LABORATORY TESTS ON STRUCTURAL ASSEMBLIES OF BRICK AND TILE

L. P. COLLIN

MINES BRANCH
DEPARTMENT OF MINES
OTTAWA
1935
NO. 766

CANADA
DEPARTMENT OF MINES
HON. T. A. CRERAR, MINISTER   CHARLES CAMSELL, DEPUTY MINISTER

MINES BRANCH
JOHN MCLEISH, DIRECTOR

Laboratory Tests on Structural Assemblies of Brick and Tile

BY

L. P. Collin

Part I : The Tensile and Shear Strength of Assemblies of Various Types of Brick with Commonly used Mortars.

Part II : Effect of Absorption of Tile on the Adhesion and Strength of Concrete Beams of Different Widths.

OTTAWA
J. O. PATENAUDE, I.S.O.
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1935

Price, 10 cents.   **No. 766**

CONTENTS

1331—1

Laboratory Tests on Structural Assemblies of Brick and Tile

INTRODUCTION

This report describes two investigations undertaken, at the request of the Canadian Ceramic Society, to furnish engineering data on certain aspects of construction with brick and tile.

Part I deals with an investigation to determine the effect of seemingly important variables of brick on the bond and strength of mortar joints, both in direct adhesion and in shear. In view of the limits which had to be placed on the undertaking, only those mortars commonly recognized by building codes were used. For the tests the Brick Manufacturers' Association supplied seven varieties of brick, selected to afford a satisfactory range of variables in their physical properties.

In his report, L. P. Collin, Ceramic Engineer, sets forth in detail the characteristics of all material used, the nature of the test assemblies, the methods of testing, and the numerical results obtained, as well as his conclusions based on these results.

Part II is the report of an investigation to determine what effect the absorption of clay or shale tile has upon the strength of intervening concrete joists of various widths, the effect of wetting the tile to various degrees of saturation prior to placing the concrete, and, also, the strength of bond developed between the tile and concrete under the conditions of the tests.

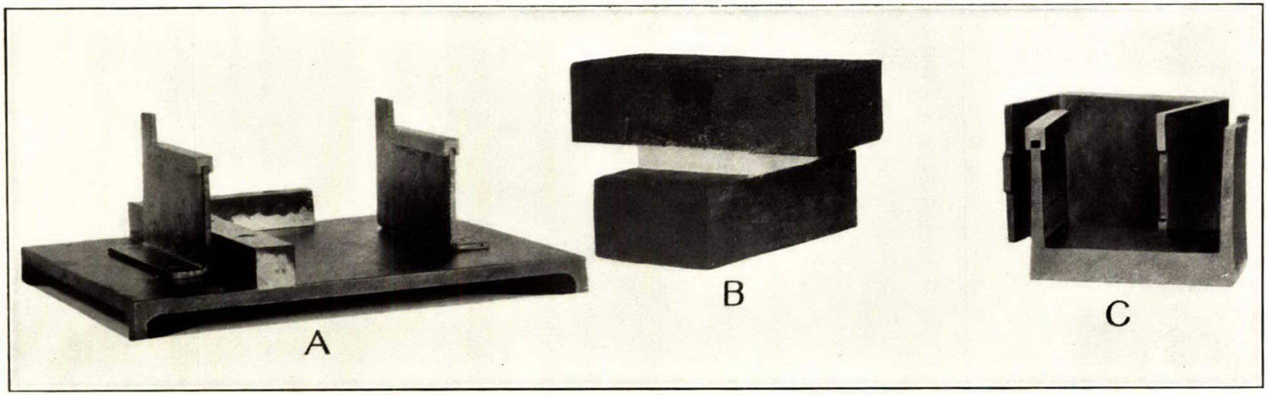
In the investigation four lots of tiles were used. These were supplied by the Structural Clay Tile Association and were chosen to represent a range of porosities over which information was desired.

The report sets forth the characteristics of the tile, the nature of the concrete and its components, the construction and treatment of the test assemblies, the method of testing, the results of these tests, and statement of the conclusions to be drawn from the investigation.

Mr. Collin was assisted in various phases of this investigation by the following engineers of the Division, R. H. Picher, J. F. McMahon, and J. G. Phillips. Acknowledgment is here made to Mr. E. Viens and Mr. J. W. Lucas of the Department of Public Works for advice regarding the obtaining of suitable sand and stone, and for assistance in formulating the concrete.

Howells Fréchette,
Chief, Division of
Ceramics and Road Materials.

1331—2



Test assembly and tools used in adhesion tests: A. Setting-up jig for adhesion test. B. Adhesion test assembly. C. Breaking tool.

Part I

THE TENSILE AND SHEAR STRENGTH OF ASSEMBLIES OF VARIOUS TYPES OF BRICK WITH COMMONLY USED MORTARS

This investigation has been carried on to determine certain physical characteristics of various types of brick and their effect on the bond and strength of commonly used mortars, both in direct adhesion and shear, in order to furnish fundamental data for the design and construction of reinforced brick masonry.

MATERIALS USED

Cement. The cement used was a Portland cement, manufactured by the Canada Cement Co., Ltd., and was of a quality to pass the specifications of the American Society for Testing Materials for Portland cement.

Lime. The hydrated lime used was "Lion Brand", produced by Gypsum, Lime and Alabastine, Canada, Ltd. It was a high-calcium, very plastic material, free from grit, and passed the American Society for Testing Materials fineness specifications for hydrated lime.

Sand. The sand used was obtained locally from a pit at Britannia Heights. It was clean, sharp, and free from impurities. Two lots of different fineness were obtained. Lot B was fairly coarse, and W was a fine wind-blown sand. These two were combined in proportions of 70B and 30W to furnish a sand of suitable grading and fineness for use in the mortars. The results of sieve analyses and other physical properties are shown in Table I.

TABLE I

Physical Properties of Sands

—	B	W	B 70 per cent W 30 per cent
Pounds per cubic ft	106·1	102·9	108·9
Per cent voids	36·5	38·5	34·9
Per cent passing No. 8 mesh	100·0	100·0	100·0
" " 16 "	91·6	99·8	94·0
" " 30 "	58·0	98·0	70·0
" " 50 "	16·0	62·0	29·8
" " 100 "	3·6	18·0	7·9
Fineness modulus	2·31	1·22	1·98
Per cent silt	0·8	0·8	0·8

Water. The City of Ottawa filtered water was used in the tests.

Brick. Seven varieties of brick were used. Table II shows the letter designations for this report, as well as the type of brick and the method of manufacture. Tables III, IV, V, VI, and VII show the physical properties of the various brick which were determined for this report.

TABLE II
Varieties of Brick

Brick	Material	Method of manufacture
A	Red-burning shale	Stiff-mud
B	Buff- " "	Dry-press
C	Red- " "	" "
D	" " "	Stiff-mud
E	" " clay	Soft-mud
F	" " shale	Stiff-mud
G	" " "	" "

TABLE III
Compressive Strength
(lb. per sq. in.)

Brick	Tested on flat	Tested on edge	Tested on end
A	15870	14760	8500
B	6630	4780	3830
C	8025	6260	5540
D	9630	6300	4730
E	9950	9200	7830
F	10880	8200	8480
G	8500	8920	7030

TABLE IV
Modulus of Rupture
(lb. per sq. in.)

Brick	Tested on flat	Tested on edge
A	2620	2300
B	810	990
C	1110	1260
D	1445	1520
E	1340	1035
F	1645	1570
G	1930	1980

TABLE V
Absorption (per cent)

Brick	1 min.	5 min.	10 min.	30 min.	60 min.	5 hr.	24 hr.	48 hr.	5-hr. boil
A	0·33	0·58	0·71	0·89	0·95	1·06	1·32	1·55	3·87
B	7·27	11·44	11·88	12·70	13·28	14·46	15·19	15·45	18·48
C	4·66	8·82	11·24	12·80	13·06	13·62	13·83	13·95	16·65
D	2·60	5·10	6·82	8·70	8·93	9·24	9·63	9·78	11·92
E	1·10	1·92	2·45	3·46	4·66	5·65	5·78	5·88	11·59
F	2·07	3·39	4·26	6·29	6·91	7·47	8·14	8·40	10·70
G	1·61	2·71	3·38	4·05	4·15	4·62	5·06	5·16	7·14

TABLE VI

Rate of Absorption

Per cent of 24-hour absorption

Brick	1 min.	5 min.	10 min.	30 min.	60 min.
A	21·8	40·8	51·4	62·7	63·1
B	43·8	72·9	79·0	84·7	89·0
C	37·8	68·6	85·5	93·2	95·1
D	27·4	52·8	69·5	88·6	91·0
E	17·2	26·4	35·6	50·5	68·2
F	23·3	40·0	50·7	76·3	84·6
G	31·8	53·6	66·8	80·0	82·0

Per cent of 5-hour boiling absorption

Brick	1 min.	5 min.	10 min.	30 min.	60 min.
A	8·5	15·0	18·4	23·0	24·5
B	39·3	61·9	64·3	68·7	71·8
C	27·8	53·0	67·5	76·9	78·4
D	21·8	42·8	57·2	73·0	74·9
E	9·5	16·6	21·1	29·9	40·2
F	19·3	31·7	39·8	58·8	64·6
G	22·5	38·0	47·3	56·7	58·1

TABLE VII

Rate of Capillary Absorption

End immersed in 1 inch of water

Brick	Height of water line above water level				
	1 min.	5 min.	10 min.	30 min.	60 min.
	in.	in.	in.	in.	in.
A	...	...	...	...	...
B	$\frac{5}{8}$	1	$1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$
C	$\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{16}$	2	$2\frac{3}{4}$
D	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
E	$\frac{3}{8}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
F	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{7}{16}$
G	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$

Edge immersed in $\frac{1}{8}$ inch of water

Brick	1 min.	5 min.	10 min.	30 min.	60 min.
A	...	...	...	...	...
B	$\frac{11}{16}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$2\frac{3}{4}$	$3\frac{13}{16}$
C	$\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{3}{16}$	2	$2\frac{7}{8}$
D	$\frac{3}{8}$	$\frac{5}{8}$	1	$1\frac{1}{4}$	$1\frac{3}{8}$
E	$\frac{1}{16}$	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{9}{16}$
F	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$
G	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{4}$

TABLE VII—*Concluded*

Rate of Capillary Absorption

Flat immersed in 1/8 inch of water

Brick	Height of water line above water level				
	1 min.	5 min.	10 min.	30 min.	60 min.
	in.	in.	in.	in.	in.
A	....	....	....	....	....
B	3/8	1 1/16	1 1/2	30 min.*	....
C	1/4	1/2	1	1 15/16	45 min.*
D	1/8	1/4	11/16	1 11/16	2 1/8
E	1/16	1/2	5/8	15/16	1
F	....	....	....	1/16	1/8
G	....	1/16	1/16	1/16	1/8

* Water line reached top surface.

All tests of the physical properties of the brick were made on five specimens each and the results given in the tables are the average of the five. Considerable care was taken in the selection of the test specimens to have them truly representative of each complete shipment, and to have the specimens used for strength determinations and absorption as nearly as possible duplicates of each other. The transverse strength determinations were made with a tool meeting the requirements of the American Society for Testing Materials for this test. The compressive strength determinations were made in accordance with the method specified by the American Society for Testing Materials, with the exception that a 4:1 sulphur-flint mixture was used for capping in place of plaster of Paris.

In general, the *compressive strength* was highest on flat and was lowest on end. The two exceptions to this, bricks F and G, may be disregarded, as the differences in both cases are less than 10 per cent, which is considered allowable tolerance of experimental error. The percentage decreases in compressive strength on edge and end are not the same in the different types of brick. This is not surprising as several investigators have found that there is no definite relationship between the compressive strengths of various brick when tested on flat, edge, and end.

The *transverse strength or modulus of rupture* is generally higher on flat, with the exception of the dry-press brick in which the strength on edge is considerably higher than on flat. This is probably due to the influence of the method of forming on the structure. Although the transverse strength on edge is higher than on flat with bricks D and G, the difference is too small to be of any importance.

The *absorption tests* were made in complete immersion for the times given in the tables. The brick were dried and weighed between each of the 1-, 5-, 10-, 30-, and 60-minute immersion periods. The brick were weighed and re-immersed after the 5-, 24-, and 48-hour immersion periods.

MORTAR MIXTURES

The compositions of the mortars used were as follows :

1. 1 part Portland cement, 3 parts sand.
2. 1 part Portland cement, 0·15 part hydrated lime, 3 parts sand.
3. 1 part Portland cement, 1 part hydrated lime, 6 parts sand.
4. 1 part Portland cement, 1 part hydrated lime, 6 parts sand (dry-mix.)
5. 1 part Portland cement, 1 part hydrated lime, 6 parts sand (grout).

The mixtures were computed by volume, but in preparing the mortars they were proportioned by weight, using the following conversion figures :

1 cu. ft. cement = 87 lb.
1 cu. ft. of lime = 46 lb.
1 cu. ft. of sand = 108·9 lb.

Experiments were made on mortars Nos. 1, 2, 3, and 4, to determine the amount of water to be used in pre-hydration and the time to be allowed for pre-hydration. In each case sufficient water was added to the mortar mixture to secure a mass of damp earth, or very stiff mortar consistency. This was then compacted with a trowel and the surface smoothed, after which it was allowed to stand until initial hardening commenced. This was judged by pressure of the thumb. After pre-hydration the mass was thoroughly remixed with sufficient water to bring it to the best working consistency as judged by the bricklayer. Table VIII shows the time of pre-hydration, the initial and total water used, and slump ; also the compressive strength of the mortars after being aged 28 days.

TABLE VIII

Mortar Data

Mortar No.	Initial water, Imp. gal. per bag cement	Pre-hydration period, minutes	Total water, Imp. gal. per bag of cement	Slump, inches	Compressive strength, lb. per sq. inch, 28 days
1......................	5·00	45	6·49	2¾	1520
2......................	4·19	60	6·55	2¼	1550
3......................	7·75	75	10·42	3	490
4......................	9·57	50	13·60	4⅜	585
5......................	....	....	18·13	*	300

* Consistency was such that one fluid ounce when poured on a glass plate from a height of ⅛-inch spread in a circle 4 inches in diameter in ½ minute.

BOND STRENGTH OF MORTAR

Type and Construction of Test Specimens

Adhesion. The test specimens for adhesion (mortar to brick in direct tension) were made by laying two brick crosswise, on the flat, with a ½-inch mortar joint.

Shear. The test specimens for double shear were made by laying three brick on the flat, the centre brick projecting 1 inch endwise beyond the other two, ½-inch mortar joints being used.

The mortars were made in such quantities that they would not be used later than one hour and a half after the final water was added. With the exception of mortar mixture No. 4, the lime was added in the form of a putty. This lime putty consisted of 48 per cent hydrated lime and 52 per cent of water by weight, and was allowed to stand at least 48 hours before use. In mortar No. 4 the hydrated lime was added dry.

The work of constructing the test specimens was all done by an experienced bricklayer. The adhesion test specimens were set up with the use of a jig to assure uniform thickness of mortar joints and proper centering of the top brick on the bottom brick. This jig consisted of a metal plate on which the bottom brick was placed, and adjustable sides so that the top brick could be placed just ½ inch above the bottom brick. After placing the bottom brick in the jig sufficient mortar was laid on it to give slightly over ½-inch joint. The top brick was then placed on this mortar bed and tapped with the handle of a brick hammer until it came in contact with the adjustable sides of the jig. The excess mortar was then struck off and the specimen carefully removed and placed in storage. Five test specimens were made with each type of brick (set dry) for each of mortars Nos. 1, 2, and 3. The test specimens were aged 28 days before testing. An attempt was made to set up the shear specimens with the use of a jig, but it was found that better results could be obtained by direct measurements of the bricklayer. Care was taken to obtain uniform thickness of joints throughout the bedding area. Five test specimens were made with each type of brick (set dry) for each of mortars Nos. 1, 2, 4, and 5. In the case of the grout (mortar mix No. 5) the brick were placed in such a position on boards that, with the aid of spacers, five test specimens could be poured at one time. The shear specimens were also aged 28 days before testing.

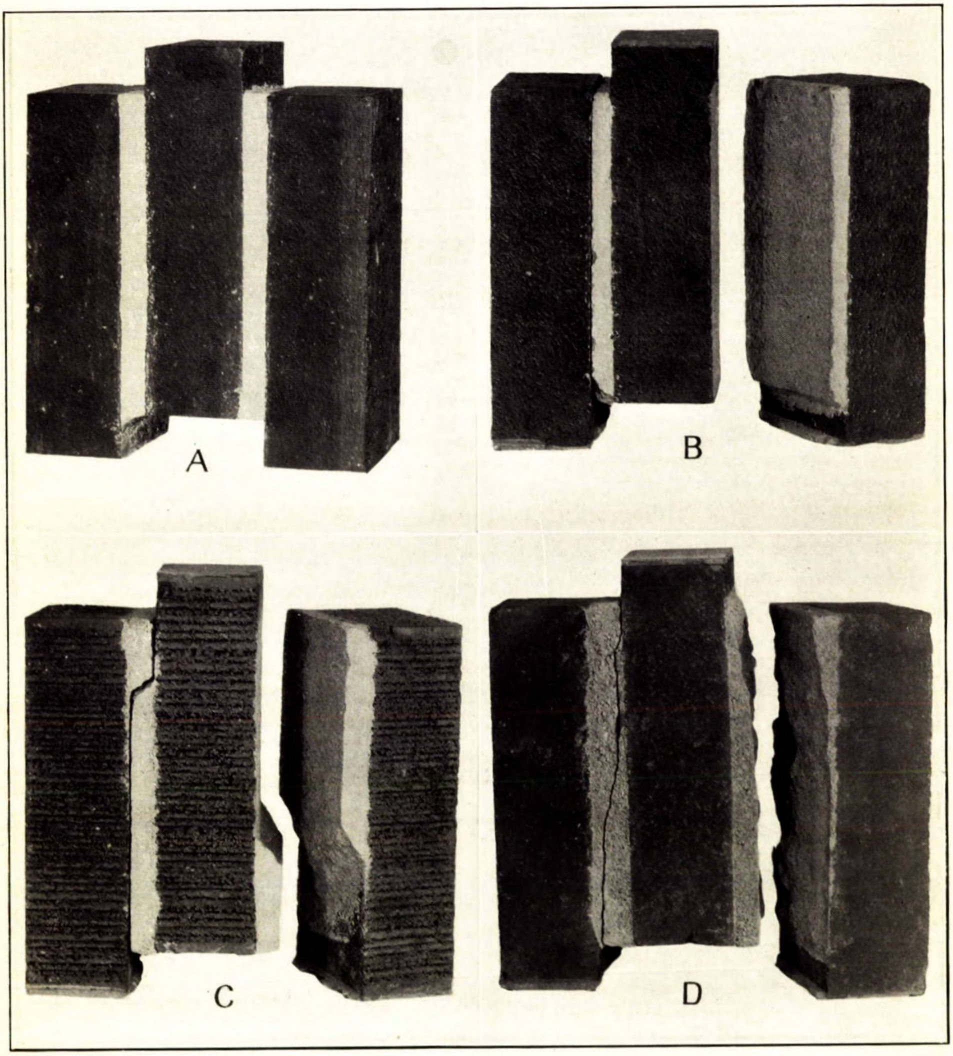
Following the construction of test specimens with brick set dry, it was decided to duplicate this work with brick set wet. An arbitrary time of immersion (based on a series of experiments) was adopted which was considered sufficient to bring each type of brick to a uniform rate of suction. The various times of immersion are given in Table IX.

TABLE IX

Time of Immersion of Brick

Brick	Time of immersion	
	minutes	seconds
A	0	1
B	4	30
C	7	30
D	1	30
E	0	5
F	1	0
G	1	0

The test specimens were constructed immediately after the brick were removed from the water, and the loss from evaporation was not appreciable. The same number of specimens were constructed as with the brick set dry, and all were aged 28 days before testing.



Shear test assembly and types of failure: A. Shear test assembly. B. Bond shear. C. Bond shear cross break in mortar. D. Mortar shear.

TESTING

Adhesion. The tool used for determining the adhesion strength in direct tension is a modification of one used by Voss[1]. It consists of two trough-shaped members, the one forming the base supporting the top brick of the specimen, and the other in reversed position bridging the top brick and resting on the bottom brick. The load is applied through this upper member by means of a spherical bearing and pushes the bricks apart. The breaking load indicates the tensile strength of the brick-mortar contact.

Shear. The ends of the test specimens were capped with a 4 : 1 sulphur-flint mixture. The specimens were placed in the testing machine so that the ends of the two outside brick rested on the base of the testing machine. Clamps were not used as there was sufficient friction between the specimens and the base of the testing machine to prevent the brick breaking away from the bedding during the test. The load was applied through a spherical bearing head to the protruding end of the middle brick. The load required to break the specimen indicates the double shear strength of the brick-mortar assembly.

RESULTS OF THE TESTS

Adhesion. The results of the adhesion tests are given in Tables X and XI, which show the mortar area, total load, unit load, and character of fracture. In the column headed "number", the letter refers to the type of brick, the first number is that of the mortar mix, and the second number is that of the test specimen. Thus B-2-3 is brick type B, mortar No. 2, and test specimen No. 3.

TABLE X

Adhesion (brick set dry)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
A-1-1	15·0	908	65	Bond failure at top of joint
A-1-2	15·2	911	60	" " "
A-1-3	15·2	770	51	" " "
A-1-4	14·4	585	41	" " "
A-1-5	15·1	539	36	" " "
A-1—Average:			51	
A-2-1	15·2	1,176	77	Bond failure at bottom of joint
A-2-2	14·3	1,272	89	" " top "
A-2-3	15·6	1,032	66	" " " "
A-2-4	15·6	1,065	68	" " " "
A-2-5	15·2	1,204	79	" " " "
A-2—Average:			75	

[1] Voss, W. C.: "Permeability of Brick Masonry Walls—An Hypothesis", The American Society for Testing Materials, Part II, Technical Papers, 1933, pages 670-687.

TABLE X—(Continued)

Adhesion (brick set dry)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
A-3-1	14·8	776	52	Bond failure at top of joint
A-3-2	15·4	841	55	Bond and mortar failure at bottom of joint
A-3-3	15·2	580	38	" " " " "
A-3-4	15·2	832	55	" " " " "
A-3-5	15·6	586	38	Bond failure at bottom of joint
A-3—Average:	....	....	48	
B-1-1	16·8	40	2	Bond failure at bottom of joint
B-1-2	....	....	....	Test specimen broke in handling
B-1-3	....	....	....	" " "
B-1-4	....	....	....	" " "
B-1-5	16·8	14	1	Bond failure at bottom of joint
B-1—Average:	....	....	2	
B-2-1	....	....	....	Test specimen broke in handling
B-2-2	....	....	....	" " "
B-2-3	....	....	....	" " "
B-2-4	17·6	32	2	Bond failure at bottom of joint
B-2-5	17·6	70	4	" " "
B-2—Average:	....	....	3	
B-3-1	16·8	317	19	Bond failure at bottom of joint
B-3-2	16·8	390	23	" " "
B-3-3	16·8	240	14	" " "
B-3-4	16·8	790	47	Bond and mortar failure at bottom of joint
B-3-5	16·8	438	26	" " " "
B-3—Average:	....	....	26	
C-1-1	15·7	94	6	Bond failure at bottom of joint
C-1-2	....	....	....	Test specimen broke in handling
C-1-3	....	....	....	" " "
C-1-4	16·0	44	3	Bond failure at top of joint
C-1-5	15·6	360	23	" " bottom "
C-1—Average:	....	....	11	
C-2-1	....	....	....	Test specimen broke in handling
C-2-2	16·0	147	9	Bond failure at bottom of joint
C-2-3	16·0	40	3	" " "
C-2-4	15·6	47	3	" " "
C-2-5	16·0	132	8	" " "
C-2—Average:	....	....	6	
C-3-1	15·2	863	57	Bond and mortar failure near bottom of joint
C-3-2	15·6	702	45	" " " "
C-3-3	15·6	905	58	" " " "
C-3-4	15·2	716	47	" " " "
C-3-5	15·2	652	43	" " " "
C-3—Average:	....	....	50	
D-1-1	16·0	1,550	97	Mortar failure near middle of joint
D-1-2	15·2	1,148	75	Bond and mortar failure near top of joint
D-1-3	15·2	1,741	115	" " " "
D-1-4	15·2	1,815	119	Bond and mortar failure near bottom of joint
D-1-5	15·6	1,675	107	Bond and mortar failure near top of joint
D-1—Average:	....	....	103	

TABLE X—(Continued)
Adhesion (brick set dry)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
D-2-1	16·4	942	57	Bond failure at bottom of joint
D-2-2	15·6	1,561	100	" " "
D-2-3	14·8	1,877	127	Mortar failure near bottom of joint
D-2-4	15·2	1,167	77	Mortar failure near top of joint
D-2-5	16·0	1,202	75	Bond failure at bottom of joint
D-2—Average:	....	....	87	
D-3-1	15·2	1,058	70	Bond and mortar failure near bottom of joint
D-3-2	15·2	265	17	Defective construction not used for average
D-3-3	15·2	885	58	Bond and mortar failure near bottom of joint
D-3-4	16·0	984	61	" " " "
D-3-5	15·2	1,193	79	" " " "
D-3—Average:	....	....	67	
E-1-1	15·2	1,455	96	Bond failure at top of joint
E-1-2	15·2	1,597	105	" " "
E-1-3	14·8	1,446	98	" " "
E-1-4	13·4	1,319	98	" " "
E-1-5	14·8	1,122	78	" " "
E-1—Average:	....	....	95	
E-2-1	15·2	742	49	Bond failure at top of joint
E-2-2	15·8	1,210	77	Bond failure at bottom of joint
E-2-3	15·2	1,458	96	" " "
E-2-4	15·3	928	61	" " "
E-2-5	15·2	1,602	105	" " "
E-2—Average:	....	....	78	
E-3-1	15·2	260	17	Bond failure at bottom of joint
E-3-2	15·2	534	35	" " "
E-3-3	14·8	946	64	Mortar failure in frog
E-3-4	14·8	332	22	Bond failure at bottom of joint
E-3-5	15·2	734	48	" " "
E-3—Average:	....	....	37	
F-1-1	16·1	1,850	116	Mortar failure near bottom of joint
F-1-2	16·0	1,923	120	" " " "
F-1-3	14·6	1,860	127	" " " "
F-1-4	16·4	1,492	91	Bond failure at bottom of joint
F-1-5	16·0	1,669	104	" " "
F-1—Average:	....	....	112	
F-2-1	16·0	1,677	105	Bond failure at bottom of joint
F-2-2	16·0	1,238	77	" " "
F-2-3	15·7	858	55	" " "
F-2-4	15·6	1,545	99	" " "
F-2-5	16·0	1,623	101	" " "
F-2—Average:	....	....	87	
F-3-1	15·6	1,739	111	Mortar failure near middle of joint
F-3-2	16·4	1,577	96	Mortar failure near bottom of joint
F-3-3	16·4	1,633	100	" " " "
F-3-4	15·6	1,508	97	Bond failure at bottom of joint
F-3-5	15·6	1,481	95	" " "
F-3—Average:	....	....	100	

TABLE X—(Concluded)

Adhesion (brick set dry)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
G-1-1	14·3	1,050	73	Mortar and bond failure near top of joint
G-1-2	15·6	1,700	109	" " " "
G-1-3	15·6	1,590	102	Mortar and bond failure near bottom of joint
G-1-4	13·7	1,520	111	Bond failure at top of joint
G-1-5	15·2	1,420	93	Bond failure at bottom of joint
G-1—Average:	....	....	98	
G-2-1	14·8	1,820	123	Mortar and bond failure near bottom of joint
G-2-2	14·8	1,600	108	Bond failure at bottom of joint
G-2-3	14·4	1,400	97	" " "
G-2-4	15·2	1,390	91	" " "
G-2-5	14·4	1,000	69	" " "
G-2—Average:	....	....	98	
G-3-1	14·8	1,380	93	Mortar and bond failure near bottom of joint
G-3-2	14·8	1,250	84	Bond failure at bottom of joint
G-3-3	14·8	1,410	95	" " "
G-3-4	15·2	1,080	71	Mortar and bond failure near bottom of joint
G-3-5	14·5	760	52	Bond failure at bottom of joint
G-3—Average:	....	....	79	

TABLE XI

Adhesion (brick set wet)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
A-1-1	13·6	510	37	Bond failure at top of joint
A-1-2	13·6	280	20	" " "
A-1-3	13·8	400	28	" " "
A-1-4	14·1	530	37	" " "
A-1-5	13·7	....	....	Broke when beam of machine was not in balance
A-1—Average:	....	....	37	
A-2-1	15·2	800	53	Bond failure at top of joint
A-2-2	13·7	670	49	" " "
A-2-3	14·4	....	....	Broke when beam of machine was not balanced
A-2-4	14·4	1,000	69	Bond failure at top of joint
A-2-5	14·8	700	47	" " "
A-2—Average:	....	....	54	
A-3-1	16·6	690	42	Bond failure at top of joint
A-3-2	16·0	730	46	Mortar and bond failure near top of joint
A-3-3	16·0	580	36	Bond failure at top of joint
A-3-4	15·2	950	63	Bond failure at bottom of joint
A-3-5	16·0	990	62	Bond failure at top of joint
A-3—Average:	....	....	50	

TABLE XI—(Continued)
Adhesion (brick set wet)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
B-1-1	16·8	1,630	97	Bond failure at bottom of joint
B-1-2	16·8	630	37	" " "
B-1-3	16·4	1,200	73	Mortar and bond failure near top of joint
B-1-4	....	....	....	Test specimen broke in handling
B-1-5	16·8	620	37	Bond failure at bottom of joint
B-1—Average:	....	....	61	
B-2-1	16·4	330	20	Bond failure at bottom of joint
B-2-2	16·8	90	5	Defective construction, not used for average
B-2-3	16·8	640	38	Bond failure at bottom of joint
B-2-4	16·8	410	24	" " "
B-2-5	16·8	540	32	" " "
B-2—Average:	....	....	29	
B-3-1	16·8	550	33	Bond failure at bottom of joint
B-3-2	16·8	610	36	" " "
B-3-3	16·8	800	48	" " "
B-3-4	16·8	560	33	" " "
B-3-5	16·8	440	26	" " "
B-3—Average:	....	....	36	
C-1-1	15·6	1,600	103	Mortar failure near top of joint
C-1-2	15·6	670	43	Bond failure at top of joint
C-1-3	14·8	370	25	" " "
C-1-4	15·6	1,310	84	Mortar failure near top of joint
C-1-5	15·6	1,470	94	" " "
C-1—Average:	....	....	70	
C-2-1	15·2	610	40	Bond failure at bottom of joint
C-2-2	15·2	490	32	" " "
C-2-3	15·2	710	47	" " "
C-2-4	15·2	660	43	" " "
C-2-5	15·2	530	35	" " "
C-2—Average:	....	....	39	
C-3-1	15·6	530	34	Bond failure at bottom of joint
C-3-2	15·6	940	60	" " "
C-3-3	15·6	670	43	" " "
C-3-4	15·6	810	52	" " "
C-3-5	16·0	570	36	" " "
C-3—Average:	....	....	45	
D-1-1	15·6	1,580	101	Bond failure at bottom of joint
D-1-2	15·6	1,340	86	Bond failure at top of joint
D-1-3	13·8	1,250	91	" " "
D-1-4	15·2	1,260	83	Mortar failure near top of joint
D-1-5	14·4	1,530	106	" " "
D-1—Average:	....	....	93	
D-2-1	16·0	680	43	Bond failure at bottom of joint
D-2-2	16·0	1,210	76	" " "
D-2-3	15·6	1,380	88	" " "
D-2-4	15·6	1,010	65	" " "
D-2-5	15·6	840	54	" " "
D-2—Average:	....	....	65	

TABLE XI—(Continued)

Adhesion (brick set wet)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
D-3-1	16·4	1,530	93	Mortar and bond failure at bottom of joint
D-3-2	15·6	1,160	74	Bond failure at bottom of joint
D-3-3	16·0	1,190	74	" " "
D-3-4	16·4	1,340	82	Bond failure at top of joint
D-3-5	16·0	1,800	113	Mortar failure near bottom of joint
D-3—Average:	....	....	87	
E-1-1	13·1	270	21	Bond failure at bottom of joint
E-1-2	....	....	....	Broke in handling
E-1-3	13·9	270	19	Bond failure at top of joint
E-1-4	....	....	....	Broke in handling
E-1-5	14·1	590	42	Bond failure at top of joint
E-1—Average:	....	....	27	
E-2-1	14·8	1,100	74	Bond failure at top of joint
E-2-2	14·4	1,090	76	Bond failure at bottom of joint
E-2-3	14·4	1,100	75	Bond failure at top of joint
E-2-4	14·4	800	56	" " "
E-2-5	14·5	870	60	" " "
E-2—Average:	....	....	68	
E-3-1	14·4	860	60	Bond failure at bottom of joint
E-3-2	14·4	990	68	" " "
E-3-3	14·8	960	65	" " "
E-3-4	15·2	1,030	68	" " "
E-3-5	14·8	980	66	" " "
E-3—Average:	....	....	65	
F-1-1	15·6	1,660	106	Bond failure at top of joint
F-1-2	15·4	1,500	97	" " "
F-1-3	14·3	490	34	" " "
F-1-4	15·4	960	62	" " "
F-1-5	14·2	670	47	" " "
F-1—Average:	....	....	69	
F-2-1	15·6	1,640	105	Bond failure at bottom of joint
F-2-2	16·0	1,450	91	Bond failure at top of joint
F-2-3	15·2	1,680	111	" " "
F-2-4	16·0	1,410	88	Bond failure at bottom of joint
F-2-5	15·6	1,720	110	" " "
F-2—Average:	....	....	101	
F-3-1	15·2	1,470	97	Mortar failure near bottom of joint
F-3-2	14·4	880	61	Bond failure at bottom of joint
F-3-3	15·6	840	54	" " "
F-3-4	15·1	820	54	" " "
F-3-5	16·0	1,300	81	Mortar and bond failure near bottom of joint
F-3—Average:	....	....	69	
G-1-1	15·2	1,270	84	Bond failure at bottom of joint
G-1-2	15·2	1,160	76	Bond failure at top of joint
G-1-3	15·2	1,430	94	Bond failure at bottom of joint
G-1-4	15·2	1,280	84	" " "
G-1-5	15·2	1,610	106	" " "
G-1—Average:	....	....	89	

TABLE XI—(Concluded)

Adhesion (brick set wet)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
G-2-1	14·4	780	54	Bond failure at bottom of joint
G-2-2	14·2	450	32	" " "
G-2-3	14·8	670	51	" " "
G-2-4	14·8	550	37	" " "
G-2-5	15·2	930	61	" " "
G-2—Average:	....	....	47	
G-3-1	14·8	970	66	Bond failure at bottom of joint
G-3-2	15·6	1,110	71	" " "
G-3-3	15·2	1,240	82	Mortar and bond failure near bottom of joint
G-3-4	14·8	810	33	Bond failure at bottom of joint
G-3-5	15·6	1,370	88	Mortar failure near middle of joint
G-3—Average:	....	....	68	

Shear. The results of the shear tests are given in Tables XII and XIII, which show the mortar area, total load, unit load, and character of fracture. In the column headed "number" the letter refers to the type of brick, the first number to the mortar mix, and the second number to the test specimen. Thus D-4-1 is brick type D, mortar No. 4, and test specimen No. 1.

TABLE XII

Shear (brick set dry)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
A-1-1	53·7	2,430	45	Bond shear
A-1-2	54·3	2,260	42	" "
A-1-3	54·3	3,260	60	" "
A-1-4	54·0	2,490	46	" "
A-1-5	55·2	3,150	57	" "
A-1—Average:	....	....	50	
A-2-1	53·6	8,300	155	Bond shear
A-2-2	54·8	4,740	87	" "
A-2-3	55·1	8,500	154	" "
A-2-4	53·0	7,560	143	" "
A-2-5	54·0	5,210	97	" "
A-2—Average:	....	....	127	
A-4-1	55·1	4,130	75	Bond shear
A-4-2	54·0	4,420	82	" "
A-4-3	52·9	2,800	53	" "
A-4-4	52·7	4,660	88	" "
A-4-5	54·0	3,310	61	" "
A-4—Average:	....	....	72	

TABLE XII—(Continued)

Shear (brick set dry)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
A-5-1	56·6	3,700	65	Mortar shear in 1 joint, bond shear in other
A-5-2	....	....	....	Beam of testing machine not balanced
A-5-3	55·4	5,270	95	Bond failure, mortar break
A-5-4	56·2	3,780	67	" " "
A-5-5	56·6	5,890	104	" " "
A-5—Average:	....	....	83	
B-1-1	60·0	4,667	78	Bond shear, mortar break
B-1-2	60·0	3,142	52	Bond shear
B-1-3	....	....	....	Specimen broke in handling
B-1-4	....	....	....	" " "
B-1-5	....	....	....	" " "
B-1—Average:	....	....	65	
B-2-1	....	....	....	Specimen broke in handling
B-2-2	59·6	3,480	58	Bond shear
B-2-3	58·4	4,135	71	Bond shear, mortar break
B-2-4	57·4	2,213	39	Bond shear
B-2-5	....	....	....	Specimen broke in handling
B-2—Average:	....	....	56	
B-4-1	60·0	3,450	58	Bond shear, mortar break
B-4-2	59·6	2,940	49	" " "
B-4-3	....	....	....	Specimen broke in handling
B-4-4	59·6	2,740	46	Bond shear, mortar break
B-4-5	58·9	2,840	48	Bond shear
B-4—Average:	....	....	50	
B-5-1	62·0	17,050	275	Mortar shear
B-5-2	60·8	16,870	278	" "
B-5-3	60·8	14,960	246	" "
B-5-4	61·6	19,530	317	" "
B-5-5	60·4	19,110	316	" "
B-5—Average:	....	....	286	
C-1-1	55·8	2,774	50	Bond shear, mortar break
C-1-2	55·5	3,658	66	Bond shear
C-1-3	....	....	....	Specimen broke in handling
C-1-4	....	....	....	" " "
C-1-5	56·3	4,815	86	Bond shear, mortar break
C-1—Average:	....	....	67	
C-2-1	....	....	....	Specimen broke in handling
C-2-2	....	....	....	" " "
C-2-3	55·6	2,835	51	Bond shear, mortar break
C-2-4	....	....	....	Specimen broke in handling
C-2-5	55·1	2,112	38	Bond shear
C-2—Average:	....	....	45	
C-4-1	56·2	1,180	21	Bond shear
C-4-2	55·4	1,250	23	Bond shear, mortar break
C-4-3	....	....	....	Specimen broke in handling
C-4-4	....	....	....	" " "
C-4-5	55·8	2,410	43	Bond shear, mortar break
C-4—Average:	....	....	29	

TABLE XII—(Continued)

Shear (brick set dry)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
C-5-1	59·2	15,260	258	Mortar shear
C-5-2	57·7	17,740	308	" "
C-5-3	57·0	15,800	277	" "
C-5-4	57·0	12,740	224	" "
C-5-5	57·4	18,030	314	" "
C-5—Average:	....	....	276	
D-1-1	57·1	5,230	92	Defective construction not used in average
D-1-2	57·9	12,090	209	Bond shear, mortar break
D-1-3	57·5	17,560	305	" " "
D-1-4	56·2	10,990	196	" " "
D-1-5	57·4	14,630	255	" " "
D-1—Average:	....	....	241	
D-2-1	56·6	6,450	114	Bond shear
D-2-2	57·0	9,890	174	Bond shear, mortar break
D-2-3	56·0	11,340	202	" " "
D-2-4	56·9	3,440	60	Defective construction, not used in average
D-2-5	56·6	13,480	238	Bond shear, mortar break
D-2—Average:	....	....	182	
D-4-1	53·6	3,650	68	Bond shear, mortar break
D-4-2	55·1	4,020	73	Bond shear
D-4-3	55·4	3,900	70	Bond shear, mortar break
D-4-4	55·1	3,990	72	" " "
D-4-5	57·4	4,730	82	" " "
D-4—Average:	....	....	73	
D-5-1	59·6	16,930	284	Mortar shear
D-5-2	59·2	11,730	198	" "
D-5-3	58·6	11,170	191	" "
D-5-4	59·6	19,420	326	" "
D-5-5	59·6	11,740	197	" "
D-5—Average:	....	....	239	
E-1-1	56·2	19,340	344	Bond shear, mortar break
E-1-2	55·4	10,740	194	" " "
E-1-3	54·4	16,800	309	" " "
E-1-4	54·7	17,510	320	" " "
E-1-5	54·4	8,800	159	Defective construction, not used in average
E-1—Average:	....	....	292	
E-2-1	55·1	21,070	382	Bond shear, mortar break
E-2-2	55·8	22,550	404	" " "
E-2-3	53·7	27,820	518	" " "
E-2-4	54·3	14,550	268	" " "
E-2-5	54·7	16,630	304	" " "
E-2—Average:	....	....	375	
E-4-1	53·8	8,500	158	Bond shear, mortar break
E-4-2	54·7	8,860	162	" " "
E-4-3	53·3	3,020	57	Defective construction, not used in average
E-4-4	55·5	14,770	266	Bond shear, mortar break
E-4-5	53·3	10,540	197	Bond shear.
E-4—Average:	....	....	196	

TABLE XII—(Continued)

Shear (brick set dry)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
E-5-1	55·8	13,800	247	Bond and mortar shear
E-5-2	56·3	12,550	223	" " "
E-5-3	56·6	10,510	186	Mortar shear
E-5-4	56·6	15,830	280	" "
E-5-5	56·6	14,350	254	" "
E-5—Average:	....	....	238	
F-1-1	56·4	17,520	311	Bond shear, mortar break
F-1-2	56·9	11,730	206	" " "
F-1-3	58·5	20,290	347	" " "
F-1-4	58·0	12,900	222	" " "
F-1-5	57·3	19,680	343	" " "
F-1—Average:	....	....	286	
F-2-1	55·4	7,350	133	Bond shear, mortar break
F-2-2	57·0	5,290	93	Defective construction, not used in average
F-2-3	55·1	7,930	144	Bond shear, mortar break
F-2-4	55·8	10,210	183	Bond shear
F-2-5	55·5	8,420	152	Bond shear, mortar break
F-2—Average:	....	....	153	
F-4-1	56·2	9,810	181	Bond shear, mortar break
F-4-2	56·2	15,310	273	" " "
F-4-3	56·6	10,600	187	" " "
F-4-4	55·8	14,490	260	Bond shear
F-4-5	57·8	11,300	196	Bond shear, mortar break
F-4—Average:	....	....	219	
F-5-1	58·4	16,950	290	Bond and mortar shear
F-5-2	60·4	13,680	227	" " "
F-5-3	60·0	15,320	255	" " "
F-5-4	60·8	19,000	312	" " "
F-5-5	59·3	18,520	312	" " "
F-5—Average:	....	....	279	
G-1-1	55·5	16,290	293	Bond shear, mortar break
G-1-2	53·5	18,180	340	" " "
G-1-3	49·7	12,000	241	" " "
G-1-4	52·3	14,840	284	" " "
G-1-5	53·6	13,840	258	" " "
G-1—Average:	....	....	283	
G-2-1	55·8	11,460	205	Bond shear
G-2-2	54·8	14,510	265	Bond shear, mortar break
G-2-3	52·2	19,210	368	" " "
G-2-4	55·4	10,040	181	" " "
G-2-5	56·2	12,910	230	" " "
G-2—Average:	....	....	250	
G-4-1	54·0	7,770	144	Bond shear, mortar break
G-4-2	54·0	8,000	148	" " "
G-4-3	55·8	7,720	138	" " "
G-4-4	53·8	8,950	166	Bond shear
G-4-5	53·3	8,620	162	" "
G-4—Average:	....	....	152	

TABLE XII—(Concluded)

Shear (brick set dry)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
G-5-1............	57·8	14,500	251	Mortar shear
G-5-2............	57·0	12,130	213	" "
G-5-3............	56·2	9,570	170	" "
G-5-4............	57·4	13,520	235	" "
G-5-5............	57·0	10,730	188	" "
G-5—Average:....	....	....	211	

TABLE XIII

Shear (brick set wet)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
A-1-1............	53·3	3,050	55	Bond shear
A-1-2............	50·9	3,100	61	" "
A-1-3............	52·8	2,540	48	" "
A-1-4............	54·3	2,620	48	" "
A-1-5............	54·3	2,810	52	" "
A-1—Average:....	....	....	53	
A-2-1............	54·1	4,200	78	Bond shear
A-2-2............	53·7	5,120	95	" "
A-2-3............	54·9	4,110	75	" "
A-2-4............	54·4	6,720	124	" "
A-2-5............	54·4	5,150	95	" "
A-2—Average:....	....	....	93	
A-4-1............	54·0	3,300	61	Bond shear
A-4-2............	54·0	4,740	88	" "
A-4-3............	52·2	2,550	49	" "
A-4-4............	55·1	3,140	57	" "
A-4-5............	53·2	3,430	64	" "
A-4—Average:....	....	....	64	
A-5-1............	57·0	4,880	86	Bond and mortar shear
A-5-2............	56·2	3,810	68	" " "
A-5-3............	55·8	3,810	68	Bond shear, mortar break
A-5-4............	56·6	4,540	80	" " "
A-5-5............	55·8	5,820	104	" " "
A-5—Average:....	....	....	81	
B-1-1............	57·3	5,830	102	Bond shear, mortar break
B-1-2............	57·8	5,220	90	" " "
B-1-3............	57·0	4,870	85	" " "
B-1-4............	60·0	3,170	53	" " "
B-1-5............	58·6	4,020	69	" " "
B-1—Average:....	....	....	80	

TABLE XIII—(Continued)

Shear (brick set wet)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
B-2-1	59·0	3,360	57	Bond shear
B-2-2	58·8	2,670	45	" "
B-2-3	58·8	1,880	32	" "
B-2-4	57·6	2,510	44	" "
B-2-5	59·6	3,310	56	" "
B-2—Average:	....	....	47	
B-4-1	56·8	5,330	94	Bond shear
B-4-2	59·6	4,560	77	Bond and mortar shear
B-4-3	60·0	2,980	50	Bond shear
B-4-4	59·2	2,770	47	" "
B-4-5	59·6	2,000	34	" "
B-4—Average:	....	....	60	
B-5-1	60·0	16,110	268	Mortar shear
B-5-2	59·2	13,750	232	" "
B-5-3	60·8	14,560	240	" "
B-5-4	60·0	15,520	259	" "
B-5-5	59·2	13,090	221	" "
B-5—Average:	....	....	244	
C-1-1	57·0	10,440	183	Bond shear, mortar break
C-1-2	....	....	....	Machine beam not balanced
C-1-3	56·4	2,770	49	Defective construction, not used in average
C-1-4	57·0	8,870	156	Bond and mortar shear
C-1-5	55·4	14,950	270	" " "
C-1—Average:	....	....	203	
C-2-1	55·9	4,240	76	Bond shear
C-2-2	57·7	2,020	35	" "
C-2-3	57·7	4,660	81	" "
C-2-4	56·2	5,900	105	" "
C-2-5	58·1	1,570	27	" "
C-2—Average:	....	....	65	
C-4-1	54·7	3,480	64	Bond shear
C-4-2	55·4	1,630	29	" "
C-4-3	57·4	2,890	33	" "
C-4-4	54·8	1,470	27	" "
C-4-5	57·0	3,440	60	Bond shear, mortar break
C-4—Average:	....	....	43	
C-5-1	58·5	14,040	240	Bond and mortar shear
C-5-2	58·5	12,940	221	Mortar shear
C-5-3	58·1	13,110	226	" "
C-5-4	58·9	12,900	219	" "
C-5-5	57·0	13,750	241	" "
C-5—Average:	....	....	229	
D-1-1	....	....	....	Machine beam not balanced
D-1-2	58·4	7,050	121	Bond shear
D-1-3	56·4	7,150	127	" "
D-1-4	57·2	21,830	382	Bond and mortar shear
D-1-5	54·1	6,050	112	" " "
D-1—Average:	....	....	185	

TABLE XIII—(Continued)

Shear (brick set wet)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
D-2-1	56·6	10,600	187	Bond shear, mortar break
D-2-2	57·6	16,640	289	" " "
D-2-3	54·4	7,460	137	" " "
D-2-4	58·2	15,620	268	" " "
D-2-5	57·4	7,050	123	" " "
D-2—Average:	....	....	201	
D-4-1	57·0	16,220	285	Bond and mortar shear
D-4-2	56·6	6,670	118	Bond shear, mortar break
D-4-3	58·0	7,980	138	" " "
D-4-4	57·4	11,060	193	" " "
D-4-5	57·4	9,310	162	" " "
D-4—Average:	....	....	179	
D-5-1	57·0	9,700	170	Bond and mortar shear
D-5-2	57·4	12,060	210	" " "
D-5-3	58·5	15,040	257	" " "
D-5-4	60·4	13,910	230	" " "
D-5-5	58·9	13,790	234	" " "
D-5—Average:	....	....	220	
E-1-1	54·3	16,400	302	Bond shear, mortar break
E-1-2	54·2	13,150	243	" " "
E-1-3	54·7	7,770	142	" " "
E-1-4	52·9	16,440	311	" " "
E-1-5	54·6	17,570	322	" " "
E-1—Average:	....	....	264	
E-2-1	53·6	15,180	283	Bond shear, mortar break
E-2-2	55·8	18,910	339	" " "
E-2-3	53·6	10,730	200	Bond shear
E-2-4	54·0	17,520	324	" "
E-2-5	54·0	10,900	202	Bond shear, mortar break
E-2—Average:	....	....	270	
E-4-1	54·8	11,000	201	Bond shear, mortar break
E-4-2	55·1	7,570	137	" " "
E-4-3	53·6	7,480	140	" " "
E-4-4	55·5	9,590	173	" " "
E-4-5	55·8	14,600	262	Bond and mortar shear
E-4—Average:	....	....	183	
E-5-1	54·8	12,540	229	Mortar shear
E-5-2	55·1	6,050	110	" "
E-5-3	55·5	6,170	111	Bond and mortar shear
E-5-4	....	....	....	Specimen broken in capping
E-5-5	57·4	10,940	191	Bond and mortar shear
E-5—Average:	....	....	160	
F-1-1	55·1	8,830	160	Bond shear, mortar break
F-1-2	55·8	10,270	184	" " "
F-1-3	55·0	6,040	110	" " "
F-1-4	56·9	11,800	207	" " "
F-1-5	56·3	8,880	158	Bond shear
F-1—Average:	....	....	164	

TABLE XIII—(Concluded)

Shear (brick set wet)

Number	Mortar area, sq. in.	Total load, lb.	Unit load, lb. per sq. in.	Character of fracture
F-2-1	54·8	12,230	223	Bond shear, mortar break
F-2-2	57·8	11,760	203	" " "
F-2-3	58·1	13,010	224	" " "
F-2-4	58·9	13,580	231	Bond shear
F-2-5	57·0	12,120	213	" "
F-2—Average:	....	....	219	
F-4-1	56·9	9,310	164	Bond shear, mortar break
F-4-2	59·6	8,630	145	" " "
F-4-3	58·9	7,390	126	" " "
F-4-4	62·0	9,500	153	" " "
F-4-5	59·6	10,030	168	" " "
F-4—Average:	....	....	151	
F-5-1	59·2	7,950	134	Mortar shear
F-5-2	60·8	11,360	187	" "
F-5-3	....	....	....	Specimen broken in capping
F-5-4	60·4	10,840	180	Bond and mortar shear
F-5-5	59·2	11,070	187	" " "
F-5—Average:	....	....	172	
G-1-1	53·9	16,840	312	Bond shear
G-1-2	54·9	16,210	295	Bond shear, mortar break
G-1-3	49·1	9,770	199	" " "
G-1-4	54·8	16,830	307	" " "
G-1-5	54·7	10,480	192	" " "
G-1—Average:	....	....	261	
G-2-1	54·8	17,120	312	Bond shear
G-2-2	55·9	19,050	341	" "
G-2-3	55·5	19,830	357	Bond shear, mortar break
G-2-4	55·8	19,420	348	" " "
G-2-5	55·1	14,600	265	" " "
G-2—Average:	....	....	325	
G-4-1	54·3	9,300	171	Bond shear, mortar break
G-4-2	54·1	11,040	204	" " "
G-4-3	54·0	11,710	217	" " "
G-4-4	52·1	9,150	176	" " "
G-4-5	55·1	4,990	91	Defective construction, not used in average
G-4—Average:	....	....	192	
G-5-1	55·8	8,450	151	Bond and mortar shear
G-5-2	57·8	11,480	199	" " "
G-5-3	56·6	10,310	182	Mortar shear
G-5-4	56·6	10,720	189	" "
G-5-5	55·8	10,090	181	" "
G-5—Average:	....	....	180	

TABLE XIV

Summary of Results

Adhesion strength (lb. per sq. in.)

Brick	Mortar No. 1		Mortar No. 2		Mortar No. 3	
	Dry-set	Wet-set	Dry-set	Wet-set	Dry-set	Wet-set
A	51	37	75	54	48	50
B	2	61	3	29	26	35
C	11	70	6	39	50	45
D	103	93	87	65	67	87
E	95	27	76	68	37	65
F	112	69	87	101	100	69
G	98	89	98	47	79	68

Shear strength (lb. per sq. in.)

Brick	Mortar No. 1		Mortar No. 2		Mortar No. 4		Mortar No. 5	
	Dry-set	Wet-set	Dry-set	Wet-set	Dry-set	Wet-set	Dry-set	Wet-set
A	50	53	127	93	72	64	83	81
B	26	77	56	47	50	60	286	244
C	67	203	45	65	29	43	276	229
D	241	185	182	201	73	179	239	220
E	292	264	375	270	196	183	238	160
F	286	164	153	219	219	151	279	172
G	283	261	250	325	152	192	211	180

DISCUSSION OF RESULTS

Types of Failure

There were three distinct types of failure in both adhesion and shear tests, as follows :

1. Failure of bond at the brick-mortar contact line.
2. Failure within the mortar.
3. Failure of bond and mortar.

The majority of the failures in the adhesion tests were of the first type, although the other two types occurred quite often where the adhesion strength was high. The majority of the failures in the shear tests were of the third type but there were a considerable number of failures of the second type, especially with the grout set-ups. In these failures the results were not true measures of bond strength as the breaks occurred in the mortar itself before the load applied was high enough to cause bond failure.

Consistency of Results

The results were quite consistent both in averages and in individual assemblies. Out of the total of ninety-eight averages, only five are questionable as to being truly representative of the particular set-ups involved. Three of these are in the adhesion strength results, the first occurring with brick E set wet with mortar No. 1. The average adhesion strength of this combination is considerably lower than that of the same set dry. The second case is also with brick E in which the adhesion strength when set dry with mortar No. 3 is relatively low. Judging from the other results, both in adhesion and shear with this type of brick these two cases fall considerably out of line of what might be expected. The third case in adhesion is with brick G set wet with mortar No. 5, in which the strength is much lower than with any of the other combinations with this type of brick.

Only two questionable averages are found in the results of the shear tests. The first is brick B set wet with No. 2 mortar in which the shear strength is lower than with the same set dry. This is at variance with the other results obtained with this brick using mortars Nos. 1 and 2 both in adhesion and shear. Brick D dry set with mortar No. 4 is much lower in shear strength than would be expected, judging from its shear strength in the other assemblies.

These seeming discrepancies may be due to lack of initial intimate contact in constructing the assemblies, although this is not evident, and considerable care was taken in the laying of the brick in all cases. On the other hand, they may be actually truly representative of these particular combinations, as it is now commonly recognized that brick-mortar assemblies give best results only when the mortar and the condition of laying are adapted to the particular brick used.

Results of Tests on Individual Types of Brick

The individual types of brick give the following general results in the adhesion and shear tests.

Type A. Low absorption, stiff-mud shale brick, medium strength in both adhesion and shear. Highest results with No. 2 mortar. Results generally somewhat higher with brick set dry.

Type B. High absorption, dry-press shale brick. Low adhesion strength with brick set dry, medium with brick set wet. Shear strength with mortars Nos. 1, 2, and 4 rather low, tending to be higher set wet than dry. Mortar No. 5 (grout) shear strengths high.

Type C. High absorption, dry-press shale brick. Low adhesion strength with brick set dry, higher with brick set wet, except with mortar No. 3 which gives medium adhesion strength both dry and wet. Shear strengths highest with mortars Nos. 1 and 5 (grout), generally higher with brick set wet.

Type D. Medium absorption, stiff-mud shale brick, generally high bond strength, higher set dry than wet with the exception of mortar No. 3. Shear strength generally high and uniform except with mortar No. 4 set dry.

Type E. Medium absorption, soft-mud clay brick. High to medium bond strength. Higher set dry than wet with exception of mortar No. 3. High strength especially when brick set dry in all cases.

Type F. Medium absorption, stiff-mud shale brick, generally high adhesion strength. Highest when brick set dry except with mortar No. 2. Shear strength generally high and, with exception of mortar No. 2, highest when set dry.

Type G. Medium absorption, stiff-mud shale brick, adhesion strength generally high and uniform both dry-set and wet, except with mortar No. 2 in which wet-set strength is only half of dry-set. Shear strength generally high and uniform both wet-set and dry-set.

Mortar Consistency

The mortars used were of the same consistencies for each type of brick. This resulted in setting up A bricks with mortars wetter than would be used in practice, and in setting up B and C bricks with mortars drier than used in practice. The mortar consistencies appeared to be very suitable for bricks of D, E, F, and G types. If drier mortars had been used for type A bricks, and wetter ones for types B and C, it is quite probable that the bond strengths would have been higher for these types than that which is reported. This is confirmed to some extent by a comparison of the results on these types of brick set wet and set dry, which show A type with higher strengths set dry, and B and C types with higher strengths set wet.

CONCLUSIONS

It is quite evident from all of the foregoing that absorption characteristics have a definite relationship to the bond strengths developed with the various mortars used.

The transverse and compressive strengths of the bricks have no direct relationship to the strength of bond resulting from construction of the test assemblies using different mortars.

Leaving mortar No. 5 (grout) out of consideration for the present, it may be stated that :

1. Low absorption brick develop a medium bond strength with both cement and cement-lime mortars, when set either dry or wet.

2. Medium absorption brick develop a high bond strength with both cement and cement-lime mortars, when set either dry or wet.

3. High absorption brick develop only a low bond strength with cement and cement-lime mortars when set dry, and this bond strength is materially increased when these brick are set wet.

All of the types of brick develop a relatively high bond strength when used with grout. This may be due principally to impregnation of pores and of surface roughness with cementing material, particularly with dry-press brick, and in part to the rapidity of satisfying brick absorption in conjunction with slow bond formation and uniformly intimate contact between mortar and brick.

With the mortars Nos. 1 and 2 used in both adhesion and shear setups the shear strength generally increases with an increase in adhesion strength.

Complete intimate contact between brick and mortar is necessary to develop the best bond strength. This is quite evident and is confirmed by the high results obtained with the use of grout which was sufficiently liquid to flow freely, thus automatically ensuring complete intimate contact.

Part II

EFFECT OF ABSORPTION OF TILE ON THE ADHESION AND STRENGTH OF CONCRETE BEAMS OF DIFFERENT WIDTHS

The purpose of this investigation was two-fold and may be briefly stated as follows :

(1) To determine what effect the absorption of tile has upon the strength of the concrete in the beams; in beams 4 inches, 3 inches, and 2 inches in width ; and the effects of various degrees of saturation of the tile.

(2) The value of the bond between the tile and concrete under the above conditions.

TYPE OF TEST SPECIMEN USED

The test specimens consisted of a concrete block uniting two hollow tiles. The arrangement with reference to 8- by 12- by 12-inch tile and a 4-inch width of concrete is shown in Figure 1.

The space between the tiles was completely filled with concrete for the entire width and to within 1½ inches of the ends of the tiles. Thus in the case of a 4-inch width of concrete the block would be 4 by 8 by 9 inches ; in 3-inch width, 3 by 8 by 9 inches ; and in 2-inch width, 2 by 8 by 9 inches, giving a tile-concrete contact 8 by 9 inches in each case.

MATERIALS USED

Hollow Tile

Four sets of tile, broadly representative of a large percentage of the total production, were used and a brief description of each, along with the designation letters used in this report, is as follows :

A. 8 × 8 × 12, low absorption shale tile.
B. 8 × 8 × 12, medium absorption shale tile.
C. 8 × 12 × 12, medium absorption clay tile.
D. 8 × 12 × 12, high absorption clay tile.

All of these tile had scored faces and were of the usual type used in floor construction. One hundred tile of each set were submitted for the tests. Five tile were selected from each lot for absorption determinations. Care was taken in this selection to obtain tile which would be representative of each complete shipment. The results of the absorption tests are shown in Table I.

TABLE I

Absorption of Tile

(Per cent)

Tile	5 seconds	24 hours	1-hour boiling
A	2·35	7·34	8·39
B	2·36	15·26	16·37
C	1·25	12·56	14·61
D	6·61	23·98	33·20

Concrete

Cement. The cement was purchased locally and was of a quality to meet the specifications of the American Society for Testing Materials for Portland cement.

Sand. The sand was purchased locally, and had the physical properties shown in Table II.

Stone. The stone used was a local limestone with physical properties as shown in Table II.

TABLE II

Physical Properties of Concrete Aggregate

——	Sand	Limestone	Combined: 55 per cent sand 45 per cent stone
Pounds per cubic foot	108·0	95·3	118·5
Per cent voids	35·2	43·5	29·5
Fineness modulus	2·69	5·85	4·11
Screen Analyses:			
Per cent passing sieve ⅜ mesh	....	100·0	100·0
" " " ¼ "	100·0	53·1	78·9
" " " 4 "	99·4	11·5	59·9
" " " 8 "	91·4	1·5	51·0
" " " 16 "	79·4	1·0	44·2
" " " 30 "	46·4	0·6	25·8
" " " 50 "	12·0	0·5	6·8
" " " 100 "	2·6	0·3	1·5

In order to secure a concrete with a compressive strength of at least 3,000 pounds per square inch, the following mix was suggested by the Public Works Department at Ottawa. This mix was based on the Canadian sack of cement as a unit :

1 sack of cement of 87 pounds net.
1·73 cubic feet of sand.
1·60 cubic feet of limestone.
4·57 Imperial gallons of water.

The above mix had a slump of 3½ inches and yielded 3·20 cubic feet of concrete per sack of cement. To produce one cubic foot batch of concrete the following quantities were required :

Cement	27·20 lb.
Water	14·30 "
Sand	58·24 "
Stone	47·64 "

To give better workability two other mixes were made, the first having a 5 per cent increase in cement and water, and the second a 10 per cent increase in cement and water. It was found that the increase of 5 per cent cement and 5 per cent water produced what appeared to be the most suitable mix.

It was determined that 3 cubic feet of concrete would be necessary to make 5 sets each of 2-, 3-, and 4-inch concrete blocks. Accordingly the mix finally used was as follows :

Cement	85 lb. 10 oz.
Water	45 " 14 "
Sand	174 " 9 "
Stone	142 " 13 "

CONSTRUCTION OF TEST SPECIMENS

Wooden forms were made to support the tile and to provide suitable spacing for pouring the various thicknesses of concrete. These forms consisted of a pallet 9 inches wide with two uprights at the centre, the width of the concrete desired. These uprights were held in place by a cross-piece at the top. The tile were then placed in their proper position on the pallet, being separated by the uprights which were 2, 3, and 4 inches wide. The tile were levelled with wedges and held tightly in position by wires.

In making the test specimens, five sets each were made with 2, 3, and 4 inches of concrete. Thus fifteen test specimens were made from each set of tile air-dry, dampened by five seconds' immersion in water, and wet by 24 hours in water. Thus a total of 45 test specimens were made from each of the four sets of tile.

After the tile were properly placed in the forms, sufficient concrete was mixed to use for 15 test specimens, 5 each of 2-, 3-, and 4-inch concrete. The concrete was thoroughly mixed dry after which the water was added and the mass thoroughly mixed again. The pouring and ramming of the concrete was done in such a way that all of the concrete had been placed within half an hour of the time when mixing was completed.

The exposed surface of the concrete was covered with damp cloths and the test specimens were allowed to set 48 hours before being removed from the forms. They were then aged for 28 days before tests were begun.

Two-inch cubes were made from each batch of concrete for use in checking the cured strength. After completing the tile set-ups, glass plates were substituted for tile in the forms and a series of concrete blocks made to determine the compressive strength of the concrete when this was not influenced by tile. These blocks were also aged 28 days before breaking.

TESTING

Previous to testing, the test specimens were capped, as indicated in Figure 1, with a 2 : 1 cement-gypsum paste on the upper surface of the concrete block (a) and on the bearing surface of the tiles (b). One of the large glass plates used as a capping surface was found to be slightly concave and the specimens capped on this were recapped on an iron surface plate with a 4 : 1 sulphur-flint mixture.

In testing the bond strength the tiles were supported on the base of the testing machine, and the load was applied to the upper surface of the concrete block through a spherical bearing head and a machined steel block. The majority of the concrete blocks remained intact and broke away from the tile at the contact surfaces. The failures were of three distinct types :

1. The concrete between the tile ribs breaking away from the main concrete block.

2. The tile and concrete separating at the contact plane.

3. The tile ribs breaking away from the tile.

The first type of failure occurred mainly with the A-tile, the second type with the B- and C-tile, and the third type with the D-tile.

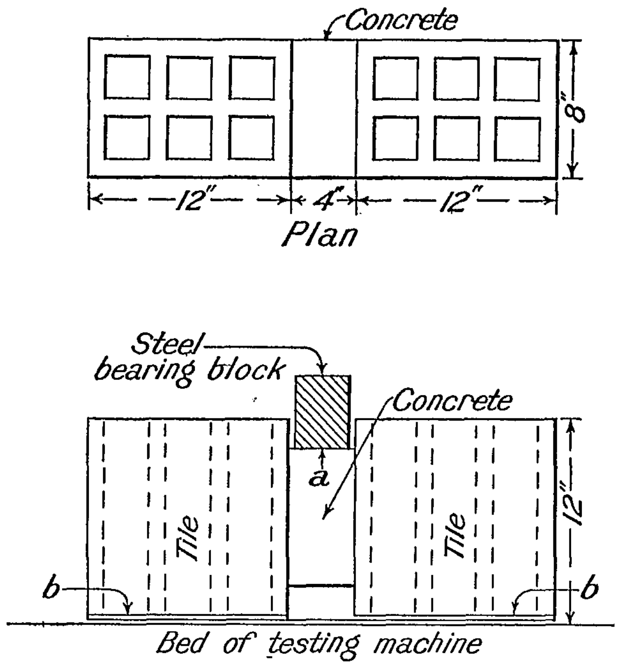


FIGURE 1. Test specimen.

In some cases there was some shear failure at or near the capping planes, but in no case was the concrete block broken so as to make it unfit for a compression test. This was to be expected as the strength of the concrete was for the most part well over 3,000 pounds per square inch. There was sufficient friction between the specimen and the base of the testing machine to prevent the tiles breaking away from the bedding during a test. There were several cases, however, in which a shearing break occurred near the bottom of the tile, particularly in tiles of A and C sets. In practically every case where the concrete sheared, it was very near the top of the concrete block. After the concrete blocks were sheared from the tile, they were capped with a 4 : 1 sulphur-flint mixture on the 2- by 8-inch, 3- by 8-inch, or 4- by 8-inch ends, after which they were tested in compression.

RESULTS OF THE TESTS

The results of the tests of bond strengths are given in Table III, the tests of the compressive strength of the concrete block in Table IV, and the compressive strength of the concrete blocks poured between glass plates in Table V.

TABLE III

Average Bond Strength

(lb. per sq. in.)

—	Concrete	A-Tile	B-Tile	C-Tile	D-Tile
	inches				
Dry	2	357	234	315	160
	3	244	164	215	164
	4	288	236	201	125
5 seconds' immersion	2	337	181	166	195
	3	325	221	195	204
	4	216	184	208	210
24 hours' immersion	2	340	98	191	221
	3	391	127	215	208
	4	318	126	203	186

TABLE IV

Average Compressive Strength

(lb. per sq. in.)

—	Concrete	A-Tile	B-Tile	C-Tile	D-Tile
	inches				
Dry	2	4,148	3,221	2,343	2,122
	3	4,533	3,508	2,879	2,502
	4	4,667	3,801	3,093	2,969
5 seconds' immersion	2	5,882	3,162	2,624	2,503
	3	5,818	3,712	2,926	3,095
	4	5,223	3,725	3,171	3,355
24 hours' immersion	2	5,038	4,251	4,128	5,322
	3	5,189	4,827	4,100	5,066
	4	4,583	4,104	4,100	5,067

TABLE V

Compressive Strength of Concrete Set in Glass Plates

(lb. per sq. in.)

2 inches—3,674	3 inches—3,623	4 inches—3,978

DISCUSSION OF RESULTS

The variable factors in tests of this kind are both many and important, consequently results are likely to be misinterpreted unless these variables are understood and due allowance is made for apparent discrepancies in tabulated results. One of the most important factors in bond strength is the percentage of intimate contact between the tile and the concrete.

It is very rarely that this contact becomes 100 per cent. In this investigation the average intimate contact was approximately 85 per cent. The concrete used was of a rather stiff consistency and the spaces for its placing were quite narrow, and the average contact obtained under these conditions, along with the necessary use of a relatively coarse aggregate, is considered to be good.

There are several variables in the tiles themselves. One is the difference in absorption between individual tiles in the same set. This difference was most noticeable in the D-tile, in which variations of as much as 20 per cent of the total absorption were noticed. The effect of these variations cannot be ascertained as complete absorption tests were made on only five tiles from each set.

Another variable was found in the formation of the ribs on the tile faces. These ribs were quite different in each set of tile. In two cases they were smooth, in one case somewhat rough with serrated edges, and in the other very rough with rough edges. The width and depth of the ribs also varied considerably. In one set of tile the formation of the ribs was quite different on individual tiles. Some of the tiles in this set had well-formed ribs, some poorly formed, and in others they were almost completely lacking. The character of the texture of the surface also undoubtedly has some effect on the bonding strength.

The curing of the test specimens was not uniform as no space was available for storage in which humidity, temperature, and air circulation could be controlled. The variation in curing conditions would influence both bond strength and the compressive strength of the concrete.

Considering the number of variables mentioned, and the list is probably not complete, allowances had to be made for these by the investigators who closely followed the work. It should also be understood that it is invariably recognized that with work of this character a variation of from 10 to 15 per cent in the average results is to be expected. Bearing this in mind, when analysing the tables, it will be seen that discrepancies which appear at first glance to be unexplainable are not serious in most cases.

Taking all of these points into consideration, it is believed that the following conclusions are reasonable and justifiable.

CONCLUSIONS

Bond Strength

(a) Neither the absorption nor the rate of absorption is a controlling factor in determining bond strength.

(b) The thickness of concrete between the tile has no definite influence on the strength of bond.

(c) The moisture content of the tile when the concrete is poured does not appear to affect the bond strength.

(d) The bond strength is sufficient in all cases to meet requirements of building construction.

(e) Care in pouring to ensure intimate bond is very important. Improperly rammed specimens were found to have a much lower bond strength in every case.

Compressive Strength of Concrete

(a) The strength of the concrete is greatly influenced by the absorption of the tile when placed between dry tile. In general, the lower the absorption of the tile, the higher the strength of the concrete.

(b) Wetting the more porous tile before placing the concrete increases the strength of the concrete very materially, particularly with a 24-hour immersion in water.

(c) In general, the thicker the concrete, the higher is its strength, although the percentage gain in strength is surprisingly low.

SUMMARY

The results show that the bond strength is not influenced in any definite way by the physical characteristics of the tile, and that the bond strength is materially influenced by the percentage of intimate contact between the tile and concrete.

The compressive strength of the concrete is influenced considerably more by the absorption of the tile and the extent to which this absorption is satisfied, than by the width of the concrete beams.