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SMALL BRICK PANEL TESTS AT HALIFAX

An Investigation of "Time", "Tap", and "Flow" Factors in the Assembly of Small Brick Panels for Leakage and Bond Strength Tests

by

J. I. Davison

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PREFACE

An extensive program of laboratory investigations of the rain penetration and bond strength characteristics of brick masonry is in progress at the Atlantic Regional Station in Halifax as well as at the laboratories of the Division in Ottawa. The standardized techniques which have been developed for this program are described in previous reports. The complexity of the problem of ensuring good performance of brick masonry as to bond strength and rain penetration are demonstrated in part by the results now reported from controlled tests in which several of the principal factors operative at the time of laying have been varied systematically.

The author, a chemist and a research officer with the Atlantic Regional Station of the Division, has devoted his full time for the past several years to performance studies of brick masonry.

Ottawa
August 1960

N. B. Hutcheon
Assistant Director

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Following the preliminary program of leakage and bond strength tests on small brick panels in the Atlantic Regional Laboratory, an investigation of some of the factors involved in the assembly of the panels was undertaken. Specifically, the effect of varying the "time", "tap", and "flow" factors was studied; this report records the results of these studies.

First, it is necessary to define the terms "time", "tap", and "flow". "Time" refers to the time interval between the placing of the mortar bed on a bottom brick and laying the next brick on that mortar. A previous study on moisture losses from mortars during early contact with bricks (DBR Internal Report No. 173) pointed to the importance of this time interval. For the purpose of this study three times--30, 60, and 90 seconds are used.

After laying a brick on the mortar bed it is given an impact by a tapping device which is in effect a weight of known size dropping through $1\frac{1}{2}$ in. This tapping device was developed at the National Bureau of Standards, Washington, D.C., where a weight of 2 lb was used in preparing crossed-brick couplets. This became known as the Standard Tap and was used during the previous study. Use of this 2-lb tap was questioned since the area of the mortar bed involved in small panel assembly (approximately 8 in. by $3\frac{3}{4}$ in.) was slightly more than double that involved in assembling crossed-brick couplets (approximately $3\frac{3}{4}$ in. by $3\frac{3}{4}$ in.). In this study two weights were used; a 4-lb weight referred to as a "heavy" tap, and a 2-lb. weight known as the "light" tap.

The third factor investigated was the flow of the mortar used. "Flow" refers to the plastic consistency of the mortar as measured by the standard flow table method outlined in A.S.T.M. Tentative Method of Test for Compressive Strength of Hydraulic Cement Mortars (C109-54T). In this study low-flow mortars having a value between 105 to 115 per cent and high-flow mortars with a value in the range 115 to 125 per cent are used.

Seventy-two panels have now been completed and results are presented in this report. Also included are results for twelve panels assembled with brown bricks in initial rate of absorption (I.R.A.) range 18.0 to 22.2 gm and three mortars in order to learn something of the bonding ability of these bricks which are in the highest suction range of local bricks.

Materials

Bricks.- Three different stiff-mud bricks manufactured in the area were used, the first a red brick having an I.R.A. below 5 gm, the second a buff brick having an I.R.A. of between 8 and 18 gm, and the third a brown brick having an I.R.A. of between 18 and 26 gm. Other absorption properties of the three bricks are listed in Table I.

Mortar.- Three different mortars were used in assembling panels for this study:

1) Masonry cement mortar containing 1 part by volume masonry cement to 3 parts sand.

2) Cement lime mortar containing 1 part by volume portland cement, 1 part lime putty, and 6 parts sand.

3) Cement lime mortar containing 1 part by volume portland cement, 2 parts lime putty, and 9 parts sand.

TABLE I

Table of the Bricks

Brick Type	I.R.A. gm/30 sq in./min (a)	Absorption (% Dry Weight) 24 hr Submersion (b)	5 hr Boiling (c)	Saturation Coefficient (d)
Red	0.5 to 2.5	0.3 to 2.2	0.6 to 2.9	0.43 to 0.73
Buff	5.2 to 19.5	6.2 to 7.3	7.8 to 9.0	0.79 to 0.82
Brown	4.4 to 22.0	1.6 to 3.2	3.1 to 5.3	0.52 to 0.59

(a) Amount of water absorbed by a dry brick when placed in water (largest surface down) to a depth of 1/8 in. for one minute (corrected to a standard area 30 sq in.)

(b) Amount of water absorbed by a brick expressed as a percentage of its dry weight when the brick is submerged in water at room temperature for 24 hr.

(c) Amount of water absorbed by a brick expressed as a percentage of its dry weight when after the 24-hr submersion test it is submerged in boiling water for 5 hr, then cooled to room temperature in water.

(d) Ratio of amounts of water absorbed in tests (b) and (c) or the ratio of the easily filled pore space to the total pore space in a brick.

All materials were the same as those used in the previous study, and mortars were mixed in a Hobart N50 mixer in a similar manner. Sufficient water, the actual quantity having been predetermined by experiment, was added to give the mortar the required flow.

Panel Assembly

Small panels were assembled using five bricks placed one on top of the other with four mortar joints, following the procedure outlined in the previous work with the necessary adjustments for variations in time and tap.

The masonry laboratory had been air-conditioned to create conditions of 70°F and 50 per cent R.H. before this project began. Although temperature and humidity were generally in this range during the study, occasional breakdowns in the unit caused some variation, the outer limits being 62 to 80°F for temperature and 43 to 60 per cent for R.H.

Leakage Tests

Leakage tests were done in the usual manner using the D.B.R. Small Panel Leakage Apparatus. During the 24-hour test period a film of water is maintained on the face of the panel which is also subjected to an air pressure of 2 in. of water. Thus conditions of a 50 mph wind-driven rain are simulated.

Bond Strength Tests

Bond strength tests were done on all panels subsequent to leakage tests. When the latter were completed, panels were kept in the laboratory until ready for bond strength tests. Three different methods were used to obtain bond strength values:

1) With the bending apparatus used in previous studies some bond strength values for panels 1 to 6 were obtained.

2) Remaining values for panels 1 to 6 were obtained with the tensile strength machine at Nova Scotia Technical College. Clamping frames from the bending apparatus were adapted to fit this machine.

3) Remaining bond strength values were obtained with the new bond strength apparatus developed by the Division at Ottawa. The method is described in DBR Internal Report No. 175; the apparatus is shown in Fig. 1. In addition to this difference in the method of testing, there was a considerable variation in the age of early panels when tested. With the arrival of the new apparatus from Ottawa the curing period was regulated, and panels 30 to 84 were tested one week after leakage tests or 21 days after fabrication. Curing periods for panels 1 to 30, however, were as high as 88 days from date of panel assembly to bond strength tests. Bond strength values are, therefore, not comparable in many cases because of the different techniques used and also because of the difference in curing periods.

Results from Panels 1 to 12

The first twelve panels were assembled with red bricks with very low suction values (I.R.A. 1 to 2.6 gm). Two mortars, a 1:3 masonry cement: sand and a 1:1:6 cement: lime putty: sand were used, the former with odd-numbered panels and the latter with even-numbered panels. Mortars were low flow (105 to 115 per cent), the average being 109 per cent. Heavy tap was used for all panels. The variable for these panels was the time factor. Time intervals of 30, 60, and 90 seconds were used for panels 1 to 4, 5 to 8, and 9 to 12 respectively. Results are summarized in Table II; a detailed discussion follows.

TABLE II

General Summary -- Panels 1 to 12

		30 Sec	60 Sec	90 Sec
Leakage	1:3	nil	nil	nil
	1:1:6	nil	nil	nil
Bond Strength	1:3	59.6 psi	75.6 psi	54.7 psi
	1:1:6	88.8 psi	67.6 psi	57.5 psi

(a) Panels 1 to 4

There was some discoloration of cement-lime mortar joints at the end of the leakage test; the masonry cement mortar joints had a lesser degree of discoloration. There was no dampness on the back of any of the panels. A comparison can be made of bond strength results and values obtained with the bending machine and the tensile strength machine from the information in Table III.

TABLE III

Bond Strength Results (psi) -- Panels 1 to 4

Panel No.	Age at Test	N.S. Tech Machine Joint #1	Joint #2	Bending Apparatus Joint #3	Joint #4	Average
1	37 days	51.7	49.9	80.4	65.7	61.9
2	36 days	47.4	70.6	108.5	95.1	80.4
3	32 days	41.3	74.0*	49.6	63.0	57.0
4	73 days	72.3	121.4	115.9	79.1	97.2

*Frame slipped during first attempt. Fracture occurred after subsequent adjustment.

Although average results obtained with the bending apparatus are higher than those obtained with the tensile strength machine, the highest individual value was obtained with the tensile strength machine; in some cases, results from the two machines are comparable, e.g., results for panel No. 4. The considerable variation in values for the same panel is typical of results for all panels no matter what method was used. Highest values occurred with cement-lime mortar joints. Visual examination showed excellent bond; many of the breaks occurred through the mortar beds rather than at an interface between bricks and mortar.

(b) Panels 5 to 8

All mortar joints for cement-lime mortar panels were discoloured at end of test while only one of eight masonry cement mortar joints showed any discoloration.

TABLE IV

Bond Strength Results (psi) -- Panels 5 to 8

Panel No.	Age at Test	N.S. Tech Machine Joint #1	Joint #2	Bending Apparatus Joint #3	Joint #4	Average
5	72 days	63.7	12.1+	75.0	Broke during set-up	69.4*
6	71 days	63.7	99.9	95.1	85.8	86.1
7**	91 days	Broke during set-up	84.3	77.5	77.5	79.8
8	88 days	53.7	67.1	30.9	44.8	49.1

\+ This joint was probably damaged during set-up.
* Two values only.
** Values for Panels 7 and 8 were obtained with the new bond strength apparatus.

Bond strength results in Table IV permit a comparison of results of the three techniques used. Results of joints 1 and 3 of panel 5, the former obtained on the N.S. Tech Machine and the latter with the bending apparatus, are comparable with the three values for panel 7 obtained with the new bond strength apparatus.

Both panels were assembled with masonry cement; higher values for panel 7 might be explained by an additional 19 days curing period. The range from the low value of 63.7 psi obtained with the N.S. Tech Machine to the high value of 84.3 psi obtained with the new bond strength apparatus is not unusually high, in fact it is not as great as the range in the values for the other panels, Nos. 6 and 8 listed in Table IV. Values for panels 6 and 8 present an interesting contrast to the foregoing results: bond strengths for panel 8, cured for 71 days, obtained with the new bond strength apparatus were much lower than values for panel 6 cured for 88 days where two values were obtained with each of the other machines. It is difficult to say how much of this spread is due to difference in techniques for such differences quite often occur in later work where only the new machine is used. It should also be noted that in panel 6 the average value obtained with the bending apparatus is higher than that obtained with the N.S. Tech Machine although the highest individual value occurred with the latter. As a result of the low average for panel 8, bond strength values for masonry cement mortar joints were better than those for cement-lime mortar. This is questionable in the light of overwhelming evidence to the contrary and in this case may be the result of a combination of circumstances including different techniques.

Visual examination revealed a good extent of bond for all panels in this group with many fractures occurring through the mortar beds.

(c) Panels 9 to 12

Leakage performance was similar to the 60-second panels: joints in panels 10 and 12 were discoloured at end of test while there was no indication of any moisture penetration on panels 9 and 11. Bond strength values were somewhat lower for this group than those previously obtained (see Table V).

TABLE V

Bond Strength Results (psi) -- Panels 9 to 12

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
9	83 days	+23.2	*---	47.9	49.9	48.9
10	84 days	*---	*---	57.2	+15.5	57.2
11	84 days	74.0	72.3	61.1	34.1	60.4
12	83 days	66.3	53.0	59.2	52.5	57.8

* No value--joint broken during set-up.

\+ Two low values probably result of damaging joints during set-up. These values not included in average.

Two low values and three broken joints in panels 9 and 10 are a result of inexperience in using the new bond strength machine. Better average results were obtained for cement-lime mortar panels than those assembled with masonry cement mortar. The best single panel result occurred, however, in No. 11, a masonry cement mortar panel.

Visual examination revealed that extent of bond was not as good as for the previous group and also that the masonry cement panel had greater extent of bond than the cement-lime panels. There were small unbonded areas in the joints of these panels, and the perimeters were not as tight as in previous panels.

General

Leakage.- Discoloration of cement-lime mortar joints indicates that panels assembled with this mortar absorbed more water than those panels using masonry cement. This is supported by results listed in the following table and obtained by weighing panels before and after the leakage test.

Time Interval	Masonry Cement Mortar Panels	Cement Lime Mortar Panels
30 sec	69 gm	90.5 gm
60 sec	78 gm	117.0 gm
90 sec	54 gm	112.0 gm

WATER ABSORBED BY RED BRICK PANELS DURING LEAKAGE TEST

The higher absorption by the cement-lime panels may be due to incomplete carbonation of lime in the mortars after the 14-day curing period. From the standpoint of leakage results the difference in time interval in assembling panels 1 to 12 does not appear to have any particular significance.

Bond Strength

For the reasons mentioned previously a comparison of bond strength values for these panels is not significant, but several conclusions may be drawn from the results:

1) Values for cement-lime mortar panels were somewhat higher than for masonry cement panels.

2) Values for cement-lime panels decrease as the time interval is increased from 30 to 90 seconds. This trend was not evident, however, in results for masonry cement panels.

Visual examination indicated excellent extent of bond for 30- and 60-second panels while 90-second panels were not as completely bonded.

Conclusions

Bricks in the low suction range bond satisfactorily with masonry cement and cement-lime mortar using three time intervals in assembling panels:

1) From visual examination and records of water absorption during leakage tests, masonry cement mortar panels are slightly superior in resistance to leakage than cement-lime mortar panels after 14 days curing period.

2) Bond strength values are somewhat higher for cement-lime mortar panels than for masonry cement mortar panels.

3) Bond strength values and visual examinations indicate decreasing extent of bond as time factor increases in the case of cement-lime mortar.

Results from panels 13 to 24

This group of panels was a duplicate of the first twelve substituting buff bricks in the I.R.A. range 11.0 to 16.8 gm for the red bricks previously used. The same two mortars were used in the low-flow range--average flow being 108.1 per cent-- with a heavy tap. Again the time interval was the variable, four panels (duplicates with each of the two mortars) being assembled with each of the three times 30, 60, and 90 seconds. Results are summarized in Table VI and then discussed.

TABLE VI

General Summary -- Panels 13 to 24

		30 Sec	60 Sec	90 Sec
Leakage	1:3	nil	562 ml*	3,350 ml
	1:1:6	nil	502 ml	1,215 ml
Bond Strength	1:3	23.1 psi	20.3 psi	14.0 psi
	1:1:6	68.9 psi	38.8 psi	25.1 psi

* One panel did not leak--other one leaked 1,124 ml.

(a) Panels 13 to 16

There was no leakage for any of the four panels and the only indication of moisture penetration was in slight discoloration at the ends of two of the mortar joints in panel 16 which had been assembled with a cement-lime mortar. Bond strength values, all obtained with the new bond strength apparatus after curing periods of 79 to 83 days, are listed in Table VII.

TABLE VII

Bond Strength Results (psi) -- Panels 13 to 16

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
13	83 days	21.6	30.0	40.3	23.4	28.8
14	82 days	79.0	78.2	64.5	56.4	69.5
15	82 days	13.7	16.8	20.6	18.5	17.4
16	79 days	80.6	55.6	62.9	74.2	68.3

Results for panels 14 and 16 (cement-lime mortars) are much higher at 68.9 psi than the 23.1 psi value for masonry cement mortar panels. Visual examination of broken joints revealed good extent of bond, but not quite as good as the extent of bond seen with the red bricks. The bonding was not as good about the perimeters, and small indentations in the surface of the brick were not completely filled with mortar.

(b) Panels 17 to 20

All four panels leaked. Only panel 20, however, started to leak immediately. The other three panels started to leak from 3 to 5 minutes after the start of test. Panel 17 had water showing on joint 2, but the leak did not continue and there was insufficient leakage to run off the back of the panel for measurement. The other masonry cement panel, No. 19, leaked the most -- 1,124 ml, starting at 5 minutes and leaking steadily throughout the test. The cement-lime mortar panels leaked 240 and 765 ml respectively and differed from the masonry cement panels in that leakage stopped prior to the end of test, probably due to a swelling shut of leakage paths. Most of the leakage for the cement-lime mortar panels occurred during the first hour of test and declined steadily thereafter. Maximum rate of leakage of 8 ml for panel 20 occurred between 10 and 60 minutes. Maximum rates were about 2.0 ml for panel 18 and 0.9 ml for panel 19. Panel 18 leaked quite profusely during the first hour and then decreased in leakage rate; panel 19 leaked steadily throughout the test as can be seen when leakage during the first hour, 55 ml, is compared with total leakage of 1,124 ml.

TABLE VIII

Bond Strength Results (psi) -- Panels 17 to 20

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
17	78 days	37.1	22.6	Broken during set-up	21.0	26.9
18	78 days	65.3	75.8	58.8	20.2	55.0
19	74 days	4.0	23.9	12.9	Broken during set-up	13.6
20	73 days	Broken during set-up	24.2	10.0	17.2	17.1

A breakdown of bond strength values for these four panels, obtained at age 78 to 73 days, is given in Table VIII. Again average value for cement-lime mortar panels at 38.8 psi is better than the 20.3 psi value for masonry cement mortar panels. Values for panels 19 and 20 are much lower than for their duplicates, panels 17 and 18. Visual examination revealed a lesser extent of bond than in the previous panel -- bonding was definitely inferior in perimeter areas. Three mortar joints were broken during setting-up operations -- a further indication of weaker bond. A comparison of typical mortar joints from panels 17, 18, and 19 can be seen in Fig. 2.

(c) Panels 21 to 24

Water came through mortar joints of all four panels as soon as the leakage test was started, but there was no measurable run-off until 3 to 5 minutes because of the absorptive power of the bricks. Masonry cement mortar panels leaked an average of 3,350.5 ml higher than the 1,215 ml average for the cement-lime mortar panels. Average maximum rate of leakage was higher for the cement-lime mortar panels at 13 ml as compared with the 11 ml rate for the masonry cement mortar panels. Maximum leakage occurred during the first 10 to 15 minutes of leakage test for both panels. The cement-lime mortar panels leaked more during the first hour and then leakage rate decreased until there was no appreciable leakage near the end of the test; the masonry cement mortar panels leaked quite steadily throughout the test. The rate of leakage during the last hour was only 30 to 40 per cent of that during the first hour but was still quite substantial. Bond strength tests were done at curing periods of 72 to 76 days; a breakdown of results is presented in Table IX.

TABLE IX

Bond Strength Results (psi) -- Panels 21 to 24

Panel No.	Age at Test	Joint#1	Joint#2	Joint#3	Joint#4	Average
21	75 days	15.3	Broken during set-up	Broken during set-up	3.2	9.3
22	76 days	20.2	43.5	Broken during set-up	17.0	26.9
23	73 days	28.4	19.0	4.0	Broken during set-up	17.1
24	72 days	27.0	21.8	21.3	Broken during set-up	23.0

Cement-lime mortar panels had a higher average bond strength at 25.1 psi than masonry cement panels at 14.0 psi. Values are lower than those for 60-second panels, and the increased number of broken joints can also be attributed to lesser degree of bonding. Visual examination revealed very little extent of bond. Joints appeared to be "dry" and in all cases the top brick lifted cleanly from the mortar bed contrasting with previous panels where breaks occurred through mortar beds or where part of mortar bed clung to upper brick when fractured. Leak channels were found in several cases, notably in panel 24, but they were not a result of slumping in the mortar beds, a change in technique having eliminated this problem. Examination of the bond strength results in Table IX points up another interesting feature also noted in later results. Best bond strength values occur in upper joints of panels rather than in lower joints as might be expected since lower joints have additional "taps" given to bricks above and also carry additional weight of upper bricks during the setting period. There may be several reasons for this trend:

1) Tapping of upper bricks may disturb bond in lower joints where mortar has not yet had a chance to harden enough to resist strain -- this is particularly noticeable where mortar has lost a lot of moisture needed for plasticity as in the above case.

2) The "shock" of breaking top joints may weaken those below and thus contribute to lower values for these joints.

<u>General</u>

This series of twelve panels gives an excellent picture of the effect of time interval during panel assembly. Leakage and bond strength results are further supported by the water absorbed by the panels during the leakage test as shown in Fig. 3.

A comparison of leakage and bond strength results for these twelve panels indicates a sharp deterioration of results at the 60-sec time interval. At this point there are some good leakage and bond strength results and some poor ones.

Conclusions

1) Leakage and bond strength results deteriorate progressively with lengthening of the time interval between placing a mortar bed and laying buff bricks (I.R.A. 11.0 to 16.8 gm) in the mortar.

2) For the conditions under which this series of panels was assembled the critical time for placing buff brick, i.e. the time limit for placing bricks in mortar to obtain satisfactory bond, is something less than 60 seconds.

Panels 25 to 32

Eight panels were assembled with red bricks in the I.R.A. range 1.0 to 2.7 gm, the same two mortars, 30- and 60-sec time intervals, but with light tap for a comparison with panels 1 to 8 (heavy tap). The masonry cement and cement-lime mortars used had an average flow of 111.3 per cent as compared with 107.6 per cent for panels 5 to 12. Results will first be discussed as a group and later compared with the heavy tap panels.

TABLE X

General Summary -- Panels 25 to 32

Mortar Used	Leakage Results		Bond Strength (psi)	
	30 Sec	60 Sec	30 Sec	60 Sec
Masonry Cement (1:3)	nil	nil	37.6	17.9
Cement Lime (1:1:6)	Mortar joints 63% discoloured	Mortar joints 75% discoloured	53.6	36.4

(a) Panels 25 to 28

There was no leakage for any of the four 60-sec panels. Discoloration of six of the eight mortar joints indicated some moisture penetration of cement-lime mortar panels. A breakdown of bond strength values for the four panels is given in Table XI.

TABLE XI

Bond Strength Results (psi) -- Panels 25 to 28

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
25	31 days	21.3	12.4	16.9	2.6	13.3
26	30 days	48.2	20.3	31.7	42.5	35.7
27	32 days	28.4	26.7	29.9	4.5	22.4
28	28 days	54.2	22.9	30.1	41.3	37.1

Average value of 36.4 psi for cement-lime mortar panels is twice the average value of 17.9 psi for masonry cement panels. Age of panels at time of test was 28 to 32 days. Visual examination revealed good extent of bond in all cases with particularly good bonding about the perimeters. There were some small unbonded areas in the centre portion of the mortar beds. In all cases the top brick lifted from the mortar bed at fracture.

(b) Panels 29 to 32

There was no leakage for the 30-sec panels. Some moisture penetration was indicated in the cement-lime mortar joints by discolouring of five of the eight mortar joints for these two panels.

Bond strength results are given in Table XII.

TABLE XII

Bond Strength Results (psi) -- Panels 29 to 32

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
29	27 days	14.4	29.6	43.0	30.1	29.3
30	21 days	34.1	39.6	70.9	58.5	50.8
31	21 days	42.5	45.5	45.8	50.0	45.9
32	21 days	38.9	73.0	48.2	65.4	56.4

Once again average result of 53.6 psi for cement-lime mortar panels is superior to the 37.6 psi value for masonry cement mortar panels. Visual examination revealed nice tight perimeters and generally good extent of bond with some small unbonded areas in the centre of mortar beds. Some of the cement-lime mortar joints fractured through the mortar beds, but fractures generally followed the pattern of breaking between top brick and mortar bed. Some of the cement-lime mortar beds were damp at time of fracture. Panel 29 was tested at age 27 days. It was the last of the backlog awaiting bond strength test and remaining panels were tested at the usual 21 days. For typical mortar joints from panels Nos. 30 and 31 see Fig. 4, bottom row.

General

Figure 5 shows water absorption by both 30- and 60-sec panels during the leakage test.

Both 30- and 60-sec panels assembled with masonry cement absorbed identical amounts of water; the 30-sec cement-lime panel was only slightly better than the 60-sec panel. On the basis of moisture absorption results and visual observations of leakage tests, tightest panels result from use of masonry cement mortars, while bond strength results show that stronger bond develops between this brick and cement-lime mortar. Bond strength results also indicate superiority of 30-sec panels over 60-sec panels.

Comparison of Light and Heavy Tap

Panels 24 to 32 vs Panels 1 to 8 - Leakage.- Results of leakage tests for panels of low-suction bricks and masonry cement and cement-lime mortars, assembled with light and heavy tap as the variable, indicate very little difference between the two taps.

1) There was no leakage for any of the panels.

2) There was some slight discoloration of joints in panels of masonry cement mortar and assembled with heavy tap.

3) Masonry cement mortar panels assembled with heavy tap absorbed more water during the leakage test than light tap panels (Fig. 6).

4) Moisture absorption for cement-lime mortar panels was slightly higher for light tap than for heavy tap panels.

Thus from leakage results there is no real evidence in favour of using either light or heavy tap in assembling low suction bricks with either of the above mortars. Evidence favouring light tap with masonry cement mortar and heavy tap with cement-lime mortar is indicated only by comparison of water absorbed by the panels during test.

Bond Strength Results

A comparison of bond strength values for these panels indicates benefit from the use of the heavy tap.

TABLE XIII

Comparison of Bond Strength Values (psi) For Panels Assembled With Light and Heavy Tap

	30-Sec Panels		60-Sec Panels	
Tap	Masonry Cement Mortar	Cement-Lime Mortar	Masonry Cement Mortar	Cement-Lime Mortar
Light	37.6	53.6	17.9	36.4
Heavy	59.6	88.8	75.6	67.6

It must be remembered, however, that values for heavy tap panels were obtained with three different machines and are therefore of limited value in a comparison of this nature.

Results from Panels 33 to 40

In previous work with buff bricks having suction rates ranging from 11 to 16.8, there was some difficulty in getting a leak-proof panel. With this in mind, a series of eight panels was assembled using buff bricks (I.R.A. range 11.4 to 16.0 gm) with the same two mortars with a higher flow range (115 to 125 per cent). The average mortar flow for the eight panels was 119.2 per cent. Two time intervals, 30 and 60 sec, were used and all panels were assembled with heavy tap. Again all panels were assembled in duplicate. Results are summarized in Table XIV and then discussed in detail.

TABLE XIV

General Summary -- Panels 33 to 40

Mortar Used	Leakage Results		Bond Strength (psi)	
	30 Sec	60 Sec	30 Sec	60 Sec
Masonry Cement (1:3)	nil	nil	21.6	21.7
Cement-Lime (1:1:6)	nil	nil	72.9	58.9

(a) Panels 33 to 36 - Leakage

There were no leaks nor was there any discoloration of mortar joints for the four 30-sec panels using either type of mortar.

Bond Strength

Bond strength values for the four panels are listed in Table XV.

TABLE XV

Bond Strength Results (psi) -- Panels 33 to 36

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
33	23 days	33.9	37.1	20.6	7.1	24.7
34	21 days	93.9	62.9	74.2	50.3	70.3
35	21 days	7.7	35.2	6.8	24.2	18.5
36	21 days	74.2	82.6	89.0	56.8	75.7

These panels were tested after the normal curing period of 21 to 23 days -- average bond strength of 72.9 psi for cement-lime mortars was much higher than the 21.6 psi value for masonry cement mortar.

Visual examination of broken masonry cement panels revealed much greater extent of bond than would be expected from the values obtained. There was good extent of bond in all cases, some small unbonded areas being noted about the perimeters. These probably developed as a result of some of this very plastic mortar being forced out of the mortar joint by the heavy tap. There was excellent extent of bond for the cement-lime mortar panels. Most breaks occurred through the mortar beds rather than between the top brick and mortar bed as in the case of the masonry cement panels (see Fig. 4, top row). Several of the cement-lime mortar beds were still damp when the joints were broken.

Sometimes there was an inconsistency of results within the same panel: Note the spread in values from 7.1 psi to 37.1 psi for panel 1 and from 50.3 psi to 93.9 psi for panel 2. This pattern of inconsistency is characteristic of all DBR bond strength tests on small panels. Bond strength tests are, however, providing valuable information. Since absolute bond strength values are not of prime concern in this study, inconsistency in values is simply noted for the record.

(b) Panels 37 to 40 - Leakage

There was no leakage and no discoloration of mortar joints for any of the four 60-sec panels.

Bond Strength

Bond strength values determined at 20 to 22 days are given in Table XVI. Once again the average value of 59.0 psi for the cement-lime mortar panels is much higher than the 21.7 psi value obtained for the masonry cement mortar panels.

TABLE XVI

Bond Strength Results (psi) -- Panels 37 to 40

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
37	20 days	33.9	18.7	4.8	29.0	21.6
38	22 days	87.1	73.4	53.2	33.9	61.9
39	21 days	12.1	29.0	25.5	20.7	21.8
40	21 days	69.3	64.5	53.2	37.1	56.0

The average value for cement-lime mortar panels is lowered by low values in the bottom joint of both panels Nos. 38 and 40. The occurrence of low values in the bottom joint of panels is similar to the discrepancy of joint-to-joint values in the same panel, an unexpected result in bond strength tests. This matter will be referred to later.

Visual examination again revealed good extent of bond. In the masonry cement panels it is again a case of good extent of bond but no strength. With these panels the top brick invariably lifted off the mortar bed; breaking of cement-lime mortar joints was usually accompanied by a shattering of the mortar joint -- many breaks occurred directly through the mortar bed itself and in some cases the break occurred between the mortar bed and the lower brick. Typical mortar joints from these panels are shown in Fig. 7.

General Conclusions

All panels in this series performed well during leakage tests. There was no obvious difference between 30- and 60-sec panels. A comparison of water absorbed during the leakage test for 30- and 60-sec panels with both mortars shows very little difference (Fig. 8).

Bond strength values indicate greater strength of cement-lime over masonry cement mortars. Values for 30- and 60-sec masonry cement panels are comparable, but 30-sec panel results are superior to 60-sec panel results for cement-lime mortar panels.

Visual examination revealed a good extent of bond for all panels. Some small unbonded areas about the perimeter of masonry cement panels possibly result from mortar being forced from the joint by the heavy tap. There was excellent extent of bond for cement-lime panels.

Comparison of High and Low Flow Mortars

Leakage and bond strength results for panels assembled with low and high flow mortars are compared in Table XVII where results for panels 12 to 20 are compared with results for panels 32 to 40. Average flow of mortars used in the former panels was 109 per cent while flow for the latter was 119.2 per cent. Bricks were buff in the I.R.A. range 11 to 16.7 gm. Panels were assembled with two time intervals -- 30 and 60 sec and the heavy tap was used for both series.

TABLE XVII

Comparison of High and Low Flow Panels

Masonry Cement

	Leakage Results		Bond Strength Results	
Flow	30 Sec	60 Sec	30 Sec	60 Sec
Low	nil	562 ml	23.1	20.3
High	nil	nil	21.6	21.7

Cement-Lime Mortar

	Leakage Results		Bond Strength Results	
Flow	30 Sec	60 Sec	30 Sec	60 Sec
Low	nil	502 ml	68.9	38.8
High	nil	nil	72.9	58.9

TABLE XVIII

Comparison of Water Absorbed by Panels Assembled with High and Low Flow Mortars During Leakage Test

	Masonry Cement		Cement-Lime	
Flow	30 Sec	60 Sec	30 Sec	60 Sec
Low	597 gm	734 gm	610 gm	723 gm
High	496 gm	420 gm	418 gm	431 gm

It can be seen that panels assembled with high flow mortars were superior to those assembled with low flow mortars. This conclusion is supported by leakage results and also by comparison of water absorbed by the panels during leakage tests. There is very little difference for panels assembled with 30-sec time interval. There was no leakage or evidence of leakage for any of these panels with the exception of some discoloration at the end of one of the cement-lime mortar joints in a panel assembled with a low flow mortar. However, panels using high flow mortars had tightest joints according to lower moisture absorption during leakage tests.

Bond strength results are comparable for high and low flow panels assembled at 30 sec. Slightly higher values for low flow masonry cement panels are offset by similarly higher values for high flow cement-lime panels. However, for 60-sec panels high flow mortars give best bond strength results, particularly for cement-lime mortar; the difference is not great for masonry cement mortar.

Conclusions

High flow mortars bond better than low flow mortars with buff bricks in the suction range 11 to 15 gm. This conclusion is based on leakage results already shown and, to a lesser degree, bond strength results.

It is interesting to note that only minor differences occur in panels assembled with a 30-sec time interval. There is, however, a marked difference in results for panels assembled with a 60-sec time interval.

Results from Panels 41 to 48

Panels 41 to 48 were duplicates of the previous eight panels using a brick having a lower suction rate. Buff bricks with an I.R.A. range 8 to 10 gm were used with masonry cement and cement-lime mortars having high flow. Panels were assembled at 30- and 60-sec time intervals using heavy tap.

Results are listed in Table XIX and then discussed in more detail. Average flow for mortars used was 123.4 per cent.

TABLE XIX

General Summary -- Panels 41 to 48

Mortar Used	Leakage Results		Bond Strength (psi)	
	30 Sec	60 Sec	30 Sec	60 Sec
Masonry Cement (1:3)	nil	nil	22.9	25.3
Cement-Lime (1:1:6)	nil	nil	50.2	55.1

(a) Panels 41 to 44

Leakage

There was no leakage nor was there any indication of moisture penetration by discoloration of mortar joints in any of the four 30-sec panels.

Bond Strength

All panels were tested after the normal curing period of 21 to 22 days. Average value of 50.2 psi for cement-lime mortar panels was higher than the 23.0 psi value for masonry cement mortar panels. There was great variation in results. Panel 41 averaged 16.3 psi vs 29.7 psi for panel 42; panel 43 averaged 38.1 psi vs 62.3 psi for panel 44. Values for panels 41 and 42 (masonry cement) ranged from 9.7 to 38.0 psi while the eight cement-lime mortar panel values ranged between 20.9 to 80.6 psi.

TABLE XX

Bond Strength Results (psi) -- Panels 41 to 44

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
41	21 days	23.4	12.6	19.3	9.7	16.3
42	21 days	25.8	38.0	34.0	21.0	29.7
43	21 days	20.9	39.5	44.3	47.6	38.1
44	22 days	44.3	80.6	71.0	53.2	62.3

Visual examination revealed good extent of bond in all cases. Some of the cement-lime mortar joints were still damp when fractured. Mortar joints from panels Nos. 41, 42, and 44 are shown in Fig. 9.

(b) Panels 45 to 48

Again there was no leakage and no indication of moisture penetration by discoloration of mortar joints for any of the 60-sec panels.

TABLE XXI

Bond Strength Results (psi) -- Panels 45 to 48

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
45	23 days	17.7	49.7	28.2	31.4	31.8
46	22 days	28.5	9.7	15.3	21.3	18.7
47	22 days	56.4	40.3	50.3	43.5	47.6
48	21 days	80.3	53.5	70.5	46.0	62.6

Bond strength tests were done at 21 to 23 days. Values for cement-lime mortar panels averaged 55.1 psi compared with 25.3 psi for masonry cement mortar panels. Great variation in values obtained was again noted. Visual examination revealed good extent of bond in all cases. Some of the cement-lime mortar joints fractured through the mortar beds while some joints of masonry cement mortar (panel 45) fractured with a "shattering" of the mortar bed. Values for panel 45 are among the best for masonry cement mortar. Extent of bond in this panel and also in panels 47 and 48 can be seen in Fig. 10.

General

Leakage results for both 30- and 60-sec panels are excellent. The water absorption results during the leakage test give a finer comparison (Fig. 11).

Results indicate that 30-sec masonry cement panels were tighter than those assembled at 60 sec. There was no great difference between the 30- and 60-sec panels for the cement-lime mortar panels. The 60-sec masonry cement panel absorbed the most water, but there was no real difference between 30-sec panels with either mortar.

Bond Strength Results

Bond strength results are consistent in indicating superiority of cement-lime mortar, and values for 60-sec panels are better than those for 30-sec panels. In comparing these values the great variation in results must be kept in mind. For example, the low value for panel 43 is the reason for the difference in values for 30- and 60-sec cement-lime mortar panels. On the other hand, values for 30-sec masonry cement panels are consistently lower than 60-sec panel values. Bond strength results indicating stronger bond for 60-sec masonry cement panels conflict with evidence shown by water absorption during leakage tests which indicated that 30-sec panels had the tightest joints.

There was no leakage for panels assembled with either bricks in the suction range 8 to 10 gm nor in the higher 11 to 15 gm range. Water absorption by panels during leakage tests, however, indicates that bricks in the lower suction range formed the tightest panels. This evidence is further supported by bond strength values for the masonry cement mortar panels, but values for cement-lime mortars are lower than those for panels assembled with the higher suction bricks.

TABLE XXII

Comparison of Panels Using Bricks I.R.A. 11 to 15 gm with Panels Using Bricks I.R.A. 8 to 10 gm Using Masonry Cement and Cement-Lime Mortars

Brick Suction	Leakage Results 30 Sec	Leakage Results 60 Sec	Bond Strength Results 30 Sec	Bond Strength Results 60 Sec
		Masonry Cement Mortar		
11 to 15 gm	nil	nil	21.6	21.7
8 to 10 gm	nil	nil	22.9	25.3
		Cement-Lime Mortar		
11 to 15 gm	nil	nil	72.9	58.9
8 to 10 gm	nil	nil	50.2	55.1

TABLE XXIII

Water Absorption During Leakage Tests

Brick Suction	Masonry Cement 30 Sec	Masonry Cement 60 Sec	Cement-Lime 30 Sec	Cement-Lime 60 Sec
11 to 15 gm	496 gm	420 gm	418 gm	431 gm
8 to 10 gm	258 gm	263 gm	337 gm	262 gm

Conclusions

1) Bricks in I.R.A. range 8 to 10 gm bond better with a high flow masonry cement mortar than bricks in the I.R.A. range 11 to 15 gm. Panels assembled with 60-sec time interval gave results slightly better than those assembled with 30-sec time.

2) According to leakage results, bricks in the suction range 8 to 10 gm bond slightly better with cement-lime mortars than bricks in the higher suction range. However, bond strength values indicate that a stronger bond is formed by the higher suction bricks.

Panels assembled with 30-sec time interval gave best results with higher suction bricks; 60-sec panels were better with lower suction bricks.

3) This indicates that as the suction of the bricks decreases the time factor in assembling bricks becomes of less importance. In fact, when using a high flow mortar, it is desirable to allow a short time interval before laying the second brick so that the first brick may remove any excess of water from the mortar.

It therefore follows that for a brick of known suction there is an optimum mortar moisture content at which best bond will occur between the two.

Results from Panels 49 to 54

In reviewing the program to date it is believed that there should be additional evidence concerning the "tap" factor particularly for the buff bricks in the suction range 11 to 15 gm. Accordingly, six panels were assembled with buff bricks in the suction range 10.6 to 14.3 gm, three with masonry cement mortar, and three with cement-lime mortar, and one panel with each mortar at each of the following time intervals: 30, 60, and 90 seconds. Light tap was used with low flow mortars. Results are to be compared with those for panels 13 to 24 for which the heavy tap was used. Average flow for the six panels was 110.4 per cent. Results are given in Table XXIV and are then discussed in more detail.

(a) Panels 49 to 51

These panels were assembled with masonry cement mortar. Panels 49 and 50, assembled with 30- and 60-sec time intervals, did not leak and there was no discolouring of mortar joints. However, panel 51, assembled at 90 seconds, leaked immediately. Total leakage during the test was 113 ml; of this 78 ml occurred during the first hour of test. The maximum leakage rate of 2.8 ml/min occurred between the fifth and tenth minute of test.

TABLE XXIV

General Summary -- Panels 49 to 54

Mortar Used	Leakage Results 30 Sec	Leakage Results 60 Sec	Leakage Results 90 Sec	Bond Strength Values (psi) 30 Sec	Bond Strength Values (psi) 60 Sec	Bond Strength Values (psi) 90 Sec
Masonry Cement (1:3)	nil	nil	113.0 ml	17.4	10.4	6.9
Cement Lime (1:1:6)	nil	6.5 ml	6.0 ml	25.4	16.9	8.0

Bond Strength

Bond strength results are listed in Table XXV.

TABLE XXV

Bond Strength Results (psi) -- Panels 49 to 51

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
49	21 days	28.4	20.2	4.8	16.1	17.4
50	21 days	14.2	24.2	1.6	1.6	10.4
51	22 days	0	5.6	21.8	0	6.9

Bond strength values give a good picture of the time effect. Values steadily decrease as the time interval is increased from 30 to 90 seconds. The last two joints of panel 50 and joints 1 and 4 of panel 51 had negligible or very low strengths. Similarly there was a low strength for joint 3 of panel 49. All of these values were included in the averages, but the relative rating of the various tests would not have been changed had they been omitted.

Visual examination further substantiated this evidence. Extent of bond for panel 49 was fairly good, although there were some unbonded areas and small crevices in the brick had not been filled with mortar. Extent of bond was not as good in panel 50 and was poor in panel 51. A comparison of typical mortar joints for these three panels can be obtained from Fig. 12 (top row).

(b) Panels 52 to 54

Leakage

There was some leakage for all three cement-lime mortar panels. Water appeared on the back of the 30-sec panel (No. 52) three minutes after the start of the leakage test. The leak did not develop, however, and there was insufficient water to run off the panel to the measuring container. Later the water on the back of the panel was absorbed. At the end of the test about 25 per cent of the joint area of the panel was discoloured. There was immediate leakage in both 60- and 90-sec panels, but it was only slight and in both cases had stopped at 30 minutes. Total leakage for panels 53 and 54 was 6.5 and 6.0 ml respectively. Joints were discoloured at the end of the test but the back of the panel was quite dry.

Bond Strength

Bond strength results are given in Table XXVI.

TABLE XXVI

Bond Strength Results (psi) -- Panels 52 to 54

Panel No.	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
52	22 days	49.2	13.0	22.2	17.0	25.4
53	21 days	33.9	0	14.5	19.0	16.9
54	21 days	10.5	8.9	4.5	0	6.0

Bond strength values for these three panels again reveal decreasing strengths with increasing time interval used in assembling the panel. Again all averages were obtained by including low and zero values (elimination of zero values for one joint in each of the last two panels would not have changed the relative picture). Visual observations were interesting. Joint No. 1 of panel 52 had a good value and fracture took place through the mortar bed. In all other cases the top brick lifted from the mortar bed. Visual examination of panels 53 and 54 revealed lesser extent of bond with increasing time interval. Bonding was particularly poor around the perimeters of all joints. Even in joint No. 1 of panel 52, the best bonding of any joint, two points were noted where water had entered to a depth of $1\frac{1}{2}$ in. After seeing the relatively poor extent of bond in panel 54, it was difficult to understand why there had not been more leakage. Extent of bond for these panels can be seen in Fig. 12 (bottom row).

General

Leakage results point to superior bonding for 30- and 60-sec panels assembled with masonry cement and to a lesser extent for 30-sec panels assembled with cement-lime mortar. The picture is clarified by examination of water absorbed during the leakage test. For both mortars there is a progressive increase in water absorption as time interval in assembling panels is increased (Fig. 13).

Bond Strength Results

Comparison of bond strength values for the two mortars again reveals the superior strength of cement-lime mortar.

Considering both bond strength and leakage results, it is obvious that these panels would not be very durable, the only exception being possibly the 30-sec masonry cement panel where the joints seem to have been comparatively tight. Water entering mortar joints, coupled with frost action, would soon result in deterioration and increased leakage for most other panels. Tooling the mortar joints might have resulted in a marked improvement in the performance of these panels. The tooling effect will be studied later.

Comparison of Light and Heavy Tap Panels

Leakage and bond strength results for panels 49 to 54 and panels 13 to 24 are now compared. The former group of panels was assembled using the light tap and the latter using the heavy tap.

	I.R.A. Range of Bricks(gm)	Average Mortar Flow(%)
Panels 13 to 24	11.0 to 16.8	108.1
Panels 49 to 54	10.6 to 14.3	110.4

Suction range and mortar flows for the two groups of panels are compared above. It is noted that lower suction rate of bricks and higher flow of mortar were used for the light tap panels.

TABLE XXVII

Comparison of Leakage and Bond Strength Results for Panels Assembled with Light and Heavy Tap

	Leakage Results			Bond Strength Results		
Tap	30 Sec	60 Sec	90 Sec	30 Sec	60 Sec	90 Sec
			Masonry Cement Mortar			
Light	nil	nil	113.0 ml	17.4 psi	10.4 psi	6.9 psi
Heavy	nil	562.0 ml	3,350.0 ml	23.1 psi	20.3 psi	14.0 psi
			Cement-Lime Mortar			
Light	nil	6.5 ml	6.0 ml	25.4 psi	16.9 psi	8.0 psi
Heavy	nil	502.0 ml	1,215.0 ml	68.9 psi	38.8 psi	25.1 psi

The leakage results for light tap panels were much better than those for the heavy tap panels; bond strength results indicate the beneficial effect of heavy tap. It had been anticipated that a consistent pattern would develop for both leakage and bond strength results. The question arises, therefore, as to the effect on the results of the lower suction of bricks used in combination with a higher flow mortar for light tap panels. The results obtained for light tap panels are for single panels only. More results are necessary to clarify the "tap" effect.

Panels 55 to 60

Some work was done with a third mortar containing 1 part cement: 2 parts lime putty: 9 parts sand.

Six panels were assembled with buff bricks having suction range 11.0 to 11.8 gm. Mortars were mixed to have low flows, the average being 110.3 per cent. Duplicate panels were assembled at 30, 60, and 90 seconds using heavy tap. Leakage and bond strength values are summarized in Table XXIX.

TABLE XXVIII

General Summary -- Panels 55 to 60

Leakage Results			Bond Strength Values (psi)		
30 Sec	60 Sec	90 Sec	30 Sec	60 Sec	90 Sec
nil	nil	nil	27.0	22.6	15.1

There was no leakage and no indication of moisture penetration by discoloration of joints during the leakage test for any of the six panels. Water absorption by the panels during the leakage test is shown in Fig. 14. Sixty- and ninety-second panels absorbed slightly more water during the test than the 30-second panels. From a standpoint of leakage results there is little difference in panels using this mortar at 30-, 60-, or 90-second time intervals.

TABLE XXIX

Bond Strength Results (psi) -- Panels 55 to 60

Time	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
30 sec	21 days	27.4	35.5	29.0	25.5	29.4
30 sec	21 days	38.4	17.7	24.2	18.5	24.7
60 sec	21 days	43.5	9.7	35.5	19.4	27.0
60 sec	21 days	25.8	19.3	22.6	14.8	18.1
90 sec	21 days	33.9	11.3	4.8	2.4	13.1
90 sec	21 days	14.5	13.9	23.9	15.8	17.0

Best bond strength results were obtained for 30-sec panels, the values then decreasing for 60- and 90-sec panels. Values for the 30-sec panels were unusually consistent. Breaks generally occurred when the top brick lifted from mortar beds; joint No. 4 of panel 55 (a 30-sec panel) fractured with a break through the mortar bed. There was good extent of bond in all cases. Again, the extent of bond for 90-sec panels was definitely not as good as for 30-sec panels, while extent of bond for 60-sec panels was rated in between. This is clearly shown in Fig. 15. In several instances water penetrated between brick and mortar of 60- and 90-sec panels but penetration was never greater than one-half inch.

Conclusions

1) Buff bricks of suction approximately 11 gm bond satisfactorily with low flow 1:2:9 cement-lime mortar. Best results occurred when bricks were placed with the shortest time interval.

2) Although there was good extent of bond, the bond strength values were low. Good extent of bond is attributed to water retentivity of the mortar.

Results from Panels 61 to 72

Effect of Tap

Twelve panels were assembled for additional study of the tap effect. Bricks in the I.R.A. range 20 to 26 gm were combined with three mortars, 1:3 masonry cement mortar, 1:1:6, and 1:2:9 cement-lime mortars. A 90-sec time interval was used in placing bricks on mortar, and six panels were assembled with light tap and the other six with heavy tap. Leakage and bond strength results are summarized in Table XXX, the figures listed being the average of duplicate tests.

TABLE XXX

Leakage and Bond Strength Results

Mortar	Leakage Results Light Tap	Leakage Results Heavy Tap	Bond Strength Results Light Tap	Bond Strength Results Heavy Tap
1:3 masonry cement	Immediate 2,655.3 ml	Immediate 1,284.0 ml	4.8 psi	8.8 psi
1:1:6 cement-lime	Immediate 464.3 ml	Not immediate 76.5 ml	11.1 psi	12.9 psi
1:2:9 cement-lime	Slight leakage, no measurable amount	Slight leakage 3.0 ml	6.8 psi	18.5 psi

Mortar flows were high (120 to 125 per cent). The 90-sec time interval was selected in order to provide panels that would leak.

Discussion of Results

There was immediate leakage for all four masonry cement panels and totals for the 24-hour test period were high. Use of the heavy tap in panel assembly, however, reduced the total leakage to slightly less than half the totals for the light tap panels.

Leakage results for 1:1:6 cement-lime panels demonstrate clearly the superiority of heavy tap panels. These panels had an average leakage of 76.5 ml and did not leak immediately; light tap panels leaked immediately and had an average total of 464.3 ml.

There was little to choose between leakage results of light and heavy tap panels of 1:2:9 cement-lime mortar. Both leaked slightly during the test. Not enough water ran off the back of light tap panels for measurement while the average for heavy tap panels during the 24-hour test was 3 ml.

Bond strength values are better in each case for heavy tap panels. The greatest difference occurred for the 1:2:9 cement-lime mortars (Fig. 16) where the combination of a mortar with high water retentivity, the 90-sec time interval, and the heavy tap produced a reasonably good result. Values for the other two mortars (Figs. 17 and 18) were as markedly different although the heavy tap panel values were in both cases higher than those for light tap panels. All bond strength values are low -- characteristic of 90-sec time interval panels.

<u>Summary</u>

Improved results occurred for panels assembled with brown bricks and three mortars using a heavy tap compared with results for similar panels using a light tap. Leakage in masonry cement panels was reduced by 50 per cent with the use of heavy tap and bond strength values were definitely better. With 1:1:6 cement-lime mortar panels leakage results were definitely better, and there was a slight improvement in bond strength values. In the case of the 1:2:9 cement-lime mortar panels leakage results were about the same, but there was a definite improvement in bond strength values for heavy tap panels.

<u>Results from Panels 73 to 84</u>

Twelve panels were assembled with Glasgo Brown Range Bricks having I.R.A. range 18.0 to 22.2 gm with three mortars:

1) 1:3 masonry cement: sand
2) 1:1:6 cement: lime putty: sand
3) 1:2:9 cement: lime putty: sand.

The suction values of bricks for these panels were among the higher values found for bricks manufactured locally, and the purpose of assembling these panels was primarily to study bonding of these bricks with the three mortars.

Six of the panels were assembled with low flow mortars (average 110.1 per cent) and the other six with high flow mortars (average 120.1 per cent). All panels were assembled with 30-sec time interval, and in all cases a heavy tap was used. Results are summarized in Table XXXI and then discussed in detail. Extent of bond can be compared in Figs. 19 and 20.

TABLE XXXI

Relation Between Mortar Flow, Leakage, and Bond Strength

Mortar Flow	Leakage	Bond Strength
	Masonry Cement Panels	
Low	nil	35.1 psi
High	nil	33.0 psi
	Cement Lime (1:1:6) Panels	
Low	nil	50.4 psi
High	nil	54.0 psi
	Cement Lime (1:2:9) Panels	
Low	nil	39.1 psi
High	nil	19.6 psi

Masonry Cement Mortar Panels

There was no leakage for panels assembled with either high or low flow mortars. Visual observation of discolouring of mortar joints on the back of the panel due to moisture penetration indicated that panels assembled with high flow mortars had slightly tighter joints. While all joint areas for low flow panels were discoloured at the end of the leakage test, high flow panels had about 10 per cent of the joint area still clear. Water absorption for low flow panels during the leakage test was 511 gm compared with 508.5 gm for high flow panels. Thus, leakage results show little to choose between high and low flow panels.

The average bond strength value of 35.1 psi for low flow panels was greater than the value of 33.0 psi for high flow panels.

TABLE XXXII

Bond Strength Results (psi) -- Masonry Cement Panels

Mortar Flow	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
Low	21 days	30.5	49.3	37.6	37.6	38.8
Low	22 days	32.3	44.8	25.1	23.3	31.4
High	22 days	55.5	40.9	30.5	12.5	34.9
High	21 days	49.1	28.3	28.7	18.0	31.0

Highest individual values (55.5 psi and 49.1 psi) occurred in the top joints of the high flow panels. It is interesting to note that for these panels bond strength values deteriorated for each successive mortar joint until lowest values were obtained in the bottom joints. Visual observation revealed a good extent of bond in all cases. Three of the mortar beds for high flow panels fractured in such a manner that some of the mortar remained on both upper and lower bricks. The lower joints of both high flow panels were poorly bonded about perimeter areas.

1:1:6 Cement-Lime Mortar Panels

There was no leakage for either high or low flow panels and visual observation left little to choose between them. All mortar joints were discoloured at the end of the test. There was some water on two of the joints of the first low flow panel but not enough to run off. Water absorption during leakage test was 430 gm for low flow panels and 536.5 gm for high flow panels.

TABLE XXXIII

Bond Strength Results (psi) -- 1:1:6 Cement-Lime Panels

Mortar Flow	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
Low	21 days	35.8	51.1	43.0	33.1	40.8
Low	21 days	78.8	78.8	55.6	26.9	60.0
High	21 days	57.3	60.0	48.4	26.9	48.2
High	21 days	69.9	60.9	68.8	39.4	59.8

Average value of 54.0 psi for high flow mortar panels was slightly higher than 50.4 psi value for low flow mortar panels. Some excellent bond was observed. Some breaks occurred through the mortar beds and in others part of the mortar bed remained on the upper brick. Examination of the results in Table XXXIII indicates very little difference in values between panels assembled with low and high flow mortar. Although the average value was better for panels assembled with the high flow mortar, the best individual value was obtained with a low flow panel while the lowest value occurred in a high flow panel.

1:2:9 Cement-Lime Panels

None of the panels assembled with 1:2:9 mortars with both high and low flows leaked during the 24-hour test. Some discoloration of mortar joints, indicating moisture penetration, was observed at 4 to 6 hours and at the end of the test period all mortar joints were discoloured. Water absorption during the leakage test was 580.5 ml for low flow mortar and 501 ml for high flow mortar panels.

TABLE XXXIV

Bond Strength Results (psi) -- 1:2:9 Cement-Lime Mortar Panels

Mortar Flow	Age at Test	Joint #1	Joint #2	Joint #3	Joint #4	Average
Low	22 days	44.4	39.1	36.7	43.0	40.8
Low	21 days	39.4	38.5	46.6	25.1	37.4
High*	21 days	10.7	10.7	24.7	20.6	16.7
High*	21 days	28.7	33.2	Broken during set-up	8.6	23.5

* First two joints tested at 21 days. Joints 3 and 4 tested at 42 days.

The average bond strength value of 39.1 psi for the low flow mortar panels was higher than the 19.6 psi value for the high flow panels. Unlike results for the panels using both the other mortars, there is a real distinction in results for these panels. A greater difference in values would have occurred if all joints for high flow panels had been tested at 21 days. The average figures for these panels include three values obtained at 42 days. In addition to higher average values, bond strength results for low flow panels were much more consistent than values for high flow panels. There was good extent of bond observed in all panels, particularly those assembled with low flow mortar where many of the breaks occurred through the mortar bed itself.

Conclusions

1) Bricks in the suction range 18 to 22 gm combine with 1:3 masonry cement and 1:1:6 and 1:2:9 cement-lime mortars (both high and low flow) to form tight panels when assembled with 30-sec time intervals and heavy tap.

2) Leakage and bond strength results on panels assembled with masonry cement and 1:1:6 cement-lime mortars were consistent for both high and low flow mortars.

3) While leakage results were comparable, bond strength results were superior for low flow mortars in the case of the 1:2:9 mortar. The combination of a high flow and a heavy tap with low suction brick is apparently not suitable for mortars with a high water retentivity.

Bond Strength Values for Small Brick Panels

During this study wide variation in bond strength values have been noted (a) for different joints in the same panel and (b) for duplicate panels. Difficulty in reproducing bond strength values has been recognized, but one aspect of the variation of values within the same panel will be considered.

In a small panel consisting of five bricks and four mortar joints (Fig. 21) it would seem logical that joint 1 would have the greatest bond strength, for it is compressed by the weight of four bricks, all placed in approximately 30 minutes or before final set of mortar has taken place. Bond strength values for joints 2, 3, and 4 should follow No. 1 in that order because each is compressed by the weight of one less brick.

It has been noted, however, that in many bond strength tests the lowest value instead of the highest occurs in joint 1 and that high values occur frequently in joint 4, the top joint, where low values had been anticipated.

Accordingly, an analysis of bond strength values was done on results for seventy-six panels. These included panels 9 to 60 in this program and twenty-four panels from a previous study. Results are shown in Table XXXV.

TABLE XXXV

Analysis of Occurrence of High and Low Values (Bond Strength) in Small Brick Panels

	High Value	Low Value
Joint 4	33	18
Joint 3	20	10
Joint 2	17	17
Joint 1	6	33

From these figures it can be noted that high values occur 33 times or 43.4 per cent in joint 4 while only 6 times or 8 per cent in joint 1 where the majority of high values had been expected. Looking at low values, 33 or 42.3* per cent occurs in joint 1 and only 18 or 23.1 per cent in joint 4 where low values were expected.

In making the analysis, "zero" values resulting from breakage during set-up (often occurring in low value joints) were not included. Inclusion of these values would have increased the percentage of lows occurring in joint 4.

Two explanations are offered for this performance:

1) In bond strength tests the pattern followed was to proceed from joint 4 to joint 1. It is possible that the recoil from the shock of breaking the top joint weakened the joints below. This would explain why values decreased from top to bottom joints in each panel.

2) The impact from tapping the third brick (joint 2) during panel assembly might be sufficient to disturb the bond between brick and mortar in joint 1 for the mortar would not have hardened at this time. Successive impacts from "tapping" of the other two

*33 of 78 values. Two extra values are included in the total because in two of the panels identical low values occurred in two joints.

joints would also contribute to weakening lower joints by disturbing contact before the mortar had hardened. The top joint, being the last one formed and only subjected to one tap, would have the best bond strength while values for each successive joint would be somewhat less.

Support for the second explanation results from the consistent occurrence of decreasing bond strengths from top to bottom in panels assembled with high flow mortars and heavy tap. This evidence suggests use of light tap for high flow mortars and heavy tap for low flow mortars and generally suggests that the tapping procedure has some disadvantages. This matter has been considered carefully, but the tapping procedure is still the best method devised for assembling small panels for leakage tests.

Summary

1) Effect of Time

Best bond between bricks having I.R.A. above 10 gm and mortars having low to normal flows (100 to 115 per cent), as shown by results of leakage and bond strength tests, occurred when bricks were bedded in mortar in the shortest time interval. This was demonstrated by results for panels 13 to 24, assembled with 11.0 to 16.8 gm I.R.A. bricks and low flow mortars (108.1 per cent) and shown in Fig. 22.

It has been demonstrated also that the time effect is of less importance when assembling panels with low I.R.A. (1 to 3 gm) bricks and also that time effect is not significant in the assembly of bricks in I.R.A. range 8 to 10 gm and high flow (123.4 per cent) mortars. Bond strength evidence for the latter panels suggests that a 60-sec time is preferable to a 30-sec time interval.

2) Effect of Tap

Leakage and bond strength results for panels 61 to 72 (Fig. 23) demonstrate the superiority of heavy tap over light tap when assembling bricks in I.R.A. range 20 to 26 gm and mortars having high flow (120 to 125 per cent) using 90-sec time intervals. Leakage and bond strength results on previous panels assembled with light and heavy tap were contradictory and further confused by differences in mortar flow and brick suction.

An analysis of bond strength results for 76 panels suggests that the heavy tap may be detrimental to bond in lower joints of small panels when these are assembled with high flow mortars and low suction bricks. Visual examination revealed poor perimeter bonding in some panels assembled with high flow mortars and low suction bricks. This was attributed to a "squeezing out" of mortar by heavy tap. This evidence was not supported by results from leakage tests.

On the basis of results of this study, it is suggested that the heavy tap is preferable in assembling panels with bricks having I.R.A. above 10 gm with mortars having low to normal flows (100 to 115 per cent) and that the light tap is adequate with bricks of very low I.R.A. (1 to 2.6 gm).

3) <u>Effect of Flow</u>

A comparison of leakage and bond strength results for panels 13 to 24 (mortar flow 108.1 per cent) and panels 33 to 40 (mortar flow 119.2 per cent), (Fig. 24), indicates a substantial improvement in bonding with the higher flow mortar. This is obvious particularly in the leakage results for 60-sec panels, where substantial leakage occurring in low flow mortar panels was eliminated in high flow mortar panels. Bond strength values for the high flow cement-lime mortar panels Nos. 34 and 36 were among the highest obtained with the new bond strength apparatus during this study.

Best bonding between bricks and mortars in small panels assembled with bricks in I.R.A. range 11 to 16 gm occurred with mortars having higher flow values.

4) Results also provide a nice comparison of 1:3 masonry cement, 1:1:6, and 1:2:9 cement-lime mortars. Relative merits of these three mortars are well illustrated in the diagram in Fig. 23. Lowest leakage occurred with 1:2:9 cement-lime mortar which also gave highest bond strength result (for panels assembled with heavy tap). Normally best bond strength results obtained during this study have occurred with 1:1:6 cement-lime mortar and the above high value for the 1:2:9 mortar is the result of using a long (90-sec) time interval where the higher retentivity of the 1:2:9 mortar compensates for the length of the time interval.

Conclusion

Panels which do not leak and have good bond strength values can be assembled with low I.R.A. bricks (under 25 gm) and three mortars with a broad range of factors (time, tap, and flow). Optimum values for these factors for best bonding appear to be dependent one upon the other.

For example, possible reduction in bonding due to a low-flow mortar may be compensated for, at least partially, by use of a heavier tap, and similarly adverse effects of using a longer time period may be offset by using higher flow mortars and/or a heavier tap.

Optimum values for these three factors vary with I.R.A. of bricks. Their values become more critical as brick suction increases.

This study has been somewhat restricted by the I.R.A. range of the bricks used and additional work is required, preferably with higher suction bricks, to assess the relative merits of these three important factors in small panel assembly.

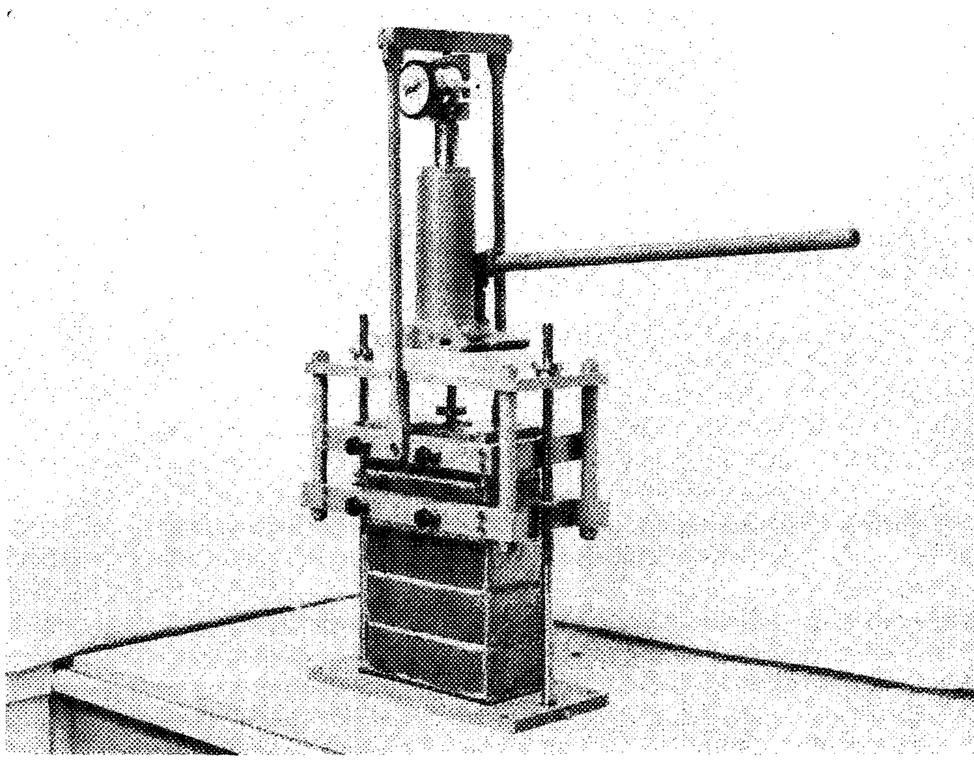

FIG. 1 NEW BOND STRENGTH APPARATUS
APPARATUS SET UP--READY TO BREAK TOP JOINT
OF A SMALL BRICK PANEL

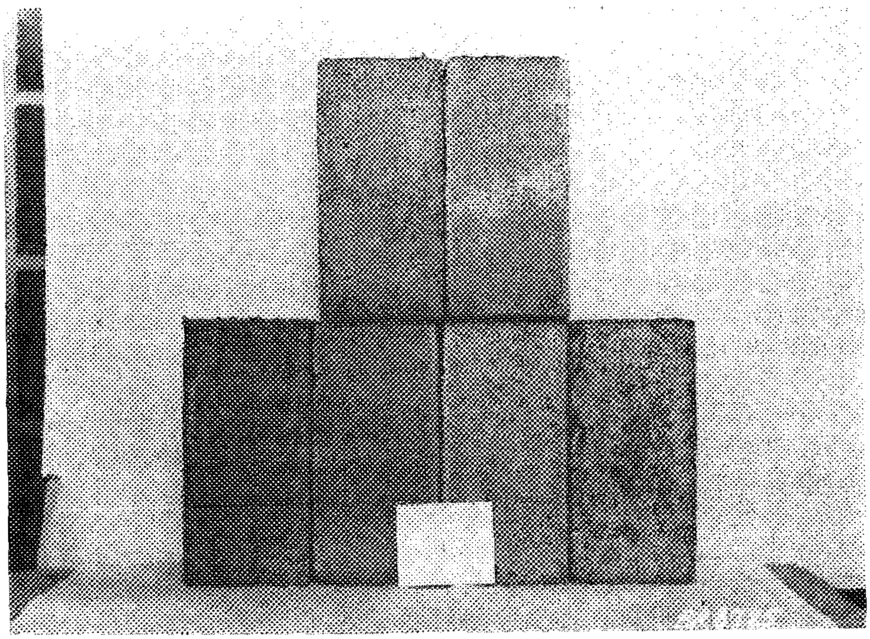

FIG. 2 PANELS ASSEMBLED WITH BUFF BRICKS, I.R.A. 11.0 TO 16.6 GM. NOS. 17 (LOWER LEFT) AND 19 (TOP) WITH 1:3 MASONRY CEMENT MORTAR AND NO. 18 (LOWER RIGHT) WITH 1:1:6 CEMENT-LIME MORTAR. NOTE "LEAKAGE PATH" IN CENTER OF NO. 19 MORTAR BED. NO LEAKAGE FOR PANEL NO. 17. MODERATE LEAKAGE FOR PANEL NO. 18. BOND STRENGTH VALUES FOR NOS. 17 AND 18 WERE RELATIVELY GOOD.

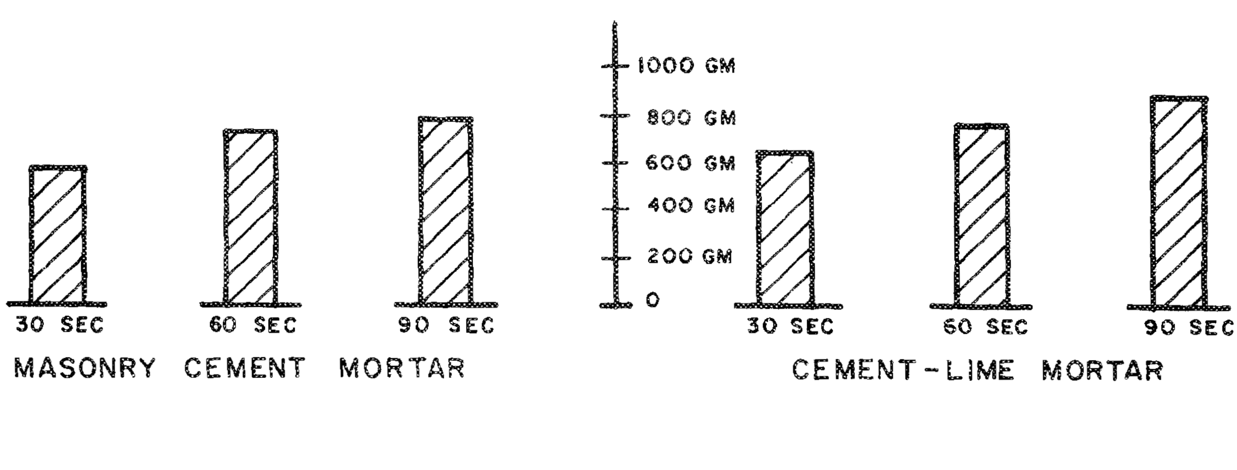

FIG. 3 ABSORPTION OF WATER BY BUFF BRICK PANELS DURING LEAKAGE TEST

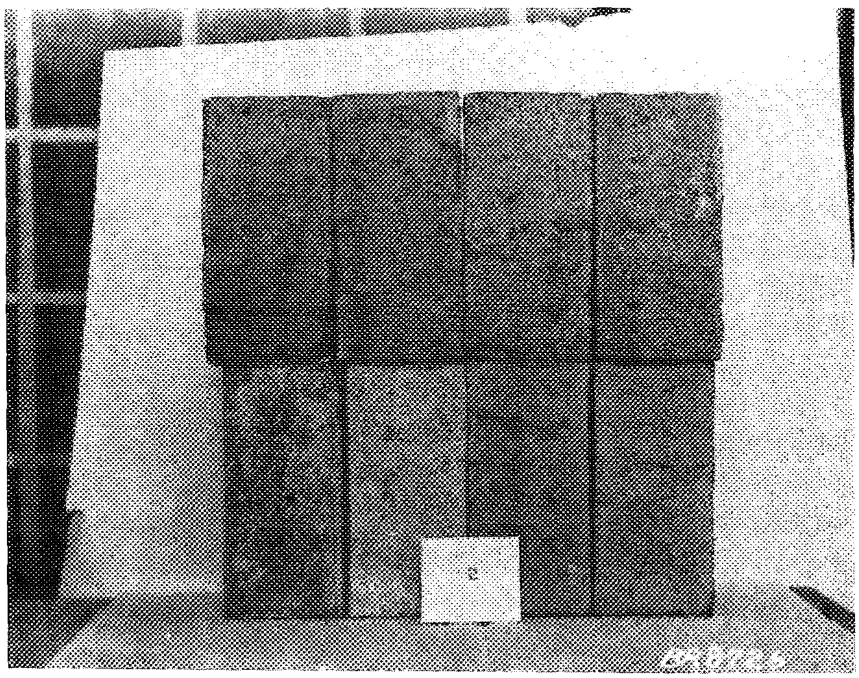

FIG. 4 TOP ROW SHOWS MORTAR JOINTS FROM PANELS NOS. 34 AND 36, ASSEMBLED WITH BUFF BRICKS I.R.A. 11.5 to 15.5 GM. AND HIGH FLOW (116 to 121 PER CENT) CEMENT-LIME MORTAR WITH 30 SEC. TIME INTERVAL AND HEAVY TAP. NO LEAKAGE AND EXCELLENT BOND (AV. 73.0 P.S.I.).

BOTTOM ROW SHOWS MORTAR JOINTS FROM PANELS NOS. 30 AND 31, ASSEMBLED WITH RED BRICKS I.R.A. 1.0 TO 2.6 GM. NO. 30 (LOWER LEFT) WITH 1:1:6 CEMENT-LIME MORTAR AND NO. 31 WITH 1:3 MASONRY CEMENT MORTAR USING 30 SEC. TIME INTERVAL AND LIGHT TAP WITH MORTAR FLOWS 110 TO 112 PER CENT. NO LEAKAGE, GOOD BOND STRENGTH RESULTS.

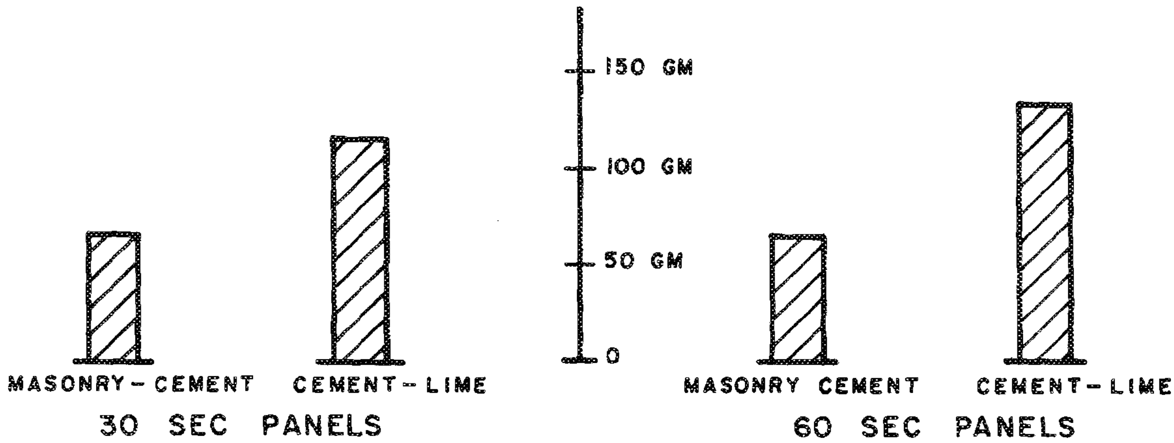

FIG. 5 ABSORPTION OF WATER BY RED BRICK PANELS (LIGHT TAP) DURING LEAKAGE TEST

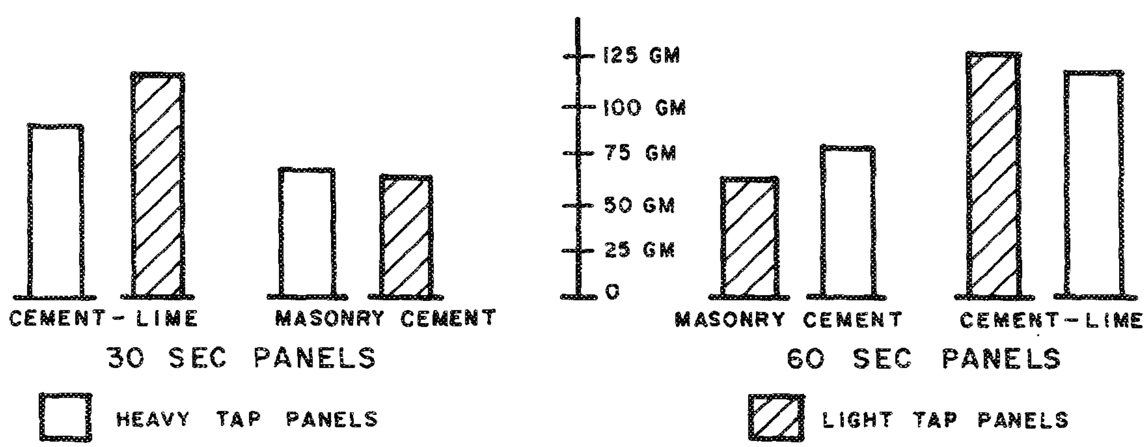

FIG. 6 COMPARISON OF WATER ABSORPTION BY RED BRICK (LOW SUCTION) PANELS DURING LEAKAGE TEST

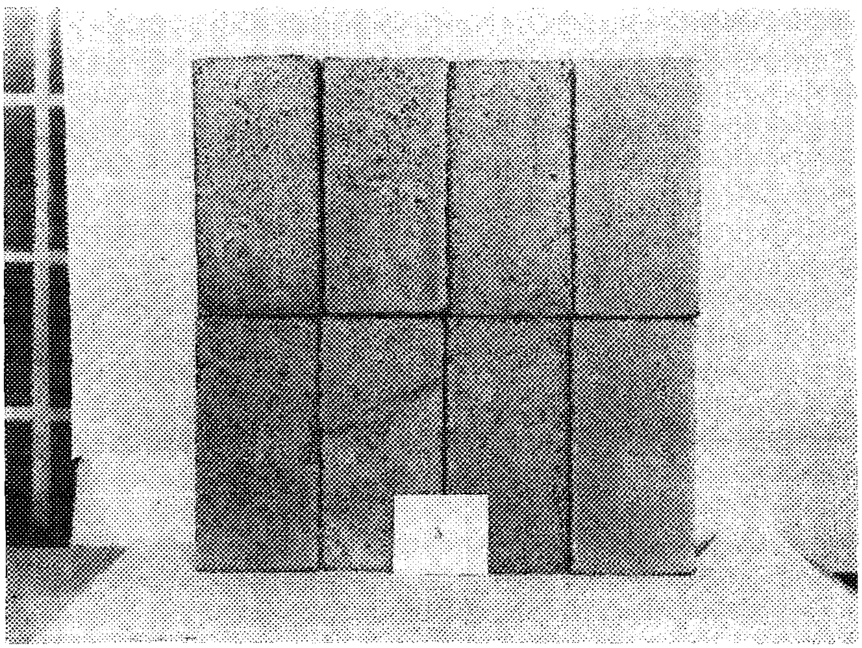

FIG. 7 MORTAR JOINTS FROM PANELS ASSEMBLED WITH BUFF BRICKS I.R.A. 11.4 TO 16.0 GM. AND HIGH FLOW (120.5 TO 122 PER CENT) MORTARS USING 60 SEC. TIME INTERVAL AND HEAVY TAP. PANELS NOS. 37 AND 39 (TOP AND BOTTOM RIGHT) HAD 1:3 MASONRY CEMENT MORTAR WHILE NOS. 38 AND 40 (TOP AND BOTTOM LEFT) HAD 1:1:6 CEMENT-LIME MORTAR. THERE WAS NO LEAKAGE AND GOOD BOND STRENGTH ALTHOUGH VALUES WERE NOT AS HIGH AS THOSE FOR PANELS IN FIGURE 3.

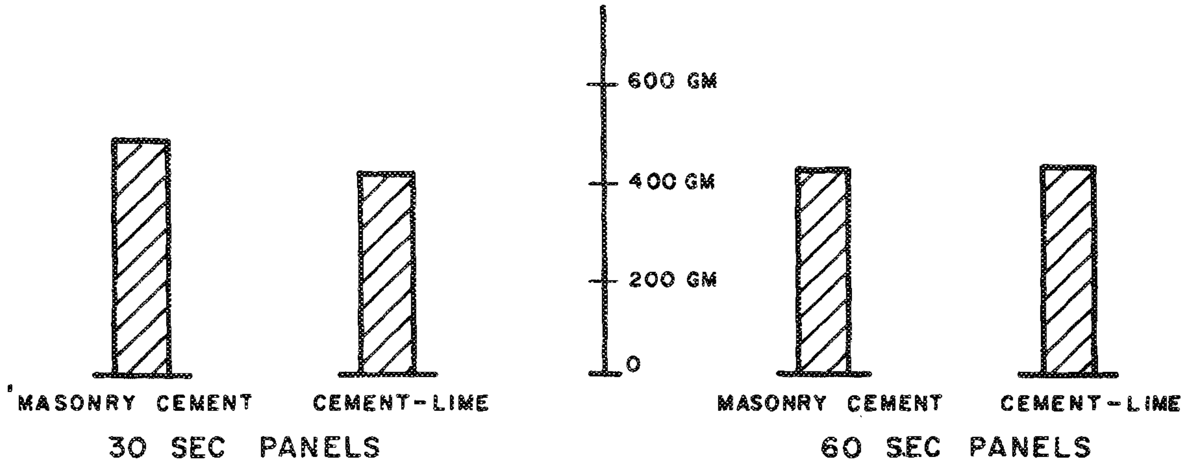

FIG. 8 ABSORPTION OF WATER BY BUFF BRICK PANELS (HEAVY TAP) DURING LEAKAGE TEST

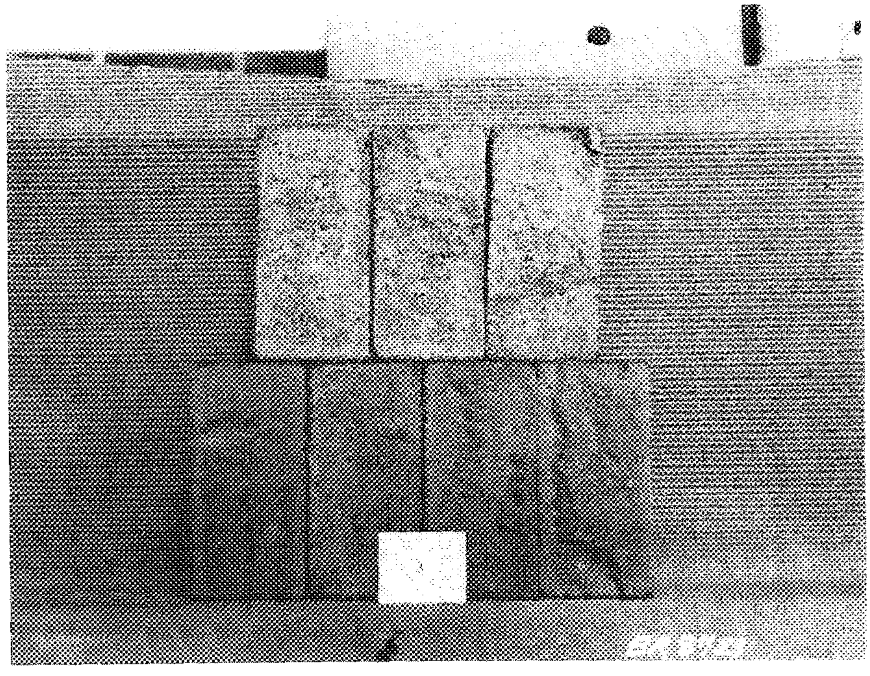

FIG. 9 MORTAR JOINTS FROM PANELS ASSEMBLED WITH BUFF BRICKS I.R.A. 8 TO 10.3 GM. AND HIGH FLOW MORTARS (AV. 123.4 PER CENT) USING 30 SEC. TIME INTERVAL AND HEAVY TAP. PANEL NO. 44 (TOP ROW) HAD 1:1:6 CEMENT-LIME MORTAR WHILE NOS. 41 AND 42 (BOTTOM ROW) HAD 1:3 MASONRY CEMENT MORTAR. NO LEAKAGE AND GOOD BOND STRENGTH RESULTS. NOTE BREAKS THROUGH MORTAR BED IN PANEL NO. 44 AND DIFFERENCE IN BONDING BETWEEN NO. 41 (BOTTOM LEFT) AND NO. 42 (BOTTOM RIGHT).

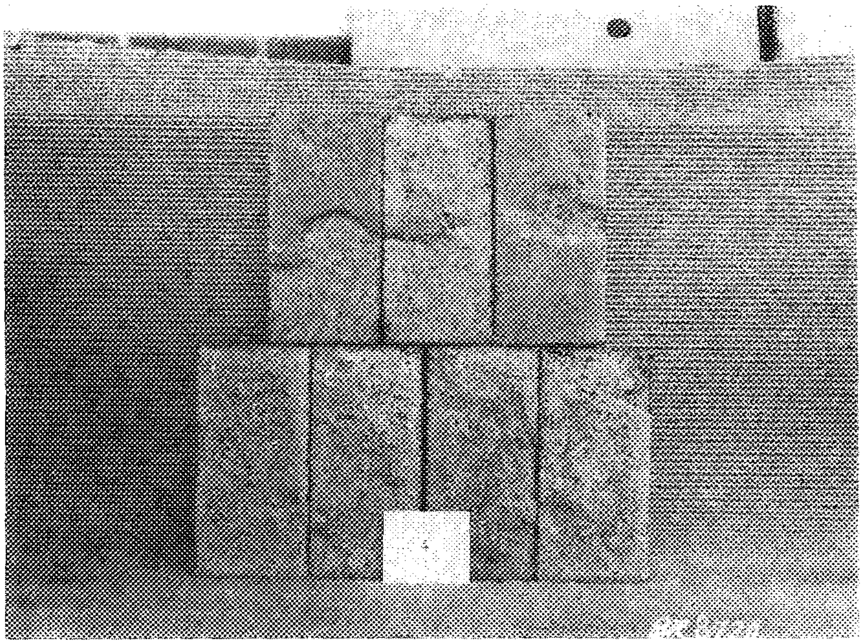

FIG. 10 THESE MORTAR JOINTS DIFFER FROM THOSE SHOWN IN FIGURE 5 ONLY IN THAT 60 SEC. TIME INTERVAL WAS USED. MASONRY CEMENT MORTAR JOINTS (PANEL NO. 45) ARE SHOWN IN TOP ROW WHILE BOTTOM ROW MORTAR JOINTS ARE OF CEMENT-LIME MORTAR FROM PANELS NOS. 47 AND 48. NO LEAKAGE. BOND STRENGTH VALUES SLIGHTLY HIGHER THAN THOSE FOR JOINTS IN FIGURE 5. BOND STRENGTH VALUES FAVOUR 60 SEC. TIME INTERVAL OVER THE 30 SEC. TIME.

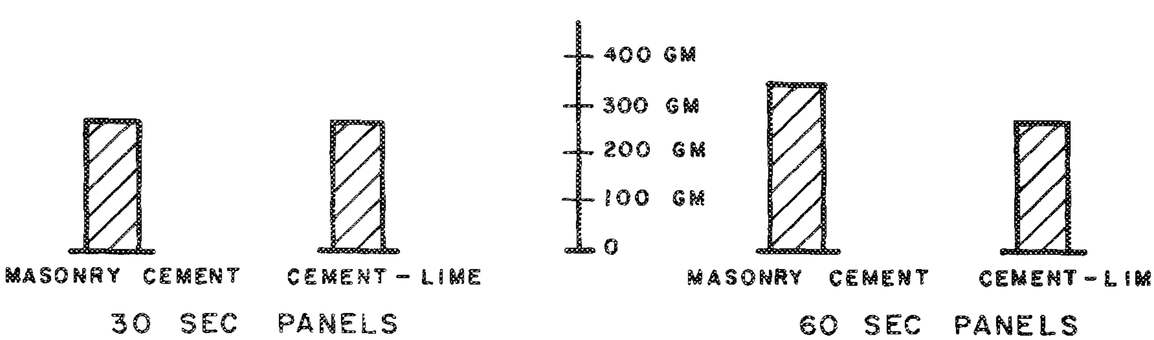

FIG. 11 WATER ABSORBED BY PANELS IN 24 HOURS OF TEST IN RELATION TO TYPE OF CEMENTING MATERIAL AND TIME FACTOR

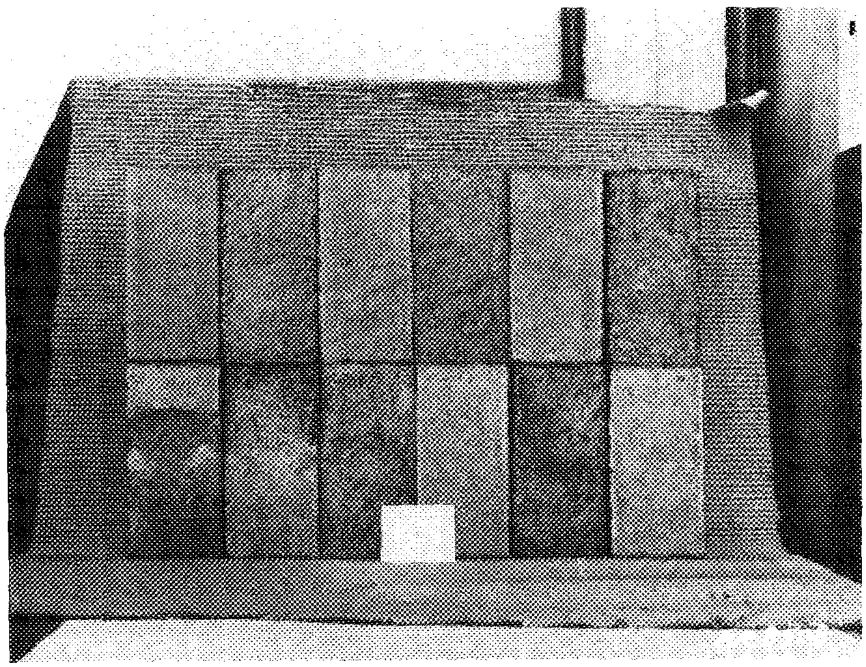

FIG. 12 MORTAR JOINTS FROM PANELS NOS. 49 TO 54 ASSEMBLED WITH BUFF BRICKS I.R.A. 10.6 TO 14.3 GM. AND MASONRY CEMENT MORTAR (TOP ROW) AND CEMENT-LIME MORTAR (BOTTOM ROW). MORTAR FLOW WAS 109 TO 112 PER CENT COMBINED WITH LIGHT TAP AND 30, 60, AND 90 SEC. TIME INTERVALS (FROM LEFT TO RIGHT IN PICTURE). THERE WAS SLIGHT LEAKAGE FOR 90 SEC. MASONRY CEMENT PANEL (TOP RIGHT) AND FOR 60 AND 90 SEC. CEMENT-LIME MORTAR PANELS (BOTTOM CENTER AND RIGHT). BOND STRENGTHS WERE MODERATELY GOOD FOR 30 SEC. PANELS BUT DETERIORATED AS TIME INTERVAL INCREASED. MORTAR JOINT AT LOWER LEFT IS NO. 1 FROM PANEL NO. 52.

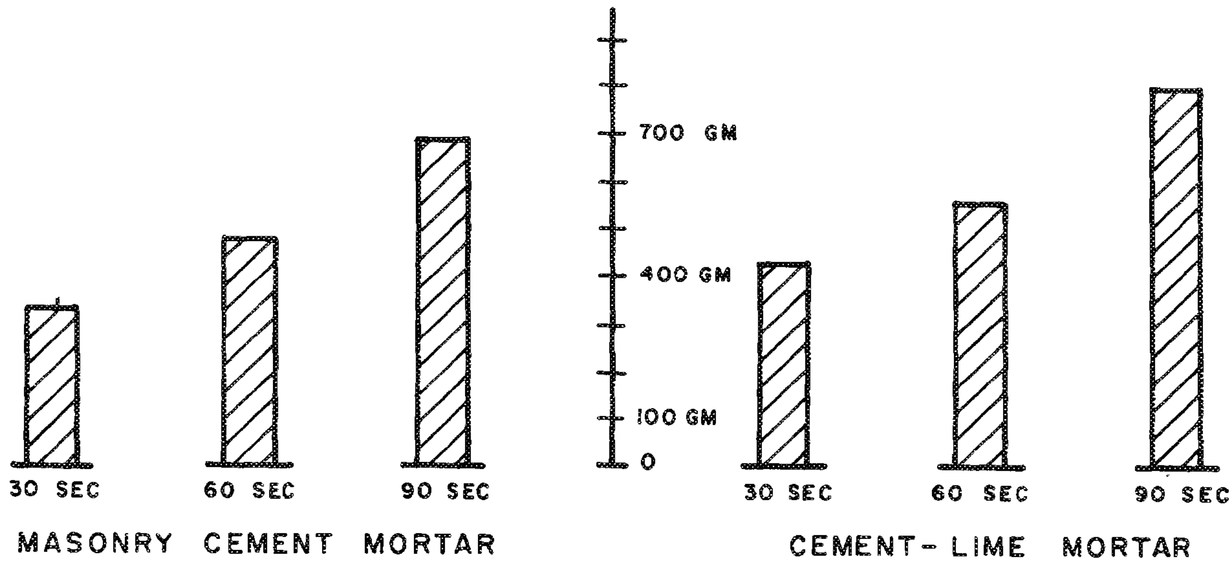

FIG. 13 WATER ABSORBED BY LIGHT TAP BUFF BRICK PANELS (I.R.A. 11 to 15 gm.) DURING LEAKAGE TEST

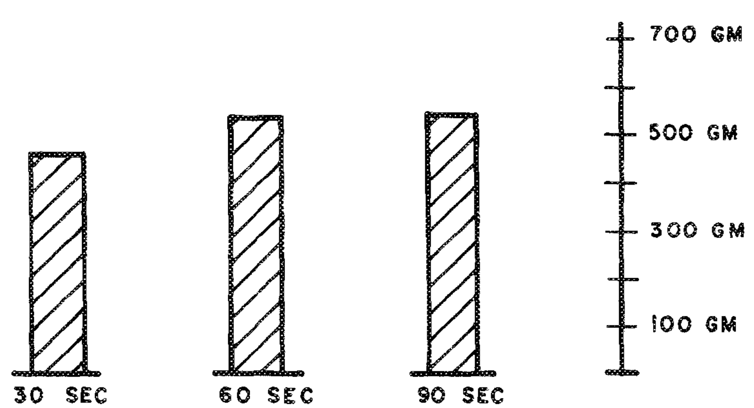

FIG 14 WATER ABSORPTION BY HEAVY TAP BUFF BRICK (I.R.A. 11 to 12) PANELS, ASSEMBLED WITH 1:2:9 CEMENT-LIME MORTAR, DURING LEAKAGE TEST

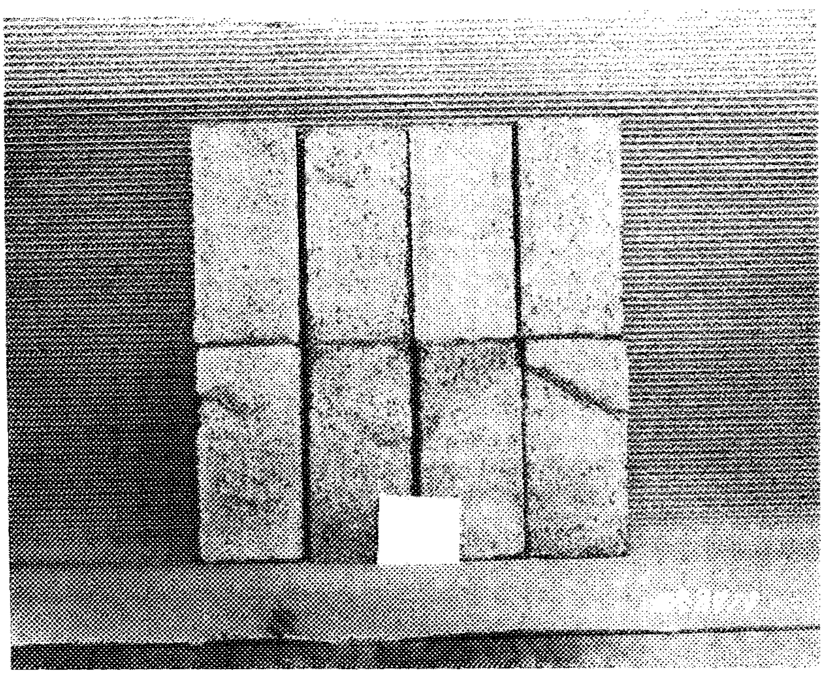

FIG. 15 MORTAR JOINTS FROM PANELS NOS. 55 TO 60 ASSEMBLED WITH 1:2:9 CEMENT-LIME MORTAR AND BUFF BRICKS I.R.A. 11.0 TO 11.8 GM. LOW FLOWS (AV. 110.3 PER CENT) WERE USED WITH HEAVY TAP AND 30 (BOTTOM ROW), 60 (TOP LEFT) AND 90 (TOP RIGHT) SEC. TIME INTERVALS. NO LEAKAGE WITH GOOD BOND STRENGTH RESULTS FOR 30 SEC. PANELS AND LESSER VALUES FOR 60 AND 90 SEC. PANELS.

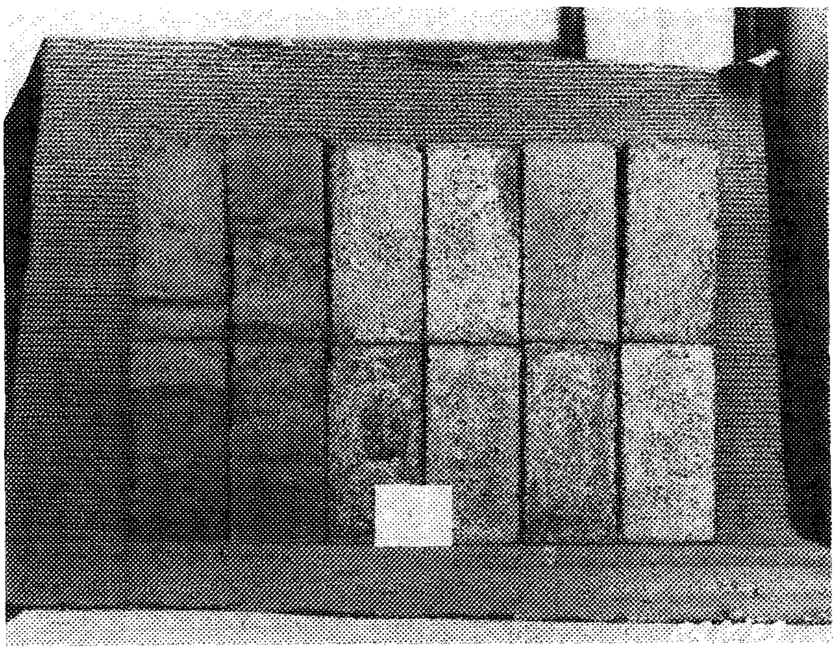

FIG. 16 MORTAR JOINTS FROM PANELS NOS. 79 TO 84. SAME AS FIGURE 9 WITH EXCEPTION THAT HIGH FLOW MORTARS (118 TO 122 PER CENT) WERE USED. NO LEAKAGE--GOOD BOND STRENGTH VALUES. VISUAL OBSERVATION BY COMPARISON WITH FIG. 9 INDICATES BETTER EXTENT OF BOND FOR MASONRY CEMENT PANELS, ABOUT THE SAME EXTENT FOR 1:1:6 CEMENT-LIME MORTAR PANELS AND A LESSER EXTENT FOR 1:2:9 CEMENT-LIME MORTAR PANELS.

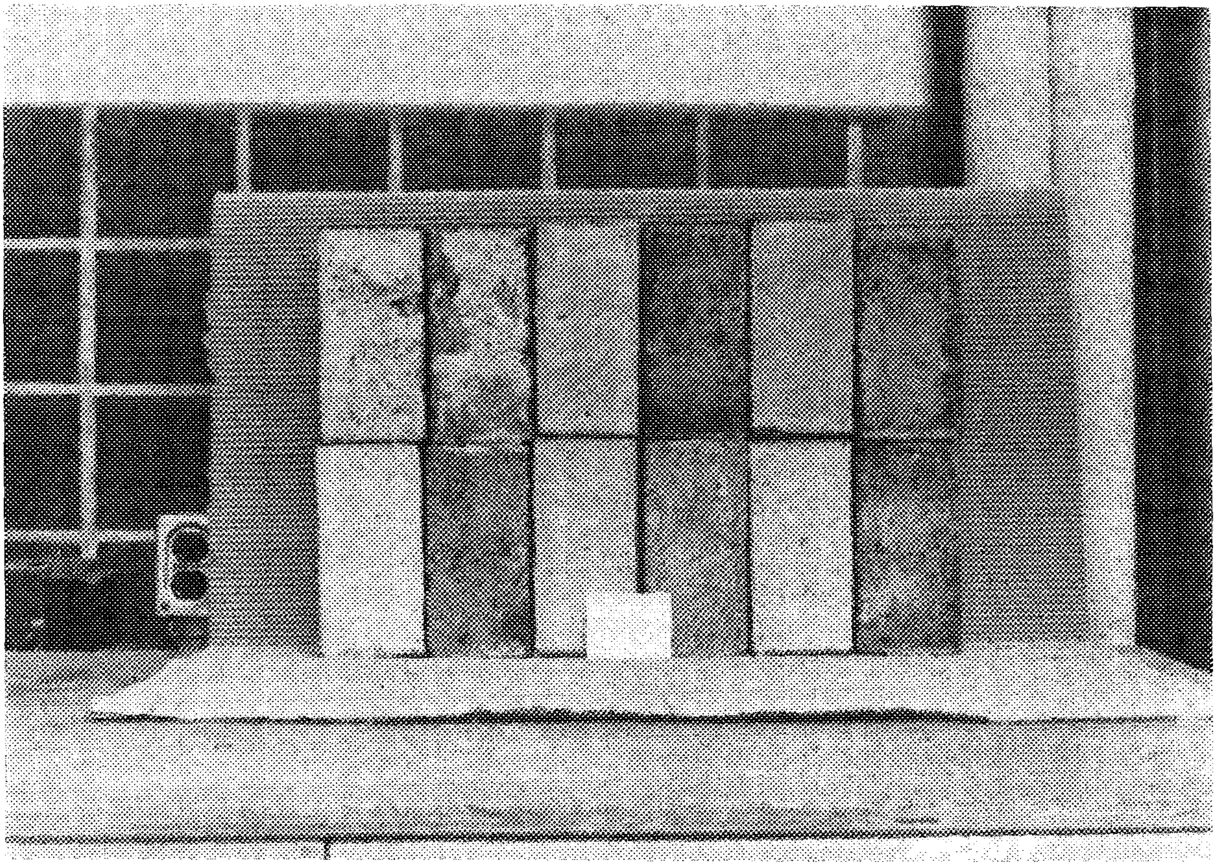

FIG. 17 MORTAR JOINTS FROM PANELS ASSEMBLED WITH BROWN BRICKS AND 1:2:9 CEMENT-LIME MORTAR--TOP ROW FROM HEAVY TAP PANELS (NOS. 71 AND 72) AND BOTTOM ROW FROM LIGHT TAP PANELS (NOS. 65 AND 66). VERY LITTLE LEAKAGE FOR ANY OF THESE PANELS. NOTE BETTER EXTENT OF BOND FOR HEAVY TAP PANELS. (AR 359)

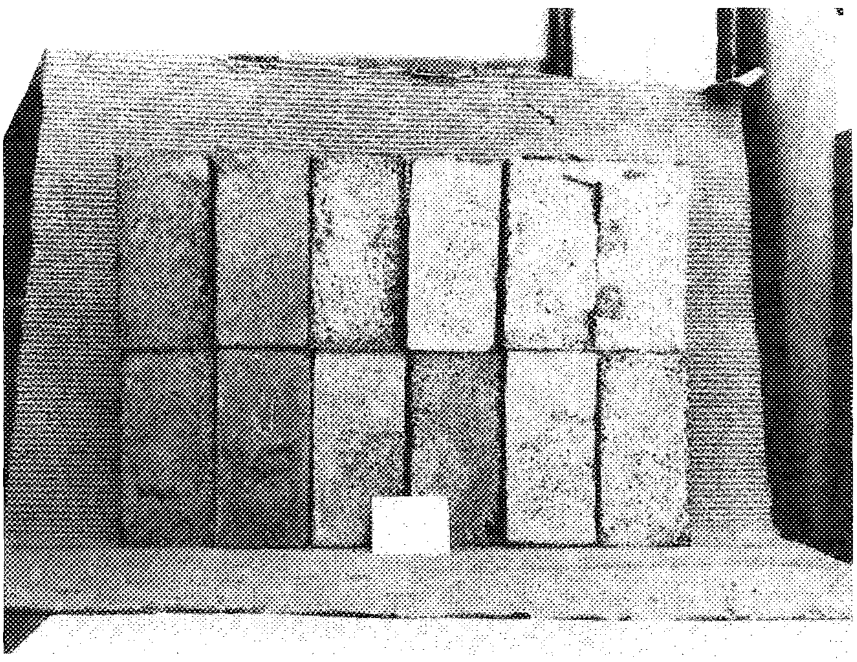

FIG. 18 MORTAR JOINTS FROM PANELS NOS. 73 TO 78 ASSEMBLED WITH BROWN BRICKS I.R.A. 18 TO 22 GM. AND 1:3 MASONRY CEMENT MORTAR (LEFT SIDE), 1:1:6 CEMENT-LIME MORTAR (CENTER) AND 1:2:9 CEMENT-LIME MORTAR (RIGHT SIDE) LOW MORTAR FLOWS 107 TO 113 PER CENT WERE COMBINED WITH 30 SEC. TIME INTERVAL AND HEAVY TAP. NO LEAKAGE, GOOD BOND STRENGTH RESULTS. NOTE BETTER EXTENT OF BONDING ALONG PERIPHARY FOR 1:2:9 MORTAR.

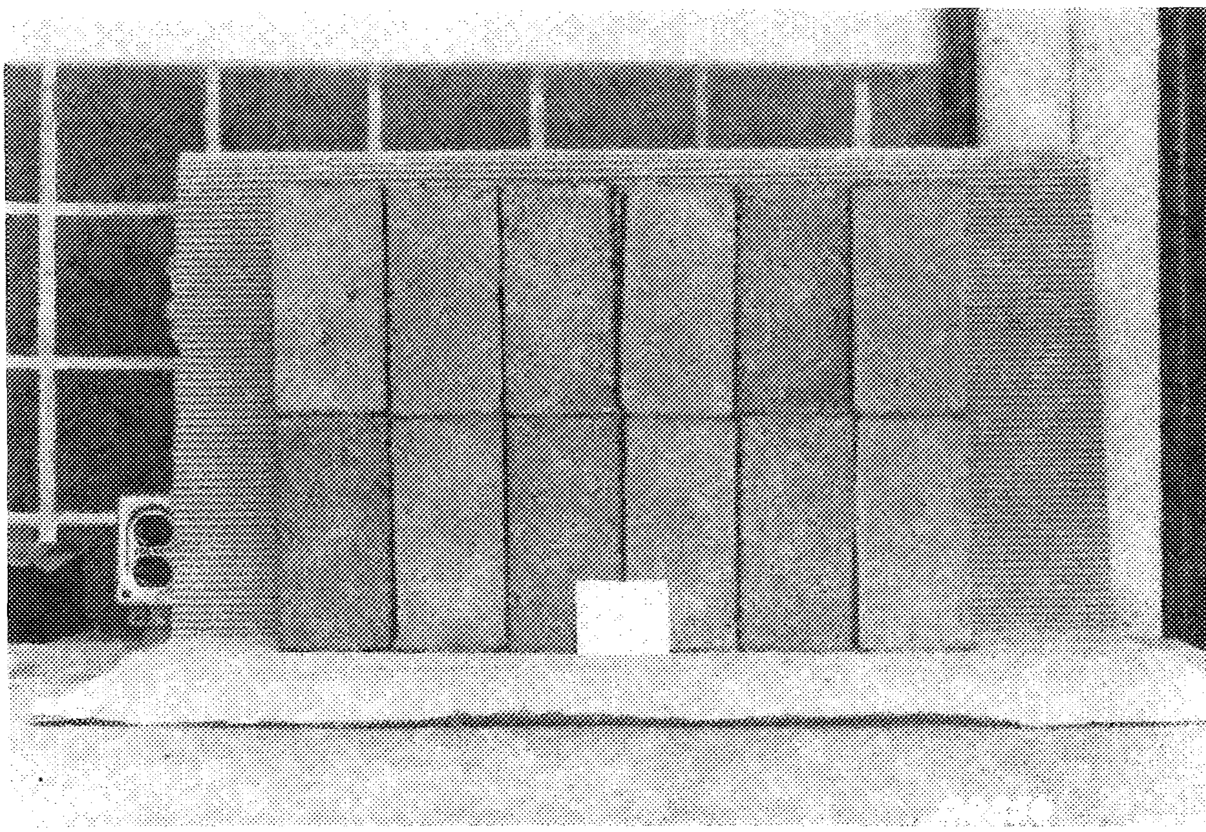

FIG. 19 MORTAR JOINTS FROM PANELS ASSEMBLED WITH BROWN BRICKS I.R.A. 20 TO 26 GM. AND MASONRY CEMENT MORTAR JOINTS FROM HEAVY TAP PANELS (NOS. 67 AND 68) ARE SHOWN IN TOP ROW WHILE THOSE IN BOTTOM ROW ARE FROM LIGHT TAP PANELS (NOS. 61 AND 62). ALL PANELS LEAKED AND BOND STRENGTHS WERE INFERIOR. RESULTS FOR BOTH TESTS WERE SLIGHTLY BETTER FOR HEAVY TAP PANELS. (AR 356)

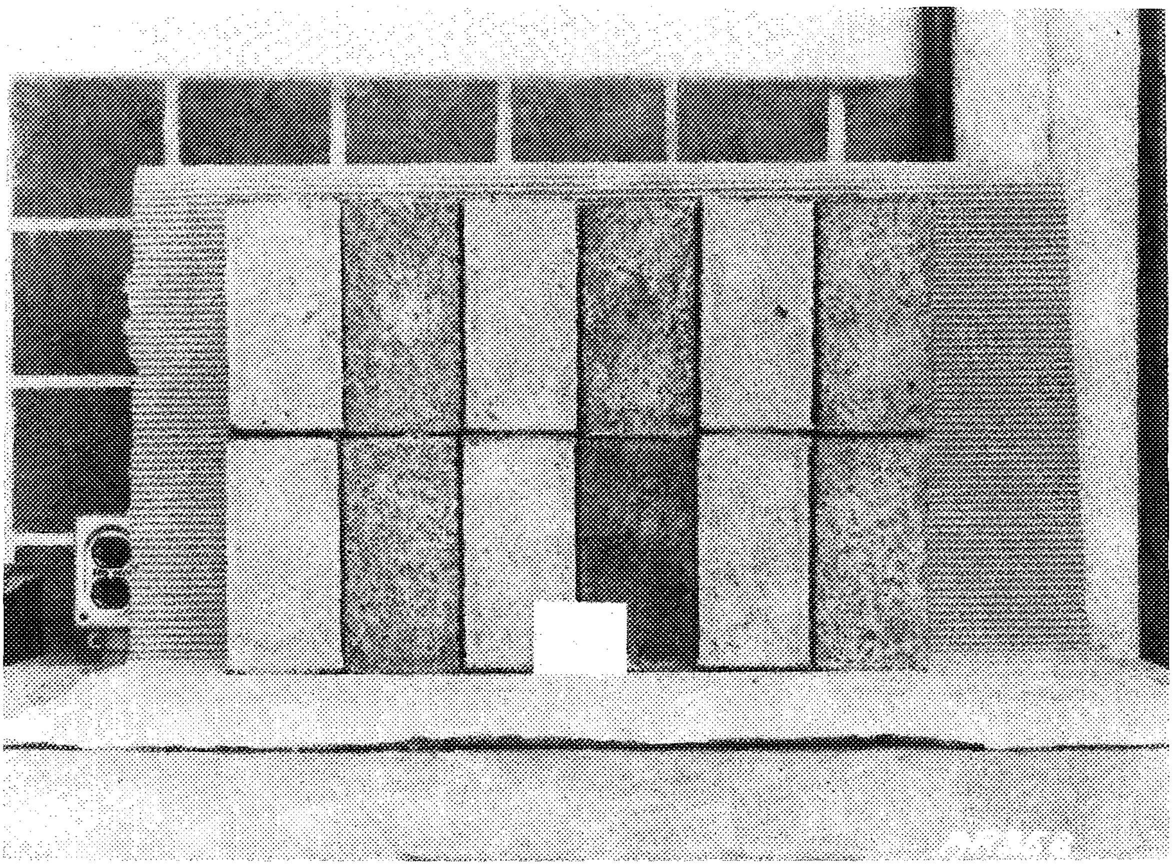

FIG. 20 MORTAR JOINTS FROM PANELS ASSEMBLED WITH BROWN BRICKS I.R.A. 20 TO 26 GM. AND 1:1:6 CEMENT-LIME MORTAR--TOP ROW FROM HEAVY TAP PANELS NOS. 69 AND 70. BOTTOM ROW FROM LIGHT TAP PANELS NOS. 63 AND 64. IMMEDIATE LEAKAGE FOR LATTER--SMALLER LEAKAGE FOR FORMER. BOND STRENGTH VALUES SLIGHTLY BETTER FOR HEAVY TAP PANELS. SOME IMPROVEMENT IN EXTENT OF BOND CAN BE NOTED IN TOP ROW JOINTS. (AR 358)

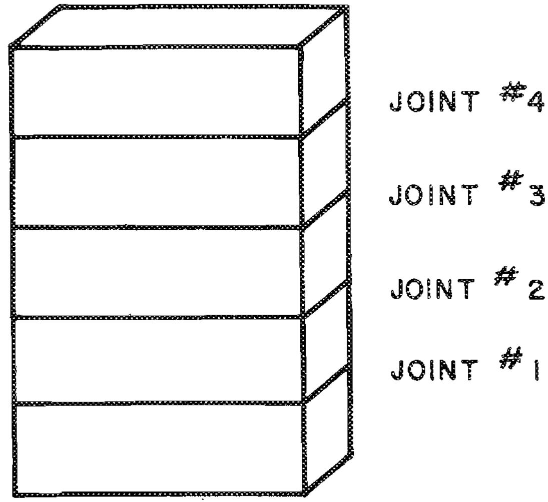

FIG. 21 SMALL BRICK PANEL

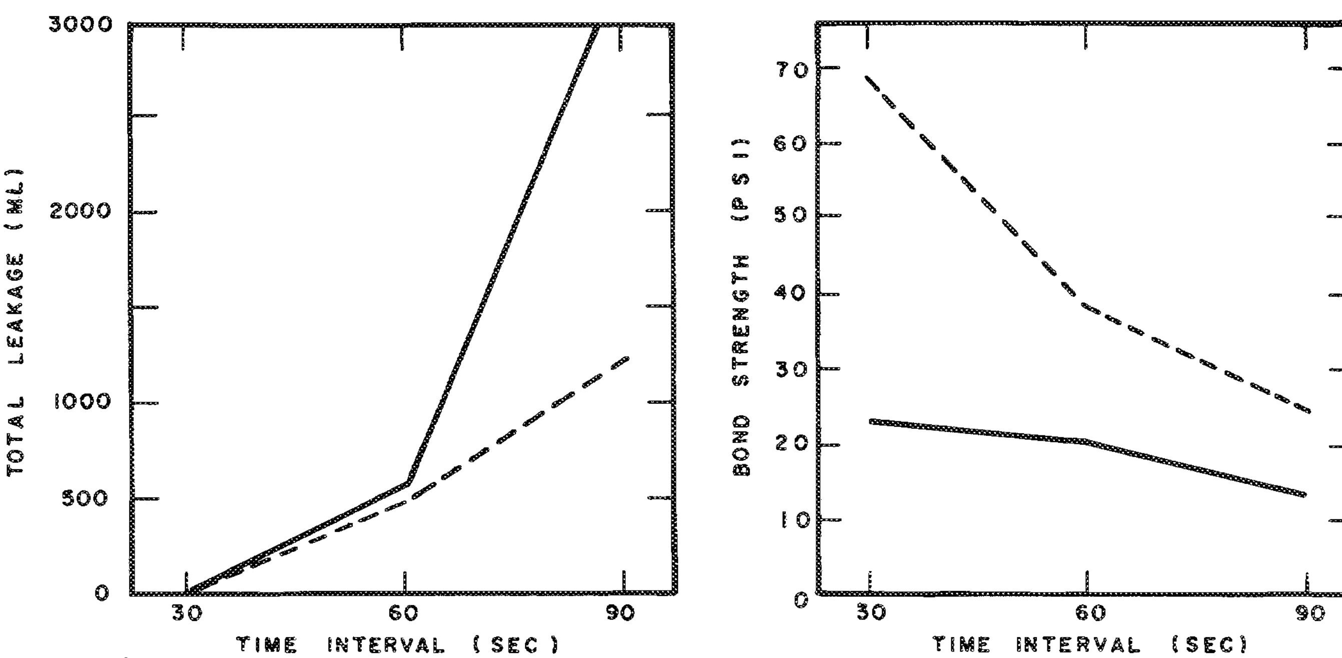

FIG. 22 EFFECT OF INCREASING TIME INTERVAL ON LEAKAGE AND BOND STRENGTH RESULTS

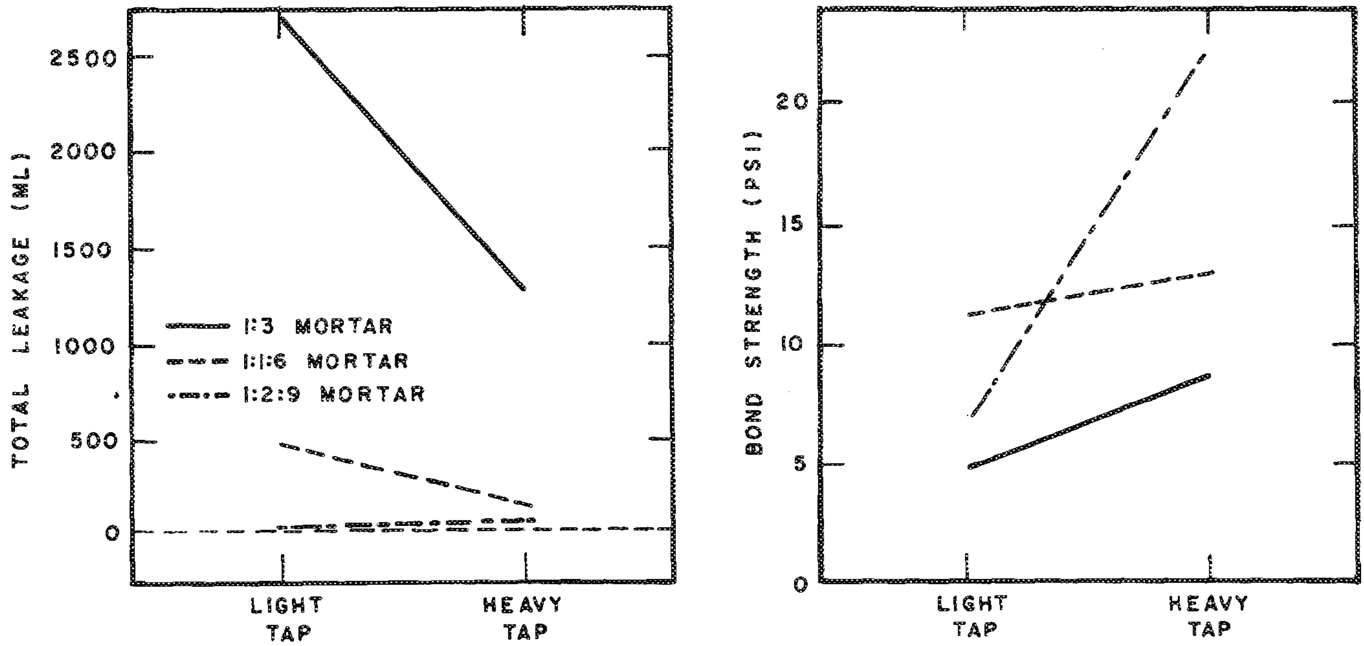

FIG. 23 EFFECT OF LIGHT AND HEAVY TAP ON LEAKAGE AND BOND STRENGTH RESULTS

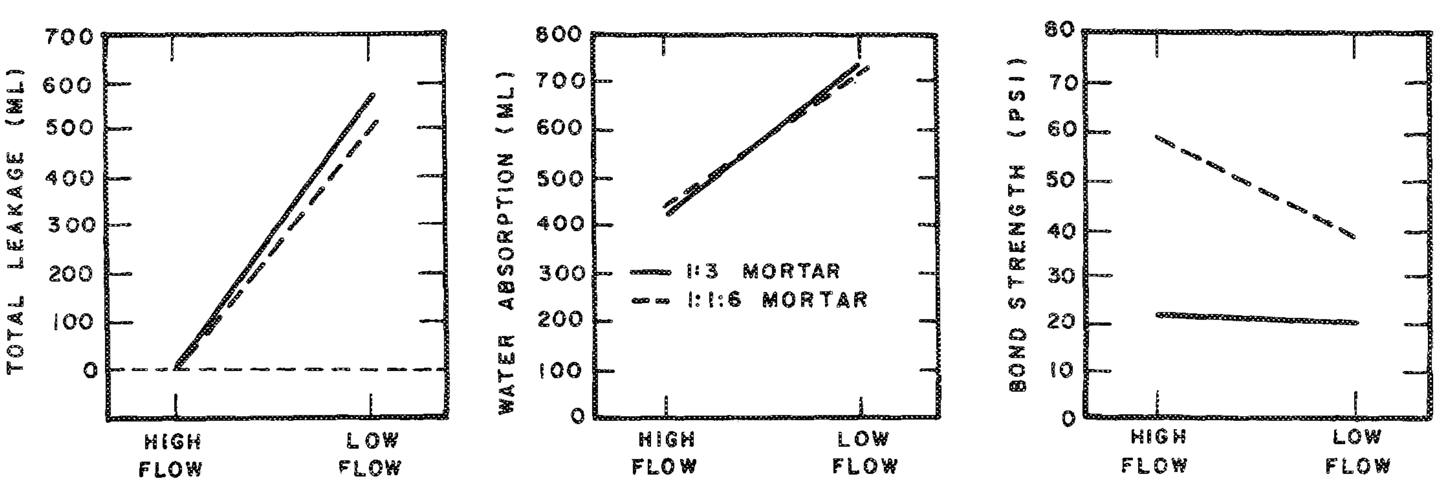

FIG. 24 EFFECT OF FLOW ON LEAKAGE AND BOND STRENGTH RESULTS