Properties of Mortar

Bond to Various Brick

A Thesis Submitted to the Graduate Committee of the Virginia Polytechnic Institute as a Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in

CERAMIC ENGINEERING

by

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Acknowledgment

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The authors also wish to express their appreciation to Dr. Boyd Harshbarger of the Statistics Department for suggestions and checking the statistical design and analysis of the investigation.

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I Introduction

Description of the Project

The bond between mortar and brick is one of the principal factors affecting the durability and performance of masonry structures. Architects, engineers, Government agencies and others engaged in the design or construction of masonry structures are required to specify materials (masonry unite and mortar) and construction techniques which will contribute to a complete and durable bond. Because technical data on which to base the specifications are lacking, it is exceedingly difficult for engineers, designers, and others to write specifications which will, with certainty, produce the desired results.

The purpose of this project is to establish and codify data essential to the efficient bonding of brick and mortar in building construction.

Program

(1) Brick from all kinds of raw material from various parts of the country, having wide variations of surface textures and suction rates, were obtained. Under closely controlled atmospheric conditions, these were made into masonry tension-bond specimens for testing the bond between the mortar and the brick.

Tests were made to:

a. Determine physical properties of selected mortar materials, sand-lime mortar and sand-lime-cement mortar.

b. Establish effect of variations of mortar flow on bond.

c. Establish effect of mortar retentivity on bond.

d. Establish effect on mortar bond of high-suction rate brick that have been adjusted to low suction rates as compared to similar brick having naturally low suction rates.

e. Establish effect on mortar bond of brick with wire-cut faces as compared to brick with die-skin faces.

All of this was done with appropriate variations of mortar suction rates, and methods of fabricating the tested specimens.

(2) The program included as nearly as possible all types of brick texture, types of manufacture, etc., so that when completed, there was sufficient data to enable recommendations and specifications for brick masonry construction as related to the bond of the mortar and representative brick types to be made.

Justification

Completion of the project with publication and distribution of results will give the building industry a basis for specifications of materials and construction technique which should improve general acceptability of masonry structures to the public.

The project will advance the technology of masonry construction, contrubute to the construction of better masonry and effect a reduction in weak or leaky masonry walls which are all too prevalent in many parts of the country. Many buildings constructed in the past have been a public liability. This could have been prevented if the mortar bond had been studied to the extent that better engineering specifications and recommendations could have been supplied designers and builders.

The successful completion of this project will contribute to the brick and tile industry (which includes 800 or more relatively small business) indirectly in that an improvement of the finished product, the brick home or other masonry sturctures, will tend to create an increasing demand for the products of the industry.

This project will extend the research work that has been conducted in the Department of Ceramic Engineering of the Virginia Polytechnic Institute, which has already resulted in publication of "Mortar Bond Characteristics of Virginia Brick", Engineering Experiment Station Bulletin No. 54.

The statistical designs of the experiment has had the variables of each proposal listed and checked by Dr. Boyd Harshbarger of the Statistical Department. The design has eliminated such variables as humidity, temperature, etc., and in this way variables are studied individually by statistical analysis.

II Review of Literature

The research previously accomplished in "Properties of Mortar Bond to Various Brick" has usually been in a very specialized division of this broad field. The conclusions have usually been quite general. This review contains a brief background of some of the author's experiments and the conclusions each has drawn relative to bond properties.

Pearson,[1] studied the measurement of bond between bricks and mortars and stated, "Experience with masonry bond tests shows that most of them give discouragingly wild results, and good reproducibility is attained, if at all, by artificial procedures which neither imitate the brick layer's manipulation nor produce results anything like those obtained in practical masonry construction." In his works he chose the following variables: Glen Grey common brick from Reading, Pennsylvania (absorption 35-60 gbm) were used in all tests. The absorption range for any given series was held to 10 gbm or less. The couplets were made by a machine using a 20 lb. weight or by tapping the top brick to promote the bond. Usually four mortars were tested at a time. The flow of the mortars was tested and held within reasonable limits.

Results of tests and Conclusions:

(1) The tests show somewhat lower bond strength for brick of higher absorption rate.

(2) Higher bond strength was obtained from heavier tapping of the

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(1) J.C.Pearson, "Measurement of Bond Between Bricks and Mortar", Proceedings of the American Society for Testing Materials, Vol. 43, p. 857 (1943)

top brick of the couplet.

(3) The effect of tapping the top brick is to increase the bond strength from 50 to 100 percent, which suggests that the contact between mortar and brick is much improved by impact or the vibration resulting from impact.

(4) The ability of masonry mortars to bond firmly to building units is important, because lateral strength and water-tightness of walls are largely dependent on this property.

(5) Magnitude of deviations in bond test is evidence of the presence of uncontrolled variables of considerable importance. As an example of the presence of unknown variables, it has been frequently noted that brick have the same absorption in the one minute test do not always produce uniform stiffening rate of a given mortar.

(6) The consistency of the mortar must be closely controlled. For example, three and one-fourth to three inch slump gave average tensile strength of 68 p.s.i. The same mortar batch, but slump of two and three-fourths to two and three-eights inch gave average tensile strength of 44 p.s.i.

(7) Greater plasticity under equal conditions usually gives greater strength.

Anderegg[2] has studied the absorption characteristics of several types of brick taken from different parts of the kiln. The effects of

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(2) F.O. Anderegg, "The Effect of Brick Absorption Characteristics Upon Mortar Properties", Proceedings of the American Society for Testing Materials Vol. 42, p. 821 (1942)

different mortars, varying brick absorption, surface texture, and wetting the bricks were studied. The ratio of molded cube strength to mortar strength in the wall is studied.

Results of Tests and Conclusions:

(1) The very rapid initial rise of water in the dry-press bricks indicates the presence of relatively large pores. On the other hand, the very slow absorption of the hard-burned bricks might be interperted as due to the pores being rather fine. However, Stull and Johnson[3] obtained indications that such pores were few in number and relatively large. (Here is a nearly virgin field needing experimental study.)

(2) When contact between brick and mortar is complete the rough surface will give a mechanical keying which is desirable. Such contact is most easily obtained with bricks of lower absorption rates.

(3) The type brick having the highest initial rate of absorption removes a very small amount of moisture from these lime mortars.

(4) Before the mortar set up, a great deal more total moisture had to be abstracted by the softest burned brick in a given series than by the hardest burned member.

(5) For brick taken from the same kiln it was noted that the product of the one minute absorption in grams and the setting time in minutes, was a constant.

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(3) Ray T. Stull and Paul V. Johnson, "Some Properties of the Pore System in Bricks and Their Relation to Frost Action", Journal of Research, National Bureau of Standards, Vol. 25, p. 711 (1940)

(6) The higher the initial absorption rate of the brick the greater was the apparent tendency to form a highly congealed layer at the surface of the mortar. Moisture is apparently removed so rapidly from the surface of the mortar by some of the bricks of high initial suction capacity that a condensed layer is formed having a permeability varying inversly with the initial suction.

(7) The bond strengths increase with the brick absorption to a maximum, beyond which they decrease.

(8) As water is added to highly absorptive brick, the bond strength increases to a maximum and then decreases. Such highly absorbent bricks should not be selected where bond strength and water-tight walls are of importance.

(9) Bricks of intermediate absorption are easiest to lay. Mortars in contact with them have setting times which are convenient for the mason. The bond strengths often run double those obtained with bricks having very high or very low absorption, while the joint mortar strength is close to the maximum. The durability of the joint is also greatest with brick of medium absorption.

(10) Bond and joint-mortar compressive strengths are given for mortars ranging from straight lime to straight Portland cement. Surprisingly high results were obtained at six months and one year from 1:1:6 mortars. The problem of securing proper balance between rigidity and durability needs more experimental study.

Palmer and Parsons[4] have studied the water retaining capacity, transverse and compressive strengths, absorption, volume changes, and moduli of elasticity of 50 mortars and the absorption rate, moisture expansion, and transverse and compressive strength of 6 makes of brick. Fifteen of the 50 mortars were used with the 6 makes of bricks in tests of brick mortar assemblies.

Results of Tests and Conclusions:

(1) Substitution of slacked lime putty for Portland cements produced considerable increase in water retaining capacity.

(2) The extent of bond was affected by the properties of both mortars and bricks, but chiefly by the water retaining capacities of the mortars and the absorption rates of the brick.

(3) With bricks of high rates of absorption set dry, the extent, and in most cases the strength of bond was best with mortars of high water retaining capacity.

(4) Although extent of bond may be good, the strength of bond obtained with impervious brick having smooth, glassy, bonding surfaces was generally lower than that obtained with other brick.

(5) Maximum bond strength was obtained in case of all mortars with brick having a ratio of absorption of approximately 20 gbm based on 30 square inches and on one-eight inch submersion in water.

(6) Bond durability, considerinal all mortars, is best maintained by keeping absorption below 40 gbm.

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(4) L. A. Palmer and D. E. Parsons, "A Study of the Properties of Mortars and Bricks and the Relation to Bond", Bureau of Standards, Journal of Research, Vol. 12, p. 609, (1934)

(7) The maximum bond strength at three months with the 15 different mortars increased with the compressive strength of the mortars provided the bond extent was good.

(8) With bricks of low rates of absorption and porous bricks made practically non-absorptive by wetting, the highest bond strength was obtained with mortars of highest strength, when the extent of bond was good.

(9) Mortars of widely different compositions may be similar proportions.

Palmer[5] outlines some of the properties of bricks and mortars necessary for the adjustment of mortar to a given brick.

Mortars deficient in water retaining capacity quickly compact and stiffen when on a porous base or between two dry, porous bricks. The unidirectional compacting occurs in a few seconds and causes depressions in the mortar joint through which water readily enters. The rapid stiffening makes it impossible to get intimate contact between the dry, porous unit and the mortar. Mortars of low retaining capacity undergo much more congestion than mortars of high water retaining capacity when they are spread on impervious units or units that have been saturated to reduce their suction. When using mortars deficient in water retaining capacity, one is somewhat at an imparse. If the unit is too porous, the mortar quickly stiffens and compacts. If the unit has a too low rate of absorption the mortar "bleeds" or segregates, forming films and pockets of water on the mortar bed. The extent of bond is poor in either case.

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(5) L.A.Palmer, "Essential Properties of Mortars for Masonry Units", Proceedings of the Brick and Clay Record, Vol. 84-85, p. 161, (1934)

As the relative amount of lime is increased, the water retaining capacity of the mortar is increased. Not only is the extent of bond improved by lime, the intensity of adhesion is also increased.

Lime, especially slacked lime putty, improves both the extent of bond and its intensity.

There are three distinct types of volume changes in mortar. They are all due to different causes and occur at different periods of time in the life of the mortar, these are:

(1) Compacting in a porous base.

(2) Shrinkage occurring during early hardening.

(3) Volume changes expansion or wetting and shrinkage on drying that occurs subsequently to hardening.

Results and Conclusions

(1) Workability of the mortar (water containing capacity being the controlling factor).

(2) Adhesiveness of bonding power, a high ratio of tensile bond strength to tensile mortar strength.

(3) Low volume change subsequents to hardening.

(4) Maximum amount of strength obtainable without any material sacrafice of plasticity, bonding power and low volume changes after hardening.

(5) Extensibility - the property of under going a relatively high degree of stretching without repture. Most mortars range between .02 and .03 percent.

(6) Freedom from soluble matter that contributes to efferescence, straining, etc.

(7) Fair degree of porosity.

The study of Burridge and Struct-E[6], may be divided into two parts, (1) Building mortars used to join bricks together to form brick work, and (2) Rendering mortars used as external finishes to brick work. Some of their results of tests and conclusions are:

(1) Immersion in cold, then hot water gives useful criterial of the probable resistance of the material to frost action.

(2) Given a batch of bricks, cementitious and finishing materials, each highly satisfactory in themselves, have we any method of predetermining how the suction shall be adjusted so as to "marry" them without danger of subsequent "divorce".

(3) Slacked lime has little or no initial cementitious power and the ultimate bond between brick and mortar depends upon the gradual development of an intimate interlock of the two materials.

Voss[7] has done extensive laboratory research and field work in this field; by the use of thin sections and microscopic studies he has drawn some definite conclusions as to the factors which have produced the existing conditions. Some of these are:

(1) Extent and permanence of bond should be given primary consideration.

(2) Plasticity and ability to gain intimacy of contact are the essentials of a good masonry mortar.

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(6) L.W. Burridge and A. I. Struct-E, "The Role of Absorption in the Application of Mortar Renderings and Plasters in Brick Work", The British Ceramic Society Transactions and Abstracts, Vol. 39, p. 71 (1939-40)

(3) The mortar which can be worked and placed with the least amount of effort on the part of the mason and which has the ability to withstand repeated stresses without rupture of bond is the mortar which will produce best results. High lime mortars usually fill these qualifications. When a brick is laid in a high lime mortar, the suction of the brick tends to densify and fill voids in the mortar at the interfacial layer or brick line. With a highly absorptive brick the high-lime mortars are harmed the least by the large water loss, and the high-cement mortar suffers because of loss of water needed for proper hydration of the cement. With a large loss of water, due to high suction of brick, the mortar attains a rigidity far beyond that caused by the state of hydration or carbonation and the beneficial act of consolidation can not take place to as great an extent.

(4) Several specimens of high-cement mortars, from widely separated districts, exhibit the same traits; namely, high porosity and tentacular contact at the brick line and rupture of the bond especially toward the weather exposed face of the point where volume changes are the greatest.

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(7) W. C. Voss, "Petrographic Study of the Bond Between Bricks and Mortars", British Ceramic Society Transactions and Abstracts, Vol. 39, p. 85 (1939-40)

III Abstract

The project was broken down into the following Proposals:

Proposal I - A comparison of the previous method of making brick couplets with a modified Pearson Method.

Proposal II - A comparison of mortar bonds using two mortar flows, three mortars, and two methods of forming couplets.

Proposal III - A comparison of mortar bond to brick with emphasis in texture of surface of brick in contact with mortar which joins them.

Proposal IV - A comparison of the mortar bond of a make of brick of original high suction rate with a representative of the same make of brick and the same suction rate but which has been adjusted to successively lower suction rates.

Proposal V - The effects of adjustments of suction rate on mortar bond properties.

Proposal VI - A comparison of the mortar bond of a low suction rate brick with a medium suction rate brick using two surface textures.

Proposal VII - A comparison of the mortar bond on one type brick using cored and solid brick. Two different suction rates were used.

IV The Investigation

Purpose and Scope of Investigation

The broad program of masonry research, initiated by the Structural Clay Products Research Board of the Structural Clay Products Institute was intended primarily to determine the most effective means of using masonry materials in reinforced brick masonry construction. This program is now being supported by the Department of Commerce.

Part I of this investigation contains the results of the tests performed with the flow tables at the Virginia Polytechnic Institute on the standard mortar assigned for this purpose.

Part II of this investigation contains the description of the raw materials and results obtained from physical tests on these materials. The raw materials will be used in a study of the effect of brick texture and suction rate on tension bond strength.

PART I

Flow Table Calibration Tests

Purpose and Scope:

The tests described were conducted with the flow table in the masonry laboratory of the Ceramic Engineering Department of the Virginia Polytechnic Institute. All tests were made on a standard mortar compounded with standard materials.

Materials Used:

(a) Ottawa Sand

The sand used in preparing the mortar for the comparison tests consisted of the mixture from 2/3 by weight of graded Ottawa sand purchased in conformity with A.S.T.M. Serial Designation CI09-37T, with 1/3 by weight of standard Ottawa sand passing a 20 mesh and retained on a 30 mesh U. S. Standard testing sieve.

(b) Lime

Mason's pressure hydrated lime, obtained from the U. S. Gypsum Company, Genoa, Ohio, was used with the above Ottawa sand mixture in the preparation of all mortar batches for the comparison taste.

Standard Mortar

The standard mortar used in all comparison tests consisted of:
(a) one part by weight of Mason's pressure hydrated lime; and (b) seven parts by weights of the Ottawa sand mixture.

Procedure

Each batch contained 4,000 grams of dry mortar materials. Water content was varied to obtain at least four different flows. All flow determinations were made at relative humidities between the values of 50 and 60 percent. The temperature of the room was kept within the limits of 70 plus or minus 2 degrees Fahrenheit. At least five determinations were made for each separate water content.

The dry mortar materials were weighed separately to the nearest gram. Less than the measured quantity of water was poured into a non-absorbent bowl (1½ gal. capacity) which had previously been wiped with a damp cloth. The pressure hydrated lime was thoroughly worked into the water with the fingers of one hand, protected by a rubber glove, until all of the lime had been wetted to produce a homogeneous slurry. The remainder of the water was added and worked into the slurry. One-third the quantity of sand was added and stirring was continued for 30 seconds.

The remainder of the sand was added and the mortar was mixed for 75 seconds by vigorous and continuous stirring, squeezing, and kneading with both hands. The mortar was allowed to stand for 60 seconds covered with a damp cloth and then mixed for another 60 seconds, after which its flow was determined.

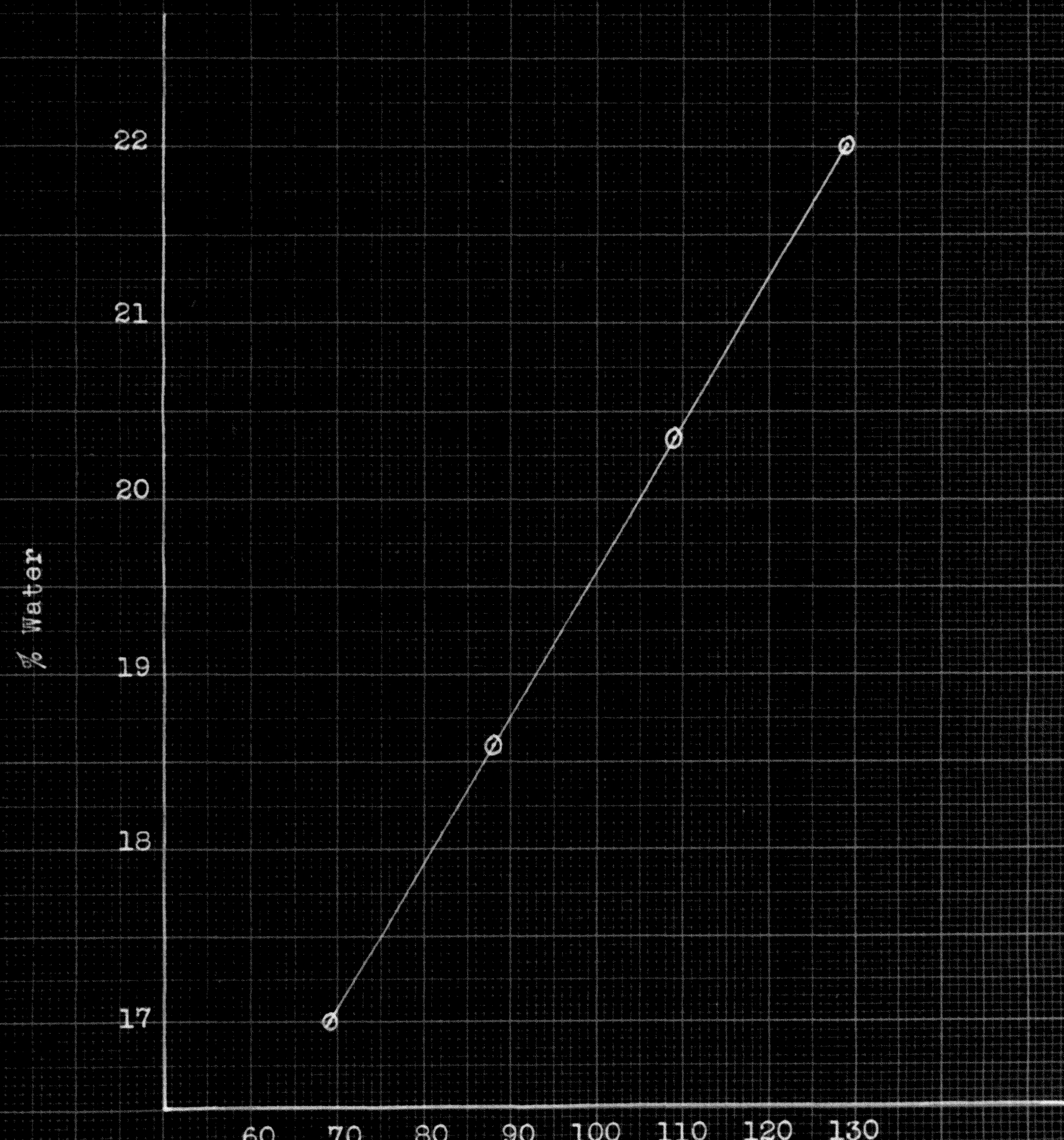
For the determination of flow, the mortar was puddled in the conical frustrum of the brass flow mold in two layers without ramming. (See Fig. 14) Excess mortar was removed from the top of the frustrum with one cut of spatula and the mold was removed. After 25 one-half inch drops of the flow table in 15 seconds, the diameter of the mortar pile was measured on four or eight radical lines, depending upon whether the pile was circular or elliptical in shape. The percentage of increase in the diameter of the pile over the original diameter of the base of the conical frustrum was the measure of the mortar flow.

Results of Flow Tests:

Table I includes the average results of flow determinations made on the standard mortar at four different water contents. Graph I shows the results.

Analysis of the variance of these tests, and the variance of the flow tests performed on a plastic lime putty-cement-sand mortar used in connection with Part II of the investigation, indicate that the standard flow table is well suited as a means of controlling the consistency of the mortar batches.

GRAPH I



Flow Curve of Standard Pressure Hydrated Lime
Ottawa Sand Mortar

TABLE I

Results of Flow Table Calibration, V.P.I. Laboratory, Standard Pressure Hydrated Lime - Ottawa Sand Mortar.

(1) Number of Tests	(2) % Water	(3) Average Flow %	(4) Relative Humidity	(5) Room Temperature
5	17.0	69.0	58%	73°F.
5	18.6	87.6	57%	73°F.
5	20.33	109.0	56%	72°F.
5	22.00	129.0	56%	72°F.

PART II

Physical Properties and Description of Raw Materials

Purpose and Scope

The tests described were performed with the object of determining physical properties of the raw materials to be used in determining the most effective means of using masonry materials in reinforced brick masonry construction.

Materials Used

(a) Mason's Sand for Mortar Bond Specimen

Fairly clean, New River sand, representative of the type used by local brick masons, was used in the preparation of all tension-bond specimen. Sieve analyses of sand after adjustments were made are as indicated on next page:

NEW RIVER SAND ANALYSES

Sieve	1st Can % Retained	2nd Can % Retained	3rd Can % Retained	4th Can % Retained
16	4.9	4.2	4.7	4.7
30	19.7	19.6	19.5	22.5
50	52.4	51.6	51.2	50.5
100	19.5	20.7	21.0	20.7
Through 100	3.6	3.9	3.6	1.7

A washing test was performed on a representative sample of the adjusted sand in accordance with A.S.T.M. Designation C117. The [1] percent of material passing 200 mesh was well within the maximum limit of 5 percent.

A test for coal and lignite was performed on a representative sample of the adjusted sand in accordance with A.S.T.M. Designation C123. The 0.08 percent of coal and lignite found was well within the maximum permissible limit of 0.25 percent.

A test for clay lumps was performed on a representative sample of the adjusted sand in accordance with A.S.T.M. Designation C142. The negligible amount of clay lumps was far less than the permissible limit of 1 percent.

(b) Lime

Washington powdered quick lime, a very active material, obtained from the Standard Lime and Stone Company, Bakerton, West Virginia, was used in the preparation of all mortars for the tension bond strength tests.

Lime putty was made up from the quick-lime according to the recommendations and instructions of the manufacturer. The lime putty was kept covered to minimize evaporation and stored at least two weeks before used. The percentage of hydrated lime solids in the putty was determined each time a set of test samples was made and necessary corrections were made to keep the lime solids content constant throughout the program. A table was made for checking lime hydrate content of lime putty.

(c) Cement

Universal Portland cement, obtained from the Universal Atlas Cement Company, was used in the preparation of all mortars for the tension-bond strength tests.

(d) Brick

Bricks classified according to method of manufacture:

1. Stiff-mud, side-cut shale:

   Roanoke Webster Brick Company, Webster, Virginia

   Belden Red, Belden Brick Company, Canton, Ohio

2. Stiff-mud, sidecut clay:

   Belden Buff, Belden Brick Company, Canton, Ohio

   Locher and Company, Glasgow, Virginia

3. Soft-mud clay:

   Old Virginia Brick Company, Salem, Virginia

   Stiles Brick Company, Connecticut

Physical tests for the following properties of each make of brick were made.

1. Compressive strength
2. Transverse strength
3. Absorption after 24 hours cold water immersion
4. Absorption after five hours boiling water immersion
5. Saturation coefficients; i.e., the ratio of items 3 to item 4. Results shown in Table II, next page.

TABLE II

RESULTS OF PHYSICAL TESTS ON BRICK TO BE USED

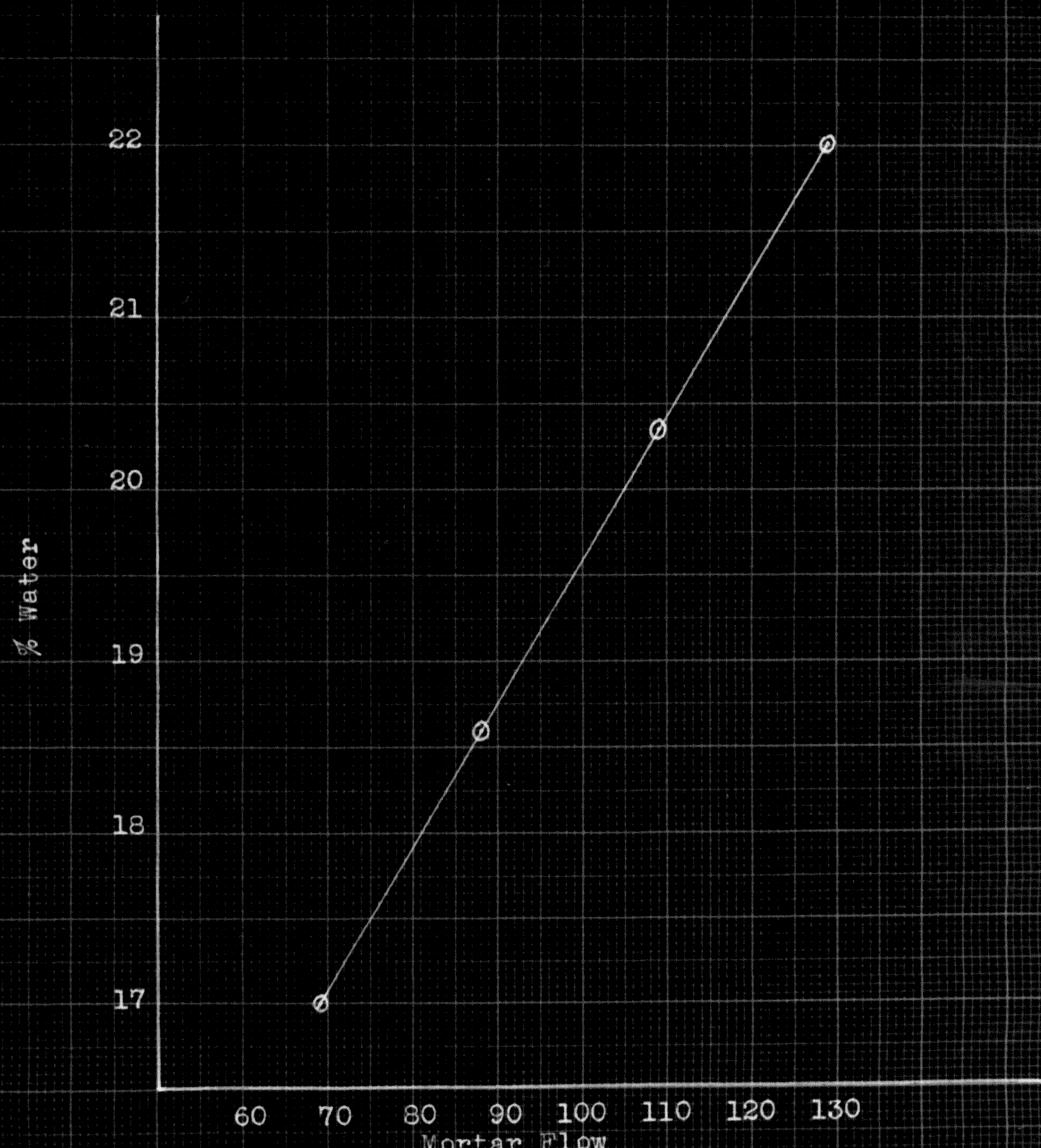
MAKE OF BRICK	DOWN FACE	COMPRESSIVE STRENGTH LBS. PER SQ. IN.			TRANSVERSE STRENGTH LBS. PER SQ. IN.		
STIFF-MUD SHALES		Max.	Min.	Avg.	Max.	Min.	Avg.
Roanoke Webster	Oil Die	7,000	4,600	6,200	1738	1352	1506
	Normal Wire Cut	7,300	5,600	6,160	1893	1547	1687
	Split Wire Cut	6,600	3,700	4,940	1738	1361	1545
Belden Red	Oil Die	24,800	15,800	20,720	3290	2239	2799
	Normal Wire Cut	25,100	18,000	20,580	2612	1687	2223
	Split Wire Cut	23,600	17,400	21,180	2879	1684	2231
STIFF-MUD CLAY		Max.	Min.	Avg.	Max.	Min.	Avg.
Locher	Oil Die	15,100	11,300	12,940	2001	1606	1793
	Normal Wire Cut	11,600	8,500	9,800	2133	1394	~~1963~~
	Split Wire Cut	15,500	10,600	12,340	1771	1325	1574
Belden Buff	Oil Die	16,100	9,500	12,420	2777	2121	2367
	Normal Wire Cut	18,200	12,200	16,100	2991	2393	2676
	Split Wire Cut	12,860	8,400	10,680	2591	1614	2103
STIFF-MUD CLAY		Max.	Min.	Avg.	Max.	Min.	Avg.
Old Virginia	Struck	4270	3630	3962	1404	1000	1212
	Mold	6009	3381	5268	963	628	783
Stiles	Struck	6090	3250	4428	1769	1032	1317
	Mold	9740	6990	8652	1544	312	1160

TABLE II (continued)

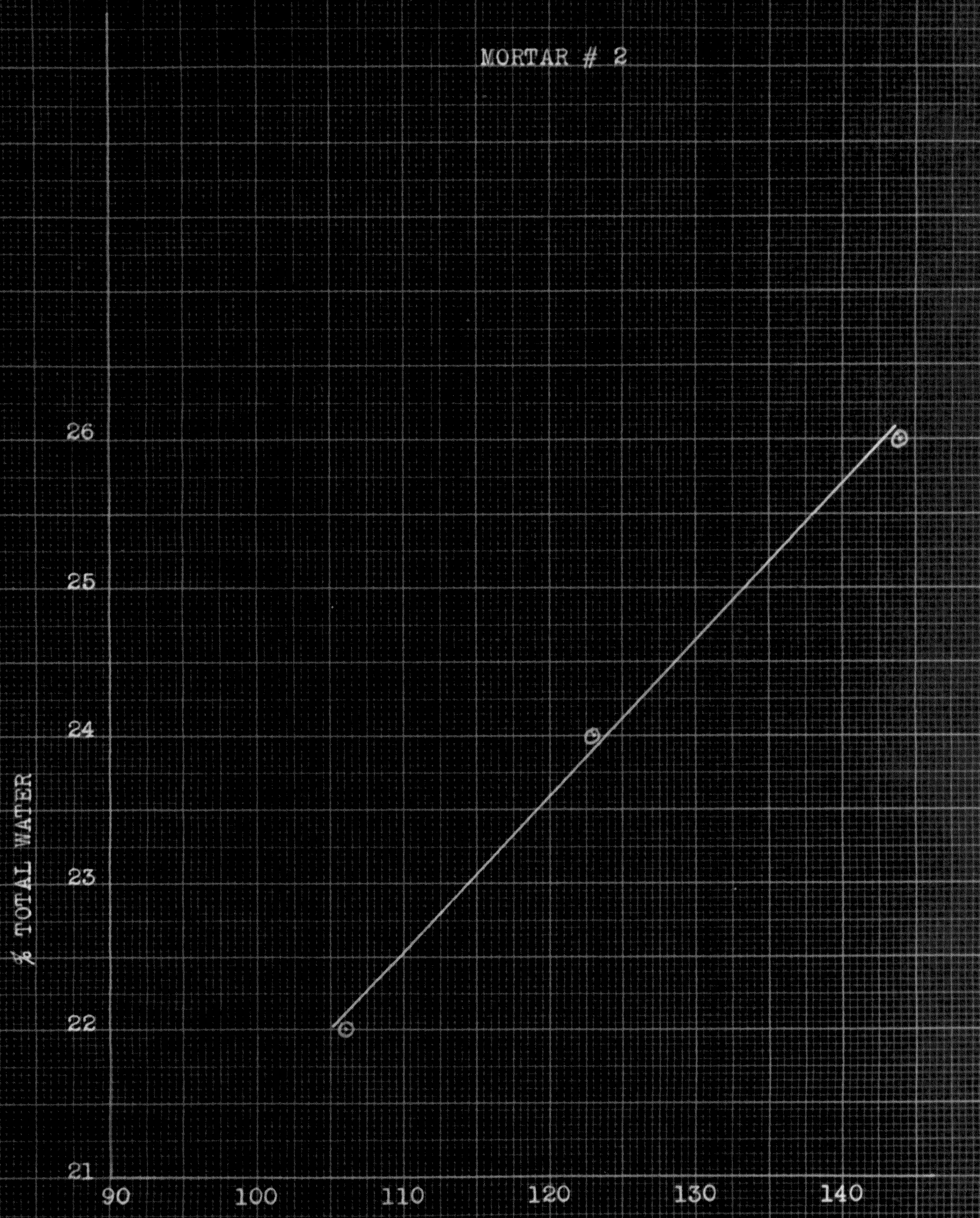
RESULTS OF PHYSICAL TESTS ON BRICK TO BE USED

MAKE OF BRICK	DOWN FACE	ABSORPTION % 44 HRS. COLD			ABSORPTION % 5 HRS. BOIL			SATURATION COEF.
STIFF-MUD SHALES		Max.	Min.	Avg.	Max.	Min.	Avg.	Avg.
Roanoke Webster	Oil Die	6.84	6.18	6.55	8.94	7.61	8.33	0.787
	Normal Wire Cut	6.47	5.69	6.55	8.54	7.64	8.16	0.754
	Split Wire Cut	6.92	6.01	6.38	8.84	8.29	8.46	0.755
Belden Red	Oil Die	0.86	1.45	1.05	3.38	0.92	2.07	0.548
	Normal Wire Cut	1.75	0.78	1.26	2.01	1.09	1.71	0.730
	Split Wire Cut	1.60	0.49	1.05	2.27	0.84	1.57	0.662
STIFF-MUD CLAY		Max.	Min.	Avg.	Max.	Min.	Avg.	Avg.
Locher	Oil Die	4.28	4.12	4.19	7.13	6.88	6.95	0.603
	Normal Wire Cut	4.30	4.17	4.20	7.03	6.82	6.97	0.603
	Split Wire Cut	4.24	4.07	4.12	7.33	7.02	7.12	0.597
Belden Buff	Oil Die	3.62	3.06	3.34	5.56	4.75	5.10	0.645
	Normal Wire Cut	3.44	2.88	3.00	5.20	4.69	4.98	0.617
	Split Wire Cut	3.27	2.76	2.98	5.56	4.60	5.10	0.615
SOFT-MUD CLAY		Max.	Min.	Avg.	Max.	Min.	Avg.	Avg.
Old Virginia	Struck	7.47	5.93	6.59	12.15	10.29	11.29	0.589
	Mold	7.34	6.11	6.60	11.93	10.90	11.40	0.582
Stiles	Struck	16.51	13.49	14.84	20.28	17.35	18.83	0.787
	Mold	16.97	14.29	15.43	21.21	18.02	19.50	0.791

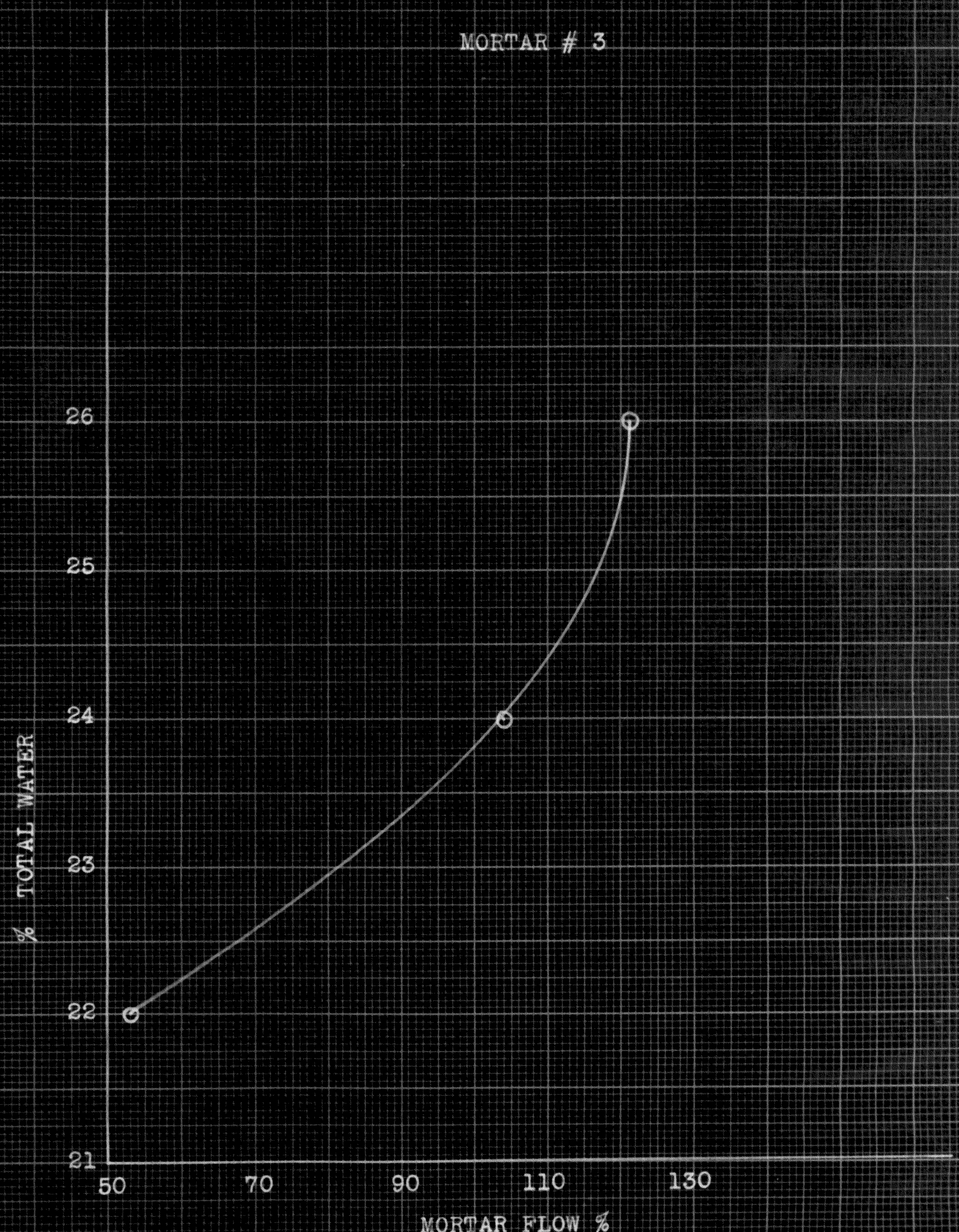
GRAPH I



Flow Curve of Standard Pressure Hydrated Lime
Ottawa Sand Mortar



Flow Before Suction Curves of Plastic Lime Putty-Cement-Sand Mortar Mix # 2



Flow Before Suction Curves of Plastic Lime
Putty-Cement-Sand Mortar Mix # 3

Apparatus

<u>Methods of Forming Samples</u>

Two methods were used throughout the proposals to form the tension-bond couplets. The first will be known as the Old Method, which is accomplished by placing two bricks at right angles to each other with a one-half inch mortar bond between them. The bond is promoted by three sharp taps with the butt of a trowel upon the top brick. The second method will be known as the modified Pearson Method which shall be shown by the following series of pictures:

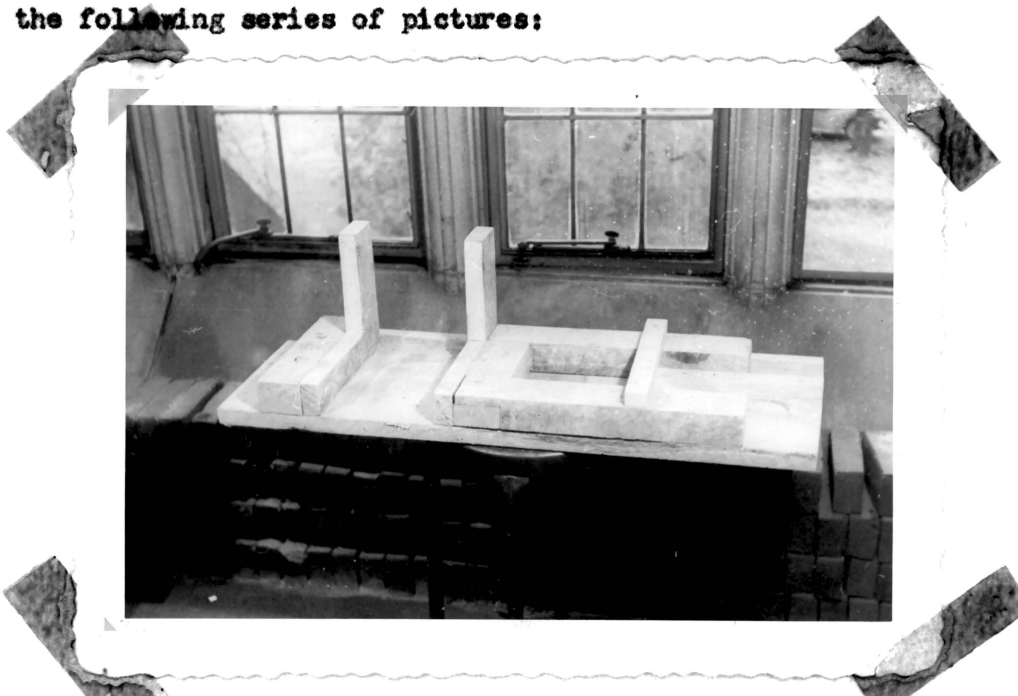


Figure 1

Figure 1 shows the apparatus with the sliding section moved back. In Figure 2, two bricks are shown, one to be placed on each side of the test specimen. These bricks are coated with wax to prevent absorption of moisture from the mortar. Figure 3 shows the bottom brick of the

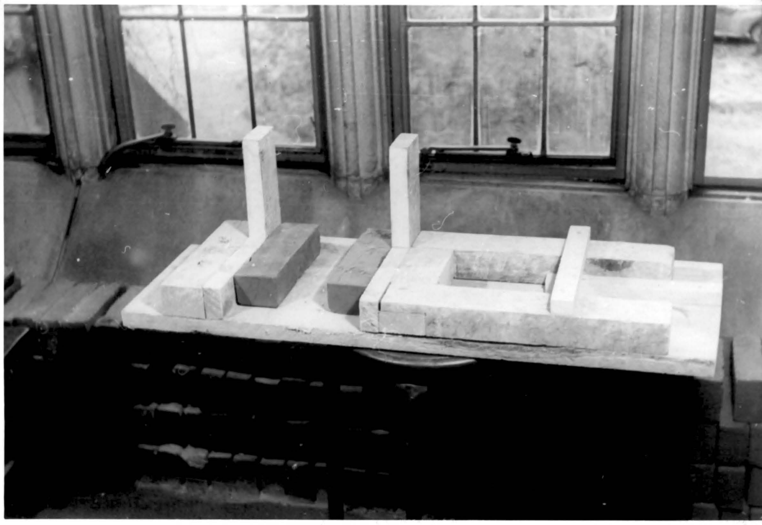


Figure 2

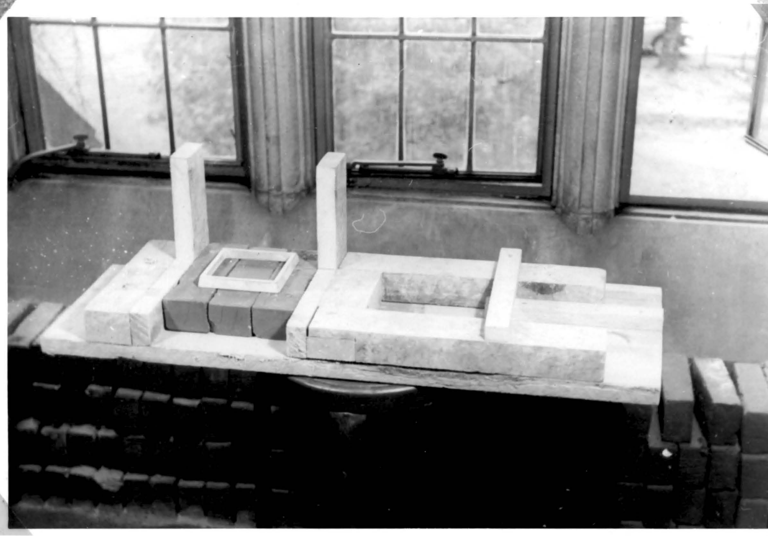


Figure 3

tension-bond couplet to be formed in place, with the mortar screed also in position. Figure 4 shows the top brick of the tension-bond couplet in place at right angles to the bottom brick.

The upright portion of the Modified Pearson Apparatus serves as a guide for centering the top brick.

Figure 4

Figure 5

Figure 5 shows the twelve-pound cast-iron weight in place. The weight remains in this position for two minutes, after which it is removed. The excess mortar is removed from the brick with the aid of a spatula and the specimen is stored for a period of seven days. The mortar bond joint is painted with a water soluble dye. The specimen is stored for an additional twenty-one days after which it is tested in the Tinius Olsen machine shown below in Figure 6.

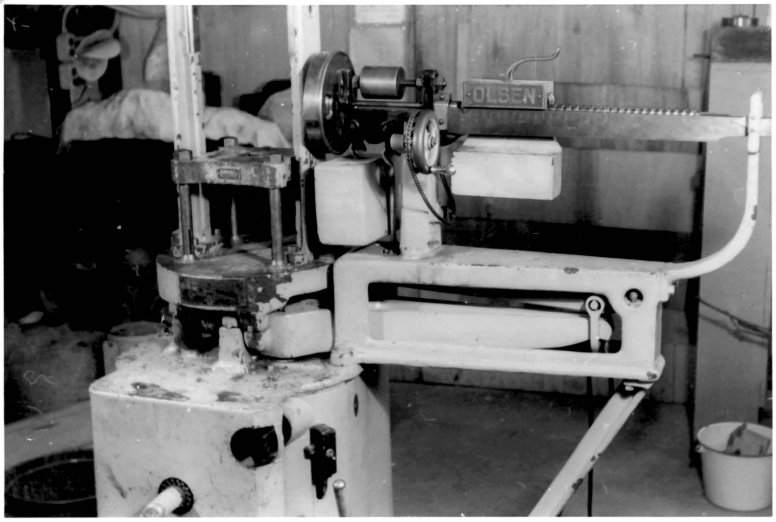


Figure 6

The sample to be tested is placed in the cross-channels shown in Figure 7 which touches each brick of the couplet at three support points. The spherical head atop the upper channel tends to eliminate eccentricity and allows a more even load to be applied to the tension-bond couplet.

The 2-inch compression samples were formed in the molds shown on the left in Figure 8 and the mold on the right was used to form the tension

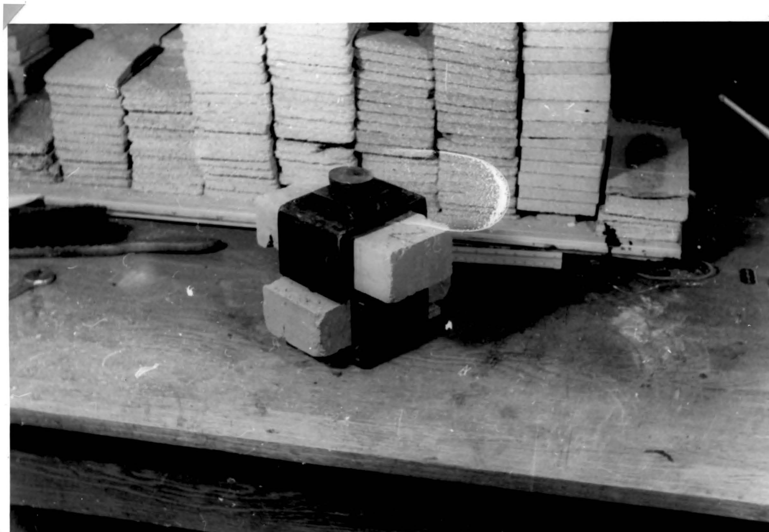


Figure 7

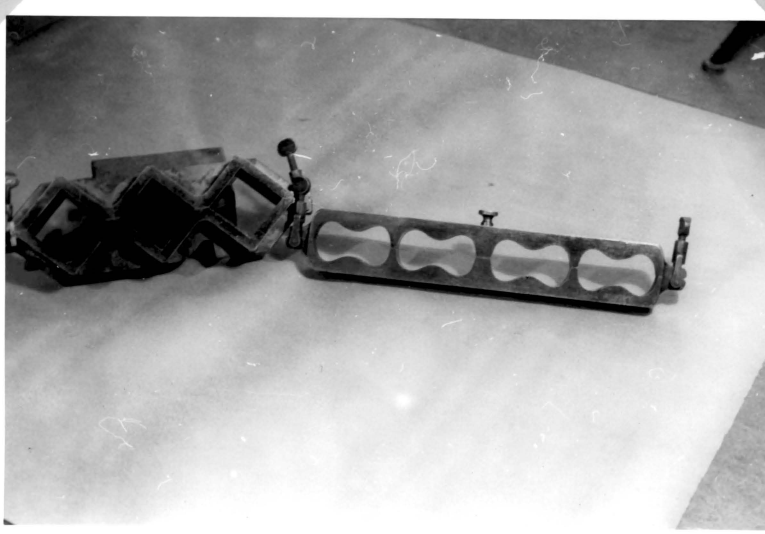


Figure 8

briquettes. These samples were formed by placing a plate glass on the bottom side and filling the mold with mortar. The mortar was puddled with the fingers and struck flush.

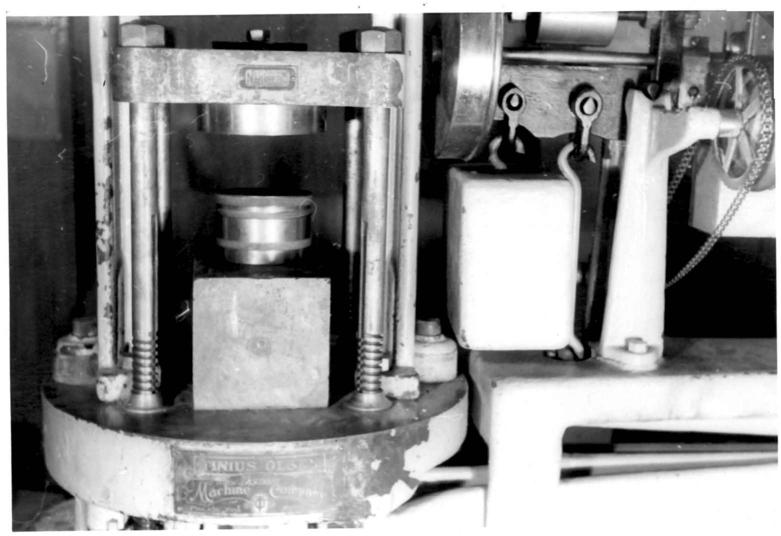


Figure 9

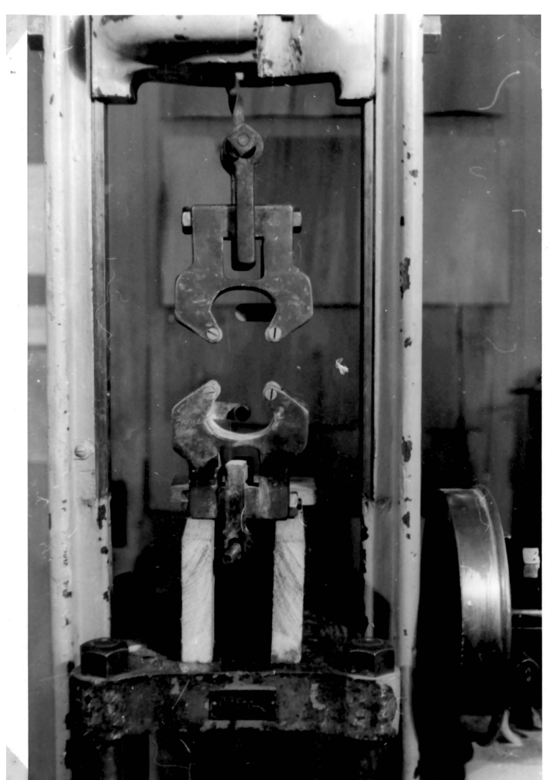


Figure 10

A glass plate was placed on the top of the mold and the mold turned over. The process of puddling and striking were repeated and the molds were placed in an atmosphere of 100 percent relative humidity for twenty four hours. The samples were removed from the molds and placed under water for the remaining twenty-seven days after which they were tested for compression and tension in the Tinius Olsen testing machine, with the aid of the arrangements shown in Figures 9 and 10.

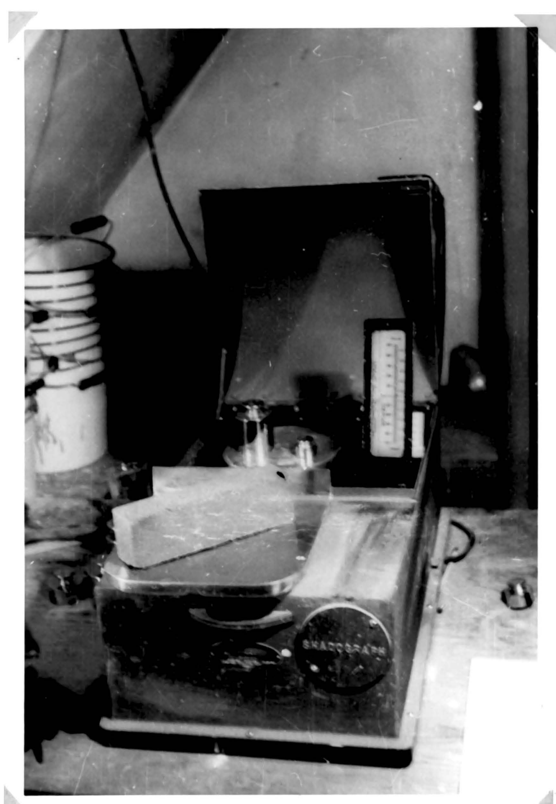


Figure 11

Suction Rate of Brick

Suction rates of brick were obtained by first weighing (to the nearest gram) the dry brick on the shadowgraph scale shown in Figure 11. The brick was then placed in one of the pans shown in figure 12 for a period of sixty seconds. Each pan* has two horizontal rods 1/8 inch under the surface of the water in the pan. This depth is kept constant with the aid of the constant head apparatus shown in Figure 12. The suction rate of brick is reported as grams of water absorbed per brick per sixty seconds based on thirty square inches of surface exposed.

Figure 12

* Specifications given in A.S.T.M.

Air Conditioning Unit

Figure 13 shows the air conditioning unit and controls necessary for keeping the laboratory at 70 ± 2^{o} F. and 50-60 percent relative humidity.

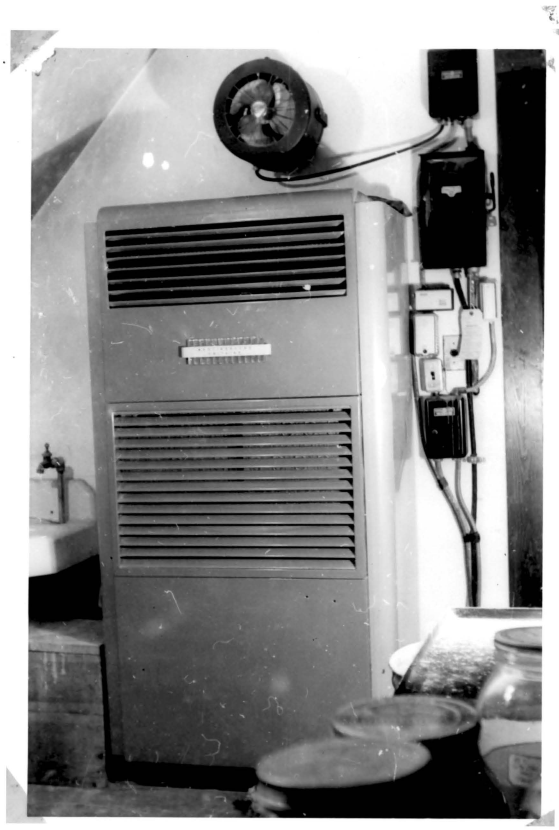


Figure 13

PART III

Proposal I

A comparison of the previous method of making brick couplets with a modified Pearson method.

Variables in the Proposal:

Kind of brick	4
Mortar flows	2
Time	4
Joint thickness....(constant)	½"
Type test	Tension
Specimens	32

The primary factors to be studied are the method of setting up the couplets or specimens, and the variance within each method.

The previous method of making brick couplets will be referred to as the Old Method, which simply placed the couplets together by hand and required tapping the top brick at three different points sharply with the butt of a trowel. The new method of making brick couplets will be referred to as the Modified Pearson Method. This method is described more fully under Apparatus. The difference is the placing of a twelve-pound weight on the top brick for two (2) minutes instead of the three taps.

Ledger of Symbols

Mortar Flows

f_1 . . . . .65 to 75 %

f_2 . . . . .115 to 125 %

Methods

m_1. . . . . Old Method

m_2. . . . . .Pearson Method

Brick

b_1 . . . . Roanoke Webster (stiff-mud shale)

b_2 . . . . Locher (stiff-mud clay)

b_3 . . . . Belden Buff (stiff-mud clay)

b_4 . . . . Belden Red (stiff-mud shale)

Treatments

f_1m_1. Flow 1 Old Method

f_1m_2. . . . . Flow 1 Pearson Method

f_2m_1. Flow 2 Old Method

f_2m_2. . . . . Flow 2 Pearson Method

Times

t_1. . . . . First Time

t_2. . . . . Second time

t_3. . . . . Third Time

t_4. . . . . Fourth Time

First Replication

	t_1	t_2	t_3	t_4
b_1	(2) f_1m_1	(3) f_1m_2	(14) f_2m_1	(15) f_2m_2
b_2	(9) f_2m_2	(4) f_1m_1	(5) f_1m_2	(16) f_2m_1
b_3	(10) f_2m_1	(11) f_2m_2	(6) f_1m_1	(7) f_1m_2
b_4	(1) f_1m_2	(12) f_2m_1	(13) f_2m_2	(8) f_1m_1

Second Replication

b_1	(17) f_1m_1	(20) f_1m_2	(29) f_2m_1	(32) f_2m_2
b_2	(26) f_2m_2	(19) f_1m_1	(22) f_1m_2	(31) f_2m_1
b_3	(25) f_2m_1	(28) f_2m_2	(21) f_1m_1	(24) f_1m_2
b_4	(18) f_1m_2	(27) f_2m_1	(30) f_2m_2	(23) f_1m_1

In the above tables the numbers in parenthesis indicate the order of forming the samples.

I. Samples formed according to the numbers givé each brick, each flow, each method and each time equal opportunity, i.e. each is made first once and each is made second once, etc. The above was performed on the smooth-to-smooth surfaces of the brick. After this part of the experiment was completed the bricks were cleaned and the same procedure was followed using the rough-to-rough surfaces of the brick. The two parts were analyzed separately and collectively. A total of eight (8) mortar batches was used in laying up the proposal. Soap bricks were used.

Procedure

Mixing the Mortar

All mixing was done at a temperature as near to 70 $\pm$ 2° F. as possible and relative humidity was maintained between 50 and 60 percent. All mixing was done in a non-absorbent vessel previously wiped with a damp cloth. To maintain uniform conditions, the same operator mixed the mortar batches throughout the proposal. Four thousand grams of dry materials were found adequate for preparing the tension-bond specimens, the 2-inch cubes for compression test of mortar, the briquettes for tension tents of mortar, and for testing the mortar flow before and after suction, before the samples were formed and after the samples were formed.

Lime putty-cement and sand were weighed out separately to the nearest gram. Lime putty, and the measured quantity of water were thoroughly mixed to give a homogeneous slurry. Cement was added and stirred with both hands, protected by rubber gloves, until homogeneity was obtained. About one-third of the sand was added and mixed for thirty seconds. The remainder of the sand was added; and mixing continued for 75 seconds by vigorous stirring, squeezing, and kneading. The mortar was allowed to stand (covered with a damp cloth) for 60 seconds and then mixed as before for another 60 seconds. The mortar was tested for flow before and after suction, adjustments being made when necessary.

Testing the Mortar Flow

The flow table (see Figure 14) was carefully wiped dry; the flow mold was placed at the center and filled with mortar prepared as above. The mortar was puddled in the conical frustrum in two layers without

Figure 14

ramming and leveled with the top of the mold by one cut of a spatula. The mold was removed and carefully, and immediately the table was dropped through a height of 1/2 inch for 25 cycles in 15 seconds. The diameter of the mortar pile was measured on four of eight radical lines, depending upon whether the pile was circular or elliptical in shape. The percentage of increase in diameter of the pile over the original base diameter of the conical mold was the measure of the mortar flow. To maintain uniform conditions, the other of the two operators performed all flow tests throughout the proposal.

Testing the Mortar Retentivity

The mortar pile was transferred to the suction apparatus, shown in

Figure 15, and sucked for 60 seconds in accordance with the standard

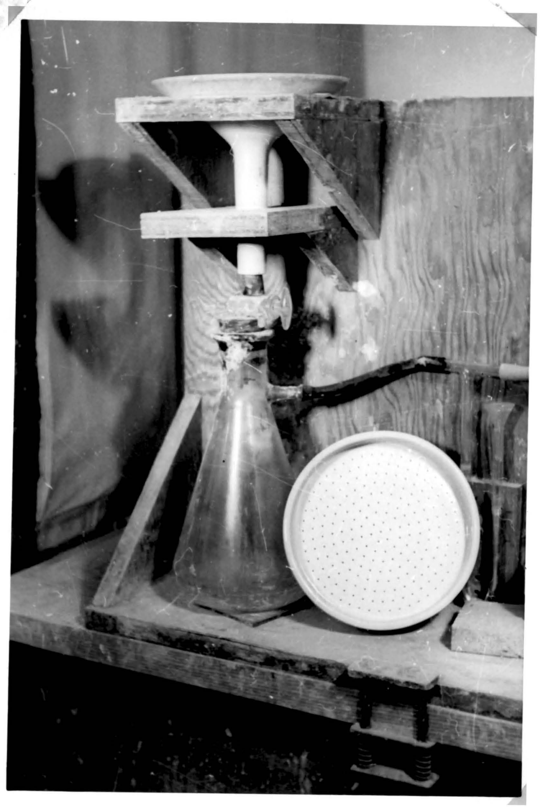


Figure 15

procedure, and its flow determined as described above. Mortar retentivity is expressed as the ratio of flow after suction to flow before suction.

<u>Making the Test Specimens</u>

For each of the eight mortar batches the two operators collaborated in making three 2-inch mortar cubes, three tension briquettes of mortar, and eight tension-bond specimens.

Trowels, and templates were moistened before bonding. The mortar was kept covered with a saturated cloth to minimize evaporation when not in use. The template (two different sizes were used depending upon the method of laying up samples) was centered with its larger opening on the bed face of the brick was laid at right angles to the first. The bond was completed by tapping the brick three times or placing a 12 pound weight on the top brick depending upon which method was used. The units were placed on shelves, and not disturbed for seven days. After all the speciemns had been made, the mortar was again tested for flow before and after suction. To maintain uniform conditions, one operator made all tension-bond specimens, while the second operator made all cubes and briquettes.

Storing the Test Specimens

Cubes and briquettes for mortar strength determinations were stored in their molds in a moisture saturated atmosphere for one day and removed from their molds to a tank of water until they were tested at the age of 28 days.

After seven days without disturbance, the tension-bond specimens were dyed at the joints and stored on shelves for 21 days before they were tested for tensile strength of bond.

Dyeing the Tension-Bond Specimens

Dyeing was accomplished by painting all four sides of the joint with a brush saturated with a water-soluble, dark blue dye. Each joint was treated in such a manner as to insure dye penetration into all joint openings.

Testing the Specimens

The mortar cubes were tested for compressive strength in a Tinius Olsen screw-type machine with a straining head speed of 0.024 inches per minute. The mortar briquettes were tested for tensile strength in a Tinius Olsen screw-type testing machine with a straining head speed of 0.024 inches per minute.

A specially made holding and loading device, consisting of two crossed-channels, (see Figure 7) each equipped with three-point bearings, was used in testing the tension-bond specimens. The top channel contained an accurately machined hemisperical depression into which was seated an accurately machined hardened-steel hemisphere to transmit the load from the straining head of the Olsen screw-type testing machine. The apparatus was very similar to that described and specified in the A.S.T.M. Journal for October 1939. The specimen was carefully centered in the bottom channel so that there would be a minimum of torsion and bending stress imposed. The top channel was likewise carefully placed and the hemisphere seated. Loads were applied at a straining head speed of 0.024 inches per minute until failure occurred. The following data were recorded: (1) load at failure; (2) cross-sectional dimensions at joint; (3) joint thickness; (4) estimated extent of bond from dye penetration measurements; (5) estimated percentage of failure in the top joint, the bottom joint, the mortar, and in the brick.

Mortar Batches of 65-75 % Flow

Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Added Water
1	1-8	67	50	.75	158	1474	19	11.4
2	17-24	71	52	.73	158	1394	19	11.4
3	1-8	74	58	.79	163	1306	20	13.4
4	17-24	74	47	.64	150	1253	20	13.8

Batch numbers 1 and 2 smooth-to-smooth surface
Batch numbers 3 and 4 rough-to-rough surface

Mortar Batches of 115-125 % Flow

Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Added Water
5	9-16	116	91	.78	151	1145	23	15.4
6	25-32	114	94	.82	135	1095	23	15.4
7	9-16	125	85	.68	129	1048	24	15.2
8	25-32	122	99	.81	150	1074	24	14.8

Batch number 5 and 6 smooth-to-smooth surface
Batch number 7 and 8 rough-to-rough surface

Surface Texture Smooth-to-Smooth

Flow 65-75 %

Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	B	M	Method of Forming
1	b_4	67	5	158	1474	1/2	95	1	100	-	-	m_2
2	b_1	67	10-20	158	1474	1/2	90	1	100	-	-	m_1
3	b_1	67	10-20	158	1474	1/2	90	1	100	-	-	m_2
4	b_2	67	10-20	158	1474	1/2	90	26	100	-	-	m_1
5	b_2	67	10-20	158	1474	1/2	85	1	100	-	-	m_2
6	b_3	67	5	158	1474	1/2	95	1	100	-	-	m_1
7	b_3	67	5	158	1474	1/2	95	2	100	-	-	m_2
8	b_4	67	5	158	1474	1/2	100	2	100	-	-	m_1

Surface Texture Smooth-to-Smooth

Flow 115-125 %

Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Forming
9	b_2	116	10-20	151	1145	1/4	100	30	-	50	50	m_2
10	b_3	116	5	151	1145	1/4	100	35	-	80	20	m_1
11	b_3	116	5	151	1145	1/4	100	31	90	-	10	m_2
12	b_4	116	5	151	1145	3/16	100	34	95	-	5	m_1
13	b_4	116	5	151	1145	1/4	100	26	100	-	-	m_2
14	b_1	116	10-20	151	1145	3/8	95	26	-	100	-	m_1
15	b_1	116	10-20	151	1145	3/8	100	21	100	-	-	m_2
16	b_2	116	10-20	151	1145	3/8	90	32	20	35	45	m_1

Surface Texture Smooth-to-Smooth

Flow 65-75 %

Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Forming
17	b_1	71	10-20	158	1394	3/8	80	1	100	-	-	m_1
18	b_4	71	5	158	1394	1/2	90	1	100	-	-	m_2
19	b_2	71	10-20	158	1394	3/8	20	1	-	100	-	m_1
20	b_1	71	10-20	158	1394	1/2	75	1	100	-	-	m_2
21	b_3	71	5	158	1394	3/8	95	27	100	-	-	m_1
22	b_2	71	10-20	158	1394	1/2	85	1	100	-	-	m_2
23	b_4	71	5	158	1394	3/8	90	1	100	-	-	m_1
24	b_3	71	5	158	1394	1/2	90	2	100	-	-	m_2

Surface Texture Smooth-to-Smooth

Flow 115-125 %

Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Forming
25	b_3	114	5	135	1093	1/8	100	36	45	25	30	m_1
26	b_2	114	10-20	135	1093	3/8	100	27	100	-	-	m_2
27	b_4	114	5	135	1093	1/8	100	29	55	20	25	m_1
28	b_3	114	5	135	1093	1/4	100	29	100	-	-	m_2
29	b_1	114	10-20	135	1093	3/8	95	31	-	100	-	m_1
30	b_4	114	5	135	1093	1/4	100	29	95	-	5	m_2
31	b_2	114	10-20	135	1093	1/4	95	25	50	-	50	m_1
32	b_1	114	10-20	135	1093	3/8	100	34	100	-	-	m_2

Surface Texture Rough-to-Rough

Flow 65-75 %

Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Forming
1	b_4	74	5	163	1036	3/8	95	22	100	-	-	m_2
2	b_1	74	10-20	163	1036	1/2	50	1	100	-	-	m_1
3	b_1	74	10-20	163	1036	1/2	90	1	-	-	-	m_2
4	b_2	74	10-20	163	1036	1/2	50	12	100	-	-	m_1
5	b_2	74	10-20	163	1036	1/2	75	35	100	-	-	m_2
6	b_3	74	5	163	1036	1/2	75	1	100	-	-	m_1
7	b_3	74	5	163	1036	1/2	95	33	100	-	-	m_2
8	b_4	74	5	163	1036	3/8	85	24	-	80	20	m_1

Surface Texture Rough-to-Rough

Flow 115-125 %

Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Forming
9	b_2	125	10-20	129	1048	1/2	100	39	-	95	5	m_2
10	b_3	125	5	129	1048	3/8	100	25	95	-	5	m_1
11	b_3	125	5	129	1048	3/8	100	40	75	-	25	m_2
12	b_4	125	5	129	1048	1/4	100	27	50	25	25	m_1
13	b_4	125	5	129	1048	1/4	100	30	100	-	-	m_2
14	b_1	125	10-20	129	1048	3/8	95	27	100	-	-	m_1
15	b_1	125	10-20	129	1048	3/8	100	36	-	-	100	m_2
16	b_2	125	10-20	129	1048	3/8	85	32	-	-	100	m_1

Surface Texture Rough-to-Rough

Flow 65-75 %

Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Forming
17	b_1	74	10-20	150	1253	1/2	80	1	100	-	-	m_1
18	b_4	74	5	150	1253	1/2	95	7	100	-	-	m_2
19	b_2	74	10-20	150	1253	1/2	50	9	-	100	-	m_1
20	b_1	74	10-20	150	1253	1/2	90	8	100	-	-	m_2
21	b_3	74	5	150	1253	1/2	95	28	100	-	-	m_1
22	b_2	74	10-20	150	1253	1/2	90	27	100	-	-	m_2
23	b_4	74	5	150	1253	1/2	90	1	100	-	-	m_1
24	b_3	74	5	150	1253	1/2	95	25	100	-	-	m_2

Surface Texture Rough-to-Rough

Flow 115-125 %

Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	B	M	Method of Forming
25	b_3	122	5	150-1075	1/4	95	52	-	90	10	m_1
26	b_2	122	10-20	150-1074	1/2	100	69	-	85	15	m_2
27	b_4	122	5	150-1074	1/4	100	31	-	100	-	m_1
28	b_3	122	5	150-1074	1/4	100	50	70	-	30	m_2
29	b_1	122	10-20	150-1074	3/8	85	31	-	100	-	m_1
30	b_4	122	5	150-1074	1/4	100	36	30	50	20	m_2
31	b_2	122	10-20	150-1074	1/4	90	43	60	-	40	m_1
32	b_1	122	10-20	150-1074	1/4	100	38	100	-	-	m_2

Proposal I

Analysis of Variance
Smooth-to-Smooth Surface

Sources of Variation	D/F	SS	MS	F	Significance
Replications	1	3.8	3.8	-	
Times	3	85.5	28.5	-	
Brick	3	300.7	100.2	2.7	
Treatments					
Methods	1	153.0	153.0	4.1	
Flows	1	5832.0	5832.0	157.0	**
Interaction	1	28.1	28.1	-	
Rep. x Times	3	258.9	86.3	2.3	
Error	18	667.5	37.1	-	
Total	31	7329.5			

Rough-to-Rough Surface

Sources of Variation	D/F	SS	MS	F	Significance
Replications	1	144.5	144.5	1.8	
Times	3	172.7	57.5	-	
Brick	3	1321.2	440.4	5.6	*
Treatments					
Methods	1	684.5	684.5	8.7	**
Flows	1	4324.5	4324.5	55.1	**
Interaction	1	4.5	4.5	-	
Rep. x Times	3	567.0	189.0	2.4	
Error	18	1412.6	78.5	-	
Total	31	8631.5			

* (F is greater than the 5 percent point; less than the 1 percent point; therefore, judged significant.)

** (F is greater than the 1 percent point, therefore judged highly significant.)

Proposal I

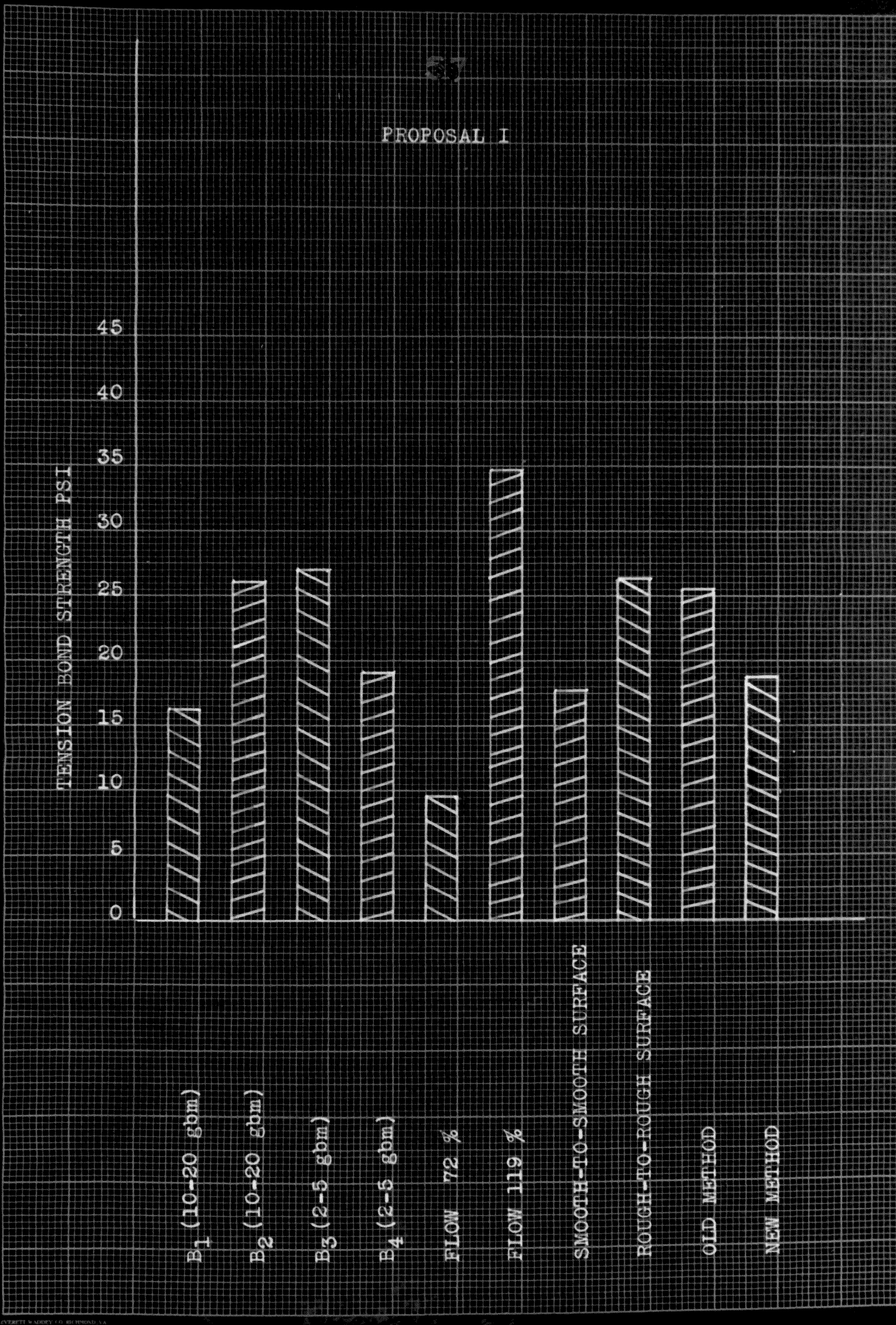
Combined Tables

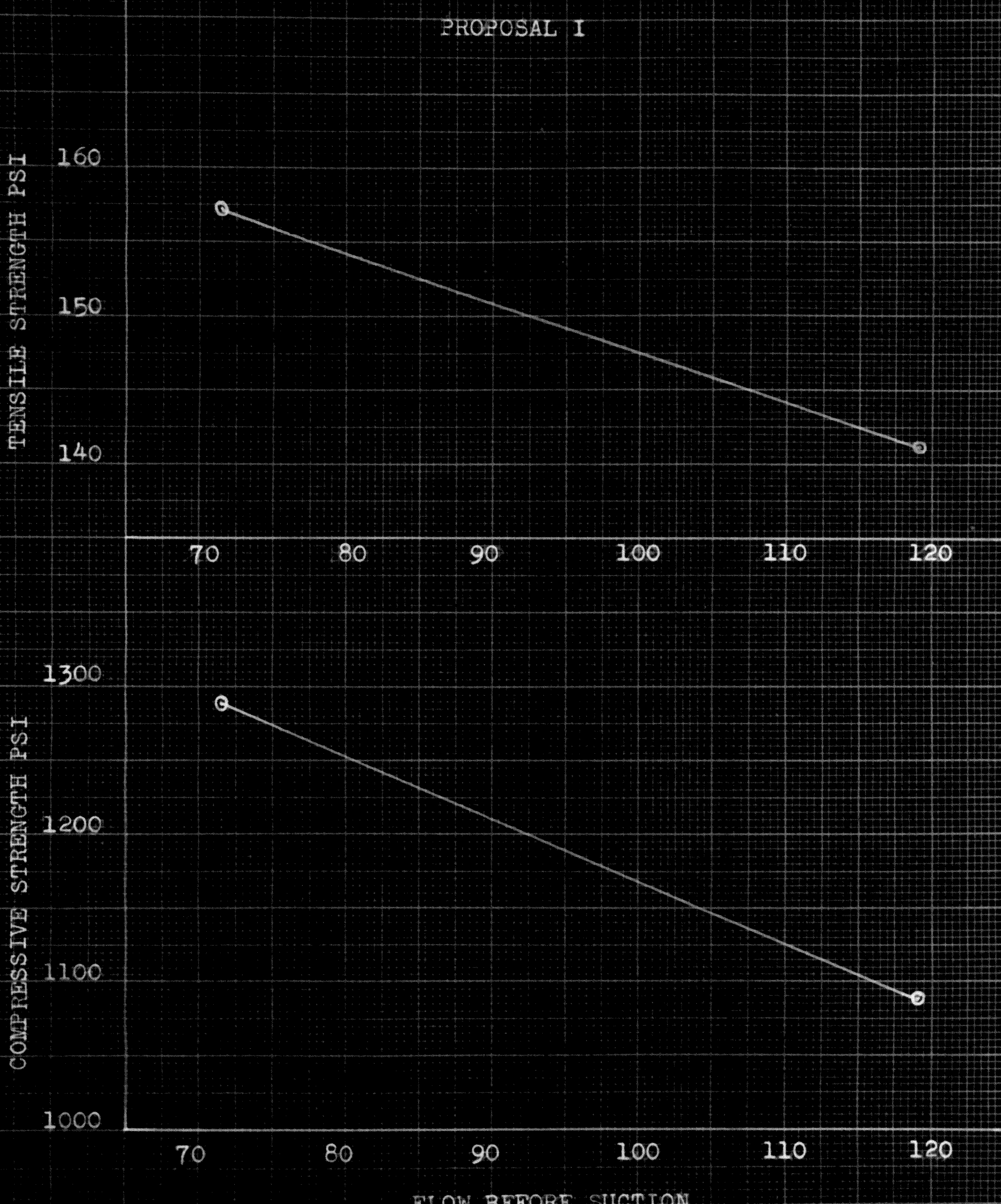
Sources of Variation	D/F	SS	MS	F	Significance
Replication	1	49.0	49.0	-	
Time	3	22.2	7.4	-	
Bricks	3	1345.1	448.4	5.4	**
Treatment					
Method	1	95.0	95.0	1.0	
Flow	1	10,100.0	10,100.0	121.0	**
Interaction	1	5.0	5.0	-	
Rep. x Times	3	266.8	88.9	1.1	
Error	49	4079.9	83.2		
Total	63	17,119.0			

** (F is greater than the 1 percent point, therefore, judged highly significant.)

Explanation of Graph Page 57.

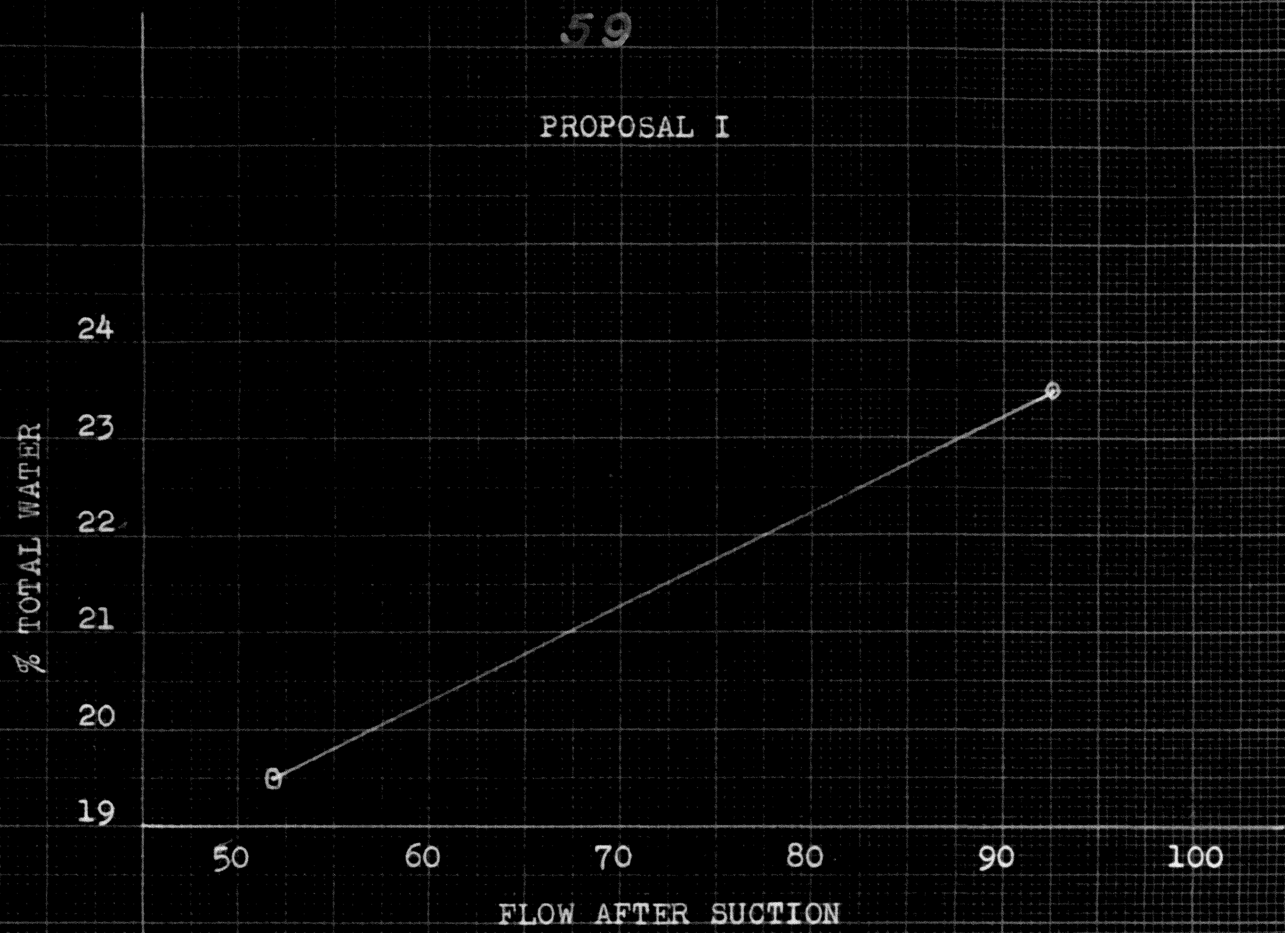
The ordinate is in P.S.I. and is an average of all samples made under all variables but the one at the base of the column. One bar in the Abscissa is the average of all samples made of the one variable represented. For example B_1 is an average of all samples made with B_1 and includes all flows, surfaces and methods. The rest are all similar to B_1 in the method they were determined.

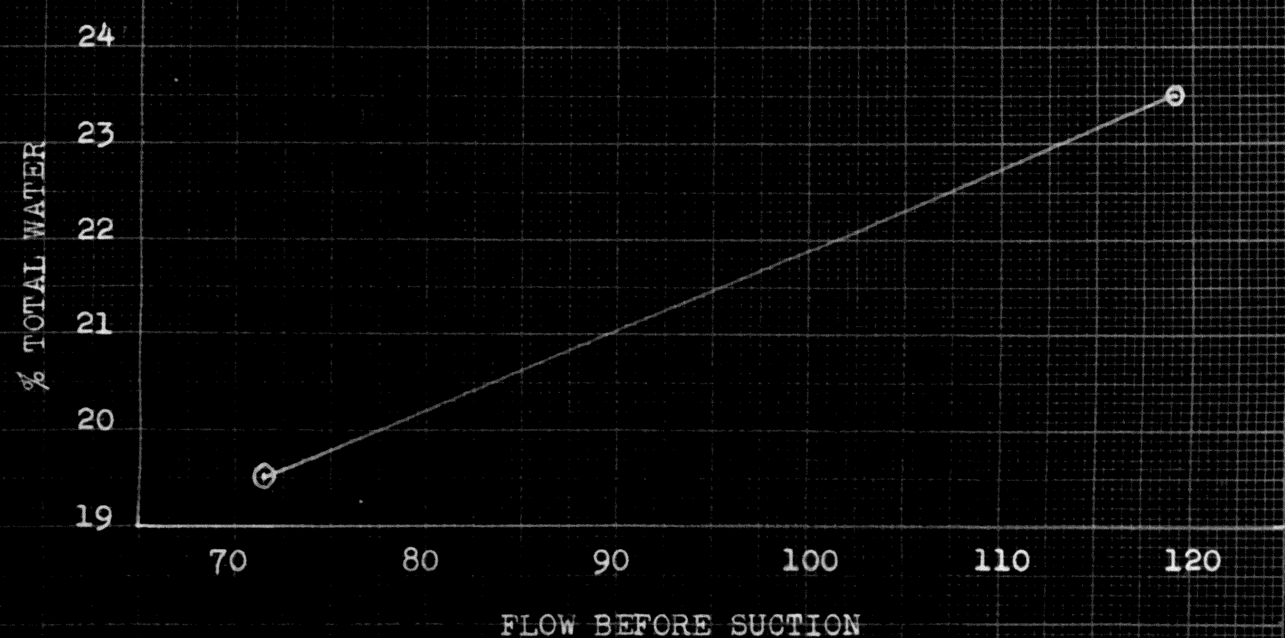

PROPOSAL I
TENSION BOND STRENGTH PSI
0
5
10
15
20
25
30
35
40
45
B_1 (10-20 gbm)
B_2 (10-20 gbm)
B_3 (2-5 gbm)
B_4 (2-5 gbm)
FLOW 72 %
FLOW 119 %
SMOOTH-TO-SMOOTH SURFACE
ROUGH-TO-ROUGH SURFACE
OLD METHOD
NEW METHOD



Tensile and Compressive Strength Curves of Plastic Lime Putty-Cement-Sand Mortar used in Proposal I

PROPOSAL I





Flow - Before and After Curves of Lime Putty-Cement
Sand Mortar Used in Proposal I

Proposal I

Discussion and Conclusions

Within the limits of the various tests performed in the proposal, the following summary and conclusions appear justified:

(1) The strength of the tension-bond specimens shows a wide range but from the analysis of variance it is evident that the results are reproducible.

(2) The effect of time of laying up the sample has been eliminated by systematic alternation of forming the samples.

(3) The experiment indicates a difference in the mortar-bond strength. The stiff-mud clay brick gave the higher average strength.

(4) Apparently there is no great difference in the average tension-bond strength due to the suction rate of the brick.

(5) It is indicated that the relative roughness or smoothness of the brick faces which are in contact with the mortar influence the properties and characteristics of the bond. In this case the normal wire-cut face gave greater average strength than the die face.

(6) Regardless of suction rate of the four brick tested, type of brick, method of forming, time of forming and surface used, the tension-bond strength increased with an increase in mortar flow.

(7) Considering which property is the most desirable, high strength or consistent results, the old method gave an higher average strength than the Pearson Method, but the statistical analysis showed no significent difference in the two methods.

Proposal II

A comparison of bonds, using three mortars with two flows each. Couplets formed by two methods. One type of brick (Roanoke-Webster, stiff mud shale) and one surface characteristic were used. The suction rate was kept within (10-20) gbn limits.

Variables in the Proposal:

Kind of brick	1
Suction rate	1
Texture	1
Mortars	3
Mortars flow	2
Methods	2
Joint Thickness	½"
Type test	tension
Specimens	48

The differences to be studied are: (1) the methods of setting up the couplets or specimens; (2) mortar mixes; and (3) mortar flows. The two methods of setting up the couplets are the "Old Method" and the "Pearson Method". The three mortar mixes are as follows: (by volume)

Mortar 1:	1.0	Lime	¼	Cement	3	Sand
Mortar 2:	1.0	Lime	1.0	Cement	6.0	Sand
Mortar 3:	1.0	Lime	2.0	Cement	9.0	Sand

The two mortar flows used are: (100-110) % flow, and (120-130) % flow.

Ledger of Symbols

Methods

m_1 . . . . Old Method

m_2 . . . . Pearson Method

Flows

f_1 . . . . 100% to 110%

f_2 . . . . 120% to 130%

Mortars

M_1 . . . . 1.0 1/4 3.0

M_2 . . . . 1.0 1.0 6.0

M_3 . . . . 1.0 2.0 9.0

Program for Forming Couplets

First Replication

M_1		M_2		M_3	
f_1	f_2	f_1	f_2	f_1	f_2
(1) m_1	(1) m_1	(9) m_1	(9) m_1	(17) m_1	(17) m_1
(2) m_2	(2) m_2	(10) m_2	(10) m_2	(18) m_2	(18) m_2
(3) m_1	(3) m_1	(11) m_1	(11) m_1	(19) m_1	(19) m_1
(4) m_2	(4) m_2	(12) m_2	(12) m_2	(20) m_2	(20) m_2

Second Replication

(5) m_2	(5) m_2	(13) m_2	(13) m_2	(21) m_2	(21) m_2
(6) m_1	(6) m_1	(14) m_1	(14) m_1	(22) m_1	(22) m_1
(7) m_2	(7) m_2	(15) m_2	(15) m_2	(23) m_2	(23) m_2
(8) m_1	(8) m_1	(16) m_1	(16) m_1	(24) m_1	(24) m_1

Numbers in parenthesis indicate the order of forming couplets

Procedure

Mixing the Mortar

Mixing of mortar in Proposal II is the same as in Proposal I.

Testing of Mortar Flow

Testing the mortar flows in Proposal II is the same as in Proposal I.

Testing the Mortar Retentivity

Testing the mortar retentivity in Proposal II is the same as in Proposal I.

Making the Test Specimens

Making the test specimens for Proposal II is the same as in Proposal I, with the exception that 12 mortar batches completed the Proposal and four tension-bond specimens were formed with each batch.

Storing the Specimens

Storing the specimens in Proposal II is the same as in Proposal I.

Dyeing the Tension-Bond Specimens

Dyeing the tension-bond specimens for Proposal II is the same as in Proposal I.

Testing the Specimens

Testing the specimens in Proposal II is the same as in Proposal I.

Mortar Batches of 95-105 % Flow

Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Added Water
				Mortar # 1				
1	1-4	106	61	.58	228	2781	20.4	14.7
2	5-8	105	58	.55	221	2305	20.4	14.5
				Mortar # 2				
5	9-12	100	64	.64	144	1185	22.0	13.5
6	13-16	102	63	.62	148	1207	22.0	13.7
				Mortar # 3				
9	17-20	100	69	.69	59	493	24.0	11.6
10	21-24	105	81	.77	54	510	24.0	11.6

g

Mortar Batches of 120-130 % Flow

Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Added Water
				Mortar # 1				
3	1-4	125	108	.86	240	2460	22.5	16.7
4	5-8	123	78	.63	223	2650	22.5	17.0
				Mortar # 2				
7	9-12	124	78	.63	127	1155	24.1	15.8
8	13-16	123	64	.52	130	1113	24.2	15.9
				Mortar # 3				
9	17-20	125	82	.66	51	418	26.0	13.0
10	21-24	124	96	.77	55	430	26.0	13.0

Roanoke Webster Brick (stiff mud, shale)

Flow 95-105 % Rough-to-Rough Surface

Sample No.	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	B	M	Method of Forming
1	106	10-20	228	2781	3/8	80	22	-	100	-	m_1
2	106	10-20	228	2781	1/2	95	23	-	100	-	m_2
3	106	10-20	228	2781	3/8	80	70	-	100	-	m_1
4	106	10-20	228	2781	1/2	95	26	100	-	-	m_2
5	105	10-20	221	2305	1/2	95	36	100	-	-	m_2
6	105	10-20	221	2305	3/8	50	1	-	100	-	m_1
7	105	10-20	221	2305	1/2	90	14	100	-	-	m_2
8	105	10-20	221	2305	3/8	80	21	100	-	-	m_1

Roanoke Webster Brick (stiff mud, shale)

Flow 95-105 % Rough-to-Rough Surface

Sample No.	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Foaming
9	100	10-20	144	1185	3/8	75	43	-	100	-	m_1
10	100	10-20	144	1185	3/8	100	45	100	-	-	m_2
11	100	10-20	144	1185	1/4	90	30	100	-	-	m_1
12	100	10-20	144	1185	3/8	100	49	100	-	-	m_2
13	102	10-20	148	1207	3/8	100	49	-	100	-	m_2
14	102	10-20	148	1207	3/8	85	31	-	100	-	m_1
15	102	10-20	148	1207	1/2	95	52	-	100	-	m_2
16	102	10-20	148	1207	1/4	50	23	-	100	-	m_1

Roanoke Webster Brick (stiff mud, shale)

Flow 95-105 % Rough-toRough Surface

Sample No.	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Forming
17	100	10-20	59	493	3/8	80	31	-	60	40	m_1
18	100	10-20	59	493	3/8	95	36	-	100	-	m_2
19	100	10-20	59	493	3/8	80	22	-	100	-	m_1
20	100	10-20	59	493	1/4	100	35	-	100	-	m_2
21	105	10-20	54	510	1/4	90	41	-	80	20	m_2
22	105	10-20	54	510	1/4	85	34	-	90	10	m_1
23	105	10-20	54	510	1/4	100	54	20	30	50	m_2
24	105	10-20	54	510	1/4	80	29	-	85	15	m_1

Roanoke Webster Brick (stiff mud, shale)

Flow 115-125 % Rough-to-Rough Surface

Sample No.	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Forming
1	125	10-20	240	2460	1/4	95	48	-	100	-	m_1
2	125	10-20	240	2460	1/2	100	36	100	-	-	m_2
3	125	10-20	240	2460	1/4	90	34	-	100	-	m_1
4	125	10-20	240	2460	1/2	100	43	-	100	-	m_2
5	123	10-20	223	2650	1/4	100	45	-	100	-	m2
6	123	10-20	223	2650	1/4	100	38	100	-	-	m1
7	123	10-20	223	2650	1/4	100	39	100	-	-	m2
8	123	10-20	223	2650	1/4	85	34	-	100	-	m1

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Roanoke Webster Brick (stiff mud, shale)

Flow 115-125 % Rough-to-Rough Surface

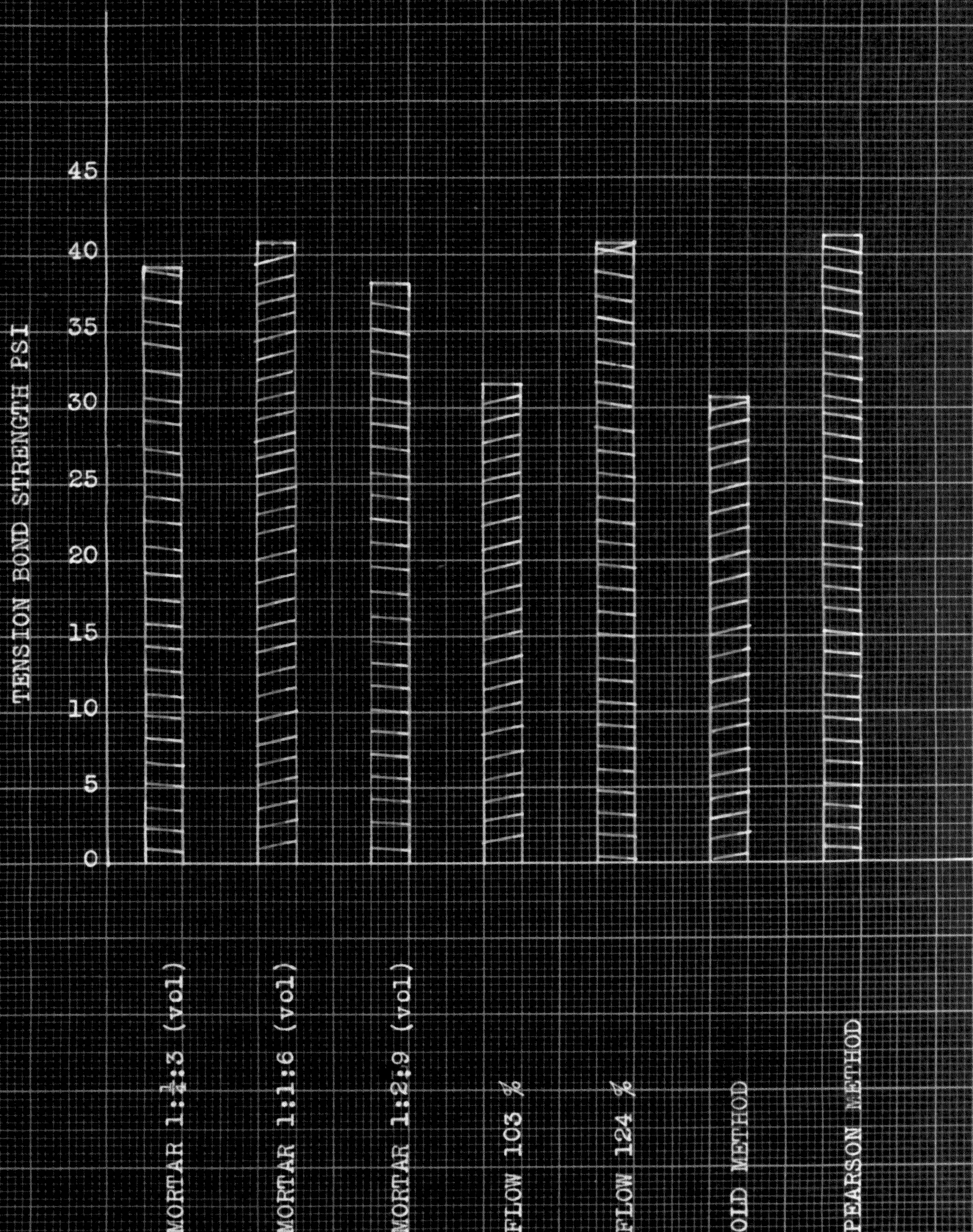
Sample No.	Flow %	Original Suction Rate gtm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Forming
9	124	10-20	127	1155	1/4	90	43	-	100	-	m_1
10	124	10-20	127	1155	1/4	100	53	100	-	-	m_2
11	124	10-20	127	1155	1/4	100	30	100	-	-	m_1
12	124	10-20	127	1155	1/4	100	41	100	-	-	m_2
13	123	10-20	130	1113	1/4	100	45	-	100	-	m_2
14	123	10-20	130	1113	1/4	90	35	-	100	-	m_1
15	123	10-20	130	1113	1/4	100	52	-	100	-	m_2
16	123	10-20	130	1113	1/4	100	33	-	100	-	m_1

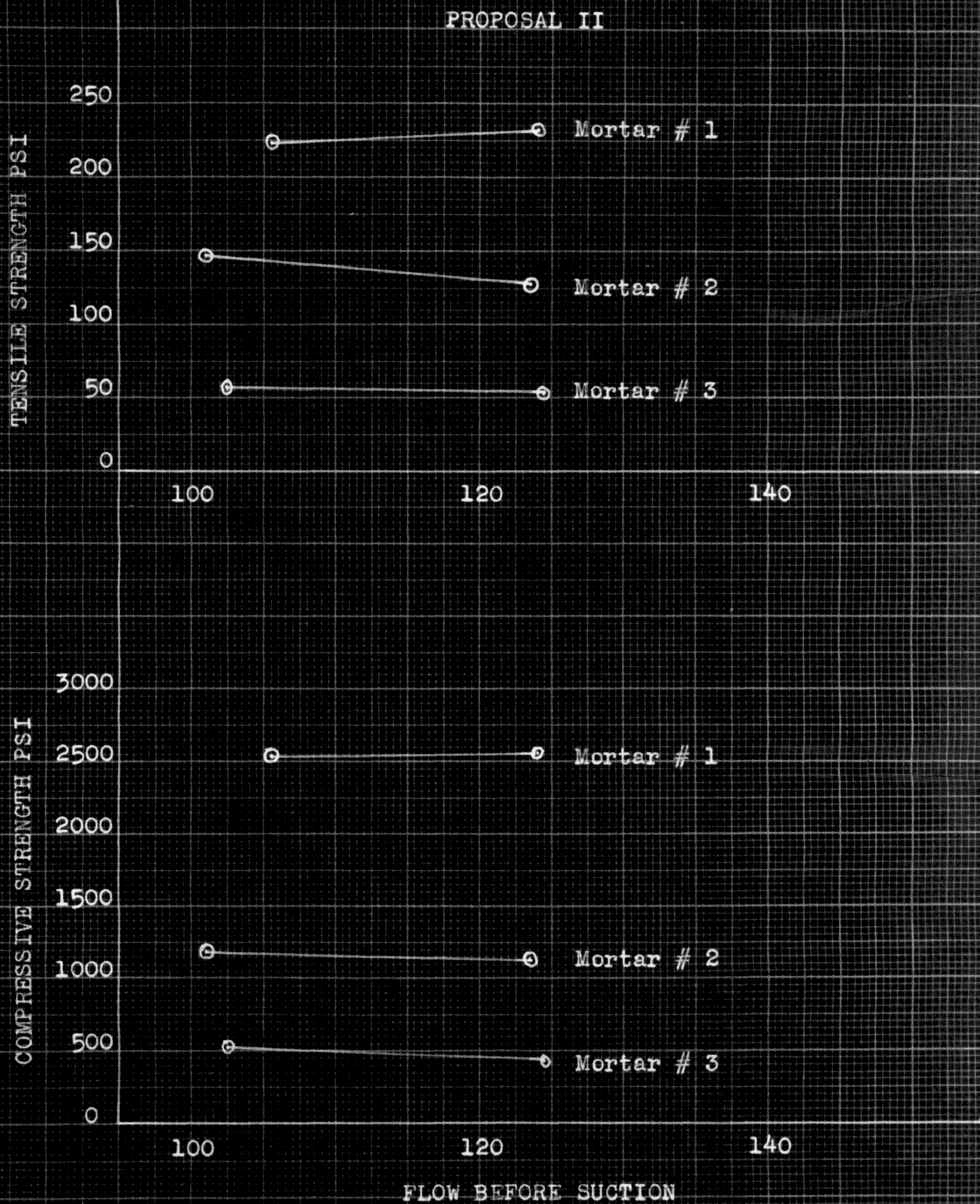
Roanoke Webster Brick (stiff mud, shale)

Flow 115-125 % Rough-to-Rough Surface

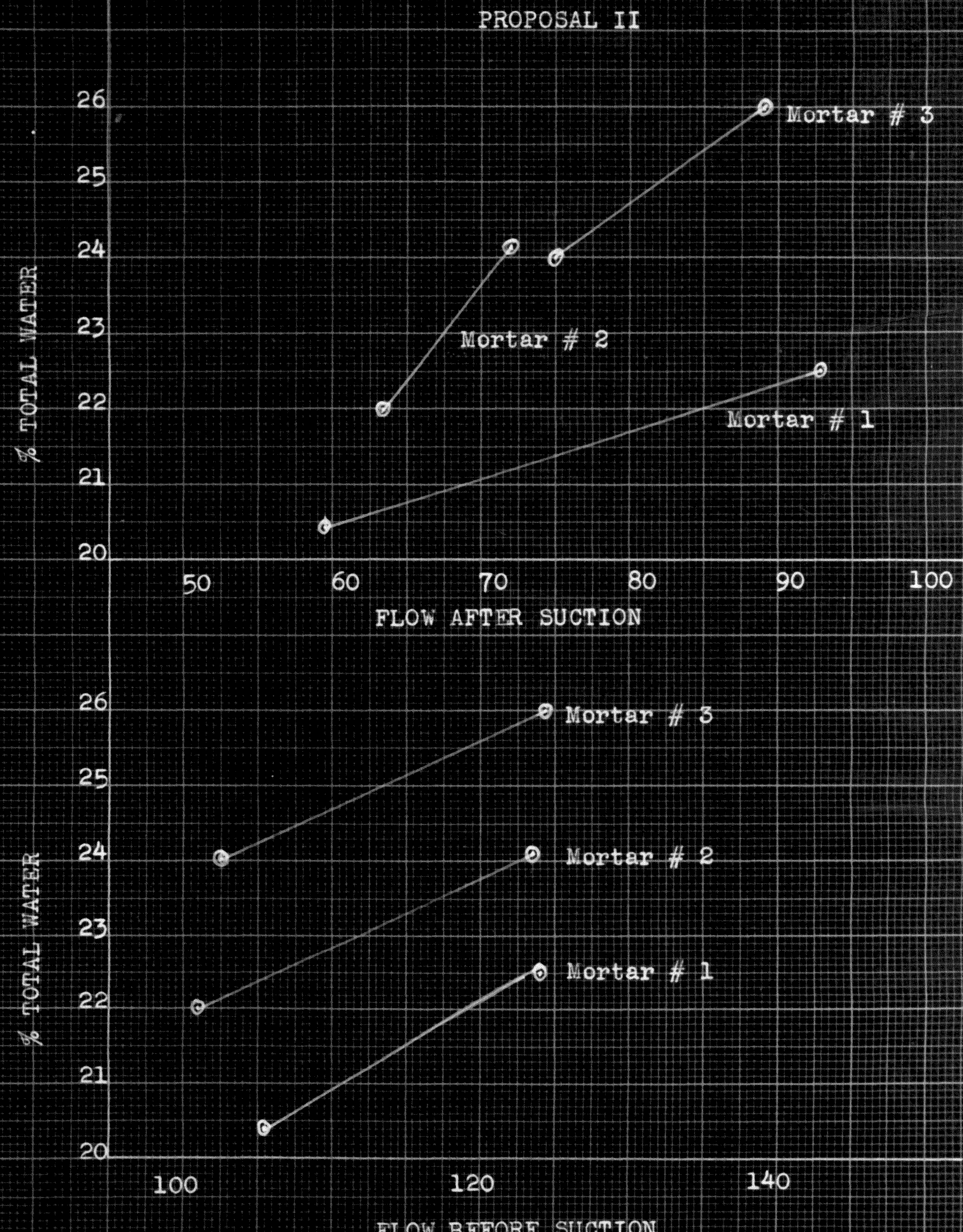
Sample No.	Flow %	Original Suction Rate gtm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Method of Forming
17	125	10-20	51	418	1/4	90	45	-	50	50	m_1
18	125	10-20	51	418	1/4	95	48	-	75	25	m_2
19	125	10-20	51	418	3/8	85	27	-	80	20	m_1
20	125	10-20	51	418	3/8	100	39	-	60	40	m_2
21	124	10-20	55	430	1/4	100	40	75	-	25	m_2
22	124	10-20	55	430	1/4	95	50	-	40	60	m_1
23	124	10-20	55	430	1/4	100	48	-	25	75	m_2
24	124	10-20	55	430	3/8	95	32	-	100	-	m_1

PROPOSAL II


TENSION BOND STRENGTH PSI
0
5
10
15
20
25
30
35
40
45
MORTAR 1:¼:3 (vol)
MORTAR 1:1:6 (vol)
MORTAR 1:2:9 (vol)
FLOW 103 %
FLOW 124 %
OLD METHOD
PEARSON METHOD



Tensile and Compressive Strength Curves of Plastic Lime Putty-Cement-Sand Mortar Used in Proposal II



Flow - Before and After Curves of Lime Putty-Cement Sand Mortar Used in Proposal II

Proposal II

Analysis of Variance

Sources of Variation	D/F	SS	MS	F	Significance
Replications	1	8.3	8.3	-	
Mortar	2	1199.0	599.5	9.3	**
Flows	1	1045.0	1045.3	16.8	**
Methods	1	1260.7	1260.7	19.5	**
Mortar x Method	2	127.7	63.9	1.0	
Mortar x Flows	2	842.1	421.0	6.5	*
Flows x Method	1	154.3	154.3	2.4	Border Line
Mortar x Method x Flow	2	13.6	6.8	-	
Error (Experimental	11	340.7	31.0	-	
Error (sampling)	24	1554.0	64.7		
Total	47	6545.7			

* (F is greater than the 5 percent point; less than the 1 percent point; therefore judged significant.)

** (F is greater than the 1 percent point, therefore judged highly significant.)

Proposal II

Proposal II, designed to test bond using one brick, three mortars with two flows each and two methods, gave the following results:

(1) The difference between the average strength of the mortars seems rather small but the statistical analysis shows a decided difference. This difference is probably due to the higher strength of mortar 1:1:6 (vol) as there seems to be very little difference in bond strength for mortars 1 and 3.

(2) Only one surface characteristic and one suction rate being used, the tension-bond strength increased with an increase in mortar flow.

(3) The use of the Pearson method gave higher and more consistent results than the old method. It was therefore chosen for all future proposals.

Proposal III

A comparison of mortar bond of brick with emphasis on difference in texture of surface of brick in contact with mortar which joins them.

Six brick types were used. The Roanoke-Webster (stiff-mud, shale) and Locher (stiff-mud, clay) were within the (10-20) gbm suction rate group. Belden Buff (stiff-mud, clay)and Belden Red (stiff-mud, shale) were both in the less than 5 gbm suction rate group. Old Virginia (soft-mud, clay) and Stiles (soft-mud, clay) were both within the (50-60) gbm suction rate group. Both rough-to-rough and smooth-to-smooth surface combinations were used. Three flows were used, (95-105) %, (115-125) %, and (130-140) % Mortar mix # 2 was used. 0.24 Lime 1 Cement 3.9 Sand (by weight).

Variables in Proposal

Kind of brick	6
Surface combinations	2
Suction Rates	3
Sand Grading	medium
Mortar mix	1
Mortar flows	3
Joint thickness	½"
Type of test	tension
Total number of Specimens	72

Ledger of Symbols

Bricks

b_1. . . . . Roanoke-Webster

b_2. . . . . Belden Buff

b_3. . . . . Locher

b_4. . . . . Belden Red

b_5. . . . . Old Virginia

b_6. . . . . Stiles

Surface Combinations

s_1. . . . . Smooth-to-Smooth

s_2. . . . . Rough-to-Rough

Mortar Flows

f_1. . . . . (95-105)

f_2. . . . . (115-125)

f_3. . . . . (130-140)

Times

t_1 . . . . First Time

t_2 . . . . Second Time

t_3 . . . . Third Time

t_4 . . . . Fourth Time

t_5 . . . . Fifth Time

t_6 . . . . Sixth Time

Ledger of Symbols continued

Treatments

s_1f_1 . . . . .First Treatment

s_2f_1 . . . . Second Treatment

s_1f_2 . . . . Third Treatment

s_2f_2 . . . . Fourth Treatment

s_1f_3. . . . . Fifth Treatment

s_2f_2. . . . . Sixth Treatment

Program for Forming Couplets

First Replication

Brick Times	b_1	b_2	b_3	b_4	b_5	b_6
t_1	(1) s_1f_1	(13) s_2f_1	(25) s_1f_2	(37) s_2f_2	(49) s_1f_3	(61) s_2f_3
t_2	(9) s_2f_3	(14) s_1f_1	(29) s_2f_1	(38) s_1f_2	(53) s_2f_2	(62) s_1f_3
t_3	(10) s_1f_3	(21) s_2f_3	(30) s_1f_1	(41) s_2f_1	(54) s_1f_2	(65) s_2f_2
t_4	(5) s_2f_2	(22) s_1f_2	(33) s_2f_3	(42) s_1f_1	(57) s_2f_1	(66) s_1f_2
t_5	(6) s_1f_2	(17) s_2f_2	(34) s_1f_3	(45) s_2f_3	(58) s_1f_1	(69) s_2f_1
t_6	(2) s_2f_1	(18) s_1f_2	(26) s_2f_2	(46) s_1f_3	(50) s_2f_3	(70) s_1f_1

Second Replication

Brick Times	b_1	b_2	b_3	b_4	b_5	b_6
t_1	(3) s_2f_1	(15) s_1f_1	(27) s_2f_2	(39) s_1f_2	(51) s_2f_3	(62) s_1f_3
t_2	(11) s_1f_2	(16) s_2f_1	(31) s_1f_1	(40) s_2f_2	(55) s_1f_2	(64) s_2f_3
t_3	(12) s_2f_3	(23) s_1f_3	(32) s_2f_1	(43) s_1f_1	(56) s_2f_2	(67) s_1f_2
t_4	(7) s_1f_2	(24) s_2f_3	(35) s_1f_3	(44) s_2f_1	(59) s_1f_1	(68) s_2f_2
t_5	(8) s_2f_2	(19) s_1f_2	(36) s_2f_3	(47) s_1f_3	(60) s_2f_1	(71) s_1f_1
t_6	(4) s_1f_1	(20) s_2f_2	(28) s_1f_2	(49) s_2f_3	(52) s_1f_3	(72) s_2f_1

Numbers in parenthesis indicate the order of forming couplets.

Procedure

Mixing the Mortar

Mixing of mortar in Proposal III is the same as in Proposal I.

Testing of Mortar Flow

Testing the mortar flows in Proposal III is the same as in Proposal I.

Testing the Mortar Retentivity

Testing the mortar retentivity in Proposal III is the same as in Proposal I.

Making the Test Specimens

Making the test specimens for Proposal III is the same as in Proposal I, with the exception that 36 mortar batches completed the Proposal and two tension-bond specimens were formed with each batch.

Storing the Specimens

Storing the specimens in Proposal III is the same as in Proposal I.

Dyeing the Tension-Bond Specimens

Dyeing the tension-bond specimens for Proposal III is the same as in Proposal I.

Testing the Specimens

Testing the specimens in Proposal III is the same as in Proposal I.

Mortar Batches of 95-105 % Flow

Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Added Water
1	1-2	100	60	.60	151	1197	22	13.9
2	3-4	100	64	.64	143	1220	22	13.9
3	13-14	100	56	.56	140	1147	22	14.4
4	15-16	100	75	.75	160	1244	22	14.1
5	29-30	97	69	.71	145	1195	22	14.5
6	31-32	103	59	.57	140	1188	22	14.5
7	41-42	103	55	.53	128	1152	22	13.9
8	43-44	105	61	.58	132	1129	22	13.9
9	57-58	103	59	.57	129	1123	22	14.1
10	59-60	102	55	.54	136	1105	21.5	13.5
11	69-70	100	58	.58	145	1261	21.2	13.3
12	71-72	103	61	.59	147	1090	21.2	13.3

Mortar Batches of 95-105 % Flow

Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Water Added
13	5-6	120	89	.74	132	1145	24	15.9
14	7-8	120	85	.71	129	1211	24	15.9
15	17-18	122	69	.57	130	1029	24	16.3
16	19-20	123	71	.58	132	1029	24	16.3
17	25-26	117	69	.59	141	1196	24	16.4
18	27-28	125	78	.62	133	1112	24	16.4
19	37-38	119	63	.53	127	1110	23.5	15.6
20	39-40	123	83	.67	141	1131	23.5	15.6
21	53-54	124	66	.53	107	1037	23.2	15.2
22	55-56	123	64	.52	134	1072	23.2	15.2
23	65-66	122	71	.58	142	988	23.2	15.2
24	67-68	122	67	.55	132	1068	23.2	15.2

Mortar Batches of 130-140 % Flow

Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Water Added
25	9-10	128	82	.64	138	1045	25	17
26	11-12	136	119	.88	143	1045	25	17
27	21-22	135	91	.67	109	1033	25	17.4
28	23-24	134	89	.66	105	1102	25	17.4
29	33-34	134	96	.72	134	1057	25	17.4
30	35-36	130	94	.72	124	1055	25	16.4
31	45-46	133	77	.58	139	997	24.5	16.4
32	47-48	133	103	.77	137	1006	24.5	16.4
33	49-50	138	85	.62	120	950	25	17
34	51-52	138	85	.62	115	1000	25	17
35	61-62	132	75	.57	132	923	24	16
36	63-64	132	75	.56	111	936	24	16

Roanoke Webster Brick (stiff mud, shale)

Sample No.	Surface Combination	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
1	s_1	100	10-20	151	1197	1/2	95	24	-	100	-
2	s_2	100	10-20	151	1197	1/2	95	30	-	100	-
3	s_2	100	10-20	143	1220	1/2	95	38	-	100	-
4	s_1	100	10-20	143	1120	1/2	100	32	100	-	-
5	s_2	120	10-20	132	1145	3/8	100	36	-	85	15
6	s_1	120	10-20	132	1145	1/4	100	45	85	-	15
7	s1	120	10-20	129	1211	1/4	100	33	100	-	-
8	s2	120	10-20	129	1211	1/4	100	47	95	-	5
9	s2	128	10-20	138	1045	3/8	100	48	-	100	-
10	s1	128	10-20	138	1045	3/8	100	42	100	-	-
11	s1	136	10-20	143	1045	1/4	100	38	100	-	-
12	s2	136	10-20	143	1045	1/4	100	59	40	30	30

Belden Buff Brick (stiff mud, clay)

Sample No.	Surface Combination	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
13	s_2	100	5	140	1147	3/8	95	49	80	-	20
14	s_1	100	5	140	1147	3/8	95	27	100	-	-
15	s_1	100	5	160	1244	1/4	100	29	65	-	35
16	s_2	100	5	160	1244	3/8	100	42	80	-	20
17	s_2	122	5	130	1029	1/4	100	54	75	-	25
18	s_1	122	5	130	1029	1/4	100	55	20	5	75
19	s_1	123	5	132	1029	1/4	100	50	25	15	60
20	s2	123	5	132	1029	3/8	100	50	20	30	50
21	s2	135	5	109	1033	1/4	100	73	20	-	80
22	s1	135	5	109	1033	1/4	100	44	25	15	60
23	s1	134	5	105	1102	1/4	100	36	50	5	25
24	s2	134	5	105	1102	1/4	100	56	65	-	35

Locher Brick (stiff mud, clay)

Sample No.	Surface Combination	Flow %	Original Suction Rate gtm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
25	s_1	117	10-20	141	1196	3/8	100	27	-	60	40
26	s_2	117	10-20	141	1196	1/2	95	57	-	100	-
27	s_2	125	10-20	133	1112	3/8	100	59	-	85	15
28	s_1	125	10-20	133	1112	1/4	100	35	50	-	50
29	s_2	97	10-20	145	1195	1/2	95	28	-	100	-
30	s_1	97	10-20	145	1195	1/2	100	29	75	-	25
31	s_1	103	10-20	140	1188	3/8	100	26	100	-	-
32	s_2	103	10-20	140	1188	1/2	95	51	-	80	20
33	s_2	134	10-20	134	1057	1/2	100	53	-	50	50
34	s_1	134	10-20	134	1057	1/4	100	38	-	70	30
35	s_1	130	10-20	124	1055	3/8	100	29	80	-	20
36	s_2	130	10-20	124	1055	1/4	100	58			

Belden Red (stiff mud, shale)

Sample No.	Surface Combination	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
37	s_2	119	5	127	1055	1/4	100	27	-	70	30
38	s_1	119	5	127	1055	1/4	100	28	80	-	20
39	s_1	123	5	141	1110	1/4	100	34	60	-	40
40	s_2	123	5	141	1110	1/4	100	23	-	100	-
41	s_2	103	5	128	1152	3/8	90	29	100	-	-
42	s_1	103	5	128	1152	3/8	100	1	100	-	-
43	s_1	105	5	134	1129	1/4	100	23	95	-	5
44	s_2	105	5	134	1129	3/8	100	39	95	-	5
45	s_2	133	5	139	997	1/4	100	57	15	30	55
46	s_1	133	5	139	997	1/4	100	38	60	-	40
47	s_1	133	5	137	1006	1/8	100	29	85	-	15
48	s_2	133	5	137	1006	1/4	95	25	100	-	-

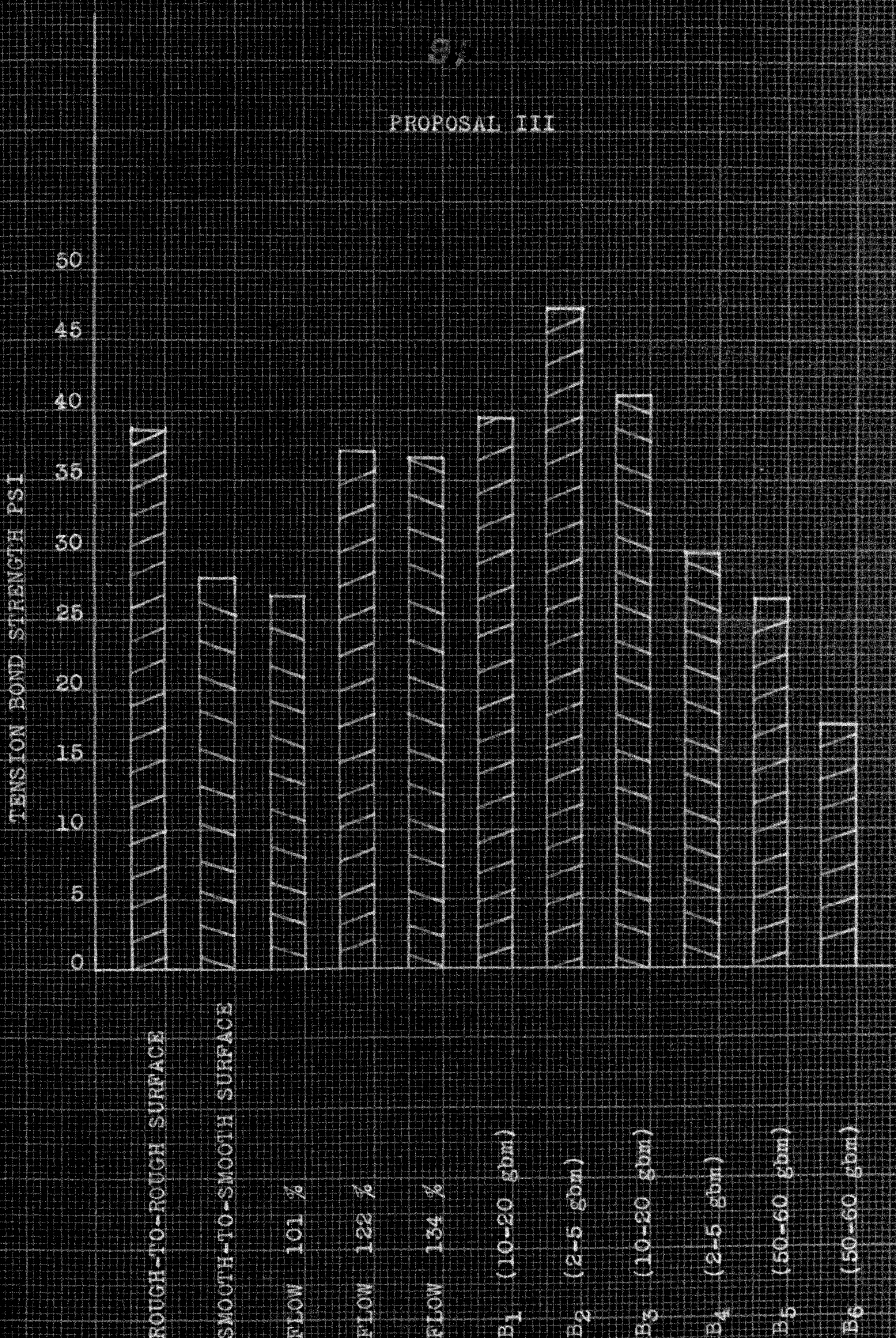
Old Virginia Brick (soft, mud, Clay)

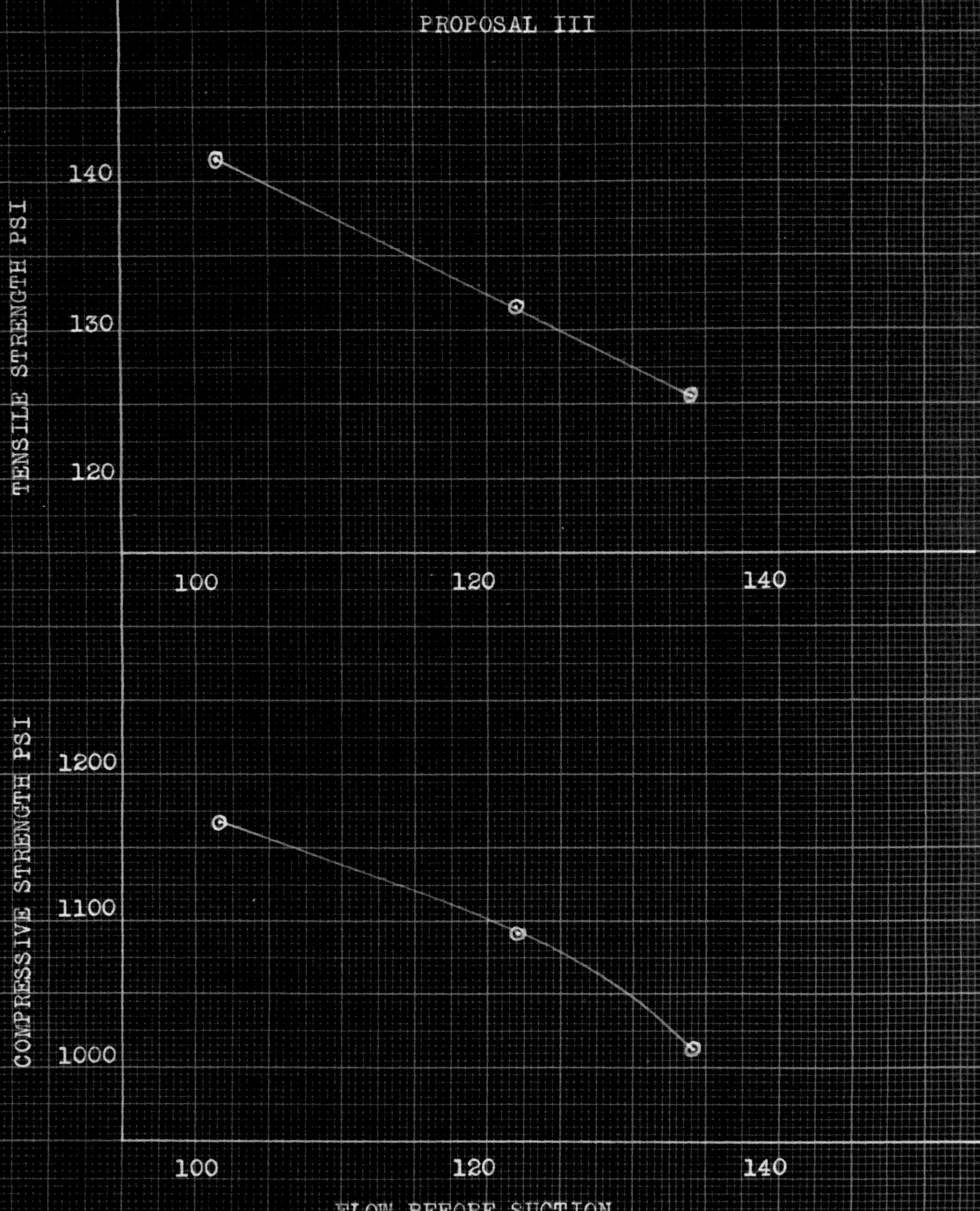
Sample No.	Surface Combination	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
49	s_1	138	50-60	120	950	1/2	95	22	-	100	-
50	s_2	138	50-60	120	950	3/8	95	31	-	100	-
51	s_2	138	50-60	115	1000	1/2	85	43	-	100	-
52	s_1	138	50-60	115	1000	3/8	95	28	-	100	-
53	s_2	124	50-60	107	1037	1/2	85	31	100	-	-
54	s_1	124	50-60	107	1037	1/2	95	21	-	100	-
55	s_1	123	50-60	134	1072	1/2	75	21	-	100	-
56	s_2	123	50-60	134	1072	1/2	80	30	-	100	-
57	s_2	103	50-60	129	1123	1/2	95	25	-	100	-
58	s_1	103	50-60	129	1123	1/2	100	22	100	-	-
59	s_1	102	50-60	136	1055	1/2	90	16	-	100	-
60	s_2	102	50-60	136	1055	1/2	95	26	85	-	15

Stile Brick (soft mud, clay)

Sample No.	Surface Combination	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
61	s2	132	50-60	132	932	1/2	100	2	-	100	-
62	s1	132	50-60	132	932	1/2	70	1	-	100	-
63	s1	133	50-60	111	936	1/2	100	21	100	-	-
64	s2	133	50-60	111	936	1/2	100	1	100	-	-
65	s2	122	50-60	142	988	3/8	80	19	100	-	-
66	s1	122	50-60	142	988	3/8	85	32	100	-	-
67	s1	122	50-60	132	1069	1/2	90	23	100	-	-
68	s2	122	50-60	132	1069	5/8	80	56	-	100	-
69	s2	100	50-60	145	1261	5/8	80	6	-	100	-
70	s1	100	50-60	145	1261	5/8	75	2	-	100	-
71	s1	103	50-60	147	1090	5/8	80	10	100	-	-
72	s2	103	50-60	147	1090	5/8	85	39	50	-	50

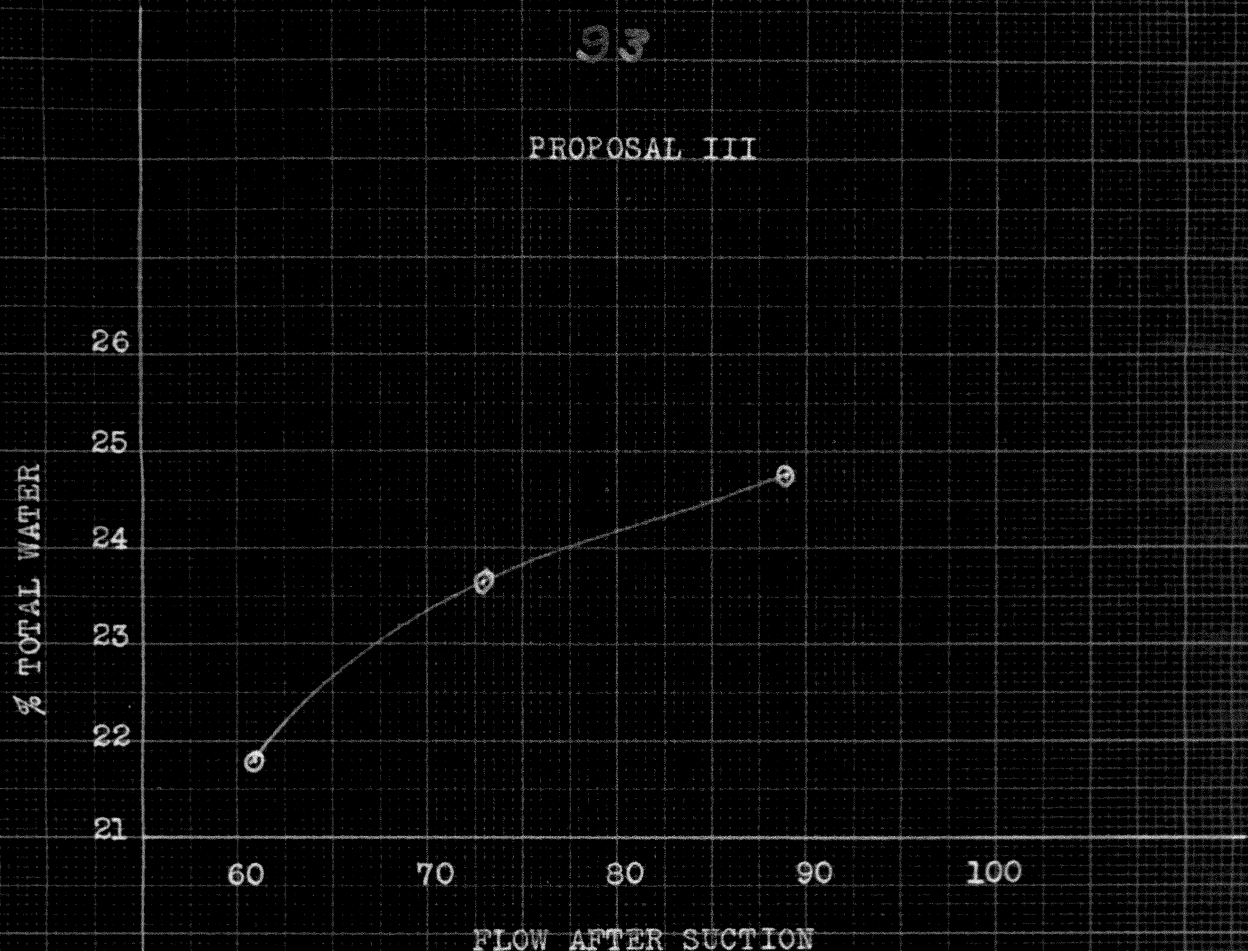
PROPOSAL III

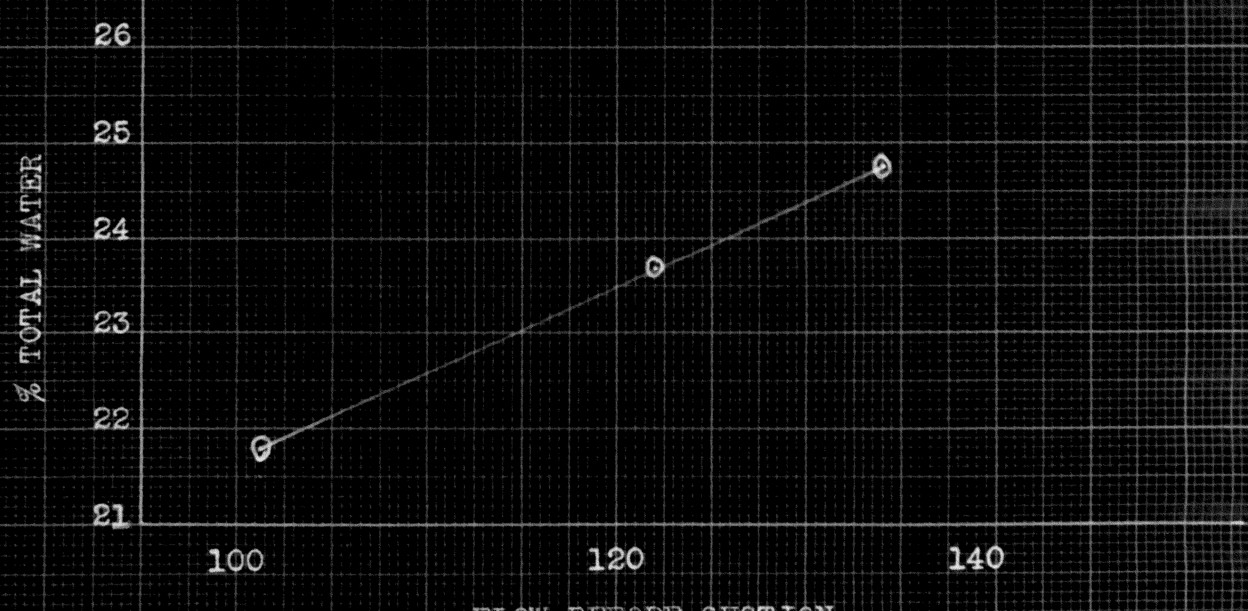




Tensile and Compressive Strength Curves of Plastic Lime Putty-Cement-Sand Mortar Used in Proposal III

PROPOSAL III





Flow - Before and After Curves of Lime Putty-Cement Sand Mortar Used in Proposal III

Proposal III

Analysis of Variance

Roanoke Webster Brick

Sources of Variation	D/F	SS	MS	F	Significance
Flows	2	501.2	206.6	5.7	*
Surface	1	161.2	161.3	3.7	
Flow x Surface	2	63.2	31.6	-	
Error	6	265.0	44.1		
Total	11	990.7			

Locher Brick

Sources of Variation	D/F	SS	MS	F	Significance
Flows	2	322.7	161.4	2.7	
Surfaces	1	1240.3	1240.3	20.9	**
Flow x Surface	2	116.7	58.4	-	
Error	6	356.0	59.3	-	
Total	11	2035.7			

* (F is greater than the 5 percent point; less than the 1 percent point; therefore judged significant.)

** (F is greater than the 1 percent point, therefore, judged highly significant.)

Proposal III

Analysis of Variance

Roanoke Webster vs Locher Brick

Sources of Variation	D/F	SS	MS	F	Significance
Brick	1	13.4	13.4	-	
Flows	2	778.5	389.3	7.5	**
Surfaces	1	1148.1	1148.1	22.2	**
Brick x Flow	2	45.4	22.7	-	
Brick x Surface	1	254.3	254.3	4.9	*
Flow x Surface	2	79.2	39.6	-	
Brick x Surface x Flow	2	99.9	49.9	-	
Error	12	621.2	51.7		
Total	23	3039.8			

* (F is greater than the 5 percent point; less than the 1 percent point, therefore judged significant.)

** (F is greater than the 1 percent point, therefore, judged highly significant.)

Proposal III

Analysis of Variance

Belden Buff Brick

Source of Variance	D/F	SS	MS	F	Significance
Flows	2	622.7	311.4	8.3	**
Surface	1	556.1	556.1	14.9	**
Flows x Surface	2	350.7	175.4	4.7	
Error	6	223.5	37.3		
Total	11	1753.0			

Belden Red Brick

Source of Variation	D/F	SS	MS	F	Significance
Flows	2	418.2	209.1	1.4	
Surface	1	184.1	184.1	1.3	
Flows x Surface	2	392.1	196.1	1.4	
Error	6	870.3	145.0		
	11	1864.9			

(** F is greater than the 1 percent point, therefore, judged highly significant.)

Proposal III

Analysis of Variance

Belden Buff vs Belden Red Brick

Source of Variation	D/F	SS	MS	F	Significance
Brick	1	1872.7	1872.7	20.5	**
Flows	2	927.2	463.6	5.1	*
Surface	1	704.2	704.2	7.7	*
Brick x Flow	2	131.6	65.8	-	
Brick x Surface	1	53.9	53.9	-	
Flow x Surface	2	609.1	304.6	3.3	
Brick x Surface x Flow	2	115.8	57.9	-	
Error	12	1094.0	91.2		
Total	23	5508.5			

* (F is greater than the 5 percent point; less than the 1 percent point; therefore judged significant)

** (F is greater than the 1 percent point, therefore, judged highly significant.)

Proposal III

Analysis of Variance

Stiles Brick

Source of Variation	D/F	SS	MS	F	Significance
Flows	2	1448.2	724.1	2.9	
Surface	1	96.4	96.4	-	
Flows x Surface	2	366.1	183.1	-	
Error	6	1493.0	248.8		
Total	11	3403.7			

Old Virginia Brick

Source of Variation	D/F	SS	MS	F	Significance
Flows	2	155.2	77.6	4.3	
Surface	1	261.2	281.2	14.3	**
Flows x Surface	2	15.3	7.7	-	
Error	6	109.0	18.2		
Total	11	540.7			

** (F is greater than the 1 percent point, therefore, judged highly significant.)

Proposal III

Analysis of Variance

Source of Variation	D/F	SS	MS	F	Significance
Brick	1	450.6	450.6	3.4	
Flows	2	609.7	304.9	2.3	
Surface	1	337.5	337.5	2.5	
Brick x Flow	2	993.7	496.9	3.7	
Brick x Surface	1	20.2	20.2	-	
Flow x Surface	2	120.3	60.2	-	
Brick x Surface x Flow	2	261.0	130.5	-	
Error	12	1611.0	134.3		
Total	23	4404.0			

Proposal III

Analysis of Variance

Source of Variation	D/F	SS	MS	F	Significance
Replications	1	144.5	144.5	1.6	
Brick	5	7092.3	1418.5	15.6	**
Surface	1	2069.4	2069.4	22.7	**
Flows	2	1602.5	801.3	8.8	**
Brick x Surface	5	448.1	89.6	1.0	
Brick x Flows	10	1883.5	188.4	2.0	
Surface x Flow	2	228.4	114.2	1.3	
Brick x Surface x Flow	10	1057.6	105.8	1.2	
Error	35	3181.7	90.9		
Total	71	17708.			

** (F is greater than the 1 percent point; therefore, judged highly significant)

Proposal III

From the results of proposal III the following conclusions appear justified.

(1) Six brick, (three types) and three flows being represented the rough-to-rough surface shows a higher average strength than the smooth-to-smooth surface.

(2) The tension-bond strength increases to a maximum as flow increases and then drops off.

(3) Of the three brick type the stiff mud, clay shows the highest strength followed by stiff mud shale and soft mud clay.

(4) The bricks in the 10-20 gbm suction rate group do not vary significant in their strength, but the brick in the less than 5 gbm suction rate group do vary considerably in tension-bond strength. This may suggest that in the 10-20 gbm group it doesn't matter if the brick is stiff mud clay or stiff mud shale, the strength will be approximately equal, but in the less than 5 gbm group the difference between the steff mud clay and steff mud shale is highly different.

(5) In the soft mud clay brick there is not a difference in brick although one gives higher average results in this proposal than in the other.

(6) From the means it is indicated the results of this proposal are reproducable.

Proposal IV

A comparison of a make of brick of original high suction rate with a representative of the same make of brick and the same suction rate, but which has been adjusted to successively lower suction rates.

In previous work it was necessary to adjust the suction rates of certain makes of brick from higher to lower values becuase the air-dry suction rates prescribed for the program of tests were not available for these makes of brick. It appeared that after such adjustment was made the performance characteristics of the tension-bond specimens were relatively stable regardless of the suction rate to which they were adjusted. It was felt that this should receive some attention by a more extensive program of testing. With this in mind the following is submitted.

Variables in Proposal

Kind of brick	1
Suction Rates	3
Sand Grading	medium
Mortar Mix	1:1:6
Mortar Flows	3
Joint Thickness	½"
Type Test	tension
No Specimens	27

In adjusting suction rate, the bricks were soaked under water for a pre-determined length of time, wrapped in a saturated canvas cloth and placed under a box for one hour, after which time they were ready to be formed into couplets.

Ledger of Symbols

Mortar Flows

m_1 .... 100–110 %

m_2 .... 125–135 %

m_3 .... 115–125 %

Brick

b_1 .... Roanoke Webster (stiff mud shale)

Mortar Mix

m_1 .... 1.0L 1.0L 6.05

Suction Rates

s_1 .... 45–55 gbm

s_2 .... 15–25 gbm

s_3 .... 30–40 gbm

All brick were originally in the suction rate range of 45–55 gbm but suction rates 2 and 3 were arrived at by the procedure given on the previous page.

Program for Forming Samples

First Replication

Mortar Flows Suction Rates	M_1	M_2	M_3
S_1	(1)	(10)	(19)
S_2	(2)	(11)	(20)
S_3	(3)	(12)	(21)

Second Replication

Mortar Flows Suction Rates	M_1	M_2	M_3
S_2	(4)	(13)	(22)
S_3	(5)	(14)	(23)
S_1	(6)	(15)	(24)

Third Replication

Mortar Flows Suction Rates	M_1	M_2	M_3
S_3	(7)	(16)	(25)
S_1	(8)	(17)	(26)
S_2	(9)	(18)	(27)

The numbers in parenthesis indicate the order of forming of the samples. A total of nine mortar batches was used in laying up the proposal.

Procedure

Mixing the Mortar

Mixing of mortar in Proposal IV is the same as in Proposal I.

Testing of Mortar Flow

Testing the mortar flows in Proposal IV is the same as in Proposal I.

Testing the Mortar Retentivity

Testing the mortar retentivity in Proposal IV is the same as in Proposal I.

The Making the Test Specimens

Making the Test specimens for Proposal IV is the same as in Proposal I, with the exception that nine mortar batches completed the Proposal and three tension-bond specimens were formed with each batch.

Storing the Specimen

Storing the specimens in Proposal IV is the same as in Proposal I.

Dyeing the Tension-Bond Specimens

Dyeing the tension-bond specimens for Proposal IV is the same as in Proposal I.

Testing the Specimens

Testing the specimens in Proposal IV is the same as in Proposal I.

Mortar Batches for Proposal IV

Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Added Water
				Flow 100-110 %				
1	1-3	105	56	.53	159	1287	21.2	13.3
2	4-6	107	58	.54	159	1249	21.2	13.3
3	7-9	110	66	.60	148	1262	21.2	13.3
				Flow 125-135 %				
4	10-12	133	83	.62	125	1056	23	15.1
5	13-15	127	64	.50	121	1013	23	15.1
6	16-18	127	66	.52	122	1055	23	15.1
				Flow 115-125 %				
7	19-21	120	64	.53	128	1138	22.1	14.2
8	22-24	119	61	.51	134	1040	22.1	14.2
9	25-27	119	61	.51	135	1151	22.1	14.2

Roanoke Webster Brick Rough-to-Rough

Flow 100-110 %

Sample No.	Flow %	Original Suction Rate gbm	Adjusted Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
1	105	45-55	-	158	1287	1/2	100	11	100	-	-
2	105	45-55	15-25	159	1287	1/2	100	14	100	-	-
3	105	45-55	30-40	159	1287	1/2	100	5	100	-	-
4	107	45-55	15-25	159	1249	1/2	100	24	100	-	-
5	107	45-55	30-40	159	1249	1/2	100	22	100	-	-
6	107	45-55	-	159	1249	1/2	100	14	100	-	-
7	110	45-55	30-40	148	1262	1/2	95	13	100	-	-
8	110	45-55	-	148	1262	1/2	95	16	100	-	-
9	110	45-55	15-25	148	1262	1/2	95	32	100	-	-

Roanoke Webster Brick Rough-to-Rough

Flow 125-130 %

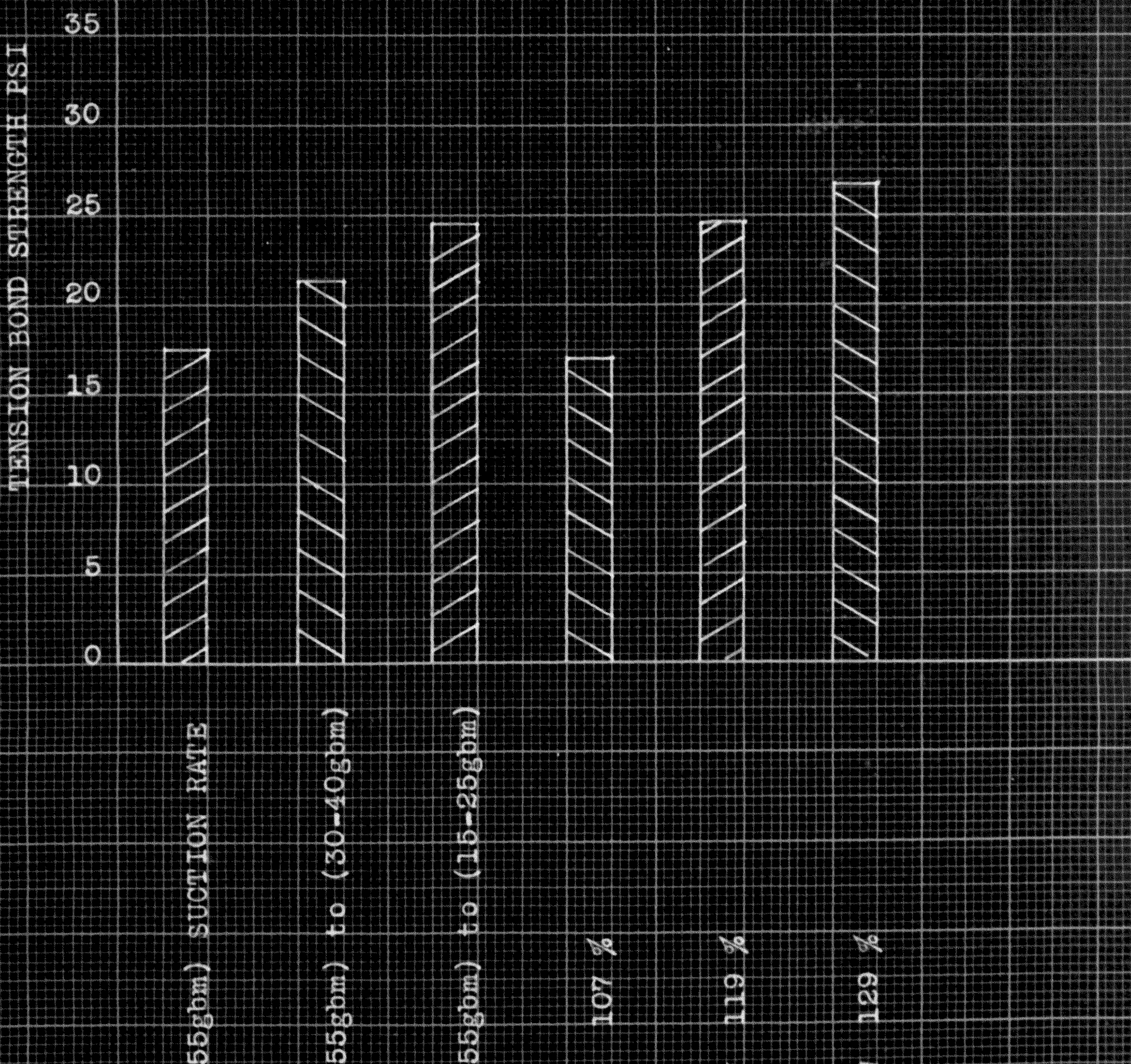
Sample No.	Flow %	Original Suction Rate gbm	Adjusted Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
10	133	45-55	-	125	1056	1/2	95	28	-	100	-
11	133	45-55	15-25	125	1056	1/2	95	36	100	-	-
12	133	45-55	30-40	125	1056	1/2	95	26	100	-	-
13	127	45-55	15-25	121	1013	1/2	95	32	-	100	-
14	127	45-55	30-40	121	1013	1/2	100	19	100	-	-
15	127	45-55	-	121	1013	1/2	100	17	-	100	-
16	127	45-55	30-40	122	1055	1/2	95	29	-	100	-
17	127	45-55	-	122	1055	1/2	95	21	100	-	-
18	127	45-55	15-25	122	1055	1/2	100	34	100	-	-

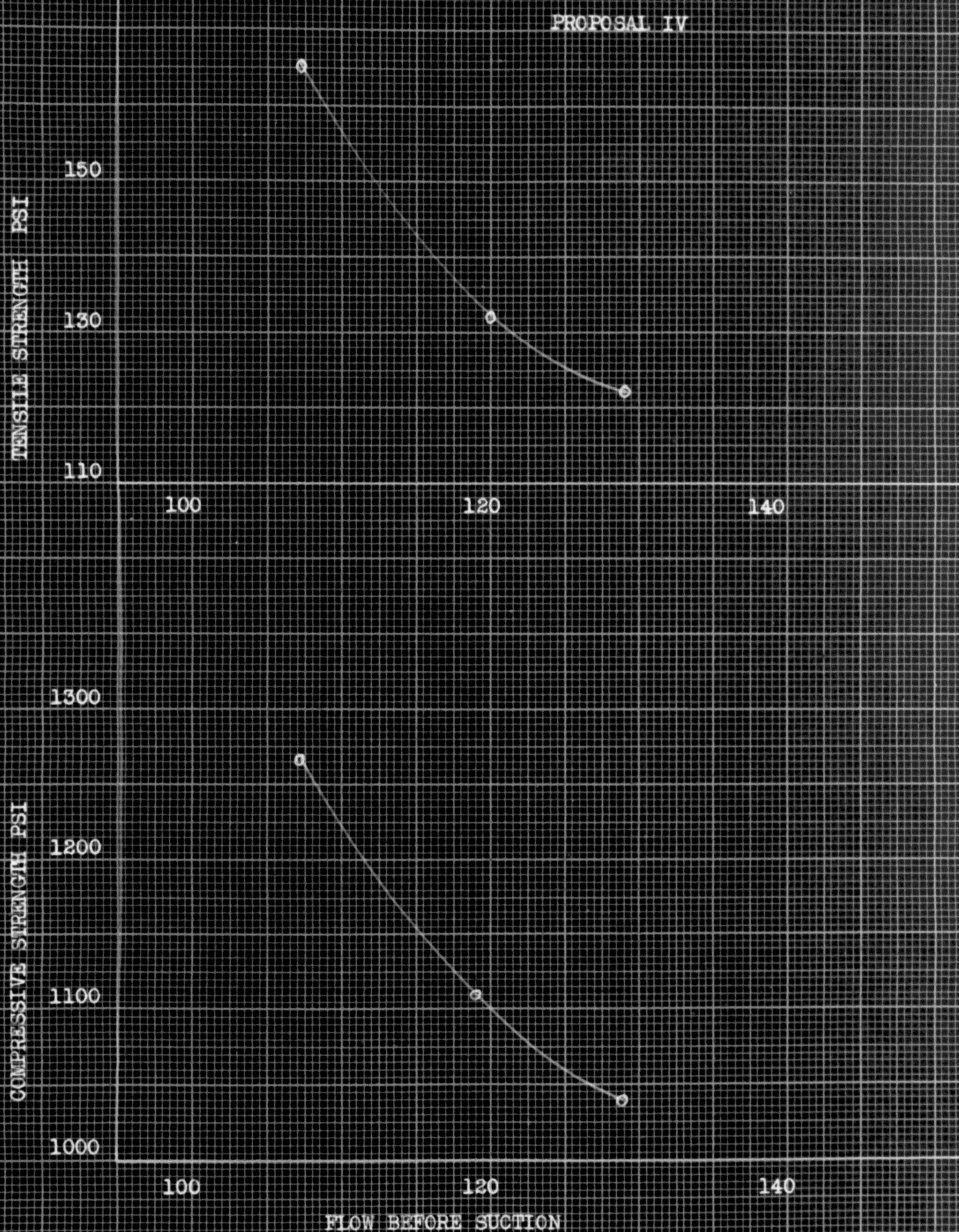
Roanoke Webster Brick Rough-to-Rough

Flow 115-125 Percent

Sample No.	Flow %	Original Suction Rate gbm	Adjusted Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
19	120	45-55	-	128	1138	1/2	95	18	100	-	-
20	120	45-55	15-25	128	1138	1/2	95	38	100	-	-
21	120	45-55	30-40	128	1138	1/2	95	28	100	-	-
22	119	45-55	15-25	134	1040	1/2	100	30	100	-	-
23	119	45-55	30-40	134	1040	1/2	90	23	100	-	-
24	119	45-55	-	134	1040	1/2	95	16	100	-	-
25	119	45-55	30-40	135	1151	1/2	95	31	-	100	-
26	119	45-55	-	135	1151	1/2	95	14	100	-	-
27	119	45-55	15-25	135	1151	1/2	95	24	100	-	-

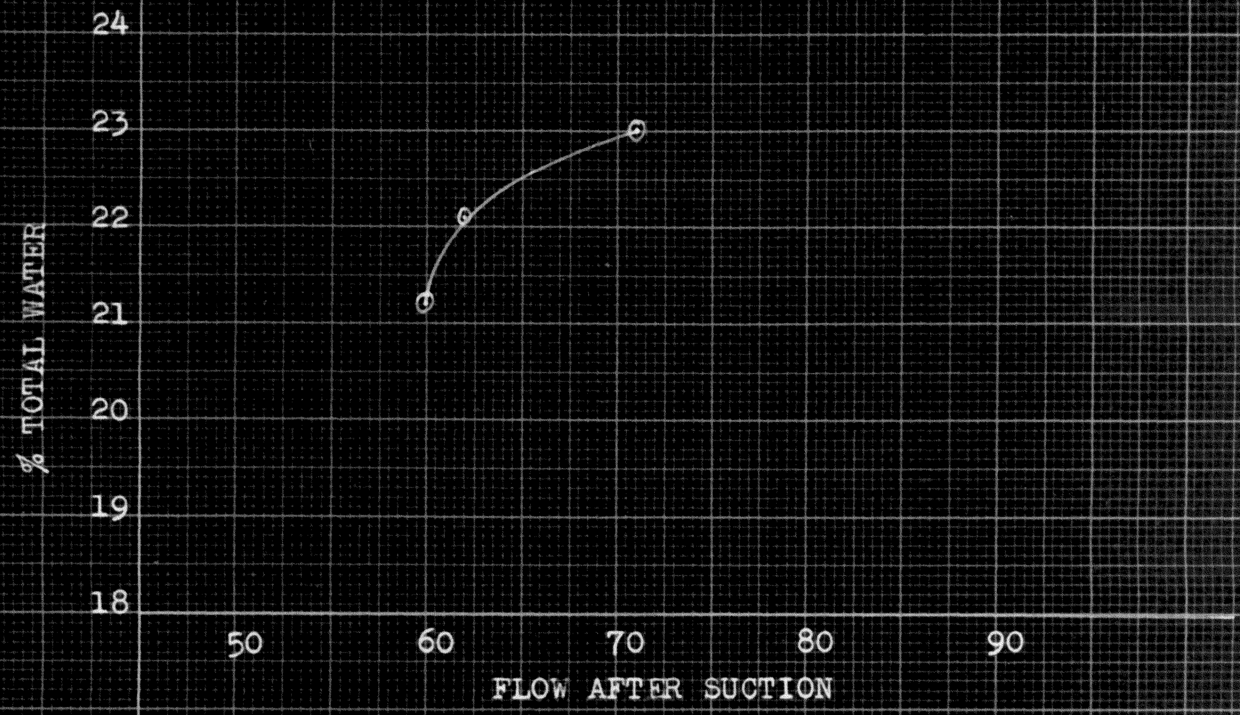
PROPOSAL IV

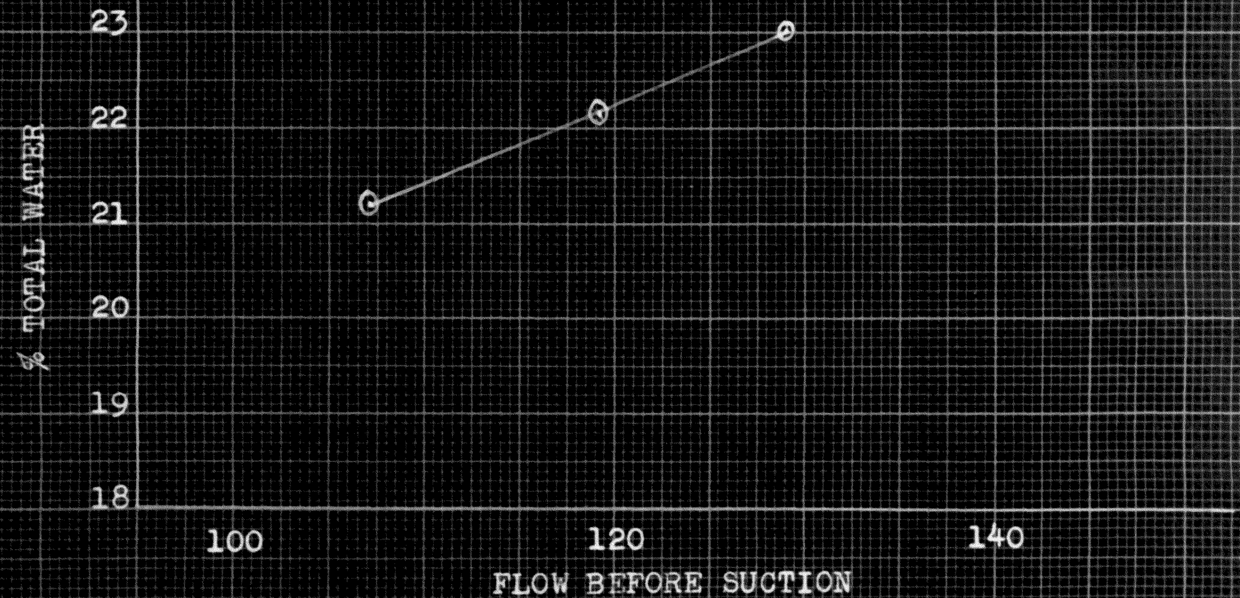

TENSION BOND STRENGTH PSI
35
30
25
20
15
10
5
0
(45-55gbm) SUCTION RATE
(45-55gbm) to (30-40gbm)
(45-55gbm) to (15-25gbm)
FLOW 107 %
FLOW 119 %
FLOW 129 %



Tensile and Compressive Strength Curves of Plastic Lime Putty-Cement-Sand Mortar Used in Proposal IV

PROPOSAL IV





Flow - Before and After Curves of Lime Putty-Cement Sand Mortar Used in Proposal IV

Proposal IV

Analysis of Variance

Source of Variation	D/F	SS	MS	F	Significance
Replications	2	20.2	10.1		
Suction Rates	2	688.2	344.1	9.7	**
Flows	2	461.6	230.8	6.5	*
Suction Rate x Flows	4	132.9	33.2	-	
Error	16	569.8	35.6		
Total	26	1872.7			

* (F is greater than the 5 percent point; less than the 1 percent point; therefore judged significant)

**(F is greater than the 1 percent point, therefore, judged highly significant.)

Proposal IV

From the results the following conclusions seem justified:

(1) The more the suction rate of a brick is adjusted to the 15-25 gbm bracket, the higher the tension bond strength

(2) With adjusted suction rates as with unadjusted suction rate, the mortar bond strength increases with mortar flows to a maximum.

(3) From the mean it is indicated the results of this propoal are reproducable.

Proposal V

Effect of adjustment of suction rate on bond properties.

In a previous project it was indicated that there is a difference in the performance characteristics of bond specimens depending upon how the suction rate is arrived at. For example, 15-25 gbm has its characteristic properties with a given mortar and brick. Suppose, however, that the same make of brick be used with the same mortar, but the suction of 15-25 gbm is arrived at by taking representatives of a higher suction rate, say 40-50 gbm, and adjusting them to the 15-25 gbm range. Will the performance characteristics be the same? That is, for a given make of brick and mortar, are the performance characteristics of the bond at a specified suction rate independent of the manner in which that suction rate is obtained?

Variables in Proposal

Kind of Brick	1
Mortar Flow	3
Suction Rate	(2 ways) 1
Joint thickness	½"
Sand Grading	medium
Total no. of specimens	12

Ledger of Symbols

Kind of Brick

b . . . . Roanoke Webster (stiff-mud shale)

Suction Rates

s_1 . . . . Unadjusted

s_2 . . . . Adjusted

Flow

f_1 . . . . 95-105 %

f_2 . . . . 115-125 %

f_3 . . . . 125-135 %

Program for Forming Samples

First Replication

Mortar Flows Suction Rates	F_1	F_2	F_3
S_1	(1)	(5)	(9)
S_2	(2)	(6)	(10)

Second Replication

Mortar Flows Suction Rates			
S_1	(3)	(7)	(11)
S_2	(4)	(8)	(12)

The numbers in parenthesis indicate the order of forming of the samples. A total of six mortar batches was used in laying up the proposal.

Procedure

Mixing the Mortar

Mixing of mortar in Proposal V is the same as in Proposal I.

Testing of Mortar Flow

Testing the mortar flows in Proposal V is the same as in Proposal I.

Testing the Mortar Retentivity

Testing the mortar retentivity in Proposal V is the same as in Proposal I.

Making the Test Specimens

Making the test specimens for Proposal V is the same as in Proposal I with the exception that six mortar batches completed the Proposal and two tension-bond specimens were formed with each batch.

Storing the Specimens

Storing the specimens in Proposal V is the same as in Proposal I.

Dyeing the Tension-Bond Specimens

Dyeing the tension-bond specimens for Proposal V is the same as in Proposal I.

Testing the Specimens

Testing the specimens in Proposal V is the same as in Proposal I.

Mortar Batches for Proposal V

Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Added Water
				Flow 95-105 %				
1	1-2	98	55	.52	150	1238	21.2	13.3
2	3-4	100	58	.58	145	1279	21.2	13.3
				Flow 115-125 %				
3	5-6	122	77	.63	144	1173	23.2	15.3
4	7-8	125	77	.62	152	1130	23.2	15.3
				Flow 125-135 %				
5	9-10	130	73	.56	118	1147	24	16.1
6	11-12	127	70	.55	125	1177	24	16.1

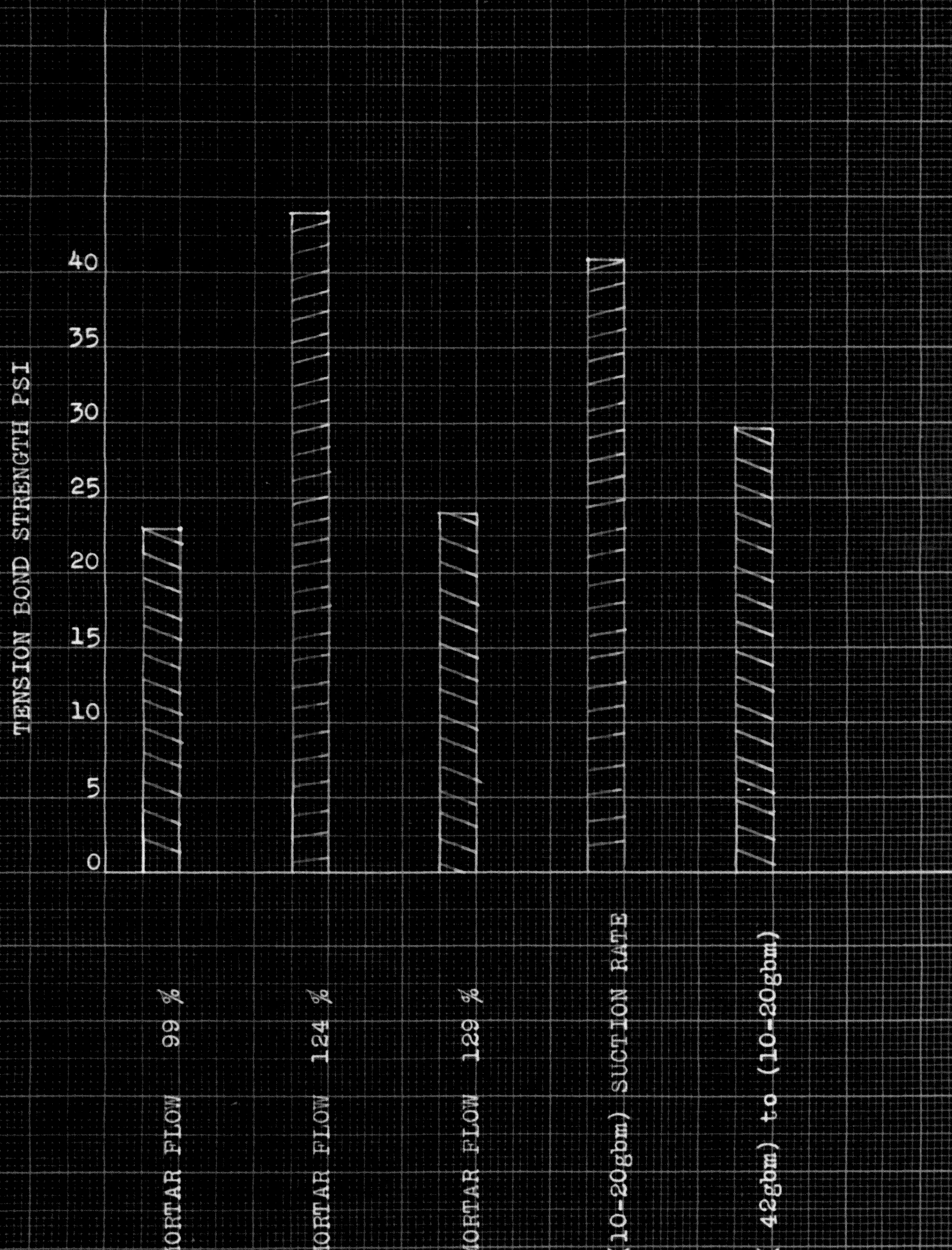
Roanoke Webster Brick Rough-to-Rough

All Flows

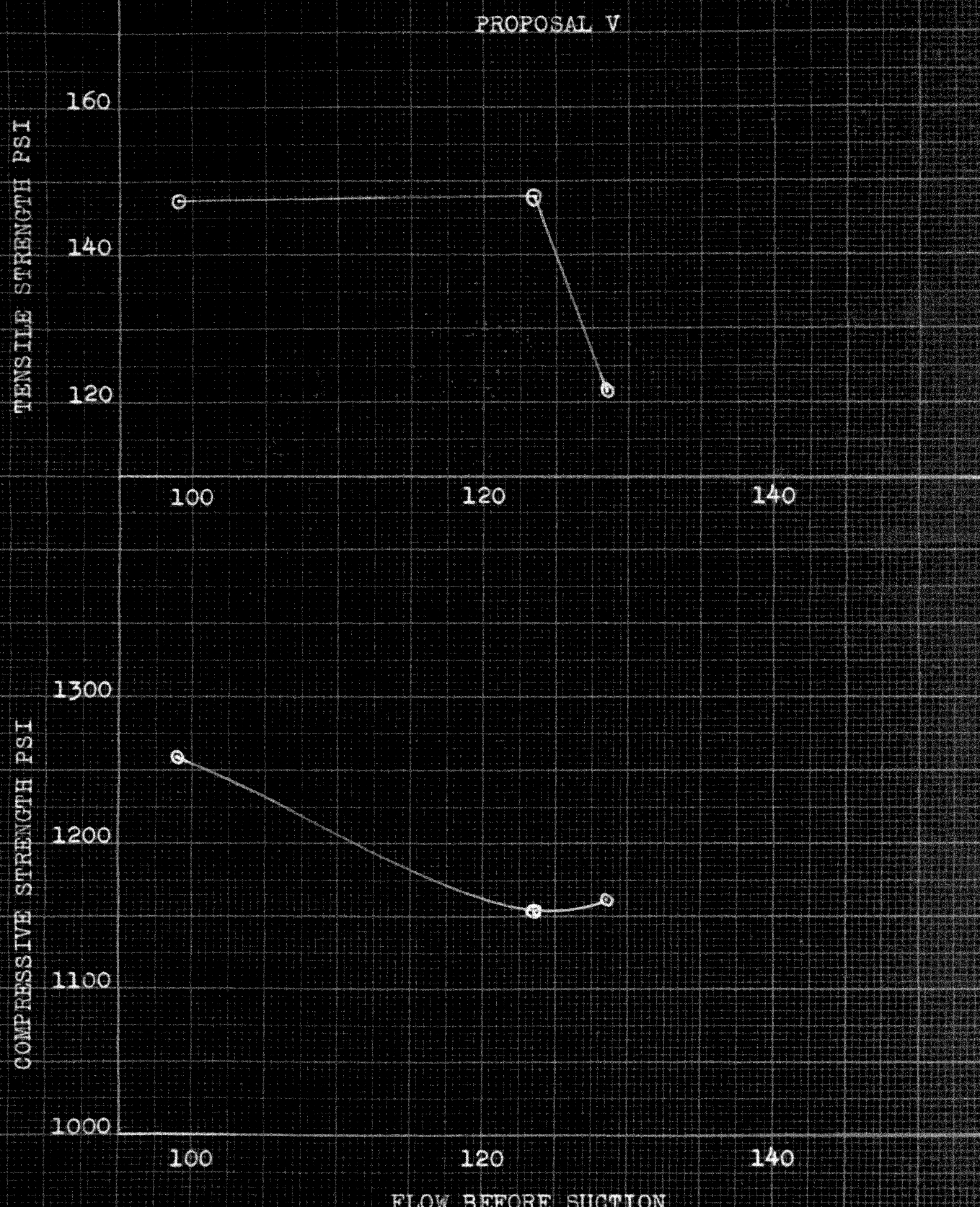
Sample No.	Flow %	Original Suction Rate gbm	Adjusted Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
1	98	10-20	-	150	1238	1/2	95	18	100	-	-
2	98	42£1	10-20	150	1238	1/2	85	14	100	-	-
3	100	42£1	10-20	145	1279	1/2	90	25	100	-	-
4	100	10-20	-	145	1279	1/2	95	35	100	-	-
5	122	10-20	-	144	1173	1/2	95	54	-	100	-
6	122	42£1	10-20	144	1173	1/2	95	22	100	-	-
7	125	42£1	10-20	152	1130	1/2	95	47	-	100	-
8	125	10-20	-	152	1130	1/2	100	53	-	95	5
9	130	10-20	-	118	1147	1/2	100	37	95	-	5
10	130	42£1	10-20	118	1147	1/2	90	1	-	100	-
11	127	42£1	10-20	125	1177	1/2	85	9	-	100	-
12	127	10-20	-	125	117	1/2	100	48	100	-	-

1

PROPOSAL V

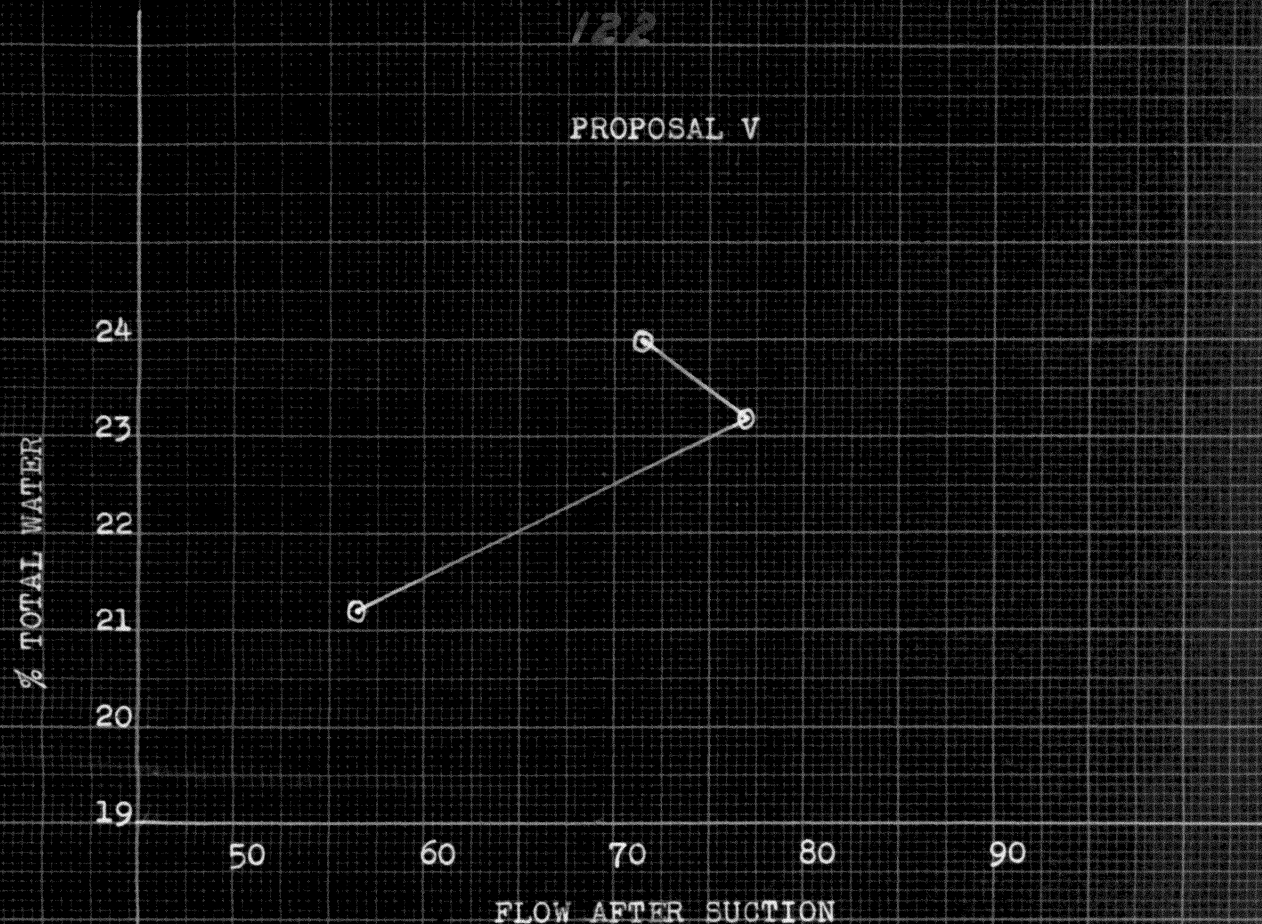


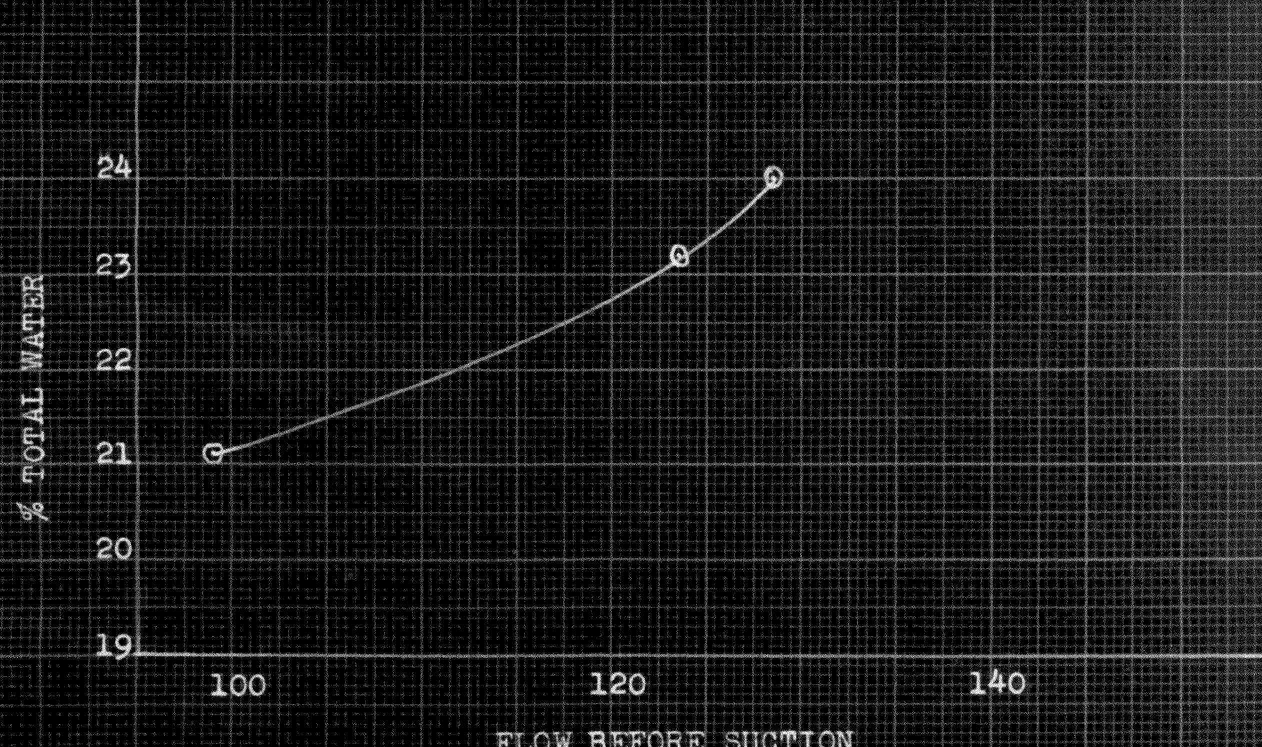
TENSION BOND STRENGTH PSI
0
5
10
15
20
25
30
35
40
MORTAR FLOW 99 %
MORTAR FLOW 124 %
MORTAR FLOW 129 %
(10-20gbm) SUCTION RATE
(42gbm) to (10-20gbm)



Tensile and Compressive strength Curves of Plastic Lime Putty-Cement-Sand Mortar Used in Proposal V

PROPOSAL V





Flow - Before and After Curves of Lime Putty-Cement Sand Mortar Used in Proposal V

Proposal V

Analysis of Variance
Roanoke Webster Brick

Source of Variation	D/F	SS	MS	F	Significance
Replication	1	450.3	450.3	14.1	*
Flow	2	1213.5	606.8	18.9	**
Suction	1	1374.3	1374.3	42.9	**
Flow x Suction	2	394.2	197.1	6.2	**
Error	5	160.2	32.2		
Total	11	3592.5			

*(F is greater than the 5 percent point; less than the 1 percent point, therefore judged significant)

**(F is greater than the 1 percent point, therefore, judged highly significant.)

Proposal V

The results make the following conclusions seem justifiable:

(1) Although the suction rate for the brick is the same, one is arrived at by adjustment, the brick of original suction rate (10-20 gbm) shown much higher tension-bond strength.

(2) The tension-bond strength varied although the suction rates are the same. This seems to indicate a difference in bond due to texture of the bricks as texture is the only variable unaccounted for.

(3) With an increase in mortar flow the tension-bond strength increased to a maximum and then drops off.

Proposal VI

Two brick types of varied suction rate; one suction rate low (Belden Buff, stiff-mud clay); one suction rate medium (Roanoke-Webster, stiff-mud shale); each brick type at two different textures, and two flows were used.

Variables in Proposal

Kind of Brick (suction rate)....................2
Texture...2
Flow..2
Mortar..1
Total No. Specimens............................32

The factors to be studied in difference in suction rates; difference in brick; difference in flows; and difference in texture of the brick.

Ledger of Symbols

Brick

b_1..Belden Buff

b_2..Roanoke Webster

Texture

s_1...Smooth-to-Smooth

s_2...Rough-to-Rough

Flow

f_1...110-120 %

f_2...125-135 %

Program for Forming Samples

First Replication

	f_1 b_1	f_1 b_2		f_2 b_1	f_2 b_2
s_1	(2)	(4)	s_1	(18)	(20)
s_2	(1)	(3)	s_2	(17)	(19)

Second Replication

s_1	(5)	(7)	s_1	(21)	(23)
s_2	(6)	(8)	s_2	(22)	(24)

Third Replication

s_1	(12)	(10)	s_1	(28)	(26)
s_2	(11)	(9)	s_2	(27)	(25)

Fourth Replication

s_1	(15)	(13)	s_1	(31)	(29)
s_2	(16)	(14)	s_2	(32)	(30)

Numbers in parenthesis indicate the order of forming samples

Procedure

Mixing the Mortar

Mixing of Mortar is in Proposal VI as it is in Proposal I.

Testing of Mortar Flow

Testing the mortar flows in Proposal VI is the same as in Proposal I.

Testing the Mortar Retentivity

Testing the mortar retentivity in Proposal VI is the same as in Proposal I.

Making the Test Specimens

Making the test specimens for Proposal VI is the same as in Proposal I, with the exception that eight mortar batches completed the Proposal and four tension-bond specimens were formed with each batch.

Storing the Specimen

Storing the specimens in Proposal VI is the same as in Proposal I.

Dyeing the Tension-Bond Specimen

Dyeing the tension-bond specimens for Proposal VI is the same as in Proposal I.

Testing the Specimens

Testing the specimens in Proposal VI is the same as in Proposal I.

Mortar Batches for Proposal VI

Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Added Water
				Flow 110-120 %				
1	1-4	116	61	.53	132	1193	21.5	13.6
2	5-8	114	58	.51	113	1188	21.5	13.6
3	9-12	114	58	.51	121	1179	21.5	13.6
4	13-16	111	58	.52	118	1104	21.5	13.6
				Flow 125-135 %				
5	17-20	130	69	.53	122	1058	23.5	15.5
6	21-24	130	64	.49	118	954	23.5	15.5
7	25-28	133	67	.50	122	1049	23.5	15.5
8	29-32	134	69	.51	124	988	23.5	15.5

Proposal VI Flow 110-120 %

Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Surface Combination
1	b_1	116	5	132	1193	1/2	95	41	100	-	-	s_2
2	b_1	116	5	132	1193	1/4	100	24	100	-	-	s_1
3	b_2	116	10-20	132	1193	1/2	100	33	100	-	-	s_2
4	b_2	116	10-20	132	1193	1/2	100	24	100	-	-	s_1
5	b_1	114	5	113	1188	3/8	100	20	100	-	-	s_1
6	b_1	114	5	113	1188	1/2	95	31	100	-	-	s_2
7	b_2	114	10-20	113	1188	1/2	100	30	100	-	-	s_1
8	b_2	114	10-20	113	1188	1/2	100	27	100	-	-	s_2

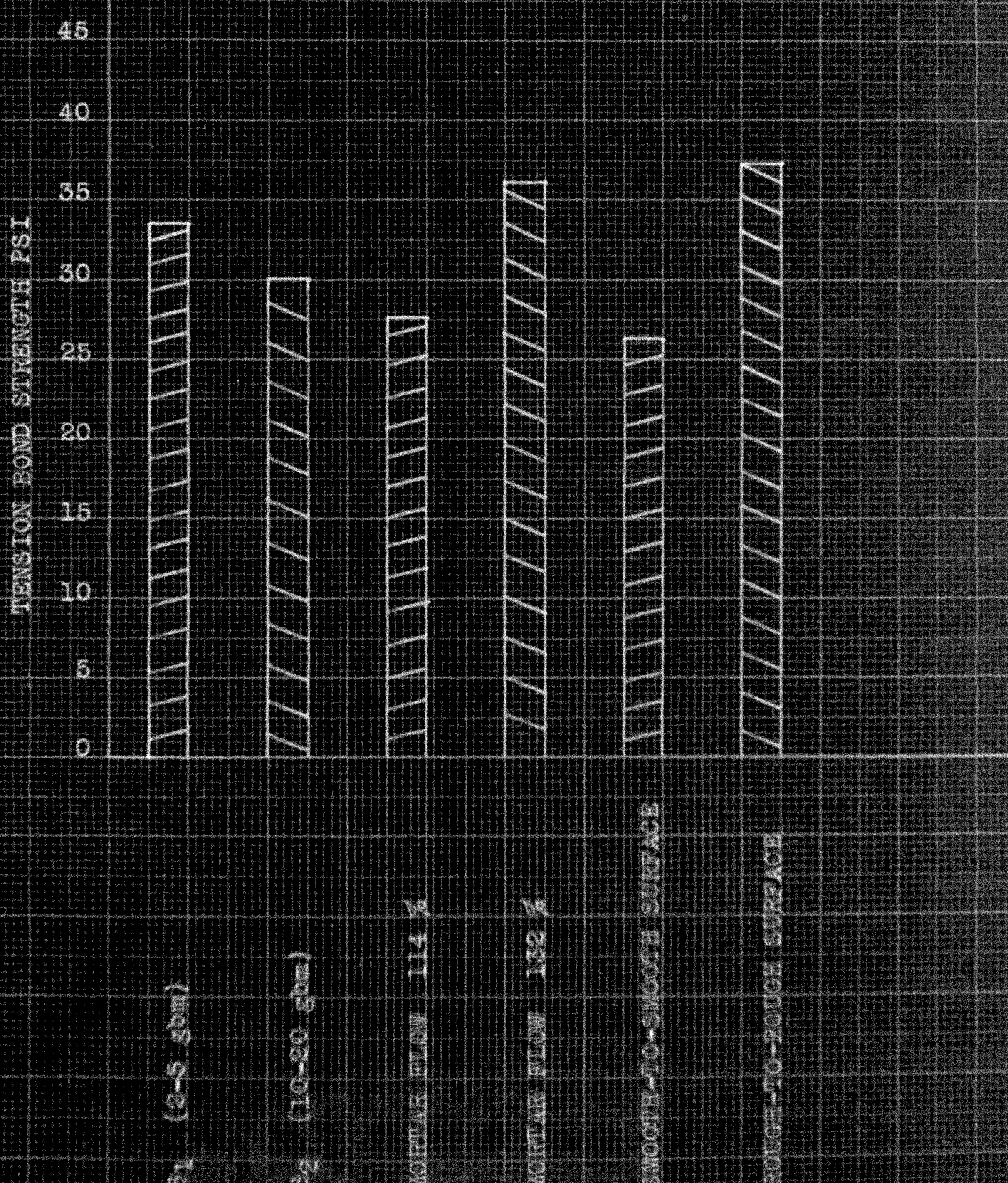
Proposal VI Flow 110-120 %

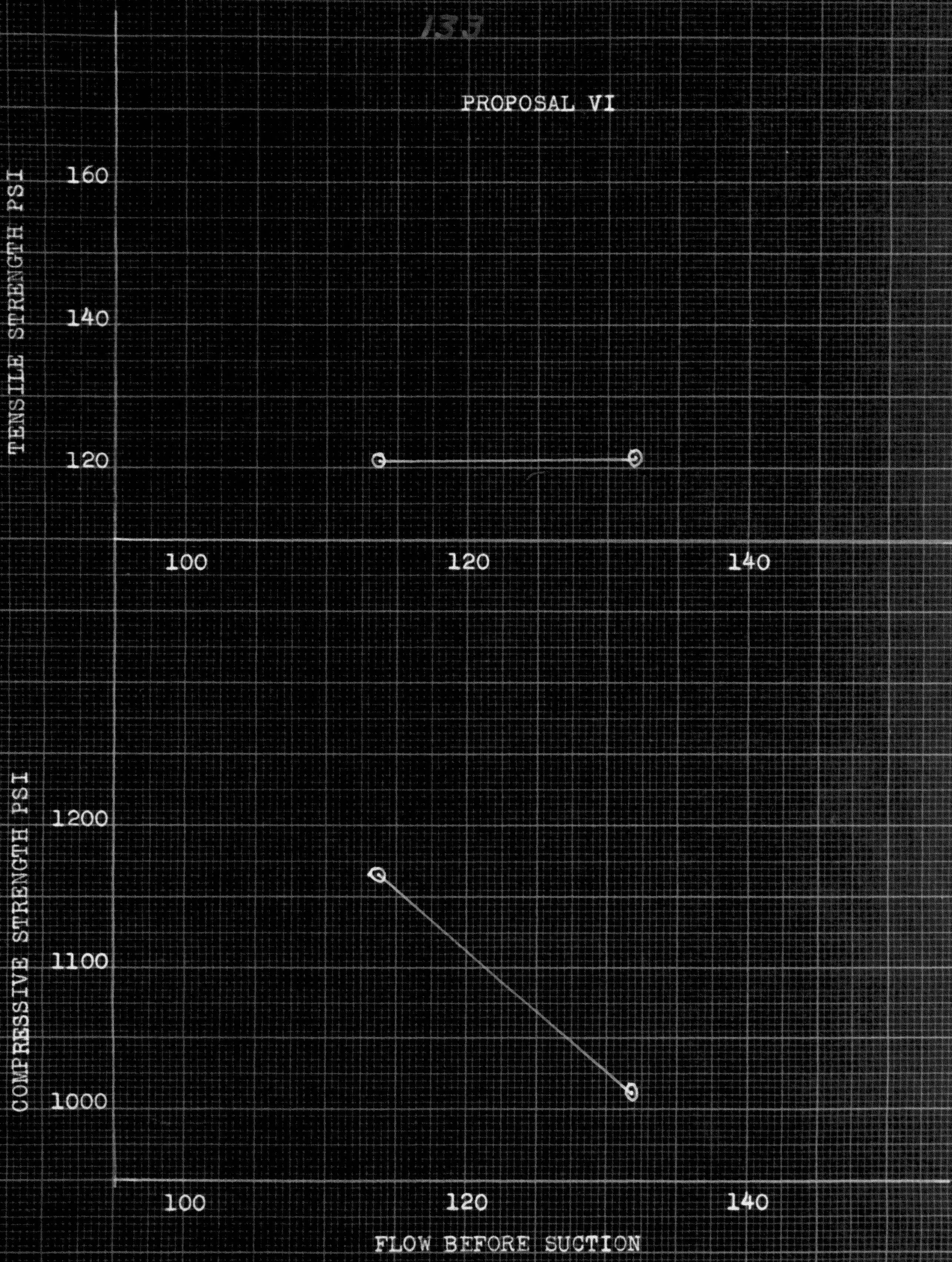
Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Strength P.S.I. T	Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M	Surface Combination
9	b_2	114	10-15	112	1169	1/2	100	30	100	-	-	s_2
10	b_2	114	10-15	112	1179	1/2	100	31	100	-	-	s_1
11	b_1	114	5	112	1179	1/2	100	38	60	-	40	s_2
12	b_1	114	5	112	1179	3/8	95	23	100	-	-	s_1
13	b_2	114	10-15	118	1104	1/2	100	22	100	-	-	s_1
14	b_2	114	10-15	118	1104	1/2	100	29	100	-	-	s_2
15	b_1	114	5	118	1104	3/8	95	23	100	-	-	s_1
16	b_1	114	5	118	1104	1/2	95	33	80	-	20	s_2

Proposal VI Flow 125-135 %

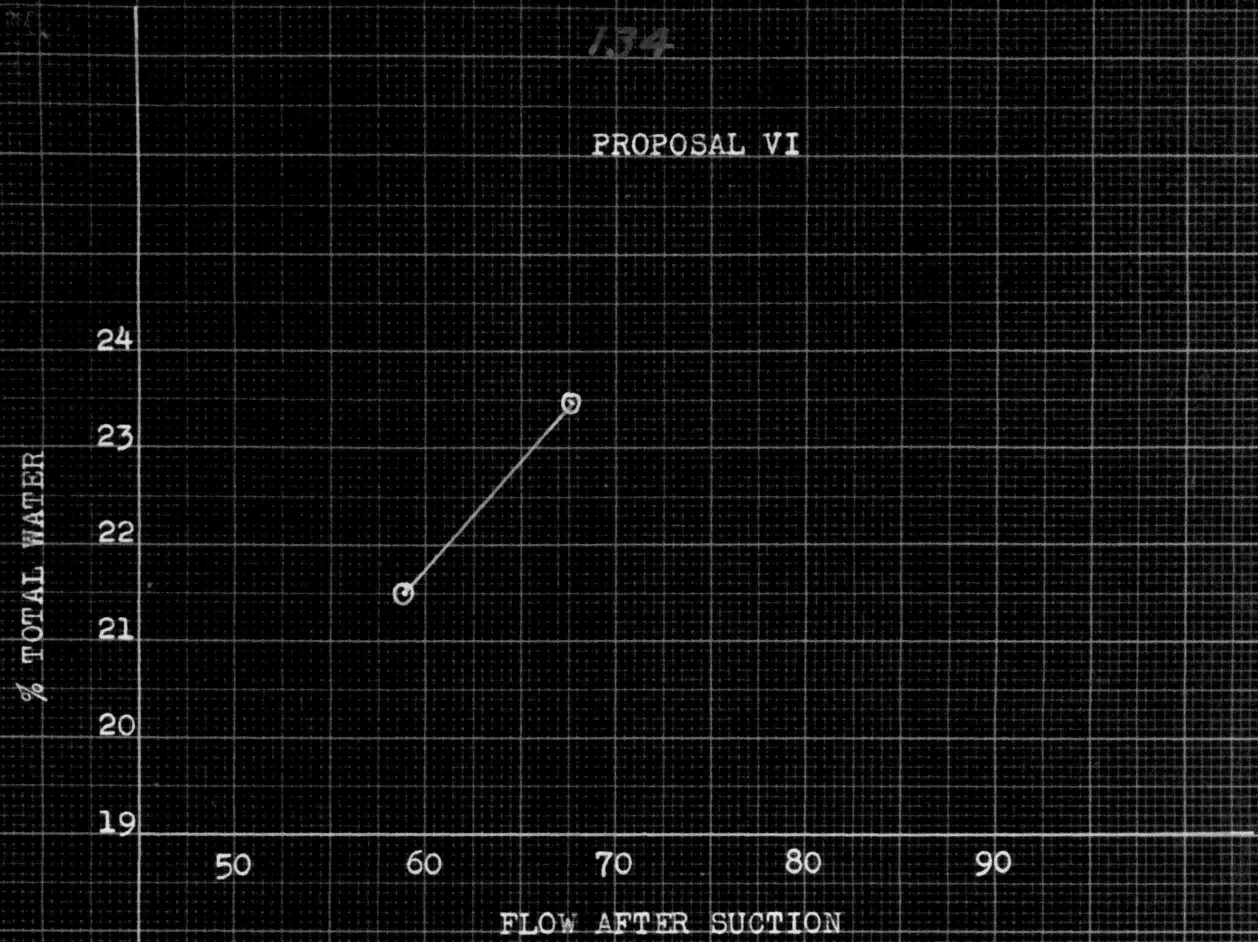
Sample No.	Brick Type	Flow %	Original Suction Rate gbm	Strength P.S.I. T	Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Failure Type T	Failure Type B	Failure Type M	Surface Combination
17	b_1	130	5	122	1058	1/2	95	42	100	-	-	s_2
18	b_1	130	5	122	1058	1/4	95	30	95	-	5	s_1
19	b_2	130	10-15	122	1058	1/2	100	39	100	-	-	s_2
20	b_2	130	10-15	122	1058	1/2	100	33	100	-	-	s_1
21	b_1	130	5	122	1058	1/4	100	24	90	-	10	s_1
22	b_1	130	5	122	1058	1/2	100	51	50	-	50	s_2
23	b_2	130	10-15	122	1058	3/8	95	36	100	-	-	s_1
24	b_2	130	10-15	122	1058	1/2	100	33	100	-	-	s_2

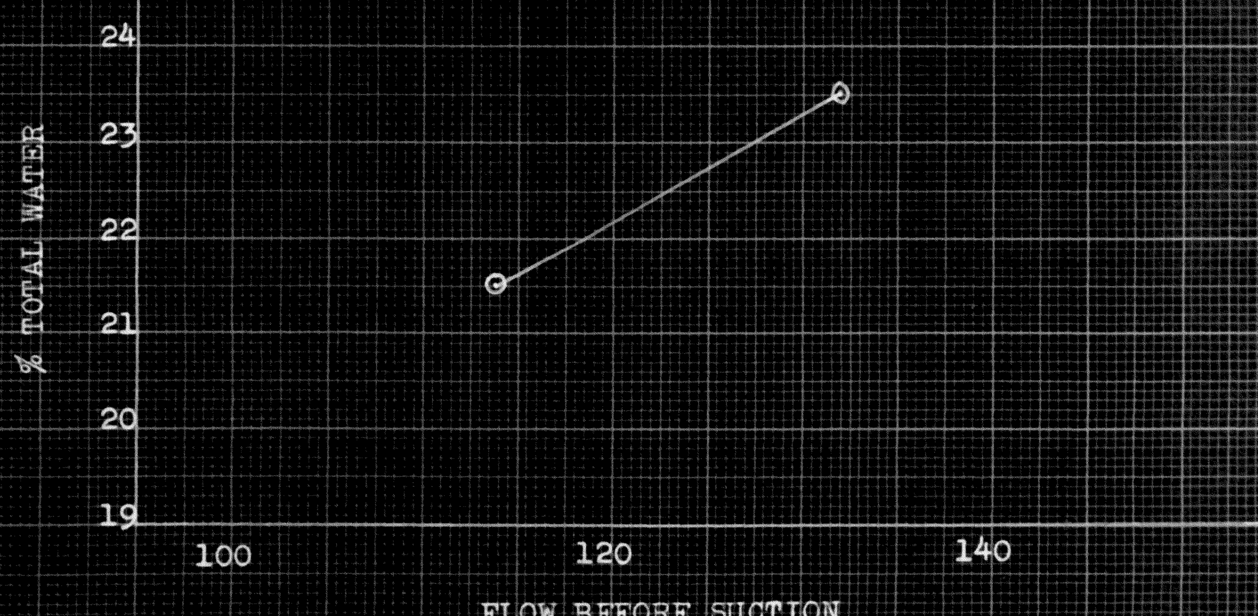
PROPOSAL VI


TENSION BOND STRENGTH PSI
45
40
35
30
25
20
15
10
5
0
B_1 (2-5 gbm)
B_2 (10-20 gbm)
MORTAR FLOW 114 %
MORTAR FLOW 132 %
SMOOTH-TO-SMOOTH SURFACE
ROUGH-TO-ROUGH SURFACE



Tensile and Compressive strength Curves of Plastic Lime Putty-Cement-Sand Mortar Used in Proposal VI





Flow - Before and After Curves of Lime Putty-Cement Sand Mortar Used in Proposal VI

Proposal VI

Analysis of Variance

Source of Variation	D/F	SS	MS	F	Significance
Replication	3	55.0	18.3	-	
Brick	1	105.1	105.1	4.7	*
Texture	1	924.4	924.5	41.5	**
Flows	1	612.5	612.5	27.5	**
Brick x Texture	1	210.1	210.1	9.4	**
Texture x Flows	1	-	-	-	
Brick x Flow	1	.2	.2	-	
Brick x Texture x Flow	1	55.1	55.1	2.8	
Error	21	467.5	22.3		
Total	31	2430.0			

* (F is greater than the 5 percent point; less than the 1 percent point; therefore judged significant)

** (F is greater than the 1 percent point, therefore, judged highly significant.)

Proposal VI

From the results the following conclusions seem justifiable:

(1) The stiff mud clay (suction less than 5 gms) gives a higher bond strength than the stiff mud shale.

(2) The four replications show the results to be reproducable.

(3) The normal wire cut face gave higher tension-bond strength than the die face.

(4) Regardless of suction rate or type of brick, time of forming and surface used the bond strength increased with mortar flow.

Proposal VII

A comparison of the bond of a make of brick that is solid with a representative of the same make of brick and the same suction rate but is a cored specimen.

Variables in Proposal

Kind of Brick..................................2
Suction Rates..................................2
Mortar Mix...................................1:1:6
Mortar Flow....................................1
Joint Thickness.............................1/2"
Total Number Specimens........................16

Ledger of Symbols

Bricks

b_1........................Roanoke Webster (stiff-mud shale) solid

b_2........................Roanoke Webster (stiff-mud shale) cored

Suction Rates

s_1.. 34-45 gbm

s_2.. 55-56 gbm

Mortar Mix ....(Vol.) 1.0 L: 1C: 60

Mortar Flows.. 120-130 %

Program for Forming Couplets

First Replication

1. Cored Brick - High Suction Rate
2. Solid Brick - High Suction Rate
3. Cored Brick - Low Suction Rate
4. Solid Brick - Low Suction Rate

Second Replication

1. Solid Brick - Low Suction Rate
2. Cored Brick - High Suction Rate
3. Solid Brick - High Suction Rate
4. Cored Brick - Low Suction Rate

Third Replication

1. Cored Brick - Low Suction Rate
2. Solid Brick - Low Suction Rate
3. Cored Brick - High Suction Rate
4. Solid Brick - High Suction Rate

Fourth Replication

1. Solid Brick - High Suction Rate
2. Cored Brick - Low Suction Rate
3. Solid Brick - Low Suction Rate
4. Cored Brick - High Suction Rate

Procedure

Mixing the Mortar

Mixing the mortar is in Proposal VII as it is in Proposal I.

Testing the Mortar Flow

Testing the mortar flows in Proposal VII is the same as in Proposal I.

Testing the Mortar Retentivity

Testing the mortar retentivity in Proposal VII is the same as in Proposal I.

Making the Test Specimens

Making the test specimens for Proposal VII is the same as in Proposal I with the exception that four mortar batches completed the Proposal and four tension-bond specimens were formed with each batch.

Storing the Specimen

Storing the specimens in Proposal VII is the same as in Proposal I.

Testing the Specimens

Testing the specimens in Proposal VII is the same as in Proposal I.

Dyeing the Tension-Bond Specimens

Dyeing the tension-bond specimens for Proposal VII is the same as in Proposal I.

Roanoke Webster Brick (Solid)

Flow 120-130 %

Sample No.	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
2	130	55-65	128	1071	1/2	95	18	100	-	-
4	130	35-45	128	1071	1/2	95	21	100	-	-
5	128	35-45	134	1052	1/2	95	27	-	-	100
7	128	55-65	134	1052	1/2	95	15	-	-	100
10	122	35-45	131	1062	1/2	95	24	-	-	100
12	122	55-65	131	1062	1/2	95	15	100	-	-
13	128	55-65	128	1036	1/2	95	36	-	-	100
15	128	35-45	128	1036	1/2	95	17	-	-	100

Mortar Batches of 120-130 % Flow

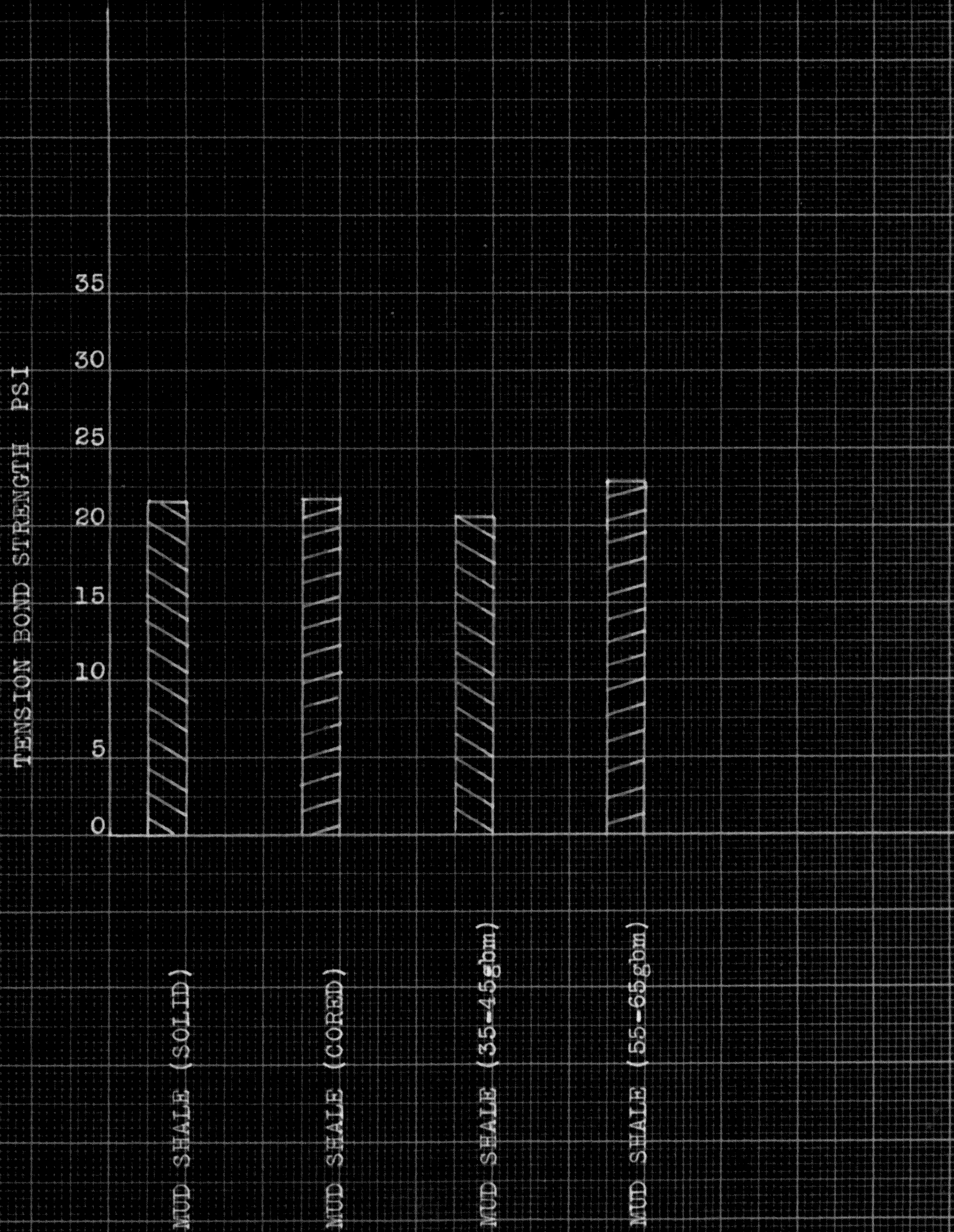
Batch No.	Sample No.	Average Flow Before Suction %	Average Flow After Suction %	A/B	Average Tensile Strength P.S.I.	Average Compressive Strength P.S.I.	% Total Water	% Added Water
1	1-4	130	77	.59	128	1071	23.2	15.5
2	5-8	128	72	.56	134	1052	23.2	15.5
3	9-12	122	69	.57	131	1062	23.2	15.5
4	13-16	128	72	.56	128	1036	23.2	15.5

Roanoke Webster Brick (Cored)

Flow 120-130 %

Sample No.	Flow %	Original Suction Rate gbm	Mortar Strength P.S.I. T	Mortar Strength P.S.I. C	Joint Thickness Inches	Bond Extent %	Tension P.S.I.	Type Failure T	Type Failure B	Type Failure M
1	130	55-65	128	1071	1/2	95	15	100	-	-
3	130	35-45	128	1071	1/2	95	16	100	-	-
6	128	55-65	134	1052	1/2	95	26	100	-	-
8	128	35-45	134	1052	1/2	95	20	-	-	100
9	122	35-45	131	1062	1/2	95	33	100	-	-
11	122	55-65	131	1062	1/2	95	29	100	-	-
14	128	35-45	128	1036	1/2	95	24	100	-	-
16	128	35-45	128	1036	1/2	95	11	-	-	100

PROPOSAL VII



Analysis of Variance

Roanoke Webster Cored and Whole Brick

Source of Variance	D/F	SS	MS	F	Significance
Replications	3	121.7	40.6	-	
Bricks	1	0	0	-	
Suction Rates	1	18.0	18.0	-	
Bricks x Suction Rates	1	21.1	21.1	-	
Error	9	602.6	66.9		
Total	15	763.4			

Proposal VII

From the results, the following conclusions seem justifiable:

(1) There is no difference in the tension-bond strength between the solid and cored brick used.

(2) There is no difference in the Tension-bond strength between suction rates. This is probably due to the very high suction rate of the group.

(3) From the means it is indicated the results are reproducable.