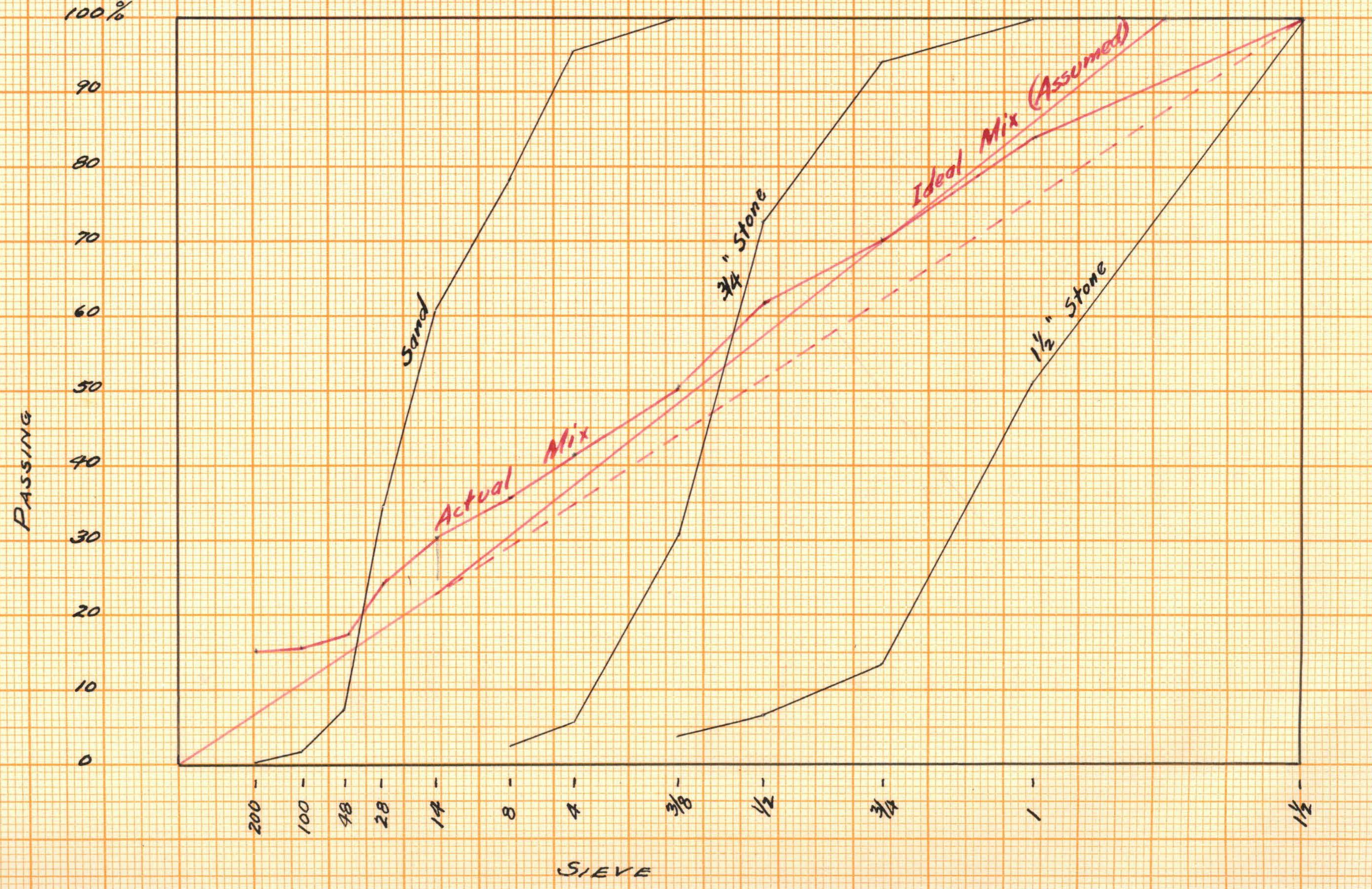
¾" Crushed Stone



SAN GABRIEL

$1:1\frac{1}{2}:1\frac{5}{8}:1\frac{7}{8}$ Mix

$\frac{3}{4}$" Crushed - $1\frac{1}{2}$" Gravel



RESULTS OF 28 DAY COMPRESSION TESTS

FOR MIXES DETERMINED BY FULLER'S CURVES.

3/4" stone Specimens.

	Eaton Canyon	San Fernando	San Gariel	Catalina
1	36,000	57,600	64,900	43,800
2	44,300	46,000	67,300	47,900
3	39,700	63,000	74,700	50,400
Arith. Aver.	40,000	55,500	69,000	47,400
Median	39,700	57,600	67,300	47,900
Aver. Stress	15,400	21,800	25,900	18,400

3/4" and 1-1/2" Stone Specimens.

	Eaton Canyon	San Fernando	San Gabriel	Catalina
1	35,500	40,800	43,700	43,800
2	41,600	48,100	37,900	47,900
3	37,600	45,200	37,100	50,400
Arith. Aver.	38,200	44,700	39,600	47,400
Median	37,600	45,200	37,900	47,900
Aver. Stress.	14,600	17,300	14,900	18,400

TESTED SPECIMENS

PREPARED ACCORDING TO FULLER'S CURVES

TABLE OF RESULTS

Notation: Catalina ....Cat.

Long Beach.........L.B.

San Gabriel.......S.G.

San Fernando......S.F.

Eaton Canyon .....E.C.

Note: The water-cement ratio of all concrete specimens was 0.84 by volume.

Units used arê pounds and inches.

	1	2	3	4
Unit Weights of Sands	S.F. 112.8	S.G. 107.9	E.C. 102.4	L.B. 97.6
Fineness Modulii of Sands	S.F. 3.27	S.G. 3.22	L.B. 2.75	E.C. 2.59
Unit Strengths of Cement-Sand Specimens	S.G. 5560	E.C. 5380	S.F. 4980	L.B. 4880
Unit Weights of 3/4" Stones	S.G. 105.5	S.F. 102.9	E.C. 95.3	Cat. 93.6
Unit Weights of 1-1/2" Stones	S.G. 107.3	E.C. 98.1	S.F. 96.0	Cat. 93.6
Specific Gravities of Stones	S.F. 2.71	Cat. 2.67	S.G. 2.61	E.C. 2.605
Per Cent Voids in 3/4" Stones	S.G. 35.2	S.F. 39.1	E.C. 41.4	Cat. 43.85
Resistance to Weathering	S.G.	Cat.	S.F.	E.C.
Geological Classification of Stones	Cat.	S.G.	S.F.	E.C.
Physical Strengths of Stones	Cat. 1830	S.F. 1710	S.G. 1400	E.C. 900

Unit Strength of Concrete Specimens

		1	2	3	4
Unit Strength of Concrete Specimens					
3/4" Stones	1.0;0.5;1.03;3.0	Cat. 26,400	S.F. 24,500	S.G. 23,000	E.C. 22,600
	Fuller's Curves	S.G. 25,900	S.F. 21,800	Cat. 18,400	E.C. 15,400
Both Stones (3/4",1-1/2")	1.0;0.5;1.03;1.0;2.0 ..	S.F. 20,500	E.C. 19,400	Cat. 15,000	S.G. Not Rec.
	Fuller's Curves	Cat. 18,400	S.F. 17,300	S.G. 14,900	E.C. 14,600
Flow of Concrete for 3/4" Stones					
	Fixed Ratio	S.F. 235	S.G. 230	E.C. 210	Cat. 173
	Fuller's Curves	S.G. 225	S.F. 220	Cat. 210	E.C. 200
Slump of Concrete for 3/4" Stones					
	Fixed Ratio	S.G. 8½	S.F. 7½	E.C. 5¼	Cat. 3½
	Fuller's Curves	S.G. 7½	S.F. 5½	Cat. 5¼	E.C. 4
Tested Specimens with Least Broken Stones..		S.G.	S.F.	Cat.	E.C.
Tested Specimens with Least Loose but Unbroken Stones		E.C.	Cat.	S.F.	S.G.

PRELIMINARY DISSCUSION.

The results given in this report should not be accepted too fully for several reasons. First, the results indicate that the accuracy was not very good. For example, in determining the unit weights of the sands with 2 different sized measuring devices there was a maximum variation of 3.6%. Incidentally, this variation was consistent throughout the 4 sets of measurements. Second, and most of important of all is the fact that the materials at the bins vary greatly from time to time. The writer made a sieve analysis of the San Gabriel 3/4" stone at 3 different times and the grading varied about as much as any 3 of the different 3/4" stones listed in this report. It can easily be seen how the grading can vary, even in a given bin. Likewise, but not to such an extent, there is the probability in variation in strength and other characteristics of a material from a given source. Because of these possible variations the results of such experiments as here recorded can only be fully accepted after a series of duplicate experiments had been conducted at different periods.

Throughout this experiment an attempt was made to secure only comparative values. For this reason the author has felt justified in diverging from common practice or the A.S.T.M. standards. For example, the finess moduluses here recorded are not standard because the Tyler standard set of sievs were not available, nevertheless the results are suitable for the purpose of this report. Then there are the empirical scales used for some of the curves, the purpose being to better illustrate the results. The water-cement ratio has been too high throughout and the curing has been very poor, yet the order and magnitude of the results are satisfactory except in a few instances were concrete was prepared with 1-1/2" stone.

DISSCUSION.

The original test used for measuring the hardness of stones by crushing them individually on the testing machine is apparently a good method of measuring the hardness of stones. It would be interesting to check the results of a series of tests made on different stones by this method and by the standard rattler test. Obviously it is necessary to test 3 or more individual stones and use as the represenative value the median rather than the arithmetic average. Incidentally, it is interesting to note the almost negligible variation between the median and the arithmetic average for the breaking stresses of the concrete specimens. The median is favored over the arithmetic average because 1 freak specimen does not throw the final result off.

The primary object of this experiment was to measure the relative strengths of the different stones here presented. When the concrete specimens that were arbitrarily designed with fixed ratios were tested the stones were graded according to their number of broken surfaces and the bond to the matrix. The order in magnitude of broken stones depends upon the strength of the matrix and its adhesion to the stones and the strength of the stones. The adhesion of the matrix to the stones is dependent upon the porosity of the stones(considering here dried stones) and the roughness of the surface of the stones. The line of failure in a concrete specimen may occur through the matrix, through the stones, along the surface of the stones,or, as is most generally the case, through a combination of the above 3 possibilities

The specimens with the 1-1/2" stones gave low strenghhs because of the weakness of the matrix itself and the poor bond between the matrix and the stones. The water cement was the same as the water and cement for the specimens with the 3/4" stones. In the latter specimens, however, more water was used by the stones for absorption and the dampening of the surfaces since there was more stone surfaces than where the 1-1/2" stones were used. The matrix was weak in the specimens with the large stone because the cement was washed out.

In the mixes with the smaller stone if the break occured along the surfaces of the stones the expected order in strength for the concrete specimens would be;1, Eaton Canyon; 2, Catalina; 3, San Fernando; 4, San Gabriel; this being the order of adhesion based on roughness. With regards to the surface the rocks may be classed in the following manner: Eaton Canyon rock was subangular stream gravel mixed with angular crushed rock; Catalina was irregular crushed gravel with flat surfaces; San Fernando rock was sub-angular stream gravel; and the San Gabriel stone was sub-angular and sub-rounded stream gravel.

If the break was through the rock the order given in the above paragraph would not necessarily hold but would probably hold if the stones were of the same strength and all other factors, except the smoothness of the surfaces, were the same. From actual observation the order for magnitude of number of broken stones in the tested specimens was: 1, Eaton Canyon; 2, Catalina; 3, San Fernando; 4, San Gabriel. This is the same order as the degree of surface roughness as given above, which indicates that the number of broken stones varies directly as the surface roughness of the stones.

A brief and complete summary of the geological survey of the stones is given on page #3 of this report.

It is interesting to note that the geological classification of the stones, which was made with no knowledge of the sources of the stones at the time, and the rock hardness test that was devised by the writer as a substitute for the rattler test because of the lack of equipment, gave exactly the same results. Also, this same order was obtained from the concrete specimens that were prepared according to the fixed ratio of 1.0 : 0.50 : 1.03 : 3.00 by volume. Portland cement, San Gabriel silt, San Gabriel sand, and the 3/4" stones were used. The water-cement ratio was 0.84 by volume.

The Eaton Canyon stone proved to be the weakest in the hardness test and the poorest from a geological standpoint. It also gave the weakest concrete in both the fixed ratio mixes and the mixes determined by Fuller's curves. Its specific gravity and its resistance to weathering were also the lowest. In the broken concrete specimens the Eaton Canyon stones had more breaks than the stones of any other source. Obviously there is no question but what the Eaton Canyon stone is inferior to the others in all respects.

The Catalina stone , which was the hardest and strongest, but t the poorest graded, made the strongest concrete for the rich mix of the fixed proportional aggregates. For the practical mix as determined by Fuller's curve the Catalina stone gave concrete that was next to Eaton Canyon's in weakness. Therefore, it seems that in a rich mix a hard strong stone is more important than the grading of the stone, while in a practical field mix the grading of the stone is more important than the kind of stone.

In the weathering test, where the stones were soaked in a concentrated sodium sulphate solution and then thoroughly dried, the San Gabriel stone proved to be far superior to the others. Therefore, where the concrete was to be subject to hard weathering, such as in a furnace or piers for a wharf, the San Gabriel stone would be chosen.

The specific gravities of the 3/4" stones were so close that the per cent voids were practically a direct function of the unit weights, the relation of course being inverse.

There were no tests made on the sands for silt, loam, or organic matter. In the first place all of the sands were washed at the plants, and second, they were brought to the Institute at different periods and were allowed to remain in the open some time before actual testing was started. These sands, unlike the stones, are known to approximately the same strengths, and since it is customary to purchase sand and rock from the same plant, little attention was given to the sands.

From a close inspection of the sands they were classified in the following order for weak and cleavable grains; Long Beach sand had the least, San Gabriel and San Fernando appeared to be in about the same class, and the Eaton Canyon sand had the most number of weak and cleavable grains. It is noted that the above grading of sands follows the classification of stones from a standpoint of texture and composition. The Eaton Canyon, San Gabriel, and San Fernando sands were angular to subangular, and the Long Beach was subrounded and therefore being least desireable in this respect for concrete. The results show that the Long Beach sand made the weakest cement-sand specimens.

By comparing the unit weights of the sands and the fineness modulii of the sands it can be seen that the densities of the sands are about the same for San Fernando, San Gabriel, and Long Beach. The Eaton Canyon sand had a fair unit weight with a low fineness modulus which indicated a high density.

The cement-sand specimens were treated alike throughout the preparation, curing, and testing. The results indicated that the strength of these specimens was not directly related to the fineness modulus of the different sands. Mr. Newberry, who is in charge of the San Fernando district for Graham Bros. informed the writer that the best fineness modulus for the particular sands here tested was from 2.85 to 3.00. San Gabriel and San Fernando were above this while Eaton Canyon and Long Beach were below this range. San Gabriel, which was closest to this range, had thegreatest unit strength for its cement-sand specimens.